NRC COMMENTS ON LANL REPORT "STATUS OF VOLCANIC HAZARD STUDIES FOR THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT"

OVERVIEW OF TECTONIC/STRUCTURAL CONSIDERATIONS

JOHN TRAPP, NRC
JUNE 9, 1993

8

SUMMARY OF PRIMARY STRUCTURE / TECTONIC CONCERNS

INTEGRATION OF STRUCTURE/TECTONICS AND MAGMATISM

EXPLORATION - EMPHASIS ON GEOPHYSICS

STATUS OF PROGRAM
- PRESENT KNOWLEDGE
- PLANNED PROGRAM

REGULATORY BASIS

DEGREE PAC PRESENT

RESOLUTION CAPABILITIES AND EXTENT UNDETECTED

APPROPRIATENESS OF ANALYSIS

POSSIBILITY OF UNDERESTIMATION OF EFFECTS

THE CHARACTERISTICS OF THE SUBSURFACE FEEDER SYSTEMS ARE POORLY CONSTRAINED

AGREE THAT CONE FORMATION PROBABLY REFLECTS FORMATION FROM UPWARD PROPAGATING DIKES.

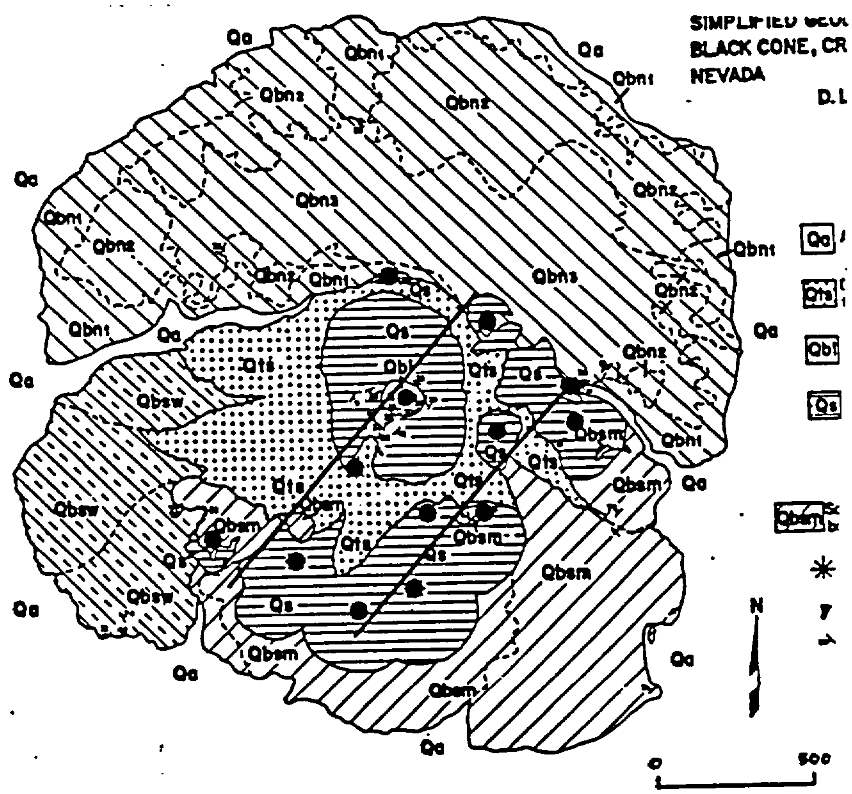
- MAPS OF RED CONE, BLACK CONE AND LATHROP WELLS SUGGEST DIKE AND NECK/PLUG SYSTEM COMPLEX.

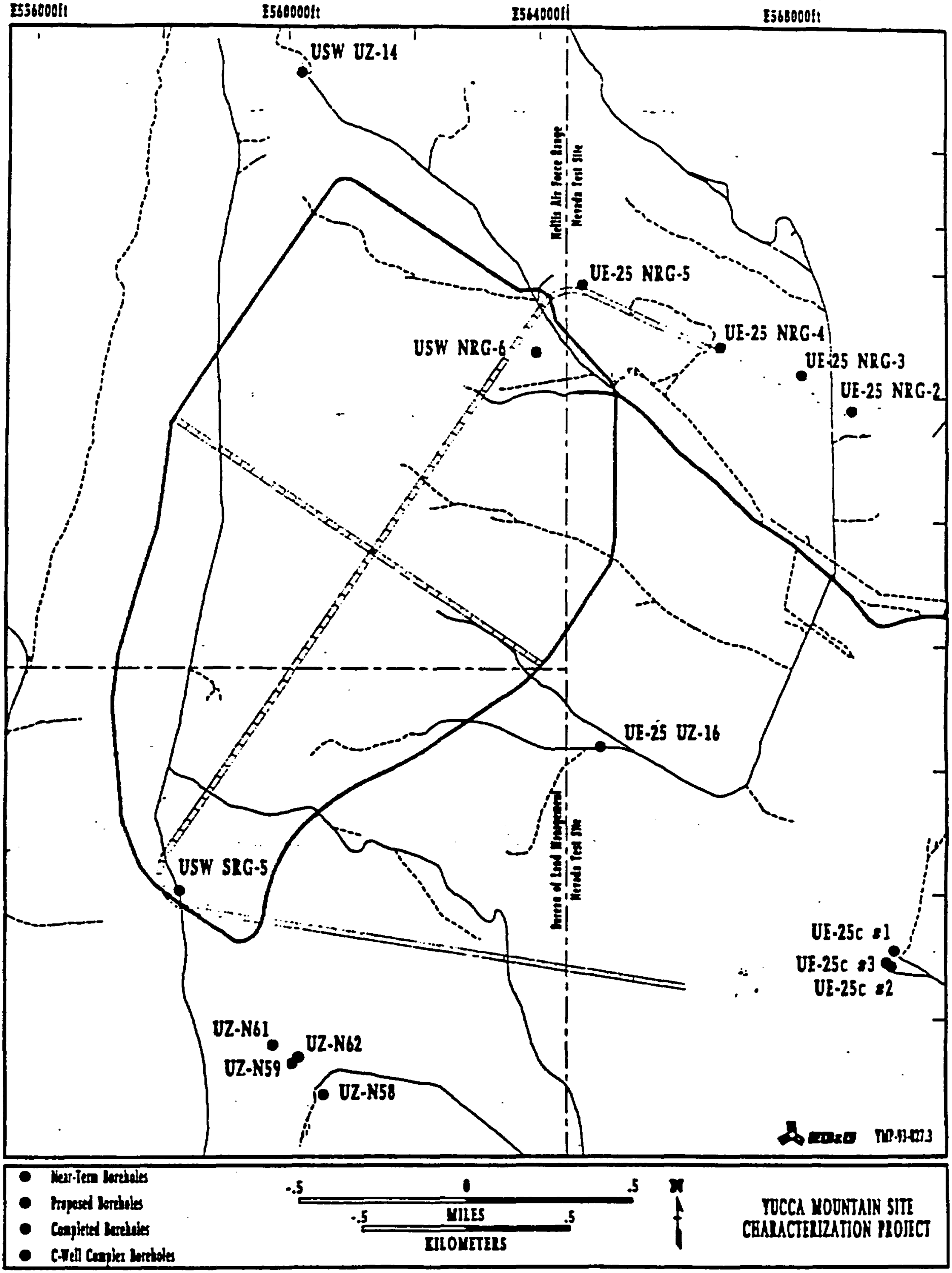
- BOTH PROBABILITY AND CONSEQUENCE CALCULATIONS DEPENDENT ON ASSUMED CHARACTERISTICS OF "FEEDER" SYSTEM.

- IT IS NOT CLEAR WHAT INVESTIGATIONS ARE PLANNED TO BETTER DEFINE THESE CHARACTERISTICS.


Qs$_{4a}$
Ql$_3$
Qs$_3$
Ql$_3$
Ql$_{4b}$
Ql$_{4a}$
Qs$_{4b}$
Qs$_{2b}$
Ql$_5$
Quarry site
(Qs$_{2d}$)
Qs$_5$
Ql$_5$
Qs$_{2c}$
Qs$_{2a}$
Ql$_6$
Qs$_6$
Ql$_5$
0
1
km

SIMPLIFIED GEO[illegible]
BLACK CONE, CR[illegible]
NEVADA
D. L[illegible]





Near-Term Boreholes

WHAT IS BASIS OF CONTENTION THAT INTRUSIVE EVENTS IN YUCCA MOUNTAIN REGION ARE ALWAYS ASSOCIATED WITH EXTRUSIVE EVENT.

REPORT CONTENDS THAT PROBABILITY OF INTRUSION EQUALS THE PROBABILITY OF EXTRUSION.

THE NRC HAS NOT SEEN THE DETAILS OF ANY PROGRAM OF INVESTIGATIONS, INCLUDING DETECTION AND RESOLUTION CAPABILITIES, WHICH CAN SUPPORT THIS STATEMENT.

THE NRC HAS NOT SEEN RESULTS FROM ANY INVESTIGATIVE PROGRAM WHICH DOES MORE THAN PROVIDE VERY GENERAL RELATIONSHIPS BETWEEN INTRUSIVE AND EXTRUSIVE FEATURES.

INFORMATION FROM OTHER VOLCANIC FIELDS DOES NOT SUPPORT. (I.E., CRATERS OF THE MOON, MONO, COSO)

IT IS UNCLEAR WHAT INVESTIGATIONS ARE BEING PLANNED WHICH WILL PROVIDE THE INFORMATION TO SUPPORT THIS CONTENTION.

WHAT IS BASIS OF SUPPORT FOR PREFERRED MODEL OF DIKE EMPLACEMENT?

THE PREFERRED MODEL OF DIKE EMPLACEMENT IS ASCENT OF PULSES OF MAGMA ALONG NORTHWEST-TRENDING STRUCTURES FOLLOWED BY A SHALLOW NORTH-NORTHEAST REORIENTATION OF DIKES.

SUCH A MODEL MAY BE TESTABLE THROUGH ANALYSIS OF GEOPHYSICAL INFORMATION.

- IT IS UNCLEAR WHAT DATA ARE AVAILABLE TO SUPPORT THE PREFERRED MODEL.

- IT IS UNCLEAR WHAT INVESTIGATIONS AND/OR ANALYSIS ARE BEING PLANNED TO TEST THIS MODEL.

WHAT IS THE DETECTION LIMIT OF THE PROGRAM OF INVESTIGATIONS?

LARGE CENTERS HAVE PROBABLY BEEN IDENTIFIED. WE QUESTION THE ABILITY TO IDENTIFY SMALLER CENTERS AND FEATURES.

EXAMPLES:

RELATIONSHIP OF DIKE COMPLEX IN NORTHERN REACHES OF SOLITARIO CANYON TO DETECTION LIMITS.

ANOMALY INVESTIGATED BY BATH AND JAHREN ALONG SOLITARIO CANYON AT SOUTH END OF PROPOSED REPOSITORY COULD BE MODELED AS 196 BY 152 METER PLUG, THOUGH NOT PREFERRED INTERPRETATION.

HOWEVER, BASALT FLOAT LOCATED ABOUT 1/2 MILE SOUTH OF ANOMALY.

CAUSE OF ANOMALY UNKNOWN.

<u>WHAT IS THE STRUCTURAL CONFIGURATION OF "PRE-VOLCANIC" ROCKS?</u>

LANL DISCUSSION ON PAGE 90 STATES "THEIR STRUCTURAL CONFIGURATION [PALEOZOIC ROCKS] BENEATH YUCCA MOUNTAIN IS NOT WELL CONSTRAINED."

DEVELOPMENT OF A TECTONIC MODEL WILL REQUIRE KNOWLEDGE OF THESE UNITS AT LEAST TO THE EXTENT THAT MAJOR STRUCTURAL FEATURES CAN BE DEFINED.

IT IS UNCLEAR WHAT ARE THE PLANS TO OBTAIN THIS INFORMATION.

IT IS UNCLEAR HOW WILL THIS INFORMATION WILL BE FACTORED INTO TECTONIC AND VOLCANIC MODELS.

IT IS UNCLEAR HOW THE TECTONIC MODELS WILL BE CONSTRAINED IF THIS BASIC STRUCTURAL INFORMATION IS NOT AVAILABLE.

HOW IS CHANGE IN BASEMENT ELEVATION BETWEEN CRATER FLAT AND JACKASS FLAT REFLECTED IN TECTONIC / VOLCANIC MODELS?

SEISMIC REFRACTION DATA SUGGEST DEPTH TO BASEMENT IN CRATER FLAT IS ABOUT 2 KM MORE THEN IN JACKASS FLAT.

GRAVITY DATA SUGGEST LARGE "STRUCTURAL STEP" ON EAST SIDE OF CRATER FLAT, UNDER GENERAL YUCCA MOUNTAIN AREA.

SEISMIC TOMOGRAPHY SUGGEST LARGE STRUCTURAL STEP IN SAME AREA AS GRAVITY DATA.

IT IS UNCLEAR WHAT INVESTIGATIONS ARE PLANNED TO INVESTIGATE THIS SUGGESTED FEATURE.

IT IS UNCLEAR HOW THIS FEATURE IS EXPLAINED BY THE VARIOUS MODELS, SUCH AS THE CALDERA MODEL, RIFT MODEL, PULL-APART MODELS, DETACHMENT MODELS.

IT IS UNCLEAR HOW STUDY 8.3.1.17.4.12 - TECTONIC MODELS AND SYNTHESIS - RELATE TO THIS CONCERN. (NOT YET ON STUDY PLAN TRACKING SHEETS)

ARE BASALTS RESTRICTED TO BASINS OR LOW ELEVATIONS?

THE DISCUSSION PAGE 138 CONTENDS THAT THE QUATERNARY BASALTS - INCLUDING BUCKBOARD MESA - APPEAR TO BE RESTRICTED TO BASINS.

PAGE 283 CONTENDS THAT BECAUSE YUCCA MOUNTAIN IS LOCATED IN A RANGE INTERIOR, MODELS OVERESTIMATE PROBABILITY.

THE GEOPHYSICAL DATA SUGGEST THAT THE EASTERN EDGE OF THE "CRATER FLAT BASIN", WHATEVER ITS ORIGIN, APPEARS TO INCLUDE YUCCA MOUNTAIN.

ELEVATION DIFFERENCE BETWEEN CRATER FLAT AND SLEEPING BUTTES IS ABOUT 2000 FEET WHILE DIFFERENCE BETWEEN CRATER FLAT AND TOP OF YUCCA MOUNTAIN IS LESS THAN 1000 FEET.

HIDDEN CONE ON SIDE OF SLEEPING BUTTE, NOT AT BASE.

REGIONAL DATA DOES NOT SUPPORT CONTENTION THAT VOLCANICS ARE ONLY IN THE BASINS (I.E., FORTIFICATION HILLS, COSO)

WHAT IS BASIS FOR CFVZ STRUCTURE?

THE CFVZ, AS PROPOSED, REQUIRES A MAJOR NORTHWEST TRENDING STRUCTURE.

WHILE SUCH A STRUCTURE HAS BEEN PROPOSED, NO DIRECT EVIDENCE OF SUCH A FEATURE REPORTED.

TECTONIC MODELS PROPOSED (DETACHMENT, RIFT, PULL-APART, CALDERA) SUGGEST DISCONTINUITY BETWEEN THE CRATER FLAT AREA AND THE AREA OF SLEEPING BUTTES/THIRSTY MESA.

GEOPHYSICS REFLECT DISCONTINUITY AS SUCH THINGS AS GRAVITY SHOW A RELATIVELY HIGH SADDLE ALONG THE NORTHERN END OF CRATER FLAT.

> IT IS UNCLEAR WHAT DATA SUPPORT THE EXISTENCE OF SUCH A STRUCTURE.
>
> IT IS UNCLEAR WHAT DATA DEMONSTRATE AN INTERRELATIONSHIP BETWEEN THE STRUCTURE AND VOLCANISM.
>
> IT IS UNCLEAR WHAT INVESTIGATIONS ARE PLANNED TO PROVIDE THIS INFORMATION.
>
> IT IS UNCLEAR HOW THE CFVZ OR AMRV IS EXPLAINED IN RELATIONSHIP TO GENERAL TECTONIC MODELS.

HOW ARE VOLCANIC AND DETACHMENT MODELS INTEGRATED?

THE REPORT DOES NOT CONSIDER DETACHMENT SYSTEMS AS IMPORTANT ELEMENTS FOR UNDERSTANDING THE STRUCTURAL CONTROLS OF BASALTIC VOLCANISM.

DETACHMENT MODELS ARE PREVALENT IN TECTONIC LITERATURE

THE STAGECOACH ROAD FAULT IS CONSIDERED BY SCOTT AS ONE OF THE MAJOR FAULTS OF THE DETACHMENT SYSTEM IN THE YUCCA MOUNTAIN AREA, POSSIBLY REPRESENTING A BREAKAWAY.

- AS DETACHMENT MODELS ARE A PROMINENT MODEL IN THE PRESENT LITERATURE, AND GIVEN THE SPATIAL RELATIONSHIP OF THE STAGECOACH ROAD FAULT SYSTEM WITH THE LATHROP WELLS CONE, IT IS UNCLEAR HOW THE VOLCANISM MODELS CAN BE EXPLAINED IN THE CONTEXT OF THE DETACHMENT MODELS.

HOW IS THE PROPOSED TIME-SPACE PATTERN OF VOLCANISM RELATED TO TECTONIC MODELS?

THE INTRODUCTION TO SUBSECTION V OF SECTION III (PAGE 113), STATES THAT THIS SECTION "... ATTEMPTS TO RELATE THE TIME-SPACE PATTERNS OF VOLCANISM TO THE TECTONIC MODELS OF THE YUCCA MOUNTAIN REGION." CAREFUL READING OF THIS SECTION SHOWS THAT THIS INFORMATION WAS NOT PRESENTED IN THIS DRAFT, WITH THE POSSIBLE EXCEPTION OF THE CFVZ.

IT IS UNCLEAR HOW THE PROPOSED TIME SPACE PATTERN OF VOLCANISM CAN BE EXPLAINED IN THE CONTEXT OF THE CALDERA MODELS, THE RIFT MODELS, THE PULL-APART MODELS, DETACHMENT MODELS, ETC.

IT IS UNCLEAR IF THIS INFORMATION WILL BE PRESENTED IN FINAL DRAFT.

IT IS UNCLEAR WHAT RELATIONSHIP THERE IS BETWEEN THE MODELS PROPOSED IN CHAPTER III AND THE PROBABILITIES CALCULATED IN CHAPTER VII.?

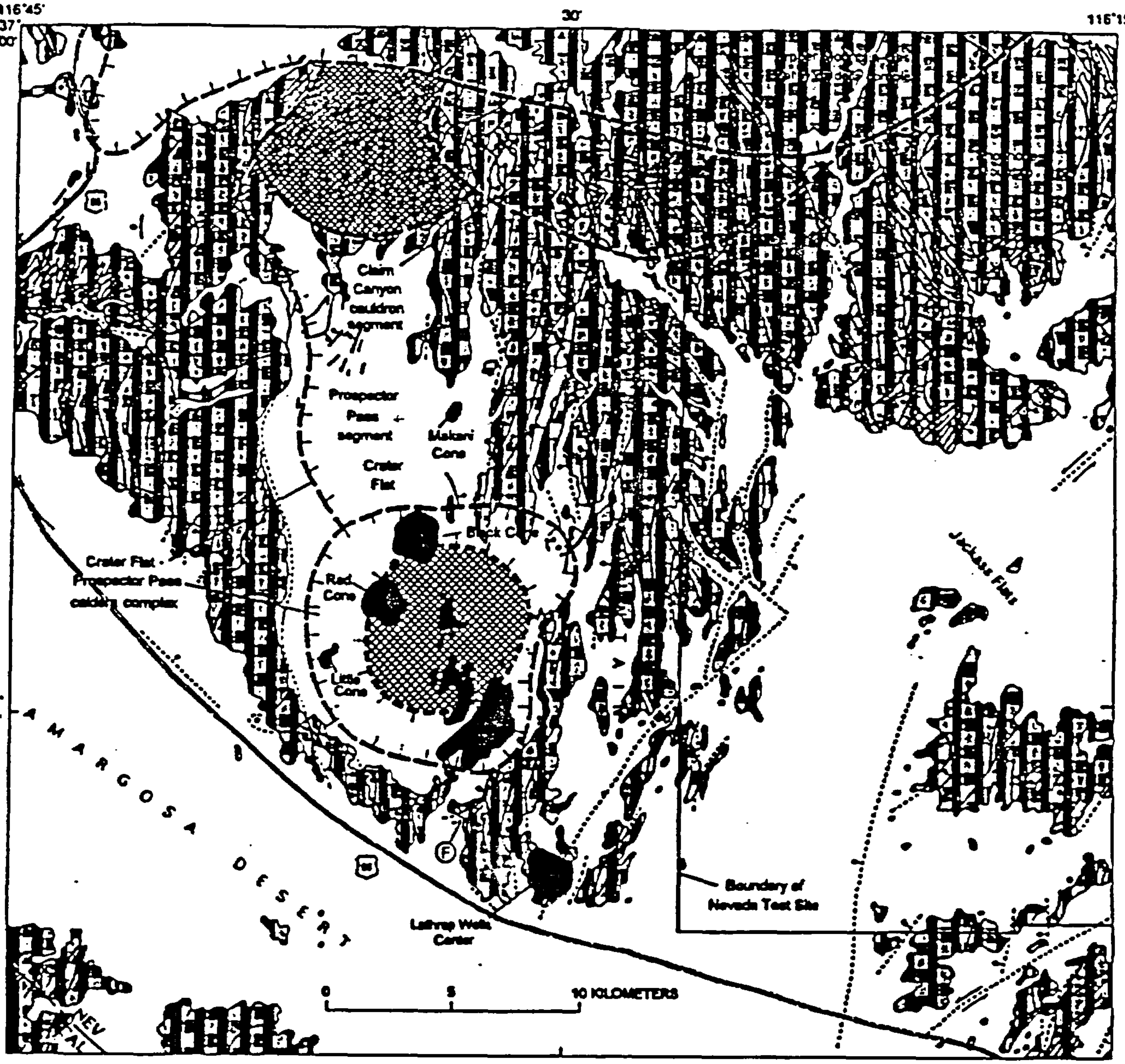


Fig. 3.6 Proposed caldera complexes and Pliocene and Quaternary basaltic volcanic rocks of the Crater Flat area (modified from Carr, 1988). Snyder and Carr (1984), Carr and Parrish (1985), Carr et al (1986) and Carr (1982; 1984; 1988; 1990) propose that the southern part of Crater Flat is underlain by the Crater Flat caldera, and the northern half of the Crater Flat basin is a segment of the larger Prospector Pass caldera. The Pliocene and Quaternary volcanic rocks of Crater Flat occur in the moat zone and across the resurgent dome of the proposed Crater Flat caldera and one center is located in the Prospector Pass caldera segment. The Quaternary basalt centers of the Crater Flat area are located and labeled on the figure.

