ACNW-0022

MEMORANDUM

TO: Martin J. Steindler, Chairman
Advisory Committee on Nuclear Waste
NRC

FROM: Ken Foland, Consultant

DATE: 8 October, 1994.

RE: Remarks on CNWRA Volcanism Peer Review Meeting

This memo is a brief report to the ACNW about the review of the volcanism research programs. It follows my attending the first two days of a meeting organized by the Center for Nuclear Waste Regulatory Analyses (CNWRA) at the Southwest Research Institute in San Antonio. Enclosed find two sets handouts (copies of overhead of presentations by Drs. Connor and Hill) that were available. I am asking Lynn Deering to distribute this report to all the members and also to facilitate the clarification of any questions that may arise.

The CNWRA is conducting a peer review of their volcanism research programs. Toward this end, they solicited names for appropriate volcanism experts and selected five scientists to constitute the review panel: Paul Delaney (of the USGS); Peter Lipman (USGS); Alexander McBirney (University of Oregon); Steven Self (University of Hawaii); and, George Walker (University of Hawaii). This panel is a distinguished group of scientists with specific expertise in volcanologic phenomena. It seems especially strong in the focused area of eruptive processes and materials upon which the review appears to be concentrating rather than the full spectrum of magmatic or coupled tectonic phenomenon. The review was held from Monday October 3 through Friday October 7. The first two days were held at the CNWRA while the last three days were devoted to field trips and associated discussions in Nevada. Along with Bill Hinze, I attended the Monday and Tuesday sessions but not the subsequent field excursion. Other participants at these sessions included, in addition to the panel and pertinent CNWRA staff, representatives from RES and NMSS. The panel is to provide written reports to the CNWRA in late November. The objectives and agenda for the review are nicely summarized in the overheads of Brittain Hill.

The sessions held on Monday and Tuesday were principally devoted to informal presentations for the benefit of the panel. At the opening, Wes Patrick of the CNWRA provided a brief introduction to the CNWRA and its role. Bill Ott outlined the NRC research program. He indicated that a new volcanism project with the title of "Integrated Hazard Assessment" should begin before the end of the year. Brittain Hill outlined the structure of the review. The rest of the time was devoted to informal presentations by Chuck Connor and Hill on the two volcanism projects (Volcanic Systems of the Basin and Range, Field Volcanism) with discussion and questions by the participants. Participants were given a brief demonstration of the of the GIS database and its application to the Basin and Range region. Finally, on Tuesday afternoon there was a session devoted to a roundtable discussion that was lead by the panel chair, Peter Lipman.

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During the roundtable discussion, a number of topics or issues were identified as important and of interest to the panel members. These included: whether the three modern sites being studied (Cerro Negro, Tolbachik, Paricutin) are good analogs for Yucca Mountain volcanism and the applicability and relevance of gathered data; the importance of intrusions especially on the repository and the need for effort that explore possible underground effects; the relation of volcanism, tectonics, and petrology in the Yucca Mountain region and the Basin and Range in the context of constraining the processes; and, the need for a conceptual model that provides a better understanding of the natural system. The ACNW is sure to be interested in the discussion of these and other issues in the panel recommendations, particularly since many of them came up during the recent Committee review and discussion of the volcanism, natural analogs, and tectonics research programs.

Any conclusions that one might report as a result of the San Antonio sessions would seem to be premature until the panel issues its report and recommendations. From my perspective, the panel members bring to bear fresh geologic insight and a great deal of experience with volcanic processes. They will no doubt also contribute insights based upon first-hand field observations in the Yucca Mountain region.

Brittain Hill presentation Oct 3.

opening presentation by technical staff

○ 1994 REVIEW OF CNWRA VOLCANISM RESEARCH ○

VOLCANIC SYSTEMS OF THE BASIN AND RANGE
FIELD VOLCANISM

OCTOBER 3-4, 1994

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
SAN ANTONIO, TEXAS

CNWRA: CHUCK CONNOR, BRITTAIN HILL, GERRY STIREWALT,
DAVID FERRILL, RONALD MARTIN, STEVEN YOUNG

CNWRA ELEMENT MANAGER: LARRY MCKAGUE

NRC PROJECT OFFICER: LINDA KOVACH

○ 1994 REVIEW OF CNWRA VOLCANISM RESEARCH ○

OBJECTIVES OF THE REVIEW

- The CNWRA has two ongoing volcanism research programs
  - Volcanic Systems of the Basin and Range. Initiated February 1992.
  - Field Volcanism. Initiated June 1993.

- Independent peer reviews of CNWRA research projects are necessary to provide the NRC with the highest possible quality research

- Prior independent reviews of CNWRA volcanism research include:
  - Expert consultants to aid in developing research project plans
  - Peer review of abstracts and publications
  - Programmatic reviews by the Nuclear Regulatory Commission (NRC), Advisory Committee on Nuclear Waste (ACNW), and the Nuclear Safety Research Review Committee (NSRRC)
  - Quality Assurance reviews by SwRI and independent experts
  - Other input by the Department of Energy (DOE), State of Nevada, and the Nuclear Waste Technical Review Board (NWTRB)

- This is the first independent expert-panel review of these research programs

○ 1994 REVIEW OF CNWRA VOLCANISM RESEARCH ○

OBJECTIVES OF THE REVIEW

- Focus of the review is on volcanism research conducted by the CNWRA.
  - DOE, LANL, State of Nevada, others, not under review
  - Scientific controversies regarding Yucca Mountain issues, such as polycyclic volcanism at Lathrop Wells, will not be resolved by the review committee.

- Review Goals:
  - Review objectives and approaches of CNWRA volcanism research
  - Improve CNWRA research scope and methodologies
  - Evaluate CNWRA interpretations of available data and explore alternative hypotheses

- Review Mechanics:
  - Format is an informal workshop
  - Panel elects a Chair
  - Review Panel sets agenda and direct the focus of the review

