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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON NUCLEAR WASTE

DATE: Monday, April 22, 1991

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

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ACNW WORKING GROUP MEETING ON

GEOPHYSICAL TESTING METHODS FOR CHARACTERIZATION

OF A HLW REPOSITORY SITE IN TUFF

***

Nuclear Regulatory Commission
Conference Room P-110
7920 Norfolk Avenue
Bethesda, Maryland

Monday, April 22, 1991

The Advisory Committee on Nuclear Waste (ACNW) working group meeting commenced, pursuant to notice, at 8:30 O'clock a.m., William Hinze, Working Group Chairman, presiding.

PARTICIPANTS:

W. HINZE, Working Group Chairman, ACNW

D. MOELLER, ACNW Member

P. POMEROY, ACNW Member

C. ABRAMS, Designated Federal Official

J. CORBETT, ACNW Consultant

A. IBRAHIM, Division of High-Level Waste Management, Nuclear Regulatory Commission

K. STABLEIN, Divisino of High-Level Waste Management, Nuclear Regulatory Commission

C. FRIDRICH, Department of Energy

W. MOONEY, United States Geological Survey

P. NELSON, United States Geological Survey

V. MURPHY, Weston Geophysical Corporation

C. JOHNSON, State of Nevada Nuclear Waste Project Office

J. DANIELS, Dept. of Geological Sciences Ohio State University

PROCEEDINGS

[8:30 a.m.]

MR. HINZE: I see that everyone has their coffee, and the Diet Pepsi, too. So it is approprite that we start.

I'm Bill Hinze, a member of the Advisory Committee on Nuclear Waste of the NRC, and I want to welcome you here to Earth Day, which seems to me very appropriate, and to the working group on geophysics on the move.

The objective of this working group on integration of geophysical tests into site charactererization of a high-level waste repository is to provie the ACNW with a knowledge base on the role of geophysical methods, both surface and subsurface, in the study of particularly the adverse, potentially adverse conditions at the proposed high-level waste repository site at Yucca Mountain.

I feel very strongly that a closely-related objective of this working group is to investigate and to learn more about the integration of these data, and their use in planning and analysis of other proposed tests at Yucca Mountain.

I think that we are all in general agreemeent, all those concerned with the Yucca Mountain site are in agreement that geophysical methods have an important role in Yucca Mountain site charactererization, especially because these geophysical methods are non-intrusive and therefore will not destroy or modify the integrity.

[Discussion off the record.]

MR. HINZE: Well, the important thing is that geophysical methods will not destroy or modify the subsurface conditions of the site and therefore preserve its integrity. However, the site characterization plan of the Department of Energy is not definitive on how geophysical results will be integrated and synthesized with other geoscience and engineering data. This we find clearly discussed by the NRC staff in their site characterization analysiss report.

In a step to rectify this situation, the DOE and its contractors have prepared an extensive document entitled "Status of Data, Major Results, and Plans for Geophysical Activities at Yucca Mountain." You have all received a copy of this so-called white paper.

This report reviews the existing geophysical data and discusses the role, potential role of geophysics in both local and regional investigations of Yucca Mountain. The report states, and I quote from the first sentence of the report, and I quote: "is intended to serve" -- that is the report -- "is intended to serve as a starting point for integration of geophysical activities. And I emphasize "the starting point."

We are interested in a discussion of this document specifically focusing on the manner in which geophysics will be used to investigate the potential adverse conditions at Yucca Mountain in a timely manner.

We look forward to developing a discussion of the importance, advantages, limitations, and potential results from geophysical methods at a variety of scales and depths of investigations.

Of special importance to many of us is the timing of the acquisition processing and interpretation. In other words, the sequencings of these studies and their integration into the results and planning of related studies at Yucca Mountain.

Geophysical data should be available to not only characterize the site, but to identify optimum sites for teh acquisition of the more direct data from drilling, trenching, drifting, and the like, into Yucca Mountain.

There are numerous questions that can and undoubtedly will be raised during this working group meeting, and I look forward to the panel of experts raising questions and providing answers to such questions as, and I had to reaally contain myself here, because there are a large number of questions that I'm sure we could all ask, but let me just point out some of these, at least for the record.

One. What are the roles of the various

geophysical methods in determining the existence and location of potentially adverse conditions as very specifically defined in 10 CFR Part 60.122?

Specifically, there are structural deformation, magma bodies, zones of bridge water table, mineral deposits, and the like.

Two. What is the sensitivity resolution of teh geophysical methods that are most appropriate for characterizing the structure, composition, and physical properties of this proposed site?

Three. How will tlhe various data sets be integrated and what does this suggest regarding the sequencing of them?

Four. Because the white paper is just, and I quote, a "starting point," what is the next step in the process of integrating geophysical data?

Five. How much testing is required, and of what nature, to validate the appropriate geophysical methods to be used in the study of this Tuff, or proposed Tuff repository? The white paper discusses so-called feasibility studies, but in no detail.

Six. Is specialized research into the acquisition, processing, and interpretation needed prior to the characterizatino study? If so, what types of research would be recommended?

Seven. Can geophysical studies at Yucca Mountain be started without permits from the State of Nevada?

Eight. Can existing data be QA'd so that it can be employed in site characterization? Is that worthwhile? How will it be done? The white paper discusses some of that. Certainly there is more that should and could be said.

Nine. Are there geophysical tests that will be compromised by geological engineeering tests that may precede the actual performance of the geophysical methods?

These are only a few of the questions we hope to discuss and we hope to try to zero in on answers.

Following the presentatino by our invited participants, our panel of experts, the meeting will move to a roundtable discussion with the presenters, committee members, and interested parties invited to participate.

The meeting is being conducted in accordance with provisions of the Federal Advisory Committee Act. And Charlotte Abrams, seated here on my left, is the Designated Federal Official for the meeting.

A transcript of portions of the meeting will be kept, and it is requested that all speakers, whether at the table here, or those htat come up from the audience, use one of the microphones, identify himself or herself, and speak with sufficient clarity and volume, hopefully with the amplifying system working, so that he or she can be heard.

I want to emphasize that in my view this an informal meeting of the nature of a Penrose or Chapman conference, which is familiar to those in the geosciences. We hope that you will all enter into the discussions and questioning, and speak as freely as possible.

On behalf of the committee, I want to thank you for taking time from your busy schedules to participate. I know it's been an imposition on our part to ask many of you to participate.

Before we begin, I would like to identify the members around the table. If we could state our name, our professional affiliation, and our expertise, and our interaction with this program, that would be most useful, so that we all make certain that we know each other.

And with that, I will start off. I'm Bill Hinze, a Professor at Purdue University, and a member of the ACNW.

And I will pass this on to my right.

MR. POMEROY: And I'm Paul Pomeroy. I'm with Roundout Associates, Incorporated, and I'm also a member of ACNW. I'm primarily a seismologist. I'm also inerested in performance assessment issues associated with this.

MR. MOELLER: Dade Moeller, from Harvard University, a member of the ACNW. I'm primarily an environmental engineer.

MR. CORBETT: Jack Corbett, consulting geophysicist to the ACNW. I'm a mining exploration geophysicist out of Denver.

MR. FRIDRICH: Chris Fridrich, and I'm a geologist with DOE, Las Vegas.

MR. MURPHY. Vincent Murphy. I'm a consuylting geophysicist with Weston Geophysical or Westboro, Massachusetts. And my specialty is in shallow exploration, and today we'll be discussing, as indicated in the program, shallow seismic studies, and we will add to that velocity measurements, which we find crittical for the site.

MR. JOHNSON: My name is Carl Johnson. I'm with the State of Nevada Agency for Nuclear Projects. Our agency has the oversight responsibiltiy of Department of Energy's activities in Nevada. I head the technical programs with the agency and my background is engineering geology mainly related to planning and conduction of earth science studies for nuclear facilities.

MR. IBRAHIM: I am Abou-Bakr Ibrahim, Divisin of High-Level Waste, Geology-Geophysics, NRC.

MR. STABLEIN: Good morning. I'm King Stablein with the NRC, with the Division of High-Level Waste Management. I'm the Project Manager who runs the reviews of DOE documents, like the SCP, the study plans, and the geophysics white paper.

I'd like to also mention as we're going around two other people that may play some role in the discussion today, Phil Justus, the Section Leader of Geology-Geophysics is over here; and next to himn is Harold Lefevre.

MR. DANIELS: I'm Jeff Daniels. I'm a geophysicist from Ohio State University.

MR. NELSON: I'm Phil Nelson, geophysicist with the USGS, working out of Denver.

MR. MOONEY: Walter Mooney, geophysicist, United States Geological Survey, Menlo Park.

MR. HINZE: Thank you very much. We all know Charlotte.

[Laughter.]

MR. HINZE: Shall we talk about that?

[Laughter.]

MR. HINZE: I wanted to say that that was a compliment.

[Laughter.]

MR. HINZE: If any of the participants, the speakers, have materials that they would like to pass out but have an insufficientg number, if you will make those available to the staff, we'll get them copied and distributed to all of the participants, and as many members of the audience as we can.

Do either of my colleagues on the committee have any comments to make before we get started?

[No response.]

MR. HINZE: All right. Well, let's do so, then.

Our first speaker, as he has introduced himself, is Carl Johnson, from the State of Nevada. And Carl is going to spend the next 45 minutes discussing with us the interface of geophysical testing with site characterization studies, what features should geophysical testing address.

MS. ABRAMS: Carl, if you're more comfortable sitting, you can even sit, since everyone has copies. So whichever. We're less formal.

MR. JOHNSON: It's probably easier up here.

MR. HINZE: Fine.

[Pause.]

MR. HINZE: For the record, is the mike on?

[Pause.]

MR. JOHNSON: Again, my name is Carl Johnson. I'm with the Nevada Agency for Nuclear Projects. I'm the Administrator for Technical Programs for that agency.

Before I start, I'd like to make one comment. Due to maybe a little bit of communication problem, the subject that I'm going to talk about is slightly different than what is on the agenda. But don't fear. By the time I get through with my presentation, I will have covered the subject matter that is on the agenda.

MR. HINZE: We'll accept that as a promise, and not a threat, okay?

MR. JOHNSON: it is a promise. So, with that, let me get started.

[Slide.]

MR. JOHNSON: These are the topics I'm going to cover. Does everybody see ethat all right?

First, I'm going to talk a little bit about the regulatory requirements. I'm going to touch a little bit on geophysical methods from a geeneric point of view. I'm going to leave the rest of the speakers to talk about the specifics of the various geophysical methods. Then I want to touch a little bit on what I view as a generic approach for defining an effective geophysical program for site characterization. And lastly, I'm going to touch a little bit on the state's views of the Yucca Mountain geophysical program as it's proposed.

[Slide.]

MR. JOHNSON: There are no specific regulatory requirements per se for providing the specific kinds of geophysical data during a site characterization program, or even as part of a license applicatino.

But despite that, implicitly, geophysics must be part of a site characterization program. They provide the types of information that assist in understanding natural processes.

MR. MOELLER: Excuse me, Carl.

MR. JOHNSON: Yes.

MR. MOELLER: We have the NRC here. I just wondered, and it's not that it's a controversial issue -- it isn't, really -- but I wondered if King Stablein or a member of the staff would comment on your first statemente that there are no regulatory requirements per se. Do you agree with that? Or is that true? I mean, I'm not disputing it; I just thought it might be helpful.

MR. JUSTUS: Carl is correct. As one reads the words in Part 60 -- and that, I believe, is what he was getting at in his first paragraph -- there is a requirement that the site not be drilled or, as we say, mucked up, in exploration, to preclude its future use as a repository, because of aggressilve, too aggressive site characterization. And that, of course, implies that remote-sense methods, surface-based testing methods, such as those that we'll hear about today, would be extensively employed in site characterization. So we have no objections with Carl's rendition.

MR. MOELLER: Thank you. That's helpful.

MR. JOHNSON: Let me add one point to that, and that is, while there are no specific requirements in Part 60, there is a requirement in at least the draft guide for processes.

MR. MOELLER: Excuse me, Carl.

MR. JOHNSON: Yes.

MR. MOELLER: We have the NRC here. I just wondered, and it's not that it's a controversial issue -- it isn't, really -- but I wondered if King Stablein or a member of the staff would comment on your first statemente that there are no regulatory requirements per se. Do you agree with that? Or is that true? I mean, I'm not disputing it; I just thought it might be helpful.

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MR. MOELLER: Thank you. That's helpful.

MR. JOHNSON: Let me add one point to that, and that is, while there are no specific requirements in Part 60, there is a requirement in at least the draft guide for format and content of the license application that if geophysical investigations are conducted, that those be described and documented in the license application.

MR. MOELLER: Thank you. That's very helpful.

MR. CORBETT: Just a questiton. What about radiometric tools down hole? Artificial sources? Is there no regulatino on that?

MR. JOHNSON: I think when I used the term "geophysical invetigations" it was a very generic use of the term "geophysical investigations." It would include borehole geophysics using a variety of sources, whether they be radiometric or otherwise.

[Slide.]

MR. JOHNSON: If you look at the regulatory guides of the NRC, this is a list of the information needs that require a geophysical data input: stratigraphy, tectonics, geohydrology, natural resources, rock characteristics,a nmd repository engineering.

[Slide.]

MR. JOHNSON: Historically, geophysical data has been the major source of licensing controversy in the earth sciences. I've just thrown out a few examples here of particular areas which have engendered controversy in the earth sciences.

These are, mainly, from my experience, in the

Western U.S., although New Madrid is certainly not in the West. But I'm sure in the Eastern United States there is a comparable list of areas which have had licensing controversy in which geophysical has played a major role.

[Slide.]

MR. JOHNSON: Given that stateement, historically, geophysical methods have played a major role in resolving earth science licensing issues, also.

[Slide.]

MR. JOHNSON: A significant requirement, though, in thec licensing process, is to estimate the extent that an adverse or anomalous condition is present, yet may go undetected by geotechnical investigatino. In this regard, then, the resolution of geophysical data plays a key role in making that kind of determination.

In the cases, I think, where geophysics cannot help to resolve geologic features of concern, then the decision process, especially in the licensing process, must rely on professinoal judgment and the experience of both regulators and the participants.

MR. HINZE: Could you amplify that with an example? It might help to clarify the point.

MR. JOHNSON: Well, an example, and I'll come back to this, this point of a condition which mayh not be detectable by geophysical methods, but still may be a problem that will have to be resolved by the regulators, and this example is specific to the Yucca Mountain, is the resolution of teh fracture system, the degree of fracturing between the repository horizon and the water table. And I'll touch a little bit more on that in some of my later remarks, Bill.

MR. HINZE: Fine.

[Slide.]

MR. JOHNSON: Let me switch and make a few comments about geophysical methods.

The primary thing that we all need to keep in mind is that geophysical methods are the only cost-effective and non-destructive way to examine large blocks of rock in three dimensions.

MR. MOONEY: What do mean by "non-destructive"?

MR. JOHNSON: Non-destructuve, meaning not adversely affecting the rock body itself that you are trying to investigate, as you would do with a drilling program.

MR. MOONEY: Are you somehow implying that drilling is going to adversely affect the repository or that we should limit the amount of borehole geophysical work done at site?

MR. JOHNSON: I think I'm going to fall back on the comment that Phil Justus made earlier in response to a question, and that is, yes, that I think there is, if you read Part 60, there is a statement made that drilling should be limited so as to not adversely affect the performance of the repository.

MR. MOONEY: Wel,l just as someone who does surface geophysics, remote geophysics, I have to admit that in a great number of cases, we rely on drill-hole control to give us ground truth for the measurements and the interpretation that we make, so we need drilling.

MR. JOHNSON: I am not saying that you don't need drilling, but that the point I'm trying to make here is that in the absence of geophysics, the only way to get three-dimensiaonal information about a rock body is to drill it. So therefore, if, you can minimize the drilling and maximize the geophysics to get the same information about the three-dimensional aspects of the rock body, then that's better.

MR. MOONEY: I guess my only point is that you never get the same information with remote geophysics. You get informatifno, but you don't get the same information.

MR. JOHNSON: I agree.

MR. HINZE: I think the point also can be made that not all intrusion into a site need be destructure. In my opening statement, I used the term "non-intrusive," and I like to think of geophysics as non-intrusive. Intrusive techniuque may modify or destroyu what you're really intersted in getting at. And I think that's Carl's point.

MR. FRIDRICH: I guess I would like to agree with you, Carl, that to get the same three-D control with drilling you'd have to turn the whole mountain into a pin cushion. And we don't want to do that.

[Slide.]

MR. JOHNSON: Another point is, most of the geophysical methods are non-unique.

Except for major geological features, geophysical is difficult to reproduce, because of many of the field variables that may be involved -- temperature, barometric pressure, fluid content, fluid chemistry, magnetic field variations, a whole host of things.

Solutions to geophysical problems are, for the most part, ambiguous and non-unique. Therefore, there is a need to combine various geophysical methods to focus in on a solution.

MR. HINZE: A question, before you remove that. Would you mind putting that back up, Carl? I think you've got some comments here.

MR. JOHNSON: Okay.

MR. HINZE: Jack?

MR. CORBETT: Yes. The question, "difficult to reproduce," your examples of this are on a different scale than we're normally talking about in some of this. If I take that literally, "difficult to reproduce" implying that

I can get a different answer each time I run it, I would say don't run any more. So I don't think that that is a statement without qualification that you can leave hang. If you're talking about fluid content, certainly it changes. Barometric pressure affects gravity, I guess. But it hardly affects electrical methods or borehole methods. So I think that there needs to be some qualification to that statement, because if they are difficult to reproduce, and in some instances they are, but one of the things we pride ourselves on is that we can reproduce these readings, or we're dead in the water.

MR. HINZE: And in fact, in the white paper, one of the methods by which the existing data can be qualified is by reproducing selected portions thereof. And that admits to the reproducibilty of geophysics if it's done properly. And I think that's an important point, that we don't want to let go by.

MR. DANIELS: I have a comment on this as well.

I think you need to distingish between "difficult to reproduce" measurements and difficulty to reproduce interpretations. I think it's correct to say that most geophysical measurements are reproducible, but the interpretations may differ and not be reproducible from one interpreter to the next.

MR. JOHNSON: Well, I don't totally agree with that, that because of some of the items that I pointed out, even the measurements may be difficult to reproduce.

MR. DANIELS: Well, then, I would say those individual techniques where that is a problem, then we shhouldn't be using those techniques.

MR. JOHNSON: Well, let me go on to my next point here, and maybe help out.

MR. MOONEY: Well, maybe I could go o nto the next item, which is: solutions are non-unique and ambiguous.

Can you tell me a field of science that is unique and non-ambiguous? And in fact, I would say that geophysics is about the most reliable thing at Yucca Mountain, given the political climate, which is highly non-unique and ambiguous.

[Laughter.]

MR. MOONEY: So I'd say that geophysical methodsh are easy to reproduce and their solutions are relatively well-constrained and the ambiguities are limited. So I disagree with your transparency.

MR. JOHNSON: Okay. Okay. I knew this was going to get comments.

[Laughter.]

MR. JOHNSON: So that's kind of why I brought it up, to get the discussion started.

MR. HINZE: It's very kind of you to throw yourself to the lions as the straight man.

MR. JOHNSON: Why not? Why not? And it's just starrted.

[Laughter.]

MR. JOHNSON: The point I was getting at, and I think it comes from my experience in working on nuclear facilities in the past, in licensing processes and that sort of thing, is that geophysical investigations usually engender quite a bit of controversy during a licensing hearing because of teh interpretations that are made, that while one individual can make one interpretation using a particular model, another individual with equal experience can make a different interpretation, based on a different model.

MR. CORBETT: That's the second point, not the first. Thatt's the second point. We aren't arguing the second point.

MR. MOONEY: I'm definitely arguing the second point.

MR. CORBETT: I'm not.

MR. MOONEY: I think that you show me a geologic interpretation which is, for example, we are pointing out geophysics here, what about geology? What about scientific investigations in general? I think that geophysics, this is somewhat being over-emphasized here.

First, to say it's difficult to reproduce and then to say that it's non-unique and ambiguous, I kind of wonder why we're meeting here, like you were saying earlier.

MR. MURPHY: Mr. Johnson, may I comment on that second item, please?

As a practicing geophysicist, with regard to the uniqueness or lack of uniqueness, I find that any set of geophysical data is ssubject to multiple interpretations. There are also multiple interpretations that do not fit. A number of solutions do not fit.

I think if we can go as far as taking a set of potential data, for example, mathematically there will be an infinite number of solutions that will fit that set of potential data. There are equally so a number, an infinite number of solutions that will not fit that set of potential data.

And I think it is very important to realize here that any set of geophysical data is subject to multiple interpretations. Rarely do we have a set of truly unique unambiguous data. That's not to say there's any problem with the things we're doing. We've beene donig them, in my own cmopany we have been donig them for 35, 40 years. There are others out there that have been doing it 45, 50 years, and with great success. We've been drilled on, dug on, and so forth. We know the limitations of many of the techniques we are using. And if we apply some common sense geologicaly to what we are donig, then we can narrow very quickly, and in a practical sense, we can arrive at what I think Dr. Mooney is getting at, what is a relatively unique solution for the data.

Mathematically, it is not unique. In the real world that we're working in, especially at Yucca Mountain, relatively speaking, it is a unique solution.

MR. HINZE: That also is controlled to a very significant degree by the synergism of the appropriate geophysical technique and the ground truthing of geological data, as Walter has alluded to previously.

MR. JOHNSON: I think we've beat that slide to death.

[Laughter.]

MR. HINZE: Remove that one in the next presentation.

[Laughter.]

[Slide.]

MR. JOHNSON: This kind of gets along with what we were just talking about, that in simply geologic systems, that a combinatino of multiple geophysical data can constrain the solutions, and that's just what Vin Murphy was just talking about, I believe, partiuclarly if calibrated with high-quality geologic data.

However, in complex geologic systems, the combining of geological data with possibly containing ambiguous or non-unique results or even sets of geophysical data with conflicting results can exacerbate the problem of trying to define a solution to a particular geological problem. And that's, I think, othe problem that we're going to hopefully get to in more of the discussions today, and that deals with the complex geological system that we find ourselves in at Southern Nevada.

[Slide.]

MR. JOHNSON: I want to spend just a few moments talking about what at least I envision to be the requirements for an effective geophysical program.

An effective geophysical program must begin with the geologist, hydrologist, and geophysicist objectively deteermining what all of the plausible geologic models are for the region -- the region here I'm going to define is the geologic setting; for the area -- that, I believe, in DOE's jargon, is called the site vicinity; and the site itself.

A geophysical program is subsequently developed from the top down with the overriding objective of identifying the presence or absence of all geological features of regulatory concern.

The second objective of a geophysical program is the establishment of geological conditions in the ranges of parameters that characterize a region, a site, or an area.

Ideally, the program is directed towards achieving an eveentual scientific consensus by the regulators and the applicant on what the probably three-D geologic models or range of models are for a region, area, or structure.

Once these models are eestablisheed, a well-organized geophysical program can be designed with the objective of refining that scientific consensus.

Fundamental to the program is the recognition that the level of detail for any teechnique, whether it be geophysics or otherwise, over a given area, is only as accurate as the least piece of data that can be obtained.

With these types of caveats, which I just describevd in mine, the next step is to lay out a program that will provide a systematic and uniform survey of the region, then of the area, and of teh site, with the level of detail that is commensurate with the geologic features of concern.

This I've defined at the bottom here as, you can see it as level of detail, or what I call scale, but it has also been defined by others as being the sensitivity of geophysical methods. And I think Bill Hinze touched on that in his opening remarks. Also another term could be "resolving power."

An example might be that if we have concern about finding geologic fault systems that over 100 kilometers in length, then remote sensing in geophysical data sets are usually adequate for that.

However, on the other hand, if the concern is for finding a uniform distribution of small fractures that are across the site that are, let's say, 100 centimeters or less in length, between boreholes that are spaced 500 to 1000 meters apart, then it may be questionable whether there is any geophysical technique that would help you in resolving that.

The point that I'm trying to make is that geological features come in all sizes and that rock properties tend to be heterogeneous over an areal extent. Therefore the program, the geophysical program, must be designed to keep the perspective of the size and heterogeneity of the features in mind.

The other point is that, it is critical also to define as part of defining your geophysical program, is to get an idea of the size of a particular geological feature that might slip through what I call the geophysical net or be smaller than can be detected by the particular method that is being used.

[Slide.]

MR. JOHNSON: Now I would like to turn and spend a little bit of time just talking about the Yucca Mountain geophysical program as we understand it.

[Slide.]

MR. JOHNSON: First, I'm going to start out with a couple of quotes from the White Paper which Bill Hinze mentioned in his opening remarks, and I think, at least from our perspective, is one of the better documents that the Yucca Mountain site program has ever put out. We'd like to see the project put out similar types of documents for geology, hydrology, and the other areas, because it certainly focuses on the current data and how one proposes to use investigations and tests to resolve issues than certainly is found in the site characterization plan.

I'd like to start out with, as I said, a couple of quotes from the geophysical White Paper: "As indicated in the site characterization plan, many geophysical activities have not been planned explicitly or in detail because of the uncertainty as to the applicability of various methods."

[Slide.]

MR. JOHNSON: Secondly: "Both the SCP and this report emphasize plans for feasibility testing on the basis of the cost of such testing is outweighed by the potential gain in added confidence of characterizing the site conditions."

I think in the essence of those two quotes is what we view defines the current status of the geophysical program at Yucca Mountain. It's still in a state of flux.

[Slide.]

MR. JOHNSON: So at least from the State's perspective, an obvious conclusion is that we've been at this for ten-plus years now, and we still don't have an integrated geophysical program to assist in understanding the Yucca Mountain geological system.

The geophysical program has so far been run in what I have called kind of a quasi-random manner with the apparent objective of seeing what kinds of geophysical information might result versus using geophysics in a more traditional manner, such as a means to objectively identify, bound, and ultimately confirm the most appropriate geologic models.

[Slide.]

MR. JOHNSON: Let me now talk a little bit about --

MR. HINZE: Excuse me, if I might, Carl. On that last point, do you have any words of wisdom from the State's viewpoint as to why we don't have an integrated program? What's the problem here?

MR. JOHNSON: I really can't answer that. I don't know why we don't have -- why we have not seen an integrated program.

MR. HINZE: Is there any technical reason that you or your staff have seen?

MR. JOHNSON: There isn't a technical reason from our perspective as to why there shouldn't be an integrated program. Our concern is that there is a lot of emphasis in the White Paper on feasibility testing.

A concern we have is that what if that feasibility testing turns out to show that some geophysical methods or a number of geophysical methods are not appropriate for use in the Yucca Mountain area? What are our alternatives?

And that is, I think, something that we need to maybe focus some of the discussion today on. What is the alternative to geophysics if it doesn't work in some areas to get the 3-D information that we need about the region, the area, and the site?

MR. HINZE: Thank you. You have a couple of comments. Walter?

MR. MOONEY: Well, if I could begin, you know, it's easy to say that there's no integrated program. You show me anyone who thinks that they have an integrated program, I mean -- this is a very easy accusation to make, but what are you trying to say?

We're collecting gravity data. We're collecting aeromagnetic data, the seismic reflection. There's a seismic network. There's borehole data.

Could you tell me what's missing?

MR. JOHNSON: What I mean by an integrated program is a uniform, systematic program to collect geophysical information across a region, area, or site in order to identify if there are any features of geologic concern, and more importantly, whether there isn't, the absence of features of concern.

I don't see that. What I see is --

MR. MOONEY: Well, let's be a little bit more specific. Why don't you -- let's refer to a technique and what's missing.

MR. JOHNSON: What I see is a program focus on evaluating those features that have been previously identified, not getting a uniform data set and evaluating whether there are other features that have not been identified, or more importantly we can say that they are absent.

MR. MOONEY: Well, I disagree absolutely with what you're saying. How can you tell me that if you have a gravity map and aeromagnetic map, that people are only looking at the features that have been previously identified?

The aeromag and gravity shows all features without exception, so how can it be targeted at only a feature which hasn't been identified, for example?

MR. JOHNSON: Let me put a caveat to that, since you've brought it up, and it comes up in one of my later transparencies.

Gravity and aeromag are the only two geophysics methods that appear to have some uniformity and systematation throughout the whole region, area, and site.

MR. MOONEY: And I question that.

MR. CORBETT: I do too.

MR. MOONEY: Could you elaborate?

MR. CORBETT: I don't know who is going to talk about it, but the map behind us, I think, elaborates all I need to. I think that's the aeromag map. And if you'll pardon my jumping in, Carl, if that's an integrated uniform data set, put some mustard on it, and I'll eat it for lunch.

MR. MOONEY: Could you be more specific? You're using very -- I don't understand what you're saying. Could you be more specific about your criticisms?

MR. CORBETT: I'm looking at probably five surveys here, different levels, different land spaces, one of which probably cuts here [indicating]. That's a north-south boundary fault, two surveys obviously. There should probably be another one here [indicating], a different survey, different level.

The absence of this character here [indicating], unless it's a vastly different geologic train, which I seriously doubt, we have four surveys in here that are giving us different resolution data, and we're trying to combine these in an interpretation of something here [indicating].

MR. MOONEY: Well, absolutely. The lower portion of the map is the non-magnetized Paleozoic rocks which are buried by alluvium. That's the Amargosa Desert. There is no aeromagnetic --

MR. CORBETT: You mean along this line?

MR. MOONEY: Yes, of course. There is no aeromagnetic --

MR. CORBETT: I'd still come back and say: How many surveys are in here? I may be wrong on what -- I don't know the geology down here, but along these lines and the different character here [indicating], I don't think that's a uniform data set, after a thorough evaluation of three minutes this morning. That's my comment. I don't think the aeromag is integrated and uniform.

MR. MOONEY: I think a lot of terms are being used here that are very easy to throw around, like uniform data sets, integrated programs, appropriate geologic models, which we're not really quantifying, and these are very difficult to counter for the people who are trying to do the work in this program when the accusations are very loose and very general.

I don't agree with what you're saying. I think it's a rather well integrated program, and you have not yet been able to tell me something that was missing.

You say -- I bring up the aeromag and gravity, and you respond by saying that it seems to be well covered. Could you tell me something which has been in a haphazard way or an unintegrated way?

MR. JOHNSON: Walter, why don't you wait and ask that question at the end, if I haven't covered it, because I think I'm going to come back to just what you are alluding to in your remarks later in my presentation?

MR. MOONEY: Okay. But let the record show that it's your transparency. You brought it up.

MR. JOHNSON: Of course, of course.

MR. HINZE: Right. I'm sure that we'll have at the end of the day ample opportunity to participate in a discussion on whether the program is integrated or not, as well as some of these other topics.

MR. POMEROY: Can someone answer the question? I thought Jack's comments were very specific with regard to the uniformity of the data set. And when one looks at that map, I certainly do see a vertical line in the left-hand portion of it that clearly --

MR. MOONEY: Of course, yes, that clearly is the boundary that is well outside the study area, in the sense that it is to the West of Bare Mountain, so it's a good 40 kilometers away from Yucca Mountain. Not 40. I don't know the exact distance, and I don't want to be quoted on that. And that's a clear discontinuity that --

MR. POMEROY: Aren't there others in that map, Walter?

MR. MOONEY: Yes, I have a coverage map. We could put it up right now if you'd like to see it.

MR. HINZE: Why don't we wait until you have your day in court?

MR. MOONEY: The features on that map are real. They're not, the features on that map are not artifacts of data coverage.

MR. POMEROY: Oh, no; I understand what you're saying there. But I wonder about the density of features, whether or not that really is representative across the entire map.

MR. MOONEY: As can you see, Paul, there are some small-scale features, and you get a sense for the resolution of the map by the scale of the features on the map. I think I'm getting the feeling from Bill Hinze that he wants to move on.

MR. HINZE: I think you're going to have a chance to bring some of these items up in a more organized fashion.

MR. MOONEY: As you know, Bill, my point was more to this transparency, that just seems, it seems to be a "free-for-all" against geophysics today. We've got an unintegrated program, there's problems with it, they are non-unique, the results are non-reproducible. I don't agree with any of these statements.

MR. HINZE: Fine. That's what we're here for, to have a chance to discuss these items and to clarify the issues. And it's appropriate that Carl has brought them up for discussion purposes, so that we'll all have a chance to better understand.

MR. JOHNSON: Let me at this point say, it's certainly not my intent to have a quote "free-for-all" against geophysics here.

The point that I'm trying to make is we don't see that geophysics is integrated into the overall earth science program for characterizing Yucca Mountain and providing the types of three-D information that are going to be required in order to license this particular facility. That's all I'm trying to bring up in my remarks.

Let me touch -- we've kind of beat up most of the items here on this particular point. Let me get to the last one, which touches on what Walter Mooney has brought up.

[Slide.]

MR. JOHNSON: And that is, we go to the geophysics white paper and look towards the back. There is this table which has the various geophysical techniques across the top, the listing of the study plans down here on the vertical axis.

The letters, the capital letters define those areas in which new geophysical data is going to be acquired. The small letters define those areas in which existing or results of new geophysical data is going to be used.

I had a lot of problems in trying to understand and make something out of this table. So what I did is I modified it slightly --

[Slide.]

MR. JOHNSON: -- to focus specifically on those areas which there will be new geophysical studies proposed.

The A's, which I've highlighted in red, are for the region. The B's, which are in blue, are for both Yucca Mountain, the site, and for the vicinity. And D is for the repository block itself.

And I'd like to make three points on this particular table, which gets to Walter Moody's comment about integrated program, and a uniform program.

We get down here to geologic features, I mean volcanic features. The only programs proposed are paleomag. There is no either area or site subsurface data proposed here.

MR. FRIDRICH: If I could address that before you go on, the reason, it's just that the data is not collected in that study plan, it's collected in the tectonics study plans down below, and it's applied in the volcanic study plans.

See, you took off all the small letters that show how things are applied. We definitely are collecting data for the volcanism study plan, it's just not collected in that study plan.

MR. JOHNSON: I question whether you actually are or not, because I really don't, I think there needs to be some studies specifically for the vulcanism studies.

The other thing is, we look here at natural resources. There is no geophysical data being collected for natural resource assessment overall, whether it be the region, area, or site. And that's an important area; even that is a disqualifying condition for the repository.

MR. FRIDRICH: That's just not true. You just took off all the small letters which show all of the data that's collected for natural resources. It's just not collected within that study plan as defined.

MR. JOHNSON: So where would I find regional --

MR. FRIDRICH: Go back to the table you had that didn't have all the small letter deleted.

[Slide.]

MR. FRIDRICH: See, now there you see it. There are all the things that we're collecting for natural resources and for volcanism.

MR. JOHNSON: Only under repository block and vicinity.

MR. FRIDRICH: That's right. We know that there are natural resources regionally. If it isn't very close to the actual site of the repository, it really doesn't matter.

MR. JOHNSON: It's part of understanding the geologic setting that the site is contained in.

[Slide.]

MR. JOHNSON: The third point is that there is no area or site stratigraphic and subsurface stratigraphic and structural data, both intermediate and deep.

If you look in the intermediate and deep column, you don't see that, except for trying to understand quaternary faults.

MR. FRIDRICH: Again, Carl, that one place is where the data is collected and it's applied all up and down. The capital letters just show where the data is collected. It's not collected in every study plan over and over and over again. We just collect it in one place and then we apply it all over.

MR. JOHNSON: Since we don't know what the quaternary fault study plan is like, since I don't think it's been issued yet, I can't comment on whether that data will be applicable for understanding subsurface stratigraphy and structure or not.

MR. FRIDRICH: It will.

[Slide.]

MR. JOHNSON: Let me touch just on a couple of items here. Now we're getting around to the point where I match with the agenda.

Here is an example of the types of geophysical anomalies that have already been identified in the Southern Great Basin, and therefore will need to be resolved here before this program is over with.

We've all heard about the resistivity anomaly near the exploratory shaft. That was identified approximately two years ago. That still is not resolved.

The "bright spot" that's on the seismic reflection data. Maybe that'll be talked about a little bit more today.

The upper crust detachment features that are shown on the seismic reflection data.

The aeromag. anomaly that's near Solitario Canyon.

An important point is the 2.5 kilometer change in depth to basement beneath Yucca Mountain.

And lastly is the tomography data, and I'd just like to, since I didn't have examples of some of those other ones easily put together, I did have an illustration for the tomography data.

[Slide.]

MR. JOHNSON: This comes from the cover of the AGU from September 1990 showing this low-velocity layer or feature here in Southern Nevada which covers a portion of certainly the Yucca Mountain area. You can't tell because of the gross scale whether it covers the site itself.

Getting to the point that was made about a uniform database, this is a uniform database. Now, I'm not saying that we need to do that for all of the Yucca Mountain, in every one of the areas. No. But this is an example of a uniform database.

MR. MOONEY: I would like to differ. Having reviewed that paper for its publication, and actually being the associate editor on that paper, that was anything but a uniform database -- and I could elaborate if you want -- with regard to the number of sources that were used to make the figure and the location of the seismographic stations that were used, that recorded. It's a uniform diagram, but it's been smoothed to a tremendous amount.

MR. JOHNSON: Okay. Then you know more about it than I do.

MR. HINZE: Well, let me ask you, what coverage was available, and --

MR. MOONEY: Yes, maybe you could put the transparency back up.

MR. HINZE: I think all of us that have looked at that diagram, we've all looked at it, have wondered just what the data were.

MR. MOONEY: Okay. This is in press, in JGR. The author is Hearne, who did the work when he was at Cornell. He's now at Secorro, New Mexico, I believe.

It is an image of the velocity of the uppermost mantle, so-called Pn, where "n" stands for "normal" in the old terminology of crustal studies, and refraction. The basis of it is the travel time of earthquakes to permanent seismographic stations. These would be the old WWSSN and other stations.

Now, as you can see, we're looking at most of the Western United States and -- most of you know this -- a large number of stations in California of various types and descriptions.

But in the State of Oregon, for example, there is I think one station at Corvalis, perhaps a second one that I'm not aware of, that I don't recall; and then in the State of Washington there is a seismic array in some stations near Seattle.

Eastern Washington and Oregon would not be covered with seismographic stations, for example.

Nevada is fairly well-covered, and Utah has some stations. Idaho and Montana have fewer stations.

The earthquakes that are used, you'd have to consult a seismicity map of the Western United States, but I think we all are familiar with the fact that large earthquakes that can be recorded by a regional seismic network tend to be concentrated in the Pacific Northwest, mostly in the State of Washington and in California, and then there's a scattering of earthquakes along the Watsach Fault and in the Rio Grande rift, and some seismicity in Nevada as well.

So there is a non-uniform distribution of earthquakes. Each of these earthquakes has an unknown origin time, depth, and latitude and longitude, recorded by seismographic stations which have an uneven distribution as well. And the beauty of the technique is that a very large number of stations were read for these travel times and a best-fitting average velocity for the uppermost mantle was derived.

You can see, though, that the scale of the figure, I think the latitude and longitude is on the bottom. It goes from 110 degrees to 120.

So some of these travel time paths, Bill, are 1,000-kilometer paths, so they are diving into the mantle. They are deeply-penetrating rays in general. They do not correspond to the same measurement, for example, as you would make if you would run a refraction profile out to 300 kilometers and measure the velocity of the uppermost mantle. So there is some depth of penetration here.

The key figures are seen, as Carl has pointed them out. But let's take a look at one of the artifacts. You look at this map and you say, isn't this exciting; here's a tomographic image of Western United States.

Look under the Sierra Nevada, see the red, the big bright red spot. Yes, that one right there. That's probably an artifact due to the root of the Sierra Nevada.

The arrivals that came to stations in that vicinity, since the Sierra has a big root, they tunnel through the crust. It's a 50-kilometer thick crust, probably. They tunnel through and they come in with a delay due to the crustal root, and the delay, that delay is then mapped into a Pn travel time delay.

So you could argue that there is in fact that whole red, big bright spot there is an artifact of the technique not having corrected for the delay caused by the root of the Sierra Nevada.

And as one continues, you could debate back and forth the influence of other features.

For example, in the Snake River Plain, you see Yellowstone has a bright anomaly, but the anomaly smears out into the Snake River Plain. To what extent do the surface deposits in the Snake River Plain and elsewhere cause a certain smearing of the anomalies?

MR. HINZE: In fact, Yellowstone doesn't. That's one of my concerns about that map, right up in there.

MR. MOONEY: Yes, Yellowstone specifically doesn't, that's right.

MR. HINZE: Yes.

MR. MOONEY: I'm sorry. I stand corrected. And so there are features in this map which are caused by the non-uniform nature of the coverage, and that's where we got started on talking about it.

MR. HINZE: Thank you. That's a helpful clarification. I think it's also true that one of the plans in mind of the United States Geological Survey is to carry forth a tomographic survey that has already been initiated. Is that not right?

MR. MOONEY: Yes. Tomographic data have been collected around in the study area, and of course there's a network that's being operated, that continues to record data that are suitable for a similar kind of study. It would be able to evaluate and test the hypothesis put forth by this illustration, that there is a low-velocity feature in Southern Nevada in the vicinity of Yucca Mountain. It would be worth doing.

The low-velocity feature, by the way, is over to the, it's located specifically a little bit to the East, Southeast of Yucca Mountain. It's not right below Yucca Mountain.

MR. HINZE: Is the East-West break that we see in so many of the geological and geophysical features, and that we see on that map, a reality?

MR. MOONEY: Which --

MR. HINZE: East-West. Right in there, on the East-West. Basically, there's an East-West break. You can see it on topography, you can see it on the aeromag. map, and so forth.

MR. MOONEY: Well, Carl, maybe you could point to the -- which East-West break?

MR. HINZE: I'm sorry. I'm talking about the Northern termination -- right there -- of the low velocity.

MR. MOONEY: Ah, yes. Okay.

MR. HINZE: And that tends to have an East-West limit.

MR. MOONEY: Right. That appears on this map. And I would agree with you that it shows up on all the other maps as well, and is probably a change in crustal or lithospheric structure that trends East-West. I know what you're talking about.

MR. HINZE: Okay. It could be an artifact of some other things, then. Right. Okay. Thank you.

MR. IBRAHIM: After I saw this in areas, I talked with the author, Herr, and I asked him if he has used any of the stations of the Yucca Mountain project. And he mentioned he didn't have a chance to use any of the stations.

And I told him it would be wise if he can go back again and use the stations and maybe can refine this type of anomaly to be exactly what is the source and everything like that, and he promised me he will get in touch with the people at Yucca Mountain.

MR. HINZE: Very good.

[Slide.]

MR. JOHNSON: Now here are some examples of some of the geologic features in the Yucca Mountain which are probably amenable to geophysical solution, but, as I understand it, have yet to be applied.

One is the Walker-Lane structural zone, which Yucca Mountain is within; the Northeast-trending Mine Mountain fault zone, which crosses Yucca Mountain south of the repository block; and also looking at the Paleozoic stratigraphy and structure in the Yucca Mountain area.

I've got a couple of illustrations here to make sure that everybody is aware of this.

[Slide.]

MR. JOHNSON: Looking at the Walker-Lane structural zone, in Nevada and California. The site is where the star is. The concern here is within that zone have been some of the major historic earthquakes in the Nevada area, specifically the 1932 Cedar Mountain event. So we need to be evaluating this portion of the Walker-Lane structural zone to see what are the characteristics of it in the site area.

[Slide.]

MR. JOHNSON: I just put this on. The specifics of it are not that important. This is Yucca Mountain here, Bare Mountain here, Calico Hills, CP Hills, and then Yucca Lake, to the right side.

This particular cross-section was part of a much larger cross-section that was presented by Tide Petroleum and Cedar Strat out of Denver, Colorado at the AAPG meeting in Dallas, what, three weeks ago now.

They have developed a Paleozoic cross-section for the Southern Nevada area, kind of going in a Southwesterly, Northeasterly direction covering across the whole state. I just copied a small portion of it, that portion that covers the Yucca Mountain area. And full-scale, the cross-section is over 80 feet long.

But the important thing here is this is an interpretation that was done for the purposes of hydrocarbon exploration. And at least they haven't interpreted that the Paleozoic stratigraphy extends down to some 25-to-30 thousand feet below the Yucca Mountain site.

The point is, why I am bringing this up, is there needs to be a geophysical program to look at the stratigraphy and structure beneath Yucca Mountain, certainly for hydrocarbon evaluation as part of natural resources, but also so we can understand what is the older stratigraphy and structure.

MR. HINZE: Is that based on any proprietary seismic reflection work? What's the basis of this in the Yucca Mountain area?

MR. JOHNSON: What they did was, they took all of the data that was available in the area, both seismic data and drillhole data, and using a standard, balanced cross-section computer program, developed the total cross-section.

MR. HINZE: Thank you.

MR. MOONEY: Has it been compared with potential field data to verify that it fits the gravity field?

MR. JOHNSON: To my knowledge, there has been no field verification of this particular data. The presentation that they made at AAPG was just to present the balanced cross-section. They know that the next step then is to do the field verification.

MR. MOONEY: Well, making a balanced cross-section assumes that you know something about what you're trying to balance. And with the lack of seismic reflection data to constrain the volumes of the various units, I fail to see how they can make a balanced cross-section.

MR. JOHNSON: The computer programs allow you to make a balanced cross-section. Now, it doesn't mean that that is correct or even that it is constrained by various geophysical data, or that sort of thing. It is there, the computer model's best interpretation, so to speak, tempered with the judgment of those people who are putting it together.

I'm not saying that it's correct. I'm just saying it is one interpretation, and that what we need is a geophysical program that helps us to address this particular issue and better defines what the Paleozoic stratigraphy and structure is.

MR. MOONEY: Well, earlier you were telling us about how we need to have an integrated geophysical approach.

And I would submit that this is an example of a totally unintegrated geophysical approach to try to make a quote-unquote "balanced cross-section" with a lack of adequate seismic control, and without integrating the potential field data to constrain the interpretation.

So this is, I would argue this is an example of the kind of work that we don't need at Yucca Mountain.

MR. JOHNSON: Let me make this point.

This is the first of a deep cross-section showing the structure and stratigraphy, and interpretation of structure and stratigraphy, all the way to the basement. We don't see one of those in the SCP. So we don't know even what the geologic model is that DOE is proposing.

Now, you may be, I think what you are saying is that because of the lack of geophysical information, you don't accept this particular interpretation of the structure and stratigraphy. But I don't see another one, either.

MR. MOONEY: Well, that is absolutely not right. I have presented it numerous times, and it's been included in every report that's been put out by the geophysics group, including cross-sections across Yucca Mountain and Bare Mountain, based on the seismic refraction results which are very tightly constrained.

And so it's simply not true to say that there have not been previous cross-sections made. These are cross-sections that are constrained by the potential field data, aeromagnetic data, and which have excellent seismic control, and which contradict the transparency that you are showing, which I consider to be worthless.

MR. JOHNSON: Okay. I'm just bringing it up as a piece of data that is out there --

MR. MOONEY: It is not a piece of data. It is a flight of fancy of someone running a computer program that doesn't have any controls on the input parameters.

MR. JOHNSON: I'm just bringing it up as a point of geologic features that are of concern, that need to be evaluated as part of the geophysical program.

MR. MOONEY: Well, later I will show a cross-section that has a basis in fact.

[Slide.]

MR. JOHNSON: I want to touch on a couple of points, and these are just examples, are geophysical or geologic features of concern for the repository which are probably not amenable to a geophysical solution.

One is the steep hydrologic gradient, north end of the site itself, north of the site, and secondly is the fracture distribution in the unsaturated zone, especially in three dimensions.

MR. MOONEY: Before you put that away -- could you put that back up?

MR. JOHNSON: Yes.

MR. MOONEY: Could you explain why you feel the origin of the steep hydrologic gradient is not amenable to geophysical solutions?

MR. JOHNSON: At this point, I don't know -- I don't think we know enough about that particular feature to say what its origin is or why it is causing the steep hydrologic gradient, but short of drilling a series of drill holes -- and I call that, contrary to you, destructive testing -- I can't see that -- where surface geophysics is going to help us out a whole lot in trying to define that particular feature.

MR. FRIDRICH: I disagree totally. I'll be talking about it later.

MR. JOHNSON: Okay. Fine.

MR. HINZE: I think we'll have a chance for some rebuttals on that.

MR. DANIELS: I would also like to disagree with that second statement, as well. I think that there are techniques that will help us to define fracture distribution in the unsaturated zone. I'm going to talk about that this afternoon.

MR. HINZE: I think Vince Murphy will probably be talking about that, too.

[Slide.]

MR. JOHNSON: I just wanted to point out that what I am talking about there is that particular area between the repository horizon and the groundwater table. As I understand it now, DOE has a program to go into the Calico Hills unit, but that will -- that particular activity will stop short of the water table.

So, there will be then a need to define the fracture distribution between those particular drifts and the water table and also to define the fracture network away from the drifts that are proposed.

[Slide.]

MR. JOHNSON: Let me finish this up here, so I can get off the podium here.

The main points I want to make is, one, that geophysical methods are the only cost-effective and non-destructive way to obtain three-dimensional data; geophysical methods are non-unique; that all appropriate geologic models must be defined before the geophysical investigations are planned; that geologic features and rock properties at all scales, thus the scaling effect is important in planning; and that some geologic features of concern for performance assessment may not be resolvable with geophysics.

[Slide.]

MR. JOHNSON: Lastly, let me just put up this quote from a paper by Wynn and Roseboom from Journal of Geophysical Research in 1987, and I think it kind of captures in a few sentences the point I have been trying to make all along, is that "Evaluation of the potential high-level nuclear waste repository sites is an area where geophysical capabilities and limitations may significantly impact a major government program.

"Since there is concern that extensive exploration drilling might degrade most potential disposal sites, geophysical methods become crucial as the only nondestructive means to examine large volumes of rock in three dimensions.

"Characterization of potential sites require geophysicists to alter their usual mode of thinking: No longer are anomalies sought, as in mineral exploration, but rather their absence. Thus, the size of the features that might go undetected by a particular method takes on new significance."

That concludes my remarks.

MR. HINZE: Thank you very much, Carl, and thank you for presenting a viewpoint that certainly has raised a certain amount of concern, and this will become a good focal point as we move through the day.

I wonder if there are any general questions that we want to pass to Carl?

If not, I've got a couple of questions, Carl, of a general nature, that I'd like to ask, that particularly relate to the State of Nevada.

I know that you and your technical group have a program in hydrology, geochemistry, geology. What are you doing in the geophysics area in terms of the Yucca Mountain site?

MR. JOHNSON: We don't have a particular program in geophysics. Part of the problem has been that we have been looking now and have been unable to find a consultant in geophysics to help us. That doesn't mean they're not out there. We just haven't identified them yet, somebody who can really help us out there.

Secondly and, I think, more importantly, it's not been, up until now, a major component of the State's oversight program.

We have covered some aspects of geophysics, remote sensing, seismicity, those aspects, but the more traditional things of evaluating seismic reflection surveys, gravity magnetics, and that sort of thing, it has just not been a high enough priority on our program to use our meager resources to do detailed reviews of the department's programs.

MR. HINZE: Do I understand by the caveats that you put on your statement that you have plans in mind to move into this area?

MR. JOHNSON: Yes. If the monies would become such that -- yes, that's one of the areas we want to go into.

MR. HINZE: Thank you.

A general question that I asked in my initial statement I'd like to direct to you, and that is can geophysical studies at Yucca Mountain be started without permits from the State of Nevada?

MR. JOHNSON: Let me respond to that -- as you're probably aware, the State is processing the permits that DOE has applied for. There have been some questions raised by the regulators, as I understand it, and DOE is responding to those questions.

Specifically, the permits deal with surface disturbance: the drilling of holes, the trenching, those type of surface-disturbing activities, and the construction of roads related to that.

If the geophysical techniques don't require those types of surface-disturbance activities, then there is no problem with doing those surveys.

The other thing that is covered, which I think Mr. Corbett brought up, and that was the use of radiological tools. There is an application in by DOE for that type of activity. We're taking a look at those.

MR. MOONEY: What is the role of the people from the University of Nevada-Reno who have been participating in all the field trips? Steve Wesnousky, Jim Brune, Keith Priestly: They regularly receive all geophysical data and have been evaluating the work.

MR. JOHNSON: Through the Center for Neo-Tectonic Studies at the University of Nevada-Reno, which Steven Wesnousky is the director of, he brings in the expertise of the rest of the university system, specifically Jim Brune, the State seismologist and some of his seismology staff, who regularly receive all of the reports, documents that are issued by DOE and its various participants and do reviews of those as we direct or not direct.

They are familiar with the information. They are familiar with the surveys. But they have not been specifically tasked to conduct detailed evaluations.

MR. MOONEY: These are written reviews.

MR. JOHNSON: No, they are not. As I sai , we have not had them routinely do detailed reviews of the specific geophysical surveys.

MR. HINZE: Thank you very much, Carl. Sorry to keep you up there so long. It's been very interesting.

Buck, I'd like to impose upon you to delay your presentation to after the break, and so, we'll take a 15-minute break and come back here shortly after quarter after.

[Brief recess.]

MR. HINZE: Our next speaker will be Buck Ibrahim, who will be giving NRC's viewpoint on the relevance of geophysics.

Buck, the floor is yours, please.

MR. IBRAHIM: Thank you. Ladies and gentlemen.

In December 1988, DOE submitted to NRC the Site Characterization Plan, and I will be addressing mainly our comments on the geophysical program which is mentioned in the SCP.