HOW WILL SEISMIC TOMOGRAPHY DATA BE INCORPORATED IN REPORT?

BASED ON SEISMIC TOMOGRAPHY, EVANS AND SMITH, 1992, SUGGESTED A NORTHEAST TRENDING LOW VELOCITY ZONE, POTENTIALLY A ZONE OF PARTIAL MELT, UNDERLIES THE SITE AREA.

HUMPHRIES, ET AL., 1992, STATES "INTERIOR DOMAIN UPPER MANTLE STRUCTURE IS DOMINATED BY THREE NE-TRENDING LOW-VELOCITY (I.E., PARTIAL MELT) ZONES THAT ARE ASSOCIATED WITH THE VOLCANICALLY ACTIVE YELLOWSTONE, ST. GEORGE, AND JEMEZ TRENDS."

THE REPORT REFERENCES IYER, 1988, AS STATING THAT SEISMIC TOMOGRAPHY HAS BEEN THE MOST SUCCESSFUL GEOPHYSICAL METHOD IN DELINEATING MAGMA IN THE CRUST OR MANTLE.

THE REPORT ASSUMES THE BASALT MAGMA ORIGINATES IN THE UPPER MANTLE AT DEPTHS OF 45 TO 60 KM, THE SAME DEPTH RANGE AS THE INFERRED ZONES OF PARTIAL MELT.

THE SEISMIC REFRACTION PROFILES WHICH ARE USED AS A BASIS TO SUGGEST THAT THE EVANS AND SMITH ANOMALY DOES NOT EXIST ONLY EXTEND TO A DEPTH OF ABOUT 30 KM. (PAGE 134, FOR EXAMPLE)

> IT IS UNCLEAR WHAT INVESTIGATIONS AND ANALYSIS OF THIS POTENTIALLY SIGNIFICANT FEATURE ARE PLANNED

THE STAFF IS UNSURE WHAT CONCLUSIONS SHOULD BE DRAWN FROM MUCH OF THE INFORMATION PRESENTED RELATED TO TECTONICS.

THE REPORT STATES THAT MOST ACTIVE TECTONICS AND VOLCANISM OCCURS IN THE WESTERN AND EASTERN EDGE OF THE GREAT BASIN, AND CONSIDER THAT THE SITE VOLCANISM REFLECT TYPICAL BASIN AND RANGE VOLCANISM, HOWEVER, THE STAFF NOTES THAT THE SITE LIES WITHIN THE WESTERN GREAT BASIN MAGMATIC ZONE, AND WITHIN THE WALKER LANE.

THE REPORT DESCRIBES THE SITE AS BEING WITHIN THE EUREKA LOW WITHOUT NOTING THAT LUNAR CRATER IS WITHIN THE EUREKA LOW.

THE DISCUSSIONS SUGGEST THAT THE SITE IS IN A TECTONIC QUIET ZONE, A ZONE OF LOW STRESS RELIEF, HOWEVER, THE PRESENCE OF NUMEROUS QUATERNARY FAULTS IN THE SITE AREA DEMONSTRATE THE SITE AREA IS STILL ACTIVE.

THE YUCCA MOUNTAIN "ZONE" CONNECTS WITH A ZONE OF LOW ENERGY RELEASE PARALLELING THE FURNACE CREEK FAULT ZONE (ROGERS, ET AL., 87), A ZONE OF RECOGNIZED MAJOR QUATERNARY TECTONISM.

SEVERAL AUTHORS HAVE SUGGESTED THAT EITHER VOLCANIC ACTIVITY OR SEISMIC ACTIVITY COULD SERVE TO RELIEVE STRESS (RYAN, 1991, TAKATDA, 1989)

> IT IS UNCLEAR HOW SUCH INFORMATION SHOULD BE INCORPORATED INTO TECTONIC AND VOLCANOLOGICAL MODELS OF YUCCA MOUNTAIN.

<u>WHAT IS THE RELATIONSHIP OF LATHROP WELLS TO STRUCTURE?</u>

LATHROP WELLS CONE APPEARS TO BE AT THE INTERSECTION OF THE GENERALLY NORTHEAST TRENDING STAGECOACH ROAD FAULT AND THE GENERALLY NORTH TRENDING WINDY WASH - FATIGUE WASH - SOLITARIO CANYON FAULT SYSTEM.

EXAMINATION OF AIR PHOTOS SUGGESTS THAT THE MAIN NORTHERLY TRENDING FISSURE ZONES EITHER LINE UP, OR IS PARALLEL TO, THESE FAULTS.

AN OLD DIKE COMPLEX EXISTS ALONG THE NORTHERN REACHES OF SOLITARIO CANYON

A GEOPHYSICAL ANOMALY WHICH HAS BEEN INTERPRETED AS A POSSIBLE PLUG IS LOCATED ALONG THE SOLITARIO CANYON FAULT SYSTEM AT THE PROPOSED SOUTHERN END OF THE REPOSITORY.

A SPATIAL RELATIONSHIP EXISTS BETWEEN THE WINDY WASH FAULT SYSTEM AND THE 3.7 MILLION YEAR OLD BASALTS.

> IT IS UNCLEAR HOW VOLCANOLOGICAL MODELS COULD INCORPORATE THE CONCEPT THAT THE WINDY WASH - SOLITARIO CANYON FAULT SYSTEM REPRESENTS A ZONE OF STRUCTURAL CONTROL OF VOLCANISM.

Comments on:

Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project.
(Preliminary Draft)

B.M. CROWE, F.V. PERRY, G.A. VALENTINE

Presented by: **TK BRADSHAW**

Center for Volcanic & Tectonic Studies
Department of Geoscience
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas
NV 89154-4010, USA

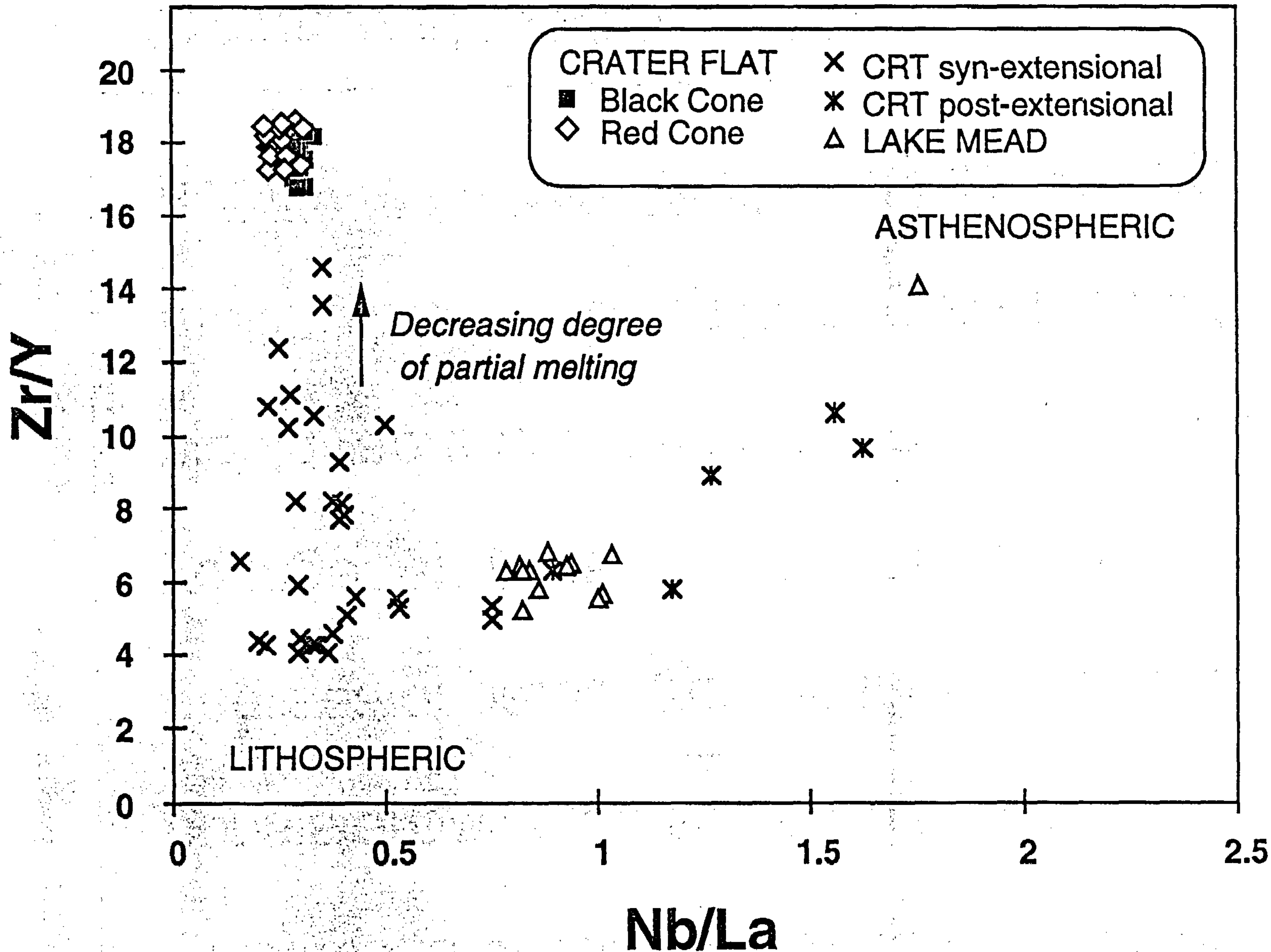
e-mail: bradshaw@redrock.nevada.edu

Main Points

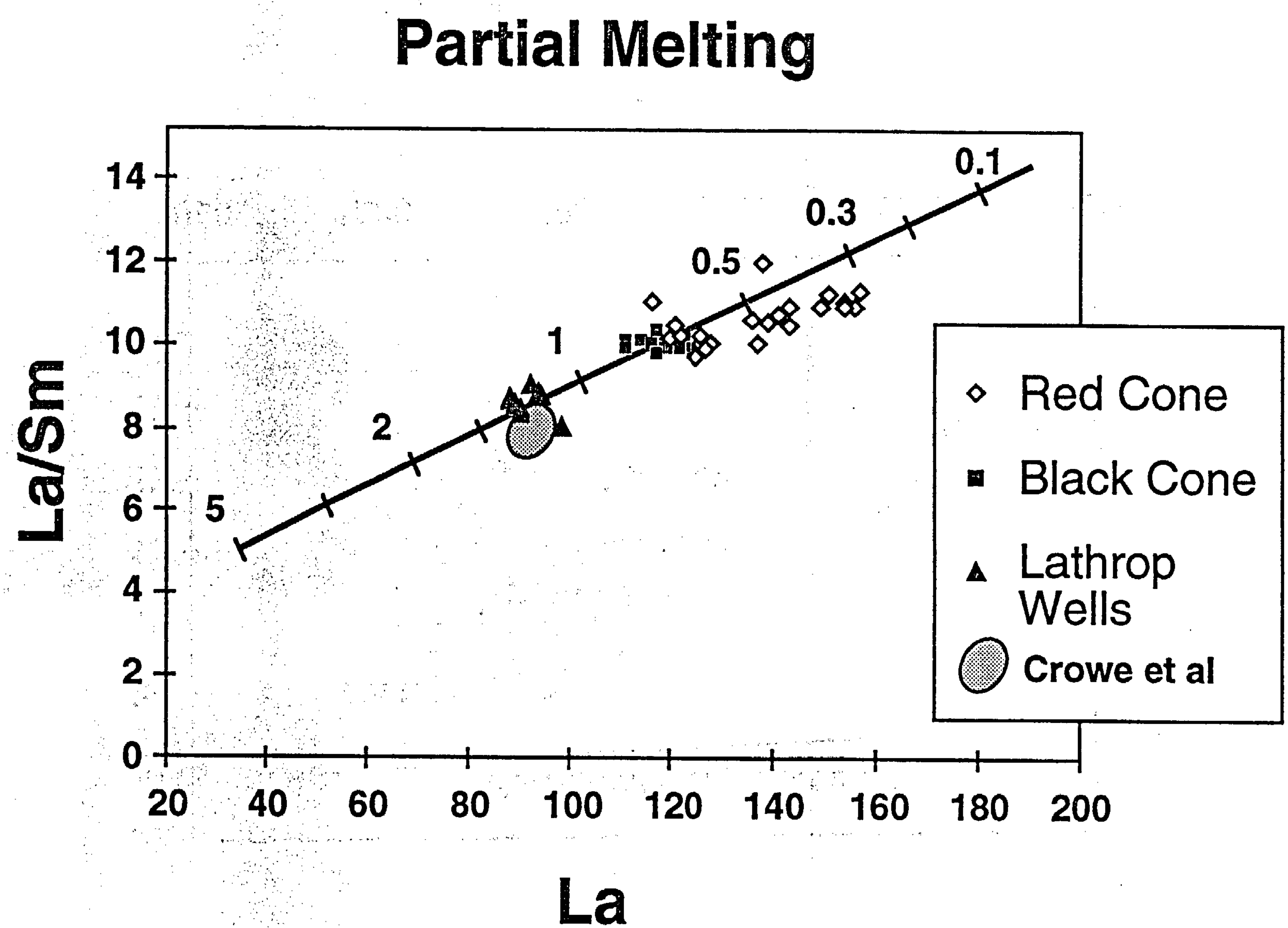
- ☐ Degree of partial melting and relationship to waning volcanism.
- ☐ Magma mixing and hybridization.
- ☐ Polycyclic volcanism and recurrence rates.
- ☐ Hydrovolcanic activity.

"Variations of La/Sm with La are, however, consistent with......slightly different degrees of partial melting in the mantle..... younger eruptive units at Lathrop Wells would represent smaller degrees of partial melting than older units, suggesting that activity at Lathrop Wells may be waning."

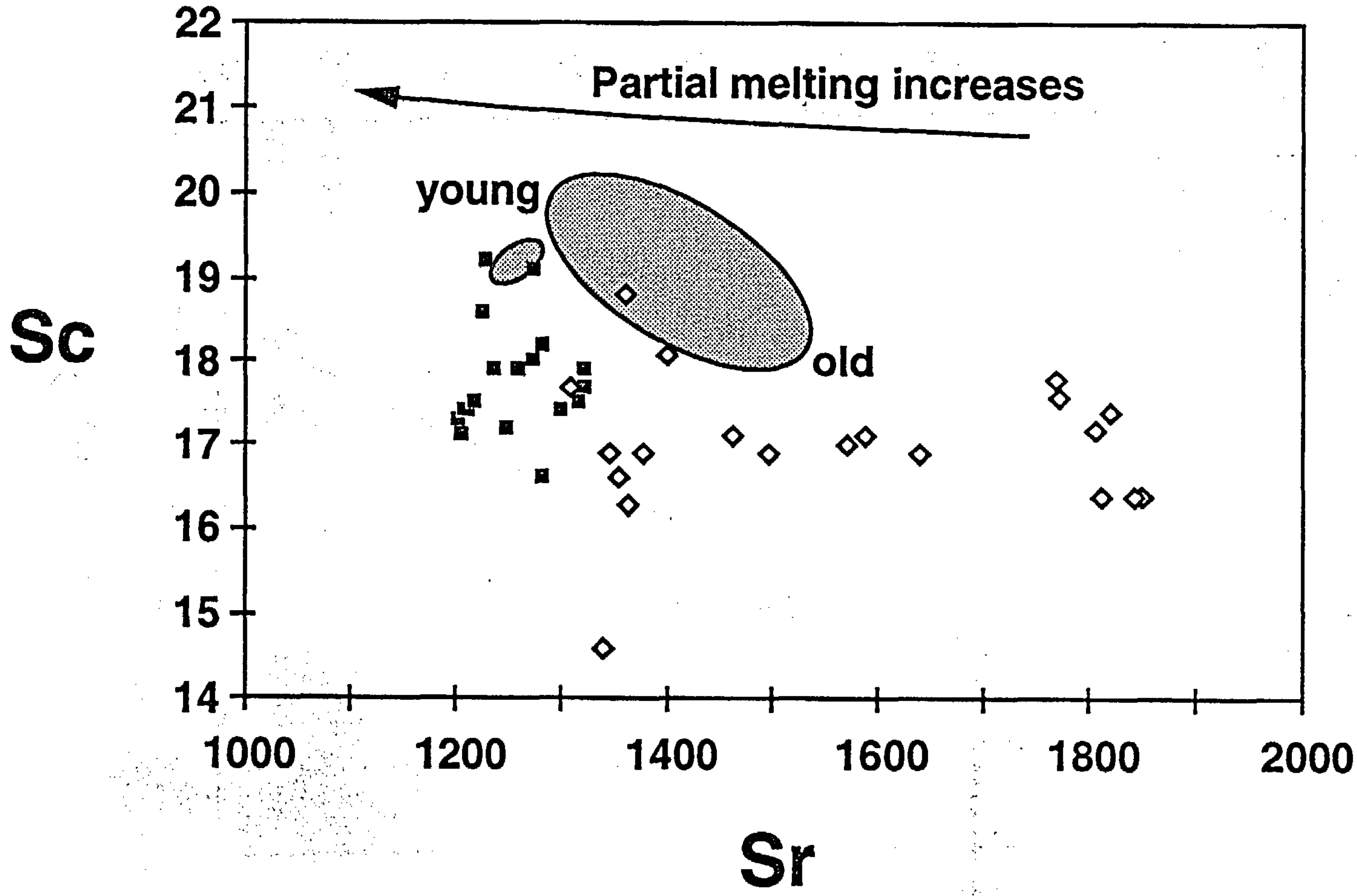
Crowe et al 1993 (pg 168)



CRATER FLAT
Black Cone
Red Cone
CRT syn-extensional
CRT post-extensional
LAKE MEAD
ASTHENOSPHERIC
Decreasing degree of partial melting
LITHOSPHERIC
Zr/Y
Nb/La
0
2
4
6
8
10
12
14
16
18
20
0
0.5
1
1.5
2
2.5

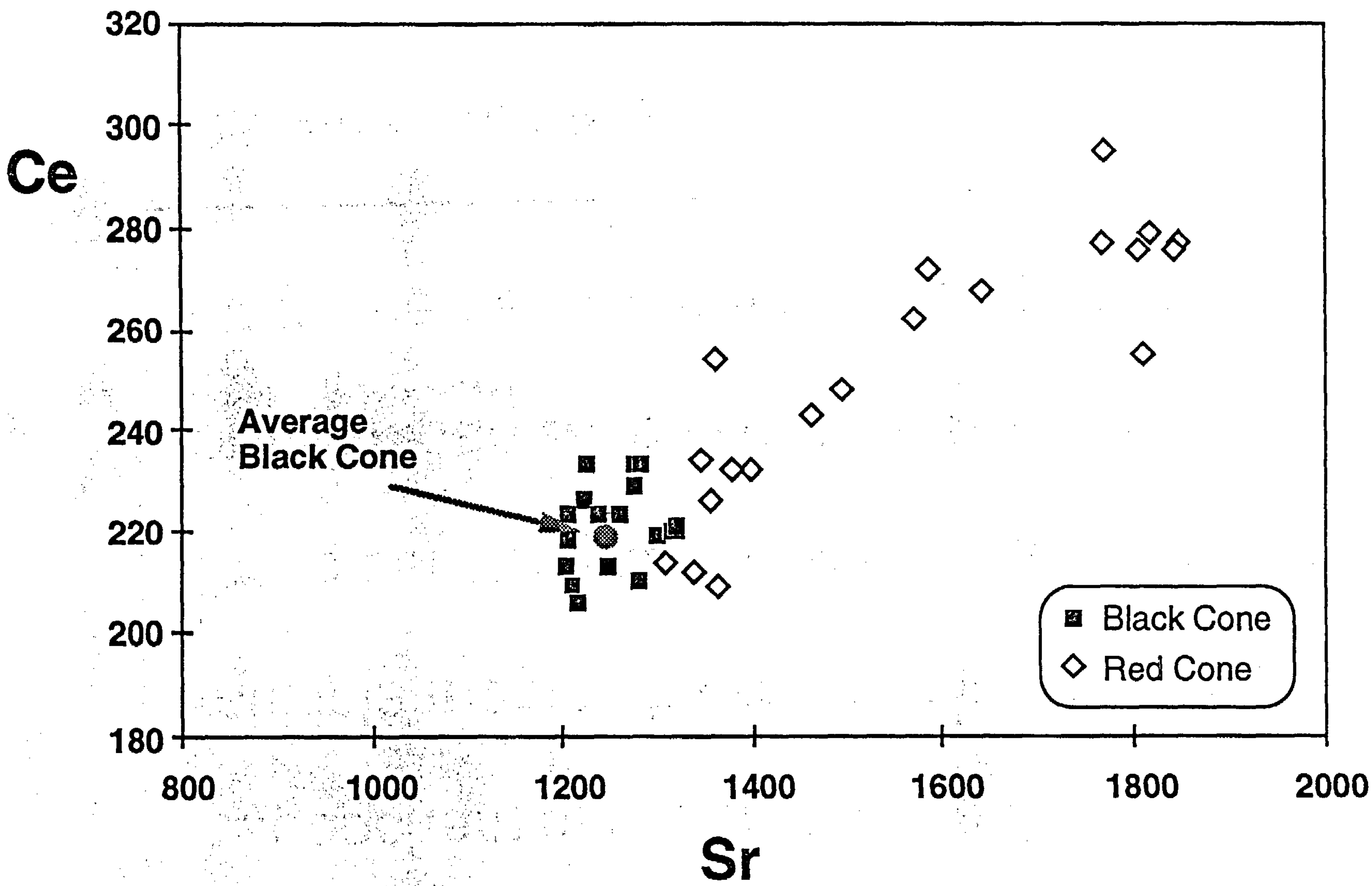


Partial Melting
La/Sm
La
0.1
0.3
0.5
1
2
5
Red Cone
Black Cone
Lathrop Wells
Crowe et al

