Rec'd with letter dtd 6/30/93

SUMMARY OF U.S. NUCLEAR REGULATORY COMMISSION AND
U.S. DEPARTMENT OF ENERGY TECHNICAL EXCHANGE ON
VOLCANISM STUDIES
June 9, 1993, Las Vegas, Nevada

On June 9, 1993, representatives of the Nuclear Regulatory Commission, U.S. Department of Energy (DOE), State of Nevada Nuclear Waste Project Office, and Clark and Nye Counties, Nevada, participated in a technical exchange on the status of DOE's volcanism studies. The purpose of the technical exchange was to hold discussions on DOE volcanism studies and to comment on a DOE Contractor (Los Alamos National Laboratory) preliminary draft report, "Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project." The technical exchange agenda is included as Attachment 1 and the list of attendees is Attachment 2 to this summary. Copies of presenters' handouts are Attachment 3.

Dr. Bruce Crowe, principal author of the volcanism status report, presented a brief overview of the report and provided preliminary conclusions related to characterization of volcanic features near Yucca Mountain and the probability of occurrence of magmatic disruption of a potential repository at Yucca Mountain.

Technical staff of the NRC and its contractor, the Center for Nuclear Waste Regulatory Analyses, provided discussion and comments on the NRC's major areas of concern, including the consideration of alternative petrologic models and alternative approaches to probability calculations. The NRC staff noted the need for integration of volcanic/magmatic studies with other ongoing and proposed tectonic studies as input into alternative tectonic models. The need for geophysical testing to support volcanism studies was also a concern discussed by the NRC staff.

Technical investigators from the University of Nevada, Las Vegas, also provided comments on the draft report for the State of Nevada. State of Nevada presenters discussed concerns related to the consideration of alternative tectonic and petrologic models for volcanic activity in the Yucca Mountain region. A State of Nevada presenter also provided comments on the uncertainties related to risk calculation for volcanic and other events.

Following all presentations time was allotted for questions and discussion by representatives of the NRC, DOE, State of Nevada, and other technical exchange attendees. DOE representatives discussed future plans to collect data for volcanism studies to address site suitability (10 CFR Part 960) and licensing issues (10 CFR Part 60).

102.8

The DOE and its contractors will revise the draft report, taking into account concerns expressed by the NRC and State of Nevada at the technical exchange. DOE participants propose to issue the final contractor report in September, followed by yearly updates. NRC comments to revisions of Study Plans 8.3.1.8.5.1 and 8.3.1.8.1.1 will also be considered in revisions to the draft report.

Charlotte Abrams 6/30/93

Charlotte Abrams, Sr. Project Manager
Repository Licensing and Quality
Assurance Directorate
Division High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission

Christian Einberg 6/29/93

Christian Einberg
Regulatory Integration Branch
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy

AGENDA
U.S. DEPARTMENT OF ENERGY - U.S. NUCLEAR REGULATORY COMMISSION
TECHNICAL EXCHANGE ON VOLCANISM STUDIES
June 9, 1993
Las Vegas, Nevada
8:00 a.m. - 5:00 p.m.

8:00 a.m.	Welcome/Protocol/Opening Comments	DOE/NRC/State of NV/Affected Counties
8:15 a.m.	Current status of DOE Volcanism Studies	DOE
8:45 a.m.	Overview of draft status report Chapter 7 (risk assessment)	DOE
9:45 a.m.	BREAK	
10:00 a.m.	Comments on status report	NRC
12:00	LUNCH	
1:00 p.m.	Comments on status report	State of NV
2:00 p.m.	Discussion of status report	All
3:00 p.m.	BREAK	
3:15 p.m.	Overview and discussion of SCA and Study Plan open items	DOE/NRC
4:00 p.m.	Open discussion	All
4:45 p.m.	Closing remarks	DOE/NRC/State of NV/ Affected Counties
5:00 p.m.	Adjourn	

	NAME (PLEASE PRINT)	COMPANY	TITLE
1	E.V. TIESENHAUSEN	CCCP	ENG. SPEC.
2	C. Einberg	DOE/HQ	Engineer.
3	J. S. FRAPP	NRC	SR. Geologist
4	PAUL W. POMEROY	ACNW-NRC	MEMBER -
5	Chih-Hsiang Ho	UNLV	Math.
6	Baker Ibrahim	NRC	Geophysicist
7	RAYMOND H. WALLACE, JR.	USGS/HQ	HYDROLOGIST/DOE LIAISON
8	Steve McDuffie	NRC	Geologist
9	Jim Dugaid	M&O/INTERA	Hydrogeologist
10	BRITTAIN E. HILL	CNWRA	RESEARCH SCIENTIST
11	BILL BARNARD	NWTRB	EXEC. DIRECTOR
12	Charlotte Abrams	NRC	Sr Proj Mgr
13	Edward O'Donnell	NRC	Geologist
14	JIM YORK	WESTON	Sr. Geoscientist
15	Stephen Nelson	WEFS	S. Geoscientist
16	Debbie Jaquez	M+O/WEFS	S. Geoscientist
17	Greg Valentine	LANL	Geologist
18	Russ DYER	DOE/YMPO	Div. Dir.
19	JAMES G. MILLS JR	UNLV/CVTS	RESEARCH ASSOCIATE
20	TIM BRADSHAW	UNLV/CVTS	RESEARCH ASSOCIATE
21	MARSHALL WEAVER	M&O/Duke	Interactions Manager
22	Lynn Brewer	LANL	Research Tech
23	ERIC SHISTAD	DOE	PHYSICAL SC/GEOL
24	Jerry Boak	DOE	Technical Analysis Branch Chief

DOE/NRC TECHNICAL EXCHANGE
VOLCANISM
JUNE 9, 1993

	NAME (PLEASE PRINT)	COMPANY	TITLE
1	Steve LeRoy	Duke/M70	Senior Scientist
2	LINDA DESELL	DOE-HQ	Ch. Reg Integration
3	Gene Roseboom	USGS HQ	Deputy Assist Director Sr. Eng. Geol
4	WILLIAM V. HINZE	NRC-ACNW	MEMBER
5	G. L. STIREWALT	CNWRA	PRIN GEOSCIENTIST
6	C. B. CONNOR	CNWRA	Sr. Res. Sci.
7	Kenneth Foland	ACNW	Consultant
8	MARTHA PENDLETON	WCFS	SENIOR SCIENTIST
9	Gene Smith	UNLV	Geologist
10	Dave Fenster	M&O/WCFS	Geologist Mgr., Requirements Analysis
11	Jane Summerson	DOE/HQ	Geologist
12	DAVID TILLSON	NEVADA	CONSULTANT
13	Donald Livingston	TRAC	Geologist.
14	ALI HAGHI	M&O/Duke	Engineer
15	W G Melson	NWTRB	Volcanologist (Smithsonian)
16	William W. Dudley, Jr.	USGS	Hydrologist
17	Steve Nisbit	M&O/Duke	Ins-Ht Engineer
18	Russell Patterson	DOE-YMPO	Phys. Scientist
19	SUSAN JONES	DOE-YMPO	Chief - Regulatory Interactions (YMP)
20	Lynn Deering	NRC	ACNW staff
21	[illegible]	M&O	Site Chief
22			
23			
24			

DOE/NRC TECHNICAL EXCHANGE
VOLCANISM
JUNE 9, 1993

	NAME (PLEASE PRINT)	COMPANY	TITLE
1	Frank Perry	LANL	
2	Julie Canepa	LANL	TPO
3	CARL JOHNSON	NEVADA	MGR- TECH. PROGRAMS
4	Marvin Johnson	Nevada	Tech. Coordinator
5	HOMI MINWALLA	WESTON	Task Ldr, Nuc Licensing
6	JOEL R BERGQUIST	USGS	GEOLOGIST
7	Craig Scherschel	LANL	Research technician
8	PHILIP JUSTUS	USNRC	ON-SITE REP
9	A Oliver	USGS	Geophysicist
10	ABE VAN LUIK	M&O	MGR, PERF. ASSESS.
11	MARK C. TYNAN	DOE	Physical Scientist
12	Mal Murphy	Nye County	Regulatory & Licensing Advisor
13	Holly Dockery	SNL	
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DOE/NRC TECHNICAL EXCHANGE
VOLCANISM
JUNE 9, 1993

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN
SITE CHARACTERIZATION
PROJECT

OBJECTIVES AND STATUS OF DOE VOLCANISM STUDIES

PRESENTED TO

NRC TECHNICAL EXCHANGE ON VOLCANISM

PRESENTED BY

DR. JEANNE COOPER

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

JUNE 9, 1993

OBJECTIVES AND STATUS OF DOE VOLCANISM STUDIES

Purpose of this presentation

- Clarify the regulatory basis for presenting the volcanism information contained in LANL draft report
- Provide a broad look at volcanism issues being addressed by DOE studies, to understand the context and focus of specific NRC concerns
- Communicate DOE's understanding of what volcanism studies have achieved so far and what they must achieve in the future

DOE/NRC TECHNICAL EXCHANGE ON VOLCANISM

- Objectives of DOE volcanism studies
- Objectives of specific volcanism Study Plans
- DOE's view of the current status in meeting these objectives

OBJECTIVES OF DOE VOLCANISM STUDIES

- Support DOE site suitability evaluations per 10 CFR 960 and, if appropriate, the recommendation to the President required by the Nuclear Waste Policy Act, as ammended
- Provide a basis for the safety analysis required by 10 CFR 60 to support the license application, including 60.122 evaluations

OBJECTIVES OF SPECIFIC STUDY PLANS

"Characterization of Volcanic Features" Study Plan 8.3.1.8.5.1--confirms that volcanism is a potentially adverse condition [10 CFR 60.122 (c)(15)], and generates additional data needed to refine calculated event probabilities

- Geochronology
- Geochemical models
- Evolutionary patterns

OBJECTIVES OF SPECIFIC STUDY PLANS

(CONTINUED)

"Probability of Magmatic Disruption of the Repository" Study Plan 8.3.1.8.1.1--calculate event probabilities for input to assessment of PACs (10 CFR 60.122)

- Determine structural and tectonic controls on basaltic volcanism
- Evaluate possible presence of magma bodies
- Calculate the probability for basaltic igneous events (E1 and E2)

OBJECTIVES OF SPECIFIC STUDY PLANS

(CONTINUED)

"Physical Processes of Magmatism and Effects on the Potential Repository" Study Plan 8.3.1.8.1.2--generate data to complete the evaluation required by 10 CFR 60.122(a)(2) of PACs related to basaltic volcanism

- Eruptive effects
- Subsurface effects
- Magma system dynamics
- Interface with Performance Assessment

DOE'S VIEW OF THE CURRENT STATUS IN MEETING THESE OBJECTIVES

What has been accomplished

- Looked carefully at E1 and E2 for eruptive events
- Site data collected
- Studies to support early site suitability

DOE'S VIEW OF THE CURRENT STATUS IN MEETING THESE OBJECTIVES

(CONTINUED)

What is left to do

- Continue to collect data for volcanism studies that are currently planned to address site suitability concerns and to begin assessments required by 60.122(a)
  - Drill 3 magnetic anomalies
  - Geochronology studies to refine the age of basaltic volcanic centers
  - Complete field mapping
  - Continue geochemistry studies to assess models for generation and evolution of basaltic magmas
  - Initiate work under Study Plan 8.3.1.8.1.2

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN
SITE CHARACTERIZATION
PROJECT

OVERVIEW OF DRAFT VOLCANISM STATUS REPORT

PRESENTED TO

NRC TECHNICAL EXCHANGE ON VOLCANISM

PRESENTED BY

DR. BRUCE CROWE

PRINCIPAL INVESTIGATOR, LOS ALAMOS NATIONAL LABORATORY

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

JUNE 9, 1993

NRC TECHNICAL EXCHANGE
VOLCANISM

Discussion topics

- Overview of Volcanism Status Report
  - Highlights of each chapter

- Volcanic risk assessment: framework of the problem
  - Tripartite probability
  - Present state: analytical models of tripartite probability
    - -- Emphasis: repository disruption
    - -- Bounds approach versus mean or most likely values

  - *YM site is* <u>not unsuitable:</u> *repository disruption associated with eruption*
    - -- Low occurrence probability
    - -- Mean value: < 1 in 10000 in 10000 yrs

PRELIMINARY DRAFT
INFORMATION ONLY

NRC TECHNICAL EXCHANGE
VOLCANISM

Next steps

- Formal applications of methods of risk assessment
  - Pdf 's: key variables
  - Risk simulation models
  - Sensitivity analyses ⇦⇨ characterization studies
  - Expert opinion panel: refine pdf's/completeness of alternative models
  - Yearly updates: probabilistic risk assessment
- E3 studies: Study Plan 8.3.1.8.1.2
  - Eruptive effects
  - Subsurface effects
  - Magma dynamics

PRELIMINARY DRAFT
INFORMATION ONLY

Data feeds are to probability studies and performance assessment

- Evolutionary patterns of basaltic volcanic fields

NRC TECHNICAL EXCHANGE
VOLCANISM

Program organization: volcanism

Three parts

- Characterization of volcanic features (F. Perry, PI)
  - Data gathering
  - Field and laboratory studies
- Probability of magmatic disruption (B. Crowe, PI)
  - Occurrence probability (E1, E2)
  - Presence of magma bodies
- Effects of volcanism (G. Valentine, PI)
  - E3 (eruption, subsurface)
  - Magma dynamics