The geophysical program in the SCP contains a lot of information. It described all the geophysical methods you would expect or think of applying for investigation anywhere. Sometimes I call it a wish list.

Can we wait for Mooney?

[Laughter.]

MR. HINZE: May I suggest that you get going?

MR. IBRAHIM: I'm saying that all the material which are written in the SCP are well-written, include every geophysical method you could expect, but unfortunately, they were not decisive. Which of these geophysical methods will be applied for the Yucca Mountain investigation?

When you open the table, you can see a description of the geophysical method and, after it, "TBD", to be determined, or in other cases, after we do the feasibility study, we will decide and make decision. Which of these geophysical methods will be applied for the investigation?

So, it was not clear for the NRC staff to decide exactly which of all of the geophysical methods identified in the SCP will be applied for the investigation of Yucca Mountain, and looking at the figure which identifies the line which would be run across Yucca Mountain and the vicinity, there was some --

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[Slide.]

MR. IBRAHIM: I'll mainly be talking about -- comment on the program itself. I am not going to specifically address any geophysical method.

[Slide.]

MR. IBRAHIM: For example, if we look at the proposed refraction work which will be done at Yucca Mountain, we can see approximate location of proposed seismic refraction survey across Yucca Wash.

This is only one refraction line, and there was not a clear rationale why they choose that line exactly here. That line will be complementing some of the work Walter Mooney has done. How will that be integrated with the other geophysical method which will be used in the area?

[Slide.]

MR. IBRAHIM: Here also some of the location of the reflection data which will be used for the investigation of the Yucca Mountain site. As you can see, some of these lines are very, very short, approximately two kilometers, and what is the rationale between these lines and the refraction line which I show you in the first picture.

Also, we were talking about wide-angle reflection survey. I would assume that most of these lines would be short for such kind of investigation.

[Slide.]

MR. IBRAHIM: Another figure shows the gravity and magnetic data which will be acquired at Yucca Mountain. Here we have two circles, one in the north and one in the south, which identifies the location of the gravity and magnetic survey which will be done by the Yucca Mountain project.

As you can see, these two locations are the optimum locations required for the investigation of Yucca Mountain, how this complements the other survey which has been done before. What is the resolution of the data that will be collected in these two areas?

[Slide.]

MR. IBRAHIM: Another figure shows you the proposed continuously cored holes at Yucca Mountain, which are represented by the square. We have three bore holes.

Will these three holes will be enough to give us all the information we need for the characterization of Yucca Mountain? Will these holes be used for getting information about USP?

There wasn't any indication, because also we have to consider what other purpose this bore hole will be used for, so we can plan for the whole experiment.

And so and so on, we can find information like that in the SCP.

[Slide.]

MR. IBRAHIM: Based on that, the NRC sent the comments, and one of our comments was the program for geophysical information, as presented in the SCP, is insufficiently described.

The correlation between different geophysical investigation is not presented, and in addition, the approach that will be used to integrate the geophysical activity and how this different geophysical activity will be complementing each other does not appear to be discussed in the SCP.

There was a question which Walter said what do you mean by integration? And of course, as you said, everyone has his own definition. I would like to clarify that.

For example, I know you have done a lot of work in refraction. You have done a lot of work of reflection data. Maybe also you collected some gravity and magnetic, and there are some in the area, also, about electrical method. There is some information also from bore holes.

We have not seen anyone combine all this data and come out with a model which tells me that A, B, and C gives this interpretation, and I confirm it by the other method used.

For example, it would be nice if USGS, for example, which has the capability, I am sure, to use the GIS, Geographic Information System, that's one of the things which most of the people there are doing, and if we can use the gravity, magnetic, reflection, refraction, electric, and bore holes, I'm sure it will be able to come out with a very nice three-dimensional model, and that's all I mean by integration.

If we can use refraction by itself, we are not getting a unique model or talking about the uniqueness, and I'm sure that if you combine reflection with refraction with gravity, the uniqueness will be coming closer to what we are looking for, and that's what I mean by integration.

We have a lot of data existing now at different parts of the USGS Yucca Mountain project, so one of the first things I would like to see, integrating all this data, and then we can fill the gap with more information later.

[Slide.]

MR. IBRAHIM: The second comment we submitted on the SCP --

MR. HINZE: Excuse me.

MR. IBRAHIM: Yes.

MR. HINZE: Buck, do you carry that idea forth from -- to the regional work that Walter has been primarily concerned with as well as to the area and the site studies? Do you see any difference in the integration approach or the need for integration at these various levels of scale?

MR. IBRAHIM: For example, I would be concerned mainly with the site location. I would like to do that for the site location first and get more information, and if we have the time for doing it on a regional scale, we'd like to see that.

MR. JOHNSON: Buck, let me follow up on that.

How are you going to understand the geology of the site which the geological investigations are supposed to support if you don't have a regional understanding of what the site is and have a regional geologic model to start with?

MR. IBRAHIM: I am assuming some of the geophysical will be -- as we discovered in the SCP, there are two programs, one for the regional scale and one for the site-specific scale.

MR. JOHNSON: I'm trying to understand why you want to focus initially on the site, as opposed to starting out with the region and understanding the region first and then putting the site within that region?

MR. IBRAHIM: I agree with you, with what you say. We usually do regional survey, and then we look where is an anomaly existing, and then we'll go back again and concentrate on this area which may be of significance for the characterization and may be used as an adverse condition for the characterization of the site, because we never usually go to the site and then go to the region.

We usually go regional survey, as in item five, the area of interest to us and concentrate on this area.

MR. JOHNSON: And basically, then try and constrain a geologic model of the region first and place the site and a site model within that regional context.

MR. IBRAHIM: That's what's usually done. I'm not proposing something new. It has been done for every other investigation. In oil exploration, for any other -- for mineral exploration, for anything, they go the regional and then go to the specific.

MR. JOHNSON: I just wanted that clarification.

MR. HINZE: I also want to see that it is clarified, if that's your point, that this integration, although the integration may take different forms, is important at all scale levels, as Carl talked about.

MR. IBRAHIM: At the regional scale and the site-specific scale?

MR. HINZE: Yes.

MR. IBRAHIM: I would say yes, I would like to see that, but I would say, for example, for the site scale, it may be high-resolution.

MR. HINZE: Sure.

MR. IBRAHIM: A high-resolution scale. But for the regional scale, I don't expect them to do high-resolution collection of data.

[Slide.]

MR. IBRAHIM: The second comment we indicated to DOE: The geophysical survey program, as indicated in the SCP, may not be sufficient to identify and characterize both the deep crustal and shallow geological feature and their interrelation.

As I showed you in the last one, the survey lines were scattered all over the area, and some of them were very short and some of them were medium-length, and they are proposing only one long line which can give us some information about deep structure.

I would like to have a correlation between the different lines, which one will be giving the shallow structure, which one will be giving you the deep structure, and how this line which is giving you the shallow structure will be correlated, so when you get the model, you have a feeling what is the deep structure correlated to the shallow structure.

[Slide.]

MR. IBRAHIM: The third comment we proposed to DOE is that no specific geophysical program appears to be planned to identify volcanic/igneous feature and their extent under or close to the site.

The SCP has indicated that we are doing geophysical measurement, but there wasn't any specific program which identified the volcanic activity. They said we are doing this geophysical measurement, and if we see anything, any activity or any anomaly, that will be fine.

For example, they are doing some refraction. Was that refraction really defined? Was the resolution needed to identify this volcanic or igneous feature? It was not clear.

I didn't see any specific program which said we are investigating this particular volcanic activity under the site or close to the site, and in the white paper, for example, they mention that this activity will be addressed on the study plan, and when I looked at the study plan, the study plan mainly addressed all of the existing data.

So, I'm going to go back to look at existing data, and if we see anything, that's very fine, we can go and investigate it. If we don't see anything, this means volcanic activity doesn't.

But suppose that all this existing data before was not of the resolution we require to identify this volcanic activity? So, we should propose another program for this.

MR. MOONEY: Buck, could you expand on what technique you think would be useful to identify, as you say, volcanic/igneous features and their extent?

MR. IBRAHIM: You can go, for example, for gravity, aeromag. I mean you're talking about -- there is some anomaly indicated in the aeromag. Some gravity measurement has been done to identify the volcanic. Some electrical methods can be used to identify the volcanic. Some refraction can be used to identify a volcanic. Some reflection can be used to identify the volcanic.

MR. MOONEY: I think the aeromagnetic map on the wall shows the igneous features very well. The blue and red dots that are in the center of the map are due to volcanic and igneous features in the study area.

MR. IBRAHIM: Fine. Is this all the volcanic activity in the area, or is there some that have escaped or we have not identified yet?

MR. MOONEY: Well, I think the purpose of the program to go back and get higher-resolution data right in the area, your figure 3, is designed to do just that.

MR. IBRAHIM: But are these the only locations where we're really looking for the volcanic activity?

MR. MOONEY: Well, the area covered to date extends to a prescribed distance from Yucca Mountain, and you could continue to prescribe greater and greater distances at your pleasure, but I think the potential field data collected to date have done an adequate job of characterizing volcanic and igneous features, and if you want more resolution fine.

MR. IBRAHIM: For example, when we are trying to do a probability for the volcanic activity, you really have to have more understanding for all of the area where volcanic activity can be existing.

MR. MOONEY: Right.

MR. IBRAHIM: And we don't have really, at this moment, a full investigation of all the volcanic activity in the vicinity of Yucca Mountain. I'd be glad to see a figure which identifies all the volcanic activity in Yucca Mountain.

MR. FRIDRICH: Well, actually -- I mean, you know, the studies have gone out at least 50 kilometers from the site, and even further, looking at all of the volcanoes that have come up in the last 5 million years, and I think that's enough. I mean how far do we have to go?

MR. IBRAHIM: Do we have an idea how this volcanic activity connected to each other? We just find an anomaly here, an anomaly here, an anomaly here, right?

MR. FRIDRICH: Well, no zones, alignments of cones, have been identified.

MR. IBRAHIM: How far is the extent of this volcanic under the site? Can you identify them for me?

MR. MOONEY: Well, they show up on the aeromagnetic map.

MR. IBRAHIM: Can you know how it is connected to each other?

MR. MOONEY: They form linear trends.

MR. IBRAHIM: That is north-south trends.

MR. MOONEY: Yes. That's right.

MR. IBRAHIM: Anything east-west?

MR. MOONEY: No.

MR. FRIDRICH: Well, actually, there are small clusters that are sort of north-northeast trending, and it defines a northwest alignment of the clusters.

MR. IBRAHIM: Okay. This cluster is just by itself or it is connected with each other down there?

MR. FRIDRICH: Well, almost every volcanic eruption out there is a different batch of magma. It isn't like there is some big mother chamber that is putting out things. It's just little batches.

MR. IBRAHIM: Do we know what is the source of this magma?

MR. FRIDRICH: The mantle.

MR. MOONEY: The mantle, yes.

MR. IBRAHIM: How deep? How large will it extent?

MR. FRIDRICH: The petrological data shows that the magma is coming from the pressure, which is not stable, and that means that we're into the upper mantle.

MR. IBRAHIM: I would like to see, if possible, what the extent of this magma looks like, if there is any extent of this magma coming under Yucca Mountain or not.

What is the correlation? For example, we have something at Listric fault. Listric fault is very close to Yucca Mountain.

MR. FRIDRICH: The batches of magma are so small that it's not at all likely that there is any big integrated magma chamber. It's just little bits. And that's probably all over the Great Basin.

MR. IBRAHIM: I would like you to confirm.

MR. FRIDRICH: At that depth and given the small size of the magma chambers, it's very unlikely that we would be able to define them with geophysics.

I mean we are going to look at all the geophysics that we get out there. It's mostly runford tectonics and everything else, and we're going to see what it shows. If we see something interesting, then we'll run more detail.

MR. IBRAHIM: That's what I would like to hear.

MR. FRIDRICH: And that's what the study plan says, if you have read the volcanic features study plan. It sets out that program.

MR. IBRAHIM: My question here is was there any specific program for the volcanic? It tells me go to the study plan.

MR. FRIDRICH: But just as an initial pass, we're just going to take all the surveys that are run for tectonics and site -- all the other site-characterization activities, just look at it, see what we've got. If we need more data, then we'll go out and collect it.

But that's the way science is done. It's always done by an iterative approach.

MR. IBRAHIM: I agree with you.

But when you referred me to the study plan, as I'm saying, the study plan will say I'm going to look at existing data, and I would like you to do that, and I would like you to do that, integrate all the geophysical methods used in the area, and come out with what is this anomaly and how we are going to do for high resolution after that.

MR. FRIDRICH: I agree. The thing that we most need to do is do tightly-focused integrative studies.

MR. IBRAHIM: That's exactly what I'm asking for. I'm not asking for anything more than that.

MR. JOHNSON: Buck, let me make a couple of comments.

I've got a question for Walter. Looking at your aeromag map over there showing volcanic features, what is the minimum size volcanic feature that would show up on that particular map?

MR. MOONEY: That would depend, Carl, on the depth of the feature, and so, it's a depth-dependent answer. If the feature is highly magnetized and close to the surface, then it would be easily detected. As it increased in depth, it would become increasingly difficult to detect.

So, maybe the best way I can answer your question is to -- you know black cone and red cone out in the Crater Flat, and their dimensions are -- they're a couple of hundred meters across -- 300 meters across, I think, is correct -- and they show up as very strong anomalies on that map, and they're at the surface, and as you increase in depth, they would become less and less visible.

But it's a tricky -- a simple answer to your question is difficult, because it depends on the magnetic susceptibility of the particular igneous feature, and these can vary by several orders of magnitude.

So, we're seeing at the surface features that are measured in hundreds of meters across.

MR. CORBETT: If you crossed one, if your flight line path crossed it.

MR. MOONEY: Right.

MR. CORBETT: A hundred meters, you could be well within a half-mile flight line and never see it.

MR. MOONEY: So, for that reason, it would be worth getting higher-resolution aeromagnetic data, ground magnetics data, and that's been proposed.

MR. CORBETT: You ought to correlate it with the surface topography.

MR. MOONEY: Yes, that's right.

MR. FRIDRICH: This is sort of an example of where geology comes in. I mean, from what we see on the surface, it suggests that the rates of burial of volcanic features is so slow that all of these aeromagnetic anomalies that we're seeing out there are probably 10-million-year-old basalts.

Now, we have to drill several of them to make sure that that's correct, that we're not missing anything major, but if we drill them all and they're all 10 million years old, then we'll know that we aren't having anything buried out there that's important.

MR. JOHNSON: Well, the point I was trying to make is what is the confidence that, with that kind of a survey, you will identify all of the volcanic features of concern? And I think, in that size of a survey, there are features that are going to be missed, and that was the point that I was trying to make.

In the licensing process, the focus is going to be on the types and sizes of features that are missed by the various geologic investigations, including geophysics, and of what concern are those relative to performance of the repository?

I'm trying to get the focus on the size of the features, and it certainly is possible that we could have a smaller volcanic feature that could be missed by the various geophysical methods closer to the repository itself, which certainly affects the scenario calculations that are made.

MR. MOONEY: Well, you could always reduce the scale of the feature. We can make finer and finer scale maps, and you can just go down by another order of magnitude the scale, the feature that you're interested in, and it's an endless process.

MR. JOHNSON: Well, the point is that I think that needs to be involved in your thinking process in developing the geophysical programs, is the size of the feature you're trying to investigate and making sure that those features that could be missed by a particular survey are too small to be of concern and that you justify that.

MR. HINZE: If I may ask you a question, Carl -- I have not reviewed the most -- well, I think, the only one -- volcanic study plan that's available.

Does that indicate a minimum size of feature that is of investigation, and does it indicate a total magnetization that would represent a minimum for these volcanic rocks, which are the kinds of information that are needed to define the minimum size that you're going to detect in how to lay out your survey?

Is that laid out in the study plan?

MR. JOHNSON: I'm trying to remember. Maybe Chris might know this better than I do, maybe Buck. But as I remember, it does not go into that kind of detail, and there is no additional proposed geophysical surveys involved in that study plan.

I think there is a mention of drilling the one additional anomaly that has been identified in Crater Flat, and I think that's where it ends.

MR. HINZE: I think this gets down to a very fundamental problem that is the very nature of the system, and that is that the strategy has been developed, and rightly so, that the study plans will be focused upon the geological problems, if you will, and geophysics is just one of the tools that is used to investigate it.

But sometimes it's not easy for one to see the geophysics and how that geophysics is determined and how it's integrated within those study plans, because the study plans are, as we all know, not available in a complete form, and so, this integration is lacking, as one reviews the study plans.

I think that's really one of the fundamental problems that we have here, is the mode in which the study plans are being developed, and I have no objection -- I think it's a great idea to focus them on the problems, but there is a concern on how to feed the appropriate disciplines into those.

MR. IBRAHIM: Also, I would like to add to that, how each study plan correlated to the other, how each one complements -- each study plan complements the other, so we can get the full investigation and characterization of the site. We don't want, really, is study plan just going in one direction without any correlation with the other.

MR. HINZE: May I ask, since the study plans have come up, and the volcanic one in particular, volcanic features one: Is the NRC staff specifically doing a detailed review on that study plan?

MR. IBRAHIM: This study really is not for volcanic investigation. It is only an investigation for the probability of volcanic activity in the area.

MR. HINZE: Well, you have to have information to feed into the probability.

MR. IBRAHIM: Right. What I am saying, all of these things that we are going to look at the existing data, and from this existing data, we'll give them the input, and if we need something else, we are going to do some more work later on.

MR. MOONEY: Dr. Hinze, did the ACNW not receive the results of our detailed technical review of the volcanic features study plan? We did issue comments to DOE on that.

MR. HINZE: Yes. Yes, we did. Right.

MR. MOONEY: And I might mention also, just for the record, that we have received a second study plan on volcanism, the probability of magmatic disruption of a repository, and we're in the process of reviewing that one right now, a Phase I review at this point.

MR. HINZE: Phase I. Do you anticipate a detailed review?

MR. MOONEY: We would anticipate a detailed technical review.

MR. IBRAHIM: And this is the second one I am talking about now.

[Slide.]

MR. IBRAHIM: Based on our comment on the SCP, the DOE went out and produced what is known as a geophysical white paper, and I would like to commend DOE for the work they have done on the white paper. They gathered all the information regarding geophysics and put it under one heading, as compared to the SCP which was scattered.

But they didn't go all the way. I know that you mentioned at the beginning that this is the first step of integration. That's fine. I'm glad to see that, but as Bill mentioned at the beginning, what is the next step? Where are we going now? We have the first step. What is the next step? What do we expect?

For example, the majority of the statements made in the white paper appear reasonable. For example, in the white paper, it is indicated current plans call for the review of existing data prior to additional surveys.

Seismic reflection profiles will be used to define framework and to provide guidance for establishing optimum location for drilling site.

Integration among activities is need to ensure that maximum benefit is obtained from geophysical surveys and interpretations to ensure that the characterization program provides timely information appropriate to support a repository license application.

That's all that we're asking for.

For example, here, for the seismic reflection profile, of course, for the Midway Valley, they are planning to do some trenching. Is this trenching based on any geophysical investigation like reflection work?

Here they mention that seismic reflection will be used to define framework and to provide guidance for establishing optimum location. Have we used any geophysical method to locate the optimum location for this trenching in the Midway Valley?

That's one of the things I would like to see, because I just know that they are going to trench in certain locations. Was this location chosen based on the optimum location for these particular places?

[Slide.]

MR. IBRAHIM: The DOE white paper: While DOE indicated that the white paper is a starting point, the NRC staff expected that DOE would be more specific about its geophysical activity planning.

The NRC staff expected that DOE would present the location of the different geophysical traverses on a map showing the interrelation among the different investigations.

The NRC expected that the rationale for choosing the location of these lines and their appropriateness for reconnaissance and adequacy of coverage and the characterization of Yucca Mountain would be provided.

By the way, most of the comments I am doing now on the white paper does not represent the management position, because it has not gone through the review, so that's, to some extent, my personal point of view.

MR. STABLEIN: Buck doesn't mean management disagrees. He is referring to the fact that we haven't issued a review of the white paper or finalized comments on it or anything like that. He is not expressing an internal disagreement.

MR. IBRAHIM: No, I didn't mean that.

MR. HINZE: King, since you did bring this up, does the NRC plan to issue a formal review of the white paper, or what mode is your evaluation going to be presented to the public and to DOE?

MR. STABLEIN: As I think you can gather from

Buck's comments here, which do reflect the internal NRC staff perceptions of the white paper to date, there really is not necessarily enough new material or different material from what was in the SCP to warrant a very detailed review and a publication of detailed comments.

You notice Buck expressed what NRC would have expected to see in an advance over the SCP. We didn't see the advances that we would have liked to have seen, and there seems little point, from our perspective, in engaging in a detailed technical review of what's in the white paper.

We do recognize it as the first step, but probably our biggest comment -- although Buck or Phil can add to this -- at least my biggest comment would be, okay, it is the first step and it's a nice first step, but what next? What happens from here that we can get our teeth into?

MR. HINZE: Have you had any indication from DOE as to their overall plan here, what the next step or steps will be?

MR. IBRAHIM: I can respond to that. If it's not the right response, let me know. Because, the w y I hear it, this is the first step, and all that you need will be coming in the study plans. So, we have to wait for the study plans, and that will be our response to the second white paper.

MR. FRIDRICH: Part of it will be in the study plans, and also, we intend to have working papers to sort of spell out specific issues and how we plan to resolve them.

MR. HINZE: What is the focus of the working papers?

MR. FRIDRICH: Whichever issues we decide are most important. For instance, I have been working on one on the large hydraulic gradient.

MR. HINZE: So, specific geologic problems or potentially adverse conditions.

MR. FRIDRICH: Right.

MR. HINZE: What will the current study by the DOE on the prioritization of surface studies do to complement the white paper?

MR. FRIDRICH: Well, I think it moves in the same direction, as far as -- that just brought together a lot of the different geology studies and showed how they interrelated and what a logical prioritization was for those studies.

MR. HINZE: Does it include geophysics in the surface studies?

MR. FRIDRICH: Yes, it does.

MR. HINZE: And does it get at a further detailing of the integration of how these are going to be combined? Are there flow charts which permit me to see how these will be staged, how they will be sequenced, and what data will be needed to help interpret what other types of geological, geophysical data?

MR. FRIDRICH: Well, we're not quite to that stage yet. That is where we need to go.

MR. HINZE: And is that going to be part of the surface prioritization study?

MR. FRIDRICH: I'm not exactly sure how far that will go. Since it tries to embrace the whole program, it can't go into too much detail. I think most of the detail is going to have to be in study plans and working papers.

MR. HINZE: As these study plans develop, do you see any of them going back and connecting with the previous study plans and show how -- you've talked about science is an iterative process.

MR. FRIDRICH: Right.

MR. HINZE: And what worries me about the study plans is that it seems to me that there is a tendency to think of thos as being kind of locked in concrete, and once they are done, that's it; that's how you study that problem.

How do you envision -- as the DOE rep here, how do you envision those being an iterative process?

MR. FRIDRICH: Well, many of the study plans contain decision points that basically say, you know, this is what we're going to do, up to this point, and then we have to make a decision as to what the program will consist of, and basically, what it is, you have to look at your initial results and decide what you're getting, what's important. You have to reevaluate. And it's true in most of the studies.

Even some of the earlier study plans that didn't say that, I'm sure that that will actually be the reality of how the studies progress.

MR. IBRAHIM: Let me just interrupt here. I mean I know Walter has done a lot of work on refraction. Do we really need a feasibility study on refraction at Yucca Mountain to get the information we need?

MR. FRIDRICH: I don't know about a feasibility study. You made one point there about why are the lines run in the specific direction that they are run, and I myself would like to see a little bit more justification for why the lines are where they are and what specific issues we're going to resolve.

MR. IBRAHIM: We are basing everything now on a feasibility study, and it seems to me that most of the work has been done. We can learn something. We should be learning if we look at the previous data.

Walter Mooney was working on refraction for Yucca Mountain for 10, 12, 20 years, whatever it is.

MR. MOONEY: Forty.

MR. IBRAHIM: I'm just saying that, from that time period, we have learned something, and we don't have to really go back again and do some testing. So, let's go and start doing some collecting of data.

MR. FRIDRICH: I agree. We need to move forward and quite concentrating so much on planning and actually starting concentrating on getting results, I hope.

MR. HINZE: Did you have a comment?

MS. STOCKEY: Jane Stockey from the Department of Energy. I'd like to respond to two of Dr. Hinze's questions, because they are things that Chris has not been directly involved in.

First of all, the test prioritization task force effort has now been subsumed into the site suitability evaluation that's going on.

We have a milestone with Dr. Bartlett on a methodology May 9th, but those people and those resources and now within the site suitability effort, and down the road, once we have got a site suitability evaluation, an early suitability evaluation method, then we will start looking at what the prioritization task force has come up with and carrying that to further levels of detail.

As far as the study plans go --

MR. HINZE: Before you go into that, help me with that just a little bit more. Site suitability evaluation, is this identifying problems, methods? Where are you?

MS. STOCKEY: At the moment, the group has been tasked with two goals.

One is an immediate reevaluation of 960 qualifiers and disqualifiers in terms of data that has been collected since the EA six years ago.

The other is to come up with a documentable methodology that will help allow us for, at the present, unsuitability evaluations; are there things that would immediate declare the site to be unsuitable and, then, later on, down the road, suitability evaluation.

MR. HINZE: So, it's really both.

MS. STOCKEY: Yes.

MR. HINZE: It's both.

MS. STOCKEY: Yes. The methodology should be the same. It's simply whether you're looking at disqualifiers or qualifiers, really.

MR. HINZE: And so, what started off 14, 18 months ago as the surface prioritization study has now --

MS. STOCKEY: Been subsumed into this group. This group was set up by --

MR. HINZE: Not consumed but subsumed, right?

MS. STOCKEY: Subsumed. They are part of our team now.

MR. HINZE: I see.

MS. STOCKEY: And we are using, to a certain extent, their methodolcgy and building on it, rather than start over again.

MR. HINZE: Well, that's exciting. May 1st is the deadline.

MS. STOCKEY: Well, May 9th is, right now, our preliminary presentation to Dr. Bartlett. Our product should be going in for a peer review in June and has a management review next fall, and the completely peer-reviewed product should be out, as scheduled, in January of '92.

We're putting together the peer review panel right now. It is an external formal peer review that we'll do.

MR. HINZE: The second point?

MS. STOCKEY: Was on the study plan. Some of the study plans have already undergone revision. They are controlled documents, and all of the pages showing those revisions have been sent to the NRC and anyone else who has a controlled copy.

So, I think there is good evidence that the process already is showing flexibility.

MR. HINZE: Okay. That's great. And those are taking into account -- what kinds of things lead to revisions? Is this because of the study itself, as Chris has talked about?

MS. STOCKEY: As a result of ongoing work. For instance, surface mapping might suggest that you need to put emphasis in a different place or something like that. Obviously, changes such as the exploratory studies facility, that tremendous change is going to affect a lot of study plans.

MR. HINZE: Very good. That's helpful.

MR. JOHNSON: Excuse me, Jean? Would there be a possible revision to a study plan based on external comments from other parties?

MS. STOCKEY: External comments from other parties have been and will continue to be taken into account during the revisions of the study plans.

We are not obligated to change according to what people's comments are, but certainly, they are taken into account as we go back to the study plans and, if, for instance, a comment said this is not clear, we don't understand what you're doing here, we try to be sure that things are clear.

MR. JOHNSON: Is there some type of process that then leads back to the original commenter so he can have an idea whether his comment was really ever considered or not?

MR. FRIDRICH: Yes. We do respond to all the comments.

MR. JOHNSON: Well, response is not what I'm asking for. Does it lead to -- is there some process that would lead to the revision, and is that reflected, then, back to the commenter?

MR. FRIDRICH: If a revision of the study plan was required to resolve the comment, then yes.

MR. POMEROY: Jane, help me out just a little bit more.

The surface-based prioritization task force now no longer exists as a separate entity, to start with? That's the first question.

Secondly, will the results of their study in January 1992 be available separately in some way, so that we can look at those as a -- if you will, a complete unit in itself or not?

MS. STOCKEY: The results of their study are out.

MR. POMEROY: I understand. But they were going further with that.

MS. STOCKEY: Their proposed Phase II has been indefinitely put on hold, and they have been fed into site suitability, so that they no longer exist as an independent entity, and any further results will actually be under the aegis of the site suitability work.

MR. POMEROY: Right. That's what I was asking. Phase II is no longer in existence. Thank you.

MS. STOCKEY: It was felt we were duplicating effort.

MR. POMEROY: Right.

MS. STOCKEY: And that did not seem productive.

MR. HINZE: Thanks very much, Jane.

MR. STABLEIN: Jane, while you're still there --

MS. STOCKEY: Yes, King.

MR. STABLEIN: A document that may or may not bear on all of today's discussions but certainly bore on DOE's response to our SCA comments was the test and evaluation plan, the TEP.

I don't know if you're -- how familiar you are with that, but since it was used heavily in responding to NRC's comments and since it sounded like it was going to be one of the integrating documents, do you have any views or contributions as to what role that would play relative to our discussions on this geophysics program?

MS. STOCKEY: To the best of my knowledge, everything is going back to that. It's a controlled document, and any changes in our program will have to be reflected in that document.

MR. STABLEIN: It wasn't clear whether that was, in a way, superseding parts of the SCP. It was hard to tell which document was going to be driving the site-characterization program.

If you're not the person to ask these questions of, it's fine to say.

MS. STOCKEY: I don't know the details on that, other than it's part of the hierarchy.

MR. STABLEIN: Okay.

MS. STOCKEY: My understanding is that they fit together. I haven't personally worked with that document.

MR. STABLEIN: Okay. Thank you, Jane.

MR. IBRAHIM: Can I ask one question, Jane?

You mentioned the peer review. There was a report about the geophysical methods. Maybe Chris can answer that. Is it available? Can we get a copy?

MS. STOCKEY: Chris?

MR. FRIDRICH: Are you talking about the peer review on seismic methods?

MR. IBRAHIM: Right.

MR. FRIDRICH: Yes. I brought a copy today, and I can let you copy it.

MR. IBRAHIM: That's only seismic or all geophysical?

MR. FRIDRICH: This was just seismic methods.

[Pause.]

MR. HINZE: Dave, is this caucusing leading to further comments?

MS. STOCKEY: Dave suggested that I should make it clear that site suitability is not looking just a surface-based testing but subsurface, as well, it's looking at the whole program, and that it should end up in another baseline document that may then supersede the baseline documents that are in effect now.

MR. IBRAHIM: Does this document include interpretation of the existing data?

MS. STOCKEY: Evaluation of it in regards to 960 qualifiers and disqualifiers, yes.

MR. IBRAHIM: It would be available to us in January 1992.

MS. STOCKEY: That's the date at present.

MR. IBRAHIM: Okay.

MR. HINZE: Thanks again.

MR. IBRAHIM: I can conclude by saying that the white paper didn't address our comment on the SCP, and we are looking forward for more work with the DOE and expecting the study plans to answer our questions.

MR. HINZE: Thank you.

Any further questions for Buck?

[No response.]

MR. IBRAHIM: Thank you.

MR. HINZE: Buck, let me ask you very quickly -- we heard some differences of opinion this morning about the use of geophysics in the detection of potential mineral deposits in and around Yucca Mountain. Is it the NRC's view that this is -- that there are sufficient amount of studies set up in the SCP and in the white paper to cover that topic?

MR. IBRAHIM: They talk about the method to be used, but how much of this method will be used is not clear to me, and that's one of the questions that -- I would like to be having a specific program; what are you going to use, where and how and what?

MR. HINZE: In other words, a continuation of a wish list type of thing.

MR. IBRAHIM: I'm sorry to call it this way.

MR. HINZE: Okay.

MR. IBRAHIM: But I am saying I really commend DOE for what they put there. I mean every geophysics that you can expect to be applied is there, but how much of this is going to be used is a question I would like to hear from you.

MR. HINZE: Thank you and Jane, too, for contributing.

We now move on to Walter Mooney's presentation on seismic refraction and reflection, and if I understand you, Walter, you're going to expand on this beyond those topics to cover -- is it the regional aspects that you're going to be covering, or how have you and Phil broken this down?

MR. MOONEY: Well, Bill, basically, I will be discussing the maps that are the wall, the 1-by-2-degree sheets on the potential field data. So, if you consider that regional -- I would say that's fairly regional.

MR. HINZE: Yes, I would, too. Right.

MR. MOONEY: So, today I'd like to talk about three -- excuse me -- four techniques that are being used to characterize the proposed -- the potential repository site: gravity, aeromagnetic, seismic reflection, and seismic refraction data. And I will be followed by Phil Nelson, who will talk about bore hole information.

[Slide.]

MR. MOONEY: Contrary to some other previous speakers, I think that we have a fairly well-integrated geophysical program to study Yucca Mountain, but to be consistent, I would have to define integrated, I suppose, if I were to justify that statement.

By integrated here, today, I mean that we are talking to each other in difference sub-disciplines and that we are trying to use the physical parameters that are determined from one method, for example, densities out of bore holes, anomalies from aeromagnetics and so on, to constraint the interpretation in each field.

So, since time is of the essence and brevity is the sole of wit, I'll be brief and try to cover each of the four areas in about eight minutes.

MR. POMEROY: Before you do, Walter, could you just expand on what you just said?

MR. MOONEY: Okay.

MR. POMEROY: You used the term "we." Does that "we" mean the U.S. Geological Survey? Does that "we" include other people who are doing geophysics in the area, if there are any? And how do you integrate, other than by being knowledgeable in the specific sub-fields, information outside?

MR. MOONEY: That's a fair question, Paul.

The data that I have been looking at have been the data that are collected by the U.S. Geological Survey; specifically the aeromagnetic gravity, seismic reflection data, bore hole data, and seismic refraction data. And then we rely on, of course, the usual published reports, like you do, to get additional information, if it be produced, by Sandia Labs or Livermore Labs or whatever.

For example, we used the seismic reflection data collected by Livermore Labs as part of the containment program to calibrate our seismic surveys.

So, does that answer your question, or is there other data you think that we might be considering?

MR. POMEROY: Well, certainly, one part of my question was what the national labs were doing, and I gather, from your response, that you don't deal directly with the national -- you don't meet together routinely with the national labs.

MR. MOONEY: Yes.

MR. POMEROY: We talk to them all anyway, so we know them.

MR. MOONEY: That's right.

Well, I am not aware of data of the same sort that's being collected by the national labs that we have missed, but Paul, we're relying on their publications, rather than going to the national laboratories and trying to get their information prior to publication, say, or in meetings like this, when people talk to each other and you ask for a copy of their transparencies and things like that.

MR. HINZE: If we could just go a little further with that, in terms of the USGS divisions, the Geological Division and the Water Resources Division, what kind of interaction do we find in terms of defining problems, defining specifications of surveys and the like?

I realize that this may be on a more local basis, but there is also very strong concern on a regional basis for the hydrologic regime. How is that integration brought about, not only in the interpretative phase but in the planning of surveys?

MR. MOONEY: Okay. If I can restate your question to be sure I have understood it, how do the hydrologic studies and geologic studies and geophysical studies get integrated, and how is geophysics incorporated into, for example, hydrologic study plans and goals?

MR. HINZE: Both the interpretation and acquisition.

MR. MOONEY: Yes, interpretation and acquisition.

Well, I'd say there's three ways that this is done.

One is, at irregular intervals, we have meetings, like the one that was held in Death Valley, I guess, about a year ago, where all USGS participants came together and presented their work related to the hydrologic environment, be it isotope work or geophysical studies, and this is -- the proceedings from that workshop -- this was an internal USGS workshop that got people together in a forum like this -- actually in a larger forum, because there were more people involved.

Then we have monthly meetings with rotating topics that are part of what's called the CASY committee, Committee for the Advancement of Science at Yucca Mountain. These meet every month in Denver, and either one or several topics are covered.

For example, there was a meeting recently that discussed characterizations of fractures and flow at Yucca Mountain. Speakers included USGS people but also those from Lawrence Berkeley Labs, where they have a lot of expertise in fracture and so on.

And then the third level, I suppose, would be just informal contact between people in their offices and such.

Yes, Phil?

MR. NELSON: There's also the exchange of study plans and review between WRD and GD when the study plans overlap.

MR. MOONEY: And that, I think, is a very critical element and one that's come up repeatedly here, is how well are the needs of each research objective addressed in the study plans, and I'll leave that to you to decide the degree to which study plans are responsive to the program goals.

Certainly, I think an important aspect of the study plans is the review process, because the first attempt to pull things together is usually not , -^ect, and the revisions of the study plan -- careful review, peer review, and revision of the study plan is critical.

Let's get away, then, Bill, from a vague question, a vague -- not vague but a general issue and move on to say something very specific, like the hydrologic gradient. That is a topic that is of great concern to the hydrologists.

[Slide.]

MR. MOONEY: This is, as you can see at the bottom, water table altitude in meters above sea level where the higher elevation is to the north, 1,200 meters varying to 750 meters.

An issue of great concern has been the origin of the hydrologic gradient in the northern portion of Yucca Mountain.

The proposed approaches to studying this include a shallow seismic refraction line across the gradient and higher-resolution aeromagnetic and gravity data to look at changes in physical properties.

Phil, are there some plans for additional analysis of bore hole data or drilling?

MR. NELSON: Well, there's certainly additional drilling that's been specified to better define the geometric surface, right where you're pointing.

MR. MOONEY: Yes.

MR. NELSON: And any hole that's drilled, logs are also required, so that would be part of that.

MR. MURPHY: Dr. Mooney, can I address that specific matter?

MR. MOONEY: Yes.

MR. MURPHY: You mentioned one line is planned, and I would pick you up on that and suggest that you consider some sort of a grid program, you know.

MR. MOONEY: I would agree with you, yes. I think it would be a far better plan to have a grid of lines rather than an individual line.

MR. MURPHY: And both for shallow and deep penetration.

MR. MOONEY: Yes.

MR. MURPHY: Thank you.

MR. MOONEY: As the importance of this gradient has become more recognized, then the priority of the proposed geophysical work has also increased.

Can I clarify anything further, Bill?

MR. HINZE: That's fine.

MR. MOONEY: Okay.

[Slide.]

MR. MOONEY: So, I will begin, then, by moving over to the gravity and aeromagnetic maps and discussing the main features on those.

First, I'd like to just review a couple of basic principles. Almost everyone here knows this, but I want to review a couple of points.

One is that the -- you will see a much higher frequency component in the aeromagnetic data, which is the color diagram on your right.

A typical response from a buried gravity anomaly is a relative simply symmetrical curve, whereas, for example, something that we do see in Crater Flat and in the Yucca Mountain area.

If there is an offset in buried strata, as shown here, where there has been vertical movement on layered beds of magnetized material, you get a two-pole response, and this generates, then, a relatively higher frequency signal, and you will notice, in the data that are plotted there in color, that there is a very distinct change in character in the grain of the two maps, and this has to do with the fundamental properties of gravity in aeromagnetic maps.

MR. MURPHY: May I make an observation in the form of a question?

MR. MOONEY: Yes.

MR. MURPHY: We have that magnetic curve, as we had the gravity curve before that. We have that interpretation for magnetics, but is not fair to say that there are many interpretations that fit that one curve?

MR. MOONEY: That's right. Yes, that's right.

So, the point here is that there are multiple models that can satisfy the observations, and in fact, in the case of the gravity anomaly, there is a tradeoff between the density contrast between the causative body and the surrounding medium, the density contrast and the radius of the body, which is inherent in gravity interpretation.

That is to say you can have a denser body with the center of mass at the same point, and you will get the same curve.

MR. CORBETT: What's the station density in the gravity?

MR. MOONEY: On the gravity --

[Slide.]

MR. MOONEY: Let's see if I can get the scale here. Yucca Mountain is here. This is 37 degrees. This is 1 degree, from here to here, so that's about 110 kilometers.

There is a great deal of -- the great density of data is -- I guess that's Yucca Flats, isn't it? And in the study area, the station spacing is -- varies from as little as a quarter-mile to a half-mile or so. You can see, as you get north towards Timber Mountain, it thins out.

But the gravity density, again, as you can see, it's not uniform, because this is -- this includes all data collected for military purposes, for petroleum exploration outside the study area, and collected specifically for the Yucca Mountain project.

But I think it would be -- it would be fair to say that the data density that is represented on the map behind you, the isostatic gravity map, is more than sufficient to define the major structural features and the regional patterns of the gravity anomalies. Quarter-mile spacing, though, is typical.

Other questions or comments?

MR. JOHNSON: How do you propose to integrate the different spacings of all of those various gravity surveys so that when you do finally develop your final map, so to speak, of features, anomalies developed from gravity surveys that there will be -- it will be uniform across that whole area?

MR. MOONEY: Well, it's not clear to me, for gravity data, that you absolutely need a uniform spacing. It's not exactly the same as, say, a geologic map or aeromagnetic data.

The absolute uniformity of the database is not the highest priority, in my opinion. It would -- it depends on the size of the features that you are trying to -- you're looking for.

For example, in the area of the Funeral Range in the Grapevine Mountains, which are located over here, these are mid-crustal, metamorphic, high-density rocks which are exposed at the surface, have a high density, and they produce a strong gravity anomaly, and that's the bright red anomaly which is behind the post.

For you, it's a little bit hard to see, Carl.

I am not sure we need to characterize that particular anomaly over here with any greater resolution.

Within the area of Yucca Mountain, the gravity observations are already at a uniformity and a density that easily characterize the features of interest, meaning offsets on the order of 100 meters and so on.

Bill, do you want to comment on the need for complete uniformity in coverage in order to produce a reliable gravity?

MR. HINZE: It really depends upon, as you have stated, the geological problem that you're interested in, and there are times when you can -- for the regional aspects, where your gridding is going to take into account the more detailed stations, but you don't need that for the regional aspect of it.

MR. JOHNSON: You hit on a point that I was trying to get to. I don't think we have really defined what are the critical features in the region that we need to be concerned about. So, in making your remarks, Walter, I am not certain we know that that type of grid pattern will identify those features of concern in the region.

MR. MOONEY: This is sort of a no-win situation, because you can always go and sample your data finer and finer and finer, and if you continue to change the size of the feature that you're interested in, we eventually will be measuring gravity every meter.

MR. HINZE: Well, one of the things that you do have to take into account are the areas of the gradients.

The gradients is where the action is in the interpretation of gravity data, and for magnetic data, for that matter, and often times, what is necessary, on reviewing a map such as that gravity map, you find that there are certain gradients that are not adequately sampled.

So, these are the areas that one wants to go into, and that's a critical evaluation of the existing data and its location, and I don't think anyone can disagree with Carl, but I don't think we want to -- in terms of defining problems, but we don't want to define detailed problems over in Death Valley.

That's not the problem to Yucca Mountain, I don't think, but there may be areas in which you need additional stations for the gradients.

MR. JOHNSON: I agree. The only response I would make to talking about Death Valley is you need that information as part of understanding the regional geologic setting.

MR. HINZE: I've been there. Right. Yes.

MR. MOONEY: One comment I failed to make, one observation, is that as features of interest have been identified and pointed out, denser observations have usually been made in transects, a series of transects.

You can see these lines here, and these were specifically to go across areas of high gradient in order to make cross sections to test -- hypothesize geologic sections or geophysical sections.

So, you can see one approach is to do gridding --

this is outside the study area here -- with very densely observed linear profiles, and in many cases, this serves the purpose of -- serves the scientific purpose without requiring a uniform two-dimensional grid of gravity stations.

Then, I'd like to -- I'm going to move over very shortly and look at the aeromagnetic map.

MR. IBRAHIM: Walter?

MR. MOONEY: Yes, Buck.

MR. IBRAHIM: I have a map here from the white paper. I would like to hear your opinion about whether the coverage is adequate or not.

MR. MOONEY: Okay. Thank you.

[Slide.]

MR. MOONEY: What's the scale on this? As best I can make out, this is 2 kilometers, 0, 1 kilometer, and so, these are stations that are spaced at everything ranging from, it looks like, 10 meters to 100 meters, and these transects here clearly were conducted to study the shallow faults.

So, although this transparency is inappropriate because it's a magnetic curve, those linear transects at 10- to 100-meter spacing were designed to look for offsets in the volcanic units, and if your question is should there be more uniform spacing and more transects, I would turn the question are and say are there geologic problems that require higher-resolution potential field data, and if there are, we should go ahead.

We certainly wouldn't want to cover the entire Yucca Mountain site with 10-meter-spaced gravity stations.

MR. IBRAHIM: I'm looking really to the area of the periphery, where we are going to put the exploratory shaft. I don't see much gravity data. That's why I'm saying do you think this coverage is adequate enough for the investigation?

MR. MOONEY: Well, I would continue to dodge your question by asking you what is the problem you're trying to solve, and whether there is a need for more gravity data in that area depends on the problem that you're trying to solve.

MR. IBRAHIM: For example, we are trying to find the optimum location for the ESF, and if I see there isn't any geophysical data around this area, I would like to know whether the coverage would be good enough.

MR. MOONEY: Yes. Well, you're suggesting, for example, in these areas here, to the north, that there could be --

MR. IBRAHIM: That's where the ESF would be located.

MR. CORBETT: Isn't part of this the reverse? I think Carl -- I don't know whether he alluded to or specified this -- that, given some of the gradients -- flat gradients now, and there is no point in coming tighter, because any condition that can be detected with gravity is less than and therefore of no particular consequence. There is no point in anticipating a model totally in advance or the only model or set of models.

Yes, you have to go in there with a plan, but afterwards you can come back and say yes, this area is uniform. There is nothing of such and such a dimension that can cause this type of thing in there.

MR. MOONEY: Right.

MR. CORBETT: I think it's a critical factor in some of this detailed work that we're coming to.

MR. MOONEY: Thank you.

Bill?

MR. HINZE: While that is on the screen, is there any discrepancy in the coverage that is shown and Figure 2.1-1 and 2.1-2 of the white paper? And those are -- this is 2 and the one you showed is 1, and I have the sense that there's a lot more stations shown on the map you showed than on this. Is that just a matter of the size of the dots?

I don't see many stations located over the repository. When I look at that map, I see it blacked out. Are the same number of stations shown?

MR. MOONEY: I'll have to ask that question. I don't want to give you an off-the-cuff answer to that.

MR. HINZE: I would appreciate it, because as we have looked at this, it's hard to be certain that we're looking at the same data.

MR. IBRAHIM: I don't think it represents the same scale.

MR. MOONEY: The scale change is so radical that it's very difficult to say. I think part of it is a xerox effect that small dots turn black.

MR. HINZE: Large circles and you can have complete coverage, right.

[Slide.]

MR. MOONEY: Okay. Finally, I'd like to -- before discussing the aeromagnetic map, I wanted to point out what are some of the large causative anomalies.

You don't need to look at all of these entries here, but I do want to emphasize that typical magnetic susceptibilities for rocks like limestone and dolomite are on the order of 75 cmu, as compared with shales and basalts at 14,000.

So, you can see that one of the largest effects of the magnetic map, which we'll be going to soon, is that the paleozoic units have a very low level of magnetization, whereas some sedimentary rocks, like thin beds of shale and particularly the basalt flows, are highly magnetized, and they account for the bulk of the anomalies.

In at least one case, there is a signature that appears to be coming from granitic rocks.

Bill?

MR. HINZE: That's very high for granite.

MR. MOONEY: I pulled them off the high end, Bill. I took the high value.

Just to be consistent, once I started pulling off one number, I thought I'd be consistent. That's a high value for granite, yes.

MR. HINZE: I guess I'd like to say that the magnetization probably is causing as much of the signal that we are seeing on that magnetic map as those, and there is some commonality, of course, with J sub R, with the magnetic susceptibility.

MR. MOONEY: Right.

MR. HINZE: I suspect Phil will be discussing that in a little more detail, hopefully.

[Slide.]

MR. MOONEY: Now, we had a brief discussion on the coverage of the aeromagnetic map, and before I go over, I'll show you the coverage, which is shown here. In fact, I'll move this up so you can all see it, because we are not so concerned with the area above the map.

What is shown here is flight line spacing, and as you can see, in the study area, we have a uniform coverage that has a western boundary. Maybe you could point to it on the map.

The western boundary is right there. There is a little corner that shows up right there, and then, the rest of that map, I think, is uniform, because I don't believe you see this rectangular pattern there.

In any case, Yucca Mountain, which is -- Bare Mountain is outlined on that map. Bare Mountain is right here, and you can point to Bare Mountain as the black kidney-shaped line, that one right there.

Okay. So, everything in the vicinity of Yucca Mountain, Bare Mountain, the Crater Flat, Jackass Flats, the Calico Hills, the Amargosa Desert and so on, these are all uniform coverage. So, we don't have different surveys spliced in, except - as we commented.

MR. CORBETT: Well, what's the difference in the 0.4 and 0.8?

MR. MOONEY: That's the difference in the flight spacing.

MR. CORBETT: But that's not uniform. It's a semantic point. Because typically, if they open up, the gradient may be higher.

MR. MOONEY: I did check that with the report, and the flight spacing is 400 feet, 120 meters on these surveys here.

Bill, do you think that the 0.4 and 0.8 perhaps refers to the east-west spacing?

MR. HINZE: No. It's usually five times.

MR. MOONEY: Five times. Okay.

In any case, the survey was carried out, as you can see, specifically to characterize the Yucca Mountain and the surrounding areas in a pattern like this, and so, the artifacts that are on the map are the large-scale artifacts of these corners that we've seen here.

Any other questions on coverage? Carl?

MR. JOHNSON: If the object of the survey was to characterize the Yucca Mountain site area, why is the survey in the configuration is and what justifies the boundaries of that survey?

MR. MOONEY: Yes. Usually, when you write a contract for collecting aeromagnetic data, you try to get as many people together who have research priorities and research interest to put areas of mutual interest together and to collect as much data as you can once you have the plane flying and have the contract.

I presume that in this particular survey, that the Yucca Mountain project had no interest in the data to be collected, say, below my pointer, and that these lines here were probably paid for by the Bureau of Land Management as a minerals assessment program.

MR. JOHNSON: So that particular survey you're talking about was not a survey that was totally funded by the DOE Yucca Mountain project?

MR. MOONEY: Well, the area to the north was and the area to the south wasn't.

MR. JOHNSON: Okay. Let's focus on the area to the north, then. Why is the configuration the way it is and the boundaries the way they are?

MR. MOONEY: Okay. It was known before it was flown that the largest anomalies are associated with the Timber Mountain Caldera, the tuffs and basalts of Timber Mountain.

If you look at the map on the wall, the one in the middle with lots of blues and reds and so on, the Timber Mountain Caldera causes these -- these tuffs and basalts cause the largest anomalies, and these have been best studied on the ground in the area north of the site.

So in order to calibrate the study further to the south, it was necessary to sample the northern area in order to use the ground base knowledge from the Timber Mountain Caldera and apply it further to the south.

Bear Mountain is right here. It was felt that the paleozoic rocks -- as you know, the Bull Frog Hills and the

Funeral Mountains, these are basically non-magnetic areas, and it would have very -- there would be very little to profit from further surveys in this area.

The wisdom of that decision is shown by the map, which, on the lower one-third, is largely a sea of fairly uniform green and light blue. So as you can see, the aeromagnetic signature south of Yucca Mountain becomes quite uniform, and I would agree with the earlier comment that it doesn't make a lot of sense collecting data when you have a field that is quite bland, if I can use that term.

Again, another reason, Carl, is that there was a particular radius chosen of interest for high resolution figures. As you know, the aeromagnetic data is most sensitive to shallow structures, structures in the shallow crest, and the attempt was being made to characterize the shallow crust in the immediate site area.

Now, if you or others choose to enlarge the area of interest for the shallow structure, that's a matter for others to decide.

MR. JOHNSON: Well, it's not for us to decide whether to expand the area of interest; it's up to the Department to make the decision whether it wants to expand the area or not. You're the ones who've got to license this site; certainly not us or the NRC.

Getting to the point that I was making about integration of the geophysical program, I would take your comments that to the west, you saw no value in continuing the aeromag survey because we are dealing with paleozoic rocks, which don't have any type of magnetic signature.

What other geophysical programs are planned, then, to evaluate those areas, the paleozoic stratigraphy? That, to me, starts an integration program.

MR. MOONEY: I would say that the primary activity in these paleozoic rocks is structural mapping, the mapping of detachment faults and evidence for the recent late tertiary tectonics of the southern basin and range.

So the primary activity in the area in Death Valley and the area adjacent to Yucca Mountain is in the area of structural geology.

MR. JOHNSON: Well, how are you going to deal with the subsurface, those areas you can't see with the surface mapping? How are you going to map the detachment structures that are buried and that sort of thing?

MR. MOONEY: It has been proposed that -- and this is something which is under consideration by the Seismic Peer Review Panel, the efficacy of both reflection and refraction studies at Yucca Mountain. But it has been proposed that some deep penetrating refraction profiles be recorded within Death Valley and across -- and east west -- well, northeast/southwest direction. This is part of the study plan regional tectonics.

So these profiles would then succeed in tying surface mapping to subsurface structure and defining the geometry of detachment faults and the mechanism of extension in the greater Death Valley area.

Yes?