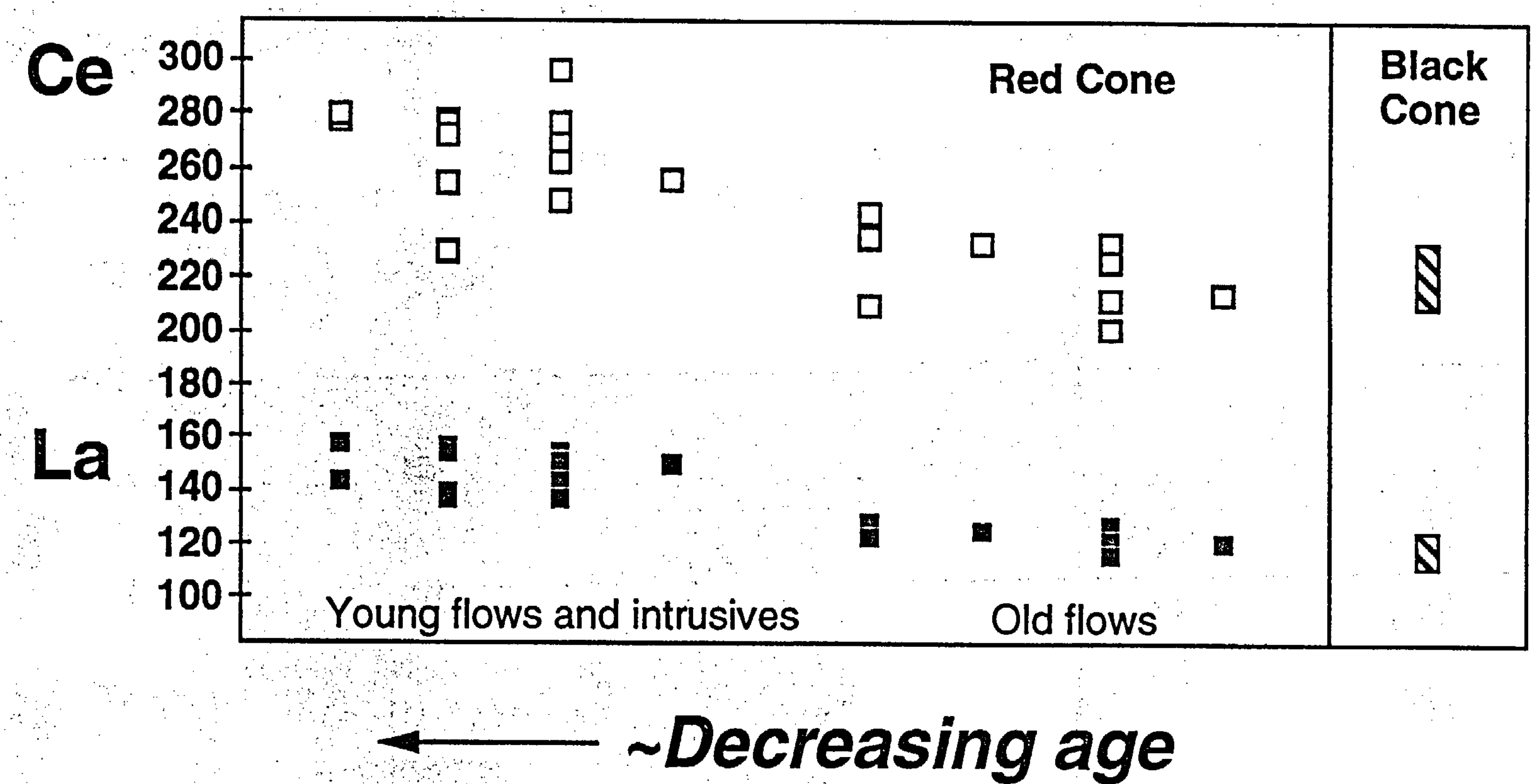

22
21
20
19
18
17
16
15
14
Partial melting increases
young
old
Sc
1000
1200
1400
1600
1800
2000
Sr

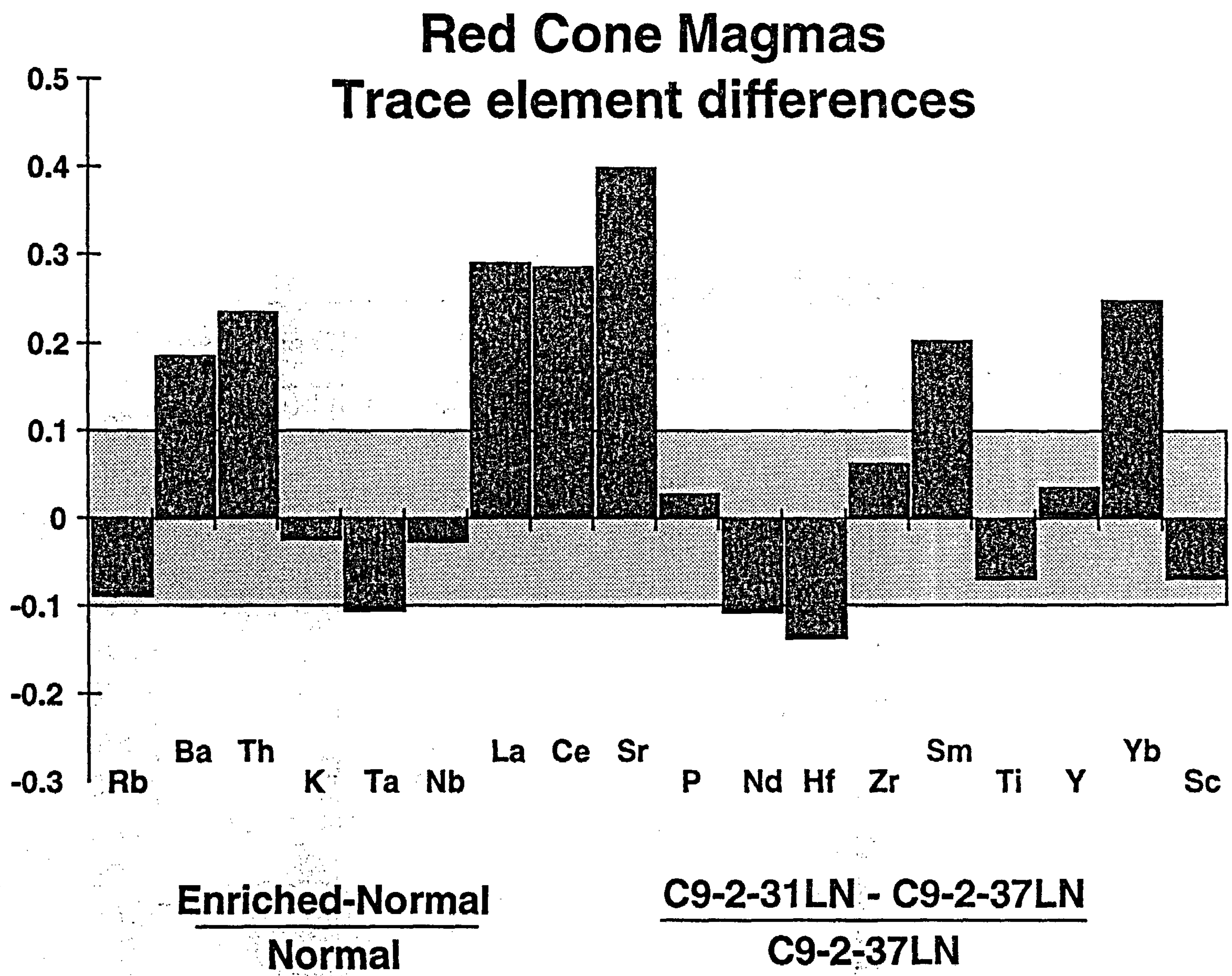
"...geochemical data indicate that multiple magma batches erupted to form these centres with no evidence for mixing or homogenization of magmas, suggesting long time periods between eruptions"

Crowe et al 1993 (pg 156)



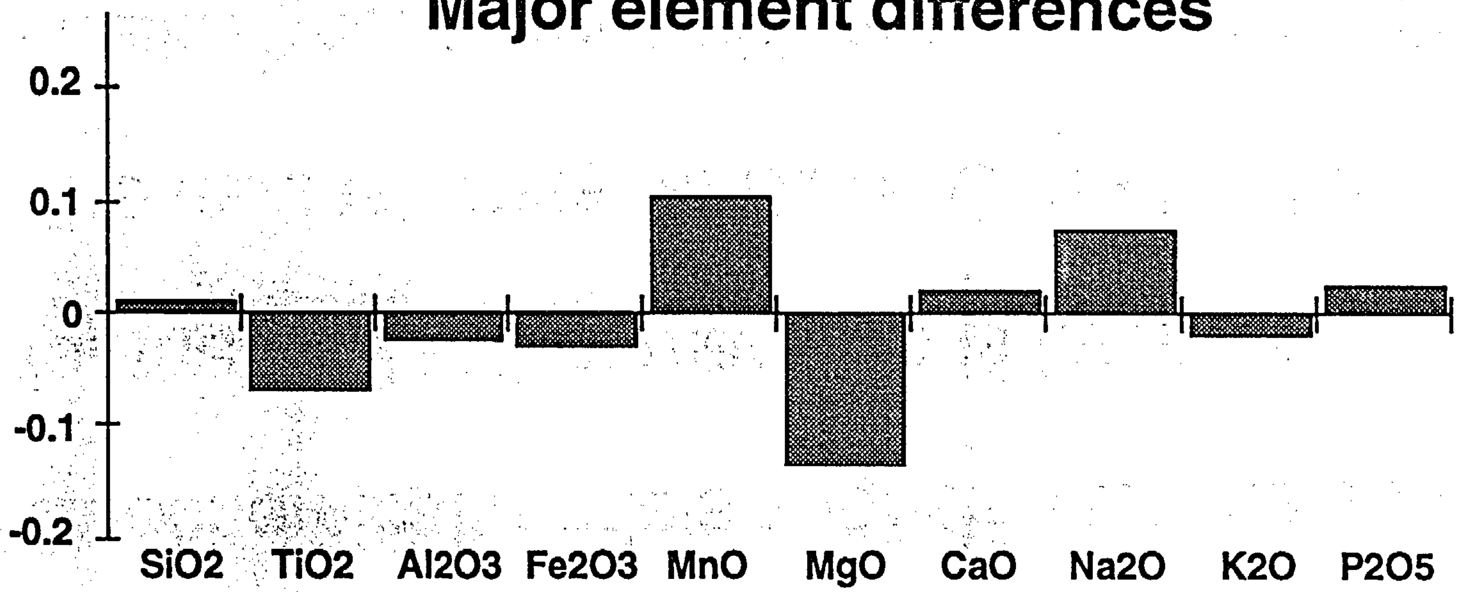
Ce
320
300
280
260
240
220
200
180
Average
Black Cone
Black Cone
Red Cone
800
1000
1200
1400
1600
1800
2000
Sr


Ce
La
300
280
260
240
220
200
180
160
140
120
100
Red Cone
Black Cone
Young flows and intrusives
Old flows
~Decreasing age



Red Cone Magmas
Trace element differences
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Rb
Ba
Th
K
Ta
Nb
La
Ce
Sr
P
Nd
Hf
Zr
Sm
Ti
Y
Yb
Sc
Enriched-Normal / Normal
C9-2-31LN - C9-2-37LN / C9-2-37LN

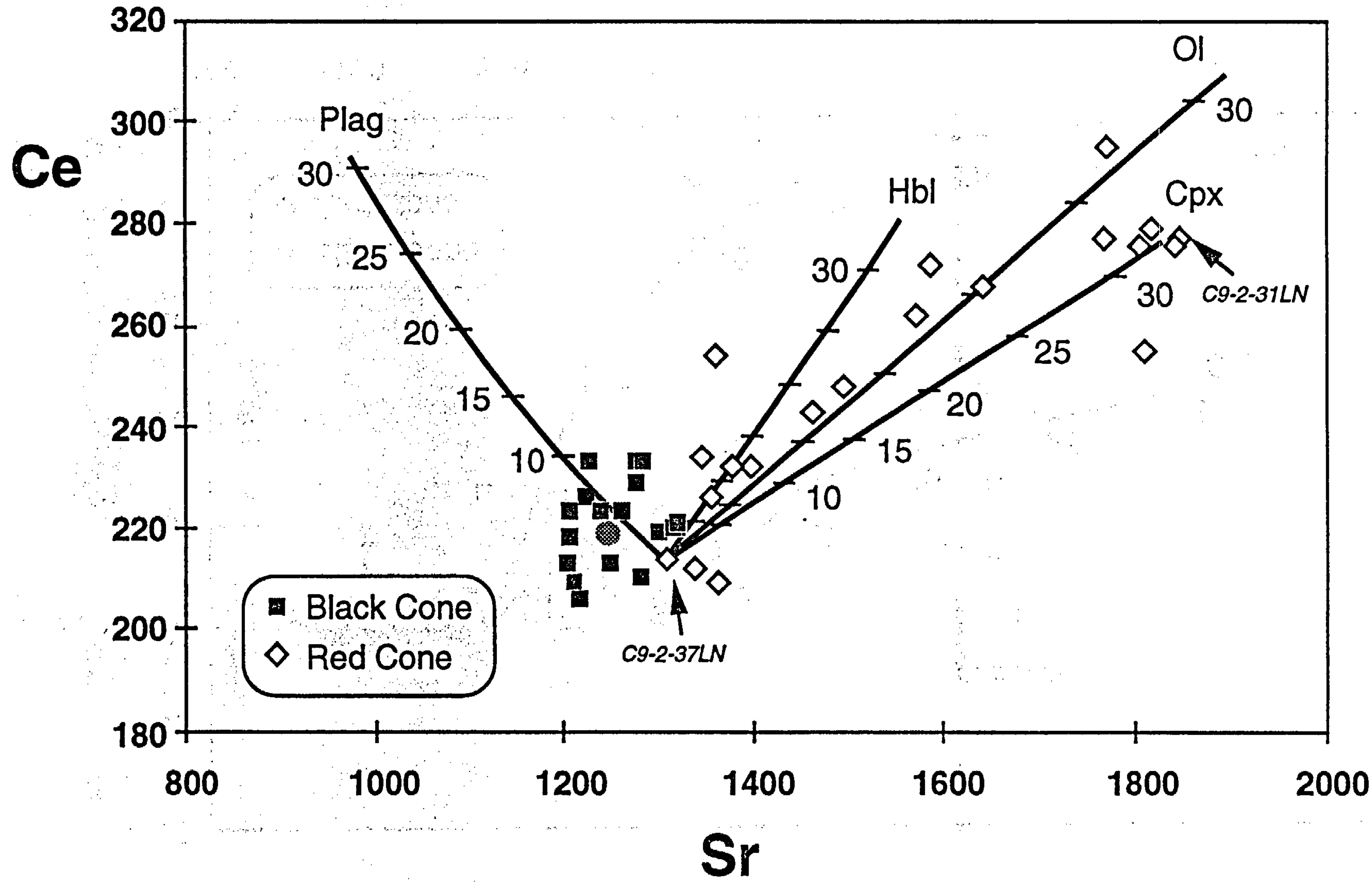
Red Cone Magmas
Major element differences



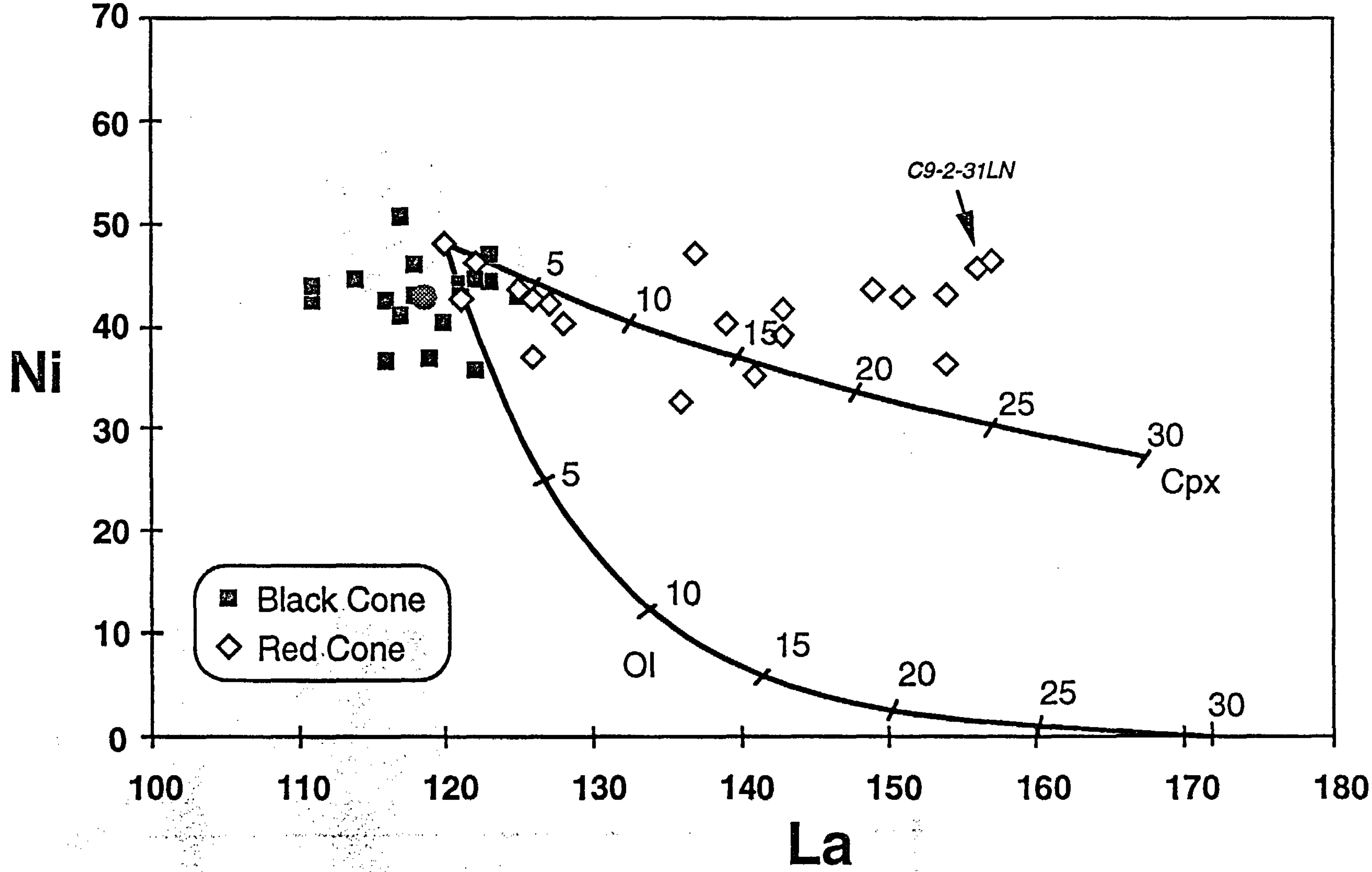
$$\frac{\text{Enriched-Normal}}{\text{Normal}} \qquad \frac{\text{C9-2-31LN - C9-2-37LN}}{\text{C9-2-37LN}}$$

Hydrovolcanic activtiy should not be ruled out because:

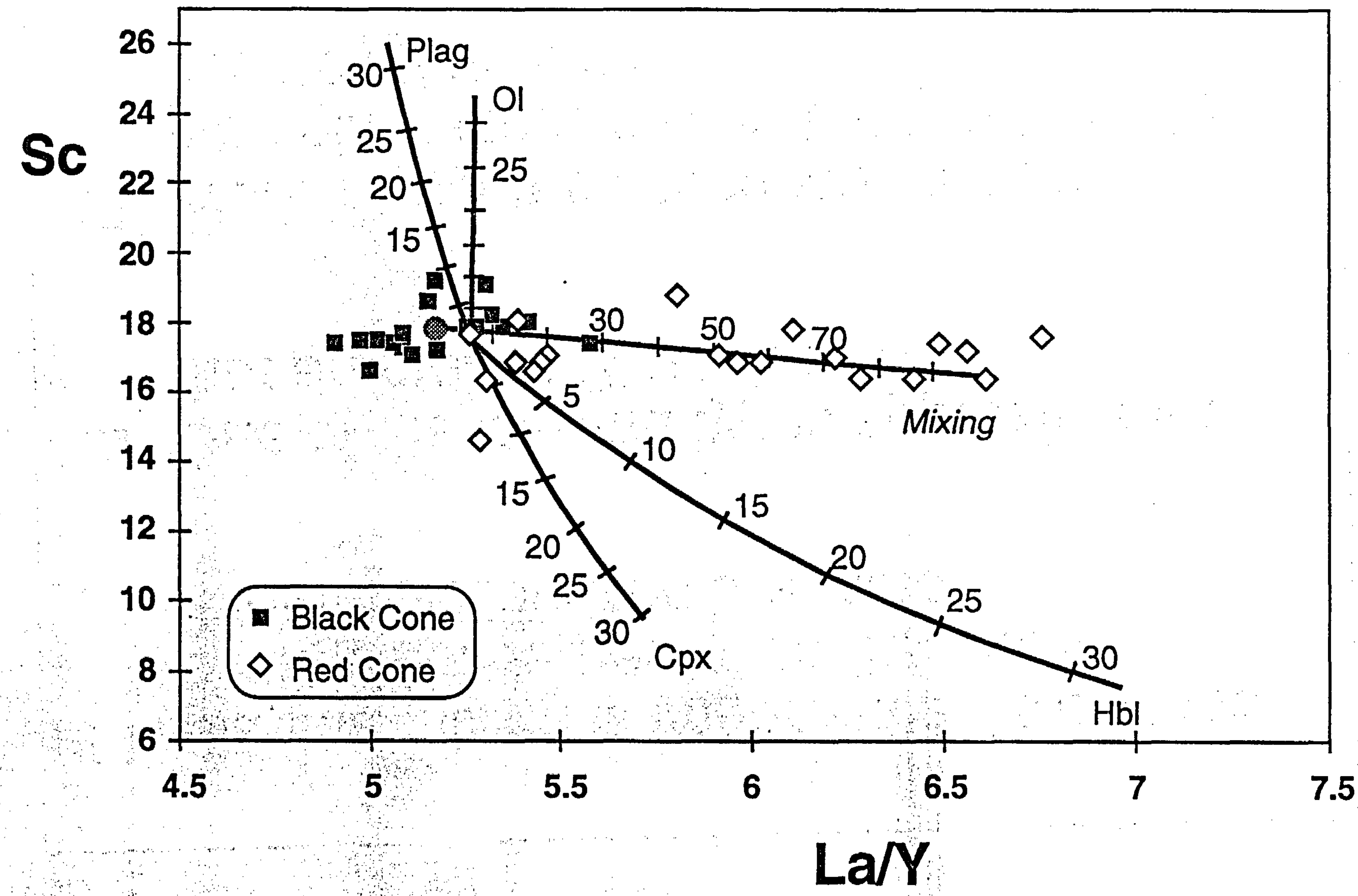
- ☐ Geochemical models suggest that the source for the Crater Flat magmas is hydrous.
- ☐ The earliest crater at Black Cone is wide and shallow, consistent with hydrovolcanic activity.