○ 1994 REVIEW OF CNWRA VOLCANISM RESEARCH ○

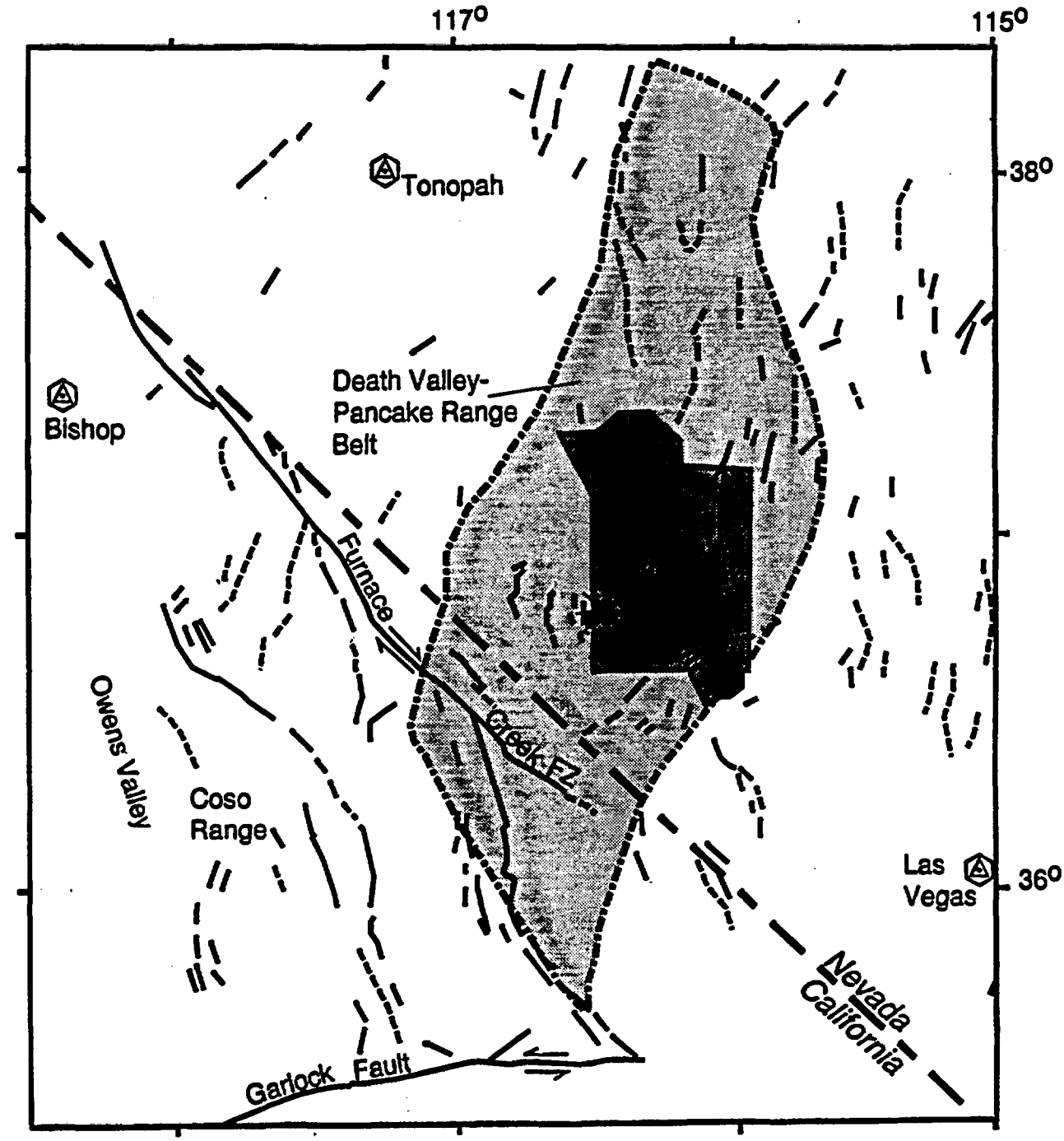
- Role of the Chair:
  - Synchronizes discussions to ensure that all panel members have sufficient time to present views on each topic
  - Serve as mediator for discussions between the review panel, participants, and the audience
  - Coallate individual reports and provide a synopsis of main recommendations - *towards the end of November*
- Products of the review:
  - Individual recommendations on general aspects of the CNWRA volcanism research projects and review goals
  - Specific recommendations for reviewer's areas of expertise
  - Impressions of the geologic problems observed during the field trip and recommendations for field research

○ 1994 REVIEW OF CNWRA VOLCANISM RESEARCH ○

GENERAL AGENDA

Monday, 10/3	•	Background material and organization
	•	Geologic overview of the Yucca Mountain Region (if desired)
	•	Field Volcanism research project
Tuesday, 10/4	•	Volcanic Systems of the Basin and Range research project
	•	Discussions on specific issues and program goals
	•	Summary discussions
Wednesday, 10/5	•	Travel to Las Vegas, Nevada
	•	Field trip to Lathrop Wells Volcano and Beatty, Nevada
Thursday, 10/6	•	Quaternary Crater Flat volcanoes
	•	Pliocene Crater Flat volcanoes and intrusions
	•	Return to Las Vegas
Friday, 10/7	•	Fortification Hill dike complex
	•	Return to Las Vegas, end of review
Wednesday, 11/23		Individual written recommendations to Chair

<2 Ma Faults in the Yucca Mountain Area



Modified from Carr (1984)

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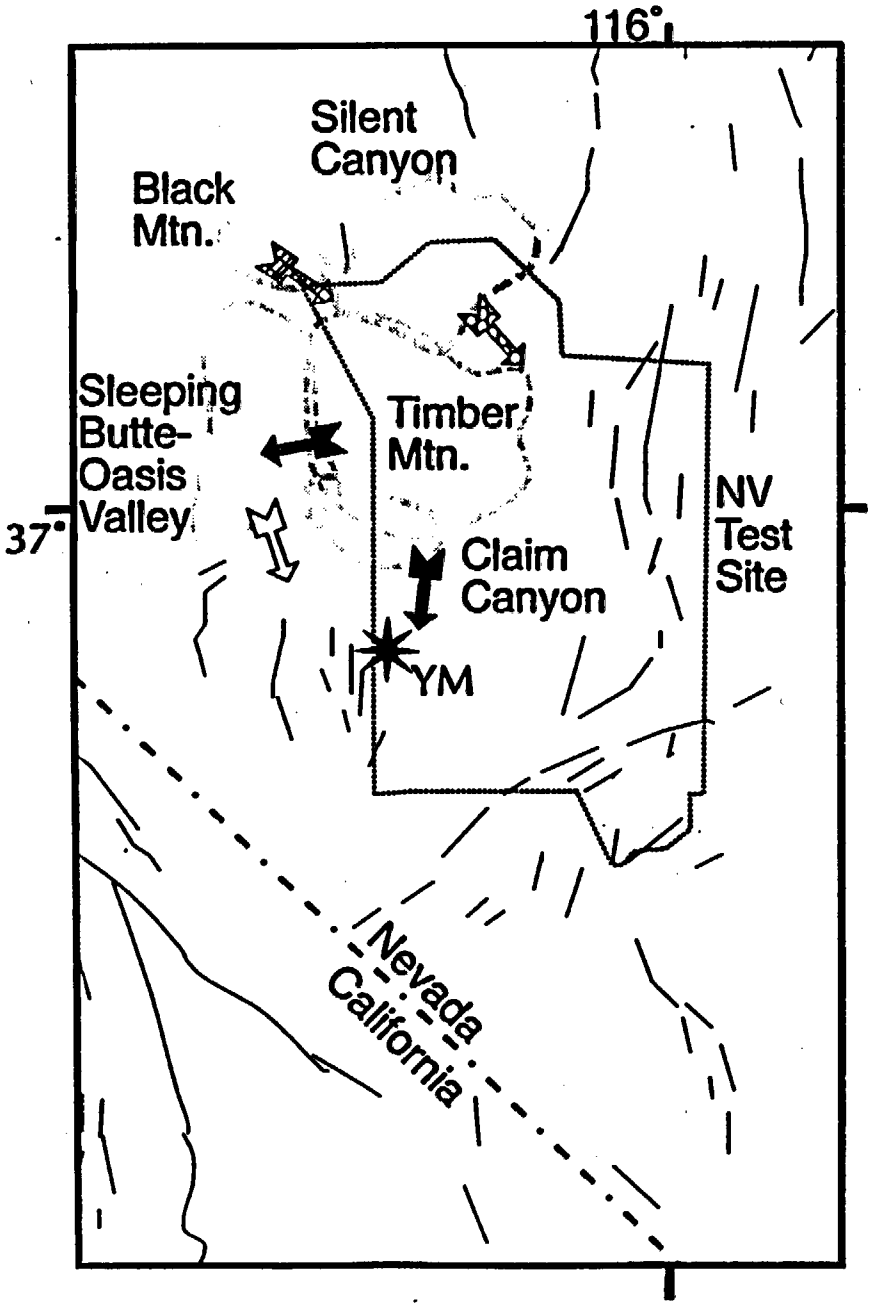