PRELIMINARY DRAFT
INFORMATION ONLY

NRC TECHNICAL EXCHANGE
VOLCANISM

Assume careful reading and general understanding of the Volcanism Status Report

Discussion of *possible differences* based on past reviews

Chapter 1: Introduction

Chapter 2: Geologic Setting of Basaltic Volcanism
- Regional perspective of volcanism studies (concern by State of Nevada)
- Basalt episodes/cycles
- Status of information for each volcanic center (increasing information with decreasing age)
- New chronology results
  - K-Ar, cosmogenic helium, paleomagnetism

PRELIMINARY DRAFT
INFORMATION ONLY

Chapter 3: Tectonic Setting: Basaltic Volcanism
- Overview of tectonic models
- time-space patterns of basaltic volcanism (migration, CFVZ)
- geophysical data

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Chapter 4: Petrology of Basaltic Volcanism: Great Basin

- Time-space waning (volume)
- Asthenospheric and lithospheric sources
- Polycyclic volcanism (monogenetic versus polycyclic)
- Decreasing eruptive volumes/increasing chamber depth/ increased frequence

Chapter 5: Segregation, Transport, and Storage of Basaltic Magma

- Segregation, compaction, ascent equations
- Dikes, magma-formed fractures
- LNB, intrusion forms
- Dike reorientation

Chapter 6: History of Volcanism Studies

- Initiated in 1979, ongoing
- Long history of studies, extensive literature

PRELIMINARY DRAFT
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VOLCANISM

Chapter 7: Risk Assessment

Chapter 8: Future Studies

- Drill holes/silicic volcanism
- Geochronology and field studies nearing completion
- Evolutionary patterns of basaltic volcanic fields
- Structural models ⇨ in progress with tectonics/geophysics studies
- Geophysical review: magma bodies
- Probability calculations: ⇨ risk simulation ⇨ expert opinion
- Data feeds to performance assessment
  - Occurrence probabilities
  - Intrusion/eruption scenarios

PRELIMINARY DRAFT
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Key Discussion Points (opinion differences):

Mean versus worst case attribute values

- Mean: well defined central tendency of data (mean, geometric mean, median, most likely ...)
- Worst case: not defined
  - Propagates undefined conservatism
  - Physically unrealistic values
- Risk simulation: well defined methods of defining attribute sensitivity

Reasonable assurance versus undefined conservatism

Small data sets: low risk ⇨ increased uncertainty

- NO: robust data sets
  tests for goodness of fit
- Probability bounds, analog comparisons

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Program issue present in virtually all studies

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Chapter 7: Risk assessment

- **Modifications of probability model**
  - Adapted to intrusion and eruptive events *(... but no evidence of difference in E1 distribution)*
  - Variable definitions of E2 (repository, controlled area, region)
- **Current data: site characterization**
  - Event = new volcanic center
  - Polycyclic and monogenetic models (important only for E3)
- **E1: Use multiple models**
  - Time trend, cone counts, magma output rate
  - Bound versus mean or most likely values
  - Modified repose and time-volume diagrams
  - *Non-robust data set:* bounds from analog basaltic volcanic fields

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2.6×10^{-6} events yr^{-1}
limited model sensitivity

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Chapter 7 (continued)

- **E2: Disruption ratio**
  - Same approach as E1 ⇨ multiple models to define data distribution
  - Limited data: robust calculations impossible
  - Random disruption models
  - Structural models (forced intersection)
  - Structural models (disruption bounds)
  - Analog basaltic volcanic fields

2.5×10^{-3}
E2 models <u>must</u> be evaluated for compatibility with E1

- **Probability of magmatic disruption: Pr(E2 given E1)Pr(E1)**

6.5×10^{-9} yr $^{-1}$ (repository)
9.4×10^{-8} yr $^{-1}$ (controlled area)
8.8×10^{-7} yr $^{-1}$ (region . . . approaches E1)

- **Analog volcanic fields**
  - Low recurrence rates, low probability of disruption

NRC TECHNICAL EXCHANGE
VOLCANISM

PRELIMINARY DRAFT
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Opinion differences (continued)

Poisson versus non-Poisson distribution models

- Cannot be tested with limited data
- Time-space distribution of volcanism: does not fit a Poisson model

waning volcanism
can define error term of Poisson assumption
differences with other distribution models ⇨ insignificant

Uncertainty

- Small data set: decreased risk ⇨ increased uncertainty
- Large data set: increased risk ⇨ decreased uncertainty

GAMBLERS RUIN: risk of low probability events (... *can you afford a run of bad luck)*

⇨ Volcanism issue: recurrence, location and effects

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VOLCANISM

PRELIMINARY DRAFT
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Data completeness:

- Probabilistic approach ⇨ iterative
- Quaternary volcanic centers are not difficult to identify
  - Geomorphic stability
  - Aeromagnetic data
- Number of undetected intrusions would have to be large
  - Factor of 3-5 to be significant
- Low velocity teleseismic anomaly
  - Long-lived feature

Do differences of opinion change attribute distributions?
Status report: defined distributions
Review: examine differences for effect on attribute distributions

NRC STAFF/CNWRA REVIEW OF THE LANL VOLCANISM STATUS REPORT

DOE/NRC TECHNICAL EXCHANGE
JUNE 9, 1993

PRESENTERS: Dr. John Trapp, NRC
Dr. Charles Connor, CNWRA
Dr. Brittain Hill, CNWRA

SCOPE AND REGULATORY BASIS OF NRC/CNWRA REVIEW

Keith I. McConnell, Section Leader
Geology/Geophysics Section
(301) 504-2532

SCOPE AND CONTEXT OF REVIEW

- SCOPE OF REVIEW WAS LIMITED TO DETERMINING WHETHER THE POTENTIALLY ADVERSE CONDITION OF QUATERNARY IGNEOUS ACTIVITY WAS BEING ACCEPTABLY ADDRESSED
- REVIEW WAS FOCUSED ON THE METHODOLOGIES AND APPROACHES DESCRIBED IN THE STATUS REPORT AND WHETHER THEY WILL PROVIDE THE NECESSARY INFORMATION TO ASSURE THAT THE SUBJECT OF QUATERNARY IGNEOUS ACTIVITY WILL BE ACCEPTABLY ADDRESSED.
- APPROACH TO REVIEW WAS TO: 1) IDENTIFY CONCERNS; 2) IDENTIFY POSSIBLE COMPLIMENTARY APPROACHES; AND, 3) IDENTIFY EXAMPLES OF FUTURE WORK TO PROVIDE NECESSARY INFORMATION.

REGULATORY BASIS FOR STAFF REVIEW

- 10 CFR Part 60.21 - Content of License Application
- 10 CFR Part 60.122(c) - Potentially Adverse Conditions (PAC)

  1) Will there be sufficient information to determine whether and to what degree the PAC is present?
  2) Will there be sufficient information to determine the extent to which its presence may be underestimated or undetected?
  3) Will the lateral and vertical extent of data collection be sufficient to determine the presence of the PAC?
  4) Will assumptions and analysis methods be used that will adequately describe the presence of the PAC and the ranges of relevant parameters?

REGULATORY BASIS FOR STAFF REVIEW (Continued)

5) Will the analyses and models used to predict future conditions in the geologic setting be supported by an appropriate combination of methods such as field tests, in-situ tests, laboratory tests that are representative of field conditions, monitoring data, and natural analog studies?

6) Are the analyses methods used to determine the hazard related to igneous activity sufficient to determine compliance with 10 CFR 60 Performance Objectives?

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

OVERVIEW

JOHN TRAPP, NRC
JUNE 9, 1993

MAJOR AREAS OF CONCERN

COMPLIANCE DETERMINATION

VOLCANIC PETROLOGY

STRUCTURE / TECTONICS

PROBABILITY

PRIMARY ASSUMPTIONS OF REPORT

WANING VOLCANISM

HOMOGENEOUS POISSON MODEL

CFVZ - STRUCTURAL CONTROL

ONGOING CONCERNS

TRIPARTITE PROBABILITY
- COMMENT 8, STUDY PLAN 8.3.1.8.1.1.
- DEFERRED UNTIL AFTERNOON SESSION

COMBINATION OF MUTUALLY EXCLUSIVE MODELS/EXPERT OPINION
- COMMENT 12 AND 13, STUDY PLAN 8.3.1.8.1.1
- DEFERRED

REGULATORY BASIS

- METHODOLOGY NOT SUFFICIENT TO FORM THE BASIS FOR OVERALL SYSTEM PERFORMANCE DEMONSTRATION

VOLCANIC PETROLOGY CONCERNS

- UNDERSTANDING OF PROCESS MODELS
- WANING MAGMATISM
- POLYCYCLIC/POLYGENETIC MAGMATISM
- WESTERN GREAT BASIN MAGMATIC PROVINCE

REGULATORY BASIS

- APPROPRIATENESS OF ANALYSIS
- POSSIBILITY OF UNDERESTIMATION OF EFFECTS
- EXTENT OF DATA COLLECTION

STRUCTURE / TECTONIC CONCERNS

- INTEGRATION OF STRUCTURE / TECTONICS AND MAGMATISM
  - ADEQUACY OF GEOPHYSICS PROGRAM
  - STATUS OF PROGRAM

REGULATORY BASIS

- DEGREE PAC PRESENT
- RESOLUTION CAPABILITIES AND EXTENT UNDETECTED
- APPROPRIATENESS OF ANALYSIS
- POSSIBILITY OF UNDERESTIMATION OF EFFECTS

PROBABILITY CONCERNS

- ALTERNATIVE MODELS
  - HOMOGENEOUS POISSON MODEL
  - PATTERN RECOGNITION AND TESTING

REGULATORY BASIS

- APPROPRIATENESS OF ANALYSIS
- POSSIBILITY OF UNDERESTIMATION OF EFFECTS
- EXTENT OF DATA COLLECTION

HOMOGENEOUS POISSON MODELS

REPORT JUSTIFIES THE APPLICATION OF HOMOGENEOUS POISSON MODEL TO VOLCANISM BY COMPARISON WITH USE IN SEISMIC HAZARD ANALYSIS.

LESSONS LEARNED FROM APPLICATION OF POISSONIAN MODELS IN SEISMIC HAZARD STUDIES. (EPRI REPORT "APPLICABILITY OF THE POISSON EARTHQUAKE-OCCURRENCE MODEL")

> "THE POISSON-BASED ESTIMATE IS A VALID ENGINEERING ESTIMATE [AS] IN ALL BUT A SMALL SUB-SET OF CASES...THE... APPROXIMATION IS UNCONSERVATIVE BY A FACTOR OF NO MORE THAN THREE."

APPLICATION TO VOLCANISM DOES NOT APPEAR TO BE JUSTIFIED

> RELATIONSHIP OF SEISMIC DESIGN VALUE TO MAGMATIC DESIGN VALUE
>
> FACTOR OF SAFETY

Models of Waning Magmatism in the Crater Flat Region, Nevada, may Underestimate Effects of the PAC: Alternative Petrologic Models

Presented by Dr. Brittain E. Hill

Volcanologist
Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
San Antonio, Texas
(210) 522-6087

June 9, 1993
Las Vegas, Nevada

Summary of Waning Magmatism Concerns

1) The eruption of inhomogeneous mafic magma is not an unusual feature of historical eruptions and does not necessarily require polycyclic, polygenetic volcanism or waning magmatism.

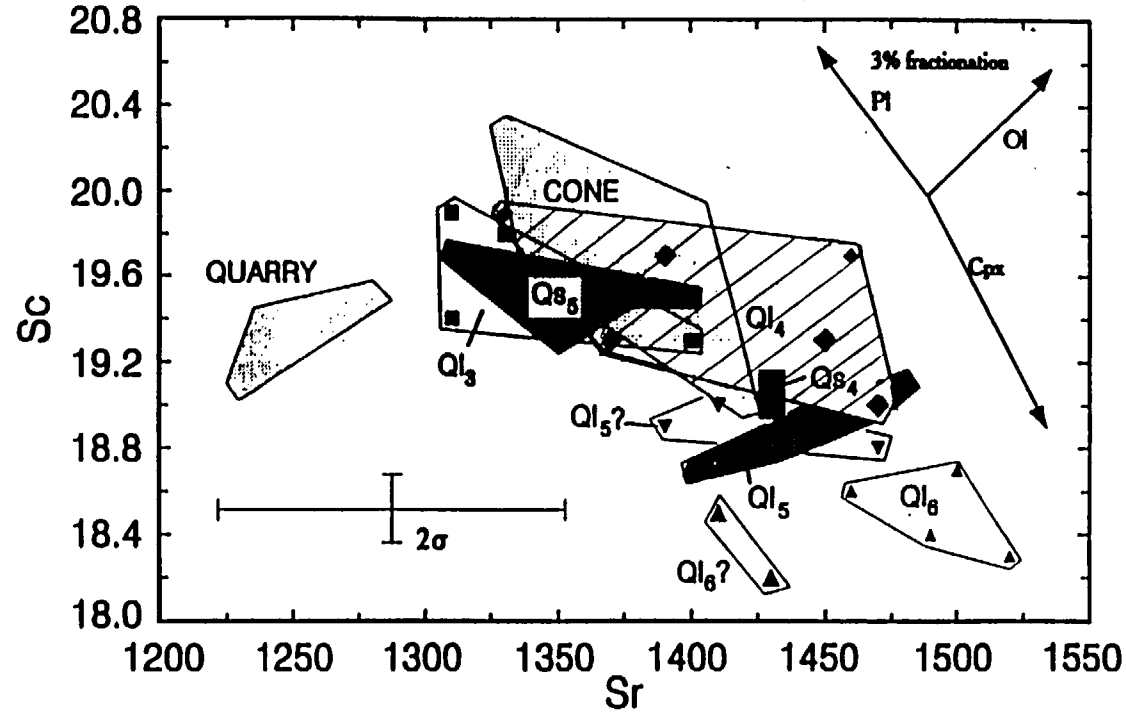
2) In addition to pressure, the mineralogy of mafic magmas is controlled by the temperature, composition, and water content of the system. Waning magmatism in the Crater Flat system cannot be concluded on a mineralogical basis.