Ce
Sr
Plag
Hbl
Ol
Cpx
C9-2-31LN
C9-2-37LN
Black Cone
Red Cone
320
300
280
260
240
220
200
180
800
1000
1200
1400
1600
1800
2000



Ni
La
70
60
50
40
30
20
10
0
100
110
120
130
140
150
160
170
180
C9-2-31LN
Cpx
Ol
5
10
15
20
25
30
Black Cone
Red Cone


Sc
La/Y
26
24
22
20
18
16
14
12
10
8
6
4.5
5
5.5
6
6.5
7
7.5
Plag
30
25
20
15
Ol
25
30
50
70
Mixing
5
10
15
20
25
30
Cpx
15
20
25
30
Hbl
Black Cone
Red Cone

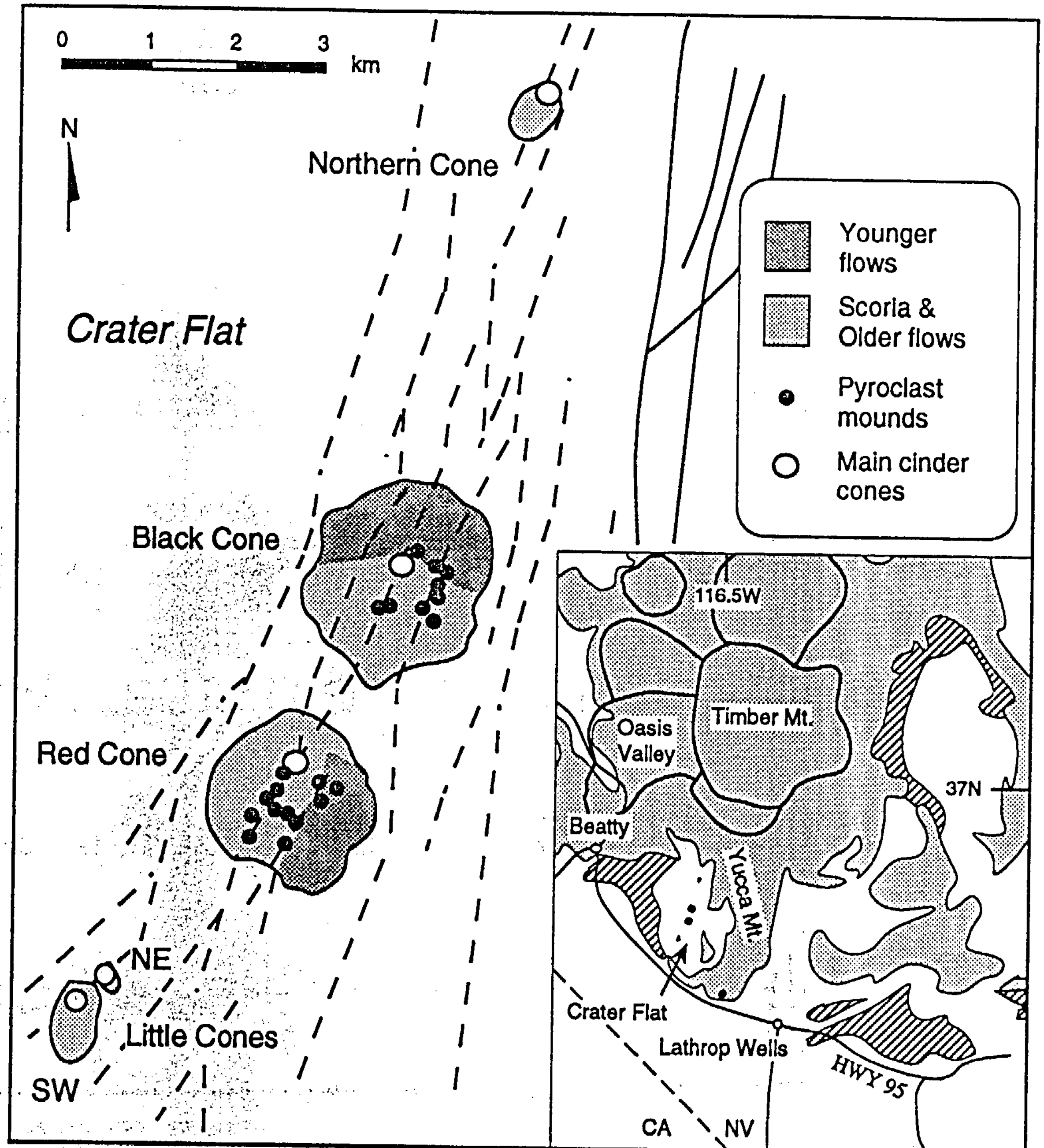
- ☐ Magma mixing is important at Red Cone-changes in degree of partial melting and/or fractionation are minor.
- ☐ One of the magma types approximates that erupted at Black Cone.
- ☐ Work in progress suggests that magma type differences are probably related to source mineralogy.

- Magmatism in Crater Flat is not just polycyclic, but polygenetic too. Thus, individual magmatic "events" (such as satellite vents) *may* be independent.
- Independent events must be considered in the estimation of E1- recurrence rate.

"The formation of satellite vents or polycyclic events at an existing centre does not represent a risk of an eruption at a new location."

Crowe et al 1993 (pg 257)

- Geochemical evidence from Crater Flat indicates that magmatic plumbing systems may have been linked.
- Activity may occur at other localities along the magmatic feeder zone (NE-SW), thus forming a volcanic chain.


0
1
2
3
km
N
Northern Cone
Crater Flat
Black Cone
Red Cone
NE
Little Cones
SW
Younger flows
Scoria & Older flows
Pyroclast mounds
Main cinder cones
116.5W
Oasis Valley
Timber Mt.
37N
Beatty
Yucca Mt.
Crater Flat
Lathrop Wells
HWY 95
CA
NV

"The exclusion of hydrovolcanic activity... based on the considerable depth of the water table..... and the low moisture content of most rocks above the water table "

Crowe et al 1993 (pg 208)

Conclusions

- ☐ Degree of partial melting *may* actually be increasing with time.
- ☐ Magma mixing is an important process.
- ☐ Polygenetic events need to be included in recurrence rate calculations.
- ☐ Hydrovolcanic activity is a distinct possibility.

DOE-NRC Technical Exchange on Volcanism Studies

Comments by

Eugene I. Smith
Center for Volcanic and Tectonic Studies
Department of Geoscience
University of Nevada, Las Vegas
Las Vegas, NV 89154

(702) 895-3971
(702) 895-4064 FAX
eismith@redrock.nevada.edu (internet)

June 9, 1993 ——— *CVTS* —

DOE-NRC Technical Exchange on Volcanism Studies

Comments by

Eugene I. Smith
Center for Volcanic and Tectonic Studies
Department of Geoscience
University of Nevada, Las Vegas
Las Vegas, NV 89154

(702) 895-3971
(702) 895-4064 FAX
eismith@redrock.nevada.edu (Internet)

June 9, 1993 ——— *CVTS*—

Purpose of Studies

Provide geological data that can be used in risk assessment studies.

——— *CVTS*—

Questions

- Are NW or NE trends more important for controlling volcanism near Yucca Mountain?
- Is there a southward migration of volcanism into the Yucca Mountain area (late Miocene-Quaternary)?
- Is the Risk Zone model proposed by Smith et al. (1990) a reasonable concept?
- What is the definition of a volcanic event?
- How can structural models be integrated into probabilistic models of risk determination?

——— *CVTS*—

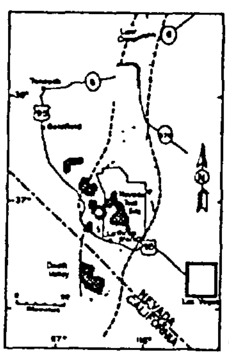
Distribution of Miocene to Quaternary Volcanism in the Yucca Mountain Area

... a southwest migration or more correctly, a southwestward stepping, through time of basaltic activity (late-Miocene to Quaternary).

p. 115

CVTS

Regional Volcanism

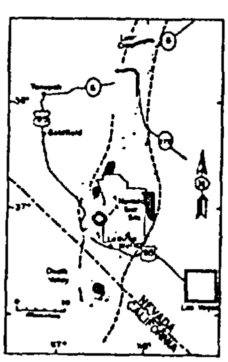


12 to 10 Ma

O Yucca Mountain

CVTS

Regional Volcanism

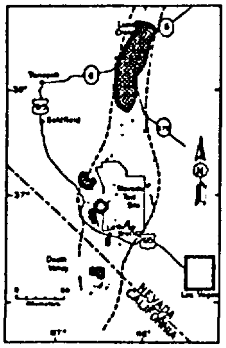


10 to 6 Ma

O Yucca Mountain

CVTS

Regional Volcanism

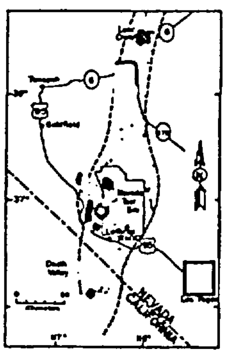


6 to 3 Ma

O Yucca Mountain

CVTS

Regional Volcanism



3 Ma to Present

O Yucca Mountain

CVTS

Focus of Volcanism near Yucca Mountain

- 11 Ma basalts occur in SW Crater Flat and as dikes associated with the Solitario Canyon Fault. Also in the ring fracture of Timber Mountain Caldera
- 3.7 Ma basalts occur in SE crater
- 1.1 Ma basalts in Crater Flat
- 0.05 to 0.13 Ma basalt at Lathrop Wells

CVTS

Conclusion

Area adjacent to Yucca Mountain was the focus of volcanism for the last 12 Ma

———CVTS—

The younger basalt cycle of the post-caldera basalt episode occurs in a northwest-trending zone called the Crater Flat volcanic zone (CFVZ).

p. 89

———CVTS—

Quaternary basalt sites do not appear to be controlled by or follow prevailing structural control.

p. 89

———CVTS—

Important Point

North-northeast striking structures are the major control of volcanism for the last 12 Ma

CVTS

Structural Control of Volcanism

- 11.66 Ma dike intruded along NS striking Solitario Canyon fault
- 8.5 to 6 Ma NE and NW structures
- 3.7 Ma basalts - NS structures
- 1.1 basalt - NE structures
- <1 Ma centers - NE and NW

CVTS

Structural Control of 1.1 Ma Volcanoes in Crater Flat

Faults in bedrock strike north-northeast and may continue into Crater Flat

At least one fault required between VH-2 and exposures of Paintbrush Tuff just east of Black Cone

NE segments are perpendicular to the least principle stress direction and may control the location of volcanoes

CVTS

Structural Control of 1.1 Ma Volcanoes In Crater Flat

NW striking faults and lineaments cross Quaternary surfaces In northern Crater Flat and Intersect the chain of Crater Flat volcanoes just to the north of Black Cone (Faulds et al. in press)

Magma did not use these structures as primary conduits even though they were available at the time of formation of the Crater Flat chain

Magma may have leaked up along NW structures to form local NW alignments of scoria mounds

——— *CVTS*—

Structural Control of 1.1 Ma Volcanoes In Crater Flat

Geochemical Studies Indicate that the magmatic plumbing systems for Red Cone and Black Cone were linked during part of their eruption (Bradshaw and Smith, In review Journal of Geophysical Research)

Several volcanoes were active along the Crater Flat chain at the same time. Coeval magma pulses used NE rather than NW structures to come to the surface

——— *CVTS*—

Buckboard Mesa:

The lavas were erupted mainly from a scoria cone in the northwest part of the outcrop area (Scrugham Peak). Additional lava flows vented from a fissure that extends southwest for about five km from the base of Scrugham Peak. This fissure is marked by a subdued linear ridge..and by the presence of scoria and agglutinated spatter...

p. 31

——— *CVTS*—

Buckboard Mesa

- Volcanism controlled by intersection of NE striking faults and ring fault of the Timber Mountain caldera
- NE striking faults control location of vent. Fault continues to the north onto Pahute Mesa NW lobe extending along axis of moat is a flow lobe
- Scoria in walls of chemical explosion crater to SE of main cone is a rootless vent

———— CVTS—

The northeast direction is the preferential direction of alignment of post-Pliocene volcanic centers in the Yucca Mountain region (Crowe et al., 1993)

———— CVTS—

Walker Lane and Volcanism

The Walker Lane was an important structure in the ~~eastern~~ western Great Basin from 15 Ma to the present

Even though these NW structures were available for rising magmas few volcanic features took advantage of them

———— CVTS—

Conclusion

NE structures are more important for controlling volcanism near the Yucca Mountain block than NW trends

NE faults are the dominant control of volcanism

Even if NW faults control ascent of magma at depth it is the NE faults that control ascent within the Miocene to younger section. Therefore the NE structures are more important for risk assessment.

——CVTS—

Regional Importance of Northeast-trending Structures

NE structural fabric is regional and extends from the Death Valley area to the Pancake Range

——CVTS—

Distribution of Quaternary Volcanism in the Great Basin

Eastern Margin- (e.g., Grand Wash and St. George Fields).

Western Margin- (e.g., Independence Field, Clayton Valley centers, Death Valley, Walker Lane).

Central Great Basin- (e.g., Central Nevada Volcanic Belt).

——CVTS—

Central Nevada Volcanic Belt

- Parallels:
  - c1. Western margin of the Precambrian Craton based on Nd data (DePaolo, 1983).
  - c2. Concentration of Tertiary calderas (Best et al., 1989).
  - c3. Railroad Valley, the deepest basin in the central Great Basin.

———CVTS—

Central Nevada Volcanic Belt

- Parallels:
  - ☐A belt of crustal thickening
    - » Sonoman Orogeny (late-Permian—early-Triassic).
    - » Antler Orogeny (late-Devonian—early Mississippian).
    - » Jurassic-Cretaceous Orogeny
  - ☐Crust is still thicker in central Great Basin even after Tertiary crustal extension (COCORP Studies).

———CVTS—

Conclusion

Central Nevada Volcanic Belt corresponds to an area of the Great Basin with a unique tectonic and magmatic history.

It is not a fortuitous alignment of Pliocene-Quaternary volcanoes.

———CVTS—

There is a 0% success rate using older sites of volcanic activity (Pliocene) to predict the location of sites of younger centers sites (Quaternary) using the criteria of Smith et al. (1990).

p. 222

CVTS

Risk Zones

AMRV is equivalent in concept to the Crater Flat Zone. It surrounds all known volcanism 4.4 Ma to the present

Risk zones are areas of greater volcanic risk within the AMRV. There are no equivalent zones proposed for the Crater Flat Zone

Risk zones are intended to predict sites of future activity and not to outline locations of previous volcanism

CVTS

Important Point

The Area of Most Recent Volcanism and NE trending risk zones (Smith et al., 1990) provide a reasonable model for the prediction of the location of future eruptions near Yucca Mountain

CVTS

Conclusions

- Volcanism focused in Crater Flat-Yucca Mountain area for at least 12 Ma
- Northeast direction is the preferential direction of alignment of post-Pliocene volcanic centers in the Yucca Mountain region
- Northeast structural fabric is regional and extends from Death Valley to the Pancake Range
- AMRV and risk zones produce a reasonable predictive model for volcanism in the Yucca Mountain region

——— CVTS—

Recommendations and Questions

Geophysics, structural geology, tectonics and volcanology must be better integrated

——— CVTS—

A preferred strategy to attempt to quantify the risk of future volcanism is to use a probabilistic approach....

p. 248

——— CVTS—

Recommendations and Questions

Specifically, how are structural models to be integrated into risk calculations?--The best risk calculation may be based on a combined deterministic-probabilistic model

CVTS

Ho et al. (1991)...defined E to include polycyclic events not the formation of a new volcanic center (see Crowe et al. 1992a). Their definition does not maintain the event independence required for the Poisson model.

p. 225

CVTS

Recommendations and Questions

If cinder cones are polygenetic then each geochemically distinct pulse of magma is independent and should be considered as a single event.

CVTS

There is a general tendency for basalt centers to occur in alluvial basins and not range interiors.

p. 90

CVTS

Recommendations and Conclusions

Volcanic and tectonic studies at Yucca Mountain must be placed in a regional perspective.

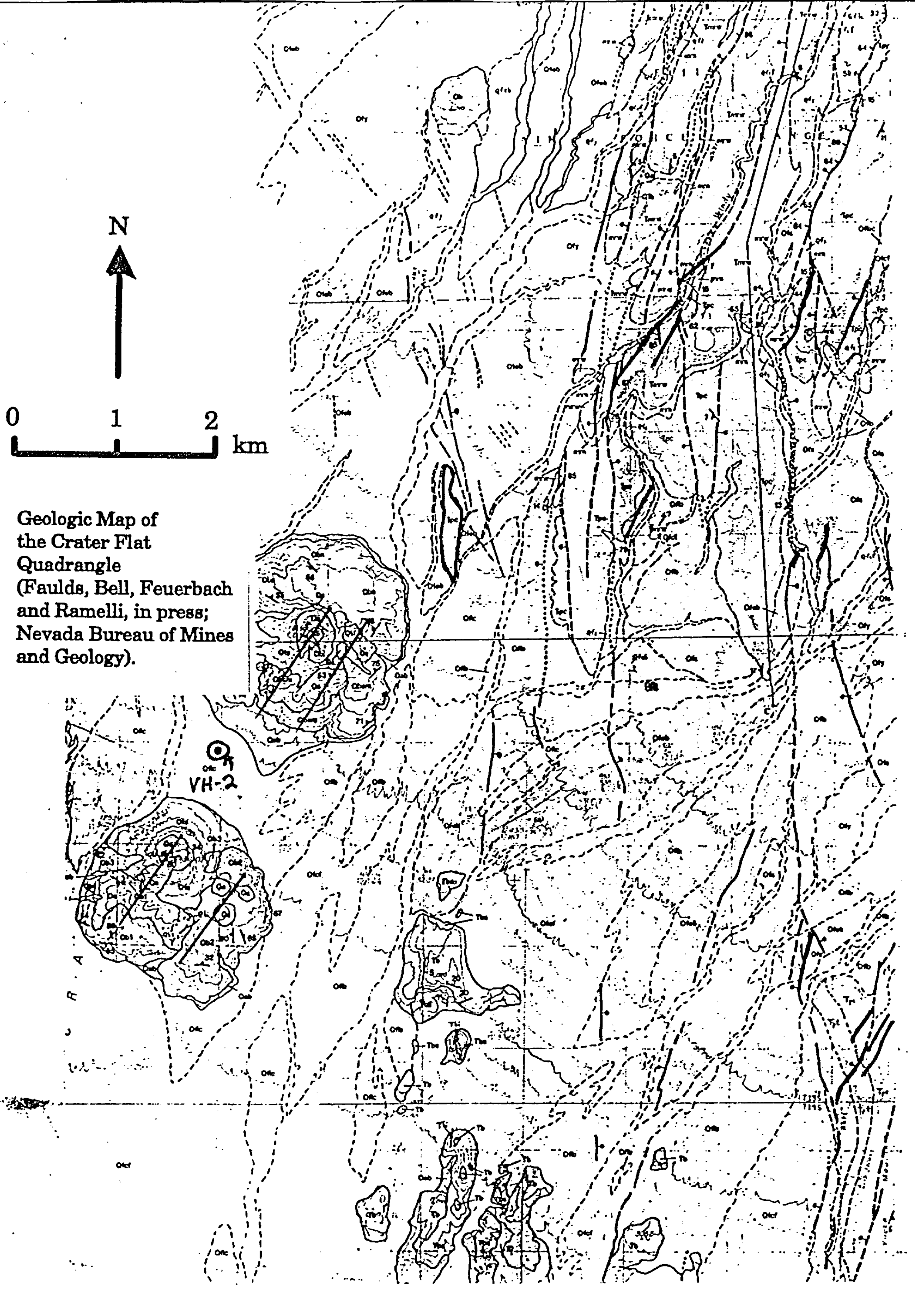
For example, in the Reveille Range Martin (1993) demonstrated that 30% of Pliocene basalt vents occur within the range. Several vents occur at the crest of the range.

CVTS

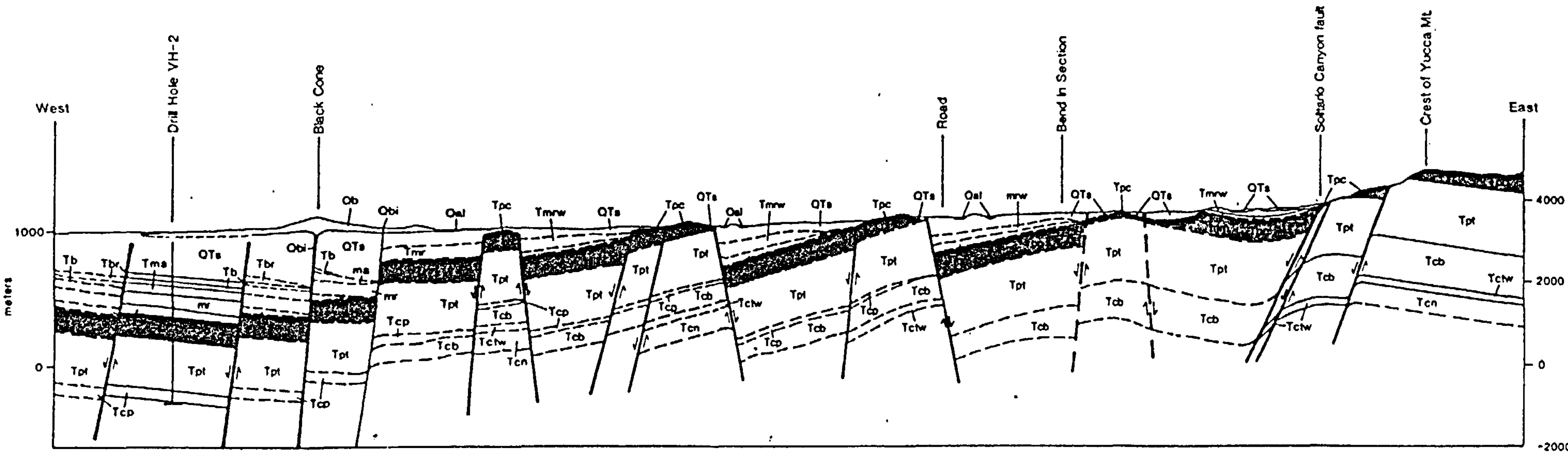
Recommendations and Questions

Research should focus on the eruptive history of cinder cones. Are polygenetic cones common or rare?