Miocene Calderas Near Yucca Mountain, Nevada

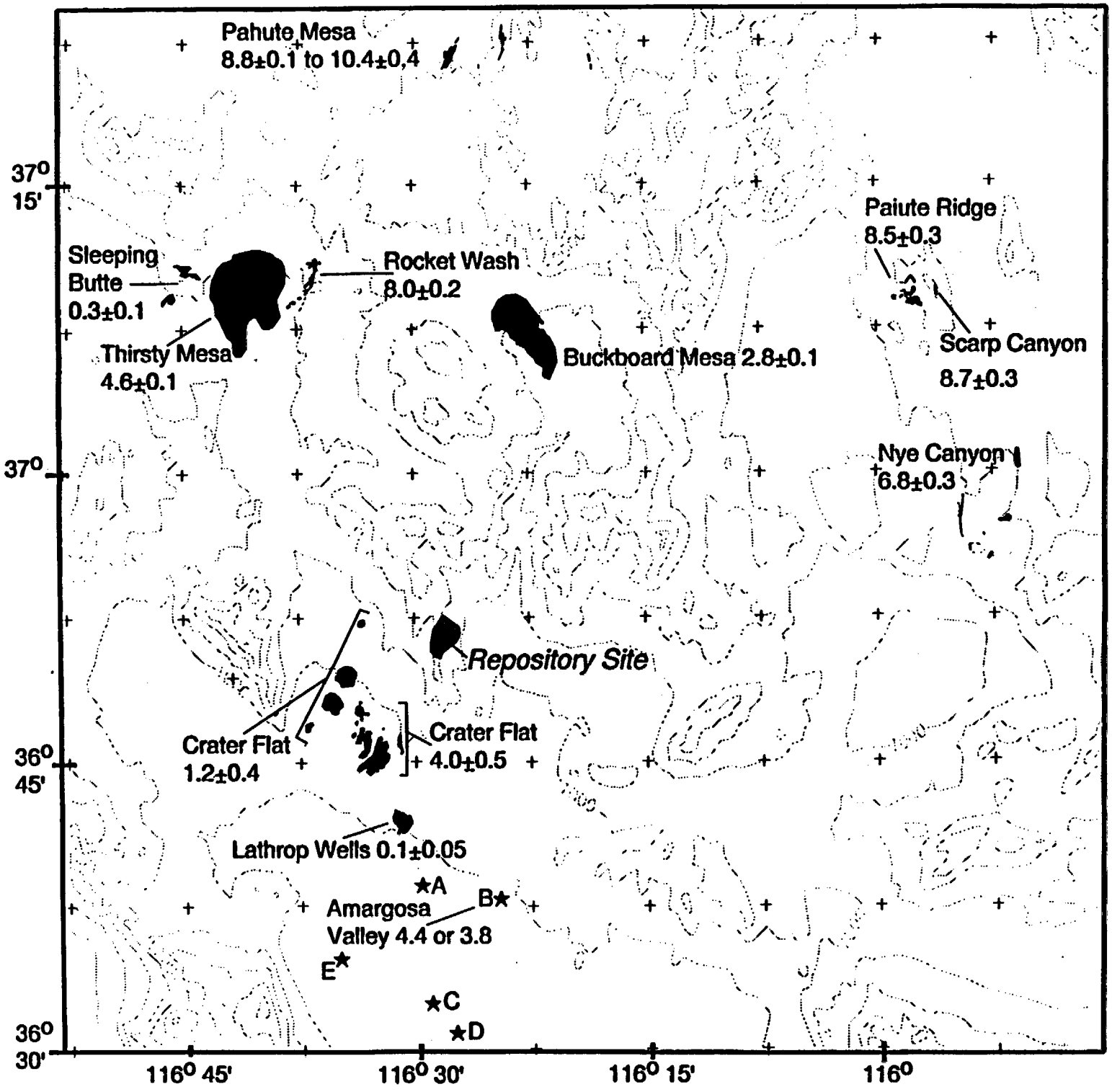
Ma	Unit	Caldera	km^3
9.4	Thirsty Canyon	Black	300
11.5	Ammonia Tanks	Timber Mtn.	900
11.6	Rainier Mesa	Timber Mtn.	1200
12.7	Tiva Canyon	Claim	1000
	Yucca Mtn	Claim	
12.8	Topopah Spring	Oasis Valley?	1200
	Prow Pass	Silent	45
	Bullfrog	Silent	650
13.5	Tram	Sleeping Butte(?)	170

/ Fault

miles 50

km 50

Modified from Byers et al. (1976, 1989), Carr (1984), Broxton et al. (1989), DOE Site Characterization Plan (1988), and preliminary revised data (USGS, 1994).



Yucca Mountain Post-Caldera Basalt

Compiled from Byers et al. (1966), Ekren et al. (1966), Carr & Quinlivan (1966), Noble et al. (1967), Tschanz & Pampeyan (1970), Cornwall (1972), Kane & Bracken (1983), Crowe et al. (1986), Crowe (1990), Frizzell & Shulters (1990), Langenheim et al. (1993), Faulds et al. (1994)

Ages in Ma

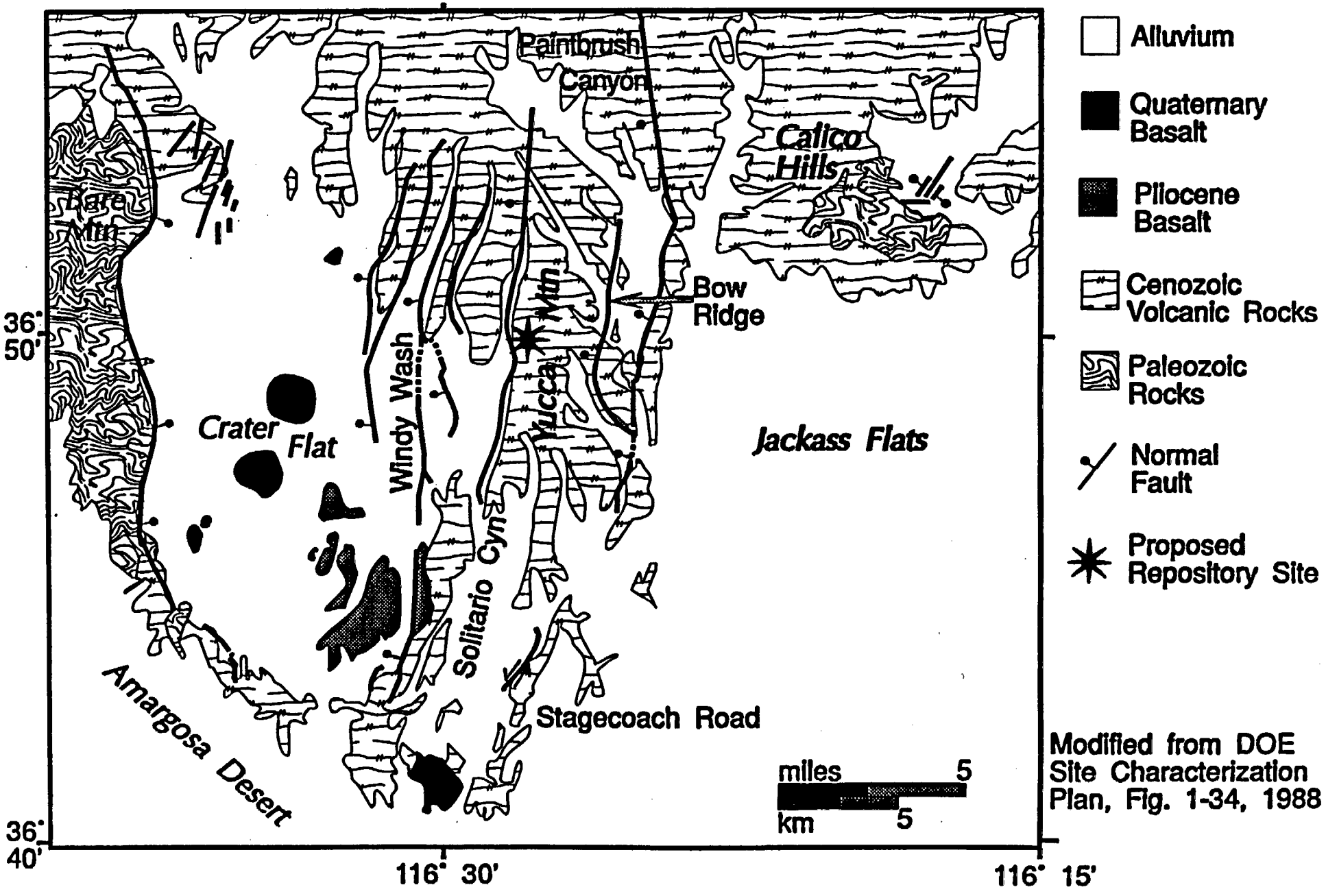
★ Aeromagnetic anomalies that represent buried (B & D) and inferred basaltic volcanic centers.