MR. MURPHY: In some recent discussions with colleagues in petroleum exploration, they've indicated to me that they're finding in paleozoic sections low amplitude aeromagnetic anomalies.

I'm wondering if, inherent in the widely spaced lines in that area, we are apt to smooth out and miss whatever the low amplitude anomalies might be with regard to existence and trend, and we may not suspect from geologic mapping that they exist there, but unless we work to conduct a closely-spaced survey, we might never know whether there are such evidences.

MR. MOONEY: Well, luckily, we have one of the world's experts on aeromagnetics maps here, and I would like to pass this question on to Bill Hinze and ask him whether a 400 to 800 meter, 120 meter drape survey in this area here that I'm pointing to right now, which produces a map that you see over there, the lower one-third of that map, whether or not much higher resolution aeromagnetics would discover significant anomalies?

MR. HINZE: It depends, of course, as you have stated, upon the depth to the paleozoic and where these anomalies occur within the paleozoic. We're talking about a few gamma, a few nano-tesla amplitude anomalies. In many cases, are you just not going to be able to pick those up even with extreme detail.

In the areas where we have the alluvium, because the alluvium will produce a noise effect superimposed upon that, and the amplitudes will be too low. I think this just goes back to the importance of developing conceptual models, if you will, and defining the limits of the physical properties of those models and running forward models on these, forward calculations on these, to come up with the sensitivity and the resolution. That is part and parcel of any good planning of surveys.

It's my understanding, from reading all this mass of material that I think Tom Hildenbrand and others are pushing for a MOMAG Survey, for a surface vehicle survey, that's the kind of thing that can lead to the detection of the so-called sedimentary anomalies.

I think we also have to ask where these sedimentary anomalies are coming from. Most of these anomalies are associated with FACIES changes within the sedimentary rocks, but there are also -- and these are the ones that are of concern to me, these are the ones that may be associated with faults.

I've seen these, for example, in some of the cratonic basins with one gamma fault anomalies that are really associated with magnetization within the fault gouge.

I didn't answer your question, but I think what I did was I answered how we can determine that, and that is to develop good conceptual models.

MR. MURPHY: The area that gave rise to the question is that area in white, yes, that's correct. There is wide spacing of the lines for an extensive area.

MR. DANIELS: I would just like to say that there's another source of magnetic anomalies, and that's we found in the Eleana shale the thermal magnetization due to the intrusive NUA25 -- I believe it was A3. It was quite a shock. We thought we'd had a shallow intrusive there, and we found that most of the magnetization or most of the anomalies were coming from the Eleana shale.

MR. MOONEY: This result, I think, appears in the open file report. I can give you the complete reference, but it's called the "Interpretation of Aeromagnetic Anomalies in the Yucca Mountain Area," and it includes alternative models for the Eleana shale and extensive documentation of magnetization and so on. Cane and Bracken are the authors on it.

MR. CORBETT: Also, that's a 50 gamma nano-tesla contra-interval review of the profiles might answer a good part of this already. It's lost in the contouring.

MR. MOONEY: Yes, you are right. That's right. The size of the anomalies on that map far exceed what you were referring to, Bill.

Okay. I really would like to walk over there and look at that map, but I'm going to review again -- the two features that I'm going to try to point out are anomalies which are due to fault offsets, and the second sort of aeromagnetic anomaly that's important is where you have an intrusive body, and it produces this sort of an anomaly.

[Slide.]

MR. MOONEY: The most dramatic features on the map are, I would say, three. One is the lower one-third, which is basically very poorly magnetized, weak aeromagnetic signature, and these correspond to both the alluviated Amargosa Desert and the exposed paleozoic rocks of the Funeral Mountains, Grapevine Mountains.

As I indicated from the table that I showed very briefly, it's not uncommon for paleozoic rocks, sedimentary rocks, to have weak magnetization. An exception is this anomaly here, Lothrop Wells, which appears to be an intrusive body, highly magnetized intrusive body.

The second feature on the map are the anomalies that occupy the central portion, and you can see a fairly linear trend to them. They have an azimuth which is roughly north/south, north, northeast trend on them, and these are interpreted based on the surface geology to correspond to offsets in the layering within the volcanic tuffs.

So these would be the first transparency I showed, which are due to near vertical movement on the magnetized layers.

MR. IBRAHIM: Can you identify how much is offset from this linear?

MR. MOONEY: These are modelled in detail in one of the open file reports. It's about 100 meters. There's a lengthy discussion in the interpretation paper of the interpretation of these offsets, and I'll have to give you the reference later, or as I walk by my desk, I can give you that.

MR. IBRAHIM: How much is that line from the reflection line? What is the location of this?

MR. MOONEY: The reflection line is down here.

MR. IBRAHIM: Okay.

MR. MOONEY: The reflection line covers the alluviated Amargosa Desert and underlying paleozoic. The depth of the paleozoic down there is very shallow. It's on the order of zero -- well, it's nearly at the surface down to maybe 100 meters to the paleozoic rock.

A couple of the small features that you can barely see from where you're sitting is like black cone and red cone here in the middle of Crater Flat, small cinder cones, and a prominent anomaly in the middle of Crater Flat which is poorly understood is this yellow anomaly here, which has been given various interpretations.

One is that the southern area of Crater Flat, rather than being a simple structural depression, had its origin as a small Caldera structure.

As you know, this is an area that, 15 to ten million years ago, was very active volcanically, and that the southern reach of Crater Flat is a dead Caldera. That would mean that there would be intrusive rocks there, and this could produce an anomaly.

Notice that the -- this is a rather broad -- this anomaly here is rather broad, indicating that the feature is deep, at least several kilometers in depth to it.

An alternative interpretation to this is that this may include some of the shales, the Eleana shale that was referred to earlier, which is known to be highly magnetized, and this would then be an interpretation that would have a non-volcanic origin.

MR. IBRAHIM: There was a mini-sosie line between the red and the black cone. Have you tried to loo. at this data and see what is this anomaly?

MR. MOONEY: Yes. The anomaly is deeper than the maximum depth of penetration for those mini-sosie lines.

MR. IBRAHIM: Okay.

MR. JOHNSON: You have alternative interpretations for the anomaly in Crater Flat. What is the proposed program to resolve those two models?

MR. MOONEY: Well, one could ask whether or not that's a high priority, whether one really needs to know whether, 15 million years ago, whether or not the area was formed purely as a structural depression, as is common in much of the basin in range, or whether or not there is a dead Caldera structure. Do you think that's an important question?

MR. JOHNSON: I don't think we have consensus that it's a dead Caldera since you have much younger basalts within the Caldera structure itself.

MR. MOONEY: Yes. Well, the structure that we're talking about is something which would have been formed about 15 million years ago, ten to 15 million years ago, and the cinder cones that you're referring to come about ten million years with no volcanism in between. So it would be hard to argue that these are related.

You'd have to be arguing that the Caldera has been dormant for ten million years, which is not the way Calderas work.

The anomalies north of Yucca Mountain are very striking. You can see that they are very close to the surface. These are magnetized tuffs and volcanic flows associated with Timber Mountain Caldera. They have very high levels of magnetization and show up very strongly.

These magnetized units, as you can see, do not continue down to Yucca Mountain. I probably didn't do an adequate job of pointing out exactly where Yucca Mountain is. I'm sorry. Yucca Mountain is right in the center of the map here.

The fact that you have a hard time even spotting Yucca Mountain on this map is probably significant because it consists of volcanic units which are very weakly magnetized with the exception of these linear trends which I referred to earlier.

As you can see, the outline, this sort of kidney bean shaped black line, is Bear Mountain, and that's paleozoic and pre-cambrium sedimentary rocks, which are right at the surface, and if they had much of an aeromagnetic signature, certainly -- they're not alluviated, in other words, they're exposed, and that's why it's called Bear Mountain. You can see the aeromagnetic signature for those rocks is very weak, indeed.

The Eleana shale unit has been proposed based on drilling and extensive modelling and laboratory measurements of the magnetization to account for this large anomaly here in the Calico Hills. Similarly, based on outcrop evidence, the anomaly here at Wamonie is believed to be due to a - granite diuretic intrusion.

The change in the aeromagnetic signature from north going south is therefore real. It's not an artifact of non-uniform flight spacing or non-uniformity of data. There really are changes in the aeromagnetic signature that are shown on this map, and they correspond to the major changes that I've tried to outline here.

The depth to paleozoic I will show in a few minutes based on seismic refraction works, and I'll show a cross section across Crater Flat at about this latitude here and another north/south profile on the east side of Yucca Mountain right here.

The grounding map is shown next to this. This is an isostatic gravity map, which is to say that there has been some correction made for the topography for roots beneath topographic highs.

That is to say, for example, the Funeral Mountains here, which are quite elevated, have beneath them an isostatically compensating root, and the data have been corrected for this, using an assumed correlation between topography and crustal root.

The point that I'm getting at is after you remove the root from a topographic feature, then what you're left with is the gravity signature, which is largely due to the shallow structure.

So what we're looking at on this gravity map is the gravity anomalies, which can be attributed mostly to the upper crust, and that's mostly what we're interested in here -- the upper crustal gravity density anomalies.

There is a fantastic gravity high associated with the Funeral Mountains, and this is due to the exposure here of mid-crustal rocks, high grade amphibolite to granulate grade metamorphic rocks that are exposed in the Funeral Mountains, and these are anomalously high density on the order of 2.9, 2.9 grams per cc. It produces a big gravity anomaly.

As you can see, Bear Mountain is located here with a modest gravity high, and then there is a very strong gradient coming off of Bear Mountain into Crater Flat and over towards Yucca Mountain.

As I think was alluded to by Paul Johnson, the gradient on the east side of Yucca Mountain occurs more or less directly beneath Yucca Mountain.

That is to say, you go from Bear Mountain, where there is exposed basement rocks, paleozoic basement rocks, and you move into Crater Flat, and there's a strong anomaly that's just to the east of Bear Mountain.

On the other side of Crater Flat, whereas you might have expected to see a similar kind of a gradient located where I'm indicating here, if there were a similar structural depression down drop block on the west side of Yucca Mountain, in fact, the gravity anomaly occurs more or less in the middle of Yucca Mountain.

The reason for this is that the paleozoic, which is at a depth of about two kilometers, 1.5, two kilometers, beneath Jackass Flats, drops down to greater depth beneath Crater Flat, starting right in the middle of Yucca Mountain.

So the proposed repository site is located above a basement structure itself rather than one being offset from the other.

Again, I will show a seismic and gravity cross section that comes across right between Black Cone and Red Cone and across Yucca Mountain and Bear Mountain at this elevation, at this latitude, that will show many of these features. But they are, in fact -- were first identified first in the potential field data. Then, I'll show a cross section of the crust along this azimuth here.

Again, as was first identified from the potential field data, the model, the crustal model that runs north/south at the position that I'm showing here is basically pancake layers. What we find in the seismic structures are what you might generalize as being very uniform layers of volcanic flows and tuffs that run up the

40-mile WASH.

So a lot of the features that are seen at higher resolution in the seismic refraction and reflection profiles are basically anticipated by the potential field data, which give a very good picture of the overall regional structure.

Any questions before I move on from these two matters?

MR. IBRAHIM: When you referred to the reflection data, whose data are these?

MR. MOONEY: Yes. The reflection data that -- I'll explain this, Buck, in a minute. The reflection are down here, and that's the one that I'll be speaking about.

MR. IBRAHIM: Okay. I thought you had some other data. I just wanted to be sure.

MR. MOONEY: You'll be the first to know when we get new data, Buck.

MR. IBRAHIM: I have been waiting.

MR. MOONEY: You have been waiting.

Any questions or comments on potential fields? Leon, you've been very quiet. That's atypical of you.

[Laughter.]

MR. MOONEY: Either it's so bad that he doesn't want to --

MR. HINZE: Is there a correlation between the topography and the geophysical data?

MR. MOONEY: Well, the topography is shown here, but it's at a much smaller scale. Yes, there's the topography on one of the figures.

Bear Mountain is a topographic high, of course, and it shows up with very little signature here, but this area here is very rough --

MR. HINZE: Let me rephrase my question.

MR. MOONEY: Yes.

MR. HINZE: The north/south variation and elevation -- we see the gradient across the southern tip, and, in particular, that break.

MR. MOONEY: The shape of some of these anomalies correlates fairly well with -- if I stand over here, I think you can see it -- with the -- the green, the onset of the green of the higher elevation to the north.

Were you looking for a very quantitative relationship between isostatic anomaly and --

MR. HINZE: No. I was really looking for some type of deep expression of that topographic change.

MR. MOONEY: I got you. Okay. I don't know of a good constraint on the actual geometry of the causative body that -- well, as you know, from the gravity -- you can see that southern Nevada has across the entire east/west latitude here an abrupt change in elevation. Lower elevation is here and higher elevation is there.

That shows up on the gravity map, on the state gravity map and on the state aeromagnetic map, even, I think, on the curie isodepth map. So there is a fundamental boundary that occurs on an east/west direction in Nevada.

MR. HINZE: Bryan Werneke has that associated with some major changes in the mode of --

MR. MOONEY: Of defamation across the --

MR. HINZE: Right. And the correlation of that with Yucca Mountain is extremely interesting.

MR. MOONEY: Yes. That's a very good point. Yes.

MR. CORBETT: Is there any difference in lithology between the break in the color pattern along that --

MR. MOONEY: Right here?

MR. CORBETT: Yes. Between the tuffs to the north and to the south?

MR. MOONEY: Well, I would say mostly it's the age of the flows. These cluster around ten million years, and they were highly magnetized, and the flows apparently didn't make it all the way down into the area. So that would be more -- of course, Yucca Mountain itself is also a volcanic, you know, welded tuffs, and what's less abundant there are these basalt flows that become more predominant as you go further --

MR. CORBETT: How about remnants?

MR. MOONEY: Remnant magnetization?

MR. CORBETT: At the lower portion.

MR. MOONEY: I'm not sure what the difference is in the remnant magnetization between the two areas. I'd have to look at that.

MR. HINZE: How about the correlation, very briefly, with a strong hydraulic gradient?

MR. MOONEY: Oh, thank you. That was one of the major points I was hoping to make. I'll show that transparency as soon as I go back over to the screen, but the hydraulic gradient is located about here in through here.

So there is a general correlation between the change in the water table, the elevation of the water table, and these anomalies, but the gradient itself is strongest I'd say right about here. It doesn't correlate with the onset of very strong anomalies.

So there's a general correlation, Bill, but it's not one for one.

MR. HINZE: You've also seen a correlation with velocity.

MR. MOONEY: I'll show that, yes.

MR. HINZE: Fine.

MR. MOONEY: Maybe I'll go on, then.

[Slide.]

MR. MOONEY: I promised to show the water table altitude diagram again, in response to Bill Hinze's question, and as you can see, the contours of the piezeometric surface range from -- go from the Calico Hills, which is highly magnetized, which is the brightest anomaly in yellow and red there, all the way over to Yucca Mountain, where the signature is modest.

So, in some places, it corresponds to a sharp change in the magnetic signature. In this area here, it does not correspond to a strong change. Maybe at the break, we can go back to that map, or I could even try to draw these contours onto the aeromagnetic.

So, there is a particular correlation between them.

I'd like to move on, then, to discussing some of the seismic results, and I will discuss, first, the seismic reflection data, which are displayed on the walls, and then the seismic refraction results.

The seismic reflection data have the potential of producing the highest-resolution image of the subsurface structure.

[Slide.]

MR. MOONEY: Here is just an example of what one might hope to get from reflection seismology, and that would be to define the fine-scale layering within the tuffs in the sub-tertiary paleozoic rocks and to identify faults, if they are present, and in fact, the reflection data have succeeded in doing this.

The seismic reflection data were collected in 1988 in the study area, and the reflection seismic effort was undertaken only after an earlier study was unsuccessful in collecting high-quality data right at Yucca Mountain itself.

You see, these volcanic terrains make very difficult targets for reflection seismology, because there is an awful lot of scattering and offsets in the volcanic units, which make it a notoriously bad data area in the view of the exploration industry.

The seismic reflection technique, of course, as you know, is most highly developed for sedimentary basins, and it works beautifully in layered and stratified sedimentary units, but when you get into other kind of media, it often becomes very difficult to get high-quality data.

Let me first give you the punch line, so that we all know where this is headed.

[Slide.]

MR. MOONEY: The profile is the so-called line AV-1, and it's located about 15 kilometers south of Yucca Mountain, in the Amargosa Desert. I had a location map, but I think I gave it in to be copied, and now I have not returned it to my pile. I can locate it on another.

[Slide.]

MR. MOONEY: The seismic reflection line, which is not highlighted on this figure, in any case, is located south of Yucca Mountain, right at the bottom of this map here. So, it ties to expose paleozoic rocks.

Now, as you all know, the structure at Yucca Mountain itself consists of a series of eastward-tilted blocks. You can see this right at the surface.

The tertiary volcanic units are tilted to the east, with westward-dipping faults indicated here, and this structure disappears beneath the tertiary alluvium of the Amargosa Desert.

The paleozoic rocks of Bare Mountain disappear beneath Crater Flat and then reappear both at the Calico Hills and in the Spring Mountains and so on.

[Slide.]

MR. MOONEY: Again, before I show the data for AV-1, the interpretation of that data are fairly unambiguous, because what you see on the seismic sections are reflections reflecting horizons, as in this blue line here, which are also eastward-tilted, in a series of asymmetric half-grabens that tilt off -- tilt to the east with westward-dipping faults and which can be correlated right up to the Spring Mountains here.

In addition, in one case, a bright shallow reflector can be identified as being a basalt flow, because it's seen at the surface and then disappears beneath the alluvium.

Now, it was known prior to the collection of this data that the paleozoic surface, paleozoic rocks beneath the volcanics would produce a good reflection, because the containment program had already collected seismic reflection data in the area of Yucca Flat, and I think I have a copy of that, as well.

[Slide.]

MR. MOONEY: So, we used this data that was collected in the Yucca Flat area to give us confidence that the paleozoic rocks would produce a strong reflection signature. These are all drilled. Unlike Yucca Mountain, there has been drilled, as you described it, as many holes as a pin-cushion for the containment program.

So, we knew that the volcanic paleozoic surface should show up as a bright reflection, and indeed, it did, in the Amargosa area, and I'll show just one example before we go to the board to look at the structure.

[Slide.]

MR. MOONEY: The results that I'm showing are reported in the orange-covered open-file report by Tom Brocher and others. It has 65 figures in the back showing all aspects of the data, comparison with other data sets, correlation with bore holes, comparison with other -- with industry data and a comparison of vibroseis versus seismic reflection.

The particular piece that I have chosen to show here, unfortunately, just is one part of that. That half-graben is a fault that comes down here. This is the tilted block that continues off the screen, and the alluviated basin and volcanic fuel basin is shown here.

This is the paleozoic surface coming along here, and the reason we know that is that, just a short distance further to the east here, paleozoic rocks outcrop at the surface.

We do not have, along this reflection line, bore hole control for the position of the paleozoic surface, but we do have seismic refraction data which are coincident with this reflection profile, and the seismic refraction data define paleozoic-type velocities right along the surface that then drop down into this asymmetric graben.

I'm allowed to go over there at all without a microphone?

MR. POMEROY: Walter, before you leave this, could you just very briefly tell me how these reflection -- this particular reflection profile was shot, what the details are? Don't spend a lot of time on it, though.

MR. MOONEY: Okay.

Because it was very difficult to get -- it proved impossible in previous attempts to get high-quality seismic reflection data right at Yucca Mountain. This study, which was done in January of 1988, was contracted with Digicon at 480 channels of channel acquisition system.

The industry standard is 96 channels, 120 channels, and so, four times the effort -- more than four times the effort was put into the number of channels.

The data were recorded with a 25-meter group interval, which means that the individual geophones were very closely spaced together, because it was known that the scattering from the volcanics and alluvium would cause big static shifts, and in order to properly calculate your static corrections, you need to have very close group internal and shot interval.

The contractor was -- specified that they must have a complete field processing unit in the field. So, every day's acquisition effort was processed overnight to find the right parameters to collect good data.

And as I recall, Paul, the arrays were put on the ground more or less linearly, but the vibrators -- they found that the vibrators had to be put in in sort of a "V" fashion -- there were five vibrators -- in order to cancel the ground roll, which was a severe problem.

Now, the report by Tom Brocher -- I don't know if you have a copy of that -- it's 150 pages, and it goes into great length about the various different sources that were attempted, both explosion and vibroseis. It was planned to use a land-air gun if needed. It turned out the land-air gun was not needed.

But these direct-comparison tests, where vibroseis was compared against dynamite, were able to demonstrate that, in the upper section, the upper four sections, vibroseis was superior, because it's been well developed for that kind of a depth range.

But at greater depth, there are some spurious harmonics that come in and obscure the data at greater depth, at the kinds of depths that would be of interest to the regional structural picture, and for that depth range, dynamite gave a much cleaner, clearer signal and produced better data.

The conclusion, then, is, Paul, that if you want to map out the volcanic paleozoic surface, vibroseis will do a very good job. If you want to search for detachment faults and mid-crustal features, go with dynamite.

MR. DANIELS: I have a question, Walter.

MR. MOONEY: Yes.

MR. DANIELS: If you were going to take this data and put it in a basin for petroleum exploration, would you do any further studies with seismic data?

MR. MOONEY: That sounds like a question that you're trying to get me to answer.

MR. DANIELS: What do you consider the data quality to be?

MR. MOONEY: Well, the data quality here is probably as good a quality data as one can collect in a volcanic terrain. It is not as good as one collects in a layered, stratified, sedimentary basin.

MR. DANIELS; Would you put a million dollars into a drill hole on a structure on that kind of data for petroleum exploration?

MR. MOONEY: The question was would I put a million dollars -- I don't think there is any oil in the Amargosa Desert.

MR. DANIELS: I guess my question, indirectly, is that the data quality, if it's not good for petroleum exploration, is it good for siting a nuclear waste repository, if that's quality data?

MR. MOONEY: Okay. So, the comment was, if the data is not good enough to find oil, is it good enough to site a repository? I think the answer is definitely yes.

See, the questions that we're looking at here -- I think there is some confusion about what the purpose of the seismic reflection work is.

[Slide.]

MR. MOONEY: Here is a transparency taken from the Geological Society of American bulletin, a paper by Laura Serpa and others from the COCORP Group, where they collected data a few tens of kilometers away from the study area, in Death Valley, and they have interpreted that the prominent ranges there, the Black Mountains and so on, which are just to the southwest of Yucca Mountain, are structurally controlled by listric faults, normal faults at the surface that become listric and which merge into the mid-crust at about 15 kilometers depth, into a kind of a detachment surface, and that the lower crust is quite reflective and is probably a fairly ductile zone that accommodates the extension.

Now, one of the topics of interest in our studies of Yucca Mountain is to understand how did Yucca Mountain tilt to the east and what happens to these faults that we map at the surface? Where do they go into the paleozoic, and what's the structural setting of Yucca Mountain, of Bare Mountain, and indeed, of the region?

And this kind of data, of course -- some of the problems that we are addressing have nothing to do with the depth range one associated with exploration for resources, but the data quality certainly are more than adequate to define the structural context of Yucca Mountain and Bare Mountain.

So, our goals are so different. No, I wouldn't use this kind of data to site a drill hole, a $100 million drill hole -- I don't think you can drill a hole for a million dollars -- a several-million-dollar drill hole for oil, but that's not our purpose.

Yes, Vince.

MR. MURPHY: This matter of deep seismic reflection is something we have been wrestling with here in this area for some time, and truly as a third party to this proceeding, I really wish to complement Dr. Mooney and the Survey for the quality of these data.

In my words, it's literally a breakthrough from what we have seen in the past. Some years ago, I worked with Dr. Ibrahim on this problem, and we wrestled with the situation: Just how can one obtain better data? And clearly, you have made a step function increase in this kind of data.

It now leads us to the next step. Would it not be appropriate to perform this type of survey not only in this area, on parallel lines, but perhaps, for sake of numbers, three parallel lines completely around Yucca Mountain? Would we not be far ahead of our knowledge base if we were to do that?

[Slide.]

MR. MOONEY: Where would you suggest, just for example, that lines might be appropriate?

MR. MURPHY: I really cannot answer your question without getting further into the geology, and I do think you are probably in a better position.

MR. MOONEY: Dare I take my wallet out?

MR. HINZE: Watch it careful.

MR. MOONEY: Thank you for that compliment.

The secret to getting good data in this area here was to, first of all, contract with the best-quality, most advanced equipment that industry had available three years ago, and then to require them to bring their field computers, so that each day's acquisition was checked.

They really weren't too happy about that and closed down the crew whenever the wind speed was greater than about three miles an hour. They weren't happy about that, because they bid on it on a per-mile basis, and they didn't read that clause --

MR. CORBETT: Nice going.

MR. MOONEY: -- and to try as many different sources as possible.

Now, all that's been proven, as many people will point out to you, is that the technique is capable of imaging the subsurface structure in the Amargosa Desert. We haven't yet proven that we can tackle, you know, as successfully the difficult problem of data acquisition right at Yucca Mountain.

The previous work that was done in 1983, by the way, was done by SSI, I think it was, and there was an industry consultant who worked on the problem, a very competent man -- Forester, I believe his name was -- and it just turned out that standard or even modified industry techniques were not suitable for this kind of environment, and with no data play back in the field, there was no way of knowing what was being obtained.

Now, what's been proposed for future work -- I think Buck Ibrahim already showed some of the locations -- having succeeded down here, it has been proposed that lines be put in across Yucca Mountain, between Black and Red Cone and then up Solitario Canyon and then across into Jackass Flats and a few other locations, and these are, in part, determined by access.

Short of doing the entire seismic reflection program using helicopters or walking everything in, one has to use the reasonable access routes, because I would agree with Vince that what you really need are a grid of lines, and if you put all your money into one very-difficult-to-obtain profile going across, trying to keep the line always straight and going across the roughest topography, then you don't have enough tie lines to control your interpretation.

Now, I haven't seen the results of the peer panel, seismic peer panel, but what the peer panel is, in case some of you are not familiar with it, the peer panel is a group of academic and industrial experts who have reviewed the seismic refraction and reflection data collected to date, have reviewed it in great detail.

They are highly experienced people and presumably are coming up with recommendations on where additional seismic reflection lines and refraction lines should be recorded.

One recommendation that's been floating around is that, since we want to cross the Solitario Canyon fault, one recommendation is to keep the line linear, I think. Is that right?

MR. FRIDRICH: That's correct.

MR. MOONEY: See, things do leak out, even though they are not supposed to.

So, I think, Buck, that some changes are being made in the program, as it appears in the white paper, based on thorough review.

MR. IBRAHIM: Will that be a test line or collecting data for good?

MR. MOONEY: This was the feasibility line down here. I think this is the real line. This would be the real data.

MR. IBRAHIM: Wouldn't you like first to do a physical study, because you know, from the previous experiment, we had a hard time of getting good data.

MR. MOONEY: Yes. It would be a real seismic line that would have an assumable amount of testing, prior to the going for line kilometers of data.

MR. IBRAHIM: That's my personal opinion. I would say, is that before we go for a longer refraction line, I would like to do the same thing like what you did in the Amargosa Desert, 15 kilometer, and test for noise study and the configuration of the array and the source, and then we'll see from there would we should use later.

MR. MOONEY: Right.

MR. DANIELS: Has any thought been given to 3-D processing? In general, if you can't get good 2-D data, you can't get good 3-D data. But yet, in this particular case, I suspect a lot of this noise and the data is coming out of the plane. Maybe 3-D processing might help, in this particular case.

MR. MOONEY: I would have to consult again the feasibility study report and see what -- what recommendations were made there, regarding 3-D arrays for reporting and so on.

One thing that we have learned is that when it comes to acquiring high-quality seismic reflection data, there is not lack of free advice that is available to the person who is proposing to do the work. But, when you're in the field, and you can't find these people, so -- let me --

MR. IBRAHIM: Just one more -- one more piece of information.

MR. MOONEY: Yes.

MR. IBRAHIM: There are people looking for oil, besides you, because you said no one would be looking for oil there.

MR. MOONEY: Buck, I stand corrected. There is a study plan, and there is an ongoing study to determine the petroleum and mineral potential in and around Yucca Mountain. And one potential barrier, I suppose, to a site, would be if it turned out that the next north slope were right here, then some people would say it would be more important to drill for oil than it would be to put waste there.

MR. JOHNSON: Didn't you make the point earlier, in response to a question from Jeff Daniels, that you didn't think that there was any hydrocarbon potential in Amargosa Valley?

MR. MOONEY: Yes. And that was a wholly inappropriate comment, because I'm not really competent to judge that.

MR. JOHNSON: Well, then, if that's the case, then how could you make the statement then that you thought line

AV-1 was more than sufficient for a high-level waste repository program siting investigation, but not sufficient for a hydrocarbon resources evaluation?

MR. MOONEY: Okay. I would like to try to go back and re-answer -- answer that.

The line AV-1 shows, at shallow depth, the well-known paleozoic rocks of the study area, with this kind of geometry. These rocks, to the best of my knowledge, have never been considered -- by these rocks, I mean the rocks of the Spring Mountains, which can be projected, based on the seismic line to be. This kind of a structure continues at the depth.

The rocks in the Spring Mountains, I am not aware of them being candidate rocks for hydrocarbons. Do you have contrary information that these are potential petroleum-bearing rocks?

MR. JOHNSON: No, but I would respond to that by saying that the Paleozoic rocks that are out-cropping to the northeast of Yucca Mountain, in the central and northern part of the Nevada test site, the Jack Ass Flats -- not Jack Ass Flats, Yucca Flats, and the area surrounding that, there is evidence of some hydrocarbon sources within the Paleozoic rocks there.

More than likely, those are the types of Paleozoic rocks that would be beneath Yucca Mountain.

MR. FRIDRICH: If I could comment on that. Yes, the Eleana Argillite does have some carbonaceous material in it. But I would point out that the Eleana Argillite, in the area of Yucca Mountain, shows up as a magnetic anomaly because it got so hot close to the Caldera that it recrystallized. And Magnetite is one of the minerals of recrystallization.

It would seem to me that if you're crystallizing Magnetite, you're too hot, that you've over cooked the formation. Unless future studies show otherwise, I think all the information we have so far suggests that the Caldera got everything too hot.

MR. JOHNSON: I think the point that we're trying to get to in this investigation here, and certainly not a complete analysis of the hydrocarbon potential of Yucca Mountain, is not the topic of discussion here, but I think the point is, what types of geophysical programs are you going to use to investigate that potential?

MR. HINZE: That may be the subject of further deliberations. But, the general Paleozoic stratigraphy and structure, I think, Walter has addressed that, if I understand it, at least as far as they have gone, at this point.

MR. MOONEY: I was going to point out a couple of features over there and then move on to the seismic refraction.

I just wanted to point out an example of some of the tilting -- the eastward tilting of the Paleozoics shown here, and the amount of down drop. It's in milliseconds, and this is one second. So, this would correspondent -- I have to do this in my head. It's about -- it's in hundreds of meters of down drop that are shown on this section here.

This is a much expanded section that goes down to five seconds, two a time. But I do want to emphasize that the data were recorded all the way down to 15 seconds. The crust -- even the crust mantle boundary was successfully imaged in the data. That shows up -- that's shown in great detail in the report by Brocher, et al. So, I won't go into that now here.

Now, here's the section -- the portion of the line that I had in the transparency. Again, the westward dipping, dipping fault. This is, again, the vibroseis data and it produced a superior interpretation -- superior data to the dynamite data for the shallow section; but for the deeper section, we did have to rely on the dynamite data.

I want to point out a couple of deeper features as well.

I find this section a little easier to look at. That section is so expanded that it begins to take on kind of a cloudy look. You can see the data. This is again down to five seconds, but much compressed.

Here we can begin to see reflectors actually within the Paleozoic rocks going in through here. The origin of these reflectors are probably lithologic glaring within the Paleozoic as is seen in Bear Mountain. If you have been out at the site you have seen the pronounced layering within the Paleozoic section in that upward exposed and tilted, rotated, block and you can see this glaring occurring very clearly here at 2 to 3 seconds, two-way time.

Now in the beginning we talked about some of the uncertainties of the interpretation of geophysical data and one uncertainty is the exact geometry on this line of the basin bounding faults, exactly where they come through here and whether they become listric into this zone of reflectivity here or whether they continue to greater depth.

This is the subject of additional processing of the data that is going on now which is trying to bring out some of the deeper features in the data and trying to put constraints on the geometry of faults at depth.

In any case, the crust mantle boundary occurs at about 32 kilometers below the line and there is a strongly reflective lower crust, that is to say a laminated lower crust, that has high reflectivity between about 7 and 10 seconds two-way time, indicating like all of the basin in range which underwent extension in the late Cenozoic that the lower crust has seen some ductile deformation which has accommodated this extension, which has accommodated the tilting of these blocks, kind of like in the transparency that I showed earlier from Serpa, et al.

I guess that the floor is open for questions on the reflection data. If not I'll go on to more detail with the refraction.

MR. IBRAHIM: Just one question.

MR. MOONEY: Yes, Buck?

MR. IBRAHIM: You mentioned the movement at some seconds?

MR. MOONEY: Ten seconds.

MR. IBRAHIM: Ten seconds. If I remember well, correct me if I'm wrong, Serpa was finding that the crust, the move occurred at 15 seconds, something like that?

MR. MOONEY: No. It wouldn't be 15 seconds, Buck, because if you multiply by roughly three, that is a two-way time --

MR. IBRAHIM: I know.

MR. MOONEY: -- and the average velocity of the crust is 6 or so and 3 times 15 would give you 45 kilometers at the crust, and it is not reasonable to have a 45 kilometers at the crust in Death Valley. That would be Colorado Plateau.

MR. IBRAHIM: Oh, no, I mean there's one very close to the California Yucca Mountain.

MR. MOONEY: Yes, they get a 10 second two-way time.

MR. IBRAHIM: 10 or 15. I thought 15. I'm just saying I don't remember the number exactly.

MR. MOONEY: Yes, it is on that transparency that I was showing. They show it there as 15.

MR. IBRAHIM: On that section here, this part of that, can you identify the attachment because there was some doubt about it?

MR. MOONEY: There are a couple of alternative interpretations of the detachment depth. Maybe we could look at -- I don't have transparencies of all the figures -- perhaps we could look at those figures at lunch and then discuss that. The general candidate depth would be at about 5 seconds, 4 to 5 seconds two-way time, and it would be at a depth of about 12 kilometers where the detachment would bottom, would become listric.

MR. IBRAHIM: Are you sure of it now? Or -- because there was some doubt about it.

MR. MOONEY: We're not sure of it. This was a feasibility profile. The data that I am showing you, it's 27 kilometers long only -- excuse me. I think it is 27 miles. The industry tends to use these units like feet and miles and I get --

MR. IBRAHIM: 15 miles then maybe.

MR. MOONEY: It's 15 miles, thank you -- 15 miles, 27 kilometers, so we would be the last people to suggest that based on 15 miles of data we have defined the structural setting of the entire area around Yucca Mountain. We do think we have found good ways of collecting high quality shallow data and mid and lower crustal data using dynamite, so this was a feasibility study rather than a, as you well know, rather than being the "last hurrah" for seismic reflection.

MR. IBRAHIM: I suppose there will be another report coming out with that interpretation of this line so I just wonder whether that will be coming out?

MR. MOONEY: Yes. I have a copy of the report with me which is called "Evidence for Mesozoic Detachments in the Southern Basin and Range" which is authored by Brocher, Ken Fox, and Michael Carr which has been submitted for review by Jack Stewart and Ernie Anderson and is currently being reworked.

It's detailed. The aim of it is to go to the GSA bulletin. It's to discuss the geometry of detachment faults and the mechanics of faulting in the Yucca Mountain area.

It has not been experiencing a simple review. It's been getting a lot of review comment.

MR. POMEROY: Can I get a one word response to this question?

MR. MOONEY: Bill, do we give him one word or not?

MR. HINZE: Half a word.

MR. POMEROY: Is this data QA'd to current standards?

MR. HINZE: Could we --

MR. MOONEY: Just one word --

MR. HINZE: Could we come back to that problem, if you cannot define it in one word?

MR. MOONEY: The data were collected as a feasibility test, which means that the QA definitions, the QA -- what constituted a quality controlled line was uncertain.

MR. POMEROY: Thank you.

MR. HINZE: I think the answer was no?

MR. MOONEY: No. It was a feasibility study. We couldn't have gotten a permit to do the work if it had been otherwise.

[Slide.]

MR. MOONEY: Okay, so let's end with the seismic refraction results.

[Slide.]

MR. MOONEY: Contrary to seismic reflection the basic idea in refraction is that you set off a -- you use a source at the surface and you try to illuminate successive layers at depth and get energy to refract along the boundary rather than reflect from the boundary.

These give travel time curves, time versus distance for the first layer, the second layer and successive layers where you assume that you can pick up successive horizons with depth on your travel time curve. In real life the data usually, like Yucca Mountain, usually are very complicated with all kinds of bends and wiggles and so on, and the interpretation of this data is quite tricky.

Vince has just about --

MR. MURPHY: I am ready to go off my chair because I will disagree on the terminology of real life that you can possibly have a negative velocity that is real life.

MR. MOONEY: I agree with you. Yes, that would be -- one of these points here where you -- well, this is a split spread.

MR. MURPHY: No, no. At the top? Any of those negative velocities where the curve changes slope and tilts downward.

MR. MOONEY: I point well taken. I don't disagree. It was meant to be a cartoon and --

MR. IBRAHIM: I think this will be better than real life because it would be a tough life.

[Laughter.]

MR. MURPHY: I would accept real data however, and in that regard we can use that data.

[Slide.]

MR. MOONEY: Now what do we measure with these seismic velocities? Just a couple of typical values that are relevant to the study area?

The dolomites, the Paleozoic dolomites get as high in velocity as 6.5 kilometers per second. The volcanic rock, the tuffs and so on are quite low in velocity, 4.5 kilometers. That can be lowered. Just for a comparison I give you an intermediate value of granite, 6.0 kilometers per second.

The sedimentary rocks in the study area are relatively high velocity and the volcanics are definitely low velocity materials reaching as low as 1.2 kilometers per second and so on.

[Slide.]

MR. MOONEY: It is generally accepted that there is some relationship between seismic velocity and density. It is, however, anything but a simple relationship. But as velocity increases towards, say, 6 kilometers per second, the densities reach values on the order of 2.7 grams per cc and you can see though that there is considerable scatter in the relationship between velocity and density.

Nevertheless, with the seismic data, we are able to identify without much difficulty at all, the depth the paleozoic surface and the paleozoic rocks definitely have a higher density than the volcanic rocks in the area. So, we're able to exploit this difference in velocity between about 4 kilometers per second and 6.5 in terms of density to control -- to constrain our gravity interpretations.

[Slide.]

MR. MOONEY: Finally, as a prelude to some of the work that Phil Nelson will be showing, I would be the first to admit that with our seismic refraction measurements, we do not pick up every single layer and every flow and every unit within these tuffs. I've shown three curves here.

One is a Sonic log that shows all the fine detail of the velocity section. This is not from Yucca Mountain. This is, again, a cartoon, and as you go down through different formations, this one says formation velocities, you can characterize formations by typical velocity gradients and fine scale features.

Again, we have not succeeded, we have not attempted to determine these highly curved and stylized velocity functions within each formation; rather, we have determined average velocities within each layer and therefore, I am presenting you with a simplified average velocity interpretation, although, in our study, we do allow the velocity within each layer to vary somewhat laterally.

This layer here, the third layer, may have a velocity of 3.0 beneath Eastern Jackass Flats and then change to 3.4 or laterally change within a limited range. Any questions on that before we go to results?

MR. HINZE: Walter, how much time are we talking about?

MR. MOONEY: A location map and then two transparencies.

MR. HINZE: Okay, fine.

[Slide.]

MR. MOONEY: The two profiles that I'll show are the East-West profile which we'll call the Yucca Mountain Profile, and this profile here, the Forty Mile Wash Profile which crosses the hydrologic gradient up at this latitude.

[Slide.]

MR. MOONEY: Now, those of you in the back of the room can't see all these numbers and values and so on, but this is a highly exaggerated, a 6:1 vertical exaggeration and a 1:1 vertical exaggeration, profile across Bare Mountain and Yucca Mountain and in contrast to some cross sections that have been presented today that had very little basis of fact, this one is, in fact, based on drill hole control, gravity control and a grid of seismic profiles. I think they are not to be compared in terms of their value.

Bare Mountain, of course, is paleozoic rocks right at the surface; we know that. The gravity gradient is not located right at the Crater Flat Bare Mountain contact. As you know, the gradient extends out into Crate Flat, and therefore we can see that the geometry here is shown at 1:1. If you want to look at any of this in terms of real structures, I request that you go every now and then for reality check onto the 1:1 scale, because this is so exaggerated that everything looks funny.

Paleozoic comes down to a depth of more than two kilometers below sea level and since the elevation is about one kilometer, Crater Flat has a fill of volcanic rocks that is about three and a half kilometers thick. As I tried to emphasize while talking to the gravity map, the paleozoic structure where the paleozoic rises again, occurs more or less right beneath Yucca Mountain. It doesn't occur --

This structure here doesn't occur on the west side of Yucca Mountain; rather, it occurs more or less beneath Yucca Mountain. Then the paleozoic surface continues in this direction here.

Now, one thing that I always have to explain and is worth explaining, is why is it that the paleozoic surface continues there whereas this boundary, the velocity boundary where the velocity is 5.6 which is a good paleozoic number, is at greater depth? We know where the PC is here because we drilled into it. This is P-1.

The reason is that the seismic velocity of a unit is dependent on its condition, its confining pressure and its degree of weathering and so on. If you look into the report by Carr and others, when the describe the silurian dolomite that was encountered in P-1 drill hole, it's a highly brecchiated, buggy dolomite which one would not expect to have a velocity like a well consolidated carbonate. In fact, it doesn't.

It's velocity has been substantially reduced. It's within this layer that has a velocity of 3.6 here. So, my point is that seismic velocities are a reliable indicator of composition, as long as the rock has not been severely altered, fracture and otherwise changed in its physical properties.

MR. JOHNSON: Before you leave that one, I might make one comment in response to your remark that this is different than the other cross sections that have been shown today. In going back to that cross section I presented, I don't see much difference in what I presented and what you presented, especially in relationship to the upper units of the paleozoic. They appear to be roughly the same interpretation.

MR. MOONEY: I don't think we really want to get into that. I think we have to compare them on the screen. That would take an hour, at least.

MR. JOHNSON: That's a lunch hour discussion topic. Fine, lunch hour discussion.

[Slide.]

MR. MOONEY: The profile along Forty Mile Wash is shown here. Remember that the hydrologic gradient crosses at the northern end of the profile.

[Slide.]

MR. MOONEY: Let's begin with the bottom one, actually. As I said, along this north-south profile, basically it's pancake layers of volcanics going into a nice, competent, paleozoic with a velocity of 5.8, 5.3, 5.2, 6.2, 5.1, 5.0, 5.6 and so on. These are velocities which one would expect if you went up to Bare Mountain and sampled along the stratigraphic section in Bare Mountain where you'd get about that kind of variation and the layering is quite uniform.

MR. IBRAHIM: I have a question about that, but I will talk with you later on.

MR. MOONEY: Okay, yes.

[Slide.]

MR. MOONEY: Here it is again, an exaggeration of 6:1 with the well control here. Now, of course, the Yucca Mountain line crosses through right at this point here, so we have a tieline. These lines are all tied together and the tuffs have a velocity of 1.5, 2.3, 3.4 and then finally 3.7 before you get into the paleozoic and the depth is --

this is zero. This is about one kilometer elevation and the depth to PZ is about 200 meters below that, so it's about 1.2 kilometers beneath Jackass Flats to get to the paleozoic surface.

The hydrologic gradient shows up, and we consider this to be a tentative interpretation because it's at the end of our line. We notice that the velocity has increased dramatically. This red line indicates the rising of the velocity contours as though the rocks to the north had a lower porosity, were more welded; in any case, they have elastic constants which produce higher velocities.

This may be part of the cause of the hydrologic gradient. The hydrologic gradient, by the way, occurs within these layers here. It's measured in hundred of meters, so we're at this depth scale here where the high hydrologic gradient occurs.

MR. MURPHY: Quick question in that regard; do you have close enough spacing of shots and/or geophones to establish that there is no vertical offset in that hydrologic gradient?

MR. MOONEY: That's a good question. No, we do not have sufficient geophone spacing or shot spacing to determine that. You can see the control partly with the way the lines are connected, Vince. Where you see a straight line, that's just connecting two points. It would require higher resolution data to determine that.

[Slide.]

MR. MOONEY: I think the Chairman is ready to adjourn, and I'll end with just the location map. What we've determined, to date, is shown by the arrow magnetic gravity, the beginning of se' .c reflection coverage and the seismic refraction profiles which are shown here; 1, 2, 3, 4, 5, and I'll end by saying that we have a well integrated geophysical program.

MR. HINZE: Thank you very much, Walter. That was a very impressive performance. We'll leave it to further discussion later on this afternoon as to the degree of integration.

I'm going to suggest that we limit our lunch hour to 45 minutes. We can come back here at quarter till 2:00. We'll start with you, Phil, and we won't cut anyone short. I know that you all have important things to say.

[Whereupon, at 1:00 p.m., the Committee recessed for luncheon, to be reconvened this same date at 1:45 p.m.]

AFTERNOON SESSION

[1:46 p.m.]

MR. HINZE: We would like to get started. And our first speaker this afternoon is Phil Nelson, and he is going to talk to us about the borehole geophysical methods for site characterization.

MR. NELSON: This is quite a change of scale, not a change of topic, but a tremendous change of physical scale. Now, I'll be talking totally about borehole data from the holes that have been drilled at Yucca Mountain. So, we're going now from the scale of kilometers, down to the scale of meters and submeters, in terms of the physical measurements that are made.

I'll be talking about, to a great extent, measurements that are made with borehole logging tools or electric wire line tools, as they are sometimes called. I made up a little sheet of paper with a title and an outline. I don't know if it got -- it did get passed around, I see. So, the first thing you want to do is to take the front page and modify it. In order to avoid controversy, we'll cross out the word "integration"

[Laughter.]

[Slide.]

MR. NELSON: I thought I was being very trendy when I made up my title to include the word, but now that I see its content -- I'm not like other people, I try to avoid contention. We'll cross it out and just talk about physical property for borehole data.

MR. HINZE: We understand then you have just eliminated all integration, okay?

MR. NELSON: We have eliminated -- done away with it. Decided after lunch -- we decided we didn't want integration after all.

I'm just going to show four examples of borehole data. The first one will be merging geology, mineralogy and core data to make sense out of the core data.

The second example, I'll show cross-sections of logs down the spine of Yucca Mountain.

Thirdly, I'll show derivation of porosity from some of the log data.

Fourthly, I'll talk about permeability and flow. I should say that all the data that I will be showing deal with the tuffs -- with the ashflow tuffs that comprise the bulk of Yucca Mountain. About 40 boreholes have been drilled in and around Yucca Mountain into the tuffs.

As Walter mentioned, o: , one penetrated deep enough to go into the paleozoics, and I won't discuss any data from that. We have it, but I'm just concentrating on the tuffs today.

So, we're off and running.

[Slide.]

MR. NELSON: Here's a map of the borehole locations. I think it's -- most of them I'll actually be talking more about data from the axis there, where the deeper holes were drilled, as opposed to the more peripheral holes that were drilled to measure the water table, called the WD holes. Instead, I'll be concentrating on what's called G and H holes, respectively, for -- drilled for geological and hydrological purposes.

[Slide.]

MR. NELSON: Here is a little portrayal of data from GU-3, which is on the southern end of the spine of Yucca mountain. It's a composite of data from three different sources. The pretty graph here is based on x-ray diffraction data done by Los Alamos, a very nice quantitative x-ray diffraction work, which we found to be crucial in looking at the core and log data.

MR. CORBETT: What king of sample interval?

MR. NELSON: You can see the location of the samples every time there's a little change in the graph. The -- it's a volumetric presentation, so it goes, if you like, from zero to 100 percent of the whole rock.

What you're looking at, for example at 800 feet, is a rock which is about 60 percent feldspar, about 25 or 30 percent tritimite and crystabolite, or the low-density phases of quartz, and about 10 to 15 percent porosity.

Down deeper, you're looking at rock which is much reduced in feldspar content and has a lot of glass in it and a very high porosity of probably almost 40 percent.

Here you see, then, the great contrast, in terms of what we call a welded rock and a non-welded or poorly welded rock with a lot of glass, and here where that glass has been altered to zeolites. So, there's a tremendous range -- tremendous change in mineralogic composition with depth. It tells you a lot.

You can already expect there's going to be a lot of change in physical properties, just from seeing what's going on with the mineralogy.

Here's a graph that's taken from a geological report by Scott Castellanos. It's the degree of welding, as how much -- to measure -- qualitative measure of how much compaction the rock underwent before it was formed. The degree of welding increases to the right. So, here it's densely welded. This is actually a demarcation of what they call the vitrophyre, or the lowest member of the Topopaw Spring. This is about the repository horizon, somewhere in here.

Here's a bedded tuff, which is not an ashfall tuff at all, or not an ashflow, but probably an ashfall or a sedimentary deposit. Here's a moderately welded, and here a non-welded tuff.

Over here you can see the effect of what happens, in terms of fractures in the core. The fracture density increases to the left. Each little blip is about 10-feet thick, so it's the number of fractures per 10-foot interval. And you can see the increase in fracture density here in the welded tuff and the disappearance of fracturing in the unwelded tuff, which is either plessy or zeolitic.

So, so far, it's all mineralogical or geological data, based on core and core samples. There's no logs on this plot. This other plot if a plot of grain density measured in the laboratory on core samples three different ways. The X's are by Archemedes and by weight. The pluses, whicn you can't discern from the X's are by pycnometer. And then the open circles are actually computed from this mineralogical chart here. That is, we just took the grain densities for the minerals and the volumetric fractions, summed them up and computed grain density.

So, that's very nice because it -- because they match up so well, it gives us good confidence in the quantitative mineralogic data. It tells us that those estimates that were done by Los Alamos are actually pretty good. Because when we multiply by textbook values of mineral grain density, sum them up, we get a nice match, with a measured bulk density. So, it's a nice consistent set of data and you can learn a great deal from it.

[Slide.]

MR. NELSON: Now, let's just broaden our perspective and look at GU-3, in its entirety. This is a somewhat -- now we're looking at log data from GU-3, in addition to the geologic data. I didn't include the mineralogic data on this graph. You are also looking at 4,800 feet of core data.

On the left is the natural gamma ray log. In the middle is the density log from the gamma gamma tool. On the right is the electrical resistivity.

The patch here shows the degree of welding again. It's the same chart you saw before with moderate to densely welded tuff here in the vitrophyre, imbedded tuff, unwelded and poorly welded. This shows the presence of zeolites and clays, where ever you see stippled graph.

You can see the correspondence between the density and the degree of welding, which is not terribly unexpected. The more compacted rock you have, the lower the porosity, and then, of course, the higher the degree of welding.

MR. DANIELS: Phil, can I ask a question? Isn't it true though that, at the Nevada test sites, the geologists use the density log to help them pick the degree of welding? So, you're going to get that correlation anyway. At least I've seen them to that before.

MR. NELSON: Oh, yes. That's no surprise. Yes. It's, like I say, the porosity goes down. So, as the degree of welding goes up, porosity drops and density increases.

MR. DANIELS: Phil?

MR. NELSON: Yes, there are no surprises here. This is all pretty standard stuff out of data that's been around for awhile. We're just leading you on a little bit, okay.

MR. HINZE: Is there any problem with the calibration of that in the tuffs?

MR. NELSON: Yes. That's another story that I wasn't going to get into, because it takes a while to tell it, but there are two things that give us problems with the density log.

One is that we are in a air-filled hole and, secondly, is that the hole is drilled very roughly. So, we have a lot of rugosity or a very un-smooth hole, and those things, in combination, give us this chatter here on the density log, which has just caused us fits.

And for that reason, the people who are collecting the data also collected bore hole spectrometry to help out with the problem of getting good density data.

MR. HINZE: Has the bore hole spectrometry been used at Yucca Mountain?

MR. NELSON: Yes. I will show you that. I have some examples.

You also see the electrical resistivity here, coinciding nicely with the presence of zeolites there and thee, and taken in combination, clearly density and electrical resistivity are very good qualitative indicators of the presence of zeolitization in the tuffs.

The natural gamma does not show as much information as you would expect in a sedimentary sequence. One thing that's quite astounding here -- and at first, you might think there is a measurement problem -- is the extreme uniformity of the gamma ray in the Topopah Spring.

These little ticks on here are because it was collected in casing. Those are casing collars. But if you take those away, you have quite a uniform level of gamma ray activity, and it's basically saying that the amount of potassium and thorium in the in the Topopah Spring member is remarkably well distributed, uniformly distributed, implying strong mixing of the flow, as it was deposited.

You see the same sort of thing in the rare earth element data that the people in isotope geology have worked up. So, it's a consistent story.

[Slide.]

MR. NELSON: Now we'll go on to some core data, which is based on about 200 samples that Len Andersen measured years ago at the USGS lab in Denver. He measured bulk density and porosity, electrical resistivity, sonic velocity, and permeability, and in addition, magnetic properties were measured by Joe Rosenbaum.

