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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Attend seminar on geophysical issues related to volcanism research, with special emphasis on recommendations for the application of seismic tomography. 20-5704-145

DATE/PLACE: Monday, March 28, 1994, Office of NRC Research, Nicholson Lane Bldg, White Flint , Maryland.

AUTHOR: Charles B. Connor

PERSONS PRESENT: NRC Res Staff: Linda Kovach, George Birchard, Bill Ott,
NRC NMSS Staff: John Trapp, Keith McConnell, Buc Ibrahim
CNWRA Staff: Chuck Connor, Britt Hill, Gerry Stirewalt, John Russell
Consultant: Chris Sanders (Arizona State University)

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BACKGROUND:

The objective of Task 4 of the Field Volcanism Research Project (FVRP) is to provide a preliminary evaluation of the utility of various geophysical methods for the characterization of intrusion geometries, and for the recognition of magmatic bodies at various crustal levels. One of the activities outlined in section 3.1.4.3 of the Field Volcanism Project Plan is an informal seminar on seismic tomographic methods and their application to the study of volcanic fields. The primary goal of this meeting was to assess the utility of the seismic tomographic method as a tool for better understanding the structure of volcanic fields and for imaging magma bodies which may be present at various levels down to and around the Mohorovitchic discontinuity, particularly in the Yucca Mountain Region (YMR). Application and limitations of other geophysical methods, including gravity and magnetics, were also discussed.

SUMMARY OF THE MEETING:

The meeting agenda is attached in appendix A.

Connor presented a summary of the key technical uncertainties (KTUs) related to volcanism and the technical basis for identification and application of geophysical methods to resolve these KTUs. KTUs that may be addressed through the application of geophysical methods in volcanological research include:

- Inability to sample igneous features
- Low resolution of exploration techniques to locate and evaluate igneous features

- Development of tectonic models related to igneous activity
- Prediction of future system states.

Connor pointed out that probability models, including CNWRA and NRC models, have relied heavily on the spatial and temporal distribution of past volcanic events. These models provide a foundation for Performance Assessment (PA) of the volcanism disruptive scenario. Models that have been used to date to estimate the probability of volcanic disruption of the candidate repository site include:

- Homogeneous Poisson
- Weibull-Poisson
- Near-neighbor nonhomogeneous Poisson
- Spatio-temporal Markov

Each of these models uses the distribution and timing of past volcanic events to varying degrees. For example, in the nonhomogeneous Poisson model, the recurrence rate at a point, $\lambda_r(x,y)$, is estimated from the age and distribution of nearest-neighbor volcanoes. A nonparametric estimate of $\lambda_r(x,y)$ can be found using varying numbers of near neighbors:

$$\lambda_r(x,y) = \frac{m}{\sum_{i=1}^{m} u_i t_i} \qquad (1)$$

where near-neighbor volcanoes are determined as the minimum $u_i t_i$, t_i is the time elapsed since the formation of the i^{th} nearest neighbor volcano, and u_i is defined as the area of a circle whose radius is the distance from the point (x,y) to the i^{th} nearest volcano., with $u_i \geq 1$ km^2. Using this approach it is possible to estimate the probability of a volcanic event within a given area anywhere in the YMR. Our analysis indicates that the probability of volcanism in the next 10,000 yr is greatest in the Crater Flat area, roughly 15 km from the proposed repository site, and decreases east of the candidate site. The probability of volcanic disruption of the repository itself is approximately 1×10^{-4} to 3×10^{-4} based on this model. This range of estimates results from uncertainty in the ages of volcanoes in the YMR and uncertainty in the area effected by future volcanism.

Other probability models will likely give other estimates of the probability of disruption. However, two statements can be made with confidence about volcanism in the YMR at this time. First, the probability of volcanism occurring in the future varies across the region. In particular, nonhomogeneous Poisson models indicate that the probability of volcanism occurring within an 8 km^2 area likely varies by more than two orders of magnitude within a twenty kilometer radius of the repository. The distance across which this variation occurs is on the scale of many geologic structures, including cinder cone alignments and faults. As a result, the utility of probability models, and their application, is limited if probability studies are not augmented using additional geological and geophysical information. Second, all probability models indicate that volcanism is a potentially adverse condition and must be addressed in detail in PA.