200 m Contour Interval

Contours from 3-arc-second Digital Elevation Data, by Brent Henderson, SwRI.

YMBASALT.AI

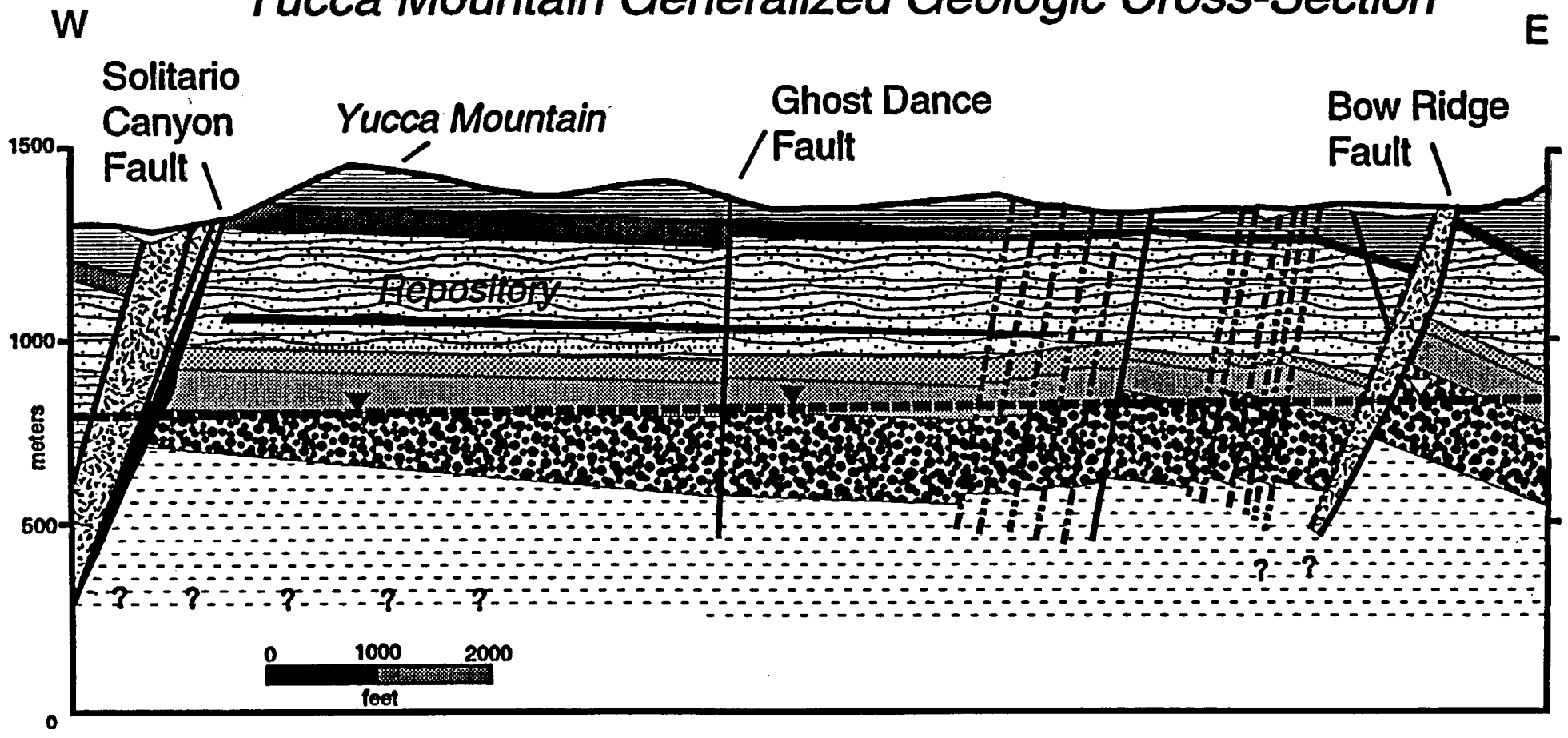
Geology of the Yucca Mountain Area, Nevada



Modified from DOE Site Characterization Plan, Fig. 1-34, 1988

YMGEOL.AI

Yucca Mountain Generalized Geologic Cross-Section



Tiva Canyon, 12.7 Ma

Bedded tuff

Topopah Spring, 12.8 Ma

Calico Hills, 12.9 Ma

Prow Pass

Bullfrog, 13.3 Ma

Tram Tuff

Fault Breccia

Alluvium

Major Fault

Minor Fault

Water Table

Modified from DOE Site Characterization Plan, 1988, Figure 2-3.

YMXSECT.AI

[Chuck Connor presentation] Oct. 3

REGULATORY GOALS OF CNWRA VOLCANISM PROJECTS

VOLCANIC SYSTEMS OF THE BASIN AND RANGE

FIELD VOLCANISM

Presented at the Volcanism Peer Review

October 3-4, 1994

by

Chuck Connor

CNWRA Participants: Britt Hill, Gerry Stirewalt, Peggy Hunka, Ronald Martin, David Ferrill

NRC Project Officer - Linda Kovach

REGULATORY BASIS FOR VOLCANISM STUDIES

The regulatory basis for volcanism studies is promulgated in the Code of Federal Regulations

10 CFR 60.112: Overall system performance objective for the geologic repository after permanent closure.

The geologic setting shall be selected ... to assure that releases of radioactive materials to the accessible environment after permanent closure conform to generally applicable environmental standards for radioactivity as may have been established by the EPA with respect to both anticipated and unanticipated processes and events.

10 CFR 60.122: Siting Criteria

(c) The following conditions are considered to be potentially adverse conditions if they are characteristic of the controlled area or may affect isolation within the controlled area.

(15) Evidence of igneous activity since the start of the Quaternary period.

(3) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that ... there is change in the regional groundwater flow system and therefore affect the performance of the repository.

REGULATORY BASIS FOR VOLCANISM STUDIES

40CFR191 Subpart B, Appendix B (remanded): The Agency (EPA) assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years.

SOME TENTATIVE DEFINITIONS

Anticipated event: probability of occurrence is greater than 1 in 100 in 10,000 yr.

Unanticipated event: probability of occurrence is greater than 1 in 10,000 in 10,000 yr and less than 1 in 100 in 10,000.

Controlled Area: A surface location extending horizontally no more than 5 km in any direction form the outer boundary of the original location of radioactive wastes in the disposal system, and the sub-surface underlying this location.

NRC RESEARCH GOALS

The NRC must evaluate the DOE license application and provide DOE with pre-licensing guidance - this requires independent research

- NRC must independently determine uncertainties in conceptual, empirical, and numerical models of volcanism in the Yucca Mountain Region
- There are numerous approaches to research on volcanic processes. Uncertainties in models are often constrained by varied approaches and scientific debate
- Scientific disagreement is common in many technical issues because the relationships between volcanic processes and their manifestations are often recondite; independent corroboration of key findings is required

The process of recognition, assessment, and reduction of uncertainty is formalized through development of Key Technical Uncertainties (KTUs).

KEY TECHNICAL UNCERTAINTIES

1. **Prediction of future system states (disruptive scenarios)** (LARP 6.1, 10CFR 60.112 and 40 CFR 191.13)

   In order to identify likely future states, it is necessary to gain an understanding of the processes that have operated and the events that have occurred in the past within the geologic setting of the site. Based on this understanding, reasonable projections about those potential processes and events that could affect the repository during the period of performance (10,000 yr) are possible.