3) Mafic eruption rates may have been relatively constant since about 10 Ma, but were perturbed by the anomalously large eruption of Thirsty Mesa. Observed time-volume relationships do not require waning magmatism in the Crater Flat system.

4) The Crater Flat system is widely recognized as part of the Western Great Basin (WGB) magmatic province. Geochemical trends in the adjacent Basin and Range magmatic province are not directly applicable to this system. Waning magmatism is not supported in the WGB.

1: Waning magmatism and polycyclic/polygenetic volcanism

Intraunit variations at Lathrop Wells are very similar to interunit variations



Modified from Perry and Crowe (1992) to include all Ql4 samples in one field and to emphasize distinctions between units Qs5 and Ql5.

- *All eruptive units are not compositionally distinct*
  - *Intraunit variations exceed 2σ error*

Compositional zonation does not require polycyclic eruptions

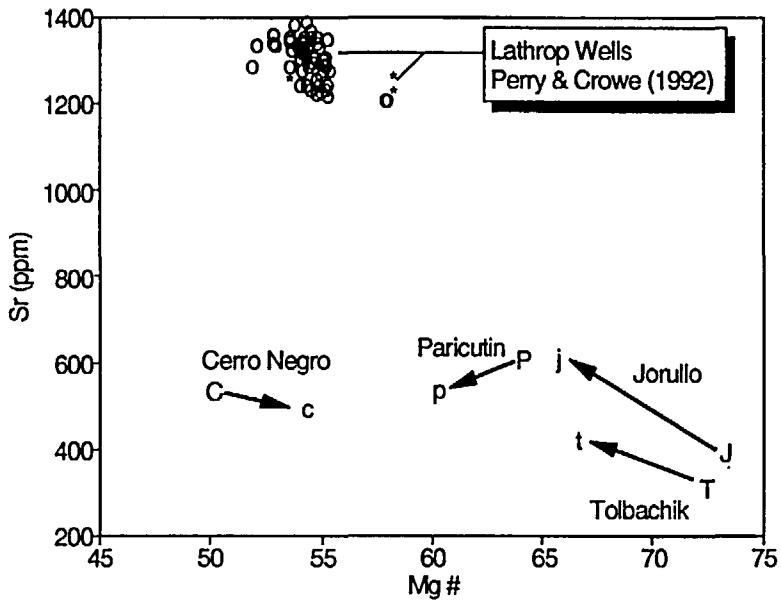
Historical, zoned mafic eruptions include:

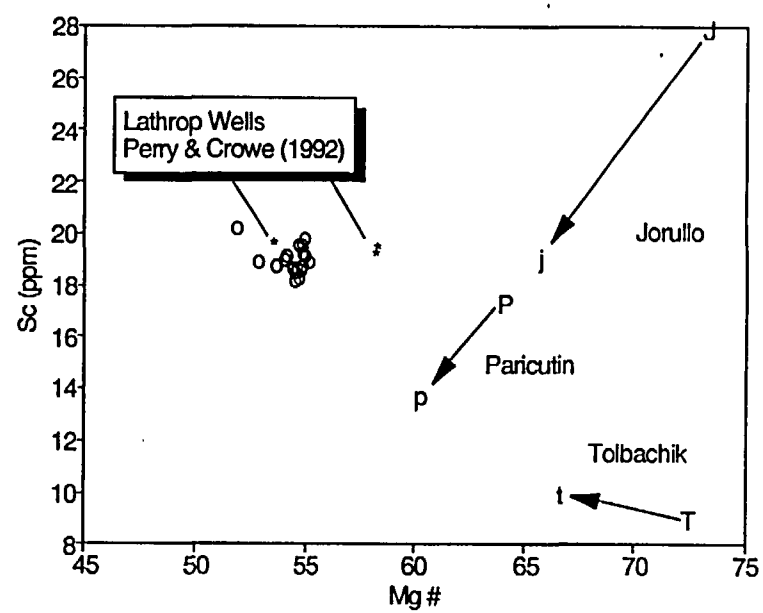
- Tolbachik, Kamchatka (1975-76), 72 days
- Cerro Negro, Nicaragua (1971), 12 days
- Parícutin, Mexico (1943-1952), 9 years
- Jorullo, Mexico (1759-74), 15 years

These eruptions each constitute a single event in the geologic record and are considered monogenetic

1: Waning magmatism and polycyclic/polygenetic volcanism

Compositional variations at Lathrop Wells are less or equal to historic zoned eruptions





Mg# = Mg/(Mg+Fe^{2+}), assuming Fe^{2+} = 0.85 Fe^{Total} UPPERCASE = Early eruption; lower case = late eruption

The geochemical variations at Lathrop Wells are not unusual for mafic eruptions and do not require polycyclic or polygenetic volcanism

5) MAFZONEC

2: Mineralogy and waning magmatism

Multiple extensive and intensive variables control the mineralogy of magmas:

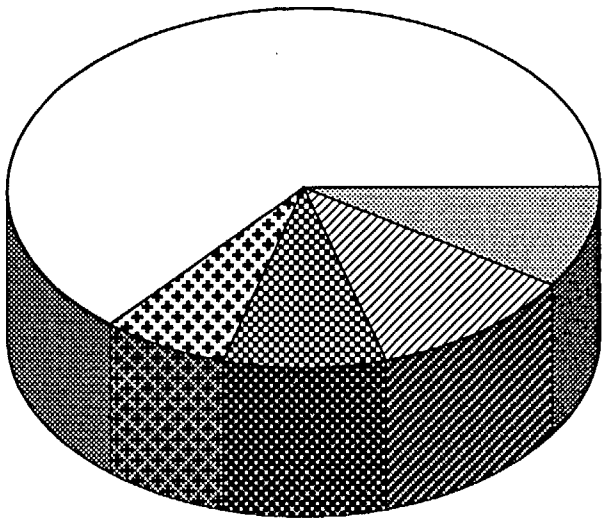
- Temperature
- Pressure
- Water Content
- Bulk Composition

- *All of these variables must be constrained before the effects of one variable can be identified*

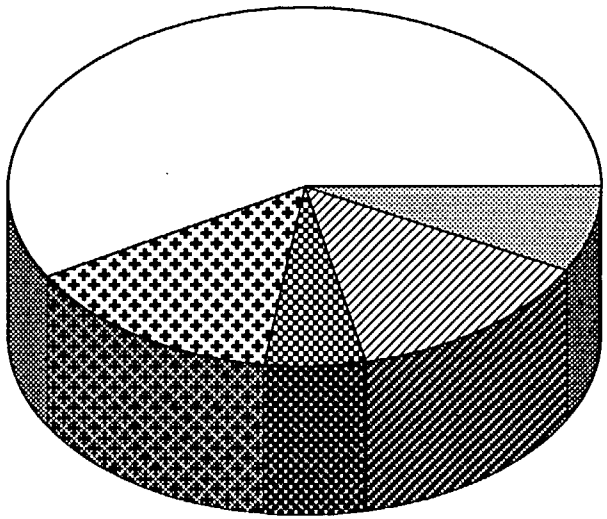
- *Multiple hypotheses besides an increase in depth can explain changes in the Crater Flat basalt mineralogy*

Normative Mineralogy

Average Lathrop Wells



Average 3.7 Ma Crater Flat



Vaniman et al., 1982; Crowe et al., 1986

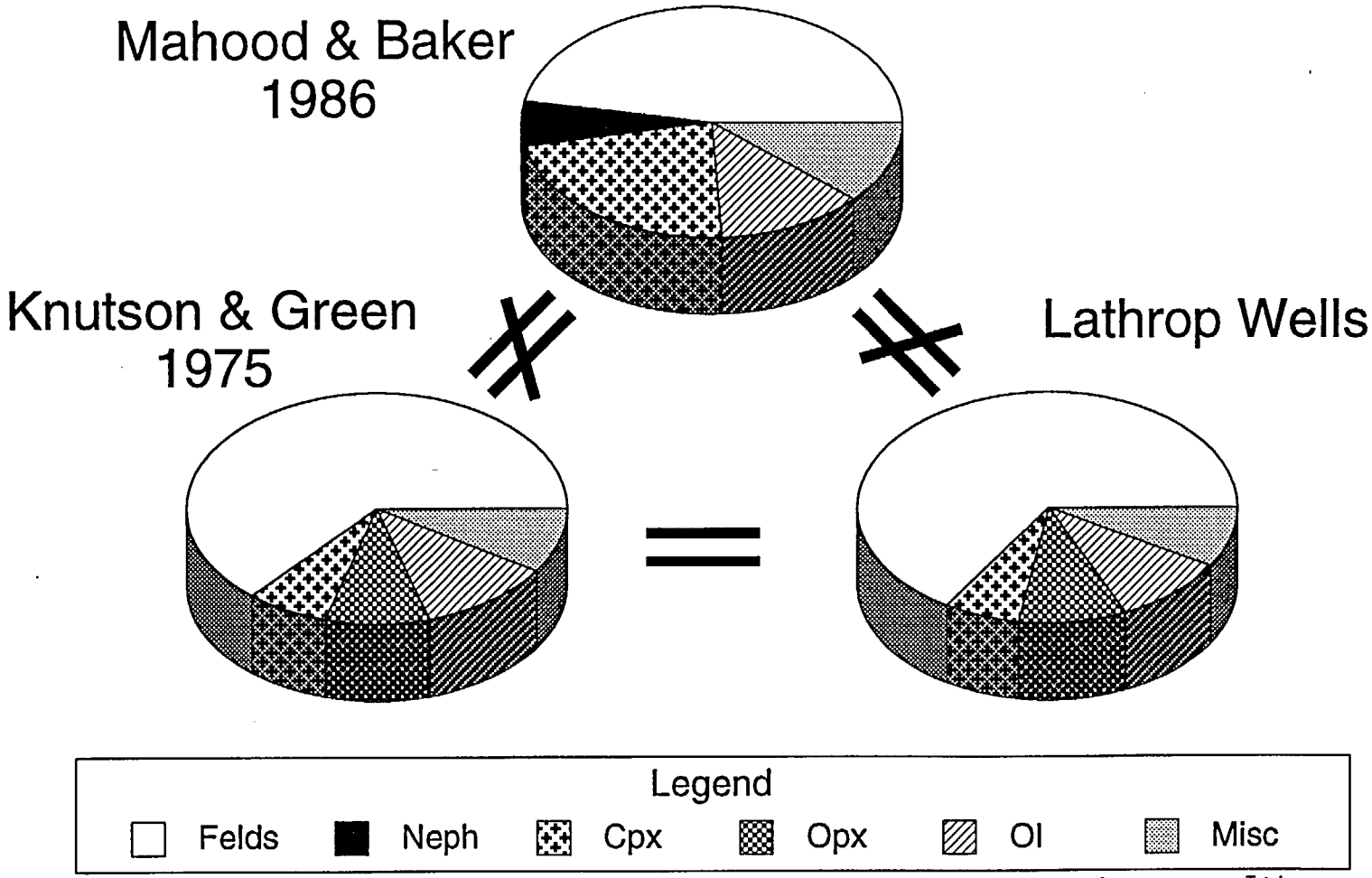
Legend

Felds Cpx Opx Ol Misc

CIPW norms calculated using MAGMA86 (Hughes, 1987) and assuming $Fe^{3+} = 0.15\ Fe^{Total}$