Connor identified five areas in which volcanism probability models can be strengthened, and their limitations explored, using geophysical investigations. These are:

- Investigation of the intrusion to extrusion ratio in basaltic volcanic fields
- Delineation of dike geometry beneath cinder cones and cinder cone alignments
- Investigation of dike - fault interaction
- Investigation of the volume of country rock impacted by volcanic eruptions as a function of depth and volcano explosivity
- Identification of partial melt zones in the mantle and magma bodies at intermediate depths.

The number of intrusive events which occur at or near repository depths may be greater than the number of volcanoes which form as a result of this activity, or the number of eruptions which occur. As a result, probability models (such as CNWRA models) that rely on the number of cinder cones in a region may underestimate the number of magmatic events that could potentially influence repository performance. Determination of the intrusion to extrusion ratio, however, is complicated by the fact that basaltic lava flows and cinder cones often mask the magnetic signature of intrusive rocks. Some investigators have used heat flow to estimate intrusion to extrusion ratios in active volcanic fields, but this is a complex and indirect approach. Connor and Sanders presented calculations that indicate that the volume of intrusive rock within a given volume of alluvium and sedimentary rock can be estimated using P -wave traveltime. This approach should work as long as the P-wave traveltime change is on the order of 0.01 seconds or greater, corresponding to 1 percent by volume dikes in "slow" alluvium, and 5 percent by volume dikes in "fast" sedimentary rock. In many areas the volume percent intrusive rocks are as high as 13 to 30 percent by volume. It seems likely that if intrusive volumes are great enough to be of concern, the seismic traveltime delay approach should aid in the identification of this concern. Expanding on this approach, 2D or 3D seismic tomographic surveys can provide additional information about the spatial distribution of intrusives within this volume, the orientation of these dikes, and the change in dike volume and abundance as a function of depth and distance from volcanic vents. Should such a survey be done, the area would ideally involve a cinder cone alignment that is similar in structure to the Crater Flat alignment. This direct approach to the determination of intrusion volume and geometry has not been attempted previously.

Dike - fault interaction may also strongly influence probability models. In essence, fault distribution may fundamentally control probability distributions if magmas can be redirected by faults as they ascend from depth. Preliminary models of dike - fault interaction have been developed at the CNWRA, based on a simple energy balance approach. Geophysical surveys can provide much needed constraint of these analytical models. Connor suggested that the Big Pine volcanic field would be a nice place to investigate this interaction, primarily because several Quaternary cinder cones lie along splays of the Owen's Valley fault in this field. Furthermore, lava flows are limited to the downslope side of these cones because of the comparatively steep topographic gradient on the alluvial fan on which several of these cones have erupted. In addition to seismic methods, magnetics and gravity surveys could provide information about the dip of these fault splays, an important parameter in our analytical models, and possibly detect dikes along the fault zone.

The volume of rock disrupted by volcanic eruptions as a function of depth, and the area of the repository possibly impacted by this type of activity, are important aspects of volcano consequence studies. Geophysical investigations can help delineate and constrain the volume and area terms used in PA disruptive scenario consequence analysis. Connor presented an example of a gravity and magnetic survey across a tuff ring in the San Francisco volcanic field. This survey was completed by Mike Conway of Florida International University. The 3D model Conway developed indicates that the area of rock fragmented and/or dispersed by this hydromagmatic eruption varied from 384,000 m^2 at the surface to 8,000 m^2 at a depth of 300 m. The elegance of this approach lies in the fact that there is excellent stratigraphic control in the San Francisco volcanic field and xenoliths can be categorized by their volume percent and the stratigraphic level from which they originate. This provides a real opportunity to develop a 3D image of the disrupted area and its consequences for xenolith transport from depth.