2. **Low resolution of exploration techniques to detect and evaluate igneous features** (LARP 3.2.1.9, 10CFR 60.112)

3. **Inability to sample igneous features** (LARP 3.2.1.9, 10CFR 60.112)

4. **Development and use of conceptual tectonic models as related to igneous activity** (LARP 3.2.2.9, 10 CFR 60.112)

Overview of the Volcanism Project Goals

VOLCANIC SYSTEMS OF THE BASIN AND RANGE

Evaluate and develop volcanic disruption probability models using a geologic perspective

- Probability model development (*the method is as important as the result*)
  - Quantitative models based on spatial and temporal patterns in small-volume basaltic volcanism
  - Must account for geochronological uncertainty
  - Must be flexible (amenable to introduction of additional geologic data)
  - Must be tested and refined by application in analogous volcanic fields
- Integrated tectonic - magmatic model development (*Any probability model will be tempered by geological insight - effectively introduces and bounds uncertainty*)
  - Geochemical constraint on waxing / waning recurrence rates
  - Volume - time prediction
  - Dike - fault interaction
  - Strain - rate
  - Recognition of the presence (or absence) of tomographic variation

V O L C A N I S M R E S P R O J E C T S

FIELD VOLCANISM

Evaluate the direct and indirect consequences of magmatic activity, because the probability of volcanism is greater than 1×10^{-4} in 10,000 yr.

- Eruption mechanics
  - The magnitude and duration of eruptions influences waste dispersal
  - A range of eruption styles, from effusive to explosive, is evinced by Basin and Range small-volume basaltic volcanism
  - Comparison of the deposits of YMR Quaternary volcanoes with those of modern analogs provides the most defensible means of characterizing this range
- Cooling and degassing
  - It is more likely that cooling and degassing may affect performance, rather than direct transport of waste by intrusion
  - Dike and cinder cone cooling and degassing may impact repository hydrologic, geochemical, and thermal settings.
  - Transient cooling and degassing is best characterized using modern analogs

A volcanologist can't burn like Empedicles... you have to work the mean streets - Umberto Eco

VOLCANISM RES PROJECTS

Field Volcanism (cont.)

- Detection and Geometry of Igneous Features
  - Probability models may be strongly affected by present but undetected igneous features
  - Dike geometry strongly impacts probability models
  - Necessary to estimate limits of detection by geophysical methods
  - Necessary to develop geologically reasonable models for intrusion geometry
  - Best accomplished by mapping and evaluation of geophysical data

It is proper to derive our explanations from things which are obvious, and in some measure of daily occurrence, such as earthquakes and volcanic eruptions - Strabo (in Principles of Geology - Charles Lyell)

Task Structure

Volcanic Systems of the Basin and Range

Task 1: Literature Review - Volcanism and Tectonism of the Basin and Range (completed 9/92)

Task 2: Compilation of Geographic Information System Database for Selected Volcanic Fields (completed 1/94)

Task 3: Critical Review of Volcanism models (to be completed 1/95)

Task 4:

(a) Probability model development (to be completed 6/95)

(b) Tectono-magmatic model development (to be completed 9/95)

VOLCANISM RES PROJECTS

Task Structure

Field Volcanism

Task 1: Literature Review and Analog volcano selection (completed 8/93)

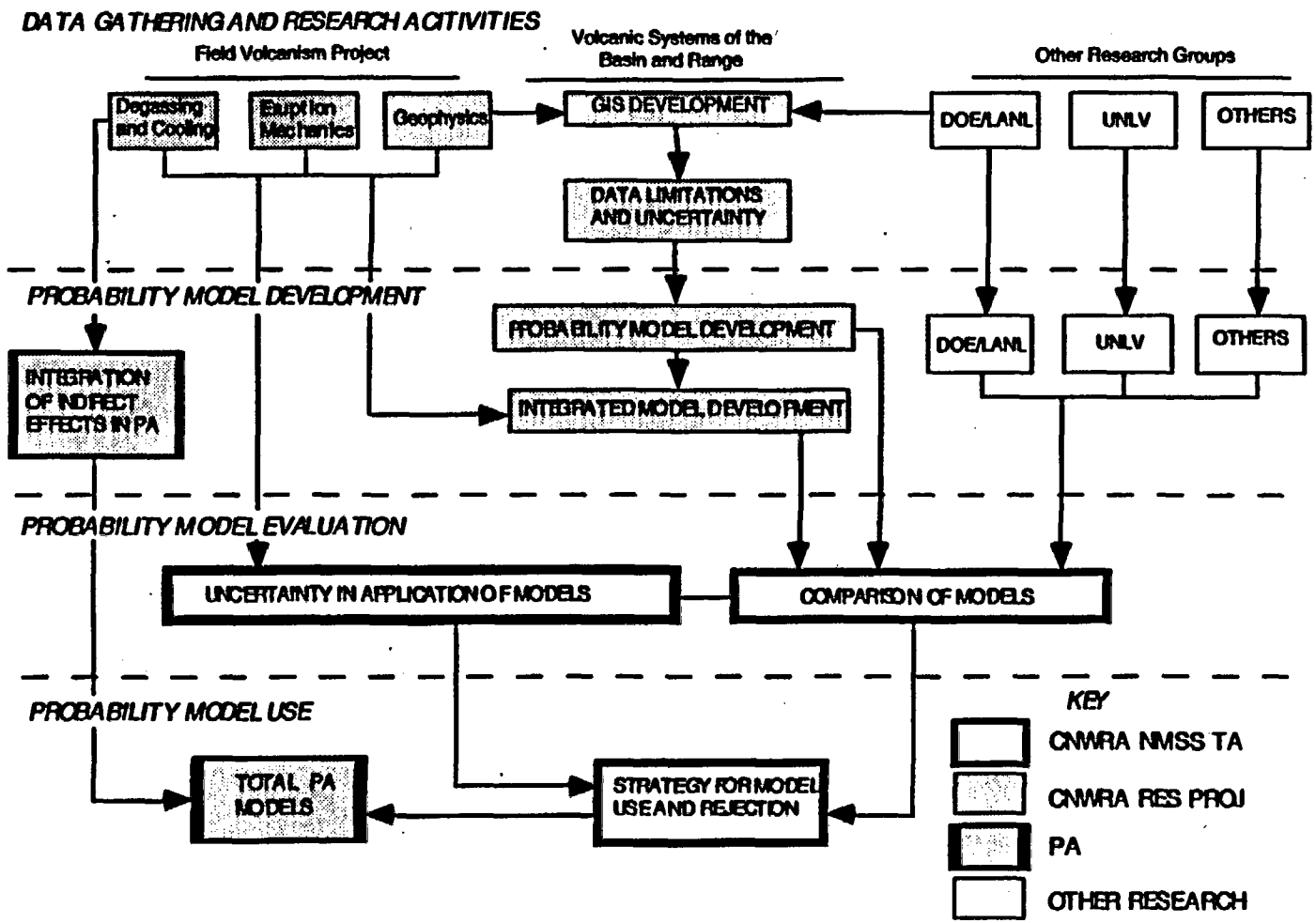
Task 2: Eruption Mechanics (to be completed 2/96)

Task 3: Cooling and Degassing (to be completed 9/96)

Task 4: Resolution of Geophysical Methods / Detection of Igneous Dikes (completed 6/94)

VOLCANISM RES PROJECTS

DEVELOPMENT TOWARD A USEFUL RESULT



VOLCANISM RES PROJECTS

Some of the Project Personnel

CNWRA

- Volcanology (PIs): Chuck Connor, Britt Hill
- Structure (PIs): Gerry Stirewalt, David Ferrill, Steve Young
- Research Computation / Support: Ron Martin
- Student Research Assistants: Peggy Hunka, Kathy Spivey, Joyce Foegelle
- *Many* other individuals for support on thermo-hydrologic model development, PA activities, geochemistry, rock mechanics, etc.

Consultants

- Petrology: Jim Luhr (Smithsonian)
- Glass (melt) inclusions: Stan Williams (ASU)
- Seismic Tomography: Chris Sanders (ASU)
- Cinder Cone Analogs (Tolbachik): Yuri Doubik, Yuri Taran (IVGG), Chris Condit (U Mass)
- Technical Reviews: Diane Smith (Trinity)
- Volcanic Systems of the Basin and Range Project Plan Development (1991): Bruce Marsh (Johns Hopkins), Bill Leeman (Rice)

Products

Volcanic Systems of the Basin and Range

Stirewalt, G.L., S.R. Young, and K.D. Mahrer. 1992. A review of pertinent literature on volcanic - magmatic and tectonic history of the Basin and Range. CNWRA 92-025. NRC-02-88-005. (MM)

Hill, B.E., B.W. Leslie, and C.B. Connor. 1993. Review and analysis of techniques for dating Neogene and Quaternary volcanic rocks. CNWRA report 93-018. U.S. Nuclear Regulatory Commission Contract NRC-02-93-005 (MM)

Connor, C.B. and B.E. Hill, 1993, Estimating the probability of volcanic disruption at the Yucca Mountain site using nonhomogeneous Poisson models, American Nuclear Society, Focus '93., 174-181.