This is the porosity data from three cored holes, 198 samples, plotted -- keyed to the degree of welding. So, here is porosity 0 to 60 percent, degree of welding increasing, non-welded, poorly welded, moderately to densely welded. Vitrophyre samples are stuck out there. Bedded tuffs are plotted here.

These are box plots, so that the horizontal line is the median. The bottom is the 25th percentile; so, 0 to 25 percent, shifts to 25 to 50, 50 to 75, and 75 to 100 percent of the samples of those classed as poorly to moderately welded.

Of course, what you see is a very clean dependence of porosity decreasing as the degree of welding increases. So, although the degree of welding is a qualitative observational parameter on core, it turns out to be a remarkably good one in terms of what's going on with physical properties.

It's highly unusual to find something that you can reserve in core that correlates so well with the quantitative measurement of core space.

[Slide.]

MR. NELSON: Now, we've got mineralogy and we've got geology and we've got these core samples, and the next effort was to use geology and mineralogy to help us understand what was going on with the physical measurements of core properties, and there are probably -- again, it's a non-unique problem.

How do you take the geological and mineralogical information and use it to categorize core properties? Well, after a lot of fiddling around, I came up with one scheme which works and I'm happy with, and it's based on this little three-axis diagram, which -- you won't believe this, but I drew it myself.

The degree of welding is shown on this X axis here: bedded, non-welded, densely, vitrophyre. The zeolite and clay content, from Los Alamos, is shown here. This is the 10 percent zeolite and clay line, and the glass is the access going into the board, again with a 10-percent line here.

Everything -- all samples in this little cube here I labeled -- gave them the term "non-welded," which isn't quite true. It actually means they are from this poorly-welded category on down to bedded. The samples that were higher than that I called welded.

If they were a glassy vitrophyre, and there is only three or four from this set, I called them vitrophyres. If the glass content exceeded 10 percent but they were not from the vitrophyre zone, I called them glassy, and if zeolite and clay exceeded 10 percent, I would call them zeolitic.

So, there's five classes here of samples. You will see later that I will split the zeolitic into two, so there will be six. So, we're going to look at different physical properties now, using those categories.

[Slide.]

MR. NELSON: The first thing I do is plot resistivity, porosity versus electrical resistivity. These are core samples, remember, categorized according to three of those classes: glass, solid dot; non-welded, open square; and plus is a welded sample.

And that's not a beautiful data set. It's got a little scatter, but given the vagaries of real-life geological samples -- oh, shouldn't use "real-life" -- it's not bad, and that line is a reflection of what's called Archie's law in the literature.

It's a simple power law, dependence of resistivity on porosity in the fluid that saturates the core space, and we came out here with a very nice match of the -- for the resistivity, the saturants.

So, we have a good empirical handle here that's pretty well known from other types of rocks, which also works for the tuffs, and that's a very nice thing to have.

This is how to estimate porosity, given a resistivity measurement and a measurement of the saturant in these particular types of tuffs.

MR. HINZE: Would I be getting out of your order to ask where you would put faults and fault gouge on that diagram and in the tuffs and where you might have the rocks adjacent to the faults that may be altered?

MR. NELSON: Yes, it would be.

MR. HINZE: Okay. Will you provide that at some point along the line?

MR. NELSON: What was the second question?

MR. HINZE: Will you provide that someplace in your conversations with us?

MR. NELSON: No.

MR. CORBETT: Phil, were those resistivities measured in whole, or are they assumed?

MR. NELSON: These are core samples.

MR. CORBETT: So, how was the resistivity measured?

MR. NELSON: They were re-saturated.

MR. CORBETT: Re-saturated.

MR. NELSON: Yes, with tap water of a known resistivity.

MR. CORBETT: All right.

MR. MURPHY: Question: As a predictor of in-place conditions, can we assume, if we have a certain porosity value on your curve, we have a certain resistivity value and vice versa? Do we have a unique relationship?

MR. NELSON: Yes. Archie's law is unique in that respect. It is a statistical fit.

MR. MURPHY: And we can take any material?

MR. NELSON: No. It's only good for those three classes. It does hold for the zeolites and clay-bearing samples, as I will show you with this slide, which does show all the data.

[Slide.]

MR. NELSON: Same graph, and this straight line is the same straight line that you just saw, and many of these symbols are the same symbols that you just saw for the glassy, welded, and non-welded samples, but now we have added all -- we now have all 198 samples plotted here, and the symbols are not keyed by degree of welding anymore, but they are keyed by the amount of clay and zeolitic content, which is shown in this little sketch up here.

I believe that line -- this line is the 0.1 line for zeolite, so that's about 0.4.

So, what you see, of course, is that, when you add the zeolite and clay-bearing samples, you get a lot of points pulled over here off this Archie law trend line, and that pulling is due to the presence of zeolites and smectites, and at first -- my first thought was I expected the zeolites to do more of the pulling, because there's more of them, and they do have a very significant cation exchange capacity, which augments the electrical properties, but that turns out not to be the case.

You'll see the open squares, in fact, come from this zone, which is not the highest zeolite content but, in fact, has a much -- has a significant smectite content and less zeolite, and the samples that are high zeolites tend to form this smear of black triangles here.

So, it doesn't look like the zeolites are contributing, in proportion, as much as the smectites to electrical conductivity.

MR. DANIELS: Phil, is smectite the only clay that you find in these samples?

MR. NELSON: I don't want to say off the top of my head, but it's the dominant one.

MR. IBRAHIM: If you take the zeolite by itself, what kind of a curve can you fit to this data? It seems to be a straight line.

MR. NELSON: Yes. I didn't try to do that, but let me explain these curves, which are really more relevant to the point that you're making.

These lines here are taken from work by people at Shell Development, and these are called -- these curves are from what they call the Waxman-Smits equation, which are really directed at what they call a shaley sand problem in the petroleum business, and these, effectively, you can read as numbers in terms of cation exchange capacity or, roughly, clay smectite content, as it happened to work out.

So, we would want to judge that these samples falling farther and farther out here are those with about 10 percent smectite content or higher.

Unfortunately, the samples on which this mineralogy was determined is not the samples that were analyzed here. We have interpolated the mineralogical data to overlap with the samples, and also, of course, that, coupled with the errors on the x-ray diffraction determinations, means we don't have quantitative information on the samples we measured.

This is as far as I would want to take this. I wouldn't want to try to do anything more with this particular dataset regarding clay content. It certainly does show you -- the reason you see those low electrical resistivity deflections on the logs opposite the zeolitic zone is because of this effect.

At any given porosity like 20 percent, the resistivity is down a lot in some cases, depending on the smectite content. That's the fundamental message.

[Slide.]

MR. NELSON: Here's density and grain density. Let's just look at the top one first. The top one is the non-zeolitic samples. Water is a function of porosity, zero to 60 percent. Density is plotted 1.6 to 2.6 grams per cc and the samples are categorized by whether they're glassy. There are only two vitrophyre samples, open squares or non-welded and the pluses are the welded samples. They are very similar.

Now, this is bulk density versus porosity, so both the slope and the intercept of these lines are determined by the grain density. If we do a least square fit, we come up with these numbers for the grain density, 2.35 for glass and then a 2.38 for vitrophyre, so they're fairly close here. Then for non-welded, 2.59 and 2.54 up in here.

So, we have a very good estimate for what the effective grain density is for each of these categories. That's very important for estimating porosity from a density measurement in a bore hole. You have to know the grain density.

This little graph tells us what grain density to use for each of these different rock classifications when we go to work up the log data.

MR. DANIELS: Is this above the water table or below the water table, primarily?

MR. NELSON: Well, it doesn't matter. These samples can be from either place because these are laboratory measurements. But to answer your question properly, in G-3, the water table depth is at 2600, so roughly half the whole depth from the graph that I showed from the entirety of G-3.

The bottom of the graph is just for the zeolitic samples. Here the scatter is a little higher. To make sense of the data, I had to break the data at about 900 meters depth into the upper class and shallower than that depth into this lower class with the z's.

You might say, well, that's arbitrary. I thought so at first, but it turns out that the dominant zeolite type in these two rocks is different. In the upper interval, I think it's predominantly clinoptilolite and then in the lower interval, it's predominantly analcime. Those zeolites have different grain densities of their own and their abundance is different, so that accounts for the reason that you get two different apparent grain densities in the two zeolitic classes.

[Slide.]

MR. NELSON: These are the three holes on which these measurements were made, G-3, G-4 and A-1 as a function of depth, zero to 1600 meters, grain density plotted 2.1 to 2.7 grams per cc. The pluses are the core data that Lynn Anderson measured. The open circles, again, are the x-ray diffraction data, and the line stair-stepping down is the statistical fit that I just showed you for those different classes.

It gives you a feel for how good those fits are to data from the different wells at different locations. There's some mismatches, the biggest one of which occurs over here in A-1 and that is an unusual zone which has a lot of opal. So, I came to the conclusion that the textbook value of opal is not the value that opal in this particular interval has, as a way of explaining that data.

But the symbols then are those classes. This W is the welded zone. Here's the vitrophyre, the glassy zone, the non-welded zone, the shallow zeolites, welded, shallow zeolites, unwelded and deep zeolites. So that rock classification seems to hold up as a function of depth in a given hole and fairly well for the three different holes.

A third class of data that Lynn measured was velocity. So, we have compressional velocity as a function of porosity. Here's a big scatter of data that they haven't really been able to untangle, probably for a variety of reasons. One is that these were basically unconfined or run at very low confining pressure and so there may be effects of low confining stress mixed in here that we'd rather not have.

The two -- but basically the story is, as porosity increases, compressional velocity goes down. It's a very similar story to what Walter was showing with his nice slide of velocity versus density. This is essentially a very typical density axis.

The two lines are actually Lee's square fit for sandstone data and I thought it intriguing that our data from tuffs were bounded by this clay free line for sandstones and that we're -- this lower line is a 25 percent clay content for sandstone samples. So it again tells you that all the tuffs, in detail, are quite different from sandstones, but again, some of their physical properties, at least obey laws that are very similar to those obeyed by sandstones.

MR. IBRAHIM: Is this compressional velocity on the core also, or from the well locks?

MR. NELSON: This is, again, still core data. I haven't switched to logs yet. I'll let you know when I do.

MR. HINZE: Have you calculated any reflection coefficients on the basis of these measurements?

MR. NELSON: Well, reflection coefficients were calculated for the paleozoic interface.

MR. HINZE: From within the tuffs itself?

MR. NELSON: Within the tuffs, I didn't. I think my predecessor may have and I'm sure that Tom Brocher, who took some of this data long ago, has done some of that.

MR. HINZE: Walter, do you have any comment on that?

MR. MOONEY: I don't remember the values of the reflection coefficients to those. They would be on the order of 0.05 to 0.1, I would imagine.

MR. HINZE: Well, that's not bad.

MR. MOONEY: It's pretty good.

MR. NELSON: In regard to the seismic properties, I should also mention that although we don't have any attenuation data, you would automatically expect the attenuation to go up appreciably in the zeolitic and the glassy zones where the porosity is high and where both velocity and density drop, particularly in the non-welded intervals which are exposed at the surface and are very punky.

So, not only do you have scattering in the volcanics, you have these layers of attenuative slabs to confound reflection seismologists.

[Slide.]

MR. NELSON: A quick summary of the data on the tuffs -- and bear in mind that this is just the samples -- Rule One is porosity declines as degree of welding increases. From the data, we find variations in porosity from 1 to as high as 53 percent. That's a tremendous range.

We find that, of course, as we expect, density, resistivity, velocity -- I'll get to permeability later -- all depend, the first order, on porosity and therefore, they vary over a large range, also. Density ranges 1.6 to 2.5; electrical resistivity, 15 to 7500 ohm-meters; velocity, 1200 to 4900 meters per second; and later we'll see permeability ranging over 6 orders of magnitude on the intact tuffs samples.

MR. HINZE: Has there been much in the way of Visaves measurement and looking -- has there been much of a study of Visaves and vp/vs ratios that might be helpful?

MR. NELSON: No, there are no Shear measurements on the core that I'm aware of; just the compressional velocities. We have Shear data from the logs.

[Slide.]

MR. NELSON: Does that answer your question?

MR. HINZE: Yes. Thank you.

MR. NELSON: So, another nice thing to learn is that sorting the samples in the rock classes that are defined in terms of degree of welding and mineralogy does enable us to distinguish the influence of zeolites and clays from the influence of porosity, and then the idea that the empirical rock property relationships, at least their fundamental form that have been established for sandstones, can be applied to the tuffs. That was very much worthwhile learning.

[Slide.]

MR. NELSON: This is getting a little redundant. I think I said this once before, that the degree of welding controls the primary porosity. How did that get back up there?

Zeolites and clays are a significant secondary control.

[Slide.]

MR. NELSON: Now, we'll go on to the logs, a change of venue here.

Here is a cross section, looking east, of the axis of Yucca Mountain, with G-2 on the left and G-3 on the right and about eight kilometers of space between them. So, this is a big expanse. I want to impress that on you. It's a long way from G-2 to G-3.

The other thing to impress on you again is that, at least in this part of the world, that layer-cake geometry of the ash flow tuffs, even though physical properties are varying, they're varying primarily vertically, because of these alternate zones of high welding, unaltered tuff, stacked in with these zones of higher porosity zeolitic units, which should become more clear, because we're going to look at logs from a line of holes down the axis here.

[Slide.]

MR. NELSON: Just remember, north is always on your left, and south is on your right.

This is density. It goes from 1 to 2.65 grams per cc. All this chatter up here shows you where we're above the water table in a rough hole. That's what it does to the density log. It gives us horrible-looking measurements.

The water table itself is shown by this narrow vertical line right in here next to each hole, and you will see it shifting around in a nonsensical fashion, and that's because you have to be careful here how you want to show logs when you show them stack holes like this.

In this case, I chose to shift to common geological data. So, this is the top of a Prow Pass member right here. They're all shifted to the top of the Prow Pass. And this set of lines here shows the bottom of the Topopah Spring unit, going right through here, and the one in between, labeled "Tht" are the tuffs of Calico Hills.

And then we go Prow Pass, Bullfrog, Tram, and then the older tuffs at the bottom of the sequence. So, you can trace the geologic horizons across the page here. But of course, what we want to look at are the density variations, and there is this, of course, dramatic effect on the density log. There are variations within the welded tuffs of the Topopah Spring.

There's generally lower densities in the Calico Hills, a unit which tends to be zeolitized. And in some cases, you can see a general increase of density with depth, which is probably a combination of two things: compaction plus the change -- gradual changeover and increase in grain density, as we move from the upper reaches, which are low-density quartz crystobalite to higher-density quartz with depth.

[Slide.]

MR. NELSON: If you are bold enough to continue on with this exercise and look at electrical resistivity, you get another cross section of wiggly lines, the most important of which, on this graph, to me, is the dramatic decrease in resistivity here at about this depth.

Now, this is three orders of magnitude of resistivity, and that's a lot. So, this shift here is about a decrease of about a factor of 100 in electrical resistivity. That's an extreme, but this shows the top of the deep zeolitization in the ash flow tuffs.

Likewise, the resistivity dips that show up sporadically here and there, here they correlate fairly well in the Prow Pass, and again, in the top of the Prow Pass are zeolitized zones.

This whole G-2 looks a little different than the others. It's got this much greater thickness at Calico Hills and a lower total thickness of the higher-resistivity, more densely-welded tuffs, which are usually more fractured, and I will just point out that between G-2 and G-1 is where the steep hydrologic gradient occurs, and I'll let it go at that.

[Slide.]

MR. NELSON: Here is a physical property that got a lot of mention this morning. It's the magnetic field. And here is what the magnetic field looks like in a bore hole. It takes a while to get used to it, because the variations are huge.

This little arrow down here is 16,000 gammas. Variations in a bore hole are huge, because you are so close to the rock. It's just that simple.

Here is G-3, which is quite a remarkable hole. Here in the upper part of the tram, we have these huge increases in magnetic field, and these are due to reversaly-polarized units.

This is magnetic remanence not magnetic susceptibility that does this, and remanence dominates the properties, magnetic properties, of the ash flow tuffs. Susceptibility is definitely a second -- a bit player on the stage.

It's remanence that causes the trouble, and these are Joe Rosenbaum's measurements. The little dots are core data. They're superimposed here with the log which is pulled in the hole, and you can't see how well they overlie in there, but just believe me that they do.

Here is an interval with no log but core, and here we get back into a place where there is both log and core, and here, there is core data up here. So, it's very nice and consistent.

The importance of the magnetic field data, of course, is it gives you this beautiful time-synchronous marker of when the tuffs were deposited, and there is the beauty of tying this to the top of the Prow Pass, because you can see this very small and relatively thin deflection in four of the holes, all the way up to G-2, which is a normally polarized bed. Topopah Spring is also normally polarized somewhat erratically.

MR. IBRAHIM: Do you have an explanation of why it doesn't show in G-1 but G-2?

MR. NELSON: The difference between G-1 and G-2 here?

It's quite remarkable, and I can only quote the story of a mineralogist, that the rocks in G-1 -- in G-2 were subjected to a much higher degree of alternation, probably at higher temperature, and they attribute that to the nearer proximity to the Caldera, which on this scale is probably up here somewhere.

So, they postulate a circulating system of ground water driven by that heat source to the north. That's in one of the Los Alamos reports.

MR. IBRAHIM: How far is G-1 from G-2, and what is the water gradient here?

MR. NELSON: G-2 and G-1 are about 2 kilometers apart, and the gradient is what?

MR. FRIDRICH: It's a drop of about 300 meters in the water level between the two.

MR. NELSON: Thank you.

[Slide.]

MR. NELSON: I do not want to ignore susceptibility. Maybe I shouldn't put this up, because I don't have the scale on it and I don't know what the scale is. These are holes in drill hole wash that were logged per magnetic susceptibility. I believe Jeff Daniels had something to do with this.

Here, again, you can see a very nice marker, in terms of the magnetic character. These holes are much closer together than the previous line holes I was showing you. It's the only comment I'm going to make about magnetic properties. I just put them up here to show --

MR. HINZE: Can we ask Jeff -- Jeff, why don't some of those spikes carry through? Is this, again, an oxidation phenomenon or alteration?

MR. DANIELS: I think so. We're above the water table, I think, in that particular case, in A-4, 6, and 7.

We are above the water table. And I think there is an oxidation effect on those rocks. But even in spite of that, the correlation is very good between holes on the susceptibility. I think it's a good stratigraphic tool in the tuffs.

MR. HINZE: Is that oxidation correlative with the fracturing that you see?

MR. DANIELS: I wouldn't go so far as to say that. I think it might be. Certainly, there's a strong likelihood that the rocks up in that zone, in the upper part, could be fractured -- highly fractured. The holes don't hold water. There is some indication of that.

MR. HINZE: Do you think one might be able to use surface magnetics to look at the -- an integrated volume of fracturing within the Topopah Springs?

MR. DANIELS: I think it would be worth looking at. I'm not sure that we can get -- that there's that much of a signature -- that high of a signature that you could get any real good estimate or good correlation. The near surface effects or near surface problems are pretty severe, in terms of physical properties in that area.

MR. HINZE: Did you record that at all?

MR. DANIELS: No.

[Slide.]

MR. NELSON: The last cross-section I was going to show is the total gamma-ray signature. Again, let me remind you that these little ticks are the casing collars. You can just ignore them. Again, the characteristic of the Topopah Spring is this remarkably uniform total gamma-ray count. There are some other correlative features; but in general, it's much less useful for correlation then are density, resistivity and magnetic field.

That's a second use -- a second style of looking at borehole data. I'm going to move on now to a third mixing of types of borehole data. In this case, it's for the purpose of estimating the porosity of the rock. This is a study that was not done by me, it was done by Doug Muller, with Rick Spengler, who furnished a very interesting set of core data. He took transects on the core from the g holes and counted the abundance of bugs -- what they call lithoph sae, and essentially did a point count on the scale of the core specimen, and came up with an estimate of the porosity, in that fashion.

[Slide.]

MR. NELSON: Doug worked with the gravity and the density log and the core estimates of density. By working these four data sets together, well, let me see if I can unravel this a little bit. There's a depth, 100, 200, 300, 0 meters, I guess, the 400 belongs down there, for the four g holes, in which we have the estimates of porosity from core and the slash line here. This goes from zero to 45 percent porosity. And the -- lithology symbol here indicates the presence of the lithophysae or bugs. The black is where they are absent.

And superposed on here then are -- also are shown the density logs and the -- here's an instance of the gravity log. Note that we have the gravity log in g-4 and g-3, but not in g-1 and g-2.

I made a mistake in the presentation here by showing you the answer first. This is essentially after the density log and the gravity log have been converted to a porosity scale. They've all been converted to a common scale. And you can see that, in some cases, there's good agreement, and in some cases, it's only fair.

Now, let me back up and talk a little bit about how that scaling was achieved.

[Slide.]

MR. NELSON: Here we are below the water table, at depths below 2,600 feet in g-3. We're comparing the density log measurement in the wiggly line -- Len Anderson's measurements on core, in the open circle.

So, at this place in the tuff sequence, below the water table, we're happy with the density log because it matches the core quite well, in the saturated rock. The reason, of course, is that the borehole is smooth and we have a water-filled borehole, so it helps to get us good density logs.

So Doug decided that that is the best estimate of density we have in the boreholes. And the gravity log requires what they call a free-air gradient, which has an uncertainty about it. It has required a small shift to the gravity log to essentially snub it in to the bulk averages of these data. So, the first step was a small change in the estimate of the free-air gradient, based upon this data from the water -- zone below the water table. And then after doing that, then the conversion was made to that in the core holes. Then finally he could obtain an estimate of porosity in the five holes where we had run a borehole gravimeter.

[Slide.]

MR. NELSON: So, here are Doug's final estimates of lithophysal porosity -- his definition, that means all the bugs, which essentially are free of water. There's considerable water in the rock above the water table, because the pores are generally very small and they have a high capillary action. But the lithophysae are big enough that they are essentially dry. So Doug felt confident in using the data to essentially make an estimate of porosity using a formula that expresses the effective bulk density, plus what's leftover, which is essentially air-filled core space.

That's -- not told too well, is the story of how he got porosity estimates in these very buggy zones, which is a very difficult thing to do.

You ask -- you might ask now, where is this useful? Well, we expect it would be useful, for example, in -- for people who want to estimate downward percolation rates, because here's a tremendous amount of storativity. It also affects anything that's related to the gross porosity, like estimates and thermal conductivity, will be tremendously estimated by these amounts of air-filled core space. So, it should be a useful result.

[Slide.]

MR. NELSON: There are more conventional ways to estimate porosity, and more conventional rocks. Usually people use a combination of these three equations. One for the density log, which relates to bulk density; to the grain density, to the amount of solid present, the fluid density, the porosity, and the water saturation. So, this equation holds either above or below the static water level, where SW is one below the static water level, or where it's less than one above the static water level.

The epithermal neutron tool has an equation which is of this empirical form or the logarithm and the count rate, is proportional, in straight line fashion, to the water present, which is essentially the product of porosity and water saturation.

The third equation is basically a combination of what's called Archie's laws, and can be applied, although we have not done that yet. So, I'm just going to show you a little first pass exercise that we're going to be talking about at the High-Level Radioactive Waste Conference next week, which essentially uses the top two equations to estimate the porosity and water content in the unsaturated zone.

[Slide.]

MR. NELSON: As soon you put an equation up, Walter disappears, have you noticed?

So here's the logs that were used. You don't need to look at the ones on the right. I'll just hide them.

For this little exercise Rick Schimschal used the gamma ray. Resistivity was not used. The epithermal neutron was used, density and one needs to look at the caliper here.

Here you can see the effect of this rough hole. Look right here. You see the caliper expanding and that is generally where you see his blips on the density log where the tool pulls away from the hole and measures an erroneously low density.

The gravity log is shown right next to it. The exercise here was first -- now we're getting into this problem of, well, I want to use this density data and the neutron data to estimate together porosity and water saturation but you get into the problem, well, I have to know the grain density. Well, I don't know the grain density because all I have are these logs so the exercise was to take the gamma ray and the density is what Rick used and said I'm going to calculate a crude feldspar estimate and then from that I'll calculate the grain density, put that into the bulk density equation, get my porosity estimate, do a calibration on the epithermal neutron tool against a little bit of water analysis that we happen to have lying around to determine the constants to that equation and then simultaneously solve for the porosity and the water saturation. I'm sure you all got that -- but that's what he did.

[Slide.]

MR. NELSON: I don't really expect you to retain all the detail of what I am going through here but the purpose of flowing through so much stuff here is just to show the utility of combining these different things. It's not an exercise to show you in detail how we are getting porosity and water saturation but just to give you the idea in order to do these things you need to rely on these different types of data.

Here is his answer, basically. These are all computed logs now. There's no original data in here except a little bit of core data to check against. Everything on this slide has been massaged from the original data set.

This is the feldspar estimate from this line over to here, zero to 40 percent here in the welded zone of the Topopah Spring.

Down in the Calico Hills unit which is zeolitic, the feldspar drops just as it did in that x-ray result that I showed you early on.

Over here is his computed porosity estimate, this wiggly line here. This is a H-hole that wasn't cored. It was spot-cored, so we have a little bit of core from H-1 to kind of confirm or deny how well we are doing here, just these about six samples.

Likewise, here is a solution for the water saturation, zero to 100 percent water saturation. It's probably averaging 60 or 70 here in the welded zone, which is about what people have gotten from the few scanty core measurements that have been made to analyze for saturation.

MR. DANIELS: Where is the water table, Phil?

MR. NELSON: In this hole? It's somewhere down here.

MR. DANIELS: Down there. Would that break at the zeolite feldspar change there? I notice it shows up strongly on the neutron/neutron log first of all. Would that give you an indication that maybe the neutron/neutron log might be useful in detecting the amount of Zeolite you have?

MR. NELSON: It probably would once -- when we get to the stage of thinking how to use it for that, yes. Sure.

MR. DANIELS: That break also might be able to tell you something about the historical water table in the area?

MR. NELSON: Well, I regard that more as a geologic problem.

MR. DANIELS: That's what we're using lights for. It would really be useful. I've noticed --

MR. NELSON: I meant in the sense that someone who's really keyed to thinking about that kind of thing. I don't want take that much time --

MR. DANIELS: I have noticed in granites for example that you get a big spike on certain logs where we have had weathering zones and those different spikes may indicate where historically in the past we have had different water levels and ˆ think it might be useful here too.

MR. NELSON: Yes, but it's more a statement of worrying how the currently mapped zeolites relate to where the water table once was, which I hope is what Chris is going to say.

MR. FRIDRICH: Yes, I was just going to comment on that. Basically glass is unstable in waters that have come out of a tuff that has crystallized. You know, if the water is going through a crystalline tuff, it gets an equilibrium with that. If it then enters a glassy tuff, it's out of the equilibrium and it will react.

So if you have steadily flowing water through a vitric tuff, eventually it just all reacts the way it's all zeolitized but I think you could have a vitric tuff under the water table and be stable if there was no flow through it but basically, you know, the glassy zones in the mountain are basically showing you areas that have virtually no flow on a real significant basis in the past.

MR. CORBETT: Is that zeolite contact as you've got the pattern there, can you correlate that well with the resistivity log, change in resistivity? You did indicate that.

MR. NELSON: Oh, yes, oh, yes.

MR. CORBETT: As a major substantial change?

MR. NELSON: I say yes with such confidence I am going to put the other viewgraph back up.

[Slide.]

MR. NELSON: Yes, those are good numbers on the induction resistivity. This is an induction log here. For those of you who don't know what that means, that's a resistivity measure with a pair of coils, so it can operate above the water table and this drop right here is what Jack's referring to.

MR. CORBETT: The casing is to 425 meters? Is that casing effect above that or is that a lithologic effect?

MR. NELSON: Oh, I'm sorry.

MR. CORBETT: 425 up.

MR. NELSON: No, this is all open hole.

MR. CORBETT: It's open hole, okay.

MR. NELSON: Yes.

MR. CORBETT: Does that go down to TD, zeolites?

MR. NELSON: No. This is just the Calico Hills. It'll swing back again once it gets down into the next flow.

[Slide.]

MR. NELSON: Okay. That was my third little exercise to try and convince you that it's worth integrating the data. I know there are still skeptics, so we've got a fourth part, and it's my last-ditch attempt to persuade you that you want to look at disparate data types in the same hole.

This is Len Andersen's permeability data, and these are, again -- now we're back in the lab. Okay? These are plugs that were drilled in a vertical orientation with respect to the core.

Porosity here is 0 to 50 percent, permeability from -- this is millidarcies, so 10 to the minus 6 millidarcies down here is really a nano-darcie, and 10 to the 3 millidarcies is 1 darcie.

So, actually, we have got not nine decades but seven decades of permeability change here on the vertical axis, and a porosity range from 0 to 40 percent. Now, this is all in one rock pile. That's a tremendous range of both permeability and porosity.

That just, again, makes the impact on you of what a tremendous range of physical properties we have to deal with.

The black dots are from the glass, and they are the most porous and the most permeable. The open squares are from the non-welded un-zeolitized rocks. These are generally poorly-welded rocks that haven't been zeolitized. And then the pluses are the welded samples. They are generally lower porosity and lower permeability.

Now, this straight line -- you've got to be careful -- this straight line is not a fit through all the data. It's a fit through everything but the Z's, which are all the zeolitic samples.

So, when you look at that line, just put your arm over those Z's, and you will see that, actually, the trend isn't that bad for permeability and porosity data, particularly over this kind of range.

So, all the zeolites, essentially, even though they are high porosity, they effectively lower the permeability by about two orders of magnitude, and that's a very significant statement.

The zeolitic units, then, are going to be much, much less permeable than the -- on a porosity-for-porosity basis than the un-zeolitized.

MR. FRIDRICH: This is just for matrix permeability. Right?

MR. NELSON: This is strictly for matrix permeability. That's an important point. These are little tiny plugs that were cut, just one-inch diameter and couple inches long. So, we're saying nothing here about the fracture porosity and the overall flow characteristics.

But it's at least useful lower limit to the permeability, and in places where there are no fractures, it represents what the permeability would be expected to be.

FROM THE FLOOR: Excuse me. You're saying porosity on the chart, though, not permeability.

MR. NELSON: It's permeability versus porosity. So, for any given core, we measured the permeability and porosity and just plotted one against the other.

[Slide.]

MR. NELSON: Okay. This one is going to take a long time to explain, because there is a lot.

MR. HINZE: As long as you can do the rest of it in five minutes.

MR. NELSON: Five minutes, huh? Actually, we're getting close. There is hope.

MR. HINZE: Great.

MR. NELSON: These are logs here and core data here and geologic data here, all on one graph, depth from 1,600 to 2,800 feet in G-4. Water level is up here now.

So, most of this hole is below the water level, and by and large, the density and the neutron logs have been plotted here so they overlay one another throughout much of the graph, but in two very significant zones they split, here and here, and if you were in the oil business, you would say well that's gas.

That where you set casing and perforate, because that's where you produce gas. That's known as the gas effect, where the density and the neutrons split. Now you can go make money in the oil business. You don't need to fool around with rad waste anymore.

Well, why does this do this? This is below the water level in the Yucca Mountain tuffs, and no, this is not a hydrocarbon occurrence. We can't disqualify the site because of this gas effect.

Doug Muller had talked quite a bit about this, and he finally convinced me that what was going on here was that because these holes were drilled with air as a drilling fluid, instead of with water, what we were looking at was the introduction of air into two select zones here and that it had not yet been expulsed by the formation, by the water in the rock, because the pressure just wasn't great enough to replace all the air.

And that story makes a lot of sense, because these zones are geologically bound, according to what the geologist sees in core. It's generally the -- I guess, in that key, it's what he calls a vapor phase zone.

But more significant or just as significant is the core permeability values, which show a high perm here and three high perm samples up here. So it does support the idea that the rock was able to essentially accommodate that additional air pressure in the hole at the time of drilling.

MR. IBRAHIM: Do you have a velocity log for that compared with this area where you have the difference?

MR. NELSON: I don't even remember. Probably.

MR. IBRAHIM: It would be nice if you have a velocity log.

MR. NELSON: That's a good idea.

[Slide.]

MR. NELSON: We have a similar case in G-3. Now, the water table is down here. So, all this hole is above the water table. So, without reading this, tell me what's going on in the hole. Here we have another thing that looks like a gas effect, but here we are above the water table, where the saturation is less than one.

Well, it turns out that G-3 -- here is the welding profile and here's where the zeolites are from core. It turns out that G-3, instead of being drilled with air, was drilled with mud, and so, here we have the opposite effect of, essentially, the mud introducing mud filtrate into the rock and invading a little bit of fluid a small distance. At least, we think that's a reasonable story.

MR. HINZE: Is this a matter of telling us that the bottom line is that bore hole measurements are less desireable than physical properties determined from core? In situ is not as good as core measurements?

MR. NELSON: Oh, no. No. I'm using the core to support what we see in these. These are not quantitative measurements of permeability. These are just indications, in the hole, of where some permeable zones are. They're not fractured. These are not fracture controlled. These are matrix perm control.

MR. DANIELS: Are you trying to stir me up, Bill?

MR. HINZE: Yes.

MR. DANIELS: Okay. You stirred me up.

MR. HINZE: Yes.

MR. DANIELS: My feeling is the neutron log above the water table is not very reliable, and Phil is, I think, pointing that out here.

The reason you get the high neutron count rate above the water table, as opposed to the density, is that actually you have had invasion into the formation, and then the fluids have drained out of the formation back into the drill hole. Okay? And those zones that are more permeable and more porous allow the fluid to drain out faster.

So, you're looking at a situation here where you have partial saturation, with the higher degree of saturation actually being in the less porous rocks -- do you follow me? -- above the water table.

So, it makes it very difficult to interpret neutron log above the water table. It's really, really tough. It's a very unreliable log above the water table.

MR. FRIDRICH: You really mean the less permeable rocks, don't you?

MR. DANIELS: Yes. The less permeable rocks will hold it after it's been injected. That's the effect we're seeing here.

MR. NELSON: Well, I'm not sure I'd say the neutron log is unreliable but, rather, the state of saturation could have changed as a result of the drilling process.

MR. HINZE: Thanks for verifying my comments there, Jeff.

MR. NELSON: Rather than run you through this, I will try to wrap up here with a little -- few concluding slides on fracture control, as opposed to the porosity control.

[Slide.]

MR. NELSON: This is another well, with another exercise, and another set of data. This is well H-4. The data set here introduces three data sets we haven't seen so far. You've seen the density and the neutron logs that are here. This is, by the way, depth scale is 2,400 to 3,600 feet. Density neutron, in this track, and resistivity here. So, by now, you know, for example, when the density and resistivity increase, you're probably in a highly-welded zone. Here you can see our old friend, the pervasive zeolitic zone in the bottom part of the tram at 3,250.

Here the new data. This is a television log here, and a little histogram. It's basically the number of fractures in a 10-foot interval as spied by the television. Here's the comparable record on a televiewer, the number of fractures in a 10-foot interval. This is all below the water table, so the televiewer can be run here. Above the water table, it can't be run in an air-filled hole.

Television, of course, works better in an air-filled hole, because you aren't -- you don't have the problem of opaque fluids in the well bore.

Here's basically, the televiewer and television data, again, this time plotting the azimuth of the dip angle. So, we can ignore that.

Here's the dip angle, itself, from the televiewer. But what you want to look at is this wiggly line over here, which is a flow log, made during a -- I believe an injection test with radioactive tracers which work at very low flow, to give you an indication of how quickly fluid is moving down the well bore. By taking differences, they can see the zones of where fluid actually left the well bore during the test. So, what you get is a percent flow record. And wherever you see changes, that's essentially where fractures that take fluid are located.

So, the instinct then, which you've already grasped, it to line up these changes with the occurrences of fractures, as demarcated by the television. There's a bump there and there are fractures there, and there's a bump there and there are fractures there. So, that's satisfying. This is the kind of data that led people to conclude, originally, years ago -- this is old data -- led people to conclude that, yes, indeed, it is a fracture controlled system, as far as hydrology is concerned.

[Slide.]

MR. NELSON: The story doesn't quite end there. I did a little bit of fooling around with the data, in terms of just trying to see, quantitatively, what happens when you plot the change in flow, in percent, versus the number of fractures at an interval.

Well, there's one high fracture, high flow point, that plots up here. And the rest tend to scatter around down here. There are a lot of fractured intervals that have no flow; which tells you that just going in an counting fractures, by itself, doesn't tell you where the flow is going to occur on a foot-by-foot interval or probably even on a 10-foot by 10-foot interval. So, that's not very rewarding.

[Slide.]

MR. NELSON: But, when you take the data and start looking at them cumulatively, I get this graph. And now I've ordered the data so that we see, from the cumulative flow -- I just got a stack of numbers now, okay, from my previous graph. I've taken the hole and I've broken it up into those flow intervals, and for each flow interval, I've counted the fracture as seen by television.

And now I've plotted it so I have cum flow here, cum fracture count here. They've been ordered by the number of fractures per interval. So that the spacing between the dots is very close here. Then, as you step along, the spacing gets bigger, because these are the intervals with the most fractures.

What you see is this little wandering track around the straight line. The straight line is what you would get if all fractures contributed proportionally to flow; each and every fracture were just as important as the next. Well, we didn't get a straight line; we got this stair-step around the straight line. That, to me, is a very significant little story, because it essentially says that, although fractures aren't important, if you just look at a 10-foot interval, if you go to a big enough interval and start counting fractures then, at some point, they do become important in terms of flow.

That's -- I'm sure there's an interesting statistical story to be told about how to count fractures, and this doesn't tell that story, but at least it points out the idea that there is one there.

[Slide.]

MR. NELSON: This last artificial slide just is put here to confirm the idea that, again, this trace here says that flow is directly proportional to the number of fractures per interval. That is, all fractures are equally important.

Number two, is that most flow occurs in just the highly fractured interval. Now we go boom to boom, really very quickly. Or you could dream up a case where there's one big fracture down there that takes all the flow, and takes 50 percent of it, as a matter of fact. All the rest of the fractures take the other half. That's what you would get.

Well, we didn't get this and we didn't get that. We got something that walked around that line there. So, it's another -- another one of those stories to be pursued, again, by enlarging and combining the data sets. So, that wraps up my story on non-integration.

MR. HINZE: Thank you very much, Phil. An impressive amount and quality of data. Are there any questions?

[No response.]

MR. HINZE: Well, I'm sure there are concerns about the physical property variations within the tuffs, but perhaps, as we listen to these next few talks, we'll here about some of those.

With that then, we'll turn to you, Vince Murphy. If you will, please, give us your view on the application of shallow seismic refraction to the site characterization problem.

Thanks again, Phil.

[Slide.]

MR. MURPHY: I imagine, by now, you are wondering why there are two presentations on the program concerning refraction and reflection. I hope I can convince you why before this brief presentation is over.

First off, I want to thank Professor Hinze for inviting me to participate, because I am a third party to your proceeding here, but I also come from a world of site characterization, where my associates and I, for something over 35 years now, have been performing site characterization activities for critical facilities.

We were one of the earliest in the nuclear power siting phase, and so we have been the whole gamut of licensing activities. We have worked on many critical structures, such as underground power houses, tunnels, etcetera.

In a sense, Dr. Mooney and I live in two different worlds. He lives in the world of kilometers of depth and seconds of time. I live in the world of hundreds of meters, perhaps, of depth and milliseconds of time.

I have the luxury that he needs my data, but I can get along without his. If he is going to interpret those deep seismic profiles comprehensively, then he needs the shallow data, and even though the upper part of his records may be smeared before one can do that comprehensive interpretation of those deep seismic records, it is necessary for the highest confidence level to have the shallow data, as well.

On the other hand, for the site characterization activities that I am going to talk about, I offer you that the shallow refraction and shallow reflection can stand alone.

The shallow reflection studies have been a problem for Yucca Mountain since day one, and I am not as optimistic as one might be in looking at these deep reflection profiles. However, it clearly is a methodology -- that is, shallow reflection -- that should be used at Yucca Mountain.

What I can offer you with a high degree of confidence is that seismic refraction is useful for Yucca Mountain, the shallow refraction.

So, what are we talking about?

[Slide.]

MR. MURPHY: We're talking a reasonably shallow depth range of 100-plus meters to as much as 1,000 to a kilometer.

We'll concentrate on refraction, but we'll also talk about reflection, a very little on reflection, because I want to pass on from refraction to other velocity measurement techniques: vertical seismic profiling, topographic imaging, vertical wide angle, performing measurements vertically and horizontally in drilled holes.

And this is a concept that I haven't heard today, is using horizontal holes. You know, if you read some of the professional journals in oil exploration in the last year or two -- Oil and Gas Journal, for example, there's a series of about six papers there -- focusing on horizontally-drilled holes, start with the vertical and then end up in the horizontal.

And I can remember some of my earlier involvements with the NRC and the statements being made: We cannot invade the repository zone. Well, let's not invade it. Let's drill outside or beside it, and then, as the oil people would do, horizontally drill our holes and make our measurements in those combined, vertical, horizontally-drilled holes.

We can also make cross-hole measurements.

[Slide.]

MR. MURPHY: One might ask why do we want to do all this?

Well, clearly, profiling is going to be of interest to us, but the bottom line on this presentation is -- and I feel very strongly on this -- we need to characterize Yucca Mountain and its immediate vicinity in terms of velocities and, therefore, moduli and strength.

I'll make a prediction for you, that if you do a thorough characterization of Yucca Mountain in your programs, you will preclude most, if not all, of the major surprises when you go underground, but I guarantee you that if you do not characterize Yucca Mountain thoroughly by velocity analysis, with all due respect to all the other geophysical techniques and parameters we have heard today, if you do not, you will get surprises, and I'd like to expand this discussion from Yucca Mountain, the repository itself, to the surface-based facilities, because virtually everything I say here today is applicable not only to the repository area but to the surface-based facilities.

I trust these are also in the safety-related aspect of this entire project. I know, when we're working on nuclear reactors, the dams holding the reservoirs and so forth are always Category 1, and so, we would transcend our thinking from the reactor site to the dam reservoir areas.

I would like to transcend our thinking here from the repository zone to the surface-based facilities, as well.

From velocities, we know, from our basic physics, any elementary text on geophysics, we can get moduli, we can get our shear modulus, and we can determine strength. We have been doing some work recently on converting seismic velocities directly to unconfined compressive strength.

This has great promise in some of the non-destructive testing work we've been doing, and we'll get into that a little later, when it comes to some performance studies that I would like to discuss with you.

MR. MOONEY: Vince, could I ask a question?

MR. MURPHY: Sure.

MR. MOONEY: It seems to me there is big non-uniqueness between velocity and strength. What do you mean by strength, exactly?

MR. MURPHY: The unconfined compressive strength, as the engineers would use it to evaluate a piece of rock or a piece of concrete, how strong is it.

MR. MOONEY: Are you implying that there is a direct relationship? Isn't there a lot of scatter? For example, you can have a welded unit that -- well, you can have a basaltic rock that has the same velocity as a granitic rock, but they may not have the same strength at all.

MR. MURPHY: If they had the same P/S velocity and they have the same density, then, by definition, they will have the same modulus and the same strength. The probability is, I think, implicit in what you're saying, that those won't be gimmes, that they will have different P wave or S wave velocities from each other.

MR. MOONEY: Okay. There is also porosity and pore pressure and lots of other factors in there.

MR. MURPHY: I would also make a plea to you that the velocity characterization be a three-dimensional one.

This is not to say that the data is analyzed in a three-dimensional manner, as the deep reflection is, but when -- back to that word again, "integration" -- when all of these suites of data are integrated, that we have a three-dimensional picture of the velocity setting of Yucca Mountain and the surface-based facilities.

We need P wave values, we need S wave values.

Anomalies will indicate faults and fractures. We're going to detect and delineate those.

And now, I would like to get to something that has concerned me for some time concerning Yucca Mountain.

[Slide.]

MR. MURPHY: On virtually every public presentation that you see, this cross-section of Yucca Mountain is used, and it's very nice to have a large zone without any structure showing.

I would suggest to you that what is probably closer to the truth in this area here is something of this nature.

MR. HINZE: What's the evidence for that?

MR. MURPHY: The evidence from this graphic is simply the topography we are looking at, and in virtually any other site-characterization program involving a critical structure, the seismic refraction program that I am talking about would be the first technique and the first studies that are made.

I've spent time in Yucca Mountain, as many of you have, and I do not understand why an intense program of surface seismic refraction profiling has not been performed up to this time. It's the easiest, it's the fastest, and it would give information.

For example -- and we'll come to the evidence -- if this is a low-velocity zone here or here, one now must start looking at all of these topographic features.

Let me show you a set of refraction data, a very simple set.

MR. HINZE: Vince, can you envision doing this without making roads or drilling into the earth?

MR. MURPHY: The second question is easier than the first.

Without drilling in, yes, you could use a weight drop, and with the stacking units today for refraction at a quiet time of the day when the wind is down, you probably would have a high enough signal-to-noise ratio that the data would be adequate for that.

If by drilling, you mean shot holes down to tens of meters, no, you don't need those, but you probably need shot holes to a few meters. If that's not allowed, then I'm back to the requirement of a weight drop or an air vent. I think that's a detail myself, part of a test program perhaps.

MR. HINZE: Thank you.

[Slide.]

MR. MURPHY: The graph here is a little more consistent perhaps than some of the ones we saw this morning on refraction. It's the kind of graph we're always looking for where the velocity lines are straightforward. What we're plotting here is time versus distance, the single set of anomalous data in here.

[Slide.]

MR. MURPHY: If we have a site wherein there is a set of lines -- personally I prefer a gridded system -- and then we have these low velocity zones, and you can start joining the points as well as I can, and you might have a different preference of drawing that low velocity zone, fine. We can always add another line and another and another. And I assure you, this is a very cost-effective method of characterizing this site, and I say that from not only my experience but a number of others' as the first technique on any site.

Then you know where to dig those trenches, and you know where to put those drill holes down, and you're not taking a shotgun approach to a site as large as Yucca Mountain.

Again, I do not understand the rationale of why this has not been attempted or completed. I assure you, it will provide useful data.

[Slide.]

MR. MURPHY: There is another method we've been involved with, and I suspect the survey who's been performing some of these measurements out here is a vertical seismic profiling.

This is a neat methodology. It's a very convenient way again of characterizing your site in three dimensions, because now, with your sensors in the hole, above the watertable, they're going to have to be clamped to the sidewall, and with source points around the hole and in three dimensions -- and you can let your imagination run to how many shot points you want, what spacing, and so forth, details, important details, but details -- you can characterize a large zone of rock from a single hole.

[Slide.]

MR. MURPHY: If we find an anomalous velocity condition, such as you see here -- and what we have taken the liberty of doing is drawing this blue line as a percolation path based on the low velocity zone -- and you wonder, was this right or not?

The way we prove this, and you can do the same thing at Yucca Mountain, and I heard using radioactive traces before, what we typically do on tracing paths is to use a salt tracer. So if it is acceptable in any part of

Yucca Mountain to trace out these features, we can put salt into fractures in the ground surface or any position that you wish to test at or near the ground surface, and then with electrodes in the hole, you can observe the travel time of that salt path in, I'd like to say, an environmentally compatible manner.

We've been doing the study for some years to trace flow under dams and reservoirs. We've adapted it with our good friends at MIT, Nafi Toksoz and his group, to trace out flows through fractioned porous media.

[Slide.]

MR. MURPHY: When this type of measurement -- that is, the down hole measurement -- is performed below the watertable, an interesting phenomenon takes place when there are open fractures, and again this traces to Toksoz and Cheng at MIT's Earth Resources Lab. And to some degree, it's almost a common-sense -- these techniques basically are so simple. I'm almost overwhelmed with some of the previous discussions I heard of zeolites and the chemistry, and I'd say, I missed something in school.

Let's take a very simple approach to what we're doing here. If we keep it simple, we will characterize Yucca Mountain with the highest confidence level. We will get repeatable data, and we will convince the world, with all due respect to Cal Johnson and the State of Nevada, that

Yucca is a safe place to build, because ultimately that's what it's all about, whether it's a repository here or a tunnel or an underground power house. It's got to be that safety is paramount, and I think we all understand that.

Okay. What's happening here in this bore hole? Below the watertable, if there is an opening and there's hydraulic conductivity there, the seismic waves travel through the rock section. They also, as they travel through the rock section, impinge, if you will, on this opening, and an interesting phenomenon takes place here.

That impinging of seismic energy onto that open fracture will squeeze a little bit of water into the hole. And if you think, that's almost a common-sense situation.

Here I have this open fracture. I've got water in it. I have seismic energy impinging. Sure, it's going to squeeze a little bit in, if it's a little fracture. And if it's a big fracture or a whole family of fractures, it's going to squeeze a lot of water in.

That's the simplicity of the technique, because all we're going to do now is look at the amplitude of that -- call it tube wave signal, as it's generated at this level by the impinging of the seismic energy in the hole on the fracture that's water-bearing and that has hydraulic conductivity.

The amplitude of that signal coming back up, as well as going down the hole, compared to the amplitude of the signal directly in rock is the criteria we use to determine the conductivity of that. Again, sort of common sense.

A fracture with little conductivity will only squirt a little bit of water, squeeze a little bit of water in, and therefore the amplitude of that tube wave would have been small. On the other hand, a lot of water, high amplitude, and look at this tube wave here [indicating].

How do we know it's a tube wave? It's got a velocity of about 5000 feet per second. It's running parallel to this one. So up here at that little fracture zone, we squeeze just a little bit of water in, and that's a lower amplitude, even though that generation took place closer to the surface, much closer, by hundreds of -- how much -- 50, 60 meters in this case.

Still, the amplitude is lesser, lesser hydraulic conductivity.

MR. MOONEY: Could you comment whether that example is taken from the volcanic terrain?

MR. MURPHY: It is not taken from volcanic terrain, but it is taken from crystalline terrain. It's from crystalline rocks. It's not from sedimentary rocks. Probably metamorphics in Northeastern Massachusetts. We've been working in some --

MR. MOONEY: Yes. Do you have any reason that this would work in volcanic rocks?

MR. MURPHY: In the saturated zone? Absolutely yes, if there is -- let me finish -- if there are open fractures and implicit in that is hydraulic conductivity, the answer is yes.

If you will bear with me one second longer -- and this is why I feel so strongly about vertical and horizontal drilling. One of the problems with this site, as I understand, for characterization is, tell me about the vertical fractures. It's fine our holes intersect all the horizontal fractures. What about all those vertical fractures we're missing? And that's the whole business of drilling horizontal holes to intersect those vertical fractures.

What better way to do that, at least in the saturated zone, than to run a VSP log right into that horizontal drill hole?

Yes, a question? Or have I answered it?

MR. MOONEY: Well, I guess if you put your example back up, the VSP one, the small amount of data that I've seen -- and I emphasize I've only seen a bit -- indicates that there is so much scattering in the volcanic units at Yucca Mountain that it's very difficult to pick out those tube waves that you're pointing out.

That looks like, if I may say, a textbook example in a homogeneous --

MR. MURPHY: I'm sorry. This is real. The data is real. The cartoon, obviously, is a cartoon. The data is real.

MR. MOONEY: Yes.

MR. MURPHY: I can send you other examples from depths of 3000 feet in the Northeast in crystalline rock.

MR. MOONEY: Well, I mean, what I mean by textbook example, I mean this is westerly granite or something like that and --

MR. MURPHY: No, no. This is a random --

[Laughter.]

MR. MURPHY: This is not a classic westerly granite at all.

MR. CORBETT: What is the angle of curvature to get a horizontal hole?

MR. MURPHY: The angle of curvature?

MR. CORBETT: You're going to start vertically.

MR. MURPHY: It's not covered. I'm sorry. I can't give you that.

MR. CORBETT: Can you do it in these dimensions? I mean, it's all well and good to do the whole 20,000 feet or some such thing.

MR. MURPHY: I thought you asked me -- no, no.

Oh, no. They're not drilling that deep, I assure you.

MR. CORBETT: I know.

MR. MURPHY: They're on the order of 3000 to 6000 feet in drilling horizontally.

I offer that, I guess, as a challenge, to look into that type of deal. I've seen no indication that that's been considered in this program. And I think it will bear fruit.

Even if we have to come in from the side with long angle holes, why not? There's too much at stake here not to do things like that.

MR. CORBETT: If you've got a vertical fracture pattern, that's the only way you're going to test it.

MR. DANIELS: I think one of the main problems with that would be instrumenting those holes.

MR. MURPHY: Doing what?

MR. DANIELS: Instrumenting the holes above the water table because you are going to have to have those holes cased off. They are never going to hold up unless you have casing in them.

MR. MURPHY: There is no question there are logistical factors. Absolutely. I'd be the first to agree on that. I hope they are details and not essentials.

MR. POMEROY: Vinnie, before you go on, can I just pose a question to Walter, because you're familiar with Tom

McEvirly's work at the Nevada test site, aren't you, and that is a more applicable --

MR. MOONEY: Yes. Have you seen it recently? I mean I am trying to recall what the data quality looked like. Do you recall?

MR. POMEROY: Well, I just saw his presentation at a meeting approximately a year ago, I think, or more, and unfortunately the details escape me, but I think the quality of the data was, impressed me as being good enough to --

MR. MOONEY: They got good quality data, okay.

MR. POMEROY: -- to do some good stuff. At least it should be looked at. Somebody should look at the quality of Tom McEvirly's VSP data from the Nevada test site.