2: Mineralogy and waning magmatism

Normative Mineralogy

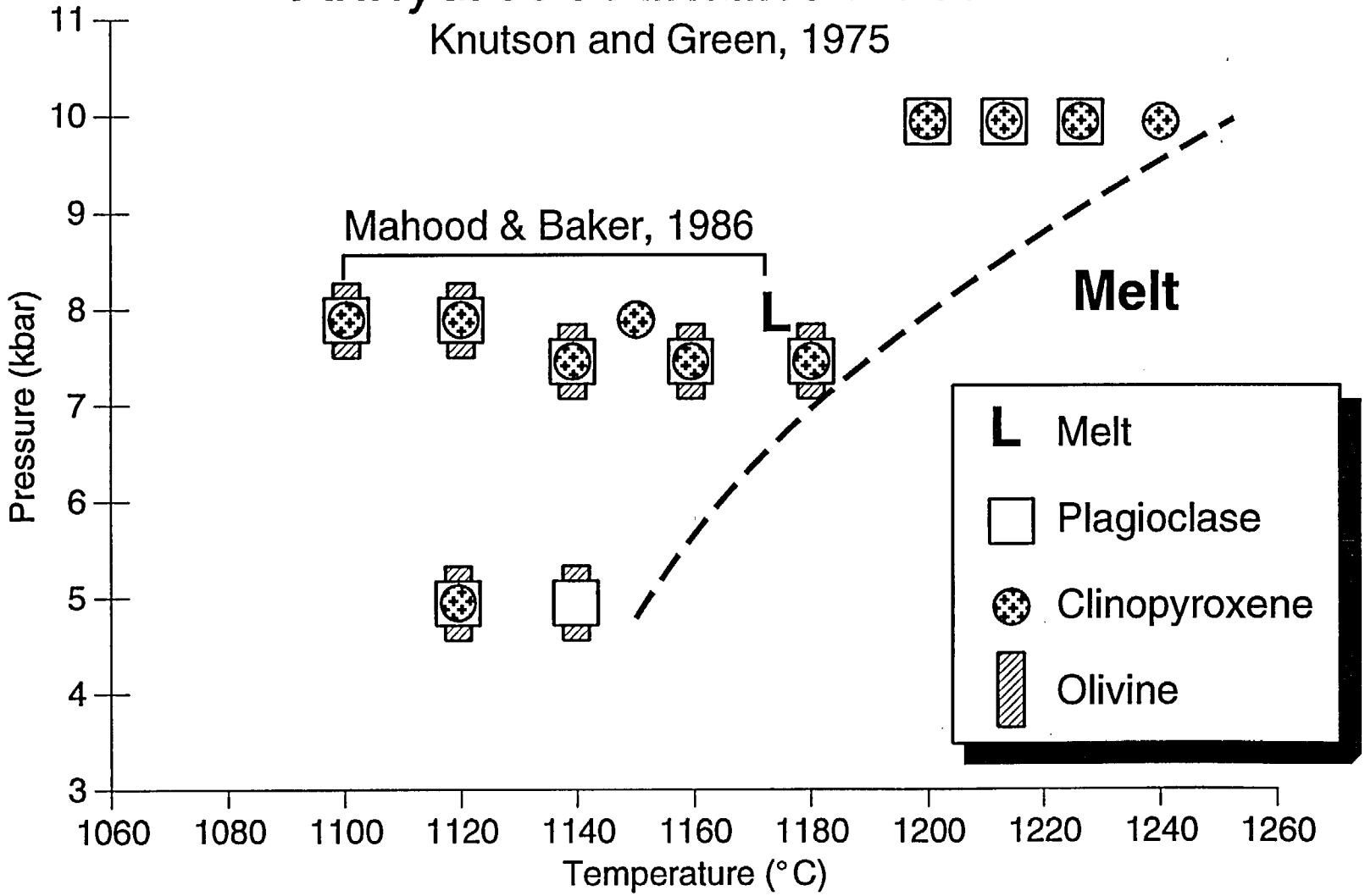


CIPW norms calculated using MAGMA86 (Hughes, 1987) and assuming $Fe^{3+} = 0.15\ Fe^{Total}$

2: Mineralogy and waning magmatism

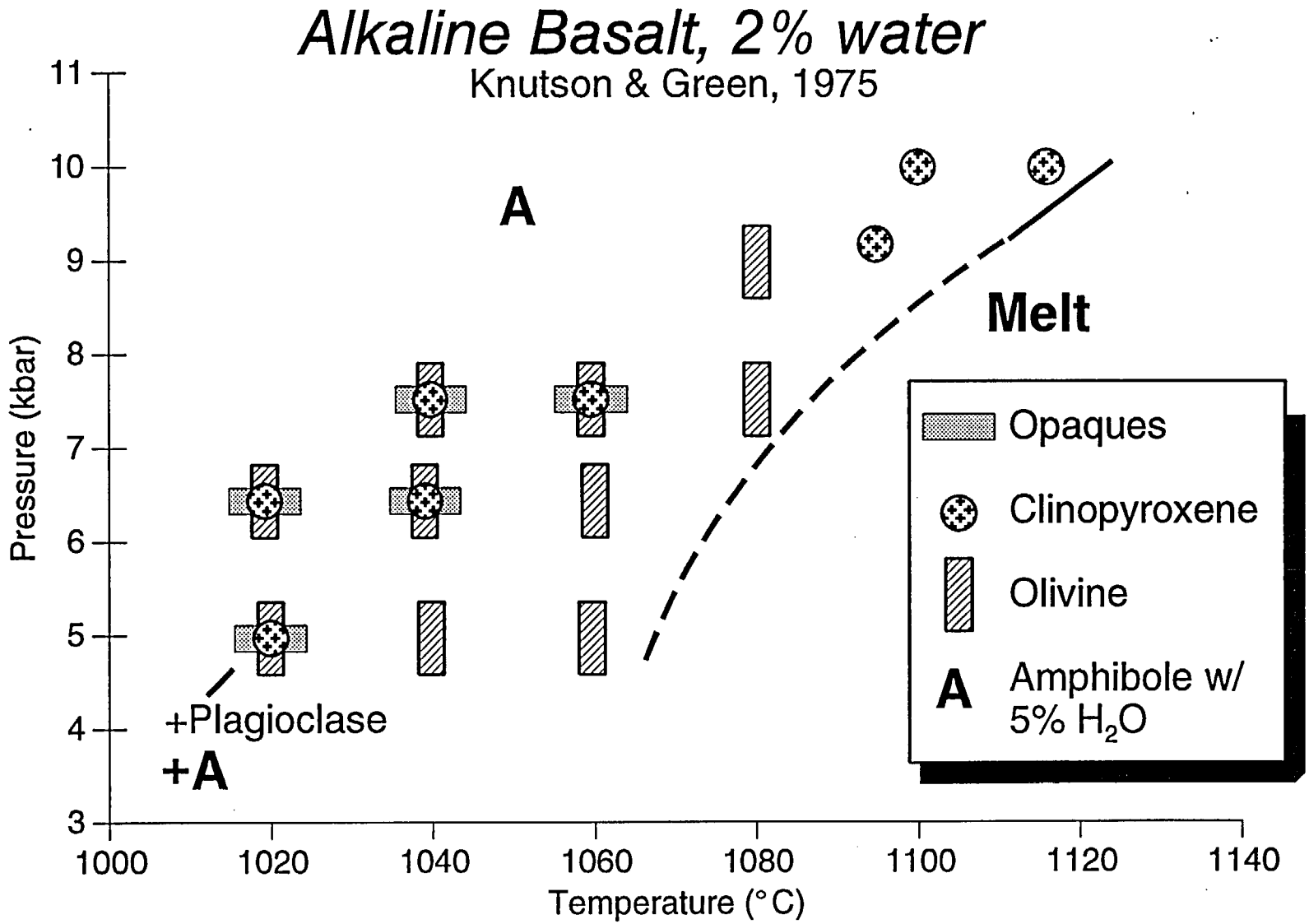
Anhydrous Alkaline Basalt

Knutson and Green, 1975



9) ABPHASE

2: Mineralogy and waning magmatism



10) ALKBASW2

Apparent problems in the mineralogy of Quaternary basalt

- Arguments for an increase in depth with time critically depend on the absence of plagioclase (e.g., p. 165). However:

"Lathrop Wells unit Ql_6 also contains plagioclase as a phenocryst phase" (p. 168)

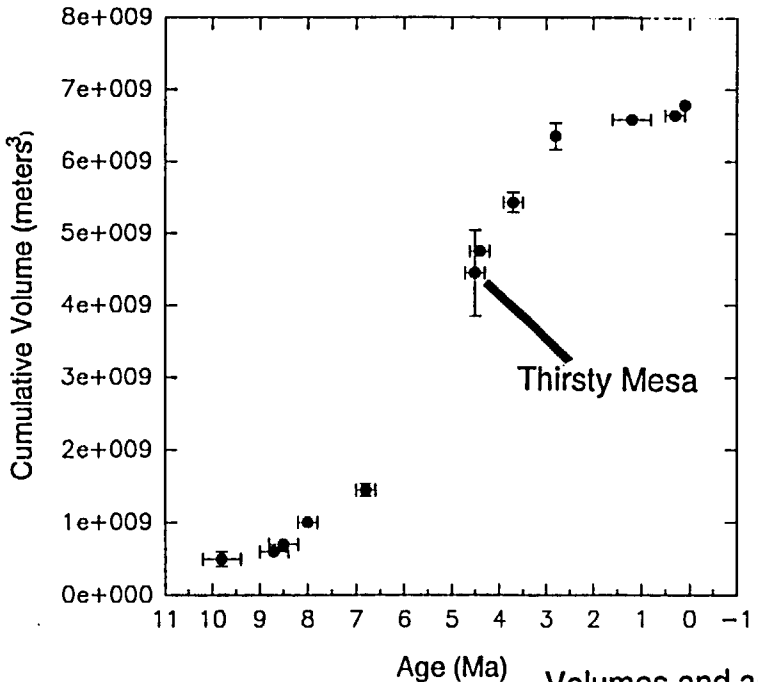
At Lathrop Wells, U-Th dates utilize coarse and fine grained plagioclase in unit Ql_4 (p. 68)

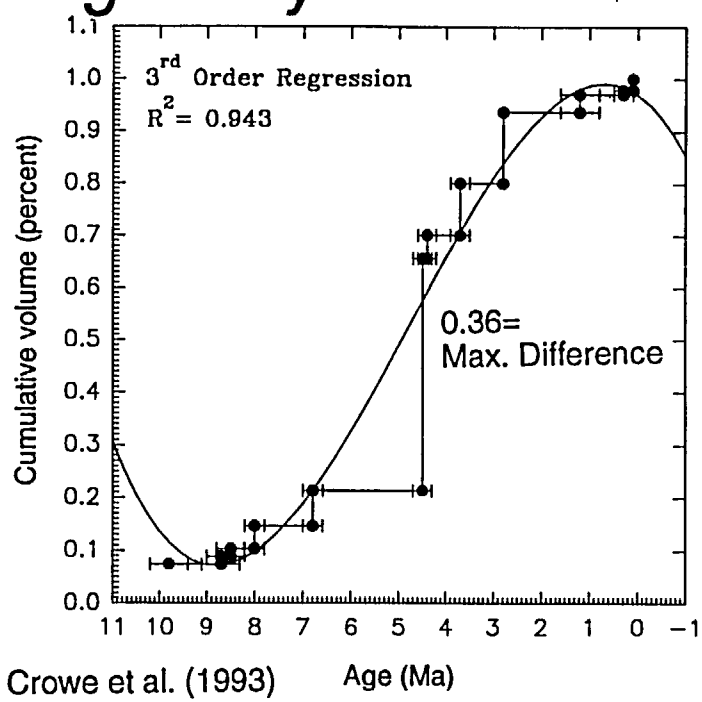
Zreda et al. (1993) also report plagioclase phenocrysts at Lathrop Wells

- Amphibole is a trace phenocryst in numerous Quaternary basalts. Amphibole may be present but undetected in basalts examined with thin-section petrography. Detailed heavy-mineral separations are required to detect small trace phases in vesicular basalt.

3: Eruption rates & waning magmatism

Time-volume relationships do not necessarily indicate a waning magma system





Volumes and ages from Crowe et al. (1993)

- Pliocene rate is strongly controlled by Thirsty Mesa, follows 2.2 Ma hiatus
- 10-6.5 Ma rates are very similar to <4 Ma rates
- Thirsty Mesa is distinct from expected trend using 2-tailed Kolmogorov-Smirnov test at 90% confidence interval
- Magma supply rate may be steady-state. Pliocene could represent recovery from eruption hiatus back to steady-state rates, i.e., not waning.

4: Regional trends & waning magmatism

The Western Great Basin is distinct from other Basin & Range magmatic provinces

Western Great Basin

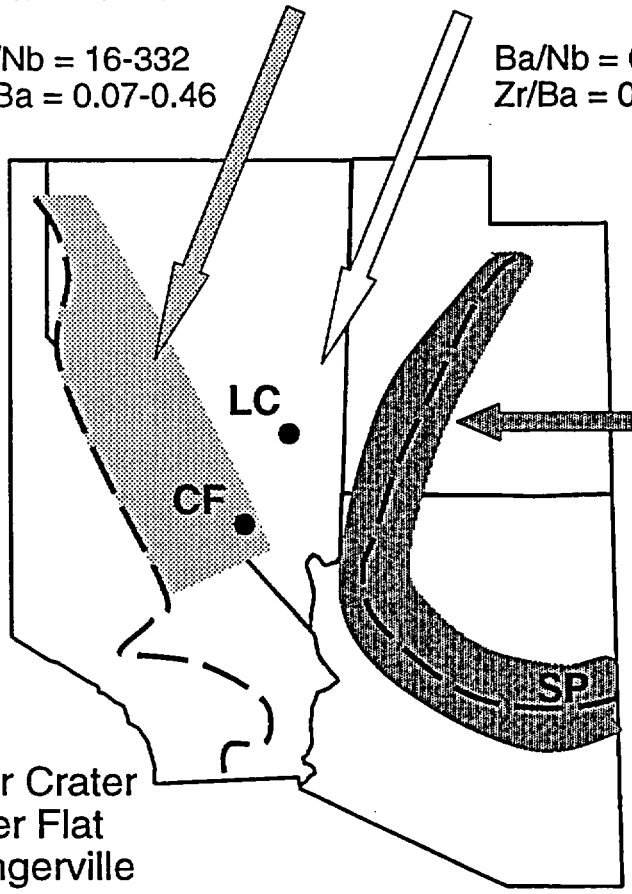
$^{87}Sr/^{86}Sr$ = 0.7041-0.7076
$^{143}Nd/^{144}Nd$ = 0.5121-0.5128

Ba/Nb = 16-332
Zr/Ba = 0.07-0.46

Basin & Range

$^{87}Sr/^{86}Sr$ = 0.7032-0.7040
$^{143}Nd/^{144}Nd$ = 0.5128-0.5131

Ba/Nb = 6-19
Zr/Ba = 0.3-1.0



Colorado Plateau Transition Zone

$^{87}Sr/^{86}Sr$ = 0.7032-0.7070
$^{143}Nd/^{144}Nd$ = 0.5121-0.5131

Ba/Nb = 9-95
Zr/Ba = 0.1-0.8

LC: Lunar Crater
CF: Crater Flat
SP: Springerville

Schematic diagram, modified from Kempton et al. (1991).