Connor, C.B. and B.E. Hill. 1994. The CNWRA Volcanism Geographic Information System Database, CNWRA 94-004 (MM).

Connor, C.B. and C.D. Condit. 1994. Estimating recurrence rate of volcanism in the Springerville Volcanic Field, AZ. Geological Society Abstracts with Programs, Fall Meeting.

Hill, B.E., G.L. Stirewalt, and C.B. Connor. 1994. Volcanism Research, NRC High-Level Radioactive Waste Research at the CNWRA January - June 1994. CNWRA 94-01S (MM).

Connor, C.B., and B.E. Hill. 1994. Spatially and temporally nonhomogeneous Poisson models for the probability of volcanic disruption of a high-level nuclear waste repository, Yucca Mountain, Nevada. *Submitted to* Journal of Geophysical Research.

Products (cont.)

Field Volcanism

Connor, C.B. 1993. Technical and regulatory basis for the study of recently active cinder cones. Letter Report to the U.S. Nuclear Regulatory Commission, Center For Nuclear Waste Regulatory Analyses, San Antonio, Tx.

CNWRA Staff. 1994. CNWRA Perspective on the Technical and Regulatory Basis for the Study of Recently Active Cinder Cones. Position (white) Paper.

Connor, C.B. and C.O. Sanders. 1994. Geophysics Review Topical Report: Application of Seismic Tomographic and Magnetic Methods to Issues in Basaltic Volcanism. CNWRA 94-013 (MM).

Connor, C.B., and B.E. Hill. 1994. Field Volcanism Research, NRC High-Level Radioactive Waste Research at the CNWRA January - June 1994. CNWRA 94-01S (MM).

Doubik, Y.M., C.B. Connor, and P. Doubik. 1993. The April 1992 eruption of Cerro Negro volcano, Nicaragua. 1993 WOVO Workshop: Volcano Observatories, Surveillance of Volcanoes and Prediction of Eruptions, Guadeloupe, 13-17 December, 1993.

Connor, C.B., L. Powell, J. Thomas, M. Navarro, W. Strauch, 1993. Comparison of volatile concentrations in three Cerro Negro, Nicaragua, eruptions. 50 Años del Volcán Parícutin, Reunión Internacional Conmemorativa, Programa y Resumenes, Uruapan, Michoacán, Mexico, February 18-20, 1993.

Connor, C.B., L. Powell, W. Strauch, M. Navarro, O. Urbina, W.I. Rose,1993. The 1992 eruption of Cerro Negro, Nicaragua: An example of Plinian-style activity at a small basaltic cinder cone. Eos, Transactions of the American Geophysical Union, 74: 640. Also presented at Colima Volcano, 4th International Meeting, Colima, Mexico, January, 1994.

Conway, M.F., A. Macfarlane, C.B. Connor. 1994. Soil degassing at a cooling cinder cone, Cerro Negro, Nicaragua. Geological Society of America, Abstracts with Programs, Fall Meeting, accepted.

McDuffie, S.M., C.B. Connor, K.D. Mahrer, 1994. A simple dike-fracture interaction model. Eos, Transactions of the American Geophysical Union, 75:345.

VOLCANISM RES PROJECTS

Products (cont.)

Related

Connor, C.B., B.E. Hill, B.W. Leslie, C. Lin, J.F. Luhr, K.D. Mahrer, G.L. Storewalt, S.R. Young. 1993. Review of: Preliminary Draft: Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project, Dated February 1993. Nuclear Regulatory Contract NRC-02-88-005. Center For Nuclear Waste Regulatory Analyses, San Antonio, Tx. (NMSS AI).

Connor, C.B., and B.E. Hill. 1994. Strategy for the Evaluation and Use of Probability Models for Volcanic Disruptive Scenarios. CNWRA 94-015 (NMSS IM).

Draper, G. M.F. Conway, Z. Chen, C.B. Connor, and C.D. Condit. 1994. Relationship between faults and cinder cone alignments in the San Francisco Volcanic Field, AZ, Geological Society of America, Abstracts with Programs, Fall Meeting, accepted.(RES grant to Florida International University).

Connor, C.B., and B.E. Hill. 1994. CNWRA review of comments by GA Valentine in a letter on volcanism to William Hinze of the ACNW. (NMSS AI)

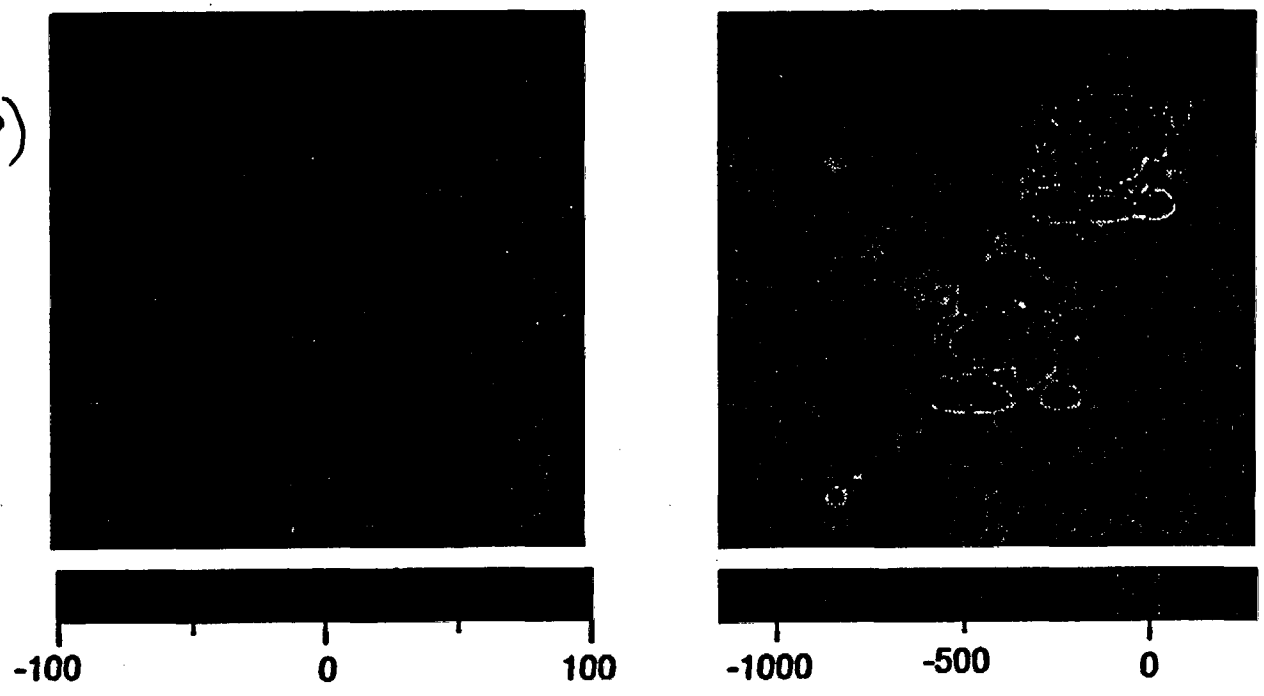
Some Practical Examples of Timely Application of Research Results in the Program

(As Time Permits)

(halt here)

Low resolution of exploration techniques to detect and evaluate igneous features. Application of geophysical methods - a sensitivity analysis of magnetic

5m dike (?)