MR. IBRAHIM: Are you sure that was in Nevada or some other site because I know they have been trying to come on line and do the VSP on G-4 and so far to my knowledge they couldn't get the permit to go in and do the experiment in G-4 so maybe they did --

MR. POMEROY: It was on the test site. That I am sure of.

MR. IBRAHIM: So I think maybe the data you looked at was at a different location.

MR. MOONEY: That would be the critical thing, to make sure that you're recalling actual test site data. I don't know.

MR. IBRAHIM: It was on the site?

MR. POMEROY: Yes, on the Nevada test site.

MR. IBRAHIM: On Nevada test site?

MR. POMEROY: Yes, NTS.

[Slide.]

MR. MURPHY: Another technique that I think is applicable, especially for the surface base facilities is cross-hole measurements.

In order to determine in place values of the elastic modulite, for design, for licensing, for establishing what the ground motions are going to be in that area.

Many of the materials that I have seen in the project area are granular and we know from sad experience on many other sites that to try and sample granular materials and get an undisturbed sample, no matter how you do it, is nearly impossible.

I would offer you that there is a better way to do it and do it in an undisturbed state, and that is with a series of drill holes granted you disturbed the ground around the drill holes, but then when you perform your measurements between the drill holes, even in the presence of a layer, an intermediate layer that may well be a high velocity layer, this is much like a model, a very large model study.

Picture if you will a mass of material the size of this room filled with sand and gravel and you want to make measurements of the physical properties. I assure you this is the best way to do it.

It's fast. It's clean. You have in-place measurement. You take people like Whitman at MIT, Seed -- passed away recently at Berkeley -- these are the kinds of measurements that they relied on for their dynamic analyses of the foundation conditions of many nuclear power plants and I'm sure their data was presented to the regulators and defended.

[Slide.]

MR. MURPHY: I had intended to get into the word "integration" and some of the objectives that we might consider here but I'm sure you don't want to, but I would like to get into something that none of us has touched on today also, and that is performance.

Once we have characterized this site to everyone's satisfaction and once it is licensed, and now we start opening it up underground, we are going to have some small surprises. There is no question -- please, I trust no one in this room thinks that this project will go from beginning to end without any surprises. There will be surprises. They'll be minimal, if we have this intense characterization, but we want to know once we have these underground openings what is the disturb zone? Whether I am blasting or using a tunneling machine or whatever, this zone of rock on the side wall and in the ceiling, how intact is it?

You know, am I going to walk away from that and have that thing fall down?

What is the damage zone? What is the stress relieve zone? How thick is it? These are some objectives and applications that Professor Don Deere and I first pioneered in Dominican Republic in some tunnels there where this was the question. We did this, I don't know, 25 years ago. What is the thickness of the damage zone around the opening, a very practical but an essential question and you can do it simply by making velocity measurements.

[Slide.]

MR. MURPHY: There are a number of techniques to do this and now I am going to get into one development on state-of-the-art and then I'll close unless you have questions.

We have been developing devices for roll along. You know, the first time we made these kinds of measurements we used to chip away little platforms, put the geophones, the sensors in the hole, and make the measurements, the directed P wave energy, the directed S wave energy. We could get the modulite.

Our recent efforts are focusing on non-destructive testing with the roll along unit currently being used in the Washington Metro but I won't tell you what stations, to test the concrete in some areas that there are some problems with inflow of water as well as deterioration of the concrete.

Well, these practical problems here in the Washington Metro are no different than in an underground opening at Yucca Mountain.

Why? Why do they exist, damaged rock? How deep is the zone? A roll along device, whether you use our device or anyone else's, it's a pretty simple straightforward measurement.

Finally, I plead for a comprehensive measurement, three dimensional manner.

[Slide.]

MR. MURPHY: Let's summarize.

The first thing we're going to do is what? Surface measurements. That's our environment we are working in.

If we have holes, we can measure up-hole, down-hole measurements, sonic logging, but when the sensors are in the hole, let's not have just one source. Let's have multiple source points and characterize it in a three dimensional manner.

Where we have multiple holes, let's do cross-holes and do those in place -- in my terms, model study, but a full-scale model at that.

Then eventually, when we can get underground, or even before that in those horizontal holes, let's perform these horizontal measurements.

Finally, when you put this entire spectrum of activities together you have truly characterized Yucca Mountain.

I won't take any more of your time.

MR. HINZE: Thank you very much, Vinnie.

Are there any questions? Phil? Please.

MR. JUSTUS: I have a question regarding measuring the damage zone. Were you referring to, say, zones in openings on the order of those expected in drifts at Yucca, or were we talking just about drill holes or something like that?

MR. MURPHY: All of the above are possible. Typically, the type of measurements that I know of first-hand and I have seen others involved with are the narrow drifts maybe 1.5 meters to as much as very large 10-15 meter diameter openings.

However, if one is concerned about a stress relieve zone around a bore hole, perhaps at that point we should be performing measurements of P/S velocities in the bore hole as well as on samples and comparing those measurements and if you wish, a mini-velocity measurement on the side wall. There is no limit to the closeness of the spacing or the distance between sensors. It is a matter of scale.

MR. JUSTUS: Have you had any experience in comparing the damage zone to, say, tunnels or drifts that have been constructed by mechanical methods or drill and blast -- and drill and blast methods that you might just summarize?

MR. MURPHY: Most of the work that I have been involved with has been drill and blast, a limited amount in 7-8 meter diameter tunnels carved by a boring machine. Clearly and again I think your common sense would tell you that the drill and blast has a sizeable zone of damage in the order of anywhere from a half a meter to as much as 2 or 3 meters.

In the case of the machine-bored tunnel, I don't recall anything more than half a meter, even less.

If you had a situation of high stress, however, then that would be an interesting exercise to go through. I would expect a much larger low velocity zone even with the bore tunnel.

MR. JUSTUS: Thank you.

MR. HINZE: Carl?

MR. JOHNSON: Vinnie, in the down-hole surveys, from your experience with at least being out at Yucca Mountain and volcanic tuffs, what do you think might be the expected range laterally from a bore hole that detection and delineation of fractures might be possible?

MR. MURPHY: Typically, we think in terms of a 45-degree zone, and I think the simple answer is about that. But I'm also reminded, as you bring up that question, we are going to need in place measurements vertically, as well as core samples to get the P and S velocity in the lab, compare that to the P and S velocity in the field, and at Dr. Moeller's location, Harvard University, Division of Applied Science, O'Connell and Budiansky have been measuring fracture densities by comparing in-place velocity measurements with the lab samples.

MR. HINZE: Vinnie, we read the white paper about feasibility studies, and I know you have done some work on Yucca Mountain; at least, that's my understanding.

Do you have any concrete evidence that we will see, by virtue of a velocity change in the P wave, either due to fracturing or faulting, a sufficient velocity contrast that we can map these out from surface measurements?

MR. MURPHY: First, I will correct your statement that I have worked on Yucca Mountain. I have visited there. I have inspected set of data there. I have, however, worked some tens of miles north, where it was originally planned for a nuclear power plant site. So, it's similar suites of rocks. Also working on pump storage sites some distance to the south.

And the answer is, quite definitely, yes. In any fractured rock sequence, your velocity, implicit in the word "fracture" is lower velocity, implicit in the word "un-fractured" is a much higher velocity.

Have I covered your question adequately?

MR. HINZE: Yes, I think so. Have you see any evidence of aniosotropy that one can measure fracture aniosotropy in fractional faulting?

MR. MURPHY: I have not seen any evidence, but again, clearly, it is implicit in my plea to you for three-dimensional characterization, that out of that an aniosotropy will fall out as a parameter.

MR. IBRAHIM: I remember some of the work which was done was the speeds that you are trying to measure the aniosotropy. So, that maybe can be applied at Yucca Mountain.

MR. HINZE: Further questions, comments?

MR. CORBETT: You mentioned, in terms of physical properties, that tuffs are internally chaotic. You mentioned two reasons. One is fracturing, the other degree of welding.

Is this a predominantly fracturing problem, or can you relate it, as well, to the degree of welding and the changes alone?

MR. MURPHY: I really cannot without actually in-place measurements, and this is where the integration is so important, taking the geology, as we know it, from the drill holes and the surface exposures.

I would also comment on this particular NUREG document that, as one of the authors, it is a slightly dated document. It is also a survey of all the possible settings for storage, not specifically focused on just Yucca Mountain, although there is one subpart or part on tuff.

MR. MOONEY: I'd like to ask a couple of questions.

What would you use for shear wave source for measuring the VS?

MR. MURPHY: It would clearly depend on the distance between the source and the receivers.

A practice picked up from the Japanese some years ago is simply a plank on the ground with a vehicle weighting it down and directional hammer blow on the side and the geophones in line, many times an unconsolidated, semi-consolidated, highly-fractured media, short travel length, excellent shear waves, remarkably high-amplitude shear wave data.

That technique is also quite applicable for shallow drill holes.

MR. MOONEY: I have great doubts that this will work at Yucca Mountain.

MR. MURPHY: At all?

MR. MOONEY: Below depths of a few tens of meters or offset -- receiver offset distances.

In our seismic profiles that we recorded there, we had to shoot up to 4,000 pounds of ammonium nitrite, fired instantaneously in a deep bore hole to get propagation to 40 kilometers.

The amount of seismic effort we expended at Yucca Mountain to get good data was extraordinary for the distances that we were covering.

It's a very heterogeneous, very scattering kind of a medium, and I don't think that, with a plank on the ground and a weight banging against it, you're going to get -- you'd be able to characterize the velocity structure to great depths.

And I think there is an interest in depths below the first few tens of meters. Obviously, as you know, there is a lot of interest.

So, I am curious whether or not we can get good VP and particularly VS data to great depths at Yucca Mountain using conventional techniques, especially for sheer wave.

Sheer wave is a difficult mode to generate.

MR. MURPHY: In my opening remarks -- I think you were out of the room -- I commented -- and I'll repeat -- you and I, in a sense, live in two different worlds.

You live in the world of the kilometers, as you just stated, and the seconds. I live in the world of the milliseconds and the hundreds of meters.

I do believe strongly that, with a directed energy source, whether it be horizontal vibrators, a horizontally-directed air gun, you will to a depth of many tens of meters.

MR. MOONEY: Right. But I am not sure that many tens of meters are the depths that we are interested in here.

It may be many hundreds of meters, and that's where my concern comes in, or maybe even a couple of kilometers of depths are of interest, and that's where it gets very difficult, in this environment, to get good quality data, particularly shear wave data.

MR. MURPHY: We may find -- and, obviously, not having done it, I can't promise you, if you go out, it's going to work 100 percent. You may be pleasantly surprised.

In some of the fractured, low-velocity media, you have high amplitude shear waves; perhaps low-amplitude P waves but high-amplitude shear waves. I'll give you a little case study, different than this problem.

I wordered for some time what would happen in the gulf sediments that are unsaturated, in New Orleans, for example, and even though you're at sea level and you're working 10 meters below that and the gaseous material is there, what kind of shear wave data are you going to record from that site, and I'm using this illustration, because I know this firsthand.

Some of the largest, highest-amplitude shear waves with small explosive sources come from those low-velocity sediments. Often, we are pleasantly surprised.

I would predict for you here, at Yucca Mountain, that you will be more pleasantly surprised, up on Yucca Mountain, with the shear wave data than you will with the P wave data.

MR. MOONEY: Could you explain that again? Where were you getting an S wave source from unconsolidated sediments by setting off a charge?

MR. MURPHY: In the organic mud, unsaturated.

MR. MOONEY: So, what's the physics of generating a shear wave with an explosive source in an unsaturated sediment?

MR. MURPHY: Well-documented -- people have been doing it for years.

We have been doing it using explosive sources, because typically where you are generating, in the near-surface materials -- by near-surface, I'm talking the first few hundreds of meters -- the materials are anisotropic enough that you will generate a considerable amount of shear wave energy.

I think what you're alluding to -- and let me put it in the form of a question -- are you not alluding that explosive sources generate only P wave energy and a minimum of shear wave energy?

MR. MOONEY: Well, explosive sources, depending on the geometry of the explosive in the hole, can generate shear wave sources, but generally, more shear wave energy is generated by free surface conversion or conversion to boundaries within the medium.

Like, for example, the base of these unconsolidated sediments, if they go into a limestone or something, then there is a good boundary for there to be conversion, but that wasn't quite what I heard you say.

MR. MURPHY: No, you did not hear me say that. I agree with you totally on your characterization, but I also offer to you that you will be pleasantly surprised at the amount of shear wave energy that you will generate with explosives in shallow drill holes.

This is a technique, on those cross-hole measurements, where we're down into the rock masses. I'd be happy to send you some data on that.

[Slide.]

MR. DANIELS: We are trying to characterize the geology. We are trying to provide a subsurface image, and the I word, integrate, physical properties with the surface geology in geophysics.

Basically all we are doing is taking standard surface geophysical techniques that have been used for a long, long time, and we are sticking them in the bore hole. It's no magic here. A lot of people have said, well, resistivity hasn't proven to work in the drill holes.

Well, it's a founded principle at the surface. Why shouldn't it work in the drill hole?

The same thing goes for electromagnetics, the same thing goes for seismic. A lot of times we don't have the capabilities to handle the data properly, but that is a developmental problem. It's a problem of developing the techniques. It is not a problem with the physics.

[Slide.]

MR. DANIELS: Okay, let's take a look. Again, we have a certain limitation and we have certain applications that are better in some areas than others. And there are different zones. The unsaturated zone up here, or the Vadose zone, as opposed to the saturated zone down here.

Obviously we have some problems in the unsaturated zone with resistivity, but at the Nevada Test Site, we simply wrapped our electrodes in foam rubber and saturated them with drilling mud, and we were able to make hole-to-hole and hole-to-surface resistivity measurements at the Nevada Test Site in UE25A4 through A7 above the water table.

So there are ways around some of these problems.

A lot of these techniques up here have not been used in the Nevada Test Site, and I think really we should seriously consider them. Seismic, gravity, and magnetics are used, maybe not as routinely as I feel they should be in the bore hole at the test side.

We have these really super high-priced drill holes, we need to use them.

[Slide.]

MR. DANIELS: Somebody mentioned a little bit earlier about resolution, the problem of resolution, and I am going to stick my neck out here, and I am going to talk a little bit about radar. And in geophysics, I like to show a curve normally that has a cross plot of resolution versus depth of penetration, and that curve shows us that basically the greater the depth of penetration of almost geophysical technique, the lower the resolution.

Here I say gravity, magnetics, and resistivity are relatively low techniques. The high resolution techniques are when you get into techniques that use waves. Seismic propagation, low frequency electromagnetics, high frequency electromagnetics, and radar.

But our tradeoff here for high resolution is the fact that we don't get very good penetration with these techniques. So a lot of these techniques are restricted to either working the drill holes or working very close to the surface.

[Slide.]

MR. DANIELS: Ground-penetrating radar and -- both from the surface and in the bore hole has become pretty well established over the past few years, thanks to the hazardous waste industry, thanks to the EPA, and the fact that we need to have high resolution techniques in the near surface to be able to clean up some of these waste sites.

I spent the last five or six years primarily working on GPR, and here basically the technique is shown in the surface mode where we have a surface transmitter and receiver. There are standard commercial systems available for this. This is not brand new technology, it is fairly well established.

You can go into a single drill hole and use a reflection technique where you space the transmitter and receiver apart, and hopefully, if you have some type of an object out here that has different electrical properties, you get a reflection off it.

Again, look at the similarity. All we have to do is take this technique and turn it on its side and we can do it in the bore hole just as well as we can from the surface.

Now one of the problems, and one of the problems that we are working on right now, is to try and give some directionality to this technique. Right now we have certain antennas that we can orient and get a 90 degree beam with, so we can get some orientation and azimuthal direction away from the drill hole.

I think we can do a lot better than tnat. So that is one of the problems with this technique. Right now it's omni-directional, whereas, at least here you're tied down to the surface.

Okay. This really should be hole-to-hole transmission. This technique, where you put a transmitter in one hole and receiver in another hole, has been used for a long time. I have worked with it in Korea. It's been used for tunnel detection across the DMZ. It's a proven technology. There are about three systems in existence right now that I know of. One is by the Swedish geological company that markets the system. Another system is maintained by the U.S. Geological Survey in Denver; and a third system is maintained and used -- the one that's used over in Korea was developed by Southwest Research Institute.

Again, this is basically what you get; if you see a similarity between this and what Vince showed us a little bit earlier, it's no accident. It's the same basic principle, only now we are using electromagnetic waves rather than acoustic waves.

You can see this is the record section you get, you use a transmitter and a receiver, and this is just going up the drill hole and this is time over here. This is a scanned section in time, and as you go up the drill hole, you can see there's this anomaly No. 3 off to the side, which is a change in dielectric constant, and you can see this diffraction off of this object.

MR. MURPHY: May I ask you a question on the uniqueness of interpretation?

MR. DANIELS: Yes. I would say the interpretation, in this particular case, is quite unique. As long as you get directionality. The uniqueness falls in the azimuthal problem. There is no question but what this is a diffraction hyperbola. It must be caused by a change in dielectric parameters. You can estimate the distance from this because, just like with seismic techniques, you know what the slope is, so you can compute the speed, and you can compute the distance of this apex away from the drill hole.

So it is very good.

MR. HINZE: Can you do anything with attenuation characteristics, where there are a series of fractures, for example, rather than a --

MR. DANIELS: That is a problem that really has not been addressed yet. However, people have worked from the surface with determining the variations in moisture content based upon amplitude, and there has been some success in the civil engineering community with doing this.

But I don't know of anyone in the geological or geophysical or electrical engineering community who has addressed this problem in terms of a diffraction off a material. But I think it is something that is certainly -- bears some investigation.

MR. HINZE: Can the matching of the antenna to the rock surface be consistent enough so that you can use attenuation?

MR. DANIELS: In the bore hole environment, I think one of the advantages -- we always complain about our environment, it's so bad to work in -- but one of the advantages we have is we do have some control on what is going on in that bore hole environment, so that as opposed to what you do at the surface, so that we can make other measurements, we can make conventional geophysical -- bore hole geophysical measurements. We can measure dielectric constant, we can measure resistivity of the surrounding rocks and of the bore hole fluids. So I believe we have a better chance of calibrating for amplitude and for source effects in the bore hole than we do on the surface, for example.

So we have a lot better shot at measuring attenuation and amplitude parameters in the bore hole than we do at the surface.

MR. HINZE: It sounds to me like that would be a pretty good research endeavor for Yucca Mountain, looking at fracture pore space, not only from drill holes, but once the exploratory facilities are developed, for working away from those.

MR. DANIELS: Go ahead, Phil.

MR. NELSON: If I could just make a comment along those lines. I pointed out all the measurements that Len Anderson had made on other physical properties, but one that has not been done yet that I think we should do is to work on dielectric characterization of some of these, of just -- you know, not that large a sample suite, but it is important to do it over a fairly broad frequency range for a select set of samples that span both the zeolitic and the welded rock type and with a range of porosity. It would help both the hole-to-hole engineering design, and it would certainly help us interpret the existing set of dielectric logs that we already have.

I didn't show any of them, but we do have a good selection of dielectric logs and enough holes that indicate that that kind of data would be useful in looking at porosity and water saturation.

MR. POMEROY: Jeff, at the Nevada Test Site, have you used this technique at the Nevada Test Site?

MR. DANIELS: I don't know of any bore hole radar work that has been done. Maybe Dave Wright has done some at the test site, but I don't believe so.

MR. POMEROY: How about, just as a general answer from the surface, for my own information, you were talking there in that example about -- I think your depth went out to something like 100 meters on your plot. Do you have some feeling for in this type of material what the penetration --

MR. DANIELS: Let me talk about that at the end. I'm going to talk about surface radar in just a minute.

MR. POMEROY: Okay, fine.

[Slide.]

MR. DANIELS: Okay, single hole reflection techniques, in my opinion, are a half a loaf. If you want to go the whole hog, you want to go hole to hole. If you want to be able to best define things. And Jeff Lytle, really one of the pioneers in the field, many years ago, before most of us had the nerve to make this suggestion that electrical measurements could be used to image things in the subsurface, was using some of the research that was being done in the biomedical engineering community, and doing some hole-to-hole radar measurements, and doing tomographic imaging, to try and not only determine whether or not you had an anomaly, but the location of that anomaly and something about the size of that anomaly.

Now if you take this and go combine this with surface techniques and hole-to-surface techniques, to me, in my opinion, you not only can determine where this anomaly falls, as far as with respect to these two drill holes, but you can also get a good estimate of the azimuth of the particular object.

[Slide.]

MR. DANIELS: Okay. Again, the data looks, for hole-to-hole techniques, looks very similar to seismic data. These are wave form data. You can use color scan data and all kinds of presentations. This is from a tunnel across the DMZ. This is third tunnel, and there is a velocity anomaly associated with it.

Now one of the problems here that we have in terms of perspective and scale is that we are talking nanoseconds across here, zero to 500 nanoseconds.

You can see the diffraction pattern as well off of the tunnel.

Now this is transmission data.

So there is a fair amount of experience with hole-to-hole, high frequency techniques. People are working on lowering the frequency so that we can get deeper and deeper penetration.

[Slide.]

MR. DANIELS: Let's look at the surface.

This is surface radar data. And this is a dipping reflector. This is from an article that was published a long, long time ago, and basically you see the diffraction patterns along this thing.

This is depth per time, and this is horizontal distance. And one of the big advantages to surface ground penetrating radar techniques as opposed to a lot of other geophysical techniques, with the exception of seismic reflection techniques, is that it does give you a two-dimensional cross section of the subsurface. And if we are going to look for things that give us good images, eventually, we need to focus in on those techniques that give us both horizontal and vertical data simultaneously, so we can get a good picture of the subsurface.

[Slide.]

MR. DANIELS: Okay. Ground-penetrating radar at NTS. I don't have any direct experience with this. I have talked with Gary Olhoeft about it, and he has taken his commercial system out there and tried to make measurements. He said he got measurements and got penetration depths down to 40 feet, approximately 15 meters. However, he had a lot of interference from microwave transmissions.

Now this is a relatively high frequency antenna system. My feeling is that we can get around this microwave noise problem. The commercial system that is out there right now is notoriously bad as far as interference from microwave noise. We have been doing a lot of work at Ohio State on this. You can solve some of the problem by shielding. You can solve some of the problem by field processing, by the antenna design itself, and not use commercial systems, but use systems that are designed for certain frequency ranges and lower frequency ranges, by averaging techniques in the field, and by data processing and filtering after you get the data.

As far as I am concerned, the jury certainly is still out on whether or not we can do good penetrating ground-penetrating radar measurements at NTS. I certainly think it is worth a fair amount of effort to give it a shot.

Certainly the kind of data that we get will ultimately lead to a good picture of the subsurface, so that hopefully we can answer this question.

I suggest that we should start looking at things in three dimensions right away, and look at some of these palinspastic reconstruction techniques and put some of the data sets that we have into a three dimensional framework, as far as moving ahead to help to integrate this data.

Maybe this is already being done. I hope it is.

MR. MURPHY: Jeff, a question with regard to penetration and surface conditions.

MR. DANIELS: Yes.

MR. MURPHY: Often we run into, in this geologic environment, a caliche layer at or near surface. Given that that exists, widespread, what happens to our radar penetration?

MR. DANIELS: I don't know what radar is going to do in caliche. Caliche -- I haven't really thought about it, because I hadn't run into caliche other than in South Texas, where we did some measurements, and I found it to be very hard and very resistive, and I thought that it would have a very high -- I would expect it would have a very low dielectric constant. And so it could cause some interference problems, but I am not sure. But certainly with GPR measurements, you have a better shot at seeing that and defining it than you would with most other techniques in the near surface. At the very least, GPR should be run where you are going to put trenches in and once you get the trenches, you should run GPR in the bottom of those trenches, and along the sides of those trenches.

MR. FRIDRICH: Well, actually, it sounds like maybe it would be good for defining caliche in the subsurface.

MR. DANIELS: That's right. Sure.

MR. FRIDRICH: Which is a worthwhile goal for some activities.

MR. IBRAHIM: Just a little information. I think the ground-penetrating radar has been tested by the people from Sandia, and I think a student of Bill -- I don't remember his name -- and they didn't come out with good results down there. But I think maybe because you were using an old analog system, and I thought maybe if they tried to use some of the new improved systems, you may be able, and I think they are planning to use it at the Midway Valley, where they are proposing to trench down there.

MR. DANIELS: I think there have been enough advances in the last -- even in the last couple of years in new antenna designs and things that there's a shot here to get good results.

MR. IBRAHIM: I am just saying that they used it already down there.

MR. DANIELS: Yes.

MR. HINZE: Has there been any attempt to look at trench 14 and the calcite silica veins at trench 14, is it, to see whether these can be detected by GPR, and that's why they're --

MR. DANIELS: Not to my knowledge.

MR. HINZE: Okay. It is very easy to visualize, speeding across with your all-terrain vehicle, across Midway Valley, with this antenna.

[Laughter.]

MR. HINZE: Trailing behind you. I can see you doing that. What happens when you hit the Yucca Mountain area and the irregular topography?

MR. DANIELS: Well, then you slow down.

[Laughter.]

MR. HINZE: The surface conditions, I thought Vinnie was going to get at, the micro topography and the problem of matching.

MR. DANIELS: Sure, you are going to have some problems with -- you have going to have some problems with micro topography, and it is going to be on an adjustment basis in the field. I mean it's like anything else. You know, we always like to say that geophysical techniques aren't affected by topography, but they have very high resolution, and you scratch your head and you say, well, gee, that's not the way it should be. If they have high resolution, then topography is going to affect them; you are going to have to correct for that.

I think in this environment you can do that, and that is another aspect of GPR data, you can collect a tremendous amount of data in a very short period of time if you have open space.

MR. HINZE: Thank you, Jeff. I do have to apologize. I have just been reminded that this is Earth Day. We have to look out for the desert toward us, and therefore you cannot go speeding across.

[Laughter.]

MR. DANIELS: And with that, I have taken my half hour.

MR. HINZE: Further questions?

MR. MURPHY: Yes. I think it is appropriate here for both radar profiling and shallow seismic profiling that some of those topographic features can be explained simply by profiling, especially if there is a horizon at shallow depth. Does it come up under one of those topographic elements, or is it a through-going horizontal layer, and therefore it's just geomorphology?

MR. DANIELS: If that topography is caused by a fracture zone, hopefully you will see it as you go across, in addition to the topographic effect.

MR. HINZE: Further questions?

Jeff, thank you very much.

We will move on then to Jack Corbett, and Jack will be discussing some of the electrical methods at Yucca Mountain.

MR. CORBETT: This will be another change of pace here. This was directed towards the electrical methods, shallow, and we will define that further as we get along into it.

A lot of the work that is referenced here in my mind is certainly not what we would call state of the art of today. I don't know how much has been done since this time, which is the late '70s in the measurements, in the early '80s in terms of interpretation, and we will touch on this as we go along, and you will see that we are reacting or responding to a number of comments regarding some of the other methods that we have already seen or heard about.

[Slide.]

MR. CORBETT: In terms of starting, I would like to review a little bit of some of the methods that have been done. This is the location of the geoelectric surveys in the Yucca Mountain area. The red dots are MT acquired in the early '80s --

MR. HINZE: Jack, could you move those up just a bit? We are having a hard time seeing them. Even a little further might help. Thank you.

MR. CORBETT: They are essentially located south of the site. The blue are the areas of geoelectric surveys of different kinds that have been done from time to time.

Several elements of this, and I commented and our protagonist is gone again, in terms of the I word, integration, this is one area that I would say this data has not been integrated, for what it's worth, and it may not be that valuable, but integrated into the seismic work. This has the potential to be deep soundings and provide some elements of the greater depth there, and has not been used, not been integrated, as far as I can see.

The same way with the Schlumberger soundings. A different technique. We won't go into great depth on this at all in discussion of this, but essentially again in another site, that have not been applied to the area itself, but still to that lower seismic line, which I believe comes across in here, and this would help evaluate whether these methods have an application at all through the particular site itself.

Of more importance, as far as I am concerned, in what I have to say, is the location of the electrical work within the site itself, and these are the patterns of mostly DC resistivity. There are Schlumberger soundings noted here, if you can see them -- I'm not sure I can, either -- within this -- yes, I see several within the area. Then here and here, but these are not mentioned or discussed in terms of the overall evaluation of the electrical data.

The lines are not quite as haphazard as they appear, but this would be a comment I would make again, I think that Murphy made this point, a grid of lines, and the attempt through several parallel lines would be better than random lines to give me some line-to-line continuity, some othe element that I can verify, not only just the down, but I have something in the strike or I don't have it. And that could be a critical factor.

Compare this with the drill holes, and Phil Nelson was mentioning, I think, this is the line coming down Yucca Ridge of his section, of the section that he was referring to earlier, and one of the, I think, very important elements in terms of the electrical interpretation done to date, has been accomplished, and what should be accomplished is to integrate the data that we heard earlier into the electrical interpretations. It's a question of zeolites, the conductivity, the three orders of magnitude that we have seen, or Phil has seen, in terms of this, should both be modeled in the forward sense, and thrown back into the interpretation of the existing data.

I think these are crucial elements in the interpretation of existing data, as well as the design of programs that we would get into.

We are going to back up a little bit on these and kind of come back and around, and we will touch on them.

Pseudo-section data of the resistivity, I think it's at 200 foot dipoles, 200 foot dipole-to-dipole array. And compared to again from what I saw in Nelson's work, in a nice layer cake situation, this is anything but layer cake geology. There are lateral variations due to something, and I think could be or should be interpreted from that. I am not sure we have the reasons why, but we are seeing differences that we must reconcile.

MR. MURPHY: Jack, what does that data mean with regard to site characterization? The suite of data we are looking at on the bottom, what do we do with that set of data for characterizing Yucca Mountain surface facility, or any other site?

MR. CORBETT: I am not sure I can answer this head on, because of the depth of water here. If the water table were shallow, relatively speaking, it would look to me as a function of fracturing. As it is not, we are looking at some other lateral heterogeneity, and this comes back to the question this morning of if this is consistent, then we have one answer. The fact that it is not consistent, we are seeing breaks, we are seeing fracture patterns or potential fracture patterns falling along this diagonal, some low resistivity feature here that could be alluvium, but this has not been plugged into the interpretation either.

So what I am saying, and I think coming back to, is electrical methods can provide a back-up information on the homogeneity or heterogeneity of these systems.

It also gives you some indication -- and we get to touch on the mineral resource evaluation.

MR. MURPHY: When I put this data together with your comments, don't I come out with a situation of lack of uniqueness?

MR. CORBETT: Absolutely. Absolutely. No question about it.

Again, the integration from other data may reduce that ambiguity. The geologic constraints, the very fact that we have now some -- we have -- we have had it -- but we have some logging data of resistivity that we can put into various holes -- I don't know where hole align -- this is A and C, where these holes fit these lines crossed relative to what hole. But what layering do we see there, and can we input that into this, to then get a better consistent interpretation of what that data is?

This is the resistivity data. Again, chargeability, I presume, was run on this, but again that is not shown, and the major problem with this was the interpretation of major faulting through here, or an alternate interpretation of lithologic blocks, and that question has not been resolved relative to the electrical data.

MR. FRIDRICH: Jack, in that the conditions out there are very dry, do you ever have trouble with coupling to the ground, that you --

MR. CORBETT: Very definitely, and that may be part of this, but that is not what we see here at the moment. That is the limitation of the galvanic methods. We will come back to that again, but very definitely it can be the coupling to the ground, contact resistance of the electrodes to the ground.

Presumably that was evaluated and reduced to a level that that should not have been a major problem. Should not have been. But again, I don't know the data.

[Slide.]

MR. CORBETT: What this has provided is some fairly serious discrepancies. This is the faulting. I think that is the Ghost Dance there, isn't it? Can someone verify that for me? That is derived from the geologic mapping, and one of the critical parameters was the Ghost Dance. Can we see this, and is that a major offset and conduit, or potential conduit, how deep does it go, of the geologic interpretation versus the geophysical interpretation. And there are some significant differences that, to my knowledge, have not been reconciled, and I can't evaluate that past that point. But I think there are some things that need to be evaluated in terms of the application of electrical methods. Then it's a question of where they apply, how do they apply, and what basis do they have in an area such as this.

MR. NELSON: Are you cognizant of what they call the TAR Report?

MR. CORBETT: Yes.

MR. NELSON: How much of these questions does that report address?

MR. CORBETT: A good portion of that, a good portion of the geophysics section addresses the problem of interpretation here.

MR. NELSON: I am a little confused. I thought you said it hadn't been looked at, but --

MR. CORBETT: It hadn't been resolved.

MR. NELSON: Hadn't been resolved.

MR. CORBETT: It hadn't been resolved. If I said "looked at," I did not mean that in that sense. It has not been resolved. The question of topography, two-dimensionality, and the topography, 3-D topography, these questions that come into that, and how well can we interpret a set of data like this regardless how unique, can we come up, given typical resistivity data.

I am more concerned in a sense about the implications of this rather than a "precise" body determination or location. What are the implications of this, given the assumptions that I think you were making about lateral continuity and certain horizons.

This comes back -- and some of Jeff's comments addressed this -- and that could be hole-to-hole electrical work. Could this resolve some of this. And is there another parameter there that we are not looking at in the same sense of the electrical, the resistivity variations. Laterally. You have demonstrated them vertically. But there is some change in resistivity, just look at the numbers, assuming they are real, that these are apparent resistivity numbers, and the contrast to develop that kind of a number has to be significant, several orders of magnitude. What are those features? Are they significant, and do we need to evaluate them, and from my point, I say yes, we need to evaluate them.

Because of implications in mineral resources, if nothing else. And this is one of the -- I think this is Smith & Ross, with the major blocks here denoting offset and faulting, and is one of the problems that need to be looked at.

[Slide.]

MR. CORBETT: Again these are the "grid of lines." There is one other point that I will make. There is a time domain line, and I don't know where the data on that is, or what it is, but it's listed there. I bring it up because I'm going to talk about it in just a minute.

[Slide.]

MR. CORBETT: We have shown these on another scale. I will bring them back. Again, the faulting data based upon the geologic map. And if I can overlay these and get away with it, the faulting based on that interpretation of the geophysical map, that has caused some consternation as to the reality of which is involved.

[Slide.]

MR. CORBETT: This is, as I say, data that goes back a number of years, 10 years, and I'm not questioning the state-of-the-art nature as it was done, but I think I might question whether or not, given the technology we have today, some of this ought to be repeated, for two reasons, and let me come back to that.

Take off on a different tack for a minute, and we will talk about some arrays and electromagnetics, because we are going to use these in the subsequent discussion.

The electrical arrays in this case, I am showing a dipole-dipole, we are going to talk about pole-dipole with one current at infinity, and we are going to talk about pole-pole with one current and one potential at infinity. And I refer to this particularly because I am going to mention the E-SKAN System later on as a resistivity method, technique, if you want, which combines information from all of these array types. So we are combining not exactly apples and oranges, but we are combining array types, throwing them all on a pseudo section, and plotting this kind of data and attempting to interpret it. Hence, the electrical array discussion on this.

We haven't touched the Schlumberger which has certain advantages, certain limitations, and we will get on to this.

As opposed to the frequency domain systems, there was some -- Flannigan did some Slingram work here, and I think came to the conclusion that it wasn't terribly applicable, in that environment, which is the upper method, horizontal loop, or Slingram loop-loop, the terminology varies. And I certainly would concur that that is not a method that I would want to recommend in this environment, period, full stop.

Combination of depth at penetration, given the frequencies used in the system, and the topographic environment. Airborne, we don't need dimension. We won't go into the type of signal particularly at this time.

More important, I think, to the recommendations to this environment are the TEM arrays, particularly the upper type of thing, where a large loop -- large being anywhere from 100 meters to 1000 meters, literally, with an in-center or in-loop measurement of the vertical component of the secondary field, and this gives us an effective vertical sounding, if you will, based on the frequencies, and where the frequencies vary on these in terms of the time domain signal over the usually -- the normal contract for expiration are three cycles or 30 cycles, or both, so you are getting a fairly low signal, low frequency component that you can use to give you the depths necessary to get to 1000, 2000 feet, given loop size and other equivalent parameters.

I think this method has potentially a great deal of application in this environment, particularly when I see what Phil's work with that zeolite zone down there, 400 meters, and what's the extent of it, we can map individual points through a sounding, and essentially generate a profile by multiple loops along a particular line.

The other method has applications, I'm not sure it has a particular application in this area. So I will be talking essentially about the in-loop method in terms of the recommendations.

[Slide.]

MR. CORBETT: The last EM could have application that essentially wasn't 10 years ago as a CSAMT, and these have been developed, and are still literally in the development stage, and basically it constitutes a large transmitting dipole grounded, some distance away. We measure the E field in the X direction and the H field, the magnetic field, in the Y direction, and from this compute apparent resistivity.

The advantages of this, as opposed to, for instance, the loop-loop or some of the time domain, is the fact that if we set our parameters a distance and frequency, we get into a plane wave distribution, and have some advantages of interpretation.

All of these methods are going to have a resolution problem in terms of the greater depth that you are looking at, the greater contrast, and/or size to detect a given body. So if we are going down 1000 feet, we are not going to see a 10-foot zone of something. We are going to have the equivalent size.

My comment again on this is that what is the importance of the size elements and the fact that we may have basically a homogenous set-up, implying that the faults are tight, they are not particularly conductive in terms of a lot of gouge and/or fluid, or they are simply small.

[Slide.]

MR. CORBETT:

Applications of these, I would break it down into several regimes, if you will. In terms of the regional evaluation, what are we looking for? And that's the structured tectonics magma chambers. These are the things from my perspective -- I am kind of like Murphy here, I have heard a lot of kilometers, and now we are going to talk in meters, we have heard deep and now we are going to come shallow -- the regional evaluations, we are going to have site characterization and very arbitrarily I am going to put these at 4000 feet and 2000 feet. Nothing magic about these numbers until you get in the skin depth phenomenon and this type of thing, but there is also an economic depth limitation, as we will touch on the mineral resources question again of where we can put something in this.

But in this we have got a number of possibilities that we might look to electrical methods to help define. Shallow faulting, economic resources, the shallow aquitards, the hydrologic gradient -- although I have seen or heard that there is very little difference in the resistivities, and somebody correct me, please, on this, between the water table and those above them. There is no significant change as we hit the water table.

Is that a correct statement?

MR. FRIDRICH: That's pretty close to being right, because the saturation is so high in the unsaturated zone.

MR. CORBETT: Now I have heard a lot more about zeolites, and now we are coming into another question, and that is the conductivity.

However, I think these things might be thrown back into a model of these, and can we in fact expect any one of these methods to give us information here that is going to be useful, or simply are we going to eliminate them because of that?

This is not a feasibility on site, it's a first pass evaluation.

[Slide.]

MR. DANIELS: Jack, I would like to ask either you or probably direct it to Chris -- you know, we keep talking about faults and fractures in the near surface. Should we be, instead of individual fractures or faults, shouldn't we be thinking about fracture zones, which is a quite different thing than --

MR. FRIDRICH: I agree.

MR. DANIELS: -- looking for an individual fracture or fault?

MR. FRIDRICH: For most applications, you know, unless you are looking really small scale, like right around the surface facilities, for all the hydrologic applications, we should be looking for fault zones.

MR. CORBETT: And there is no question, we are looking at fault zones at depth. We are not looking for a fracture or a fault, unless it's a magnificent one. But in general, we are looking at fault zones. What are they going to do, and how are we going to do it?

Going back to my three -- not my three, my two site characterization bases on here, the zero to 4000, the DC resistivity -- and I throw this out as not an advocate so much as the possibility of this E-Skan system. And I have got to be a little careful here, because I do not disagree with the technology involved. I disagree with the interpretation of the results that he has proposed.

So I think there is the potential here for the characterization of a deep -- I would say prospect in terms of mapping in depth a prospect area that has already been defined fairly well on the surface. Go back to the Carlin trend for this type of thing, take some of those areas and potentially put that in, and look at it. It is one of the best DC methods, in my mind, again, taking the constraints of interpretation.

TEM, and we are touched on the TEM in terms of the contract TEM versus some of the Keller's time domain EM where he is looking at crustal studies, he is looking at -- I can't think of what the power he zapped into it, but he was talking about a different order of magnitude, and I'm not sure what this is.

But there is potential for some of the TEM methods to give us information as low as -- as deep as 4000 feet, CSAMT also has that.

In a sense we are looking at increasing depth to features here in between the 2000 and 4000. I should have probably put a GPR up there above VLF because of the penetration and the frequency, if we want to throw in electromagnetics. The top two VLF and airborne have very limited depth of penetration because of the frequency, skin depth problem.

The loop-loop or Slingram, again the frequency response, I don't think has any particular future applications.

As we get into the DC resistivity, whether we are talking about E-Skan as a particular application or we are talking about just straight dipole-dipole resistivity, with the description that I have heard today, with the zeolites, then I would look very seriously at the question of spectral IP.

It is feasible to distinguish between zeolites and sulfites with spectral IP. In this environment, one of the questions is, is there a mineral resource involved. You may not say there is, but you can certainly come up with the other statement, and it is highly unlikely. You are going to be overpowered with the zeolites, and that in itself tells you something geologically. But you are going to eliminate, after the feasibility, the question of major sulfite distribution of that epigenetic hydrothermal origin.

Schlumberger soundings, I think, are in my opinion are relatively passe for the greater depths. Not for necessarily the shallow resistivity environments. There needs to be more work done on the very shallow alluvium/colluvium question as involved in the interpretation, because normally if we get into a deep environment, the arrays are so big we do not know what happens at the surface, and that can influence the interpretation.

They have been replaced in my mind partly because of the geometric problems, the resolution problems, by the time domain soundings, that give us a better vertical control at a given point, due to the frequency range.

CSAMT is another one that has that, it's a frequency domain system. You are talking about .1 or .01 to about 8000, 8 kilohertz, and again there are some problems in interpretation with this, but it has potential for a deeper mapping again of the larger structures, which is understood in this.

Then I would come back to the elements here, particularly the economic resource question. I touched on the spectral IP and the use of it there. What are we looking for in this environment? The immediate response, the few deposits in tuffaceous rocks. You are probably looking for centers and an epithermal gold system, very low grade of gold, very subtle anomaly, if any, in terms of the electrical parameters, and you certainly would not start with this, start with an electrical array to look for these, given the distribution we know already exists in this type of environment. But you would follow up, for instance, in a normal exploration sequence, you would use the geochemistry first and follow this up with electrical methods, attempting to map that again in the third dimension that you won't get in the geochemistry as well, or you won't get it.

If we go to another type system, and implied with the intrusive base porphry, copper porphry moly or gold system associated with this, then we are back to a basic element of magnetic interpretation. As a starting point, where are the intrusives, are there any within the site, and have we the initial for a porphry system within this, and I think we can reduce or eliminate that from a high probability.

The last one I would come back to is the paleozoic surface, and using the post-American example of the major gold deposit found at a depth of a thousand feet, if you will, below modest, if any, geochemical signature; substantial debate on how it was found, geologic projection or otherwise; but nevertheless, there is a gold system that can be mined profitably at a depth of 1000 feet.

How do you eliminate this? You eliminate the probabilities in several ways. One is evaluation of the paleozoic. This comes back to hopefully another hole or more in the paleozoic units, look at those in terms of their siliceous carbonate nature, and carbonaceous, and carry that evaluation out.

That post-American barrack, to the best of my ability and knowledge, is a detectable IP anomaly, given reasonable background conditions, et cetera. This is modeling. There is a rumor that it was found with geophysics, but the methods are certainly far from -- well, that particular system and method is far from well demonstrated or documented.

MR. FRIDRICH: Jack, do you think that 4000 feet is a good number for the maximum depth that those techniques, the TEM, will work at?

MR. CORBETT: Maximum depth, probably, yes. Maybe substantially less than that. It depends on the resistivities. You are not going to get IP chargeability and the dipole-dipole down there, to any significance, so you have got -- that's why the 2000. Very arbitrary, though. I mean there's a skin depth that you've got to bring back into it.

As you get into the size of things, you certainly can get that with certain TEM methods by just reducing the frequency. That is a major problem as you get past the point. As you get into the geometric systems, the IP, your arrays get so big that your resolution goes to hell, and whether you could get penetration, the anomalies you are going to find are going to have to be caused by such big systems that you have lost, I think, the resolution that you need in this environment.

We could go through a number of things of what electrical problems, things we must consider; I have said skin depth, the resistivity contrast itself to provide lateral-vertical resolution, equivalence problem. I have touched on the secondary characteristics, the chargeability. We haven't touched on the reverse of the EM coupling problem. We have touched again on the frequency of time, but I don't think there is any point in going into those now.

I would like to kind of wrap up my point and open it up for discussion, if there are any questions, with a number of points that need to be addressed in terms of the use of the electrical methods. Very important the bore hole data that we have seen, the size and depths of these units. You probably will not pick up more than four lumped units in a time domain vertical sounding, and then you are going to run into the equivalence problem of either very high or very low thin units.

So that is a forward question that needs to be looked at, in my mind, with the logs that we have seen that are available, I believe, now.

There certainly are resistivity contrasts in the environment, and I would maintain that there are resistivity contrasts not only vertically but laterally as well, and what is the significance.

The density can plug into this, and I would use this more as a lithologic control of attempting to find again where are we getting these zeolites or these clay layers, where are the more welded tuffs, and the interpretation of this as again a lumped system.

Forward model some of this, take a look at whether the electrical methods, given this environment, are going to be practical. You certainly are going to start with a feasibility in one sense of the word as you get out there, and not so much as they are going to give you information, but that needs to be, as in the seismic, needs to be evaluated on a daily basis until it is established that they can give you something useful and not further confuse the thing.

The state-of-the-art techniques, these are TEM, which essentially little was available 10 years ago. This is instrument sensitivity, as well as the processing and interpretation software. Very important factors you get in the TEM is the interpretation. These are available to handle this kind of data. Someone mentioned a GIS-based system, and that is a whole other problem that can or should be brought into the ultimate interpretation.

But the processing software available we can do some good things on modeling on the dipole-dipole, but we are still limited to the two-dimensional EM features and most of these are still based on a one-dimensionality, one-dimensional problem.

Holman, as far as I know, is one of the few working on this head on. Maybe some of you guys know some others.

Again, I emphasize in this case I have not seen the integration of this data, and I will make the point, as long as Walter is back again, of the deeper electrical work integrated with the potential field in that lower seismic. That's part of my thing, I don't see the integration. We need to look at this.

Looking at the faulting, is this Ghost Dance problem, is this Ghost Dance displacement still a significant problem? We are seeing something in the electrical data, and is this aiding in this resolution? And I guess my conclusion on some of this is that I would repeat one of those lines of state-of-the-art technology with a dipole-dipole, as much for the chargeability parameter as the resistivity.

I guess I will leave it at that and open it to questions.

MR. HINZE: Thank you very much, Jack. It's comprehensive coverage of the electrical methods.

Unless there are some pressing questions at this point I would suggest that we leave these to the termination of the meeting, and move on to our final discussion by Chris Fridrich, who will be talking about, what is it, the I word, in terms of integration of geophysics.

MR. FRIDRICH: Actually, the talk that I was going to give was going to be about half programmatic and about half technical, and I think we have actually done a pretty good job of covering the programmatic issues.

So what I am going to do is just skip right over the I word and move right to the technical part of my talk. Of course, if people have programmatic questions, I will be glad to answer them.

[Slide.]

MR. HINZE: Can I ask a question, then, about integration, since you are going to skip it?

We heard a rather vociferous defense of integration on the regional geophysical studies this morning. What is the status of integration plans, activities, in terms of the characterization of the proposed Yucca Mountain site? The site itself, the characterization?

MR. FRIDRICH: What is the status of the integration plan?

MR. HINZE: Yes, sir.

MR. FRIDRICH: Well, we have the SCP, which basically laid out, you know, as other people put it, the wish list of all the data that we want to collect, and the SEP sort of made an initial breakdown, just sort of saying, okay, this is all what it is, and just sort of disaggregating it, but saying, okay, all of these parts of the program want a common type of data and all of these parts of the program want a common type of data, and that's sort of what you ended up with with the White Paper. The White Paper sort of took that step to its logical end, and sort of like in the creation of this diagram here, basically what we have laid out -- and let me just take a for instance here.

For deep seismic reflection, what was decided that the data would actually be collected under the fault study plan, but the surveys done here would have to address the needs of subsurface faulting, natural resources, volcanic problems, and regional flaws, and that's basically -- this is the sort of the thing that was done in the White Paper, to make sure that we have that type of intercoordination between the different studies that needed the data, and the ones that were actually going to collect the data.

Now this doesn't mean that we have all of the details worked out as far as prioritization and integration of different things, but it is a start, and I think that the study plans take it even further, where each one of the study plans has tables that show interfaces with other study plans, particularly if they are requiring data from another study plan, or they are feeding data to another study plan, that will be noted in the study plan. So that those sort of things are flagged, and they are being collated as time goes on and eventually we are going to sort of jell out here and have an overall plan for integration.

Now I would like to say that we were there already, but we are not there already, obviously.

I think one of the biggest outstanding things that hasn't been done is there are many areas where we need to go back and take a really good look at the data that we have and make some basic decisions about what do we know, what do we not know, and therefore what are we going to do in the future, based on what we know and don't know. And those sorts of things, that type of real in-depth evaluation can't be done through more planning documents.

I think we have maxed out on what you can get through all the planning documents, and I think we have to move forward into some real technical nuts-and-bolts analysis of what the problems are, what the issues are.

MR. POMEROY: I have some problem here in the integration with the I word, if you will, and I guess it bears on one of the questions that Bill asked at the beginning of this discussion, in terms of essentially what comes next.

We have heard a lot today about what's actually happening. I think you have an outstanding regional integrationist sitting on my left here. I am not sure that I see the same type of integration to follow on with what Bill was saying at the site. I am not sure that I see that the geophysicists necessarily have a complete input into the decision-making process in terms of what's the optimum number of lines.

For example, there are a number of recommendations in the White Paper of things that should be done. I don't have any idea from this discussion yet what percentage of those are going to be done, but I know it's not 100 percent, and I am wondering finally if there shouldn't be one, in essence, one person or one small group of people who are responsible for the integration of the geophysics picture of the site in a similar way to what I guess I assumed the role of the regional integration to Walter in terms of gravity, magnetics and seismic.

But it is a far greater problem at a site level, and yet I think there should be somebody or some small group of people who have that identification, who have that responsibility. There are a number of questions there, so whatever you can do with it.

MR. FRIDRICH: All I can say is that I agree with you, that the point you are making is correct, it really hasn't been done the way it needs to be done. I'm not sure how it's going to be done. But you're right.

MR. POMEROY: Is there any plan to address it, other than the surface-based prioritization testing, which I understand has now been subsumed?

MR. FRIDRICH: Well, maybe that will answer part of the question.

MR. POMEROY: I frankly doubt that, and I am not sure that that's entirely the proper way that --

MR. FRIDRICH: I don't think that more of these giant bureacratic planning exercises are going to do it. I think it's like you said, a small number of people, just one or two people, have to sit down and really work through the technical issues. It's really got to be based on -- it's got to be issue-driven. What do we need to learn and what do we know now?

MR. POMEROY: I couldn't agree more with what you're saying, and I'm concerned that that actually will -- whatever we can do to make this happen.

MR. FRIDRICH: I wish I could just say something that would make it all better, but --

[Laughter.]

MR. POMEROY: I don't want Carl to burst right here in public.

MR. JOHNSON: I would just like to make one comment. This discussion bears -- I understand the frustration that Paul and Bill are feeling, because it is the same frustration we have. It is my understanding that was the purpose of site characterization, the site characterization plan, and that is to define what we know and the plan for what we intend to obtain in the way of information in order so we can make a determination whether the site is a suitable one or not; and if it is suitable, to go forward into characterization.

Now what you are telling me is no, it was not; that there is some other plan out there yet to be developed that is supposed to do that.

MR. FRIDRICH: Well, that's the way it seems. I think the site characterization plan did a lot towards -- I think it was a very important starting point and the geophysics White Paper has taken us a little bit further, and all these other things bring us a little bit further.

I have the same frustration as you do, that sometimes it's like a series of snakeskins that just keep being molted off and you wonder what we're really going to get there.

[Laughter.]

MR. HINZE: Chris, I think that one of my concerns is this diagram, as I see it, is not an integration diagram.

It's a --

MR. FRIDRICH: No, it's a coordination diagram.

MR. HINZE: It's an overlap diagram in a vertical sense. I see the integration as really being horizontal, that is between the methods.

I guess I also have another concern about what you have said here, and that is that I wonder if we really can do these quasi-feasibility tests with the existing data, until those existing data are QA'd.

Now that is not my problem, but I'm just wondering where that fits in.

MR. FRIDRICH: Well, I don't think it's part of the idea of feasibility tests that they will be QA'd at all. I mean they are developmental, and when you are trying to develop a new technique, you just can't plan things the way that things have to be planned if you are going to do QA. I mean you have to have the flexibility to see what works.

MR. HINZE: So it isn't necessary to QA data that is used to determine the applicability.

MR. FRIDRICH: No.

MR. HINZE: Ah, ha. Okay.