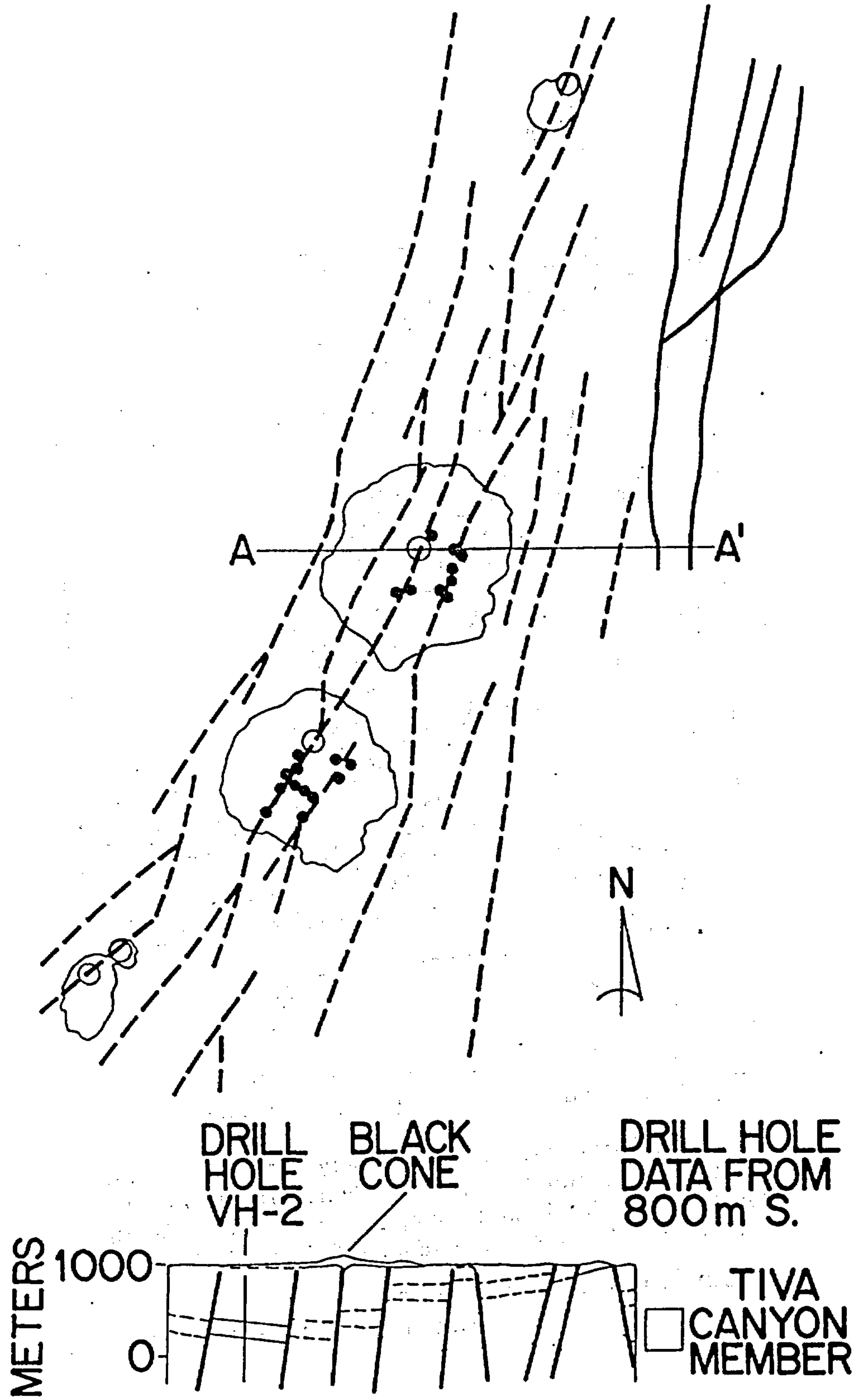
CVTS



Geologic Map of the Crater Flat Quadrangle (Faulds, Bell, Feuerbach and Ramelli, in press; Nevada Bureau of Mines and Geology).



Drill hole data projected from 800 m to the south


A
A'
N
DRILL HOLE VH-2
BLACK CONE
DRILL HOLE DATA FROM 800m S.
METERS
1000
0
TIVA CANYON MEMBER

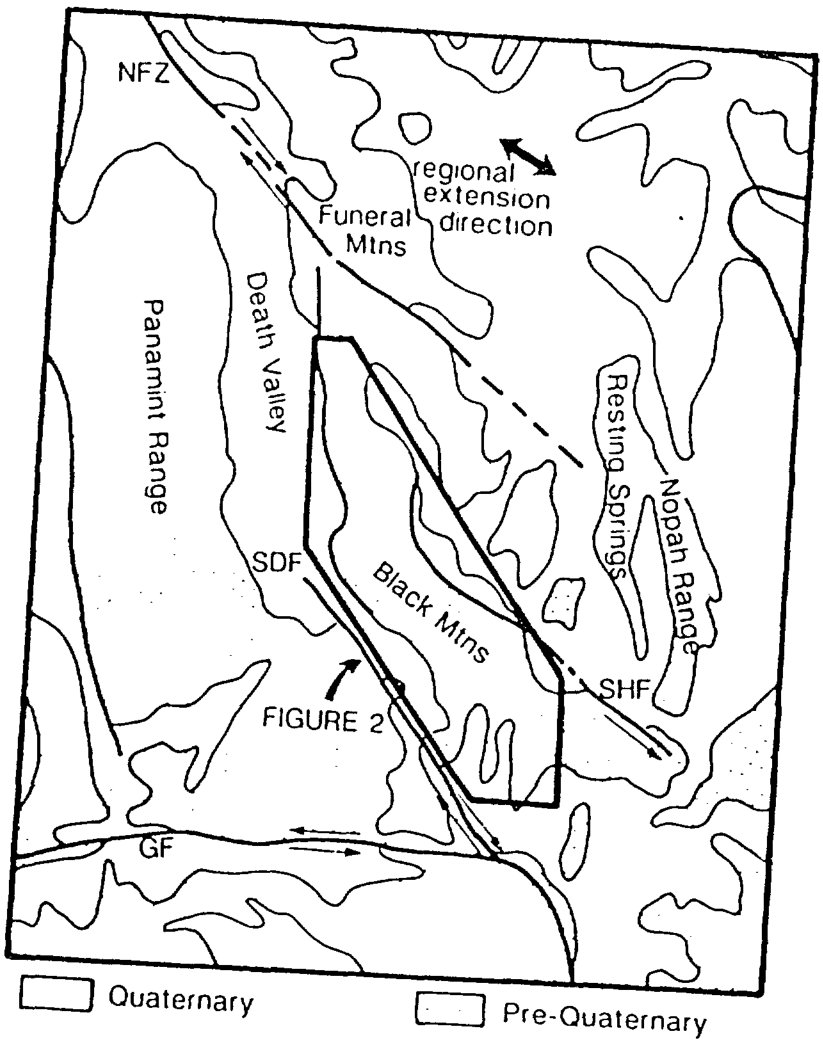
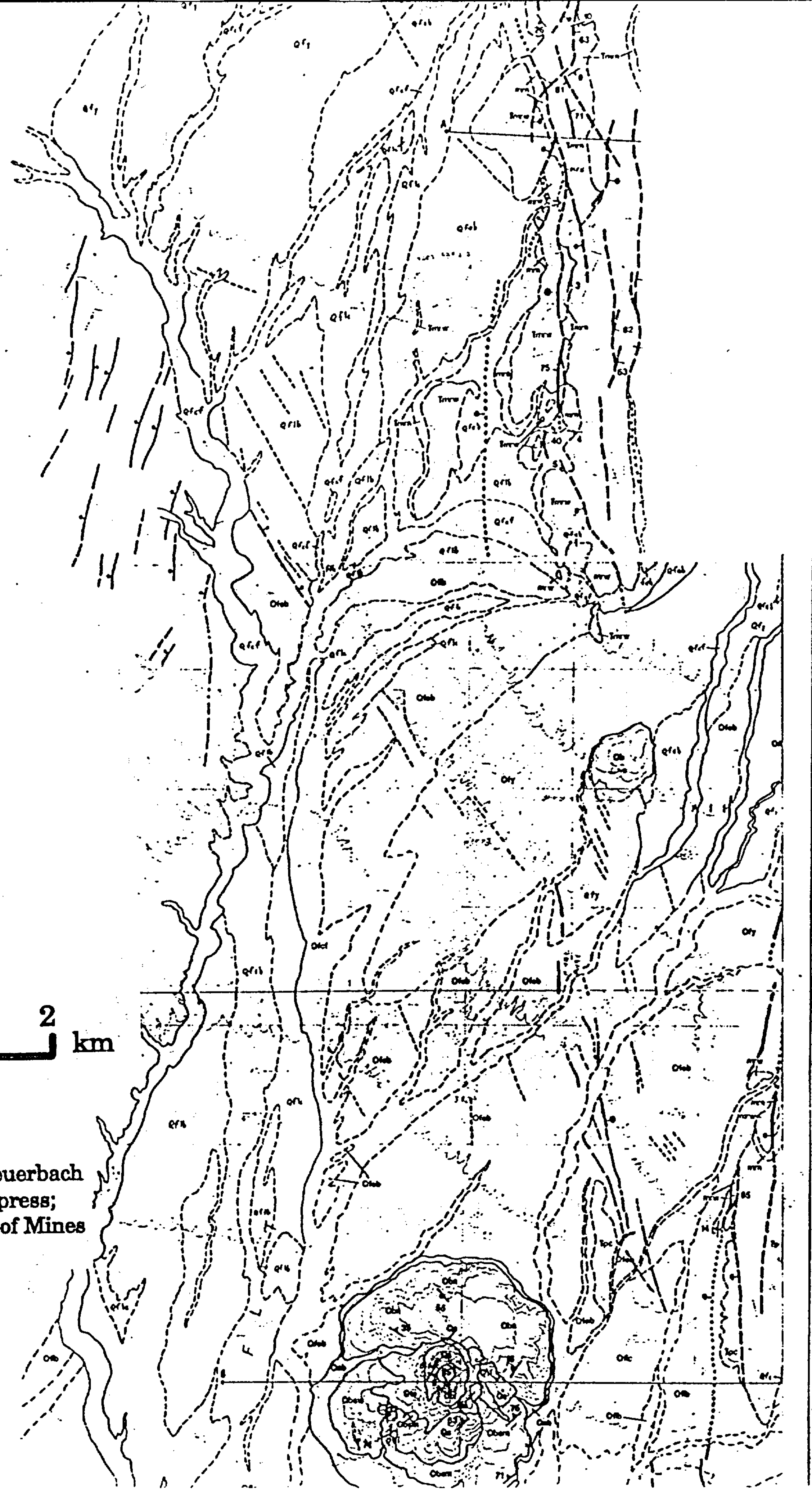


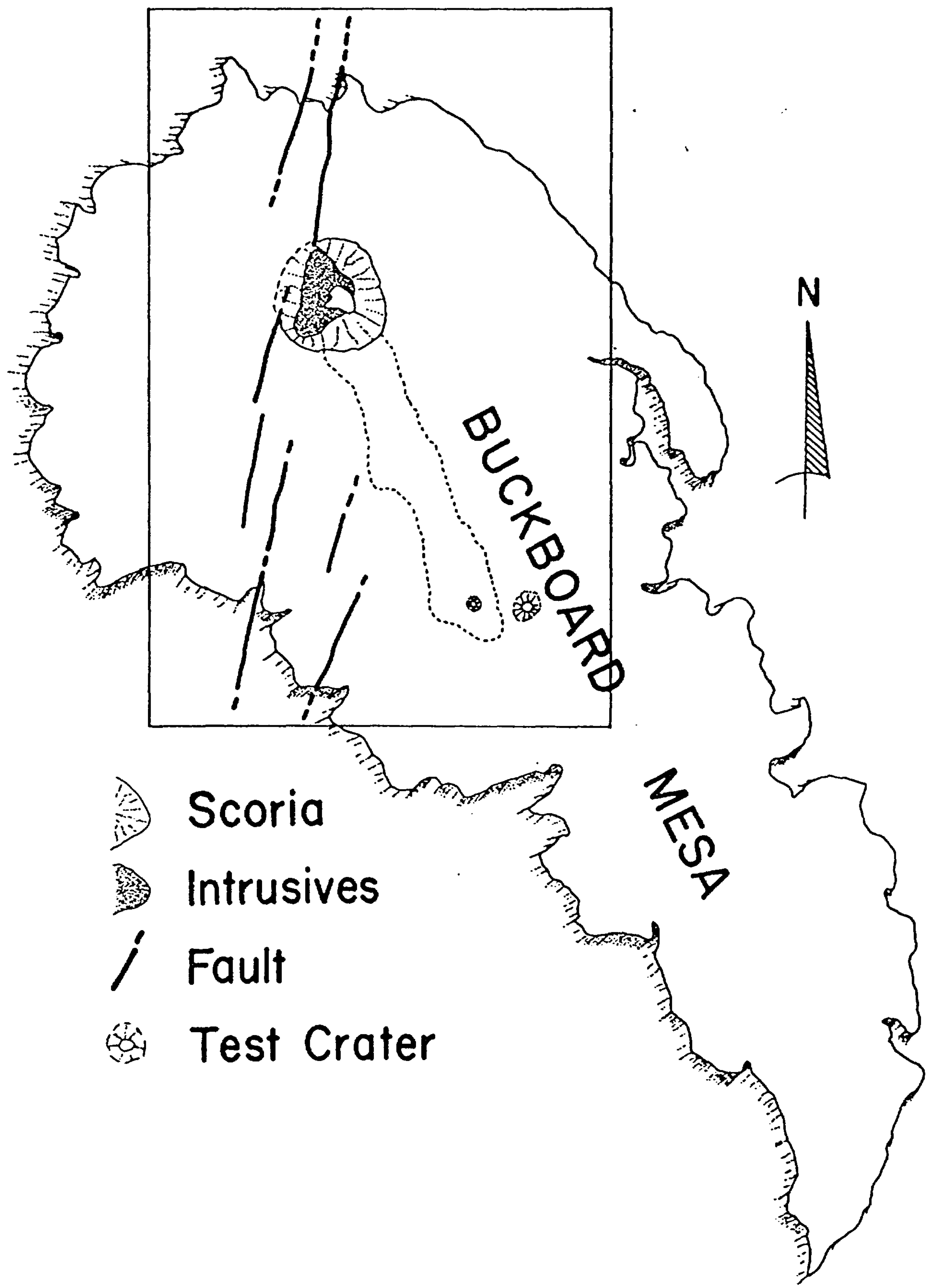
Figure 1. Index map of Death Valley region depicting ranges and major faults. NFZ = Northern Death Valley–Furnace Creek fault zone, SDF = Southern Death Valley fault, SHF = Sheephead fault, GF = Garlock fault.

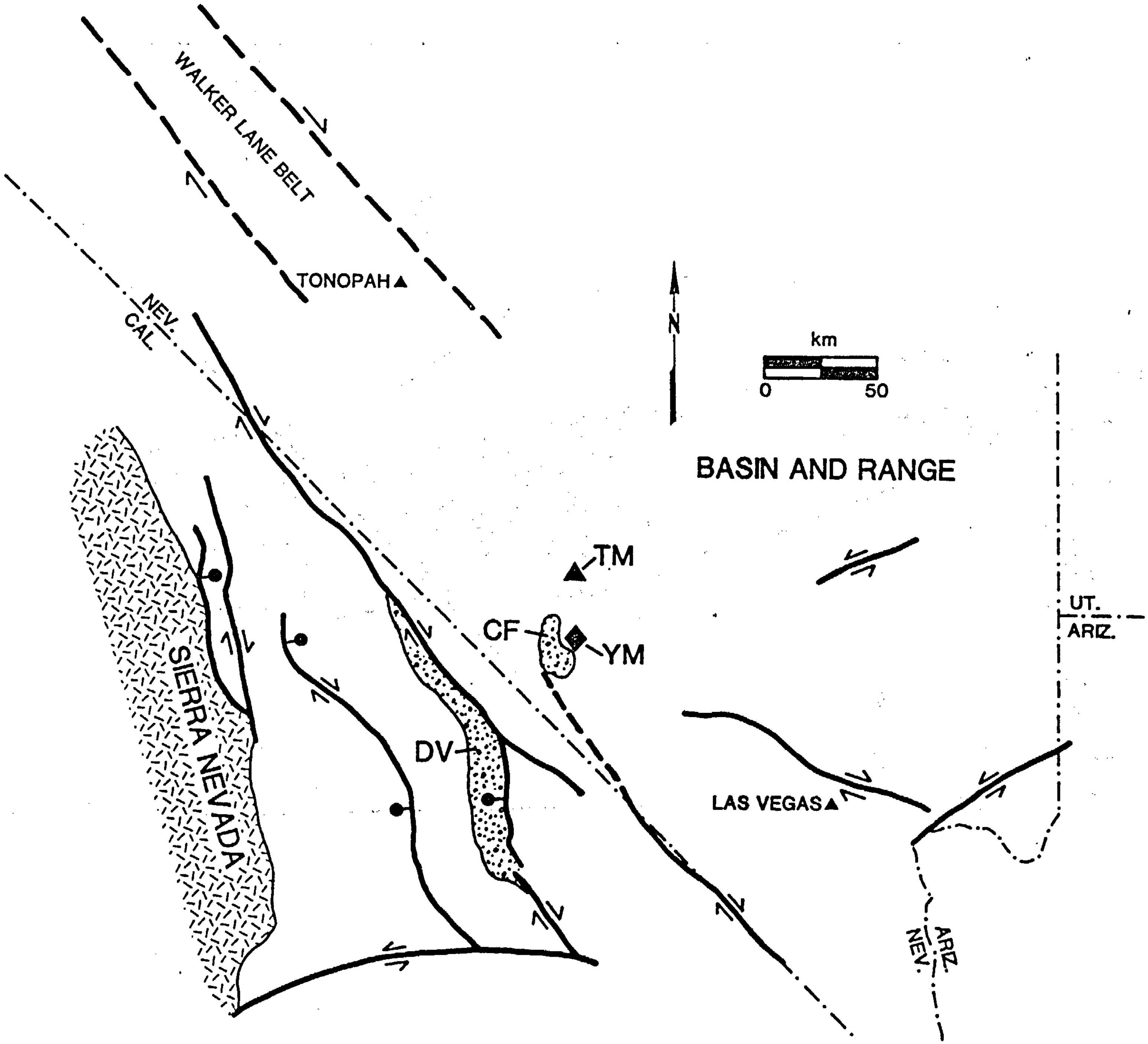
From Holm and Wernicke

GEOLOGY, v. 18, p. 520–523, June 1990

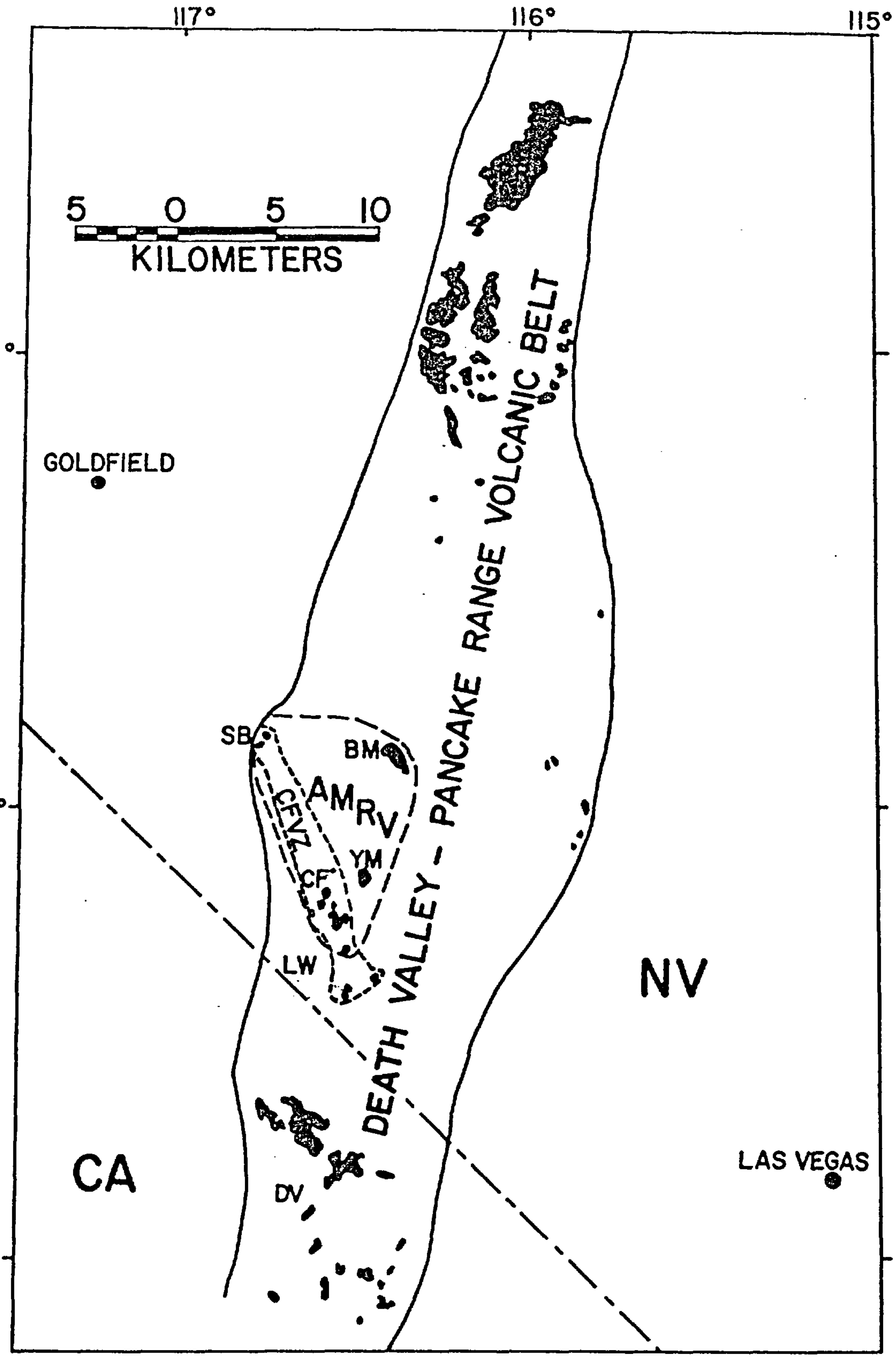


Geologic Map of the Crater Flat Quadrangle (Faulds, Bell, Feuerbach and Ramelli, in press; Nevada Bureau of Mines and Geology).