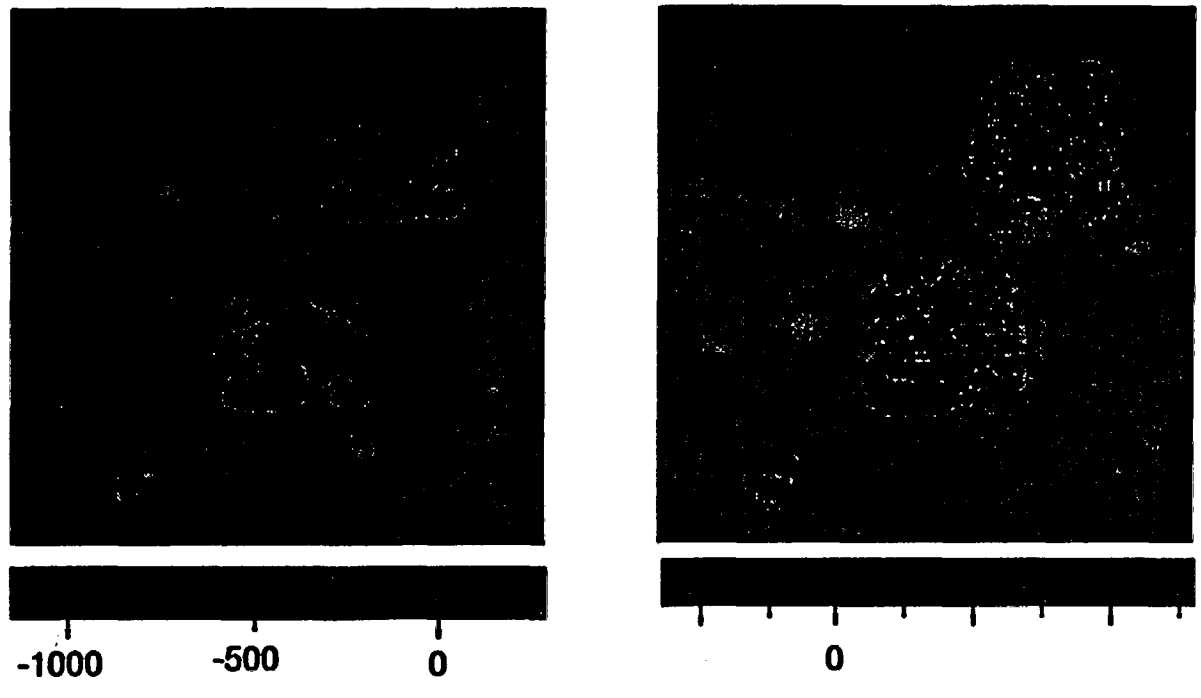


anomalies related to dikes

Theoretical aeromagnetic anomalies associated with dikes, beneath a magnetized topography, using Crater Flat as an example. Topography is contoured in 10 m intervals; magnetic data contoured in nanoTeslas (note change in scale).

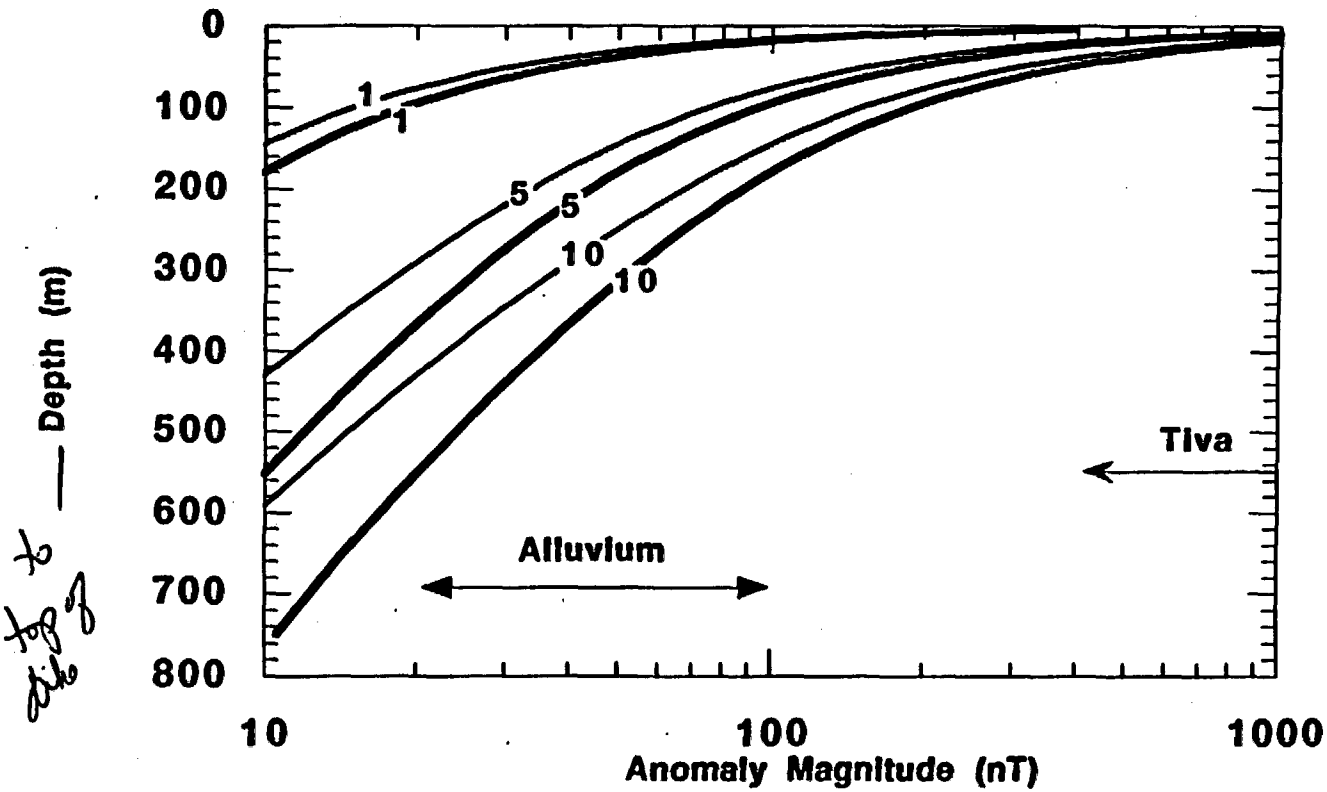
Low resolution of exploration techniques to detect and evaluate igneous features

Enhancing Magnetic Data Through Digital Filtering



Calculation of the second vertical derivative of the total magnetic field can, in fortuitous circumstances, help in the identification of dikes and dike swarms.