MR. FRIDRICH: The feasibility would be a separate exercise from actually collecting the data under the QA program.

MR. BROCOUM: This is Steve Brocoum from DOE.

I would like to make a couple of comments to address some of the things that Carl Johnson said.

I think that our site characterization plan did lay out at a high level our total characterization program. At a detailed -- when you get into diagrams like this, you talk about a much more detailed level of a study plan level. So I don't think it is correct to interpret what's going on here as saying we have to write another plan in addition to the site characterization plan.

As we, of course, change our plans to any degree, that will be reported in the progress reports.

I want to make one other comment about integration, and I know you people here talk about the detailed geophysics. I am going to talk at a little bit higher level, and that is the department has recently signed a contract with the management operating -- for management operating contractor, TRW, one of their major tasks in their statement of work is to integrate the program, both at the whole level across the top of the program and at the detailed level at the project. In a sense, they are tasked to provide technical direction and decide what information is necessary in terms of collecting information on site characterization.

So I just wanted to point out there is a major transition going on right now, and a major effort to try to integrate the program, and I just wanted to put that on the record.

MR. POMEROY: Steve, may I ask a question? As TRW is doing that -- is it Woodward & Clyde that is the subcontractor that is concerned with the earth science issues?

MR. BROCOUM: Yes, that is correct. Woodward & Clyde is a subcontractor concerned with the earth science issues.

MR. HINZE: Carl, did you have a question?

MR. JOHNSON: It's a question for Steve. Given that we have had quite a discussion here today over the subject of integration of geophysics into the overall earth science program for Yucca Mountain, what is the time frame by which TRW and its team is going to address the integration specifically of geophysics into the overall earth science program?

MR. BROCOUM: I can't answer that at the moment. TRW just came onboard about, I guess, two months, and they are in a 12 to 18-month transition period. In about four more months they will give us what they call their transition plan for our review, where I presume they will address how they will handle that.

So I can't give you an answer at this moment.

I also want to make one final comment about the

SCP. The SCP follows the standard format on site characterization plans issued by the NRC, and so I think the way we laid out the SCP was as the NRC requested it to be laid out in their standard form and content guide.

MR. FRIDRICH: That is a good point.

MR. POMEROY: It seems an awful long to me, at this point, Steve, to think of a 12-to-18-month transition period, because many of the integration issues, I think, ought to be started. Certainly, there should be a start on considering those issues, about 10 years ago, but at least today.

MR. BROCOUM: Well, I am not trying to defend the history. I am trying to tell you how we're moving on in the future. I am the first to concede there have been problems in the past.

I just wanted to lay out that we do have an intense effort to integrate the program, and that's one of the reasons we moved to this management operating contractor, because I think people have told us and we have realized ourselves that we need to integrate the program better.

I'm talking on a much higher level than the detail now of the geophysics here, which I think the experts can talk about, but I just wanted to put that on the record, that we are making a major effort in that direction.

MR. HINZE: That's very helpful, Steve. Thank you very much.

I am just wondering how does the Woodward Clyde study -- how will the Woodward Clyde study be comparative to the site-suitability evaluation that Jane mentioned this morning.

MR. BROCOUM: I wasn't here this morning, so I'm not sure. I missed the morning meeting.

MR. HINZE: Well, she mentioned that there is an ongoing study and that there will be completion of a report on a site suitability, the first pass, by May 9th, I believe the date was.

MR. BROCOUM: We have a major effort to reassess site suitability. I may be repeating some of the things that Jane said. That effort is due to be completed very early next year. It will undergo an outside peer review this fall. That effort consists of two parts.

One is to develop a methodology for site suitability and a second to implement it. I'm not sure if I'm answering your question.

This is independent and in-house and separate from the M&O contractor, because that started before he was onboard.

MR. HINZE: That answers it. Thank you very much.

Further questions for Steve, since he has opened himself up?

[No response.]

MR. HINZE: Thank you very much, Steve. That's very helpful.

Chris, you want to get back to the hydraulic gradient, I would guess.

MR. FRIDRICH: Right.

[Slide.]

MR. FRIDRICH: Okay. I am going to try to give you an example of integration from a geologist's point of view, and I'm going to talk about the large hydraulic gradient here. Just, first, let me describe what it is.

Between welds G-2 and G-1, the water table drops 300 meters, and that's in a distance of only 2 kilometers. Now, the contours here are not an equal distance apart, but the hydraulic gradient here has a slope of 15 percent.

Above that, we have a slope of only 1 1/2 percent, and below that point, we have a slope of only 1/100th of 1 percent, and so, not only is this large hydraulic gradient very significant but, also, the change in gradient across it.

The gradient down here, south of the large gradient, is less than 1/100th of what the gradient is above the large gradient. That suggests that there is a huge change in permeability of at least two orders of magnitude across this zone, and that's remarkable, because when you look at all the surface rocks, there is nothing going on there.

You know, it's just basically layer-cake, ash flow tuffs going right across there, and on the surface, you'd swear there was nothing there at all.

[Slide.]

MR. FRIDRICH: And this is the reason why the large gradient has been such a thorny issue for so long. No one can seem to figure out what it is.

So, I'm going to show you what I think is the proper approach to sort of -- to work through an idea like this. I can't guarantee that I will come up with the right answer, but I am just going to present a philosophy of science approach to resolving this type of a question.

First, I'm going to forget all the previous preconceived notions about why this feature is there. I'm going to review all the types of existing data, see what correlates with the large gradient and what doesn't.

It's such a focused feature that I expect that there must be a geologic feature there is similarly just as focused in location and is right there underneath it or right where it is.

I'm going to look at the rest of the saturated zone flow system and decide what else I need to explain in my model. I'm going to review the regional context, because whatever explanation I come up with has to make sense in terms of that context.

I'm going to try to let the data drive the interpretation, instead of letting my preconceived notions drive the way I interpret the data. I'm going to try to use OCCAM's razor and come up with the simplest interpretation.

Finally, when I come up with mine, I will go back and look at all the other hypotheses and try to develop a strategy that's applicable to testing all the hypotheses.

[Slide.]

MR. FRIDRICH: So, I have gone through this exercise, and basically, what I decided is that there is nothing in the upper kilometer of Yucca Mountain that correlates well with the large hydraulic gradient. I could not find any feature that correlates well with it at all.

There are features that are developed sort of gradationally across the whole mountain but nothing that's located right there. However, I did find four features that do correlate very well with the large hydraulic gradient. They just aren't part of the upper kilometer of the geology of the mountain.

I have an aeromagnetic anomaly, I have a heat flow ancmaly, a gravity anomaly, and I have very strong stratigraphic changes right across the zone that are deep;

they are below one kilometer.

I also decided four other things that I needed to talk about, needed to include in my model. I'm not going to talk about most of these, but there are linear thermal anomalies south of the gradient. There are all sorts of hydrochemical variations under the mountain.

The tuff aquifer is confined at the large gradient, and most importantly -- and this is what I'm going to start with -- the large gradient in Yucca Mountain is continuous with a regional large gradient. I think that's one of the most important features.

MR. NELSON: Could you repeat your last point?

MR. FRIDRICH: My last point is that the large gradient at Yucca Mountain is continuous with a regional scale large gradient.

[Slide.]

MR. FRIDRICH: This is the Ash Meadows groundwater basin. It's an area of about 5,000 square miles. And you notice that there are three large hydraulic gradients in this basin.

There is one on the western side of the Spring Mountains, one in the Funeral Mountains, right above Death Valley, and then there is one here that goes from Yucca Mountain up and wraps around Yucca Flat and then goes off to the northeast.

So, the large gradient in Yucca Mountain is continuous with a regional feature, and I think whatever explanation we come up with for it, it better make sense in terms of this regional context.

MR. JOHNSON: Which flow system did you just talk about? Did you talk about the regional carbonated aquifer system, or did you talk about the tuff alluvial aquifer system?

MR. FRIDRICH: You're just getting ahead of me. Okay?

MR. JOHNSON: Well, I want to know what you just talked about in your explanation back to Phil.

MR. FRIDRICH: I'm going to talk about that right now. Okay?

[Slide.]

MR. FRIDRICH: Now, there are two major aquifers in the system. There is the upper volcanic fracture tuff aquifer. That's underlain by the basal tuff aquitard, which is all un-welded altered tuffs.

And then, in the paleozoic rocks, we have the carbonated aquifer, which is by far the best aquifer in the system. It's at least 100 times as transmissant as the tuff aquifer.

Then we have clastic aquitards in the paleozoic rocks. Now, what I have done on this map is just mapped out where the clastic aquitards actually outcrop on the surface, and I have shown that in the dark colors, and I have also shown where it is -- these clastic aquitard blocks are very near the surface or at least near the water table, and I have shown that in the lighter colors here.

The thing I hope you see right away is there is an excellent correlation between where these clastic aquitards are and where the large gradients are in the basin, which suggests that there is a very strong geologic control.

I'm going to focus particularly on this large gradient feature right here.

You will notice that there is a contact between the carbonated aquifer and the clastic aquitards that basically just wraps around and follows this regional large gradient through every little twist and turn, and that just can't be an accident, when you have a geologic contact like that's following a hydrologic feature.

Now, there are two things that are going on here. The traditional explanation is people have focused on the role of these clastic aquitards as dams to flow between the major area of discharge to the north -- or recharge to the north and discharge areas to the south.

Another thing that's just as important as the dam to flow is that there has got to be a down gradient receptor below that dam to allow the water table to drop 300 to 500 meters over a very short distance, and so, the fact that this is sort of the up gradient limit of the carbonated aquifer is just as important as the damming effect.

Basically, what's happening is the water is coming through the tuff aquifer from the north, it's going through this dam or over it, and then, all of a sudden, when you get to the up gradient limit of the carbonated aquifer, there is a huge drop in the effective base of the hydrologic system where that carbonated aquifer comes in, because it's so much more permeable and the permeability in it is developed to so much greater depth than the other aquifers in the region that it's almost like an underground waterfall, in a sense.

That is how I interpret the regional large gradient. And now I want to show how the large gradient at Yucca Mountain fits in.

[Slide.]

MR. FRIDRICH: I don't have much geology to go on, so I'm going to go on geophysics.

First of all, as was mentioned before, there is an aeromagnetic anomaly under northern Yucca Mountain. Now, here, the large gradient is right in here between wells G-2 and G-1.

The Eleana Argillite, which is one of the clastic aquitard outcrops in the Calico Hills and it's been shown to be the cause of this huge aeromagnetic anomaly, as Jeff was talking about before.

Now, when we come out to the west, over to Yucca Mountain, we don't see the Eleana Argillite outcropping at all. However, the simplest interpretation of this magnetic anomaly is basically just to allow the contact between th Eleana Argillite and the carbonate aquifer to just project over -- under northern Yucca Mountain. And you could argue about exactly where that contact is, but it's close to where the large hydrologic gradient is.

So, I think it is a pretty good guess that under Yucca Mountain, the large gradient corresponds, generally, to the position of the contact between the clastic aquitard and the carbonated aquifer. It's sort of the upgrading limit of the carbonate aquifer, as it does regionally, along the rest of this large gradient.

The next geophysical anomaly I want to --

MR. MOONEY: Can I ask a question? Isn't -- this gradient is occurring at a -- what's the depth below the surface that --

MR. FRIDRICH: I will get to that. Yes, it's very deep. Yes, the carbonated aquifer is buried at least two kilometers under northern Yucca Mountain. That's one of the reasons it's hard to -- hard to figure out why this is happening.

MR. MOONEY: Right. Okay.

MR. FRIDRICH: But, bear with me.

[Slide.]

MR. FRIDRICH: The next thing that correlates with the large gradient is the huge heat flow anomaly. This is defined by Bass, et al. in 1987. We have heat flows in here that are as low as .75 heat flow units, which is one of the lowest values anywhere in the great basin.

Basically, here's the large gradient. You can see that this is just a contouring interpretation up there. Basically, the heat flow anomaly starts right at the large gradient, and then goes south then to the center part of Yucca Mountain.

Now, I guess there are different ways that you can get a heat flow anomaly. But the standard interpretation for features like this is that it's caused by down-welling water. This is such a big heat flow anomaly, the value of it is so high, it suggests down-welling water on a massive basis, and basically occurring at the large gradient and then, generally, southward flow of that cool water through the south.

Now, the obvious candidate here is for the water to be down-welling into the carbonated aquifer. I can't see any other way that it could down-well enough to give you an anomaly of this magnitude. So, what it suggests is that just as we have regionally, this could be the local recharge point for the carbonate aquifer, right at its up gradient limit, which is right about in here.

Then we come to the question of how can that be, in that there's at least two kilometers of tuff over the carbonate aquifer, including this basal tuff aquitard, which is at least a kilometer thick. How can you have a hydraulic connection between the tuff aquifer to the north and the carbonate aquifer under here, unless you have a really good pathway somewhere?

So that's what -- to make sense out of this, we must have a pathway.

MR. MOONEY: Maybe, at the end, you can also mention where all the heat shows up. Because if you --

MR. FRIDRICH: Well, there are more --

MR. MOONEY: -- if you have a heat sink --

MR. FRIDRICH: -- to the south.

MR. MOONEY: Right.

[Slide.]

MR. FRIDRICH: Okay. So the next anomaly we have to talk about is the gravity anomaly. You see, here's the large gradient. And you notice that there is a little northeast trending gravity anomaly that's right there under a central Yucca Mountain.

Now, this is just one version of the gravity data. There are different ways that it's been filtered and modified. I like this particular version of the data because it fits best with the stratigraphic data and the boreholes.

Now, Spengler and Fox interpreted this little feature here as a buried extensional axis. In order to check that out, I looked at the deep stratigraphy in the holes.

[Slide.]

MR. FRIDRICH: Now, basically, this cross-section here goes from north to south, across the zone of the gravity anomaly. Are large gradient is rignt here. The gravity low is right in there. I base the offset of the paleozoic tertiary contact here on the gravity. I called up Howard Oliver and had him do some quick calculations for me.

What I find in the stratigraphy, basically, is that in the upper kilometer of the mountain, everything is pretty much layer cake right across. But starting with the tram tuff and in all of the deeper tuffs, basically, I'm coming through from the north and all of a sudden everything is twice as thick; then I go to the south and everything thins up again. And it does that all the way down to the bottom of my control. Because there are about six wells in there and they all uniformly get about twice as thick in the area of the gravity low, I believe that the gravity low is a buried graben.

Now, if that's true, if this feature really is a buried graben, as the stratigraphic evidence suggests, then the northern bounding fault of the graben is directly underneath the large hydraulic gradient, right between wells G-1 and G-2. That fault then can provide the pathway for down-welling from the tuff aquifer to the north, into the carbonate aquifer.

[Slide.]

MR. FRIDRICH: Here's my schematic model of the system. Basically recharge and the Timber Mountain Caldera complex is somewhere up there, southward flow of that water. Basically, we have the buried contact of the clastic aquitard and the carbonate aquifer, but we actually have to have a fault to allow water to down-well. Basically, what's happening there is the carbonate aquifer is capturing the flow.

So, then the reason for the change from -- the reason for the large hydraulic gradient there is because all of a sudden you have dominantly downward flow into the fault drain. The reason for the change in the hydraulic gradient, north and south of the large gradient, is that there is a huge increase of permeability across the zone; but not because of any change in the tuff section, necessarily, but because all of a sudden we've added the carbonate aquifer to the system.

Now, it turns out that there's actually a lot of hydro-chemical data that really supports this model very well. I'm not going to go into that too much. But I think it's a pretty good model. It explains all of the major things that I started out needing to explain. But, like any hypothesis, it could be wrong.

[Slide.]

MR. FRIDRICH: What I have done here is just collated the seven major different hypotheses for the large gradient. I just talked about the fault drain model.

There are three different models that call for some kind of a dam across the tuff aquifer. Those models are okay, in terms of the regional context. They basically will sort of continue the dam formed elsewhere by the clastic aquitards.

I'm really puzzled as to what that heat flow anomaly is doing there, if it's a dam across the tuff aquifer, but it's possible.

Then we have the tectonic control models, such as Szymanski's model. Basically, I don't like the tectonic control models at all because those models sort of suggest that there should be no durable feature that correlates with the large gradient when in fact I think, we've seen that in fact there are many geophysical features -- anomalies here that correlate very well with it. So, I think that there is a durable geologic explanation.

But these models are testable also. I would propose that the main test for the large gradient is to drill a well right in the center of the large gradient, approximately between wells G-1 and G-2, and take it down at least to the base of the tuff aquifer and, better yet, into the top of the paleozoics.

Basically, I've listed out here, each one of these different models for the large gradient would give us a different set of predictions for a test such as that. I think we also need a lot of different geophysical surveys across there. I think better gravity and magnetics would help. Some better analysis of the heat flow data would be good, and more heat flow data.

But, basically, in the end, I think you have to have the ground truth of the hole right into it. You know, for instance, with the fault drain model, if this model is correct, what we should find is that the downward hydraulic gradient into the fault drain should exceed the lateral hydraulic gradient across the zone. That's a very different prediction than what any of these other models make for a test such as that.

MR. DANIELS: Chris, am I correct that the faults bounding this graben would be perpendicular to the trend of drill hole wash, then?

MR. FRIDRICH: That's about correct. That's right. Let me go back to the gravity.

[Slide.]

MR. FRIDRICH: That's right. Drill hole wash is oriented just about like that, just about perpendicular.

MR. DANIELS: Where is this Ghost fault that people are talking about?

MR. FRIDRICH: Ghost Dance fault?

MR. DANIELS: Whatever it is. How does that trend?

MR. FRIDRICH: I think it's right there.

MR. DANIELS: Does it bound drill hole wash?

MR. FRIDRICH: No. It also cuts across the large gradient.

MR. DANIELS: Okay.

MR. FRIDRICH: It's oriented at a high angle to the large gradient, and all of the surface faults are.

Anyway, it's just a model, but the reason that I brought this up is because I think it's a good example of the type of really detailed analysis that we need.

I don't think it's enough to just produce a whole lot of planning documents and coordination exercises and strategy planning and stuff. I think, a lot of times, one or two people have to sit down with the data and really dig into it and find out what's going on.

So far, not much of this has been happening, but I hope that a lot more is going to happen in the future.

MR. HINZE: Thank you very much, Chris. That's a very excellent example of what integration of data can do, not only geophysical but, as you point out, hydrochemical and geological.

Are there any questions or comments regarding Chris' presentation?

MR. MOONEY: I would like to make a comment that -- second and third, your last few comments -- that this kind of integration is just fantastic.

I've sat in on two or three meetings where the hydrologic gradient was discussed without nearly as much data pulled together, and that's really a superb job you've done.

MR. FRIDRICH: Thanks.

MR. HINZE: I think we are all very much interested in bringing this working group to a close, no matter how much fun it's been. Right, Carl?

In an attempt to bring us to a conclusion quite rapidly, what I would like to do is I would like to make a few remarks about what I think are some of the more critical conclusions I have come to as a result of today's meeting, and then, if anyone wishes to disagree, that forms a target on which you can disagree.

First of all, it is not surprising that we have come up with that geophysics has a major role in characterization at all depths and that there are problems in the interpretation of geophysical data, as in all of our sciences, and this requires that we have multiple methods, not all methods, but we do have multiple methods, and we must very much, as Chris has shown to us, very much constrain this -- and as we all know -- constrain this by our geological data as well as any other data that we can put together.

It also seems to me that part and parcel of this is not just the surface methods but that, to increase our resolution, the resolution that we really need for characterizing the local site, that we have to focus in upon the -- putting our measurements at depth through drill hole methods, surface to hole, hole to hole, and so forth.

The second is that integration and proper sequencing of our geophysical data is very important. I don't think there is a person around this table that doesn't agree with that.

The regional studies, up to this point, have indicated and Chris' analysis of high gradient show the importance of the integration, and I don't think we have really seen the proper sequencing, but I would like to believe that the proper sequencing is very important.

As we look at the documents presently available to us, it is not clear that the sequencing and integration is there at the local site characterization, but it seems to me that what we have heard from DOE here today is that they do have several programs to put this underway, both internally and through TRW and Woodward Clyde, and that we can look forward to further information on this whole topic, and I say this as a very positive factor. I think we have got to look at this in a positive sense.

The third item that -- a kind of conclusion that I have reached -- and again, I think Chris has illustrated this very well, and that is that the existing geophysical data -- and there is a lot of it -- can be very valuable to us and that it's very important that we get on with QA'ing that data for the eventual characterization but, in the meantime, that we can very well use this as a first step towards the quasi-feasibility studies, modeling studies, which finally will go into the field work.

It's obvious that some of the data and, particularly, the data in the electrical methods and the seismic methods at the site itself are out of date, antiquated, certainly need to have some upgrading and that feasibility studies here are warranted.

I would also like to hope that those feasibility studies would be conducted in a fashion so that they wouldn't be, in any way, interfered with as a result of too much modification of the site by drifting or whatever might be.

Those are three general observations that I tried to put together here, while having one-half here on Chris, and I am wondering if we have any arguments against those or any additional items. The floor is open.

MR. IBRAHIM: Steve Brocoum mentioned that the TRW would be coming on site and would be doing the integration, and I am afraid that if we leave that to TRW, at least, we will not see this integration before three or four years. I may be mistaken, but that's my personal feeling.

I would suggest that, if it is possible, we can just get the USGS people together, and we'll start the integration as soon as possible.

MR. HINZE: Other comments?

MR. IBRAHIM: Because it will be hard -- I would assume it will be very hard for the TRW to collect all the data within the different sections of the USGS and put it together, because the USGS are the people who collected the data, they know where it is, and they will be able to handle it much faster than TRW.

MR. HINZE: That ray be for the NRC to say but certainly isn't for the ACNW to say. I don't know.

MR. IBRAHIM: Again, that is my personal opinion.

MR. HINZE: Okay.

Any further comments? Phil?

MR. NELSON: I have a general comment. I don't think we want to minimize the object lesson here that Chris has just made in his talk, and that is that -- you know, what Chris has done, basically, is interpretation, which is what we should be striving to do, and to talk about integration in a mechanistic, planned format is, I think, going quite aside from what we gain from this object lesson, in that the interpretation happens when you focus on a problem.

He focused on the large hydraulic gradient, and a lot of data came together from some surprising sources when you do that. He mentioned, for example, the geochemistry, which isn't something you automatically think of when you think large hydraulic gradient, and there are a lot of other things that kind of naturally fall in, and you come out with a test plan.

To me, that's the way you want to focus any further work that really brings together data and creates plans, and you can think, you know, of a number of other problem areas at Yucca Mountain that would do similar sorts of catalytic types of operations.

For example, the state of stress at Yucca Mountain is a good one. It's been worked on, and there has been good measurements and interpretations of those measurements, but it's kind of been left there.

Another good one is the near-surface percolation. There are people in WRD who have been gathering some very, very interesting data for a number of years in boreholes, looking at infiltration after rainfall events, and it's a very good data set, but it needs to be worked in the geologic and geophysical context, not just left out there alone, by itself.

Another one is designed for excavation. There are a lot of things that really come up when you start thinking about a mining excavation plan. I know that's off somewhere else, for instance. Of course, there are the regional problems that have been mentioned today like tectonics and volcanology issues. Each of those has its own peculiar set of problems that it wants to wrestle with.

But, I think, if we have enough data now that -- and what it really says is that the SCP isn't all that ill closed. By and large, it's not altogether cast around these subjects, but a lot of it is at least addressed that way toward problem areas. To me, you are a lot better off not just thinking about integrating geophysical data, but thinking about working on real problems that lead you to the licensing step.

I rest my case.

MR. HINZE: Carl?

MR. JOHNSON: Yes. I would like to first compliment Chris on the fine job he did in the analysis of the hydrologic gradient. I think he type of analysis that -- interpretation that Chris went through is the type of analysis and interpretation that we, in the state, fully expected to occur for all the known geologic features of concern in the SCP.

Based on those interpretations, then study plans could be developed around resolving those particular features of concern. So far, we haven't seen the connection between the features of concern, of which I, in my presentation listed a few of those as examples, and the study plans.

I hope that Chris' presentation sets the stage for future analysis of the existing data for all kind of features, and that the Department focuses attention on those types of analysis and interpretation of those features before defining a set of studies plans. Because I think the interpretations and the various models are needed before a comprehensive well-focused program of investigation can be carried out.

I just want to add one more thing. The types of interpretations and analysis that Chris has gone through is not something that you need environmental permits for.

MR. HINZE: Anyone else around the table? Walter?

MR. MOONEY: I would like to respond to both or all of these comments, I suppose, by saying that the fact that most of the people who work in the Yucca Mountain project feel that these study plans are fixed documents, means that you need to specify, before you begin the work, what you're going to need to know, in order to come to a conclusion on a given topic.

What Chris illustrated was that to solve certain problems, you draw on many things, some of which you don't anticipate in the future. So, these rigid study plans, not only are they terribly boring to produce, they are probably rather ineffective in their wisdom, in thinking that we can anticipate, prior to beginning work, everything that we're going to need to attack a given problem.

MR. NELSON: If I may interrupt. None of the data that Chris used were gathered under a study plan.

MR. MOONEY: Yes. So, the moral of the story is, most of us would like to get back to work and we're envious of the job that he's done and the excellent conclusion that he's come to. If we weren't spending most of our time writing these study plans, we would intend to do similar work.

MR. HINZE: Thank you, Walter. Further comments?

[No response.]

MR. HINZE: Is there anyone in the audience that would like to respond? Jane? No?

[No response.]"

MR. HINZE: Well, with that, I -- before adjourning, I want to say two things. First of all, the ACNW is in -- I don't know -- go ahead Jane, excuse me.

MS. STOCKEY: I just -- on the study plans, according to Dave Dobson, last week, every one of our data acquiring study plans, is into the review process. So, hopefully, our PIs are not still feeling themselves totally bound with writing study plans. I think we're moving right along on this.

MR. HINZE: Thank you very much, Jane. Carl, you have three seconds.

MR. JOHNSON: Jane, does that mean all 106 study plans are in review and we will see those?

MS. STOCKEY: Data acquiring, as opposed to ones that are down the road, interpretative modeling.

MR. JOHNSON: How many data inquiring study plans are there?

MS. STOCKEY: Carl, numbers are not my forte.

FROM THE FLOOR: Sixty-two.

MS. STOCKEY: Sixty-two.

MR. JOHNSON: Sixty-two. Okay. So, I can expect 62 study plans for review.

MR. HINZE: Well, we won't see Carl for a few days.

MS. STOCKEY: If anyone is complaining about how fast those study plans are coming out, I have to take a personal responsibility for things being held up, as having been out on five weeks medical leave, and things are stacking up on my desk. So, if you want to complain, aim it at me.

MR. JOHNSON: I am not complaining.

MR. HINZE: Going back to the comments I was about to make. First of all, the ACNW is very much interested in holding these kinds of forums, so that we can learn and, hopefully, that others will come long with us in this learning process.

We encourage any of you that would have ideas about working groups, and I'm speaking personally now, as a follow-up to this specific working group on geophysics, if you have ideas on how we can follow up with this in which we might learn, Paul and I and the Committee, I think, are very much interested in learning of your ideas and suggestions.

Secondly, of course, I do want to thank all of you very sincerely for your preparation and your presentations. The presentations were universally excellent, very informative, well-presented, and we do appreciate it.

With that, I call the meeting adjourned.

[Whereupon, at 6:00 o'clock p.m., the meeting was adjourned.]

REPORTER'S CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission

in the matter of:

NAME OF PROCEEDING: ACNW Working Group

DOCKET NUMBER:

PLACE OF PROCEEDING: Bethesda, Maryland

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Marilyn Estep

Official Reporter
Ann Riley & Associates, Ltd.

United States Nuclear Regulatory Commission

Advisory Committee on Nuclear Waste

Working Group on Geophysics

Presentation by

Carl Johnson

Nevada Agency for Nuclear Projects

April 22, 1991

TOPICS

- Regulatory Requirements
- Geophysical Methods
- Generic Approach for an Effective Geophysical Program
- Yucca Mountain Geophysics Program

REGULATORY REQUIREMENTS

There are no regulatory requirements per se for providing specific kinds of geophysical data during the characterization program or as part of any license application.

Implicitly, geophysical methods must be a significant element of the characterization program. They provide information which assist in understanding natural processes.

LICENSING INFORMATION NEEDS WHICH REQUIRE GEOPHYSICAL DATA INPUT

- Stratigraphy
- Tectonics
- Geohydrology
- Natural Resources
- Rock Characteristics
- Repository Engineering

Historically, geophysical data has been a major source of licensing controversy in the earth sciences.

EXAMPLES:

- New Madrid Fault Zone
- Olympic-Wallowa Lineament
- Hosgri Fault
- Newport-Inglewood Fault
- Juan de Fuca Subduction Zone

Historically, geophysical methods have also played a major role in resolving earth sciences licensing issues.

A KEY REQUIREMENT

A significant requirement in the licensing process is to estimate the extent that an adverse (anomalous) condition is present and yet may still be undetected. In this regard the resolution of the geophysical data plays a key role in that determination.

GEOPHYSICAL METHODS

Geophysical methods are the only cost-effective and non-destructive way to examine large blocks of rock in 3-dimensions.

Most geophysical methods are non-unique

- Difficult to Reproduce
- Solutions Non-Unique, Ambiguous

In simple geologic systems, the combination of multiple geophysical data sets can constrain solutions, particularly if calibrated with high-quality geologic data.

In complex geologic systems, combining geophysical data sets may exacerbate the problem, even when calibrated with high-quality geologic data.

GENERIC APPROACH FOR AN EFFECTIVE GEOPHYSICAL PROGRAM

Program Objective:

1. Identify presence or absence of all geologic features of regulatory concern.

2. Support establishment of geologic conditions and ranges of parameters that characterize region (geologic setting), area, site.

Program Requirements:

1. Define all appropriate geologic models for region, area, site.

2. Define geophysical program:

    - Level of detail (scale)

    - Systematic and uniform.

YUCCA MOUNTAIN GEOPHYSICAL PROGRAM

"As indicated in the SCP, many geophysical activities have not been planned explicitly or in detail because of the uncertainty as to the applicability of the various methods." (DOE/USGS YMP/90-38 "Geophysics White Paper" - p. 1, paragraph 1).

"Both the SCP and this report emphasize plans for feasibility testing, on the basis that the cost of such testing is outweighed by the potential gain in added confidence of the characterization of site conditions." (DOE/USGS YMP/90-38 "Geophysics White Paper" - p. 1, paragraph 3).

The obvious conclusion is that after 10+ years the DOE does not have an integrated geophysical program plan that will assist in full understanding of the Yucca Mountain geological system.

YUCCA MOUNTAIN GEOPHYSICS PROGRAM CONCERNS

- Lack of an integrated program
- Incomplete definition of appropriate geologic models
- Problems with some geophysical techniques
- No uniform geophysical data sets for region, area, site
  (Exceptions - Gravity - Aeromagnetic)
- No plan for systematic acquisition of uniform geophysical data

Study Plan 8.3.1.X.X.X	Seismic: Reflection: Deep (Regional)	Seismic: Reflection: Intermediate	Seismic: Reflection: Shallow	Seismic: Refr.: Upper Crustal	Seismic: Refr.: Shallow	VSP & Crosshole	Potential Field: Aeromagnetics	Potential Field: Detailed Mag	Potential Field: Detailed Gravity	Paleomagnetics	Geoelectric Methods	Ground Penetrating Radar	Remote Sensing: LANDSAT	Remote Sensing: SLAR	Remote Sensing: Radiometric	Borehole Geophysics: Crosshole Gamma	Borehole Geophysics: Neutron Logging	Borehole Geophysics: TV & BATV	Borehole Geophysics: BHEM & VHF	Borehole Geophysics: Gravity & Magnetics	Borehole Geophysics: Other BH Methods	Related SB Drilling Program
.2.1.3 Regional Flow (Czarnecki)	a b	a b	b				a b	b	b		b	d	b				b	b		b	B	WT-holes; UZN-holes
.2.2.1 UZ Infiltration (Flint)			d		D							d	d			D	B	d	B		d	UZN-holes
.2.2.3 UZ Percolation SB (Rousseau)						D										D	d	d	D		d	UZ-holes; SD-holes
.2.2.4 UZ Percolation ESF (Yang et al.)						c											C	C			C	MPBH activity
.2.3.1 SZ Flow (USGS)		b		b			b	b	b		b							b			B	WT-holes
.2.3.2 SZ Hydro-chem. (Steinkampf)																				d	d	WT-holes
.5.2.1 Quatern. Reg. Hydro. (Stuckless											b		b	b				b			B	WT-holes
.4.2.1 3-D Strat. (Spengler)				b						b							B D	b d	B D	B D	B D	G-holes, & others
.4.2.2 3-D Structure (Spengler)		b				D				a b								b	b d	b	d	G-holes, & others
.4.3.1 Systematic Drilling (Rautmann)										d							d	d		d	B D	UZ-holes; SD-holes
.8.1.1 Prob. Volcanic Eruption (Crowe)	a	a b		a b			a				b											
.8.5.1 Volcanic Features (Crowe)							b	b	b	A B										b		V-holes
.9.2.1 Natural Re-sources (USGS	d	d					d	d			d		d		d						d	G-holes; SD-holes
.14.2.3 Geotechnical (SNL)			c		c			c				c						c			C	
.15.1.5 Excavation Invest. (SNL)						c																
.17.4.2 Faulting, Surf. Fac. (Shephard)			c									C										
.17.4.3 Quat. Faults w/in 100 km (Fox)	A	A	b	A B			a	A	A	A B	A		a								b	
.17.4.4 Proximal Faulting (Yount)			B		B						B											
.17.4.7 Subsurface Faulting (Fox)	a	B	B	b			B	A BC	B	a b	b		b		B							
8.3.4.2.4.4 Engr. Barrier Tests (LLNL)																			C			

NOTES:

(1) a = Regional, b = Yucca Mtn & vicinity, c = Surface facilities, d = Repository block & vicinity.

(2) CAPITALIZED indicates actual data collection activities, vs. studies where geophysical data are used.

Figure 3.2-1. Matrix correlating categories of geophysical methods, with SCP studies wherein geophysical data will be collected and used.

Study Plan 8.3.1.X.X.X	Seismic: Reflection: Deep (Regional)	Seismic: Reflection: Intermediate	Seismic: Reflection: Shallow	Seismic: Refr.: Upper Crustal	Seismic: Refr.: Shallow	VSP & Crosshole	Potential Field: Aeromagnetics	Potential Field: Detailed Mag.	Potential Field: Detailed Gravity	Potential Field: Paleomagnetics	Geoelectric Methods	Ground Penetrating Radar	Remote Sensing: LANDSAT	Remote Sensing: SLAR	Remote Sensing: Radiometric	Borehole Geophysics: Crosshole Gamma	Borehole Geophysics: Neutron Logging	Borehole Geophysics: TV & BATV	Borehole Geophysics: BHEM & VHF	Borehole Geophysics: Gravity & Magnetics	Borehole Geophysics: Other BH Methods	Related SB Drilling Program
.2.1.3 Regional Flow (Czarnecki)																					B	WT-holes; UZN-holes
.2.2.1 UZ Infiltration (Flint)					D											D	B		B			UZN-holes
.2.2.3 UZ Percolation SB (Rousseau)						D										D			D			UZ-holes; SD-holes
.2.2.4 UZ Percolation ESF (Yang et al.)																	C	C			C	MPBH activity
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.4.2.1 3-D Strat. (Spengler)																	B D		B D	B D	B D	G-holes, & others
.4.2.2 3-D Structure (Spengler)						D																G-holes, & others
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.17.4.2 Faulting, Surf. Fac. (Shephard)												C										
.17.4.3 Quat. Faults w/in 100 km (Fox)	A	A		A B				A	A	A B	A											
.17.4.4 Proximal Faulting (Yount)			B		B						B											
.17.4.7 Subsurface Faulting (Fox)		B	B				B	A BC	B						B							
8.3.4.2.4.4 Engr. Barrier Tests (LLNL)																			C			

NOTES:

(1) a = Regional, b = Yucca Mtn & vicinity, c = Surface facilities, d = Repository block & vicinity.

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Figure 3.2-1. Matrix correlating categories of geophysical methods, with SCP studies wherein geophysical data will be collected and used.

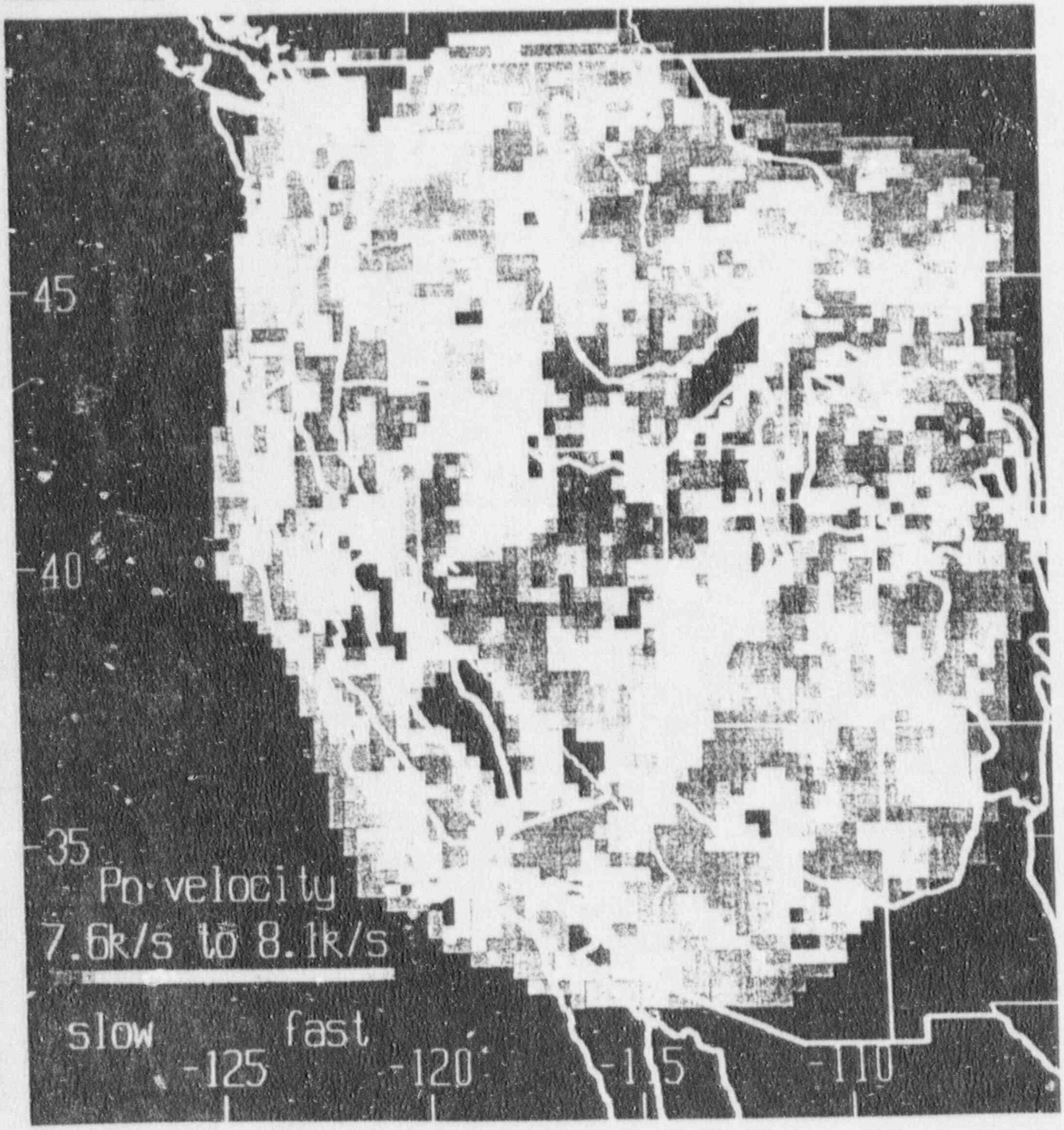
GEOPHYSICAL ANOMALIES ALREADY IDENTIFIED IN SOUTHERN GREAT BASIN

EXAMPLES:

- Resistivity anomaly near Exploratory Shaft Facility site
- "Bright Spot" on seismic reflection data near Lathrop Wells
- Upper crust detachment structures on seismic reflection data in Yucca Mountain area
- Aeromagnetic anomaly along Solitario Canyon Fault
- 2.5 km change in depth to basement beneath Yucca Mountain
- Low velocity tomography data southeast of Yucca Mountain

EOS

Transactions, American Geophysical Union
Vol. 71 No. 38 September 18, 1990



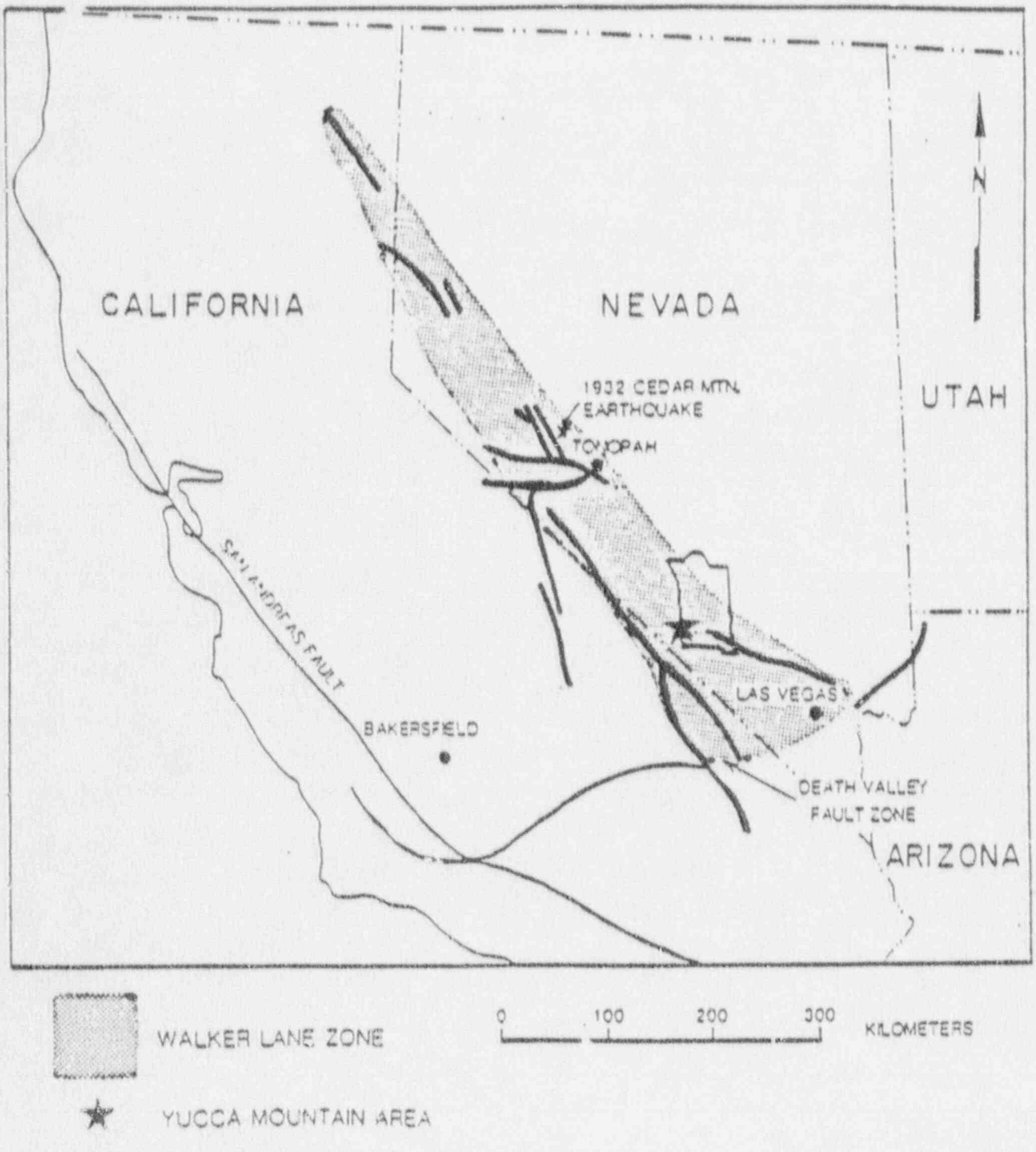
Tomography of the Western United States

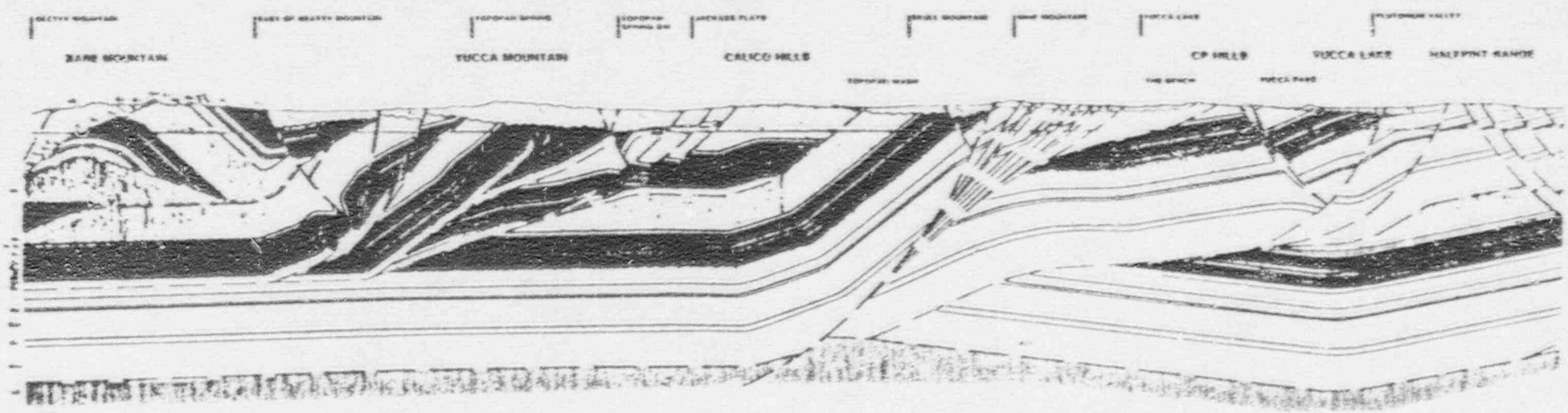
GEOLOGIC FEATURES OF CONCERN PROBABLY AMENDABLE TO GEOPHYSICAL SOLUTION

EXAMPLES:

- Walker-Lane Structural Zone
- Mine Mountain Fault Zone
- Paleozoic Stratigraphy and Structure

WALKER LANE STRUCTURAL ZONE



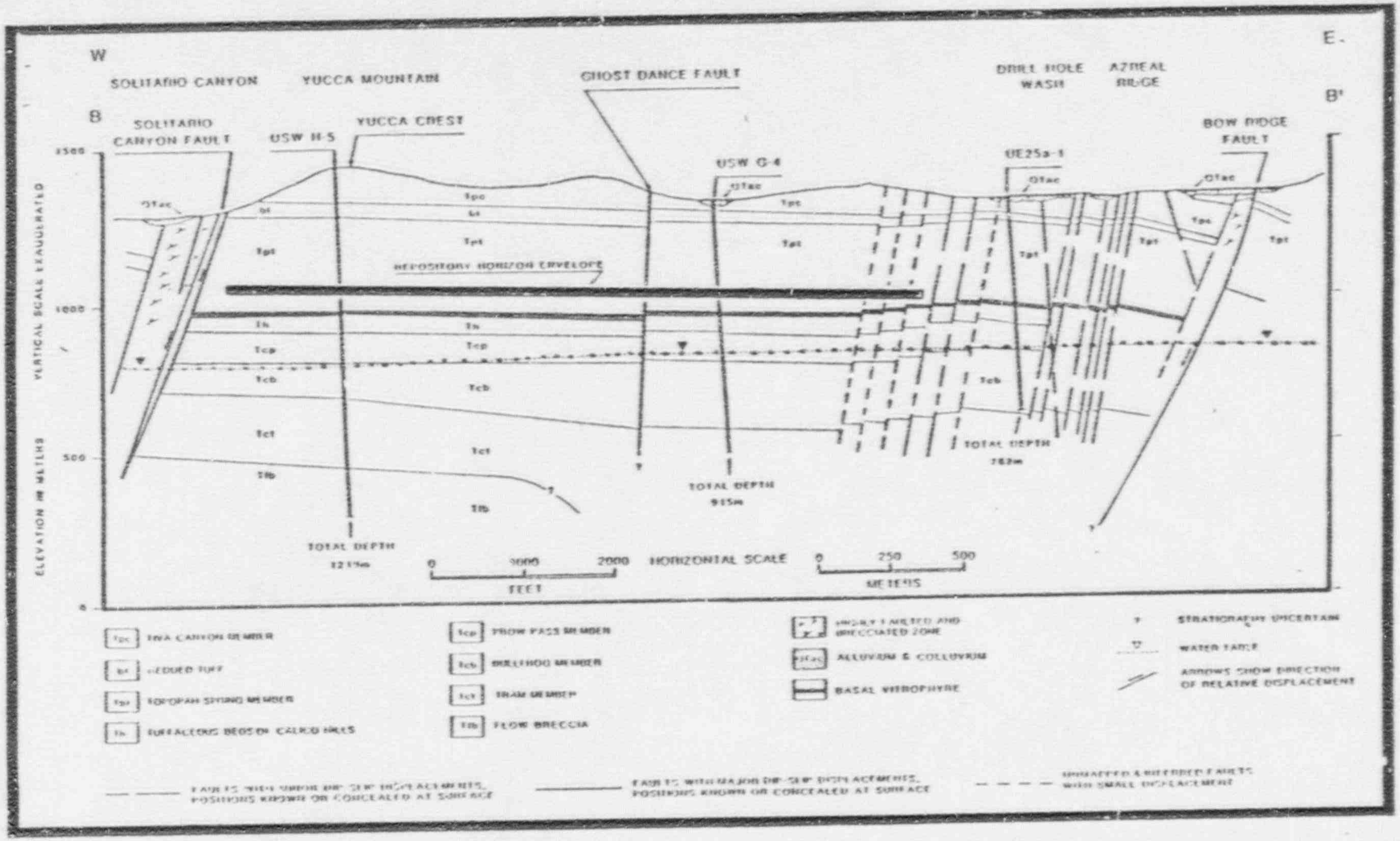


BARE MOUNTAIN
YUCCA MOUNTAIN
CALICO HILLS
CP HILLS
YUCCA LAKE
HALFPINT RANGE

GEOLOGIC FEATURES OF CONCERN PROBABLY NOT AMENDABLE TO GEOPHYSICAL SOLUTION

EXAMPLES:

- Steep hydrologic gradient
- Fracture distribution in the unsaturated zone - in 3-dimensions


W
E
B
B'
SOLITARIO CANYON
YUCCA MOUNTAIN
GHOST DANCE FAULT
DRILL HOLE WASH
AZREAL RIDGE
SOLITARIO CANYON FAULT
USW H-5
YUCCA CREST
USW G-4
UE25a-1
BOW RIDGE FAULT
REPOSITORY HORIZON ENVELOPE
TOTAL DEPTH 1219m
TOTAL DEPTH 915m
TOTAL DEPTH 762m
ELEVATION IN METERS
VERTICAL SCALE EXAGGERATED
1500
1000
500
0
HORIZONTAL SCALE
0 1000 2000
FEET
0 250 500
METERS
Tpc TIVA CANYON MEMBER
Tpp PROW PASS MEMBER
Tcb BULLFROG MEMBER
Tct TRAM MEMBER
Tfb FLOW BRECCIA
ALLUVIUM & COLLUVIUM
BASAL VITROPHYRE
STRATIGRAPHY UNCERTAIN
WATER TABLE
ARROWS SHOW DIRECTION OF RELATIVE DISPLACEMENT

MAIN POINTS

- Geophysical methods are the only cost-effective and non-destructive way to obtain 3-dimensional earth science data
- Geophysical methods are non-unique
- All appropriate geologic models must be defined before geophysical investigations are planned
- Rock property heterogeneity occurs at all scales, thus scale effects are important in planning geophysical investigations
- Some geologic features of concern for performance assessment may not be resolvable with geophysics

"Evaluation of potential high-level nuclear waste repository sites is an area where geophysical capabilities and limitations may significantly impact a major governmental program. Since there is concern that extensive exploratory drilling might degrade most potential disposal sites, geophysical methods become crucial as the only nondestructive means to examine large volumes of rock in three dimensions. Characterization of potential sites requires geophysicists to alter their usual mode of thinking: no longer are anomalies being sought, as in mineral exploration, but rather their absence. Thus the size of features that might go undetected by a particular method take on new significance."