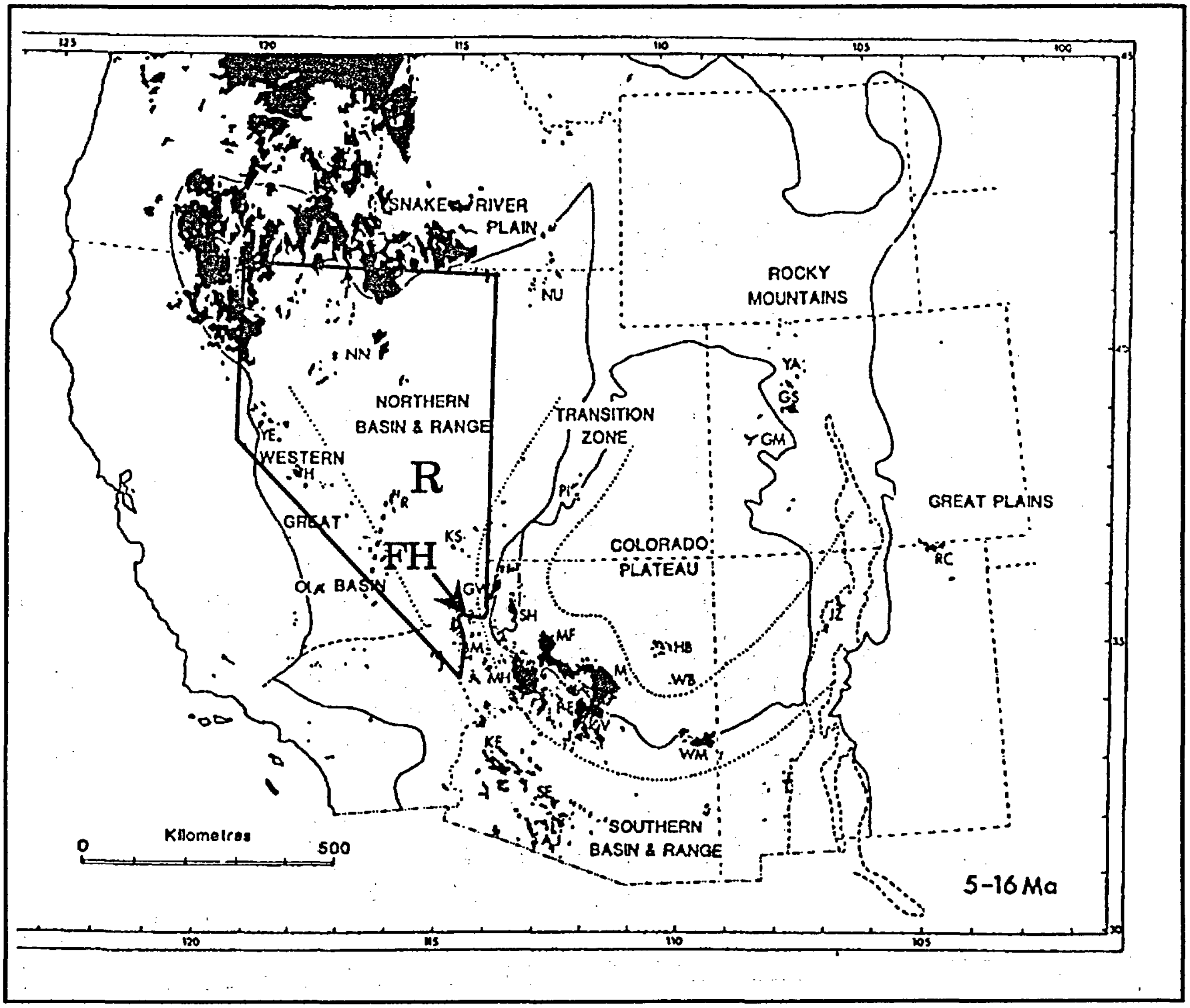

N
BUCKBOARD
MESA
Scoria
Intrusives
Fault
Test Crater



WALKER LANE BELT
TONOPAH
NEV.
CAL.
N
km
0
50
BASIN AND RANGE
TM
CF
YM
DV
SIERRA NEVADA
LAS VEGAS
UT.
ARIZ.
ARIZ.
NEV.

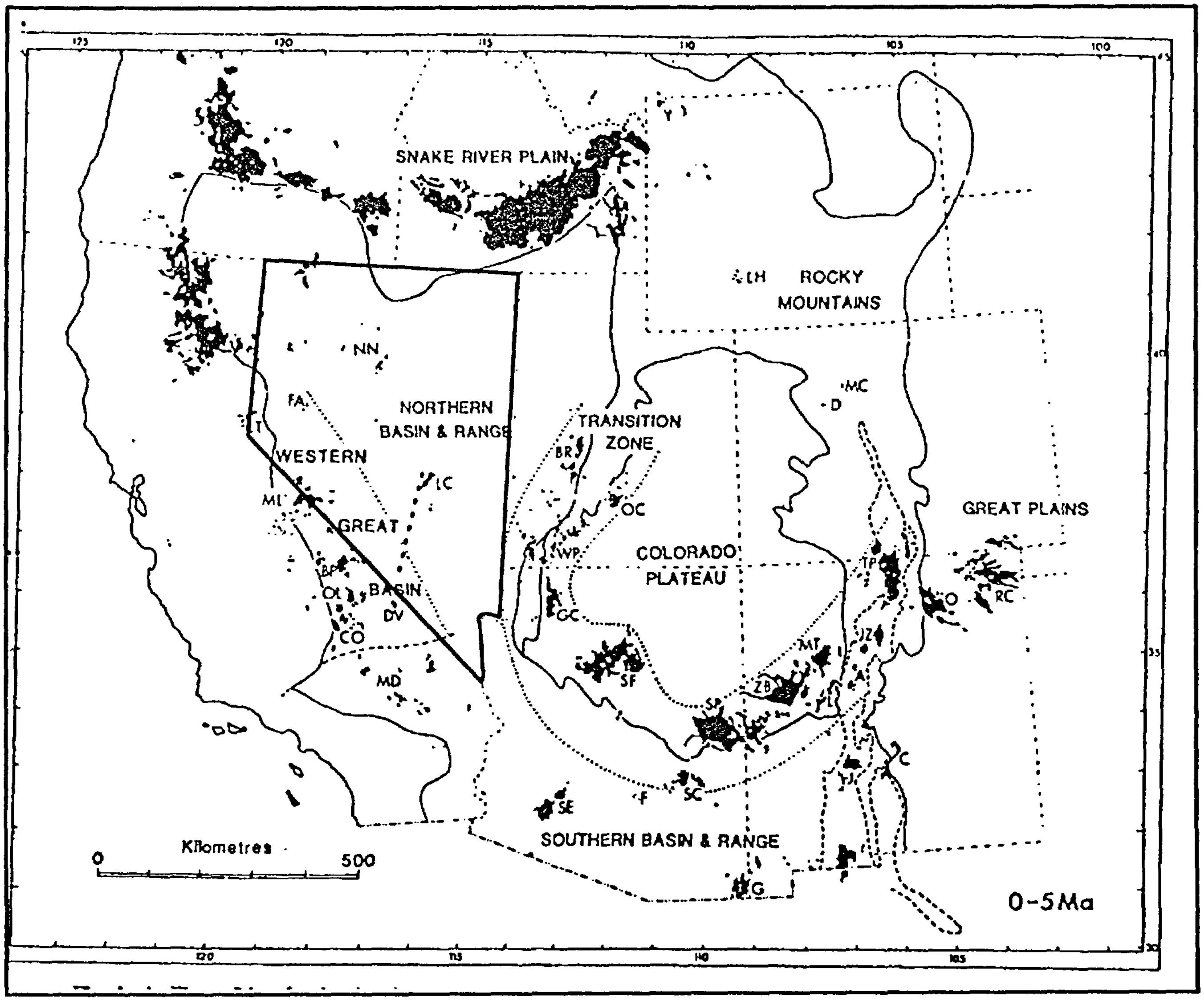

117°
116°
115°
5 0 5 10
KILOMETERS
38°
37°
36°
GOLDFIELD
LAS VEGAS
DEATH VALLEY - PANCAKE RANGE VOLCANIC BELT
SB
BM
AMRV
CFVZ
YM
CF
LW
DV
NV
CA

Mafic Volcanic Rocks in the Western USA 16-5 Ma



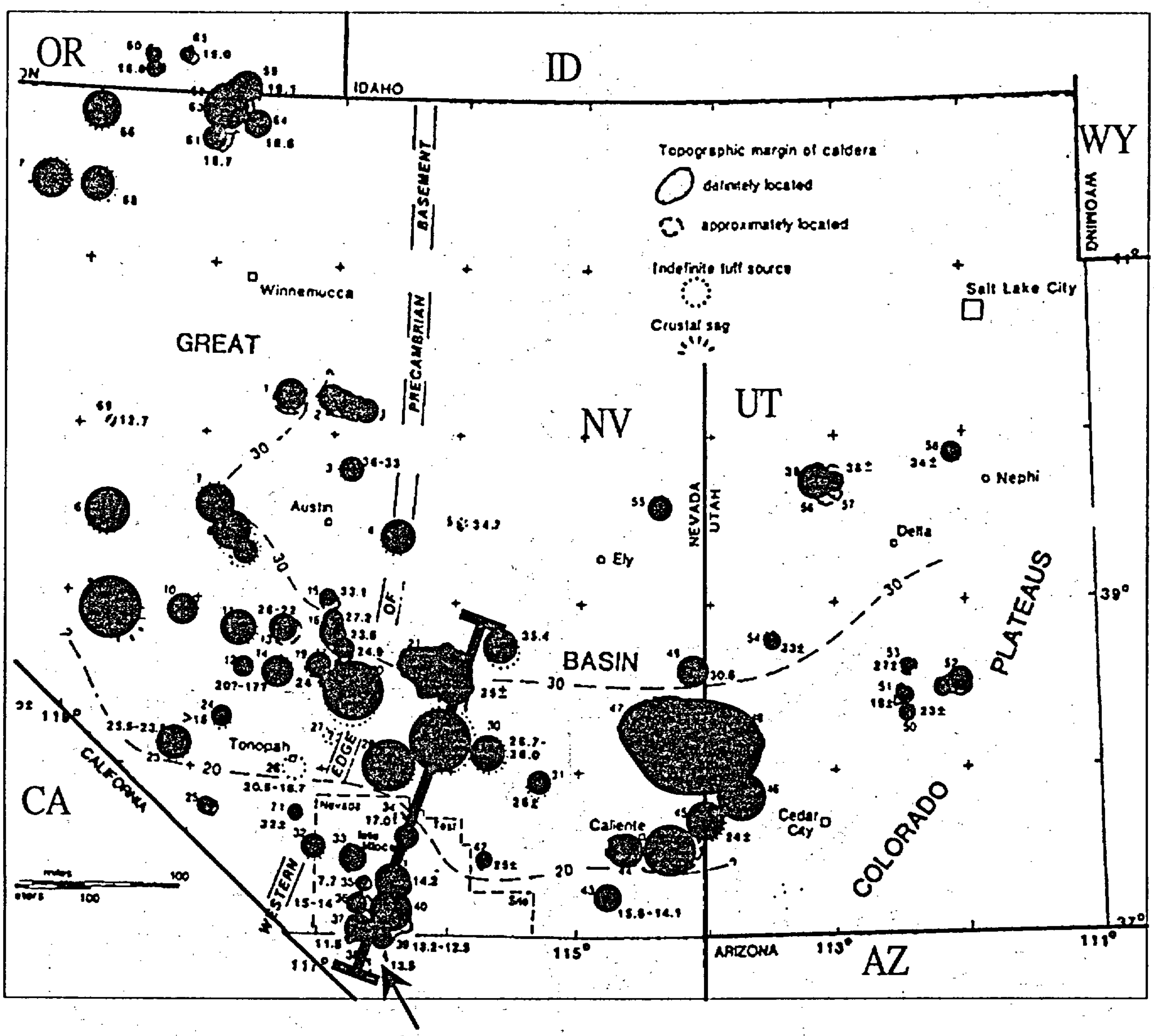
after Fitton et al., 1991

Distribution of Mafic Volcanic Rocks in the Western USA 0-5 Ma



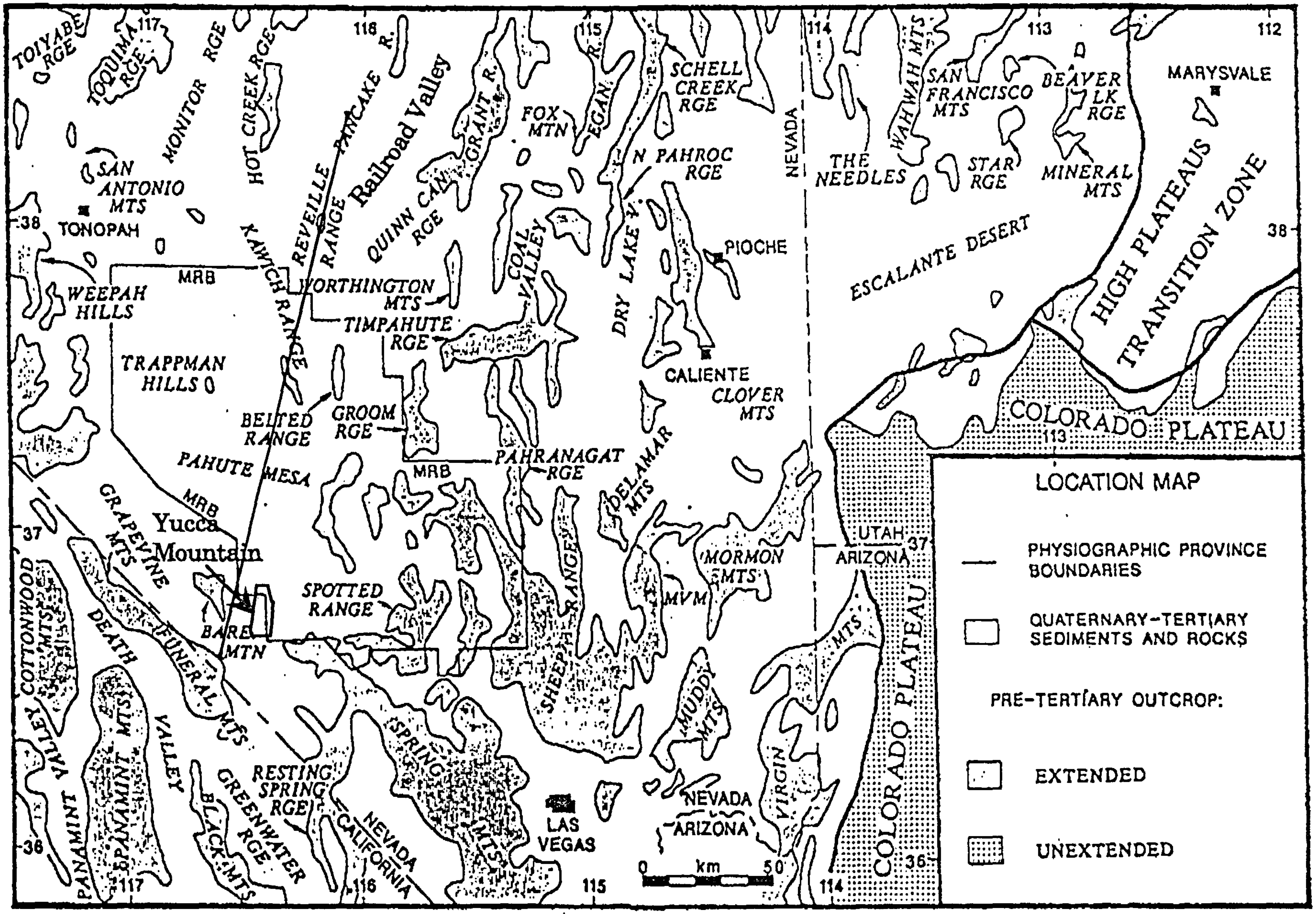
after Fitton et al., 1991

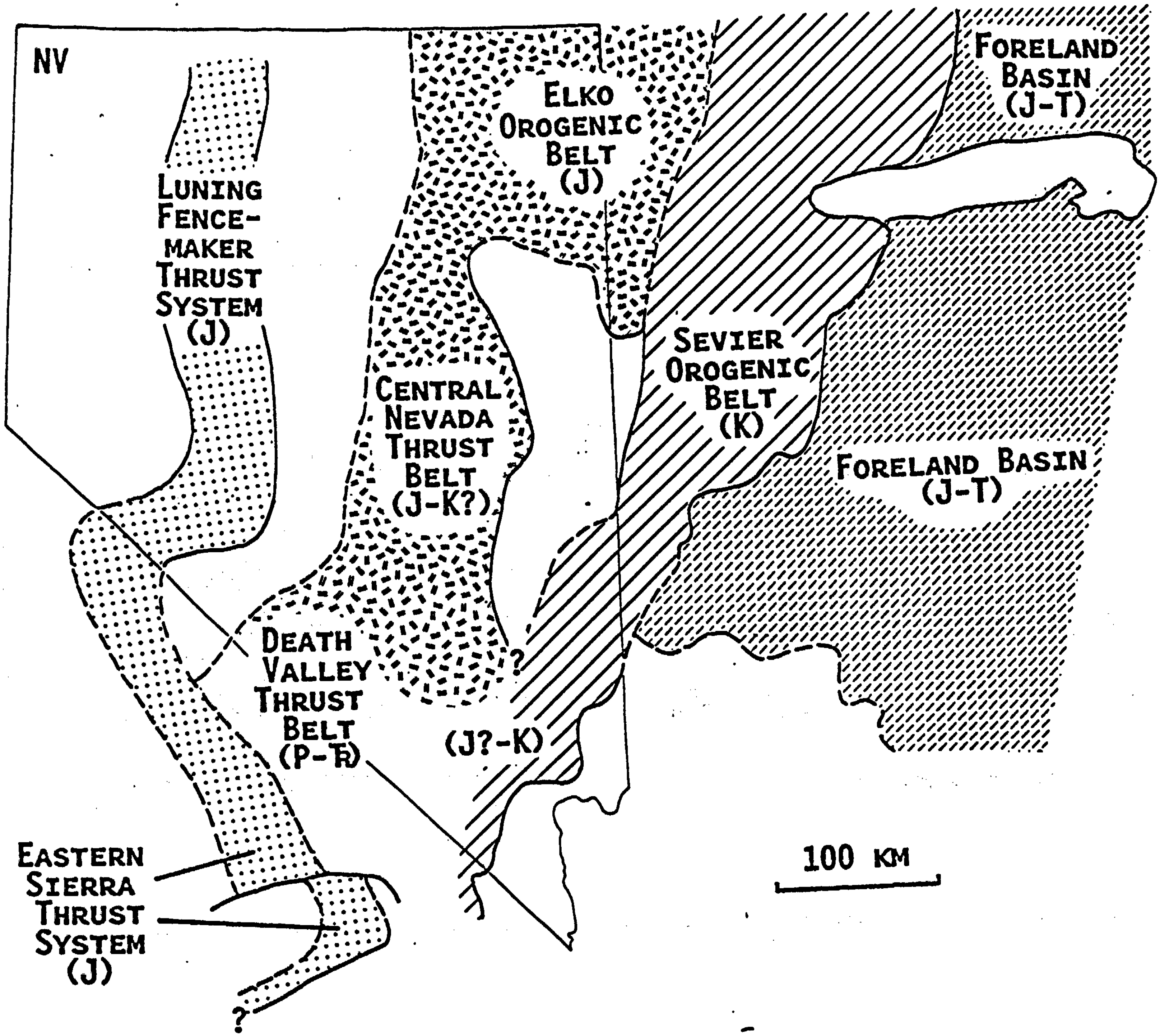
Distribution of Known or Suspected Calderas in the Great Basin and Adjacent Areas