- WGB systems do not show distinct petrogenetic shifts at 5 Ma.
- WGB magmas still have lithospheric mantle signatures, <5 Ma B&R are asthenospheric
- CF is petrogenetically distinct from LC & SP systems & does not show a trend of waning magmatism

Several alternative hypotheses to waning magmatism

- Magma supply rate has increased in the Quaternary, resulting in a crustal density that is lower and inhibits the eruption of the higher density, more primitive magmas
- The system has been steady-state since about 10 Ma. Magma ascent is occasionally inhibited (6.7-4.5 Ma), resulting in larger eruptions as the system returns to a steady-state eruption rate
- Increasing magmatic volatile content with time results in higher ascent rates and smaller, more frequent Quaternary eruptions with no change in magma supply rate
- Like other Western Great Basin systems, Crater Flat has yet to change to an asthenospheric magma source. Other nearby Basin & Range systems have at least several million years of activity after this transition.

Conclusions

- Small geochemical variations at Lathrop Wells do not require the polycyclic eruption of discrete magma bodies in a waning system.
- Mineralogic and petrologic variations attributed to changes in depth also could represent changes in temperature, composition, or water content of the system and do not require a waning magmatism.
- Observed time-volume relationships do not require a waning magma system. Volcanism could be steady-state or waxing in the Crater Flat system.
- The Crater Flat system is part of the Western Great Basin (WGB) magmatic province. Petrogenetic trends in the Basin and Range province are not directly applicable to this system. Waning magmatism in the WGB is not supported by analogy to Basin & Range systems.

Under 10CFR60.122, a potentially adverse condition such as Quaternary Igneous Activity must be adequately investigated so as to not underestimate its effects on the repository. Alternative hypotheses are possible to many of the conclusions reached in the Volcanism Status Report. These hypotheses significantly affect probability and consequence models in the repository area.

HOMOGENEOUS POISSON MODELS MAY UNDERESTIMATE THE EFFECTS OF THE PAC: ALTERNATIVE APPROACHES

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June 9, 1993
Las Vegas, Nevada

SOME PROBABILITY CONCERNS

• Several valid estimates of recurrence rate in the YMR are much higher than the range reported [1.6 - 4.0 volcanoes / million years] Recurrence rate has a significant impact on models and must be better constrained.

• Homogeneous Poisson models fail to characterize important aspects of volcano distribution in the YMR. Because YM is close to late Quaternary volcanoes, homogeneous Poisson models tend to underestimate the probability of volcanic disruption.

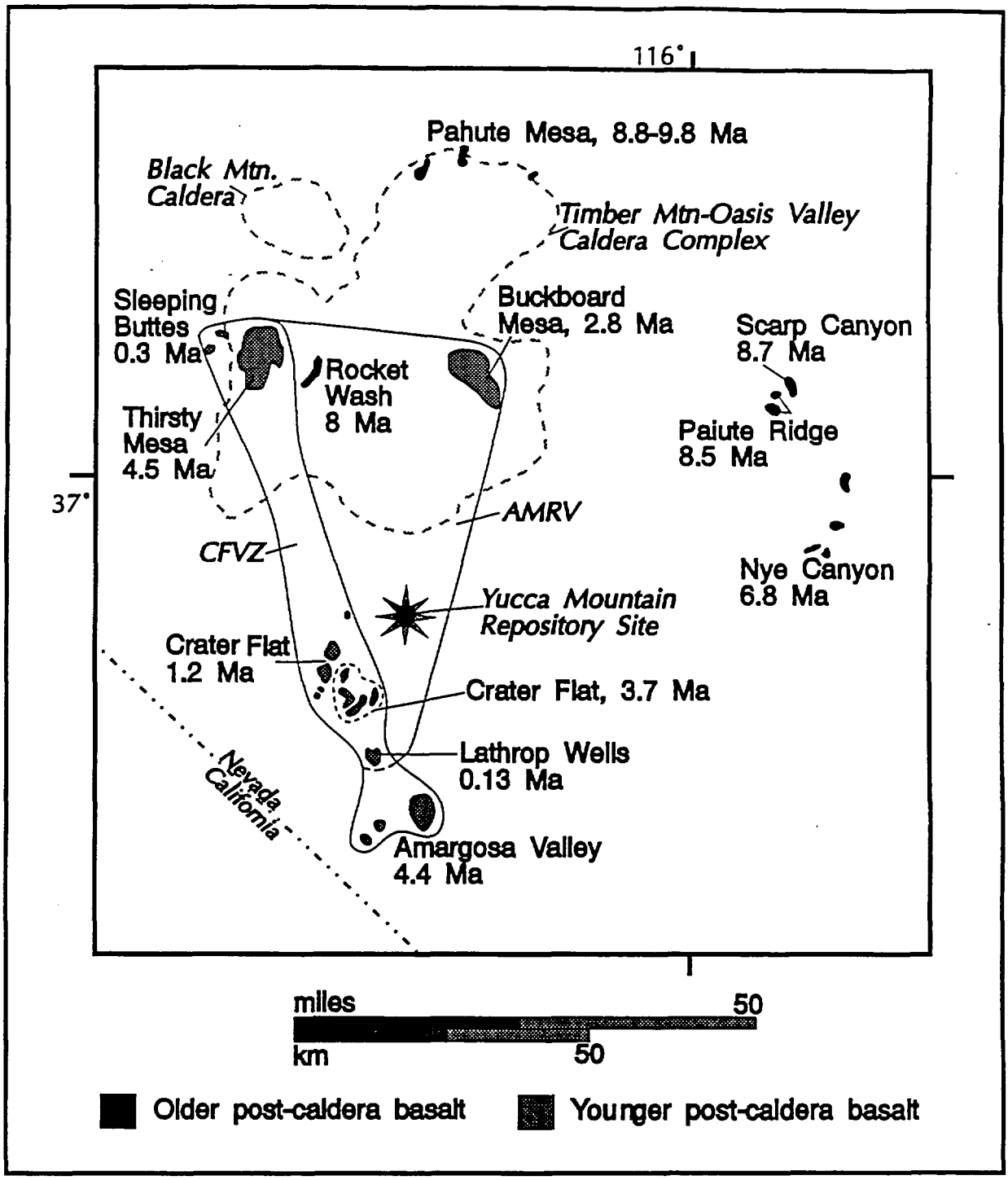
• Significantly higher probabilities of volcanic disruption are estimated from nonhomogeneous models. Alternative models need to incorporate additional geologic information.

• NNW -trending pattern in cinder cone distribution in the CFVZ is not statistically significant and does not provide evidence of deep-seated structural control on volcanism.

OUTLINE OF TECHNICAL DISCUSSION

- Distribution and ages of volcanoes in the YMR
- Estimates of YMR recurrence rate
- Testing the homogeneous Poisson model
- An example of a spatially and temporally nonhomogeneous Poisson model
- Alignment analysis of YMR volcanoes

DISTRIBUTION AND AGES OF VOLCANOES IN THE YMR



FROM:

CROWE (1990)
CROWE ET AL. (1982; 1983)
VANIMAN AND CROWE (1981)
CROWE AND PERRY (1991)
CROWE (1992, WRITTEN COMMUNICATION (NWTRB))

Name	Age (Ma)	UTM easting	UTM northing	Name	Age (Ma)	UTM easting	UTM northing
Amargosa Valley SW	≈4.0	543376	4048820	Hidden Cone	0.3±0.2	523301	4113698
Amargosa Valley	≈4.0	544817	4050859	Thirsty Mesa	≈4.5	528129	4112249
Amargosa Valley NE	4.4	550306	4053139	Rocket Wash	8.0±0.2	535539	4109028
Lathrop Wells	0.13±0.05	543737	4060073	Buckboard Mesa	2.8±0.1	554946	4109111
Crater Flat S	3.7±0.2	541493	4066057	Pahute Mesa W	9.8±0.4	548758	4133489
Crater Flat E	3.7±0.2	543704	4067644	Pahute Mesa	8.8±0.1	554170	4134467
Crater Flat W	3.7±0.2	540584	4067787	Pahute Mesa E	≈9.8	561927	4132182
Crater Flat NW	3.7±0.2	539915	4070959	Paiute Ridge S	8.5±0.3	593698	4101888
Crater Flat W	3.7±0.2	536879	4068573	Paiute Ridge N	8.5±0.3	593611	4103166
Little Cone SW	1.2±0.4	534626	4069423	Scarp Canyon	8.7±0.3	595625	4103906
Little Cone NE	1.2±0.4	534825	4069884	Nye Canyon N	6.8±0.2	603210	4091744
Red Cone	1.2±0.4	537259	4071648	Nye Canyon	6.8±0.2	602370	4085671
Black Cone	1.2±0.4	538257	4074275	Nye Canyon SE	6.8±0.2	600999	4082470
Northern Cone	1.2±0.4	540088	4079455	Nye Canyon SW	6.8±0.2	599557	4083139
Little Black Peak	0.3±0.2	521298	4111346				

Table 1. Locations of volcanic centers and ages used for statistical models. Vent locations from Crowe (1990), and ages from Crowe et al. (1982; 1983), Vaniman and Crowe (1981), Crowe and Perry (1991), and Crowe, B.M., 1992, written communication. Vent coordinates in Universal Transverse Mercator, zone 11, Clarke 1866 spheroid.

UNCERTAINTY IN CRATER FLAT VOLCANO AGES

RED CONE		
VANIMAN AND CROWE: (1981)	1.14 ± 0.3	
VANIMAN ET AL. (1982)	1.50 ± 0.1	
HO ET AL.: (1991)	0.98 ± 0.1 1.01 ± 0.06 0.95 ± 0.08	**WE USE 1.2 ± 0.4 TO ATTEMPT TO REFLECT PRECISION AND ACCURACY OF THESE DATES**
SINNOCK AND EASTERLING (AVERAGED) (1983)	1.41 ± 0.6	
NORTHERN CONE		
VANIMAN ET AL : (1982)	1.14 ± 0.3 1.07 ± 0.04	
BLACK CONE		
VANIMAN AND CROWE (1981)	1.09 ± 0.3 1.07 ± 0.4	
LITTLE CONE SW		
VANIMAN AND CROWE (1981)	1.11 ± 0.3	

UNCERTAINTY IN SLEEPING BUTTES VOLCANO AGES

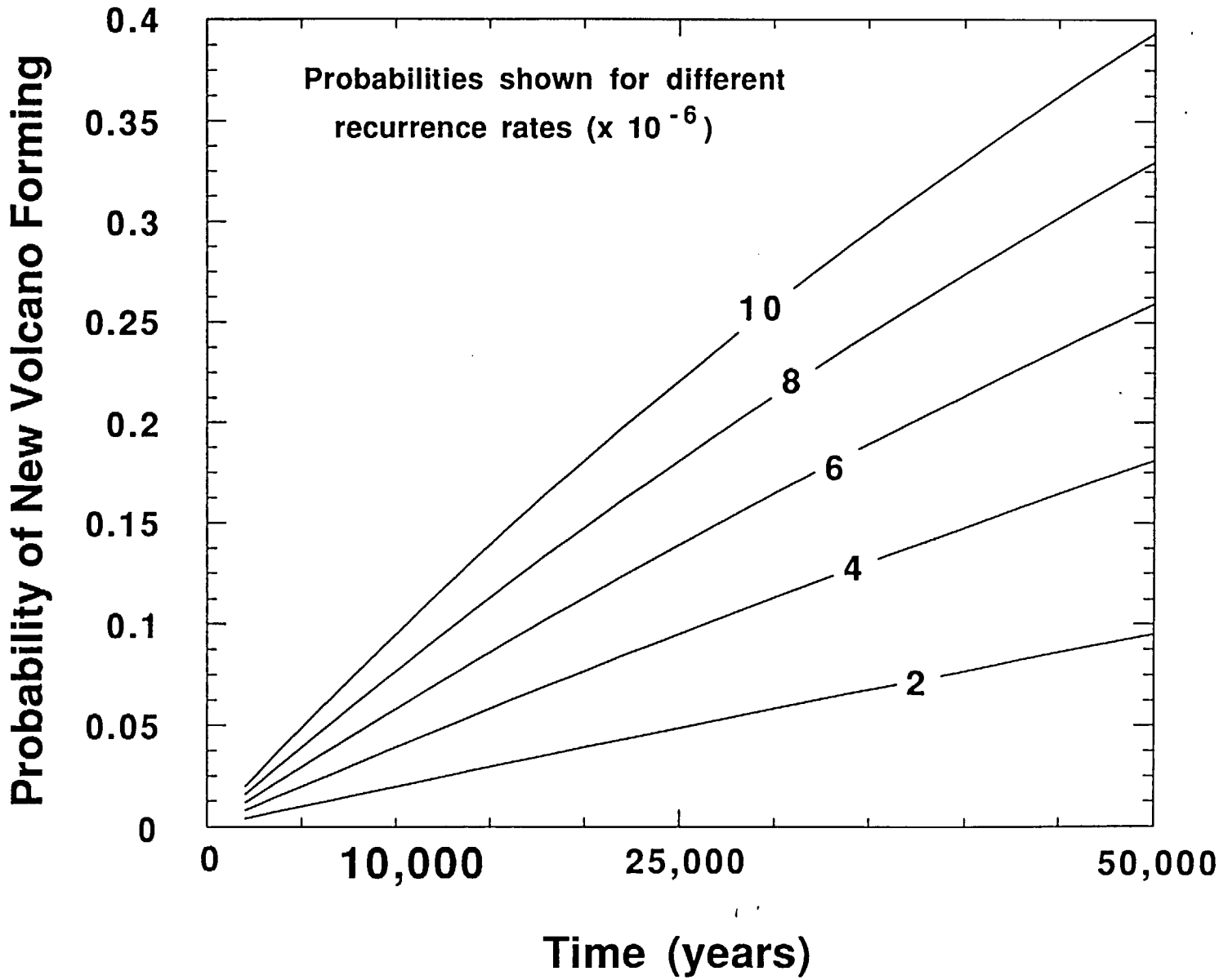
LITTLE BLACK PEAK		
CROWE ET AL. (1982)	0.29 ± 0.11	**WE USE 0.3 ± 0.2 TO ATTEMPT TO REFLECT PRECISION AND ACCURACY OF THESE DATES**
	0.32 ± 0.15	
	0.24 ± 0.22	
CROWE AND PERRY (1991)	0.208 ± 0.134	
	0.223 ± 0.1	
HIDDEN CONE		
CROWE AND PERRY (1991)	0.316 ± 0.2	