Wynn and Roseboom
Journal of Geophysical Research
Vol. 92, July 1987

ACNW WORKING GROUP MEETING ON GEOPHYSICAL TESTING METHODS FOR CHARACTERIZATION OF A HLW REPOSITORY SITE IN TUFF

COMMENTS ON DOE GEOPHYSICAL PROGRAM

ABOU-BAKR K. IBRAHIM
GEOSCIENCES & SYSTEM PERFORMANCE BRANCH
DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

APRIL 22, 1991

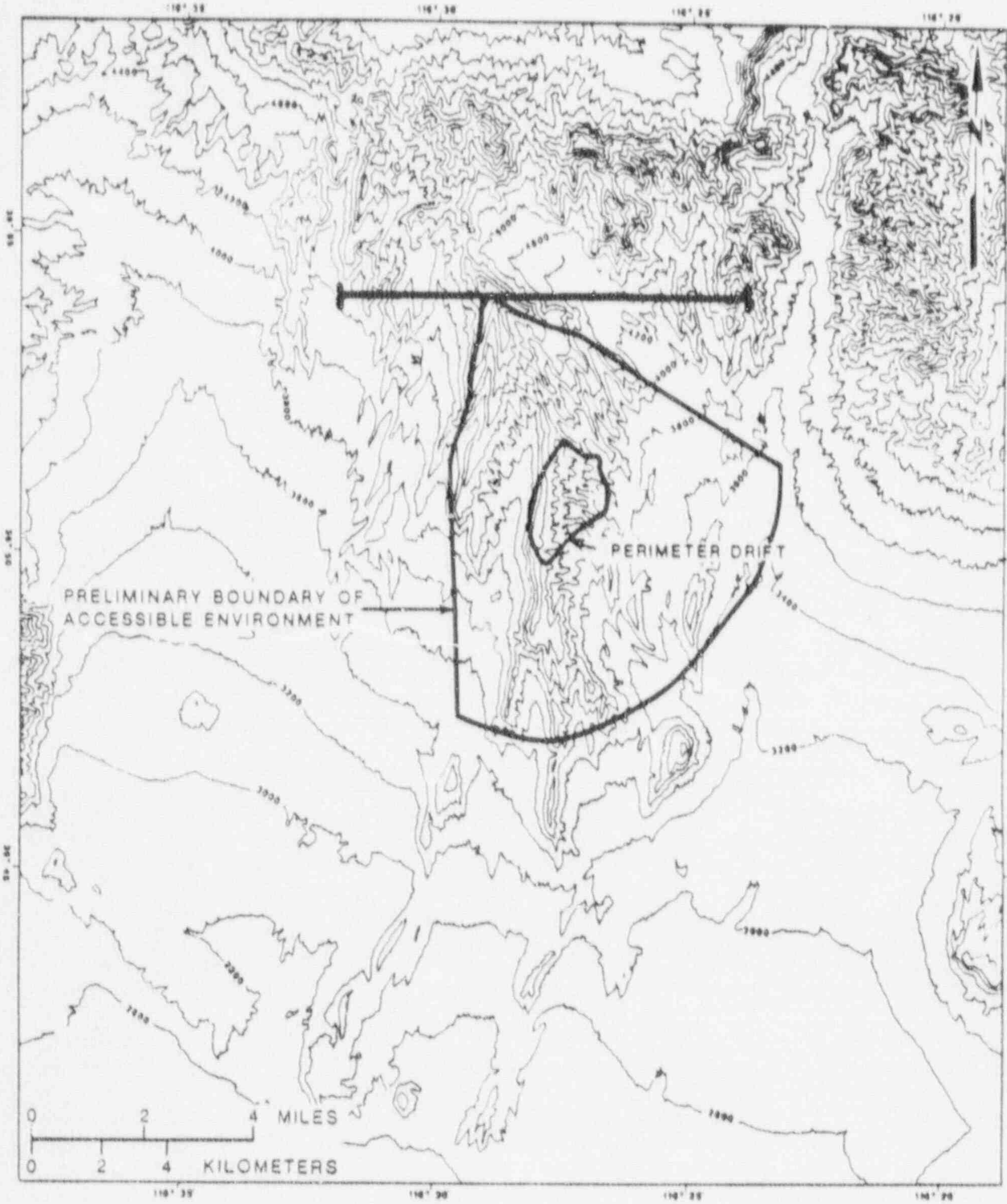


Figure 1 Approximate location of proposed seismic refraction survey across Yucca Wash

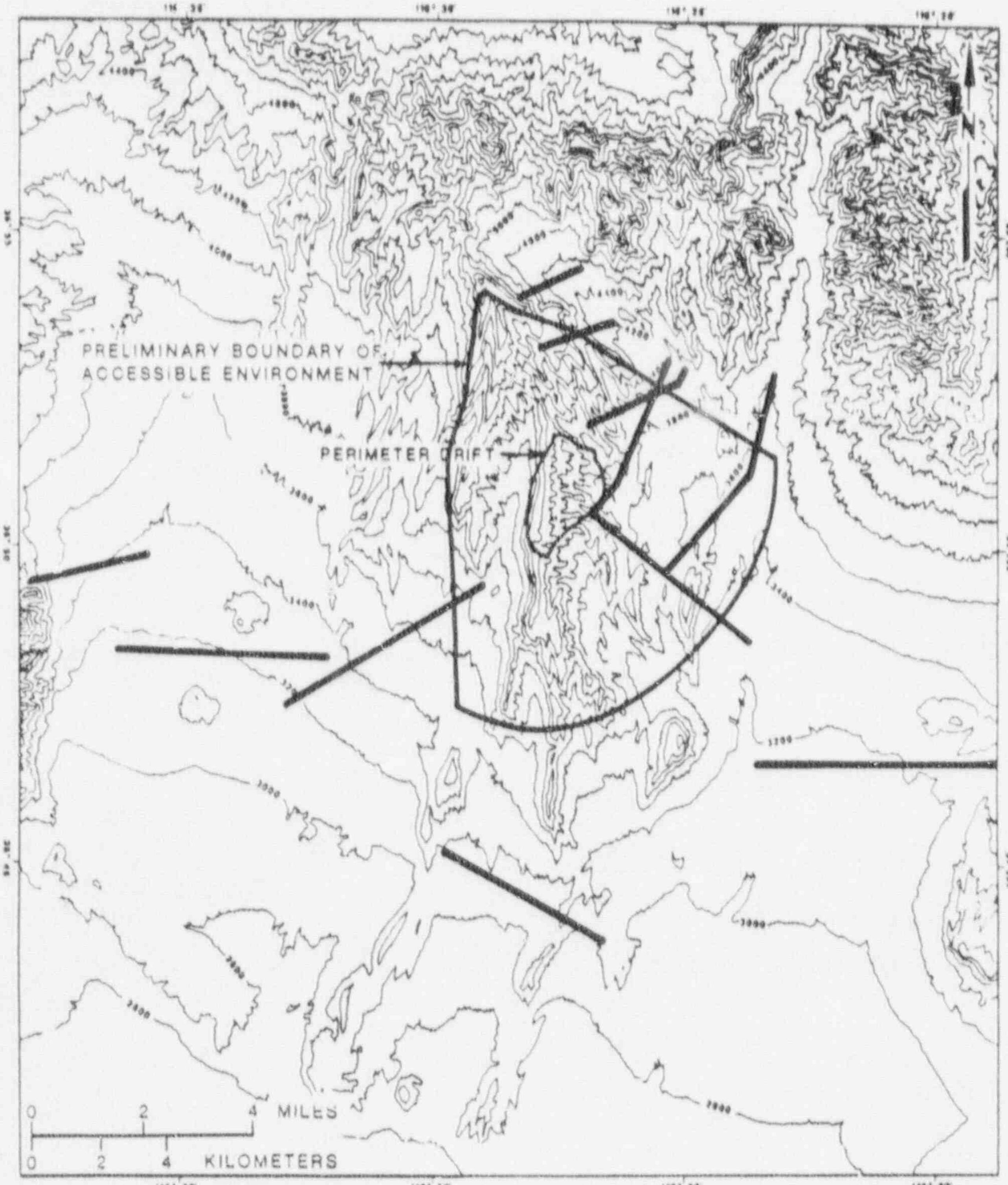


Figure 2 Approximate location of proposed seismic reflection surveys at Yucca Mountain.

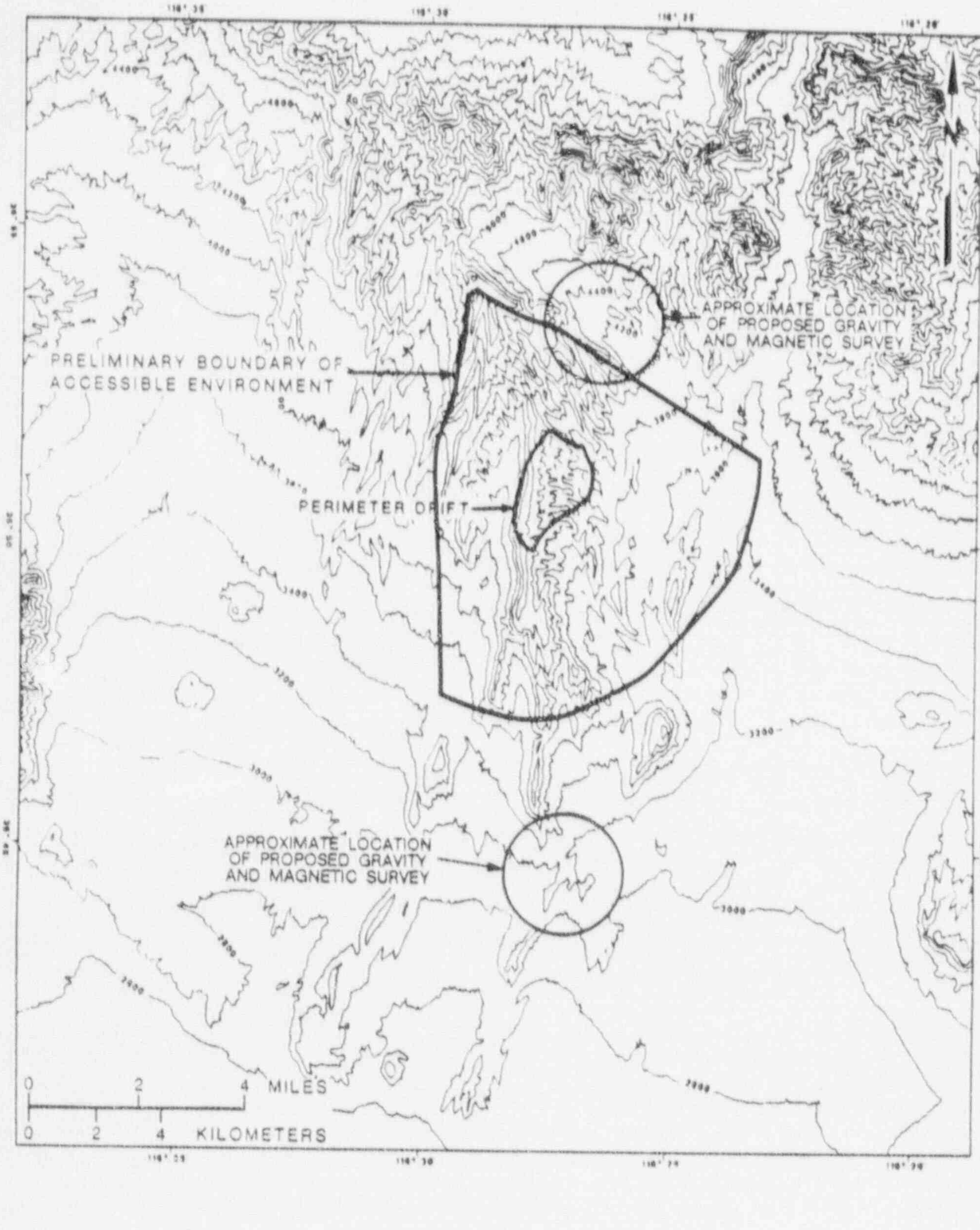


Figure 3 Approximate locations of proposed gravity and magnetic surveys near proposed coreholes

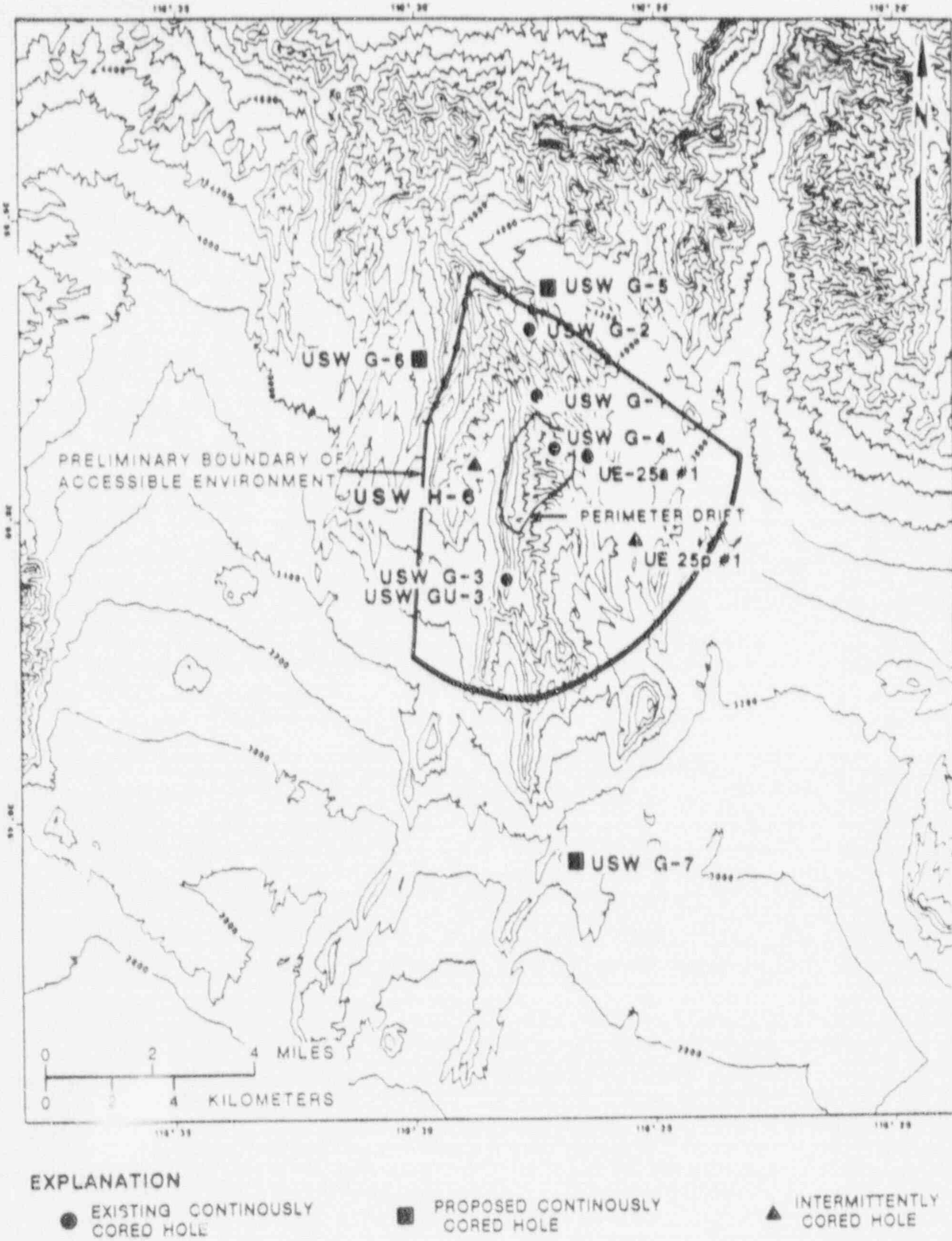


Figure 4 Locations of existing and proposed continuously cored holes at Yucca Mountain.

COMMENT 32

THE PROGRAM FOR GEOPHYSICAL INTEGRATION AS PRESENTED IN THE SCP IS INSUFFICIENTLY DESCRIBED. THE CORRELATION BETWEEN THE DIFFERENT GEOPHYSICAL INVESTIGATIONS IS NOT PRESENTED AND, IN ADDITION, THE APPROACH THAT WILL BE USED TO INTEGRATE THE GEOPHYSICAL ACTIVITIES AND HOW THESE DIFFERENT GEOPHYSICAL ACTIVITIES WILL COMPLEMENT EACH OTHER DOES NOT APPEAR TO BE DISCUSSED IN THE SCP

COMMENT 51

GEOPHYSICAL SURVEY PROGRAMS AS INDICATED IN THE SCP MAY NOT BE SUFFICIENT TO IDENTIFY AND CHARACTERIZE BOTH THE DEEP CRUSTAL AND SHALLOW GEOLOGIC FEATURES AND THEIR INTERRELATIONSHIP

COMMENT 52

NO SPECIFIC GEOPHYSICAL PROGRAM APPEARS TO BE PLANNED TO IDENTIFY VOLCANIC/IGNEOUS FEATURES AND THEIR EXTENT UNDER OR CLOSE TO THE SITE

DOE WHITE PAPER

- o THE MAJORITY OF THE STATEMENTS MADE IN THE WHITE PAPER APPEAR REASONABLE

- o FOR EXAMPLE, IN THE WHITE PAPER IT IS INDICATED

  * CURRENT PLANS CALL FOR THE REVIEW (OF EXISTING DATA) PRIOR TO ADDITIONAL SURVEYS

  * SEISMIC REFLECTION PROFILES WILL BE USED TO DEFINE FRAMEWORK, AND TO PROVIDE GUIDANCE FOR ESTABLISHING OPTIMAL LOCATIONS FOR DRILLING SITES (OR TRENCHING)

  * INTEGRATION AMONG ACTIVITIES IS NEEDED TO ENSURE THAT MAXIMUM BENEFIT IS OBTAINED FROM GEOPHYSICAL SURVEYS AND INTERPRETATIONS TO ENSURE THAT THE CHARACTERIZATION PROGRAM PROVIDES TIMELY INFORMATION APPROPRIATE TO SUPPORT A REPOSITORY LICENSE APPLICATION

DOE WHITE PAPER

- o WHILE DOE INDICATED THAT THE WHITE PAPER IS A STARTING POINT, THE NRC STAFF EXPECTED THAT DOE WOULD BE MORE SPECIFIC ABOUT ITS GEOPHYSICAL ACTIVITIES PLANNING

- o THE NRC STAFF EXPECTED THAT DOE WOULD PRESENT THE LOCATIONS OF THE DIFFERENT GEOPHYSICAL TRAVERSES ON A MAP SHOWING THE INTERRELATION AMONG THE DIFFERENT INVESTIGATIONS

- o THE NRC STAFF EXPECTED THAT THE RATIONALE FOR CHOOSING THE LOCATIONS OF THESE LINES AND THEIR APPROPRIATENESS FOR RECONNAISSANCE AND ADEQUACY OF COVERAGE AND CHARACTERIZATION OF YUCCA MOUNTAIN WOULD BE PROVIDED

Integrated Geophysical Studies

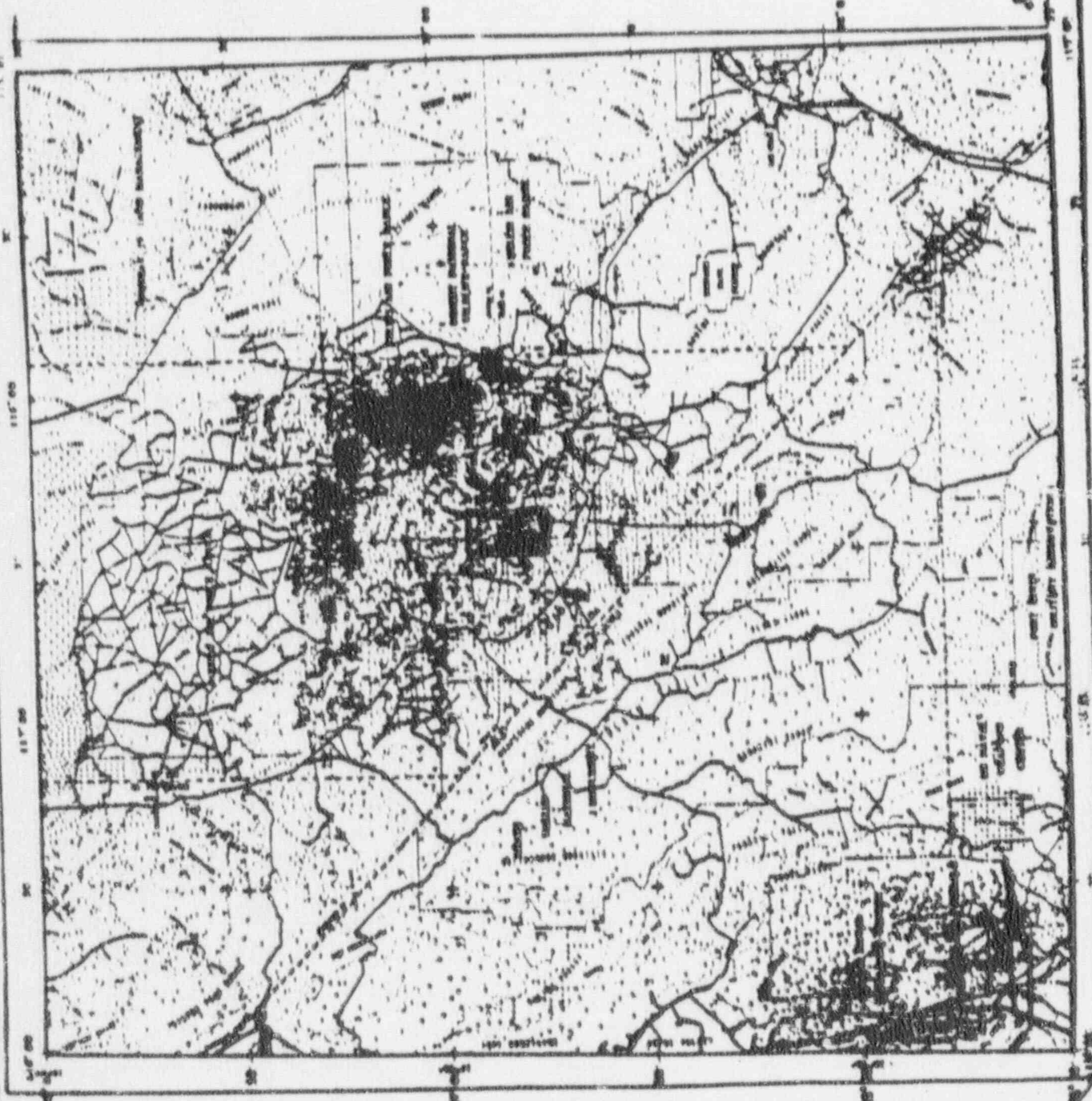
Walter D. Mooney
U.S.G.S.

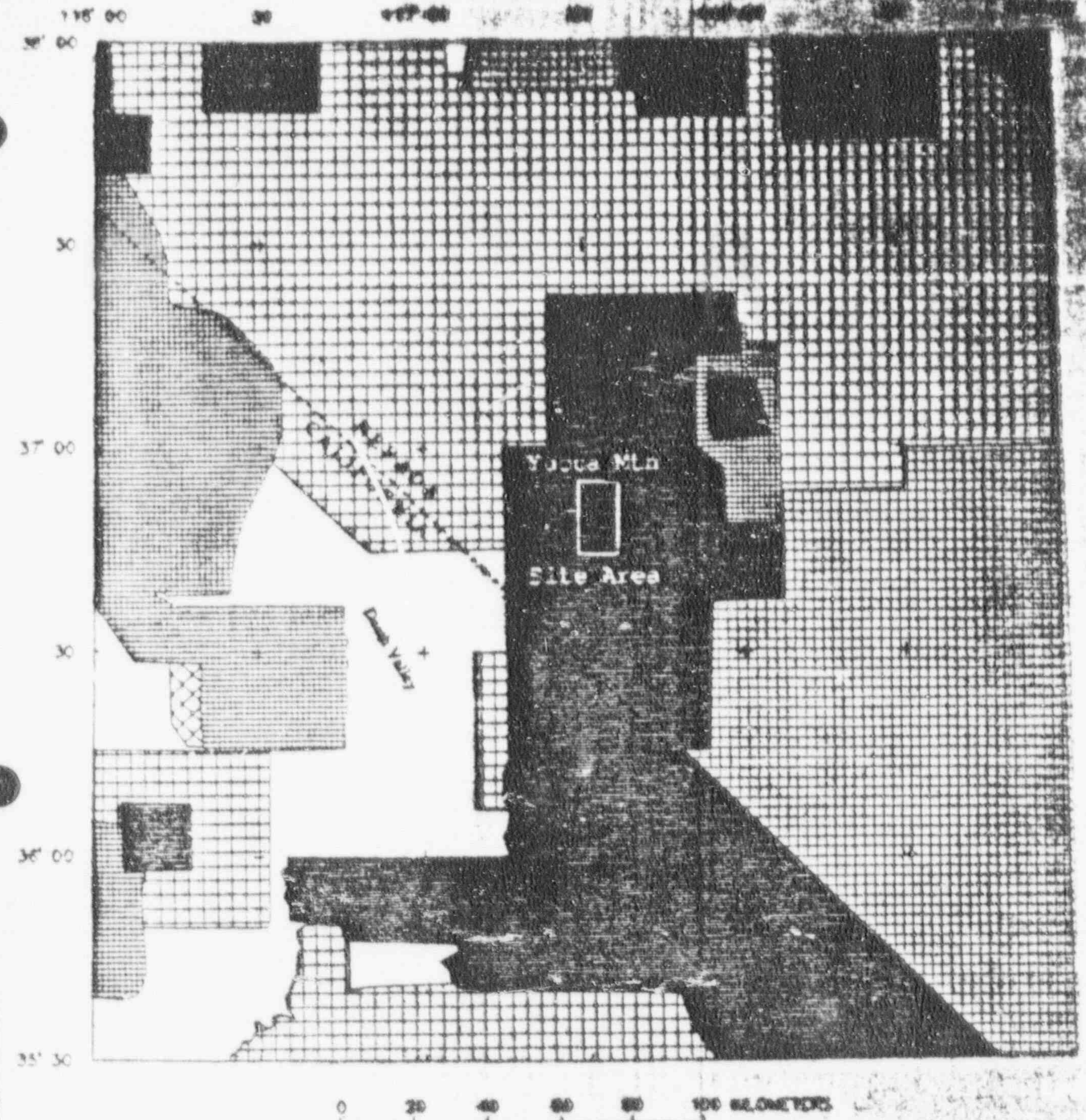
ACNW
April 22, 1991

REGIONAL AREA

YUCCA MTN.

GRAVITY STATIONS

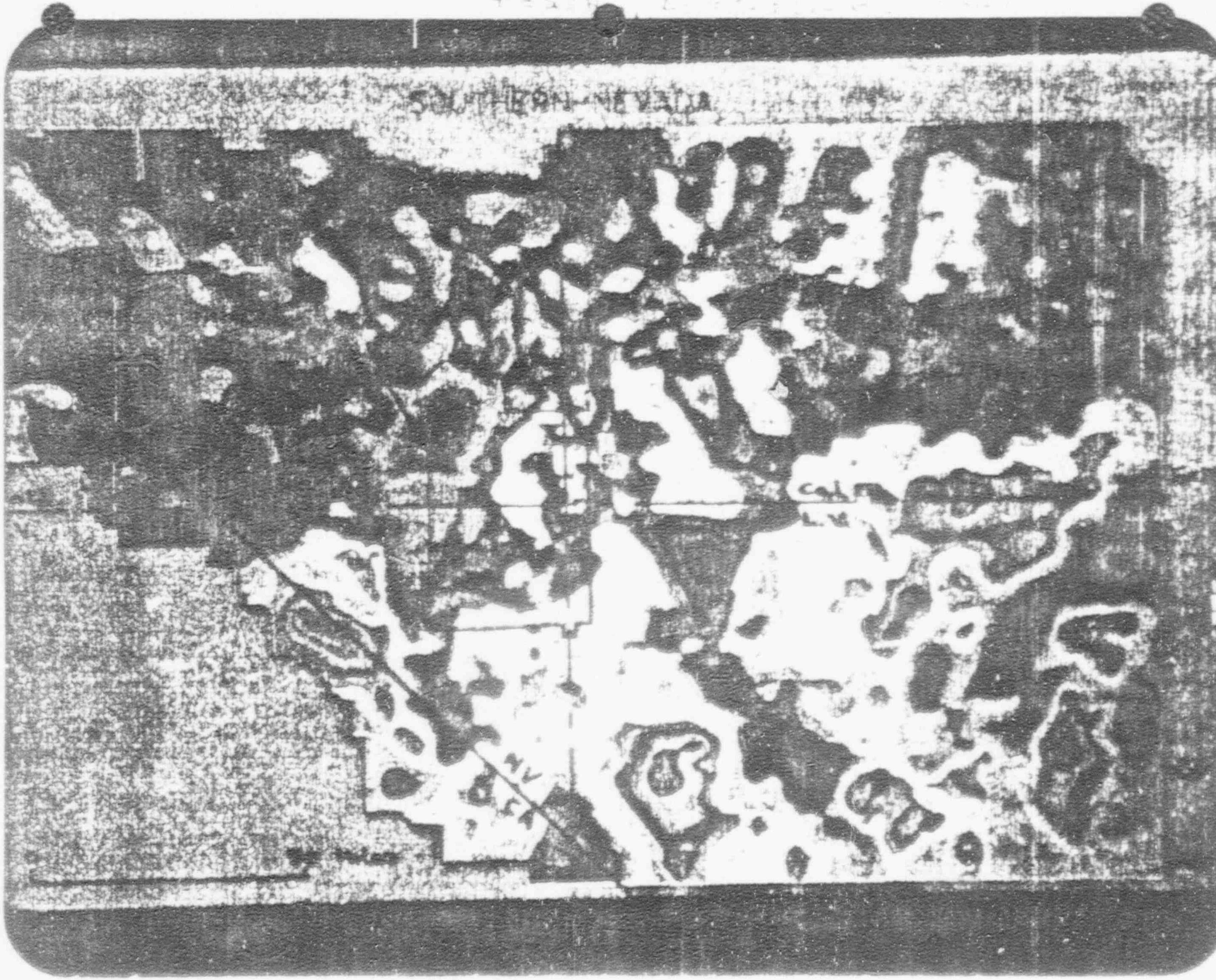


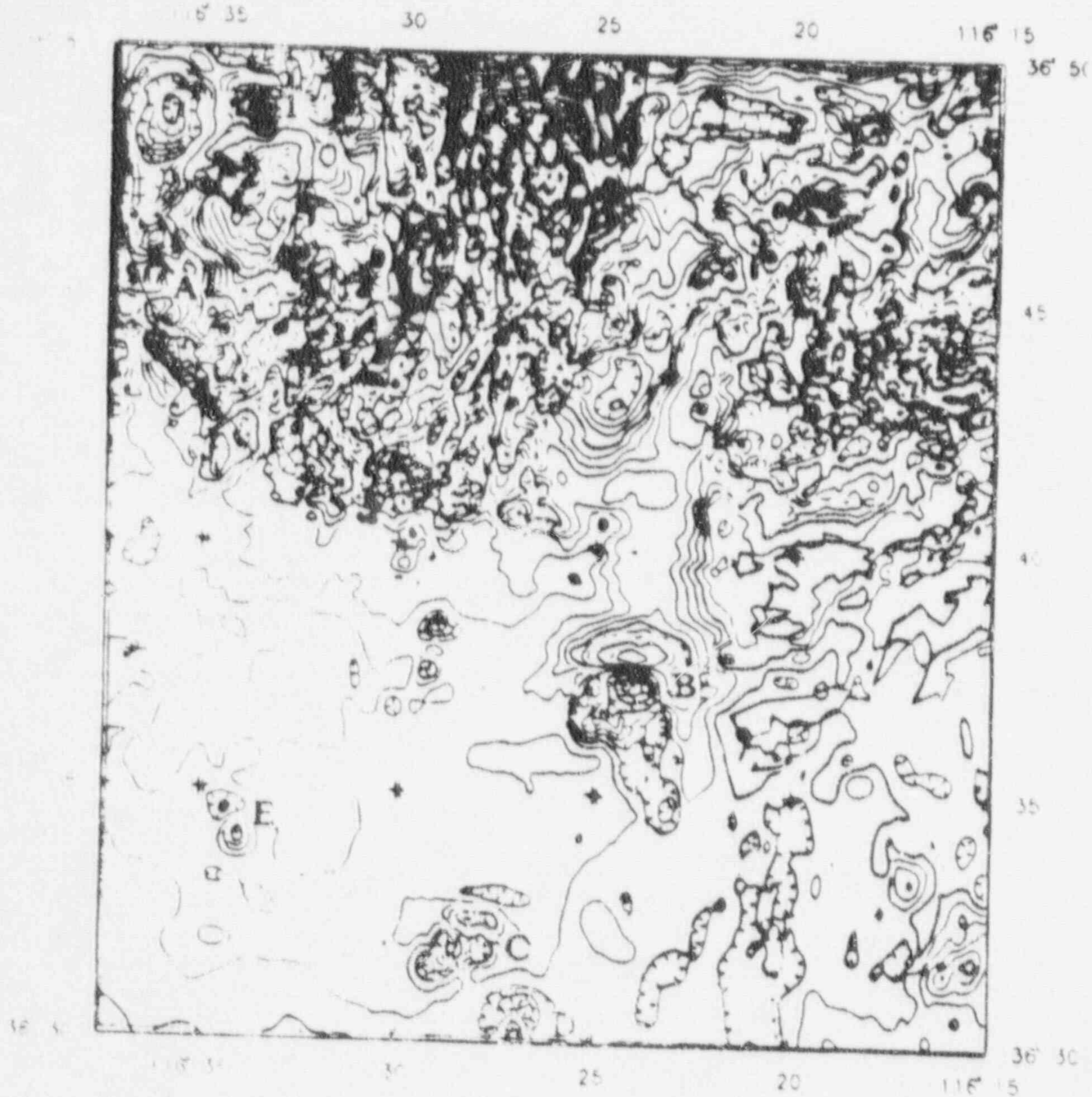


AEROMAG INDEX MAP-REGIONAL AREA

FLIGHTLINE SPACING

- 0.4 & 0.8 km draped
- 0.8 km barometric
- 1.6 km draped
- 1.6 km barometric
- 3.2 km barometric
- 1.6 & 4.8 km NURE

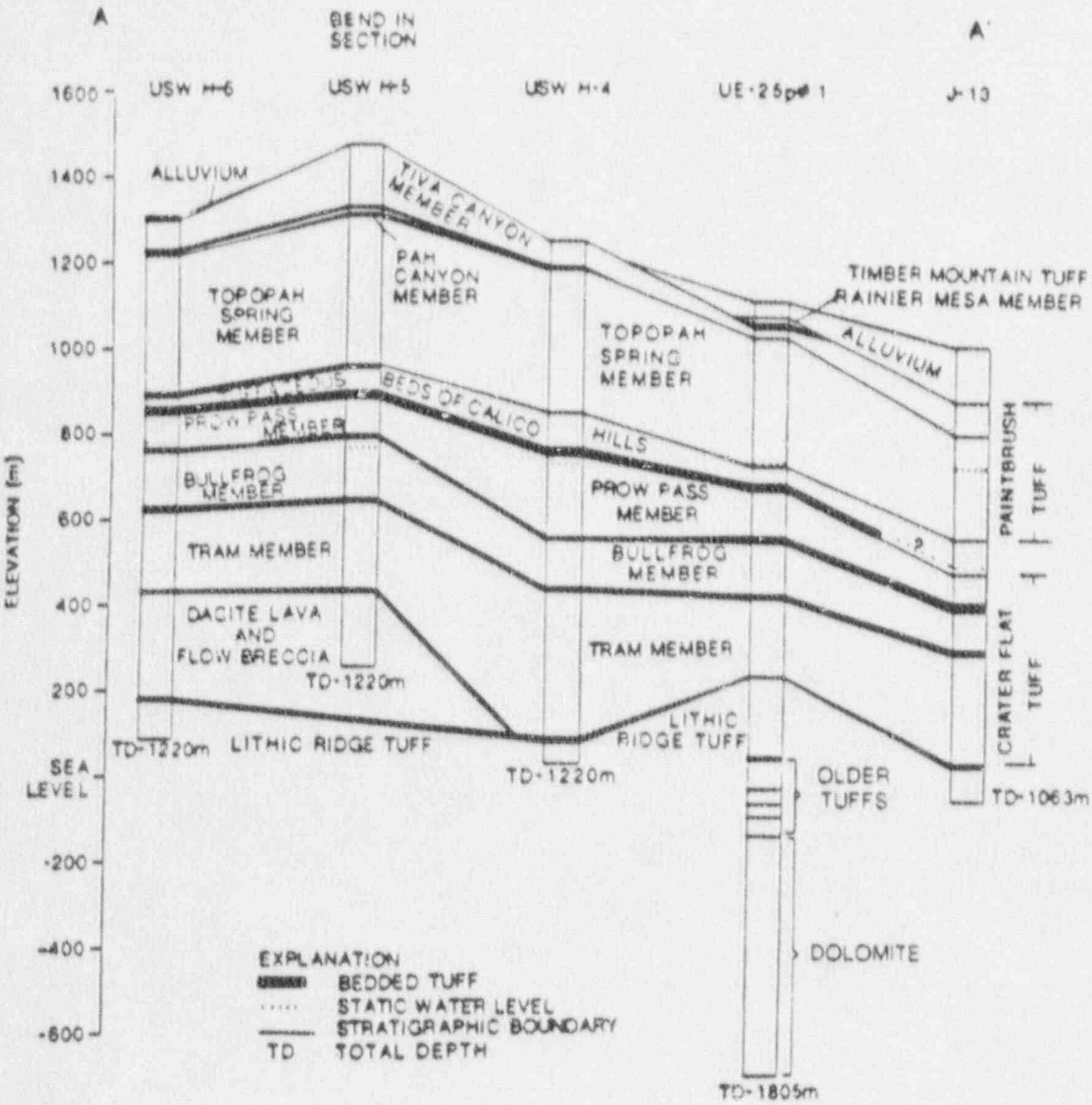

SOUTHERN NEVADA
NV



Aeromag Survey - South YM

See comment 3

Yucca Mtn Stratigraphy



1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

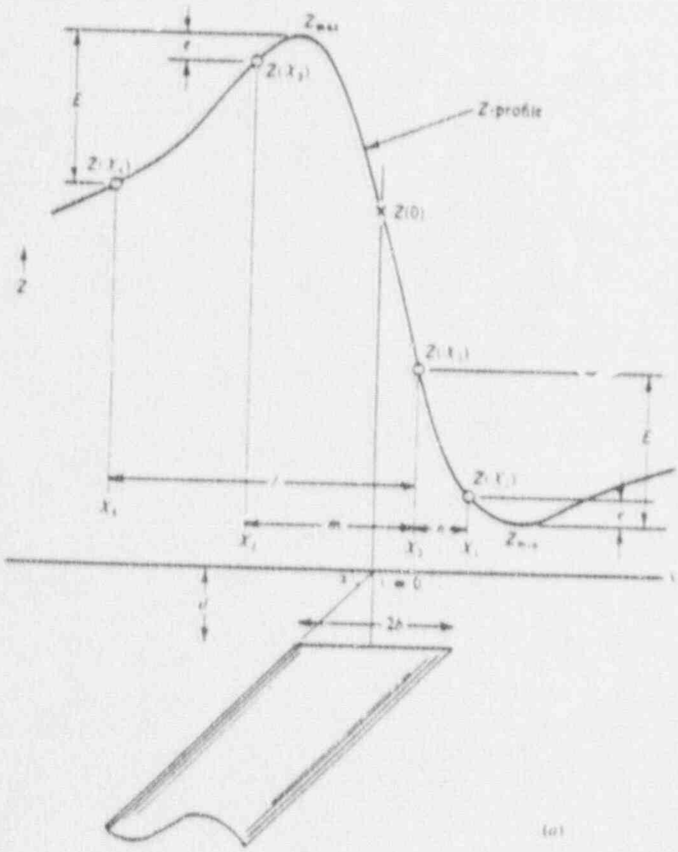
Magnetic Susceptibilities

Type	Susceptibility × 10^6 emu Range	Average
Sedimentary		
Dolomite	0-75	10
Limestones	2-280	25
Sandstones	0-1660	30
Shales	5-1480	50
Av. Var. Sed. (48)	0-4000	75
Metamorphic		
Amphibolite		60
Schist	25-240	120
Phyllite		130
Gneiss	10-2000	
Quartzite		350
Serpentine	250-1400	
Slate	0-3000	500
Av. Var. Met (61)	0-5800	350

Type	Susceptibility × 10^6 emu Range	Average
Igneous		
Granite	0-4000	200
Rhyolite	20-3000	
Dolerite	100-3000	1400
Augite-Syenite	2700-3600	
Olivine-Diabase		2000
Diabase	80-13,000	4500
Porphyry	20-16,700	5000
Gabbro	80-7200	6000
Basalts	20-14,500	6000
Diorite	50-10,000	7000
Pyroxenite		10,500
Peridotite	7600-15,600	13,000
Andesite		13,500
Av. acid Ign.	3-6530	650
Av. basic Ign.	44-9710	2600

Dolomite 75
Shale 1480
Basalt 14,500
Granite 4,000

Magnetics



(a)

U. S. G. S. REFRACTION PROFILES - NEVADA TEST SITE '83 & '85

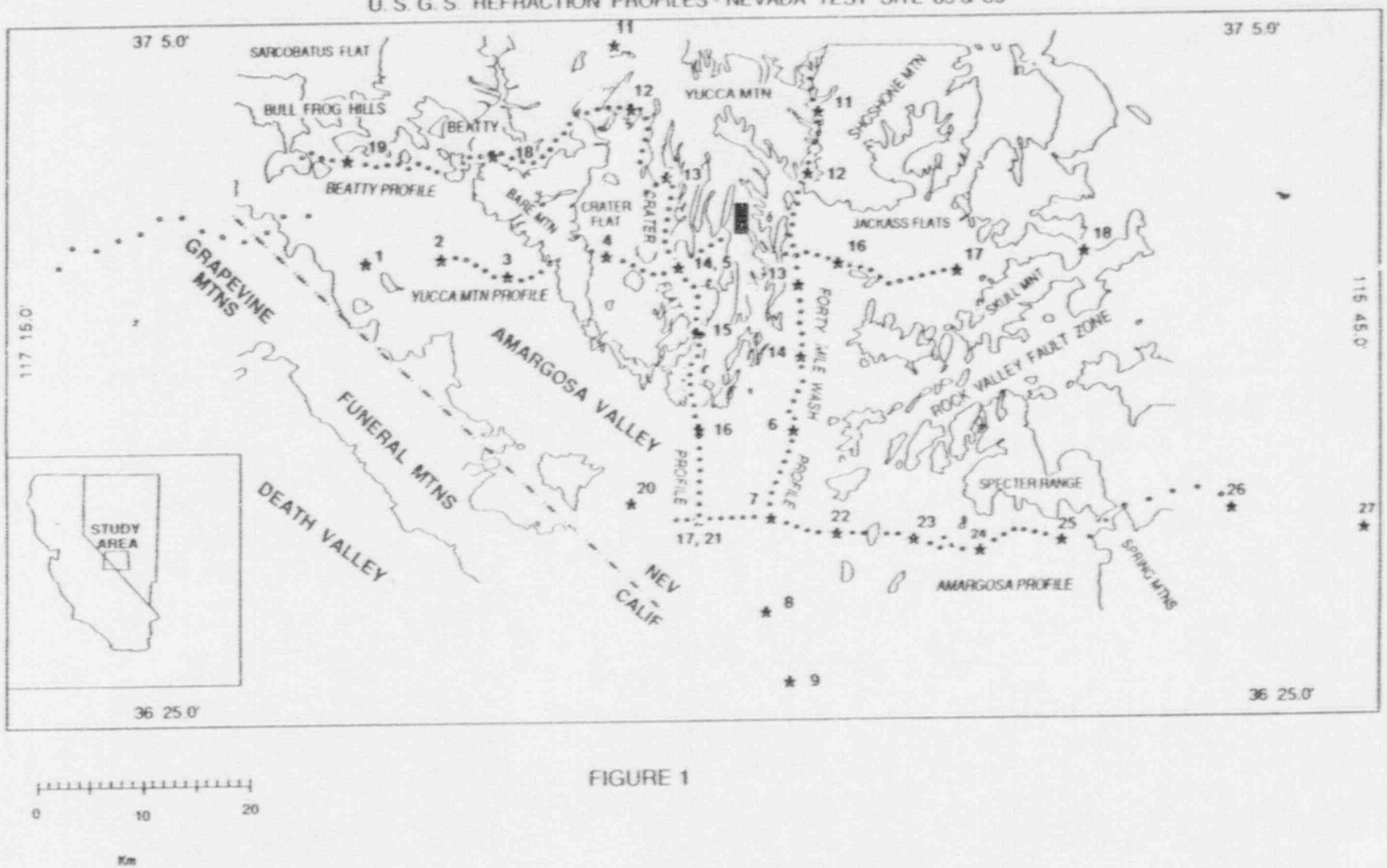
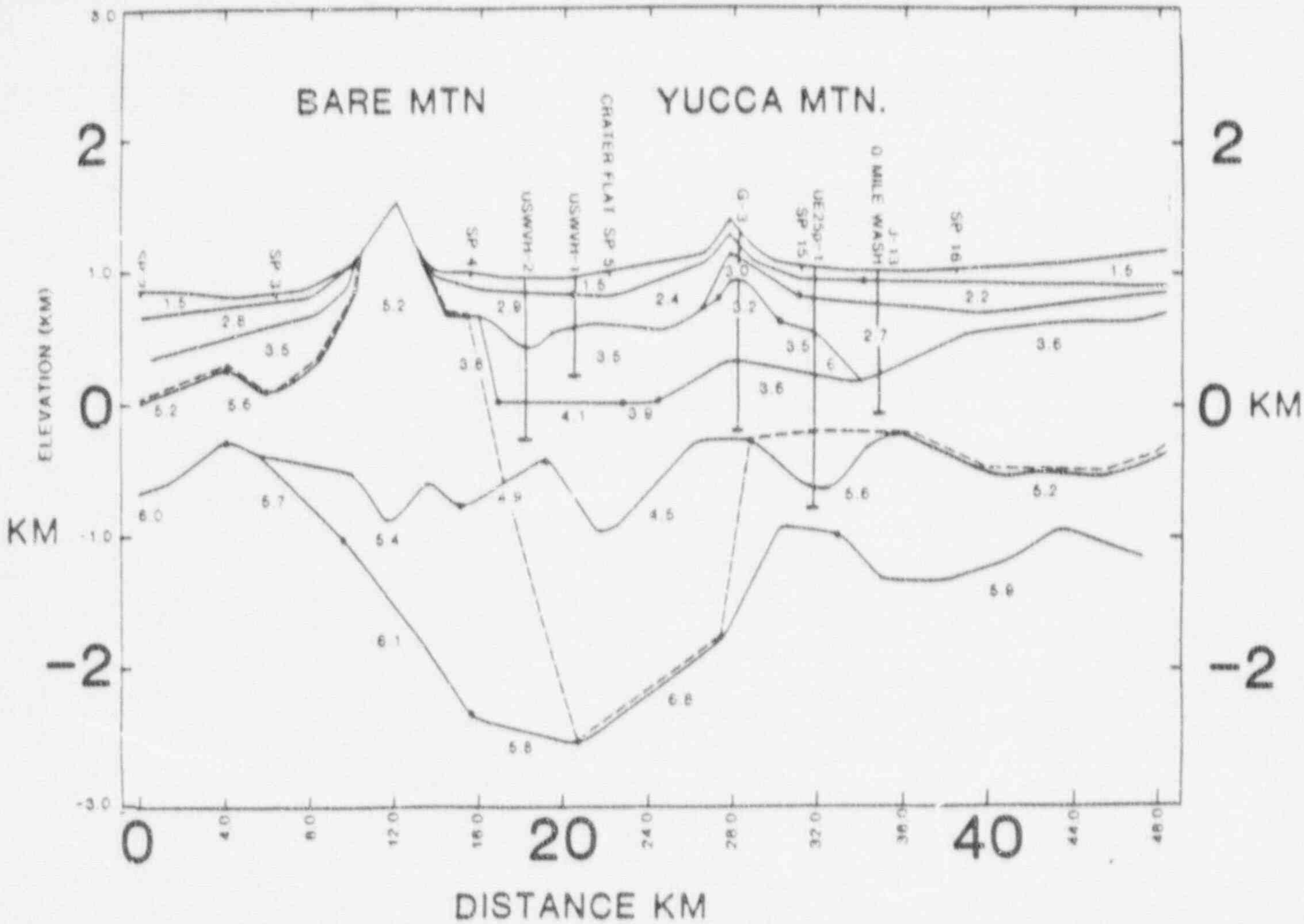
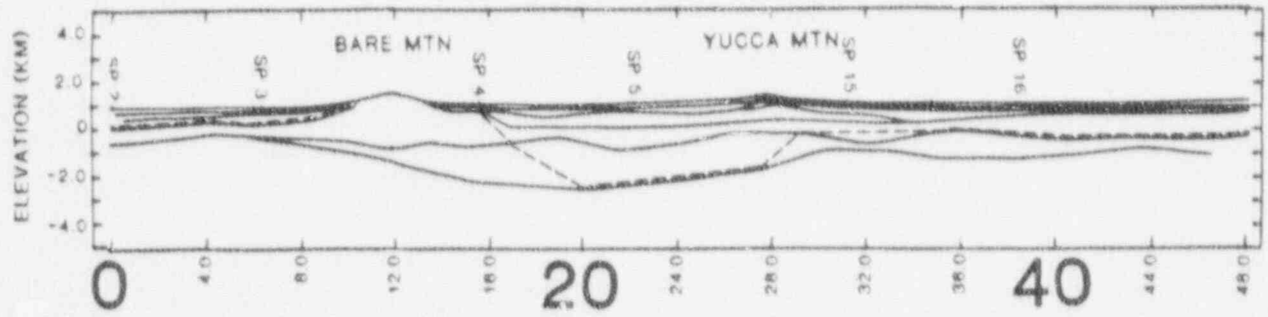
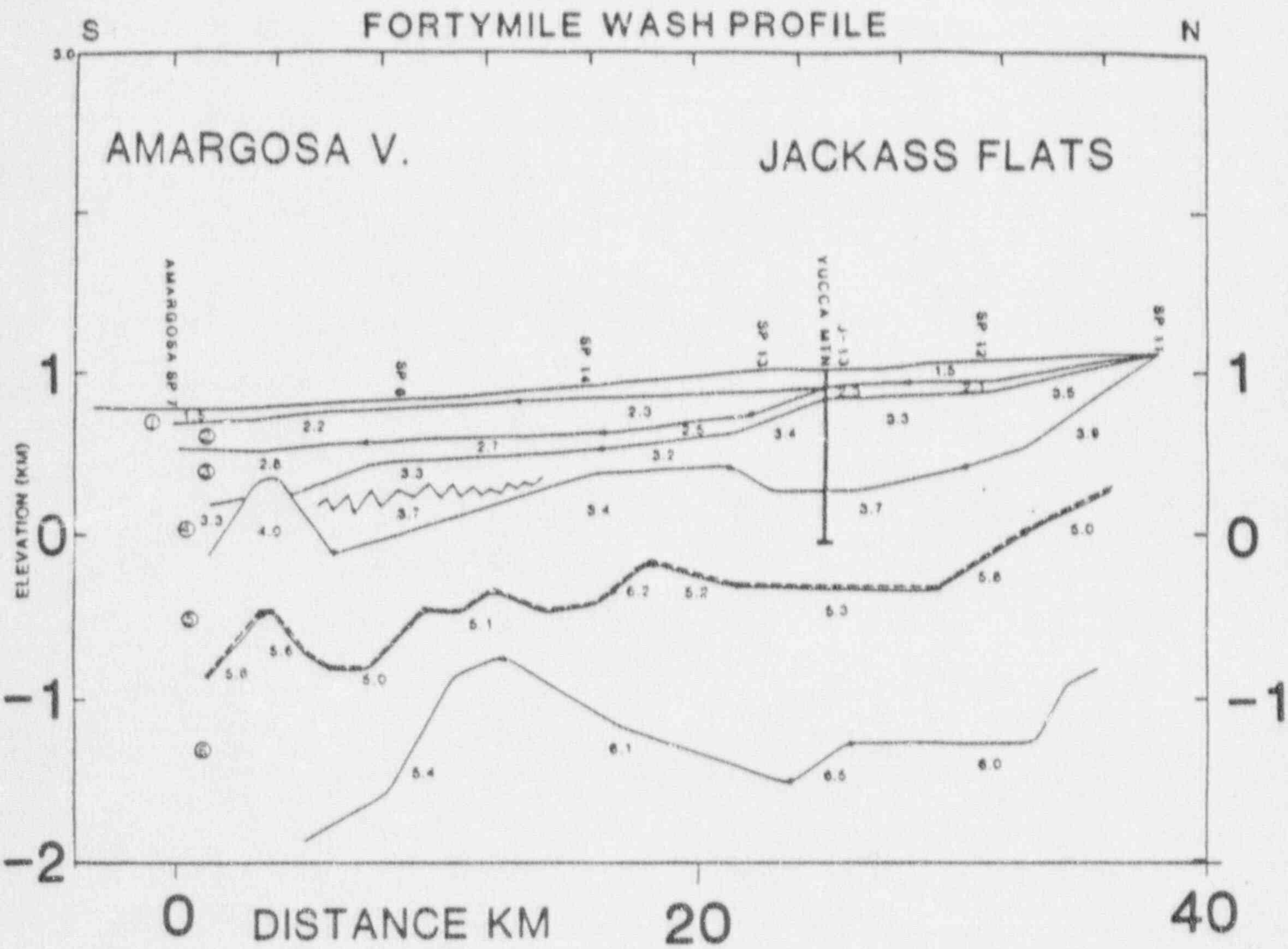