Connor and Sanders discussed the use of seismic tomography to identify magma bodies at intermediate crustal depths and partial melt zones in the mantle down to the Moho discontinuity. Connor presented an example of developing, steady-state, and waning volcanic activity in the Springerville volcanic field, Arizona, showing that specific areas within the field persist as active clusters for hundreds of thousands of years. This timing suggests that magma source regions may persist on this time frame and indicates a mechanistic basis for probability models may be provided by the identification of these zones. Sanders also pointed out that velocity anomalies near the Coso volcanic field indicate the presence of magma south of the field, in Indian Wells Valley. This anomaly is recognized by P-wave velocity, the attenuation of S-waves, and velocity ratio studies. This is an interesting result because the anomaly is offset from the Coso volcanic field by 10 to 20 km. There has been at least one prior shift in the locus of basaltic volcanism over time in the Coso volcanic field. Pliocene cinder cones are grouped in the northern part of the field. Pleistocene cones are found in the southern part of the field. Indian Wells valley is south of this area. The seismic tomographic data may provide the basis for extending a hazard zone south of the Pleistocene vents into the vicinity of Indian Wells, which has not been the site of Quaternary volcanic activity. Identification of similar velocity anomalies in the YMR may have important implications for probability models and volcanic disruptive scenarios.

Sanders also briefly reviewed the work of Evans and Smith. Evans and Smith made a teleseismic tomographic survey in the Yucca Mountain region. They relied on P-wave traveltimes and used the existing NTS network. As a result, their survey has resolution of approximately $7 \times 7 \times 10$ km at depth and has no resolution in the upper 8 km. Evans and Smith identified slow velocity zones in the YMR, which they interpret as possible partial melt zones. Sanders pointed out that their paper, which was presented at the HLW conference, 1992, does not contain details of the precision and accuracy of the survey, but he believes it provides an adequate basis for suggestion that partial melt zones, or at least low velocity zones, exist in the YMR.

Sanders strongly advocated the use of seismic tomography as a basic site characterization tool. He demonstrated tomography's utility by constructing a synthetic tomographic survey centered on the proposed repository site. This model used the U.S. Geological Survey velocity model for the YMR, developed through refraction profiling. Sanders found that using an array of 100 stations spaced at 1 km intervals and eight shots at a distance of about 50 km from the site, velocity anomalies as small as 2 percent and with volumes of 1 km^3 can be discerned. Larger anomalies with smaller velocity contrasts may also be discerned. Resolution on this scale has been achieved in other tomographic studies, and would provide a useful means of testing volcanological, structural, and tectonic models of the site.

Following the presentations there was discussion about the utility of these techniques to the program. Keith McConnell and John Trapp indicated that all of the experiments discussed would be useful. McConnell indicated that it would not be appropriate to pursue this type of investigation in the Yucca Mountain vicinity. However, the techniques discussed may provide a technical basis for comments to DOE concerning site characterization activities. Kovach suggested that the intrusion to extrusion ratio and alignment geometry experiments using seismic tomographic methods should be pursued. Trapp and McConnell agreed that these experiments would be appropriate and useful, provided appropriate analogous alignments could be identified. Connor indicated that this would not be a problem.

There was some brief discussion of the way this Task would be funded. Connor pointed out that it would be best to fund it within the Field Volcanism Project, but currently there are no funds to support this research activity. Kovach suggested that an appropriate approach may be to move GIS work out of Volcanism Research and into NMSS, thereby freeing some funds to be used in the Field Volcanism Project.

OTHER ACTIVITIES:

Following the geophysics seminar and discussion, Connor, Hill, Stirewalt, and Kovach discussed delays in the Field Volcanism Project and the Volcanism Research Project. It was verbally agreed that the Geophysics MM may be delayed. Connor indicated that the MM on uncertainty in the GIS database needs to be pushed back to January 15, 1995, with subsequent delays in the Model Development MM to April, 1995. Furthermore, Connor indicated that it would not be possible to develop a reasonably useful volcano-tectonic model by April, 1995. Rather, Connor suggested, the April 1995 MM should be a summary of probability models of volcanism developed at the CNWRA and elsewhere. An additional MM would be delivered in September of 1995 dealing with the incorporation of geological and geophysical data into these probability models. The Volcanic Systems of the Basin and Range Research project is currently funded through the end of FY95. Kovach concurred with this approach and the addition of a second milestone, but voiced serious concerns about delays. Connor and Hill indicated that the delays result from the fact that the volume of reactive work related to volcanism was not anticipated. Bill Ott returned to the meeting to reinforce Kovach's statements that the request for these delays is a problem. The issue of delays in the Volcanic Systems of the Basin and Range Research Project is currently unresolved.