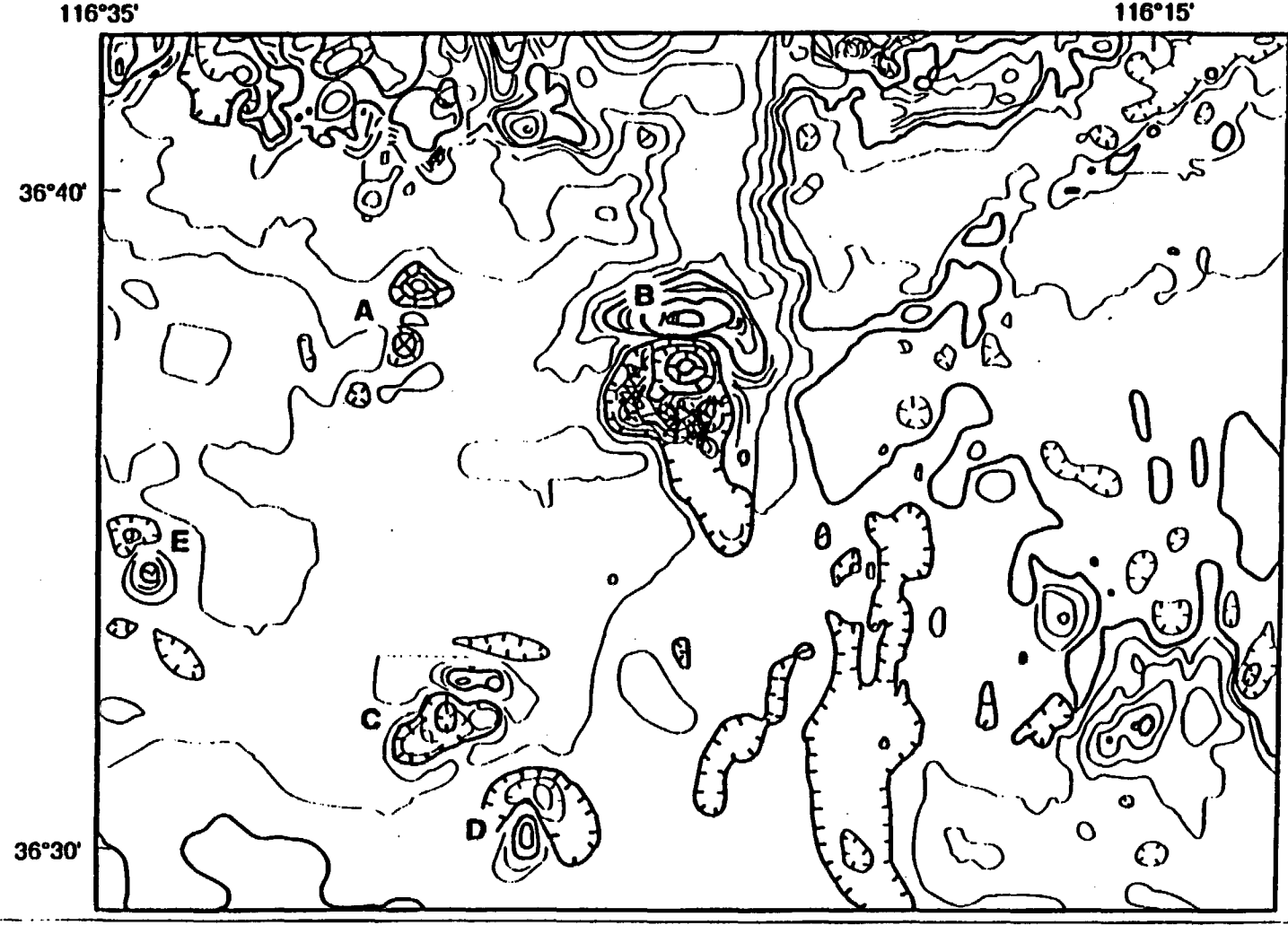
Summary of Parametric Study (KTU 1)



Task 4 research has resulted in quantification of these limitations for magnetic data.

VOLCANISM RES PROJECTS

Low resolution of exploration techniques to detect and evaluate igneous features. Application of our understanding of the limits of aeromagnetic data, Amargosa Valley:



VOLCANISM RES PROJECTS

Prediction of future system states (disruptive scenarios)

Indirect effects of volcanism include: thermal loading, change in hydrologic setting, change in geochemical setting

DOE TSPA 93:

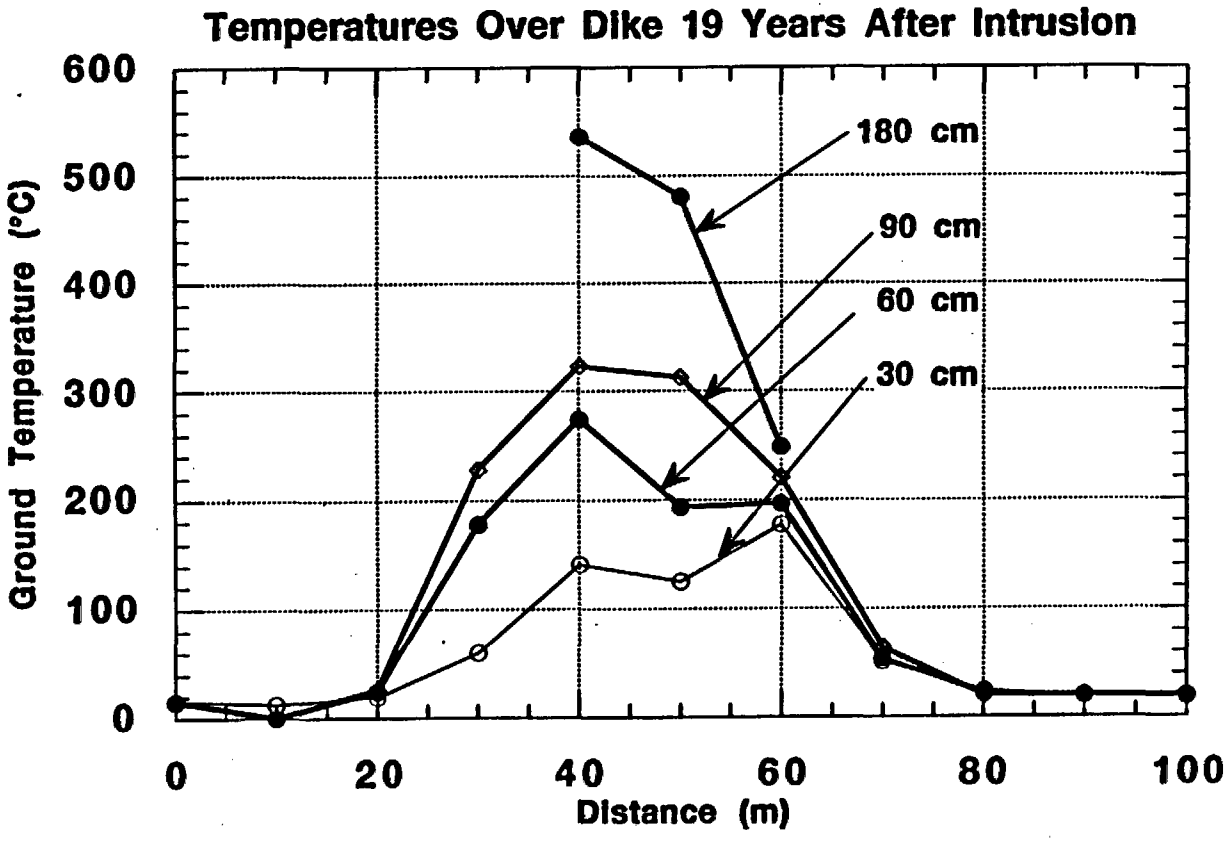
- Assumes 2-D heat conduction to model dike cooling and degassing
- Dike remain hot (> 600°C) for less than one year and do not efficiently heat the surrounding rock
- Concludes that their model assumptions are restrictive and nonetheless, the indirect effects of magmatic intrusion into the repository are not great (virtually no effect 80% of the time)

CNWRA research on cooling cinder cones provides a pragmatic test of model assumptions. At cooling cinder cones and dikes we:

- Measure temperatures
- Collect gas samples
- Map geophysical anomalies

Example:

Following the formation of Cinder Cone I, at Tolbachik, Kamchatka, Russia, a dike intruded close to the cone to shallow depth causing ground deformation and rock alteration.



Prediction of future system states (disruptive scenarios)

Maximum Temperatures at Cooling Cinder Cones

Cinder Cone	Years Since Eruption	Max Surface Temp. (°C)
Cerro Negro	2	385[1]
Tolbachik (Cone I)	19	618
Tolbachik (Cone II)	19	558
Tolbachik (Cone III)	19	389
Tolbachik (Dike)	19	536
Tolbachik (South Cone)	19	458
Parícutin	30	473
Parícutin	40	285
Jorullo	210	125

1. hot fumaroles in crater not accessible

Prediction of future system states (disruptive scenarios)

Preliminary Conclusion

Observations of:

- ground temperature
- gas geochemistry
- geophysical anomalies

made at recently cooling and degassing cinder cones will greatly enhance our ability to develop geologically reasonable models of cinder cone and dike cooling and degassing. Observations to date indicate that models must be substantially revised to include gas convection and three-dimensional conduction (heating from depth) in order to adequately assess the indirect effects of volcanism.

VOLCANISM RES PROJECTS

Volcanism Research must provide reasonable and defensible means of assessing the probability and consequences of igneous activity in the YMR during some performance period.

The Bottom Line