ESTIMATES OF YMR RECURRENCE RATE

SOME ESTIMATES OF YMR RECURRENCE RATE

	volcanoes / million years
Crowe et al. (1993):	
minimum event rate:	1.6
maximum event rate:	4
most likely event rate:	3.3
geometric mean most likely event rate:	2.6
Ho et al. (1991):	
maximum likelihood estimator:	5-6
Ho (1992):	
Weibull process (90% confidence interval):	1.85-12.6

Given the uncertainty in the ages of Crater Flat volcanoes (1.2±0.4 Ma), seven to eight volcanoes have formed in the last 0.8 to 1.6 million years. YMR recurrence rate is *7±2 volcanoes / million years*, based on time since start of Quaternary activity.


Probabilities shown for different
recurrence rates (x 10 -6)
10
8
6
4
2
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Probability of New Volcano Forming
0
10,000
25,000
50,000
Time (years)

Techcc-11

TESTING THE HOMOGENEOUS POISSON MODEL

H_o: VOLCANOES IN THE YUCCA MOUNTAIN REGION HAVE A HOMOGENEOUS POISSON DISTRIBUTION

H_1: VOLCANOES IN THE YUCCA MOUNTAIN REGION DO NOT HAVE A HOMOGENEOUS POISSON DISTRIBUTION

TWO METHODS TO TEST THE NULL HYPOTHESIS

- CLARK - EVANS TEST
- HOPKINS *F*-TEST

CLARK - EVANS TEST:

$$CE = \frac{d - \delta}{s_e}$$

$$\delta = 0.5\sqrt{A/n}$$

$$s_e = \frac{0.26136}{\sqrt{A/n^2}}$$

where:

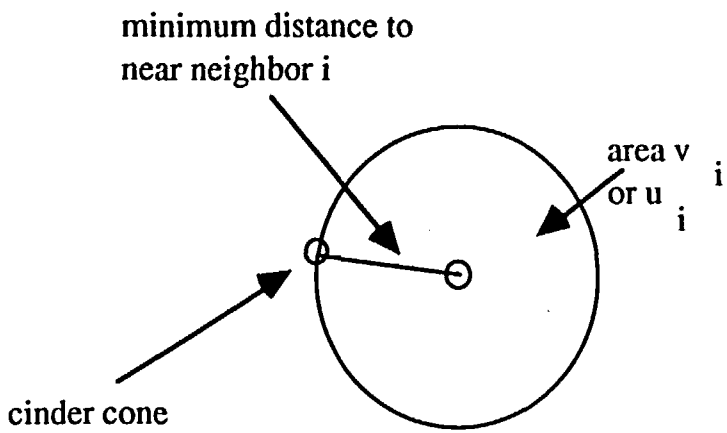
CE is the Clark - Evans Statistic
d is the mean distance between volcanoes
δ is the expected distance between volcanoes
A is the area of consideration (AMRV or CFVZ)
n is the number of volcanoes
s_e is the expected standard error

H_o is rejected with greater than 90% confidence for all volcanoes within the AMRV

HOPKINS *F* - TEST: $Hop_F = \frac{\lambda_p}{\lambda_v}$

$$\lambda_p = \frac{m}{\sum_{i=1}^{m} u_i}$$

$$\lambda_v = \frac{m}{\sum_{i=1}^{m} v_i}$$



Where: u_i and v_i are areas from point to volcano and volcano to volcano, respectively

m is the number of near neighbors

Hop_F is the Hopkins statistic

Hop_F = 2.4 to 3.2, H_O is rejected with greater than 99% confidence

VOLCANOES CLUSTER IN THE YUCCA MOUNTAIN REGION

- RECURRENCE RATE MUST VARY WITHIN THE YMR
- HOMOGENEOUS POISSON MODELS DO NOT ADEQUATELY DESCRIBE VOLCANO DISTRIBUTION

Homogeneous Poisson models will overestimate the probability of volcanism in some parts of the YMR, far from Quaternary volcanoes, and underestimate the probability of volcanism close to late Quaternary Crater Flat volcanoes.

AN EXAMPLE OF A SPATIALLY AND TEMPORALLY NONHOMOGENEOUS POISSON MODEL

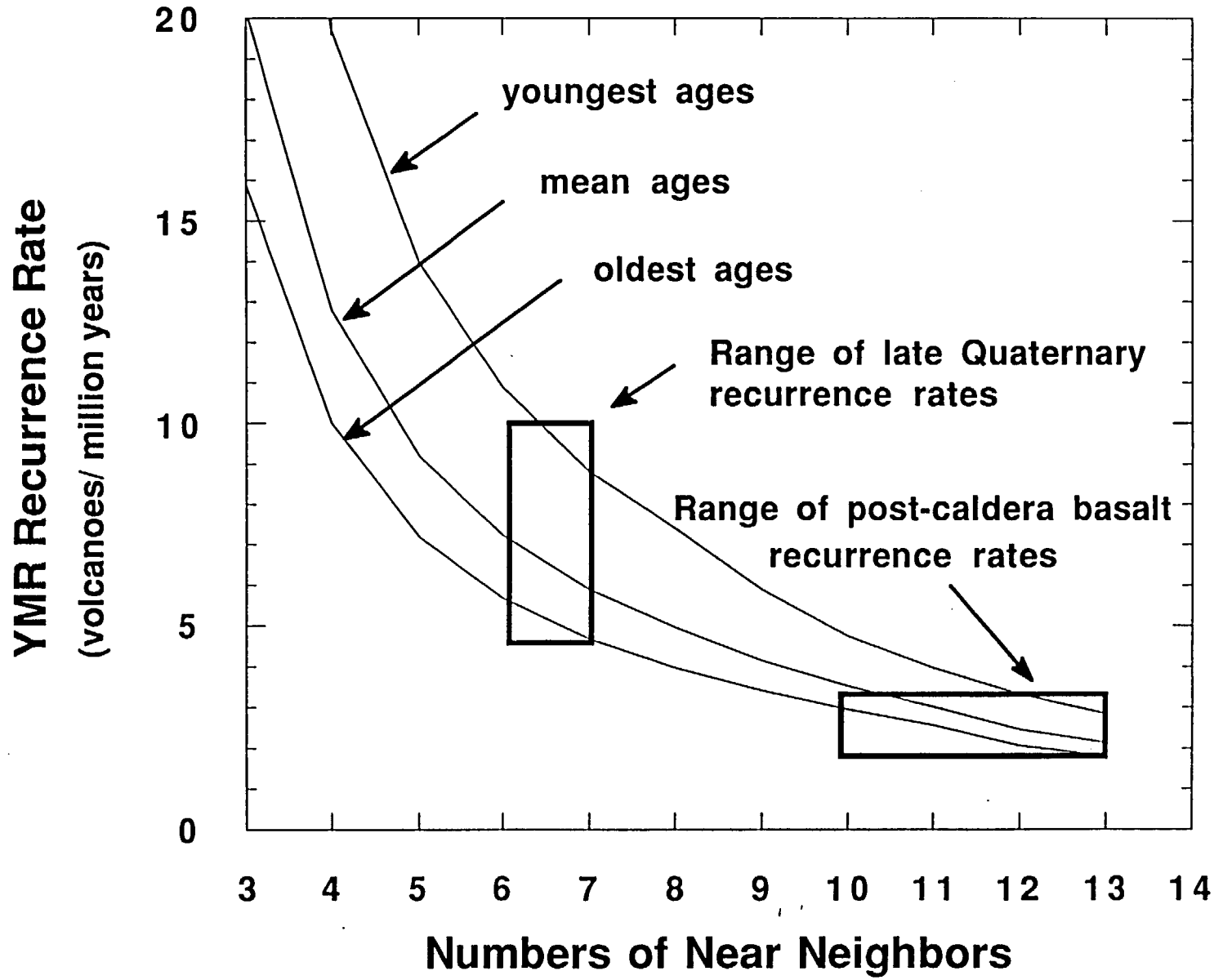
Estimating Recurrence Rate in a Nonhomogeneous Model

One approach is to use near neighbors: $$\lambda_r = \frac{m}{\sum_{i=1}^{m} u_i t_i}$$

where: λ_r is the recurrence rate at a point
t_i is the time since the formation of the volcano
and $u_i t_i$ is minimum for the nearest *m* neighbors

The number of near neighbors can be constrained by integrating the recurrence rate over the entire region to estimate the recurrence rate in the YMR, λ_t:

$$\lambda_t = \sum_{i=0}^{m} \sum_{j=0}^{n} \lambda_r (i, j) \, \Delta x \Delta y$$


YMR Recurrence Rate
(volcanoes/ million years)
20
15
10
5
0
3
4
5
6
7
8
9
10
11
12
13
14
Numbers of Near Neighbors
youngest ages
mean ages
oldest ages
Range of late Quaternary recurrence rates
Range of post-caldera basalt recurrence rates

Techcc-19

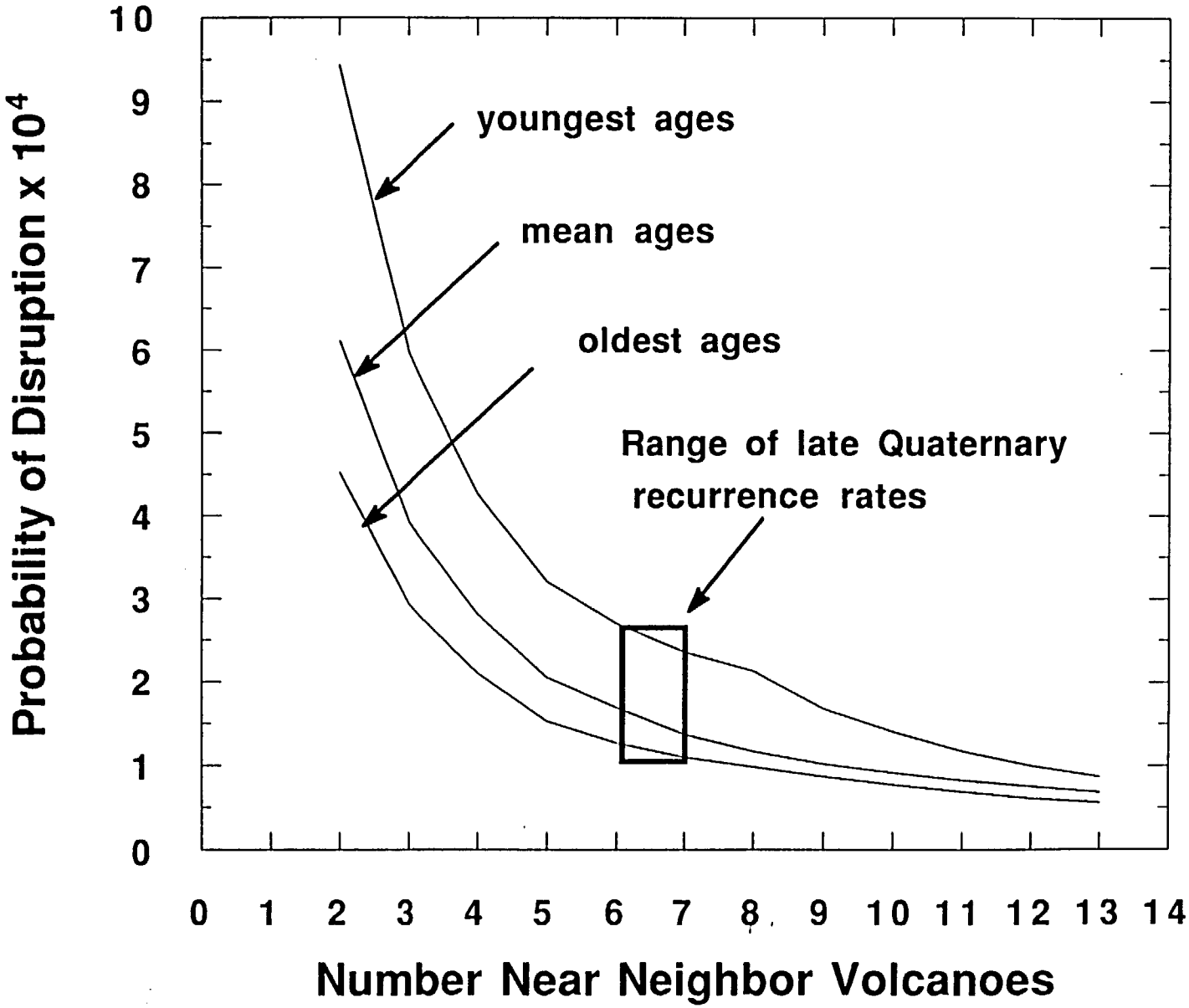
Using a spatially varying recurrence rate, it is possible to estimate the probability of a new volcano forming within or near the repository block:

$$P\,[N \geq 1] \;=\; 1 - exp\left[\, -t \iint_{XY} \lambda_r\,(x, y)\; dy dx \,\right]$$