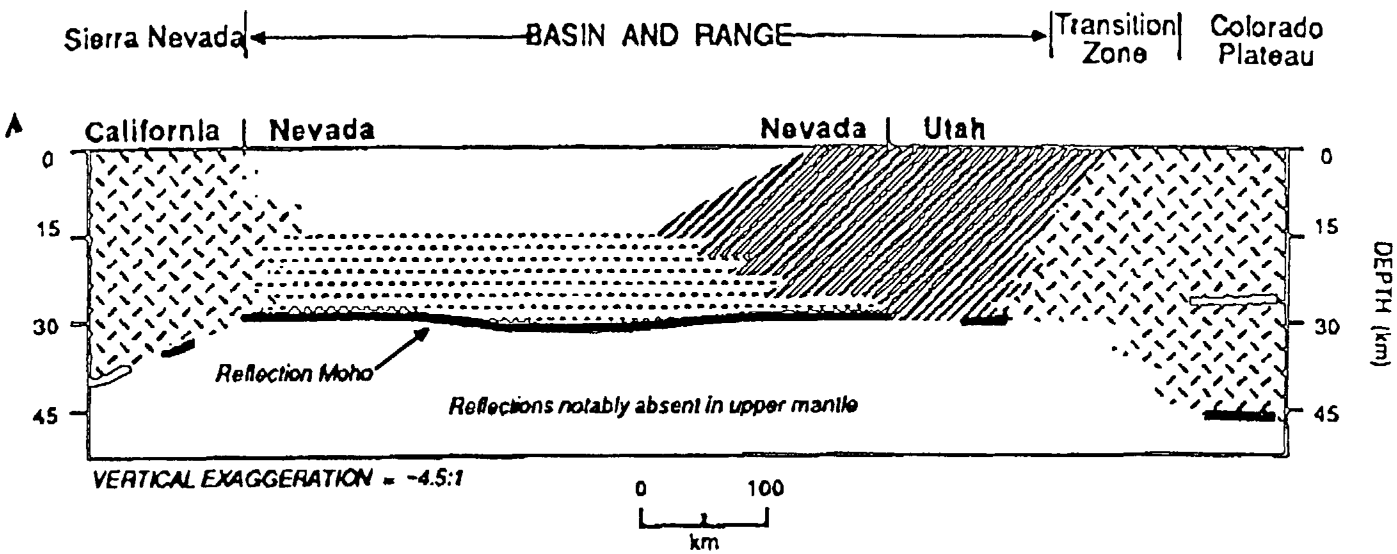
Yucca Mountain

from Best et al., 1989

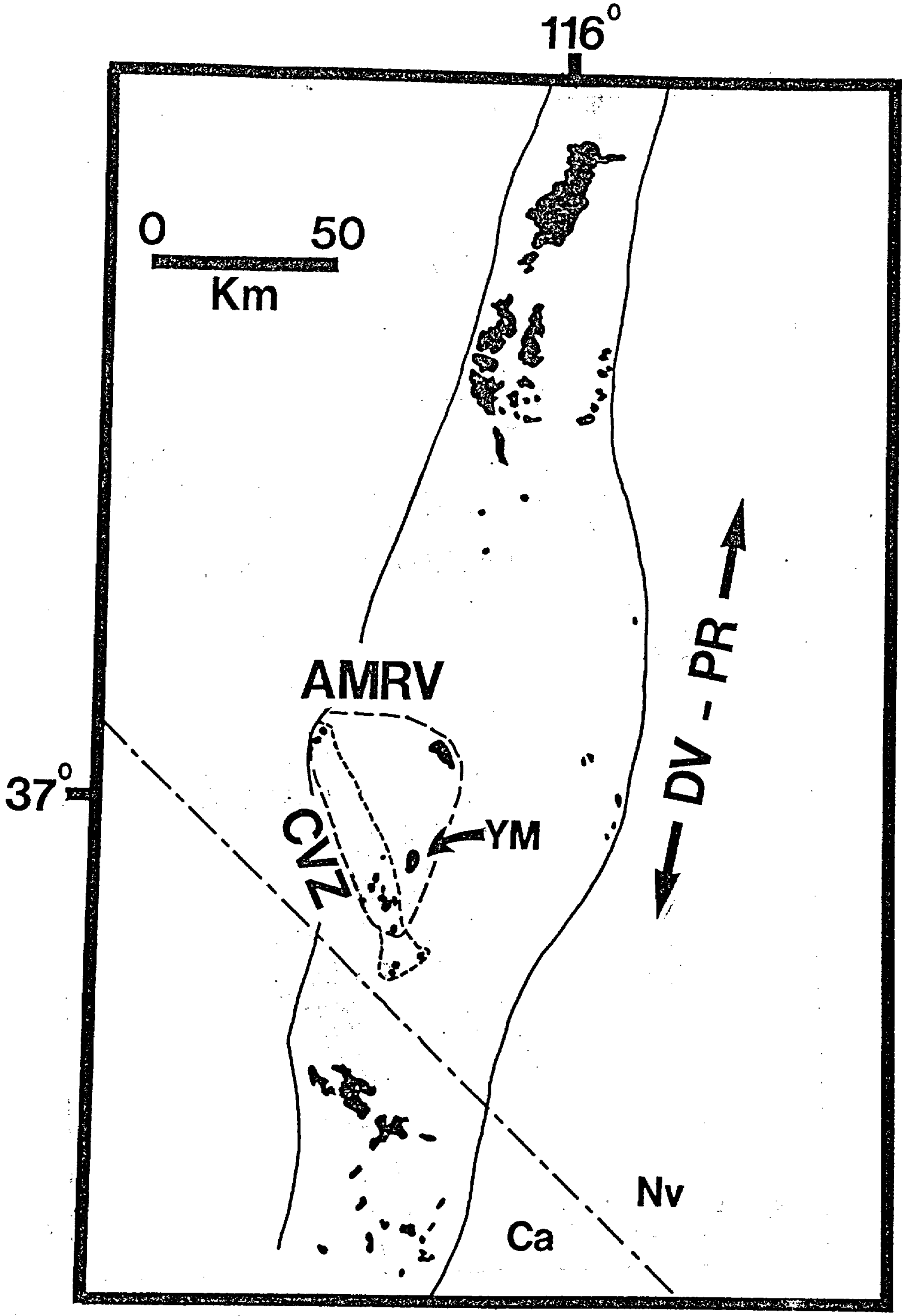

LOCATION MAP
PHYSIOGRAPHIC PROVINCE BOUNDARIES
QUATERNARY-TERTIARY SEDIMENTS AND ROCKS
PRE-TERTIARY OUTCROP:
EXTENDED
UNEXTENDED
TOIYABE RGE
TOQUIMA RGE
MONITOR RGE
HOT CREEK RGE
PANCAKE R.
Railroad Valley
GRANT R.
FOX MTN
EGAN R.
SCHELL CREEK RGE
NEVADA
WAH WAH MTS
SAN FRANCISCO MTS
BEAVER LK RGE
MARYSVALE
SAN ANTONIO MTS
TONOPAH
REVEILLE RANGE
QUINN CAN RGE
N PAHROC RGE
THE NEEDLES
STAR RGE
MINERAL MTS
KAWICH RANGE
COAL VALLEY
DRY LAKE V.
PIOCHE
ESCALANTE DESERT
HIGH PLATEAUS
TRANSITION ZONE
WEEPAH HILLS
MRB
WORTHINGTON MTS
TIMPAHUTE RGE
TRAPPMAN HILLS
CALIENTE
CLOVER MTS
BELTED RANGE
GROOM RGE
COLORADO PLATEAU
PAHUTE MESA
PAHRANAGAT RGE
DELAMAR MTS
GRAPEVINE MTS
Yucca Mountain
UTAH
ARIZONA
MORMON MTS
MVM
SPOTTED RANGE
BARE MTN
COTTONWOOD MTS
DEATH VALLEY
FUNERAL MTS
SHEEP RANGE
MUDDY MTS
VIRGIN MTS
RESTING SPRING RGE
SPRING MTS
PANAMINT VALLEY
PANAMINT MTS
BLACK MTS
GREENWATER RGE
NEVADA
CALIFORNIA
LAS VEGAS
NEVADA
ARIZONA
km
0
50
38
37
36
117
116
115
114
113
112


NV
Elko Orogenic Belt (J)
Foreland Basin (J-T)
Luning Fence-maker Thrust System (J)
Central Nevada Thrust Belt (J-K?)
Sevier Orogenic Belt (K)
Foreland Basin (J-T)
Death Valley Thrust Belt (P-Ћ)
(J?-K)
Eastern Sierra Thrust System (J)
100 KM
?

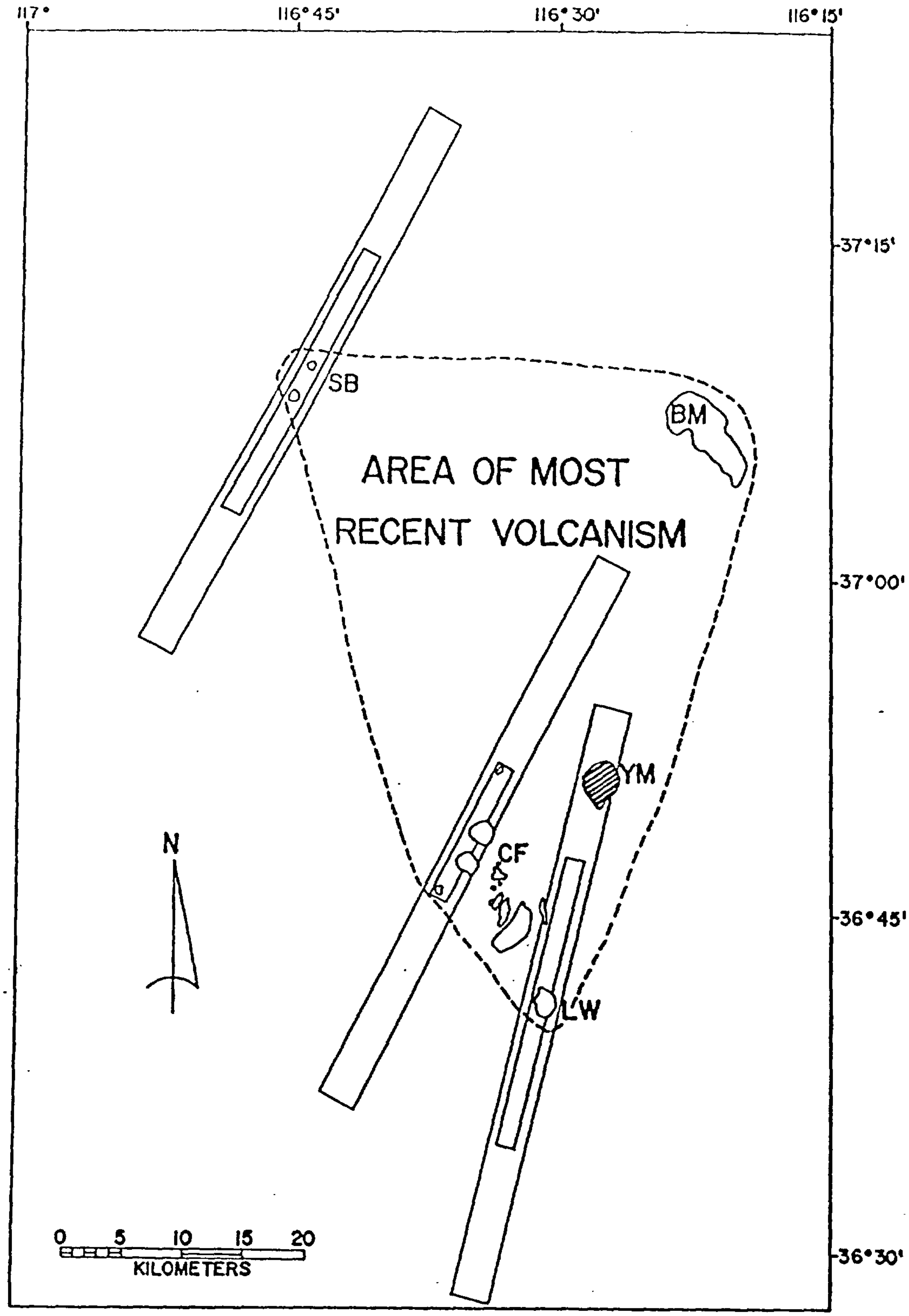
85?



Sierra Nevada
BASIN AND RANGE
Transition Zone
Colorado Plateau
A
California
Nevada
Nevada
Utah
0
15
30
45
0
15
30
45
DEPTH (km)
Reflection Moho
Reflections notably absent in upper mantle
VERTICAL EXAGGERATION = ~4.5:1
0
100
km



PROPOSED ZONES



117°
116°45'
116°30'
116°15'
37°15'
37°00'
36°45'
36°30'
SB
BM
AREA OF MOST
RECENT VOLCANISM
YM
CF
LW
N
0 5 10 15 20
KILOMETERS

NRC COMMENTS ON LANL REPORT "STATUS OF VOLCANIC HAZARD STUDIES FOR THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT"

UNITED STATES NUCLEAR REGULATORY COMMISSION

CLOSING COMMENTS

JOHN TRAPP, NRC
JUNE 9, 1993

THE REPORT ONLY DISCUSSES PRESENT STATUS OF STUDIES 8.3.1.8.1.1 AND 8.3.1.8.5.1. BASED ON THE ORGANIZATION OF THE DOE PROGRAM, THE NEED FOR INTEGRATION, AND THE NEED FOR ADDITIONAL INFORMATION TO RESOLVE MANY OF THE NRC CONCERNS, THE STATUS OF AT LEAST THE FOLLOWING STUDIES IN RELATIONSHIP TO MAGMATIC PROCESSES SHOULD ALSO BE ADDRESSED:

8.3.1.4.2.3 - THREE-DIMENSIONAL GEOLOGIC MODEL
8.3.1.8.1.2 - PHYSICAL PROCESSES OF MAGMATISM AND EFFECTS
8.3.1.8.5.2 - CHARACTERIZE IGNEOUS INTRUSIVE FEATURES
8.3.1.17.4.1 - HISTORICAL AND CURRENT SEISMICITY
8.3.1.17.4.3 - QUATERNARY FAULTS WITHIN 100 KM OF YUCCA MT
8.3.1.17.4.4 - QUATERNARY FAULTS PROXIMAL TO SITE WITH NE-TREND
8.3.1.17.4.5 - DETACHMENT FAULTS AT OR PROXIMAL TO YUCCA MOUNTAIN
8.3.1.17.4.6 - QUATERNARY FAULTING WITHIN SITE AREA
8.3.1.17.4.7 - SUBSURFACE GEOMETRY AND CONCEALED EXTENSION OF QUATERNARY FAULTS AT YUCCA MOUNTAIN
8.3.1.17.4.8 - STRESS FIELD WITHIN/PROXIMAL TO SITE AREA
8.3.1.17.4.10 - GEODETIC LEVELING
8.3.1.17.4.11 - CHARACTERIZE REGIONAL LATERAL CRUSTAL MOVEMENTS
8.3.1.17.4.12 - TECTONIC MODELS AND SYNTHESIS

FUTURE WORK (EXAMPLES)

1. DETAILED MINERALOGY OF QUATERNARY VOLCANICS

2. DETAILED CHARACTERIZATION OF TEMPERATURE, PRESSURE, VOLATILES (H2O), COMPOSITION

3. GEOPHYSICS
   - TOMOGRAPHY
   - POTENTIAL FIELDS
   - REFLECTION/REFRACTION
   - MAGNETIC

4. EXPLICIT CONSIDERATION OF ALTERNATIVE TECTONIC MODELS

5. MORE PRECISE / ACCURATE DATING OF QUATERNARY CONES

6. ALTERNATIVE PROBABILITY MODELS INCORPORATING GEOLOGIC DATA

DOE-NRC Technical Exchange on Volcanism Studies

Comments by

C. -H. HO

Department of Mathematical Sciences

University of Nevada, Las Vegas

(this work is supported by the Nevada Nuclear Waste Project Office)

June 9, 1993

$$Pr_{dr} = Pr(E_3 \text{ given } E_2, E_1) \times P(E_2 \text{ given } E_1) \times P(E_1).$$

where

WRONG! → E₁ denotes the recurrence rate of volcanic events, ... etc.

"RISK"

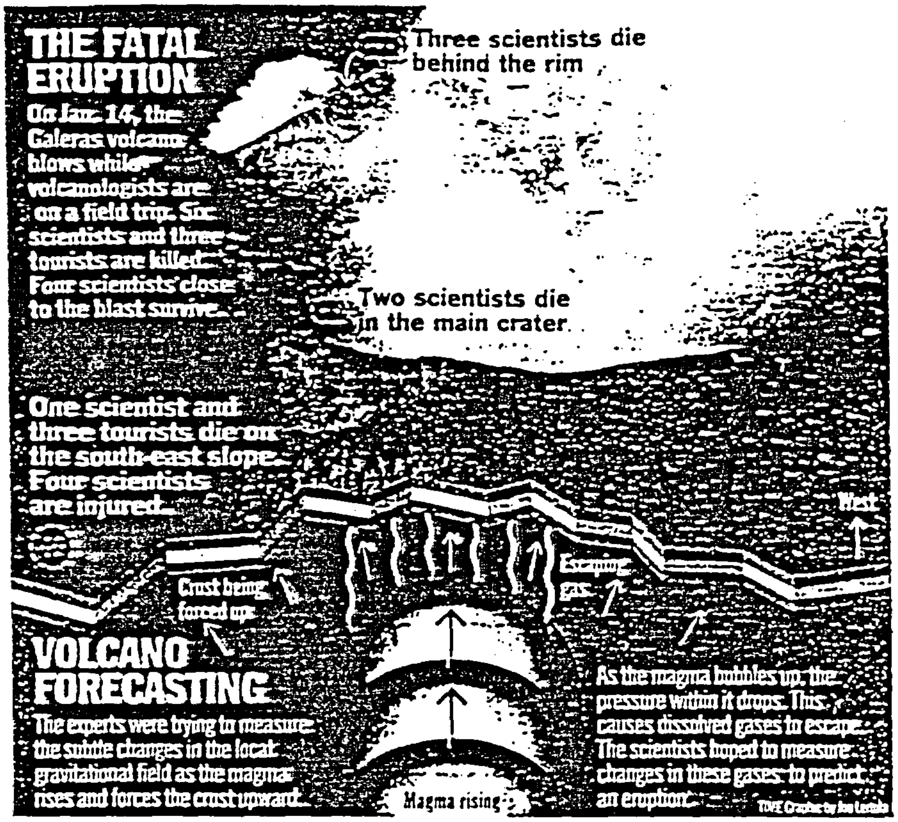
assessment of

Probability & <u>CONSEQUENCES</u> of

repository disruption

↑

Hard!



NATURE

DEADLY SCIENCE

A sudden and fatal eruption in Colombia shows again that volcanology is tragically imprecise

By LARA MARLOWE

WHAT LITTLE VOLCANOLOGISTS have learned over the centuries has come at a fearsome price. Beginning in A.D. 79, when the Roman scientist Pliny the Elder was killed while observing an eruption of Mount Vesuvius, volcanology has been one of the world's more dangerous fields of study. Over the past 11 years, sudden eruptions—including major blasts in Colombia, Mexico and the Philippines—have killed an estimated 26,000 people; since 1979 at least 12 scientists have perished while seeking to plumb the fiery mysteries.

Last month, to improve methods for predicting eruptions and thus save lives, 90 scientists from around the world gathered for a U.N.-sponsored conference in the southwestern Colombian city of Pasto. New techniques for detecting pre-eruption changes in the composition of vented gases had shown theoretical promise, and the scientists hoped to test them on Galeras, an active volcano several kilometers to the west that had not erupted since July 1992. Once again though, the insights of science were employed too late to be effective.

On the morning of Jan. 14, Stanley Williams, a U.S. volcanologist from Arizona State University, led a team of nine other scientists to the 4,170-m summit. Williams stayed on the rim and watched as two colleagues clambered down ropes toward the volcano's inner cone—Nestor Garcia, a Colombian, to set up a temperature probe; Igor Menyailov, a Russian, to sample gases coming out of vents. Williams and Menyailov, who had taught himself English by listening to Elvis Presley records, had been friends since they first met in 1982 on a volcano watch in Nicaragua. "Igor was excited because he was using a new device," Williams recalled last week from a hospital in Phoenix, Arizona. "He was smoking a cigarette, and he was all happy." Andrew McFarlane, of Florida International University, had just taken a snapshot of the two men when, without the slightest warning, the ground heaved and the mountain erupted.

"The volcano seemed to take a big breath, first sucking in air, then exploding," said a Colombian tourist who survived unhurt. Garcia and Menyailov died in an instant in the 600°C blast of toxic gases. On the western rim of the cone, British geologist Geoffrey Brown and two Colombian colleagues were also incinerated as gas and heat spurted upward.

"After seeing those people die," Williams recalled last week, "I just said 'Goddammit, I don't want to die,' and I started running as fast as I could." Scrambling down the slippery, ash-coated outer slope of the cone, he and three other scientists were bombarded with boulders the size of TV sets. "They split open when they hit the ground," said McFarlane. "Inside they were glowing red." One of the flying boulders crushed to death Colombian geochemist José Arles Zapata. Williams was felled as well, but managed to drag himself to partial shelter behind a huge rock.

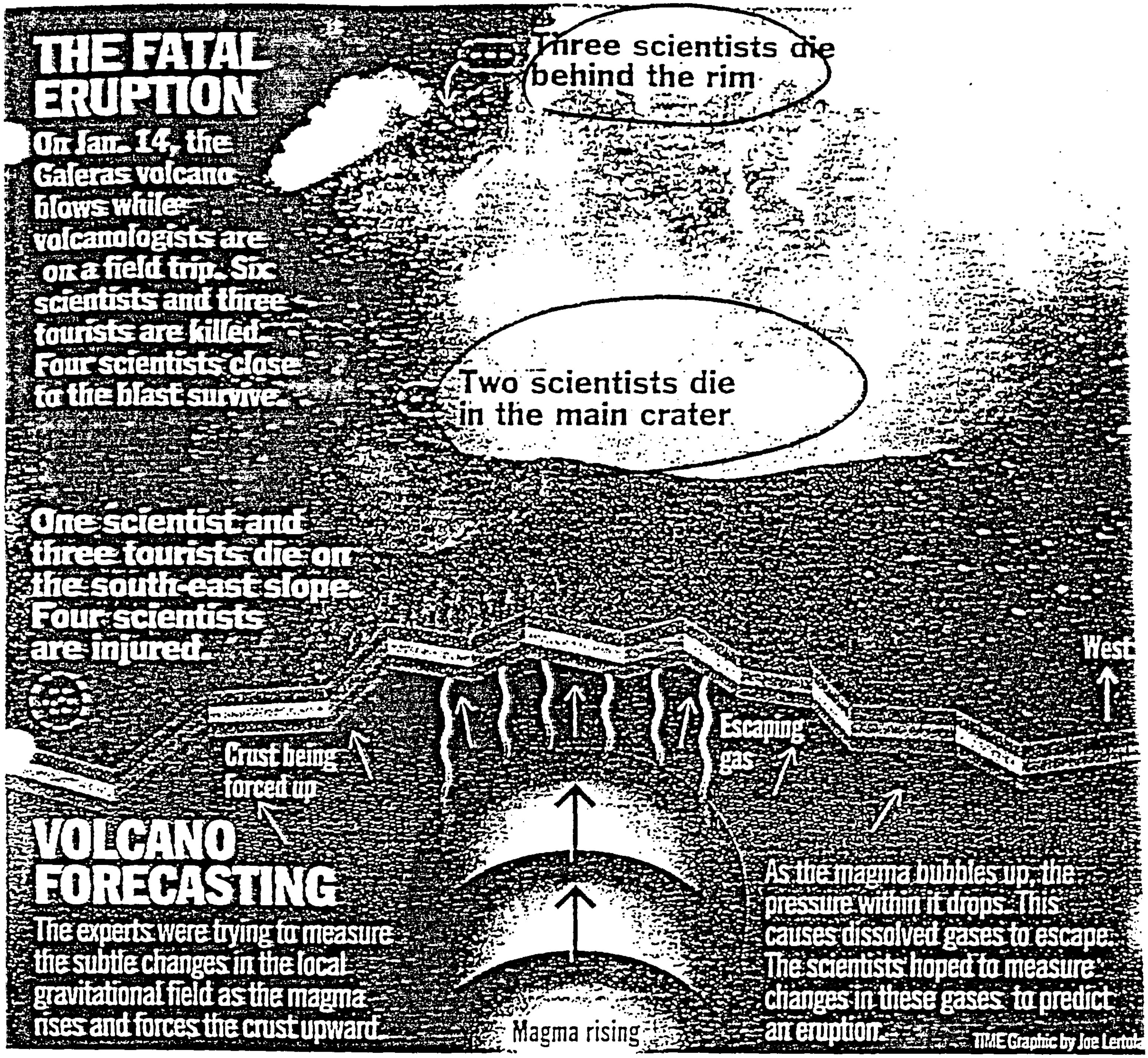
Williams and Mike Conway, from Michigan Technological University, said the thought of their wives and children made them determined to survive; McFarlane remembers wishing he had told his aging father that he loved him. "I was sure we were all going to die," he said. "The violence was shocking. Nature doesn't care—there was no mercy out there."