IMPRESSIONS AND CONCLUSIONS:

All participants seemed to agree that seismic tomographic experiments should be pursed as part of the Field Volcanism project. This will likely involve subcontracting part of this task to Arizona State. Sanders is working on a final budget, but this may be up to $125,000 over a two-year period. Site selection activities, additional gravity and magnetic work and volcanological interpretation of the results would be done at the CNWRA.

PENDING ACTIONS:

Kovach and Ott indicated that they would prepare a formal request for addition of this Task in the Field Volcanism Project. The project plan will be modified based on this request.

There are on-going concerns about delays in volcanism research due to reactive work. These concerns will need to be addressed at tne management level. Currently, the request for delays, already incorporated into the Volcanic Systems of the Basin and Range Project Plan, are not resolved.

PROBLEMS ENCOUNTERED: None.

SIGNATURES:

Charles B. Connor
Senior Research Scientist

April 6, 1994
Date

CONCURRENCE SIGNATURES AND DATA:

H. Lawrence McKague
Manager, Geologic Setting

4/8/94
Date

Budhi Sagar
Technical Director

4/8/94
Date

TENTATIVE AGENDA
VOLCANISM-GEOPHYSICS MEETING

Location: NICHOLSON LANE Building, White Flint, Maryland

Time: Monday, March 28, 9:30 AM - 12:00 NOON, 1:00 - 2:30 PM

Tentative Participants:

NRC Res Staff: Linda Kovach, George Birchard, Bill Ott
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PURPOSE

The objective of Task 4 of the Field Volcanism Research Project (FVRP) is to provide a preliminary evaluation of the utility of various geophysical methods for the characterization of intrusion geometries, and for the recognition of magmatic bodies at various crustal levels. One of the activities outlined in section 3.1.4.3 of the Field Volcanism Project Plan is an informal seminar on seismic tomographic methods and their application to the study of volcanic fields. The primary goal of this meeting is to assess the utility of the seismic tomographic method as a tool for better understanding the structure of volcanic fields and for imaging magma bodies which may be present at various levels down to and around the Mohorovitchic discontinuity.

Task 4 of the FVRP will result in recommendations about the types of geophysical work that likely will aid in the resolution of key technical uncertainties related to volcanism. At this meeting, various tomography experiments that may assist in the resolution of these KTUs will be described in detail.

9:30 - 10:00	Introduction: Regulatory basis for geophysical studies related to volcanism. What's the issue? (Connor)
10:00-10:30	Overview of geophysical methods that have been applied to the study of the structure of volcanic fields What's the problem? (Connor)
10:30 - 12:00	Seismic tomographic method (Sanders) i) brief description of the method ii) review of the Evans and Smith tomographic work in the YMR - emphasis on resolution of the survey and interpretation of the low velocity anomaly iii) Examples of higher resolution surveys in volcanic areas

a) Coso volcanic field
b) Newberry Caldera

iv) Example of a "high-resolution" synthetic survey in the YMR

v) Tomography experiments

a) imaging a dike complex (CFVZ)
b) estimating intrusion to extrusion ratios (YMR)
c) imaging mid-crustal low velocity anomalies (Sunset Crater)
d) imaging mantle lithosphere low velocity anomalies (Sunset Crater?)

1:00 - 2:30 Discussion (all)

i) Is the seismic tomography method of utility for the resolution of KTUs? Relation to other projects and tasks.

ii) Do the tomography experiments outlined address volcanism KTUs and assist volcanism research in general? For example, might they provide deterministic bounds on probability models?

iii) Should some or all of the experiments outlined be done by the NRC? If so, what should be the timing of this work?