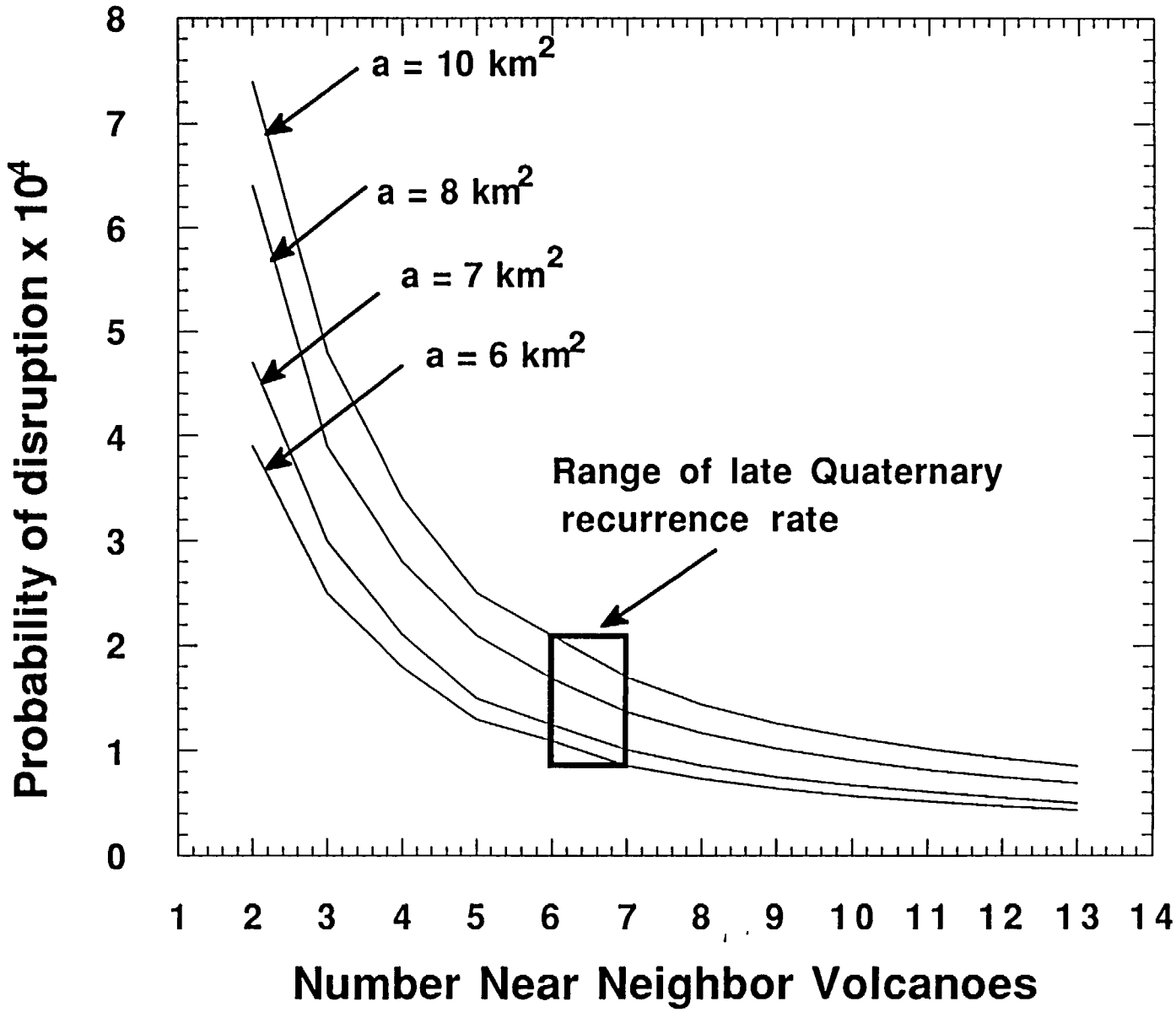
or

$$P\,[N \geq 1] \;=\; 1 - exp\left[\, -t \sum_{a} \lambda_r \Delta x \Delta y \,\right]$$

where: t = 10,000 years
λ_r is the expected recurrence rate at point x,y
a is the area of the repository


Probability of Disruption x 10^4
10
9
8
7
6
5
4
3
2
1
0
youngest ages
mean ages
oldest ages
Range of late Quaternary
recurrence rates
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number Near Neighbor Volcanoes

Techcc-21


a = 10 km2
a = 8 km2
a = 7 km2
a = 6 km2
Range of late Quaternary recurrence rate
Probability of disruption x 10-4
0
1
2
3
4
5
6
7
8
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number Near Neighbor Volcanoes

Techcc-22

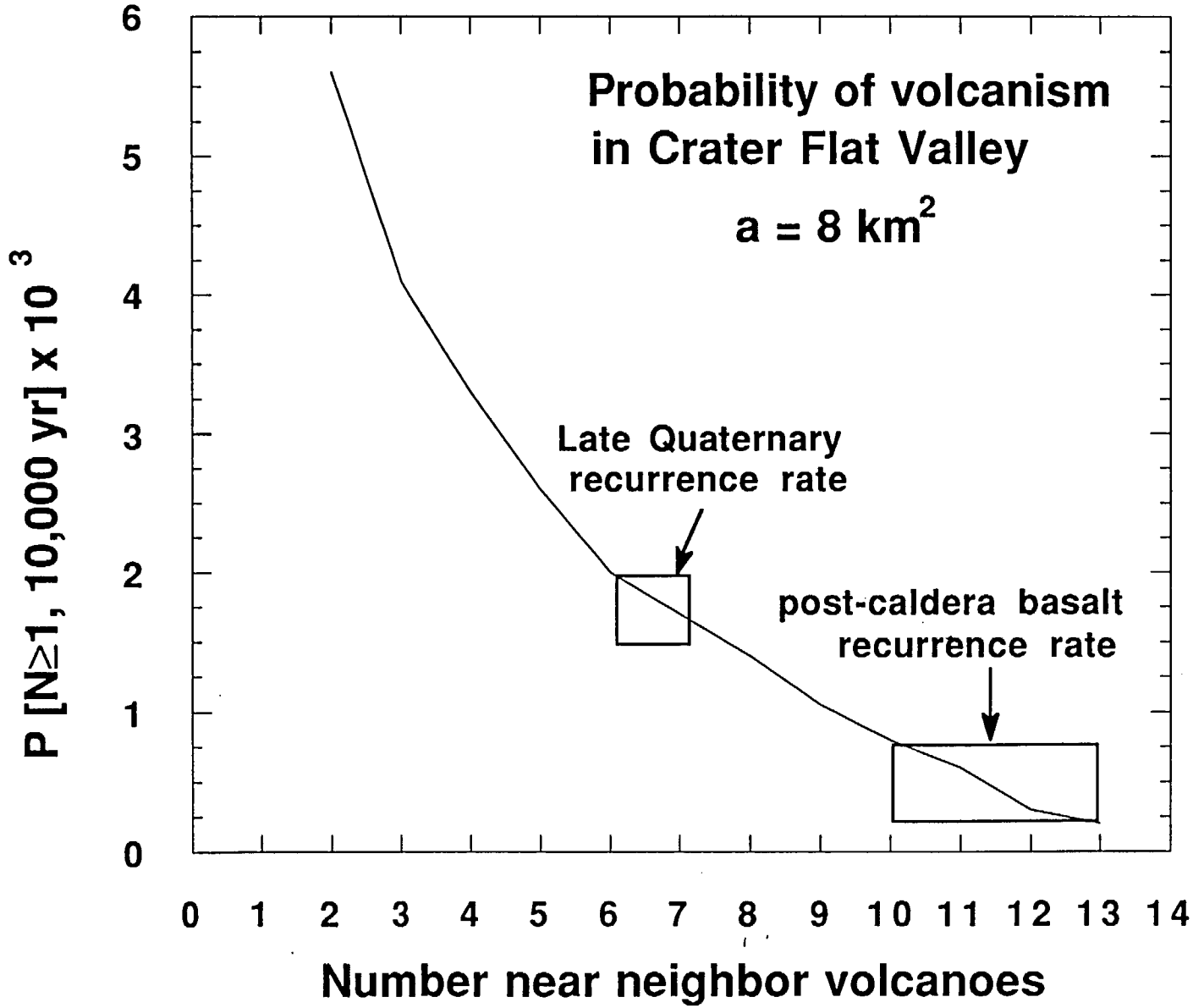
PROBABILITY OF DISRUPTION IN 10,000 yr USING NEAR NEIGHBOR NONHOMOGENEOUS POISSON MODEL

late Quaternary YMR recurrence rate:

8.0×10^{-5} to 3.5×10^{-4}
with most estimates between 1×10^{-4} and 3×10^{-4}

post-caldera basalt YMR recurrence rate:

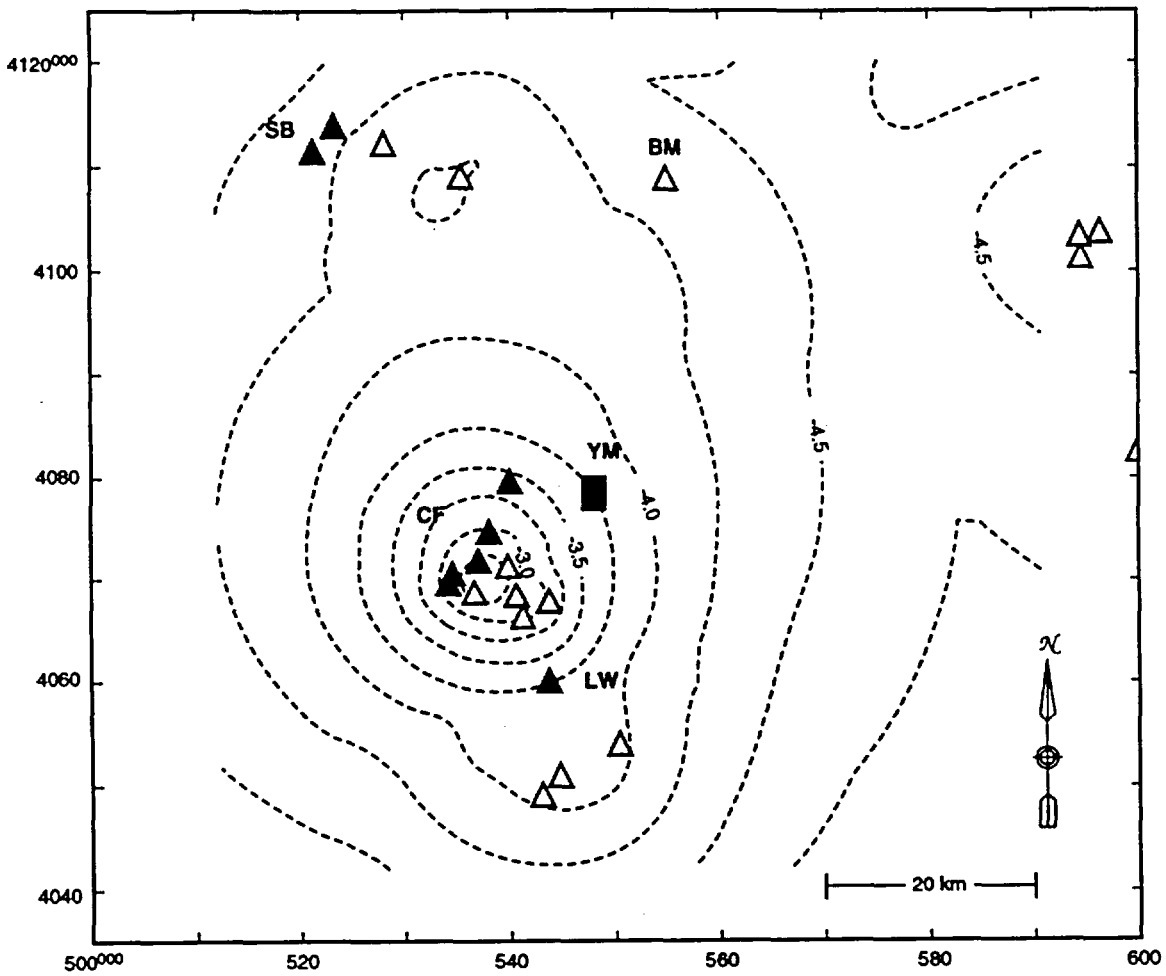
6.9×10^{-5} to 9.2×10^{-5}


Probability of volcanism
in Crater Flat Valley
a = 8 km2
Late Quaternary
recurrence rate
post-caldera basalt
recurrence rate
P [N≥1, 10,000 yr] x 10 3
0
1
2
3
4
5
6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number near neighbor volcanoes