Stunned by a skull fracture, blinded by blood flowing down his forehead, his hands scorched, McFarlane at first tried to carry Williams, whose jaw and both legs were broken. "I was dazed from the impact and I was too weak to carry him, so I just kept running," said McFarlane. "I felt pretty guilty. I was very glad he made it." When rescuers finally reached the four survivors two hours later, they found Williams' backpack, altimeter and sunglasses melted and $6,000 in traveler's checks burned in his pocket. Somehow he was alive.

Conway was the only survivor able to walk away from Galeras; on his way out, he passed the body of a dead tourist whose shirt was still on fire. The fourth survivor, Ecuadoran scientist Luis Lamarie, had to be carried out on a stretcher.

After learning of the deaths of their six colleagues and the three Colombian tourists, many of the volcanologists attending the Pasto conference quietly left. The few who remained for the final session completed proposals to pursue gravity and gas analysis forecasting. The deaths on the mountain also led them to call for more rigorous safety measures on volcanic sites—and to demand an end to tourism at Galeras. Visitors are no longer permitted to approach the volcano.

Williams is recovering. His jaw is wired shut, and doctors will graft bone from his pelvis to replace crushed leg bones. The explosion, he says, "shows how unpredictable these volcanos are, even for so-called experts like ourselves." He relives Galeras in nightmares, yet he feels driven to find more answers. He says he will resume his work. *—Reported by Patrick E. Cole/Phoenix and Tom Quinn/Bogota*



NATURE

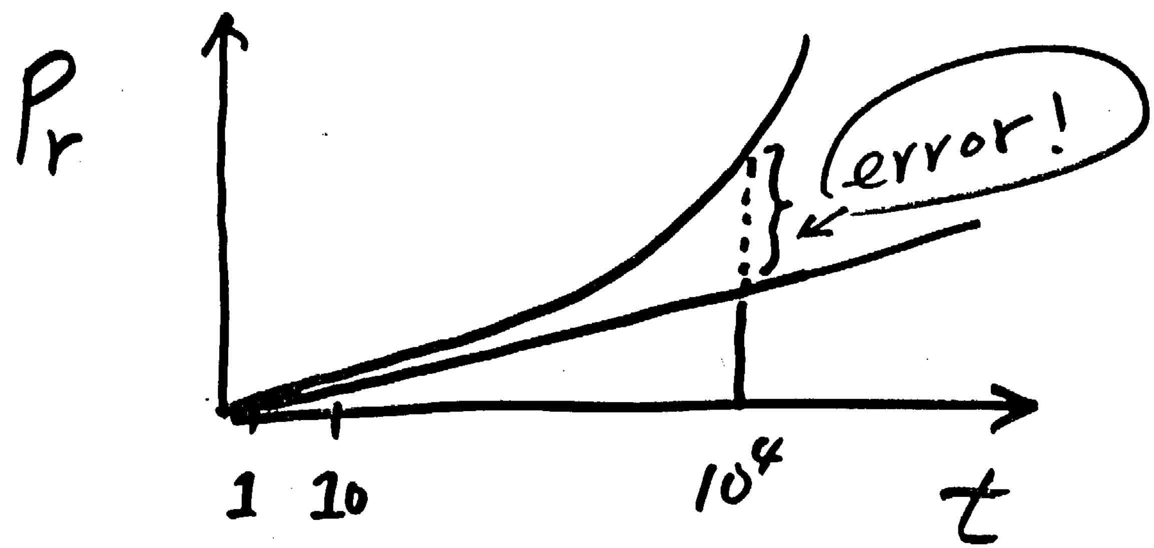
DEADLY SCIENCE

sudden and fatal eruption in Colombia shows again that volcanology is tragically imprecise

5

1. Can volcanic risk be expressed as an annual value? i.e. $10^{-8}\ yr^{-1}$

2. $P_r(t) = \lambda t$, $e^{-\lambda t}$, $\theta e^{-\lambda t}$



No!

Misleading!

The **annual** disease-free survival rate after operation of lung cancer patients is *xx* percent.

The estimated annual probability of future volcanic eruptions is 5.5×10^{-6}.

The following statements, which reflect the projected time frame, are more informative.

The overall cumulative five-year disease-free survival rate is *xx* percent.

The estimated risk for an isolation time of 10^4 years is about 5%, which increases to 42% if 10^5 years is the required isolation time.

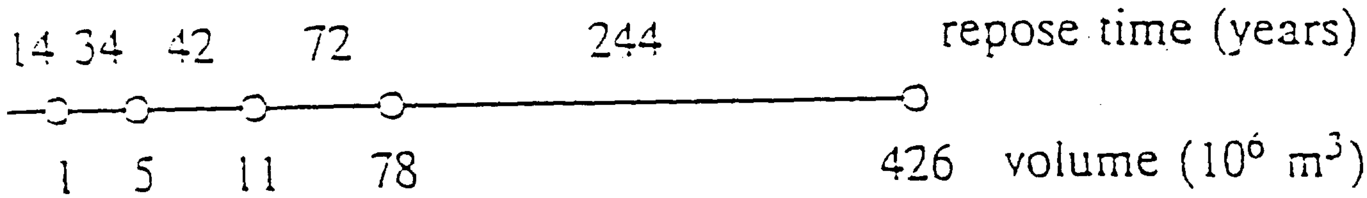
nonlinear

$42\% \neq 5\% \times 10^5$

What is
steady state eruptive behavior ?

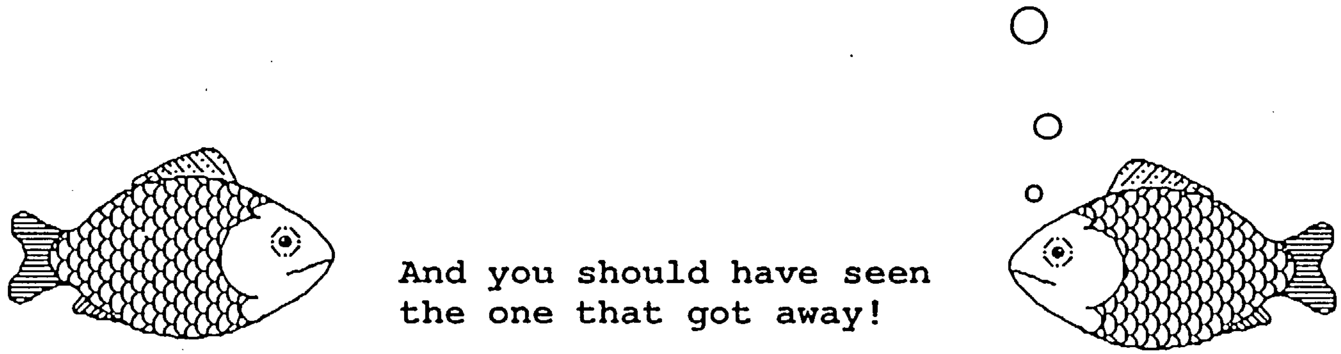
time trend ?

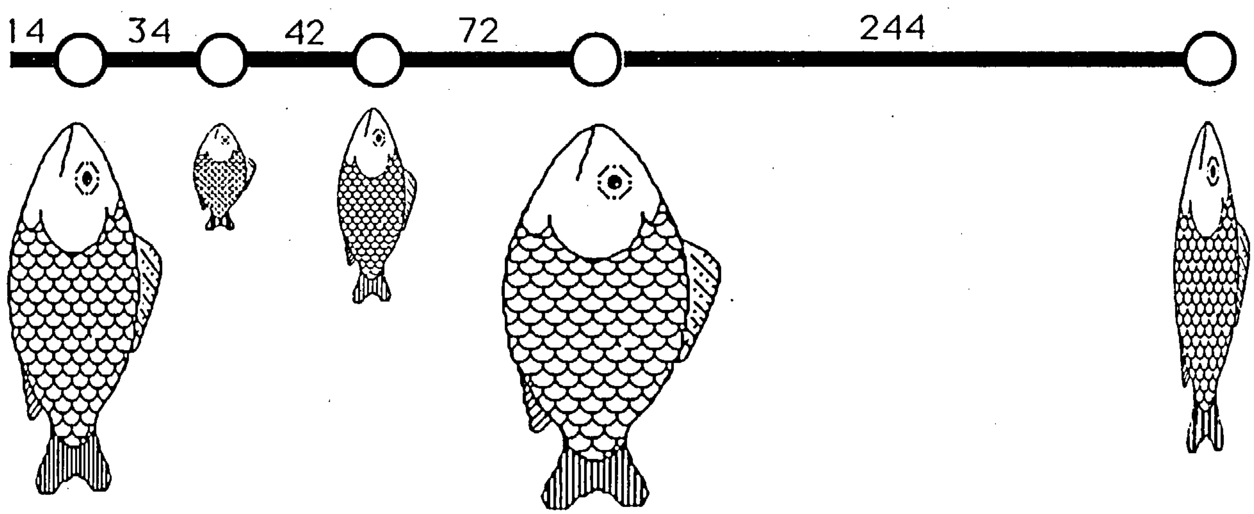
First, a simple Poisson model requires a constant rate of occurrence, which is not the same as magma production. Also, the trend of magma volume has not proved relevant to that of the frequency of the volcanic events (eruptions) at the NTS area. For example, the data set which has a waning time trend can also have an increasing trend in magma volume. The following data demonstrate this possibility:



w.r.t. what ??

Time trend in a "small data set."





1. GENERALIZE a constant λ with $\lambda(t)$, a function of time

2. Model $X(t)$ = number of events in $[0,t]$

   $X(t)$ follows a nonhomogeneous Poisson process (NHPP) with parameter $\mu(t)$

$$\mu(t) = \int_0^t \lambda(s)\, ds$$

(Parzen, 1962, p. 138)

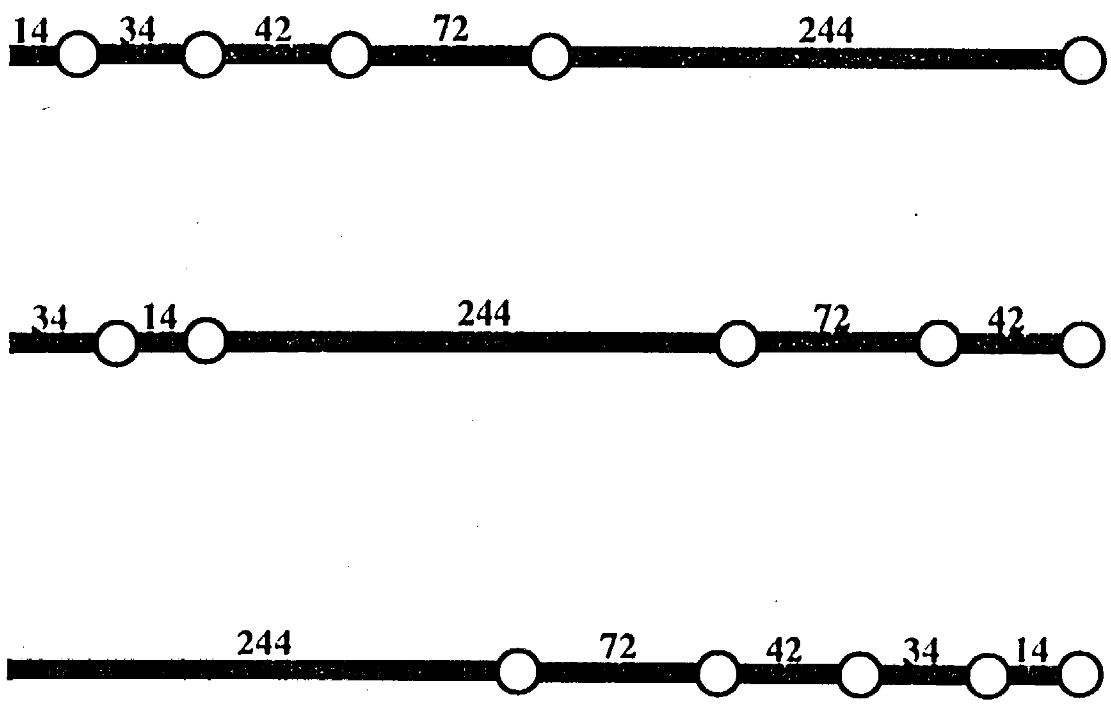
- **Choice of** $\lambda(t) = (\beta/\theta)(t/\theta)^{\beta-1}$
- **yields** $\mu(t) = (t/\theta)^{\beta}$
- **implies a Weibull** (θ, β)

$$\beta \begin{cases} > 1 & \text{increasing} \\ = 1 & \text{simple Poisson} \\ < 1 & \text{decreasing} \end{cases}$$

Weibull includes "a simple Poisson"

Weibull process modeling

= A car with (auto-transmission)



	$\hat{\beta}$
14, 34, 42, 72, 244	0.63
34, 14, 244, 72, 42	0.99
244, 72, 42, 34, 14	5.4

A simple Poisson process

= A car with only (one gear.)

REMARKS

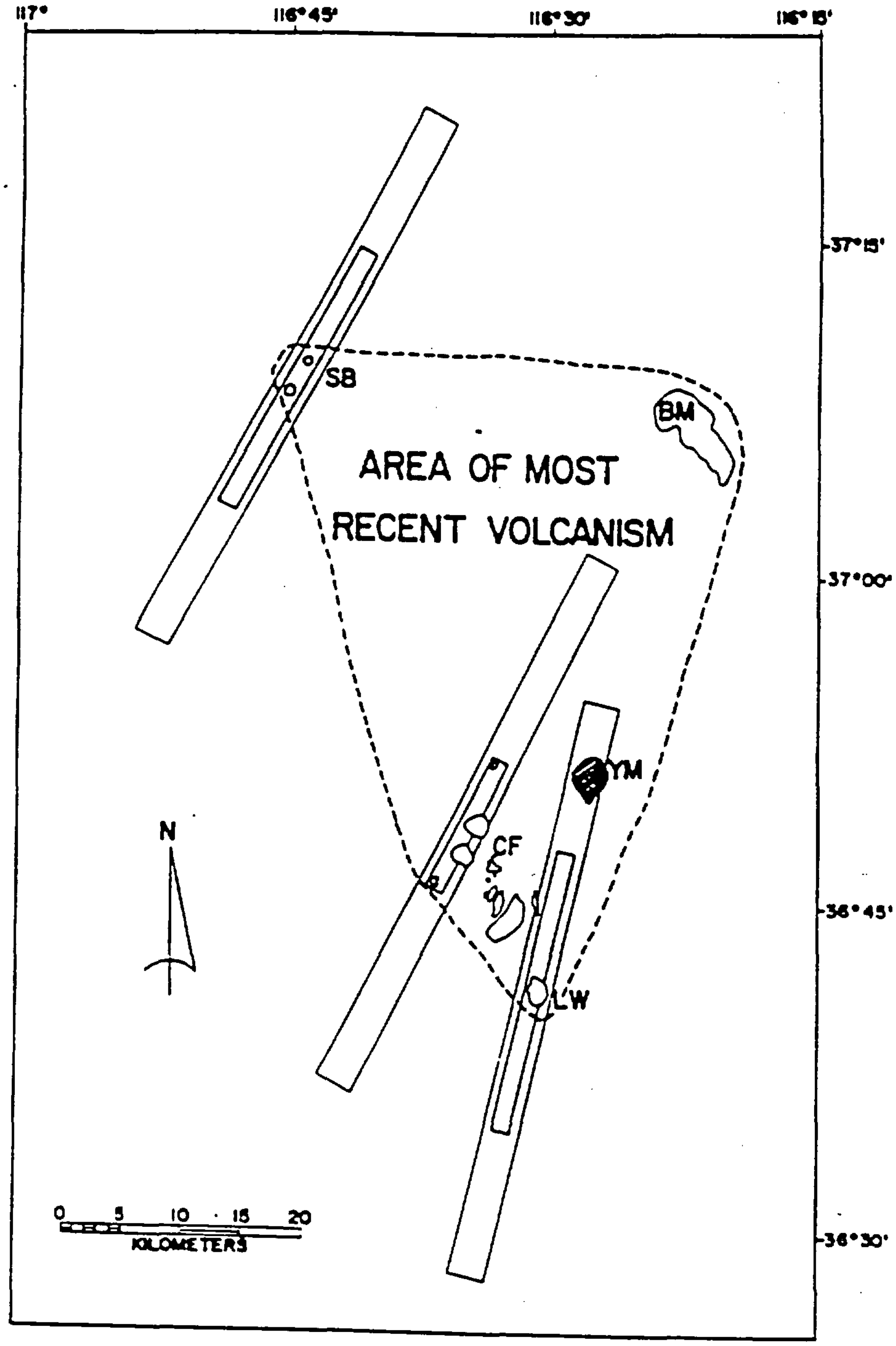
1. In this study, we restrict the risk to bull's-eyed volcanic events which result in the formation of volcanic cones and site disruption.

2. In so doing we neglect the potential impact of all other types of events such as a series of dikes, plugs, and sills, etc.

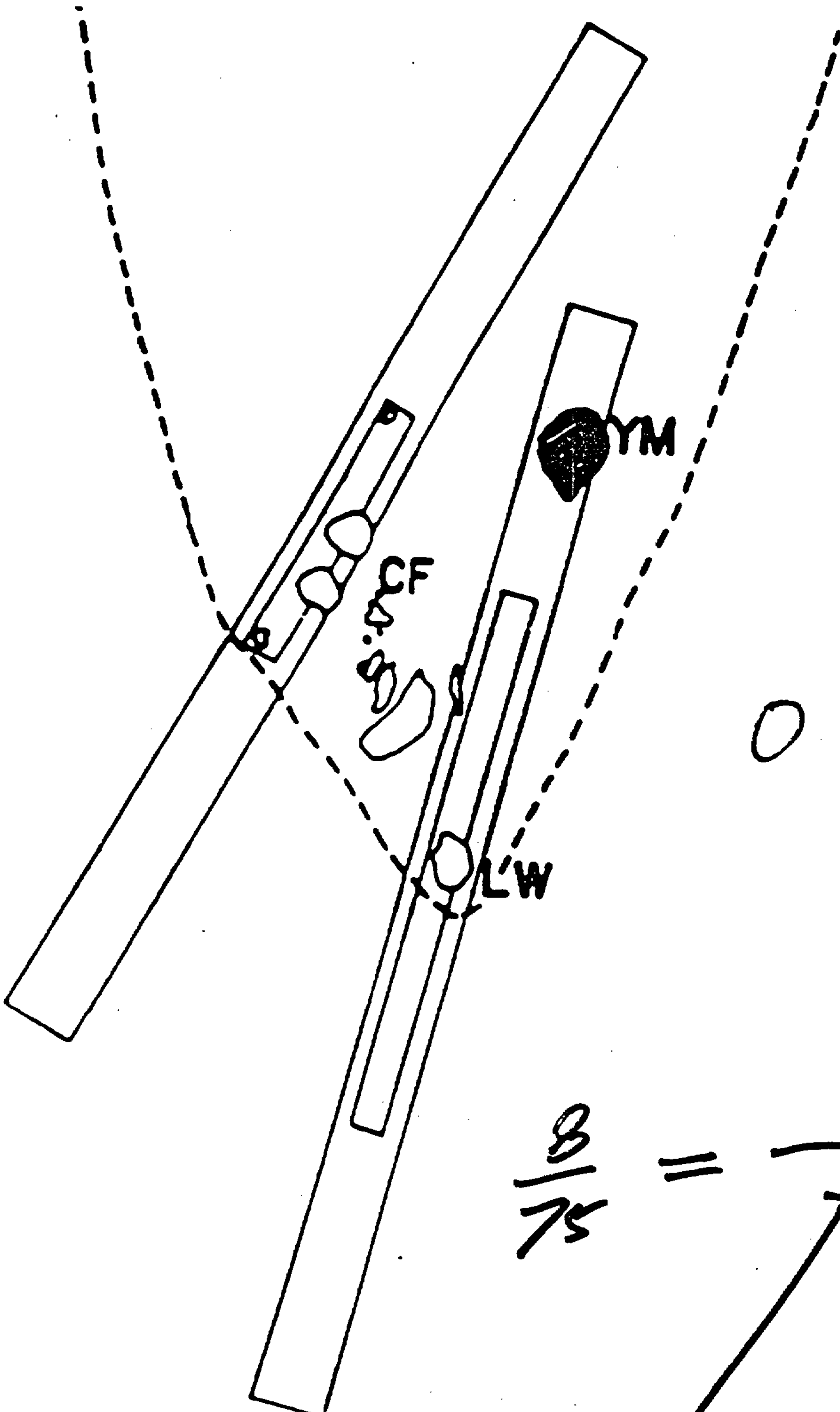
(What goes on under the surface?)

$$\text{Risk} = 1 - \int_p \exp\left\{ -\lambda(t) p t_0 \right\} \pi(p)\, dp$$

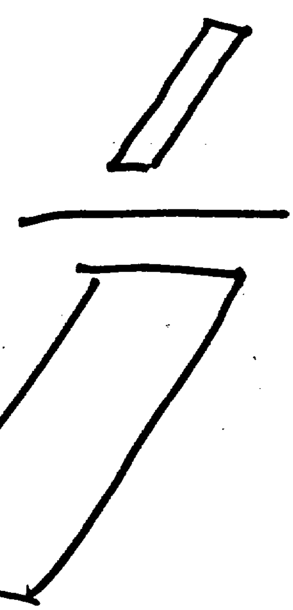
The technical machinery (Bayesian approach) involved in the risk calculation would support much more informative answers if the prior distribution $\pi(p)$ is adequately chosen.



Map outlining the AMRV (dashed line) and high-risk zones (rectangles) in the Yucca Mountain (YM) area that include Lathrop Wells (LW), Sleeping Butte cones (SB), Buckboard Mesa center (BM), volcanic centers within Crater Flat (CF). (Source: Smith et al., 1990a, fig. 7)



0 = lower limit

$\frac{8}{75}$ = 

= upper limit

$\pi(p) \sim U(0, 8/75)$

We have

1. $A = 75\ km^2$ (= half of the rectangle)

2. $a = 8\ km^2$ (area of the repository, Crowe et al, 1982)

3. $\pi(p) \sim U(0, 8/75)$, which assumes 8/75 as the upper limit for p

RESULT

A 90% confidence interval for the probability of site disruption for an isolation time of 10^4 years is

$$(1.0 \times 10^{-3}, 6.7 \times 10^{-3})$$

Ref: C.-H. Ho. (1992)

Mathematical Geology, 24, 347–364