Techcc-24

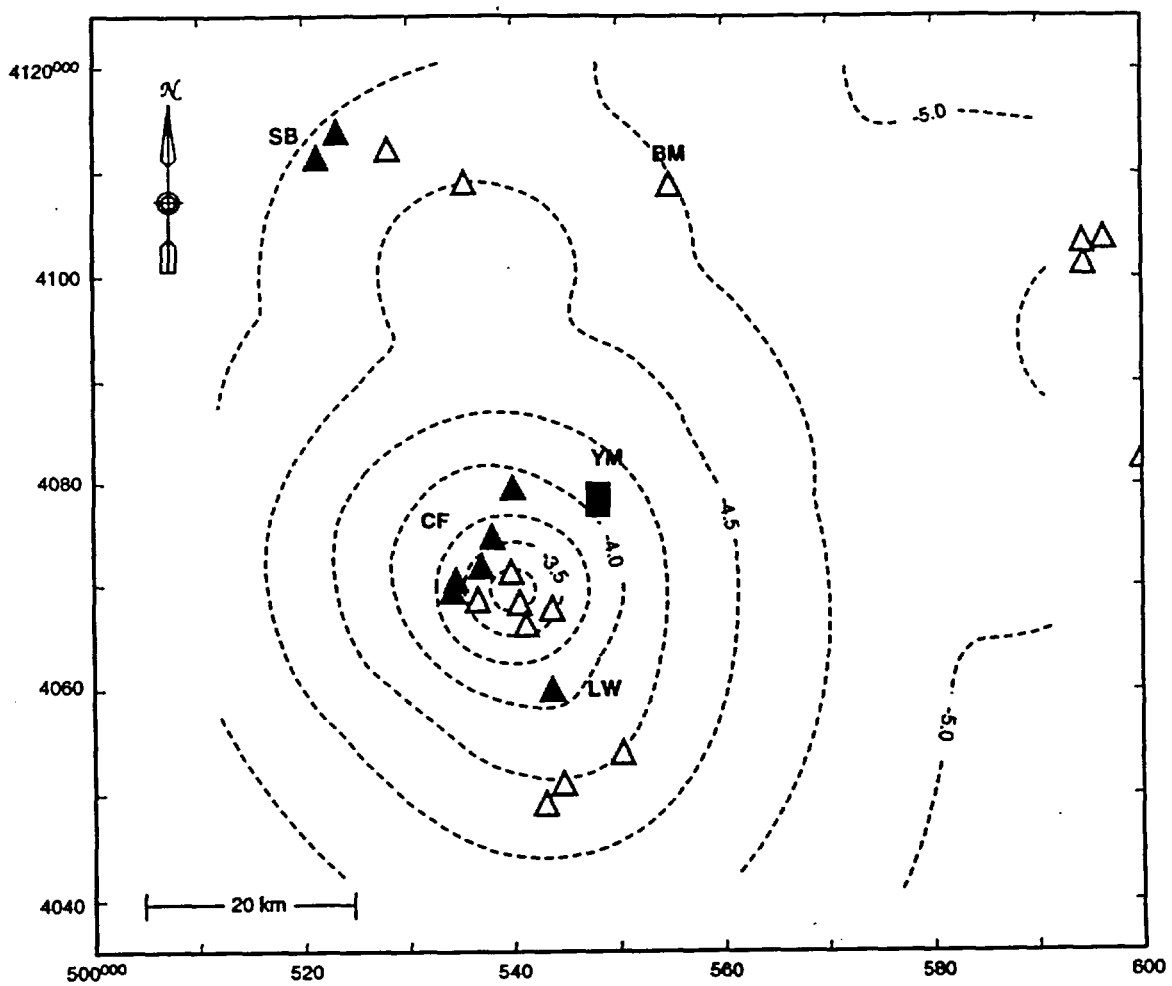
SIX NEAR NEIGHBOR NONHOMOGENEOUS POISSON PROBABILITY MODEL

- Reflects late Quaternary recurrence rate (7 volcanoes / million years)
- Contour interval is Log(P[N ≥ 1, 10,000 yrs, a = 8 km^2]) (e.g., -4.0 is a probability of 1 in 10,000 in 10,000 year of a new volcano forming within a 8 km^2 area)



TEN NEAR NEIGHBOR NONHOMOGENEOUS POISSON PROBABILITY MODEL

- Reflects post-caldera basalt recurrence rate (3 volcanoes / million years)
- Contour interval is Log(P[N ≥ 1, 10,000 yrs, a = 8 km^2]) (e.g., -4.0 is a probability of 1 in 10,000 in 10,000 year of a new volcano forming within a 8 km^2 area)



ALIGNMENT ANALYSIS OF VOLCANOES IN THE YMR

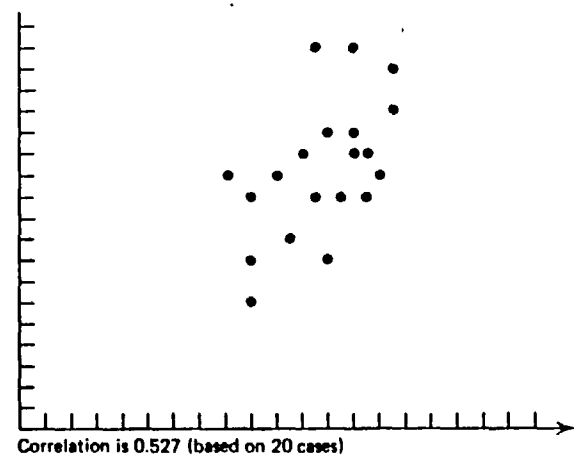
OUTLIERS AND CORRELATION COEFFICIENTS

DATA OUTLIERS AND CLUSTERING CAN CREATE SPURIOUSLY HIGH CORRELATION COEFFICIENTS

CINDER CONE CLUSTERING AND
ITS EFFECT ON ALIGNMENT IDENTIFICATION
HAS BEEN DISCUSSED AT LENGTH IN THE
LITERATURE

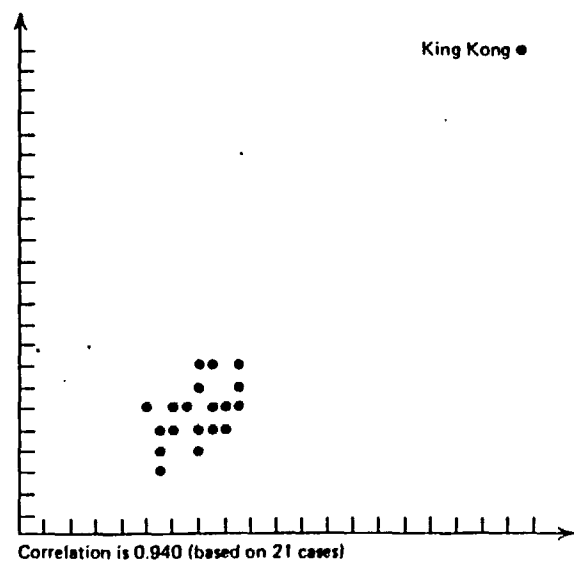
LUTZ (1986)
WADGE AND CROSS (1989)
CONNOR (1990)
CONNOR ET AL. (1992)

MODIFIED FROM MAKRIDIKAS ET AL. (1983)



Correlation is 0.527 (based on 20 cases)

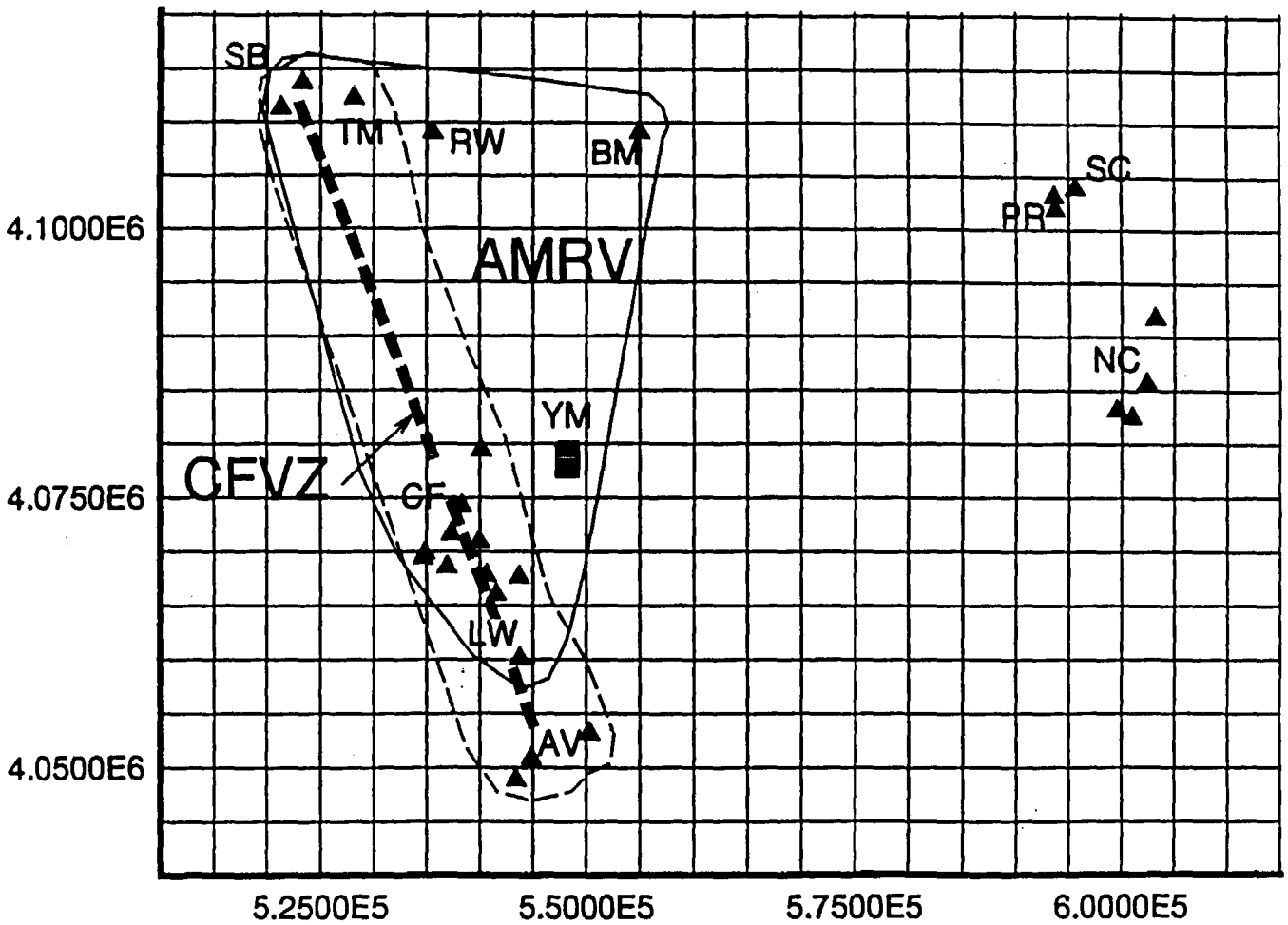
(a)



Correlation is 0.940 (based on 21 cases)

(b)

REGRESSION ANALYSIS IN THE CFVZ IS CONTROLLED BY SLEEPING BUTTE CLUSTER. THE RESULTING CORRELATION COEFFICIENT IS SPURIOUSLY HIGH.



SUMMARY OF ALIGNMENT ANALYSIS

- REGRESSION METHODS ARE NOT APPROPRIATE BECAUSE THE VOLCANOES CLUSTER

- IN A PRACTICAL SENSE, 3-4 CINDER CONE CLUSTERS DO APPEAR TO ALIGN IN A NNW DIRECTION.

- TWO-POINT AZIMUTH METHOD INDICATES THAT ONLY NE -TRENDING ALIGNMENTS ARE STATISTICALLY SIGNIFICANT IN THE CRATER FLAT - LATHROP - AMARGOSA VALLEY "CLUSTER"

- ADDITIONAL GEOLOGIC EVIDENCE NEEDED TO JUSTIFY ALIGNMENT MODEL. DISTRIBUTION OF VOLCANOES IN THE YMR DOES NOT PROVIDE EVIDENCE OF DEEP-SEATED STRUCTURAL CONTROL

SUMMARY COMMENTS

- SOME REASONABLE ESTIMATES OF RECURRENCE RATES ARE MUCH HIGHER THAN IS CONCLUDED BY THE STATUS REPORT. THE PROBABILITY OF FUTURE VOLCANISM IN THE YMR IS MUCH HIGHER THAN THE $8.8 \times 10^{-7}\ yr^{-1}$ REPORTED.

- HOMOGENEOUS POISSON MODELS DO NOT ADEQUATELY DESCRIBE THE DISTRIBUTION OF CINDER CONES IN THE YMR OR ELSEWHERE.

- NONHOMOGENEOUS MODELS USING A RANGE OF RECURRENCE RATES AND VOLCANO AGES SUGGEST THAT THE PROBABILITY OF DISRUPTION EXCEEDS 1 IN 10,000 IN 10,000 YEARS.

SUMMARY COMMENTS (CONTINUED)

- THE NEAR NEIGHBOR NONHOMOGENEOUS POISSON MODEL TAKES INTO ACCOUNT ONE BIT OF GEOLOGIC INFORMATION: CINDER CONES TEND TO FORM CLUSTERS THROUGH TIME. ALTERNATIVE MODELS SHOULD INCORPORATE ADDITIONAL GEOLOGIC INFORMATION.

- THE NNW -TRENDING CRATER FLAT CINDER CONE ALIGNMENT IS NOT STATISTICALLY SIGNIFICANT.