FIGURE 1

YUCCA MOUNTAIN EAST-WEST PROFILE







FORTYMILE WASH PROFILE
S
N
AMARGOSA V.
JACKASS FLATS
AMARGOSA SP 7
SP 8
SP 14
SP 13
YUCCA MTN
J-13
SP 12
SP 11
ELEVATION (KM)
1
0
-1
-2
DISTANCE KM
0
20
40

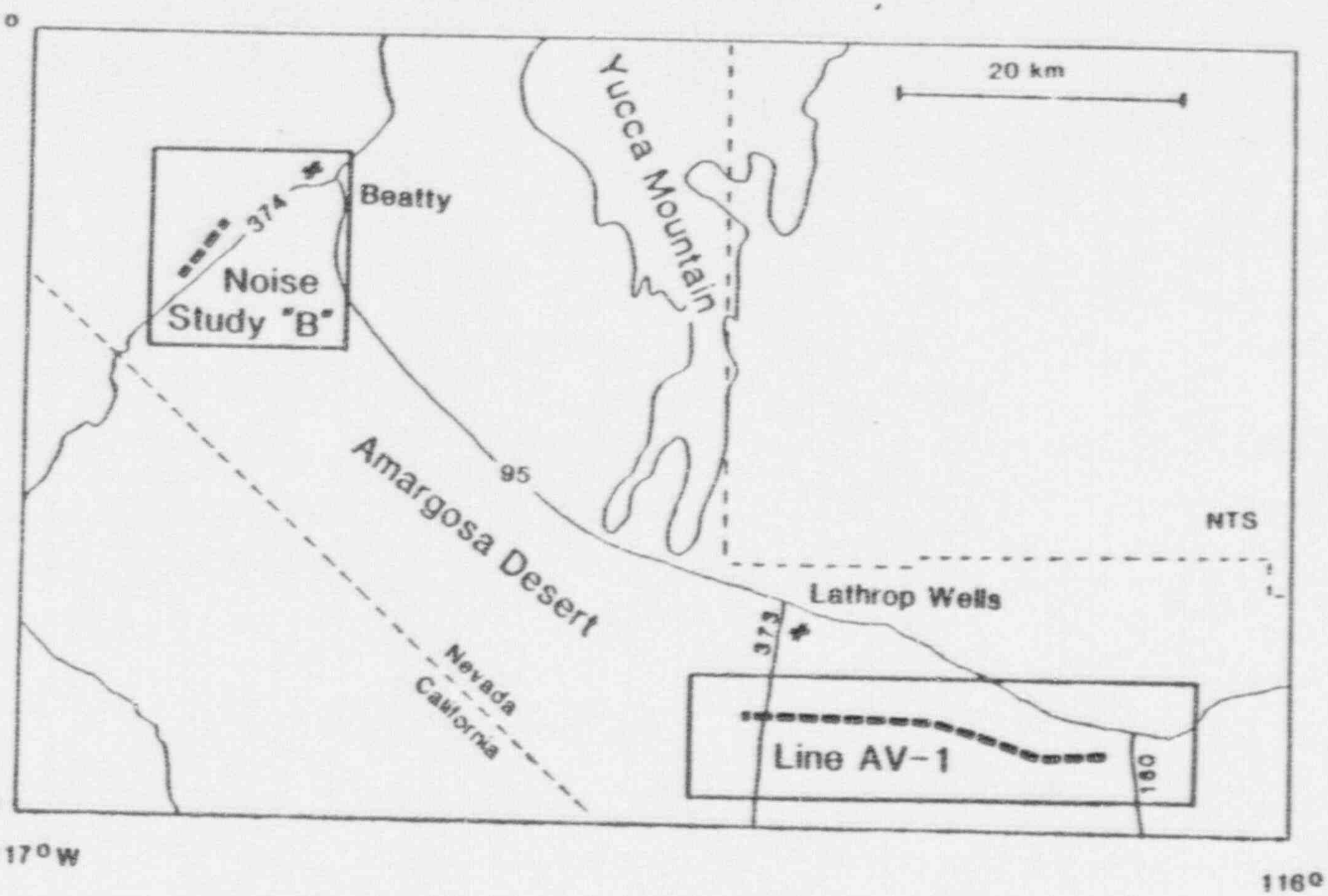
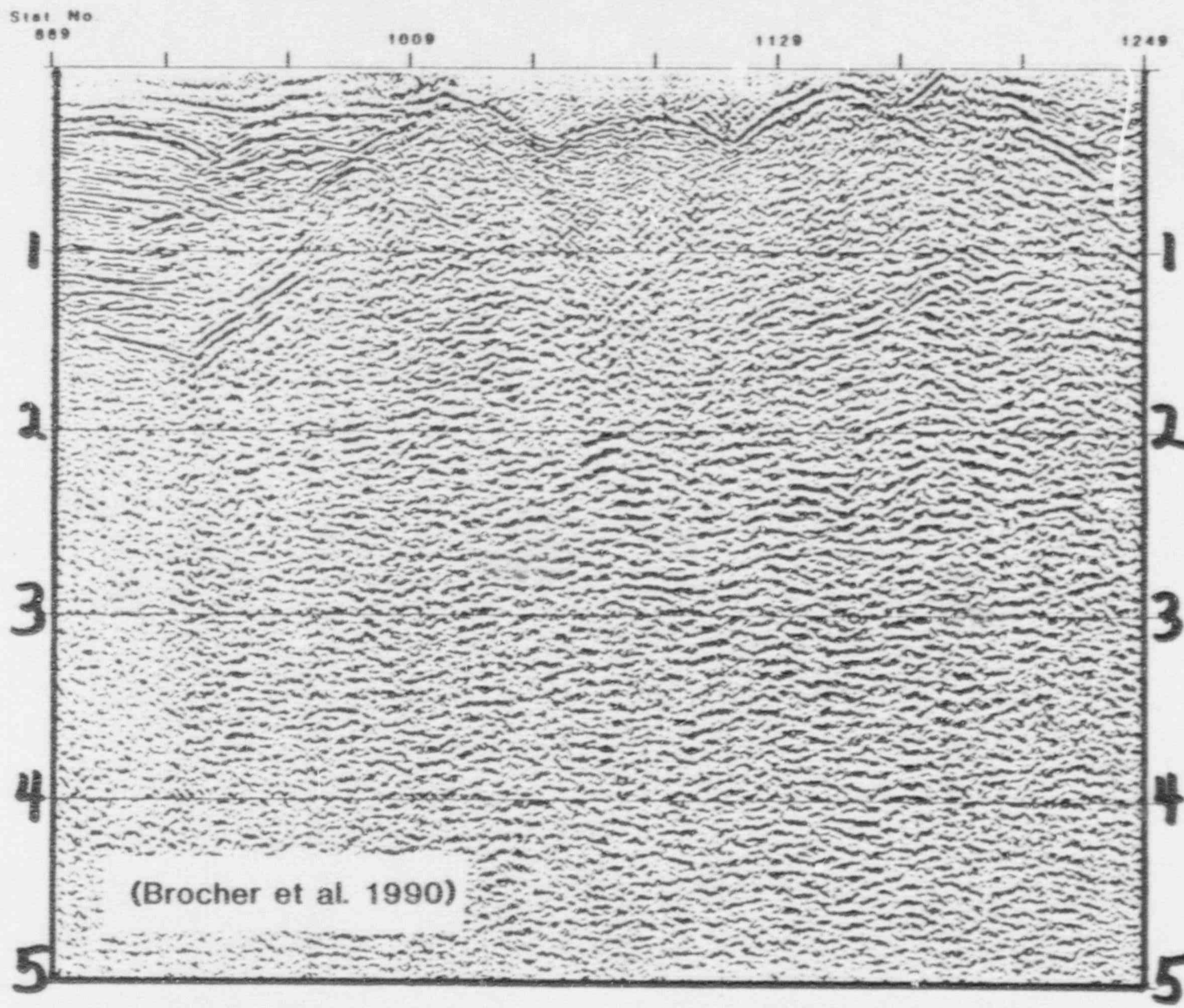
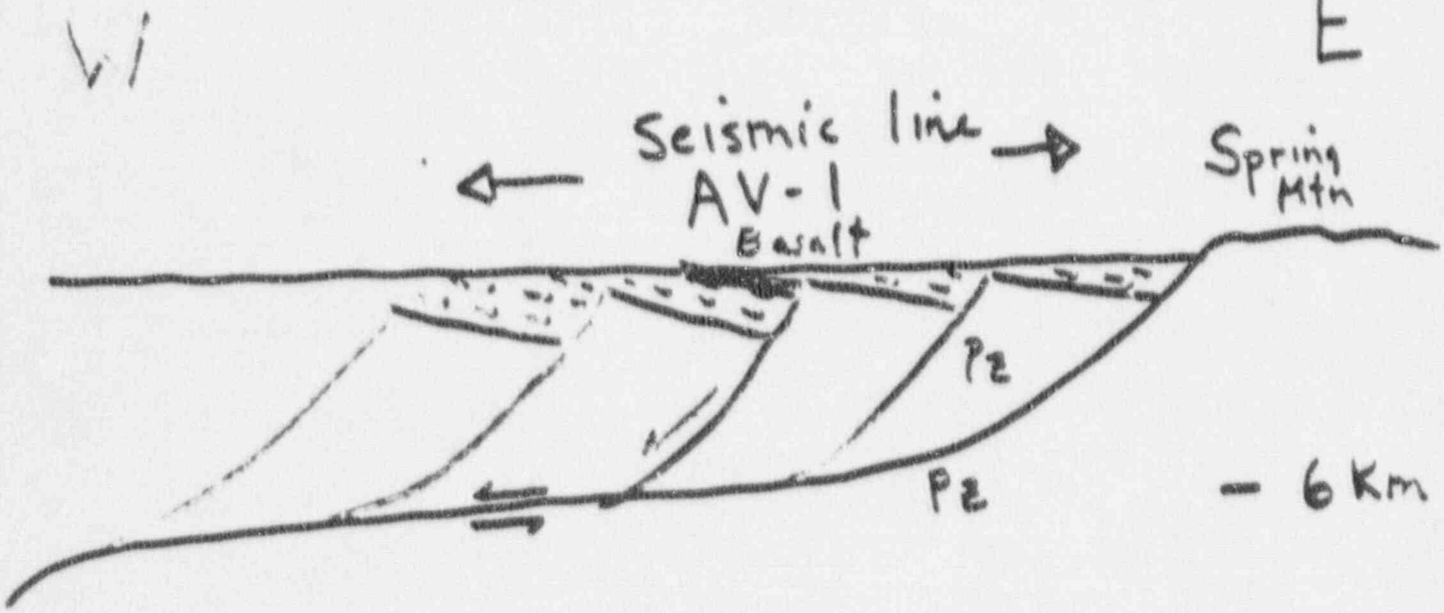

37°
Yucca Mountain
20 km
Beatty
374
Noise
Study "B"
95
Amargosa Desert
NTS
Lathrop Wells
373
Nevada
California
Line AV-1
160
36° 30'N
117° W
116°

Fig. 2

AMARGOSA DESERT REFLECTION



(15 KM South of Yucca Mtn.)



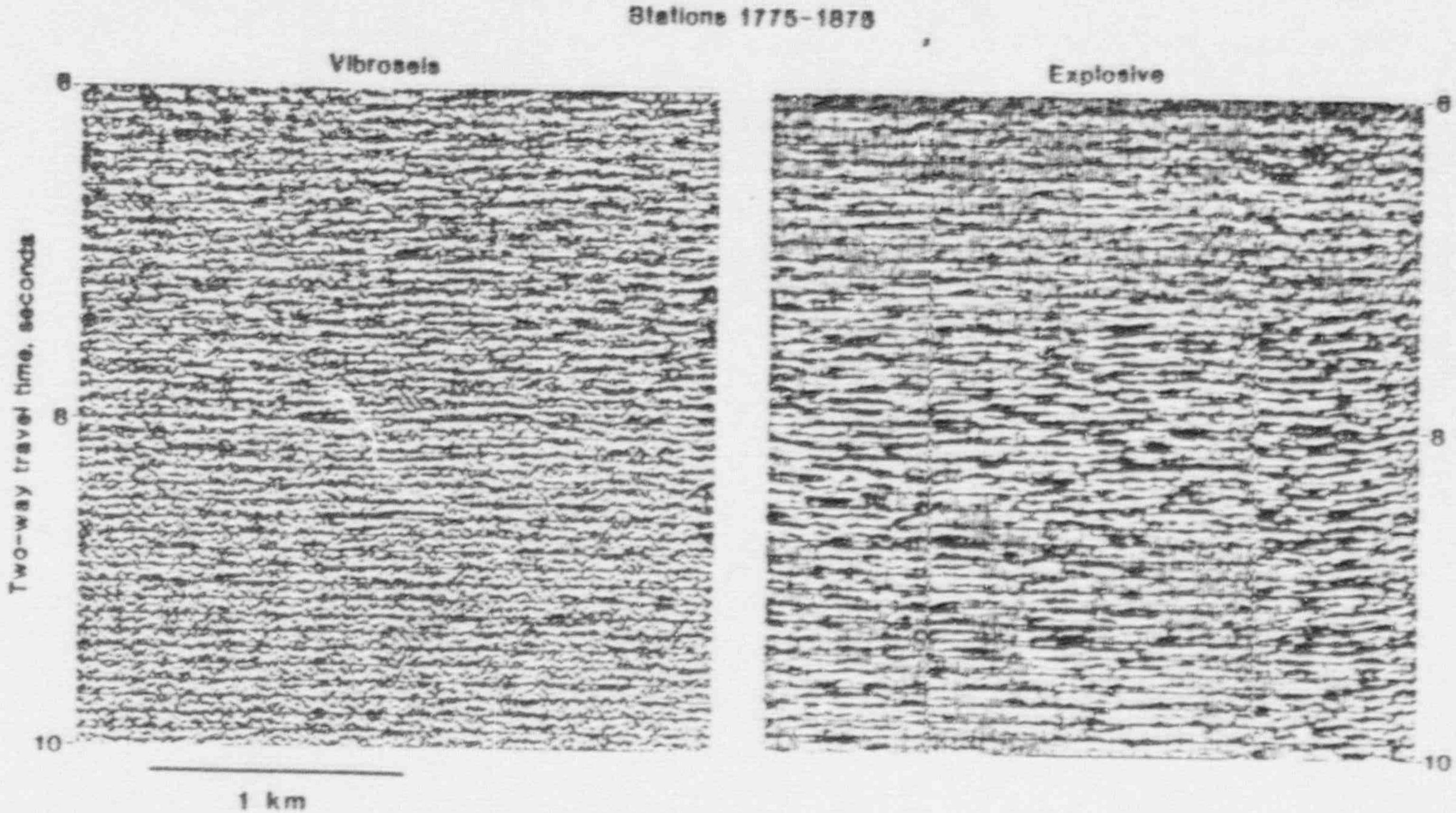
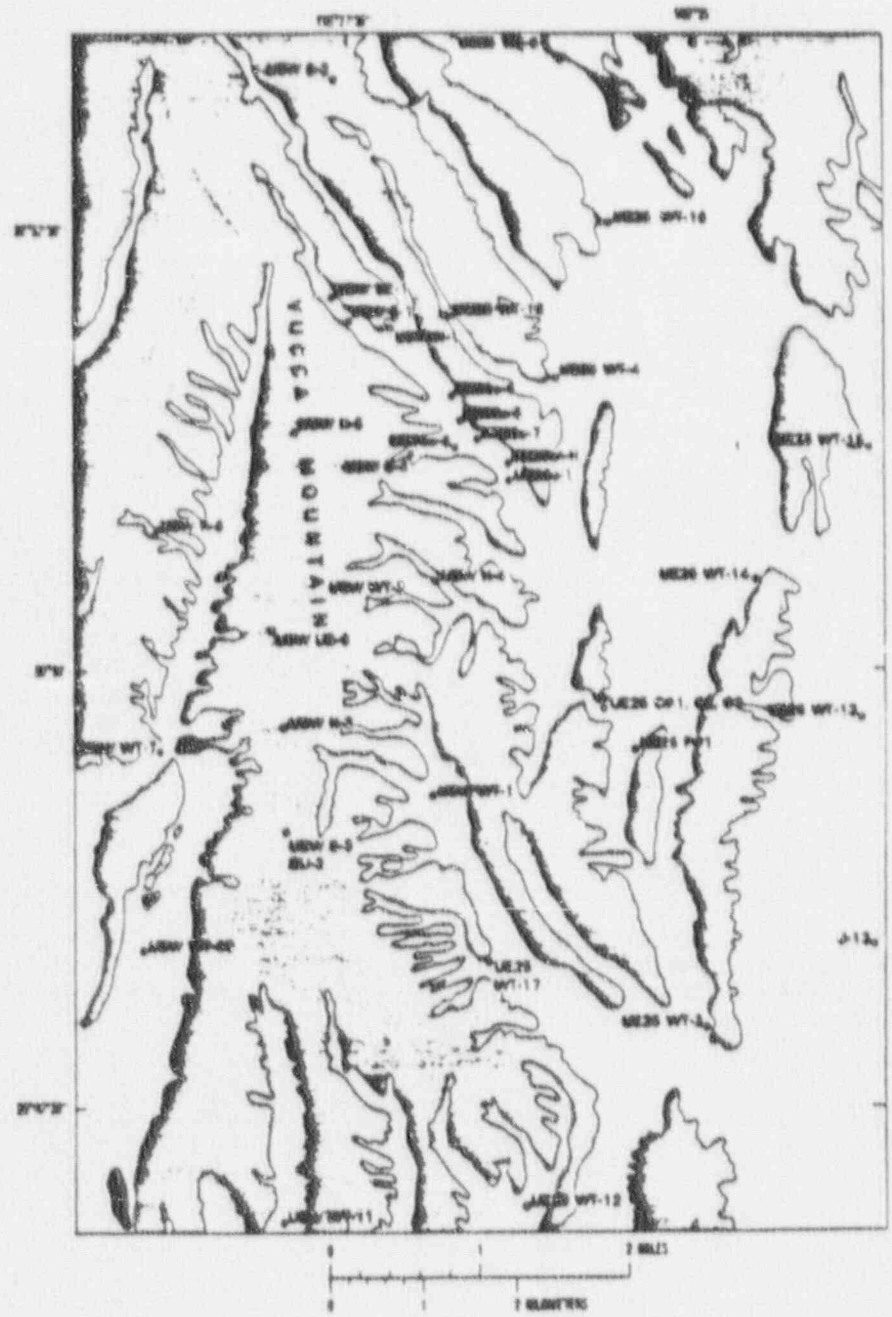

Stations 1775-1878
Vibroseis
Explosive
Two-way travel time, seconds
6
8
10
1 km

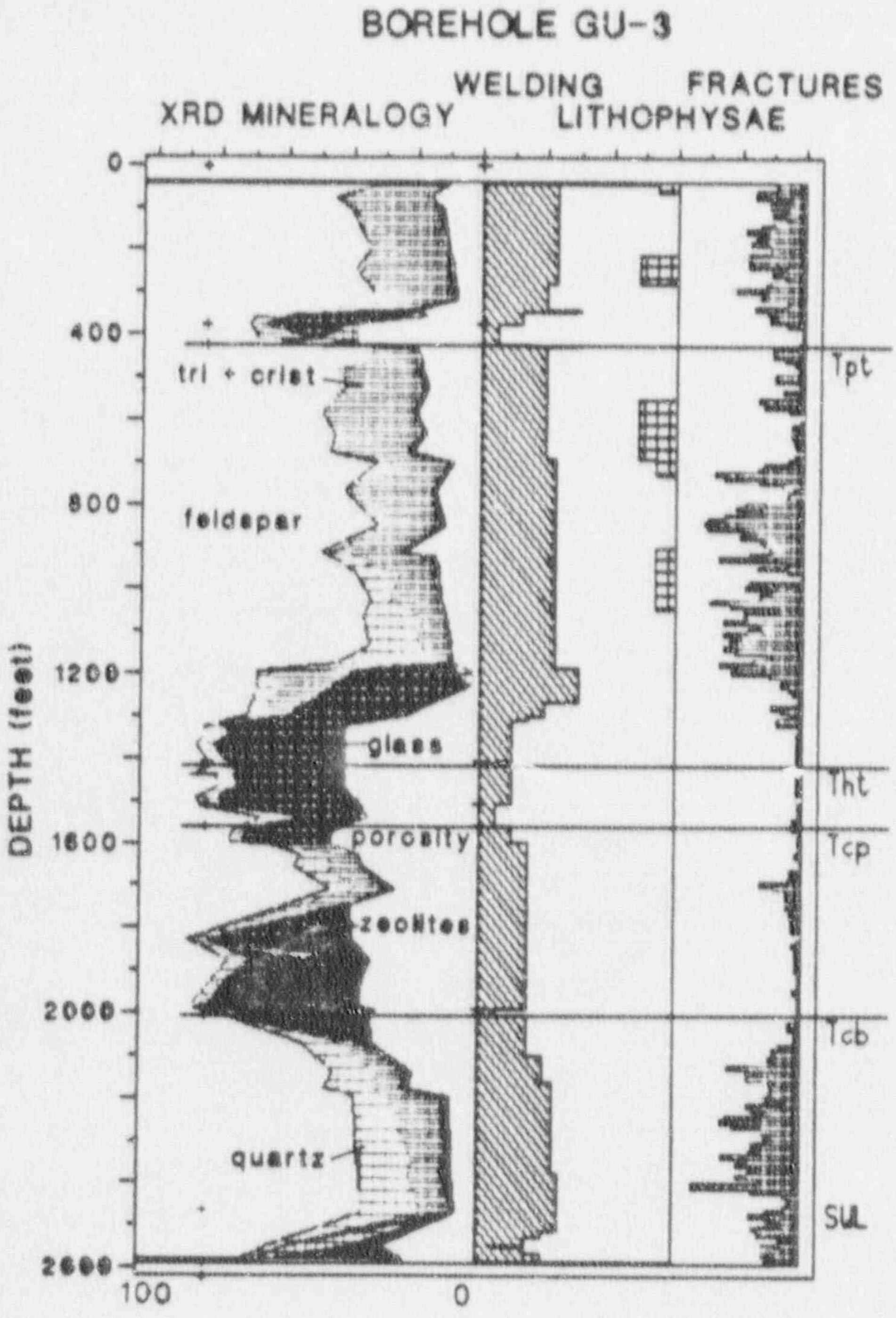
Fig. 12

Physical Properties from Integration of Borehole Data

1. Geology, mineralogy + core
2. Cross-Sections of logs.
3. Porosity
4. Permeability + Flow

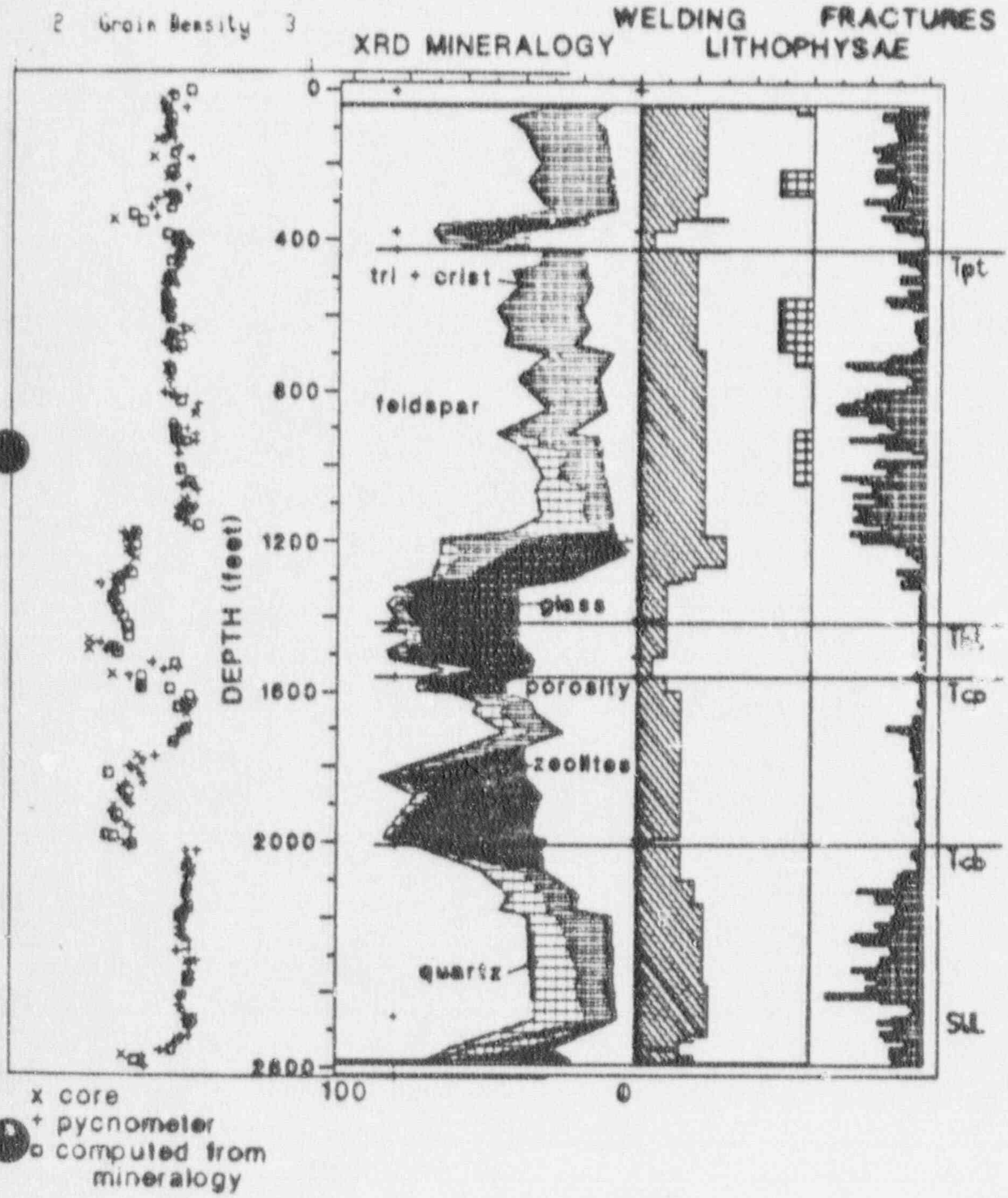


YUCCA MOUNTAIN
UE25 WT-16
UE25 WT-4
UE25 WT-14
UE25 WT-13
UE25 p#1
UE25 WT-17
UE25 WT-3
UE25 WT-12
USW WT-11
2 MILES
2 KILOMETERS

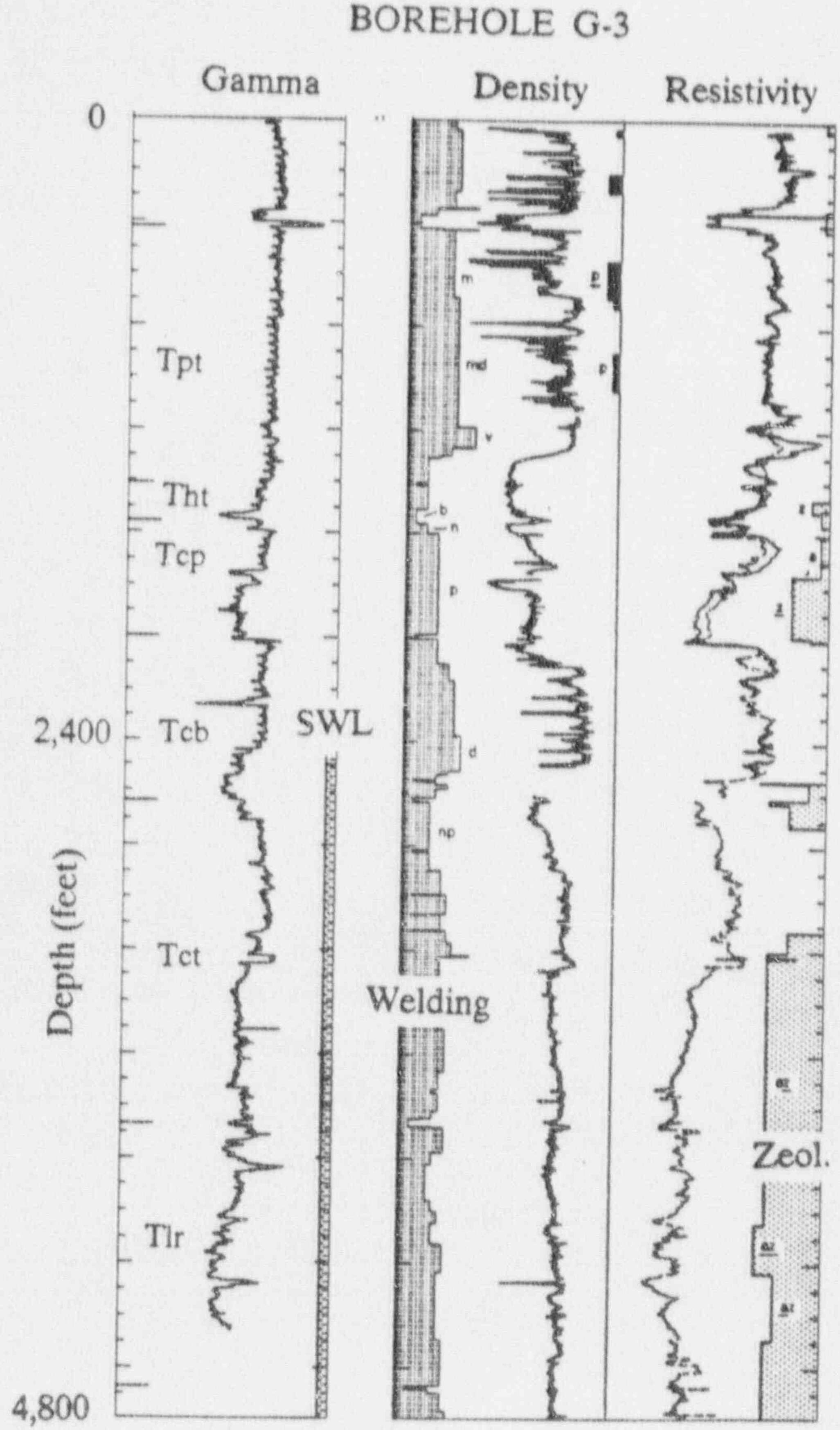

BOREHOLE GU-3
XRD MINERALOGY
WELDING
LITHOPHYSAE
FRACTURES
DEPTH (feet)
0
400
800
1200
1600
2000
2600
100
0
tri + crist
feldspar
glass
porosity
zeolites
quartz
Tpt
Tht
Tcp
Tcb
SUL

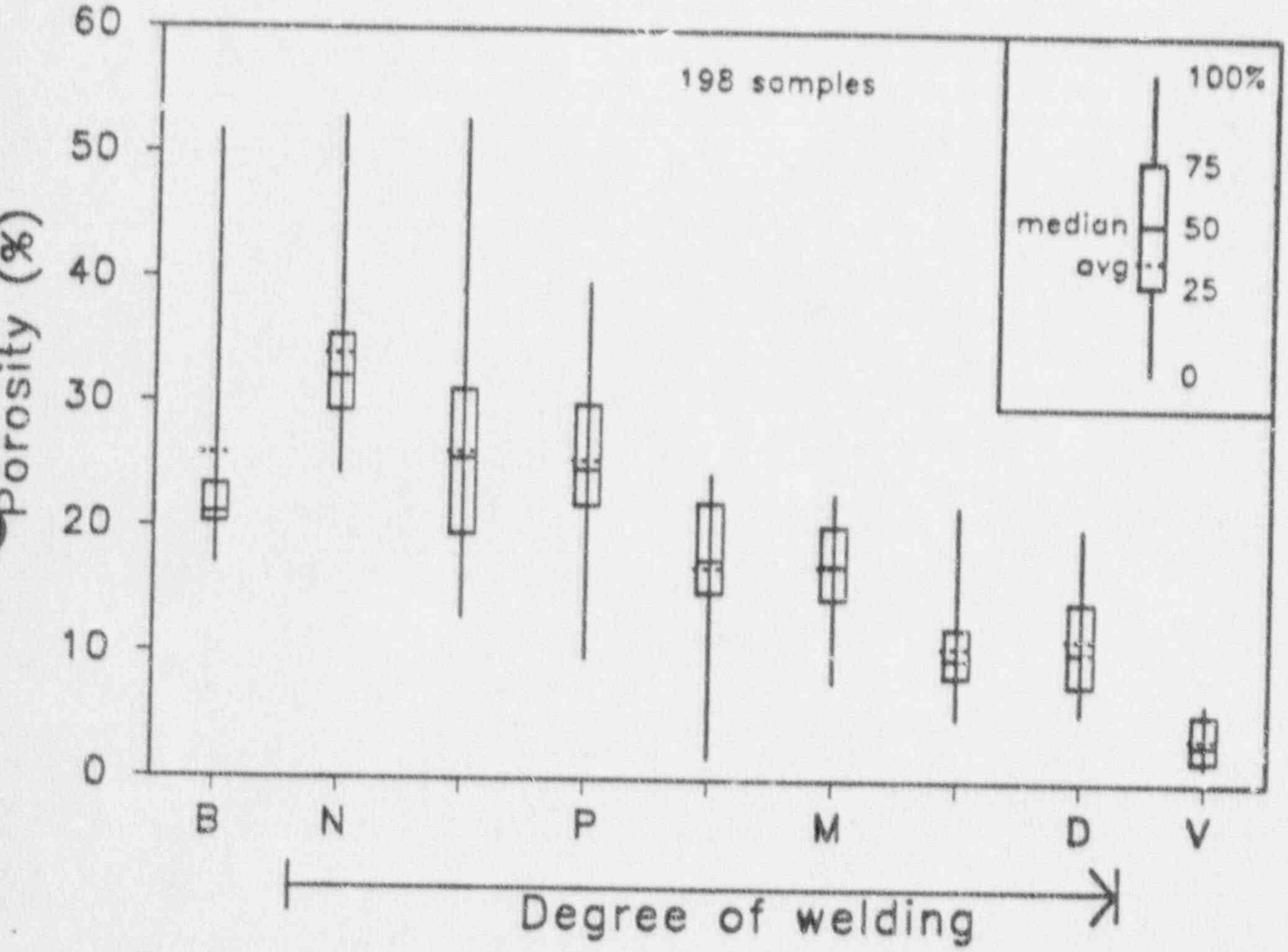
6

BOREHOLE GU-3

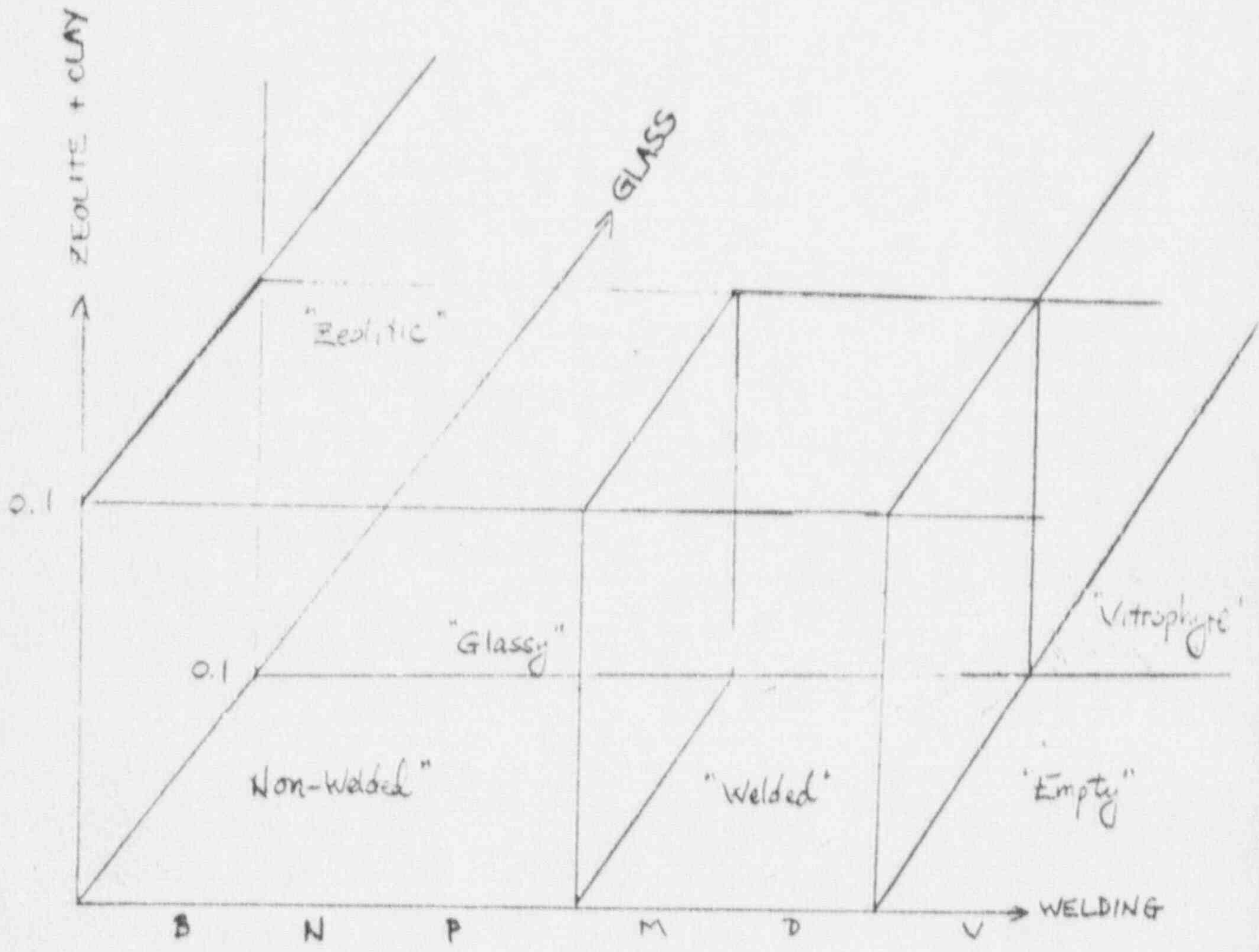


6

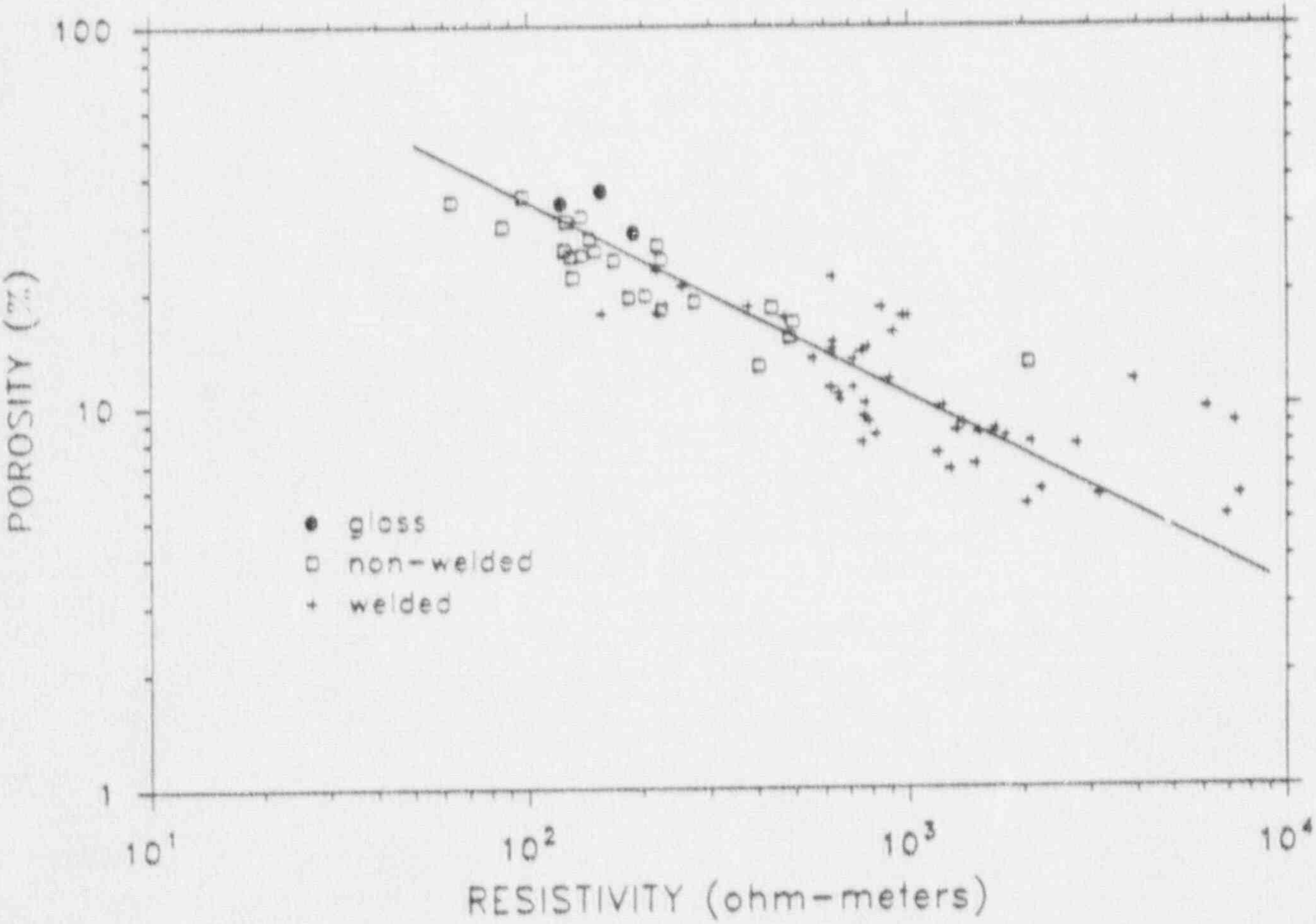

BOREHOLE G-3
Gamma
Density
Resistivity
0
2,400
4,800
Depth (feet)
Tpt
Tht
Tcp
Tcb
Tct
Tlr
SWL
Welding
Zeol.



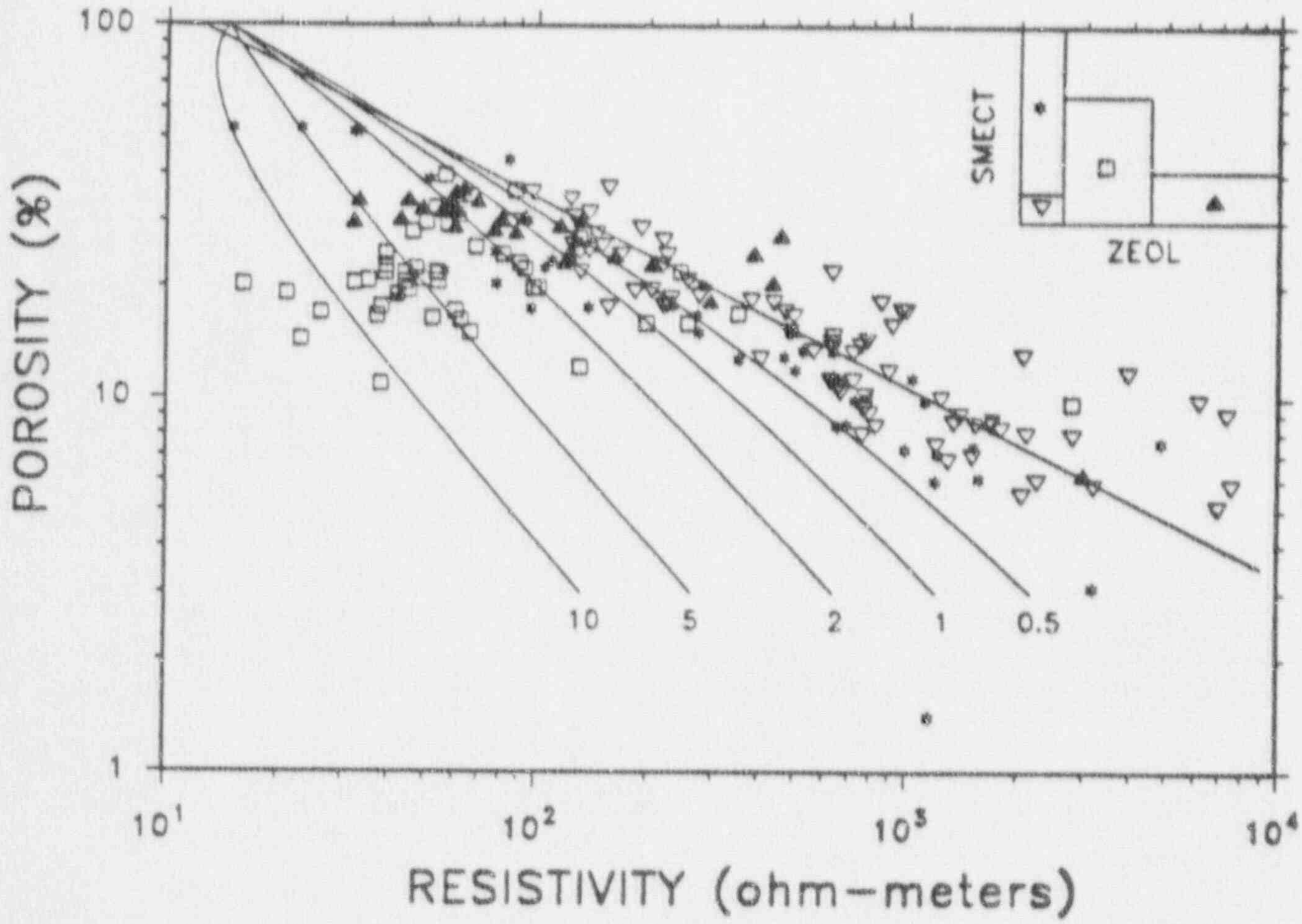
B = bedded tuff
N = non-welded
P = poorly welded
M = moderately welded
D = densely welded
V = vitrophyre



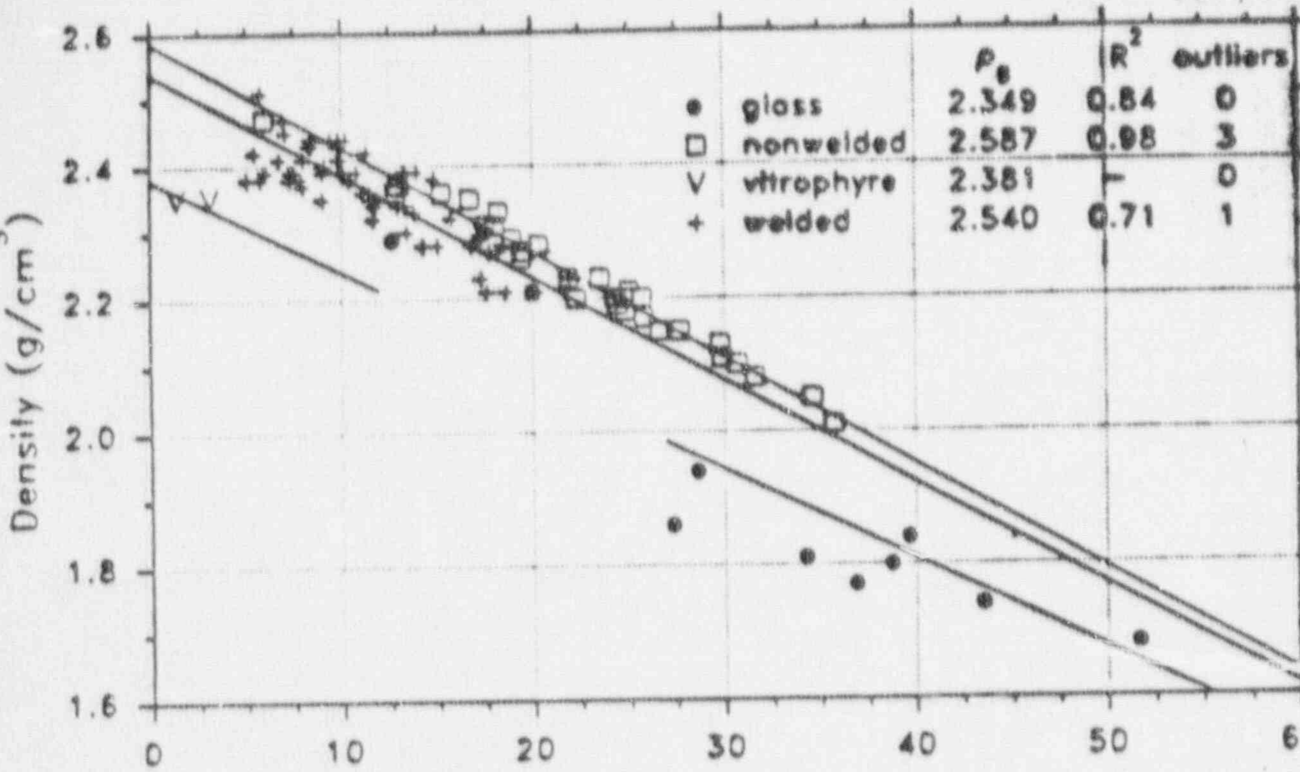
ZEOLITE + CLAY
GLASS
0.1
"Zeolitic"
0.1
"Glassy"
"Vitrophyre"
"Non-Welded"
"Welded"
"Empty"
B
N
P
M
D
V
WELDING



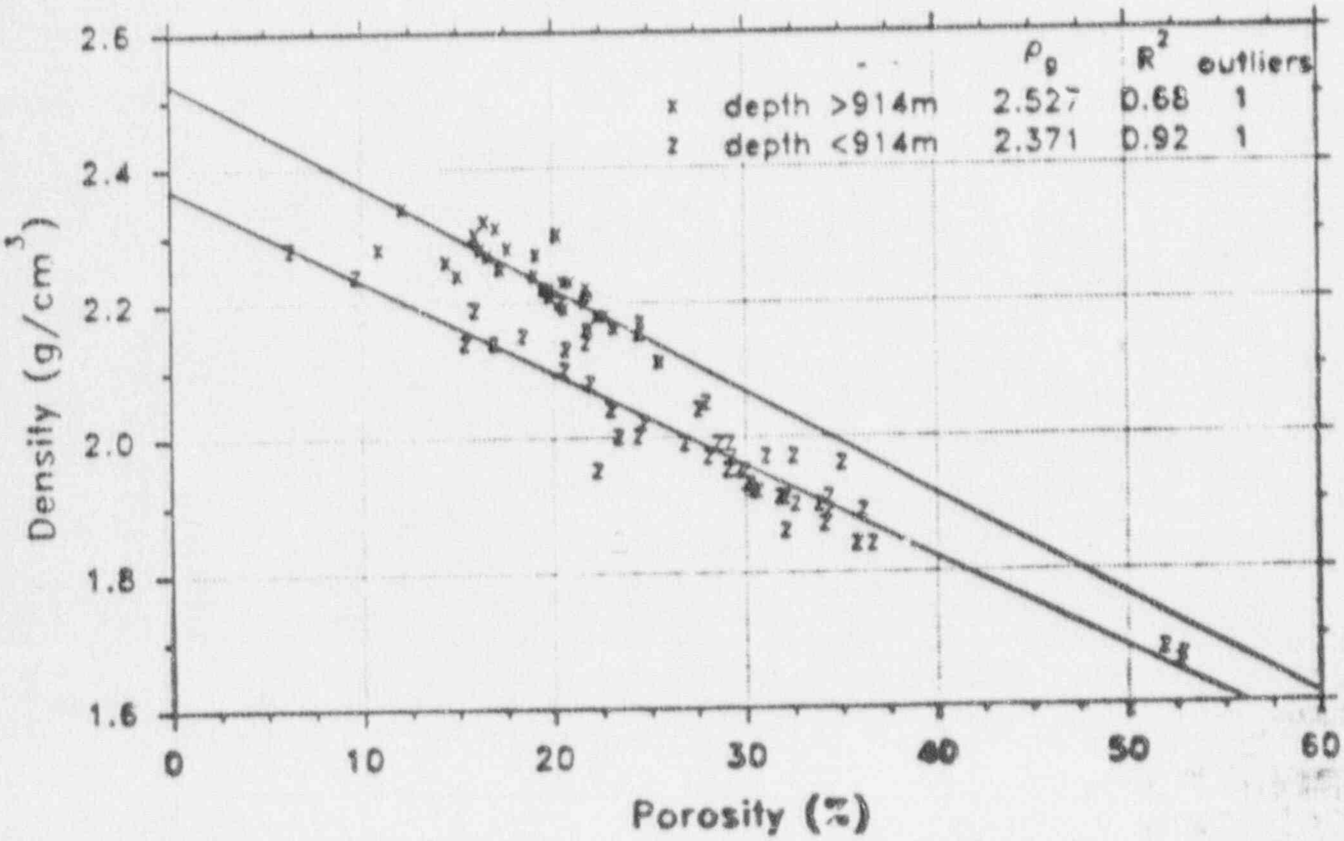
100
10
1
10^1
10^2
10^3
10^4
POROSITY (%)
RESISTIVITY (ohm-meters)
glass
non-welded
welded

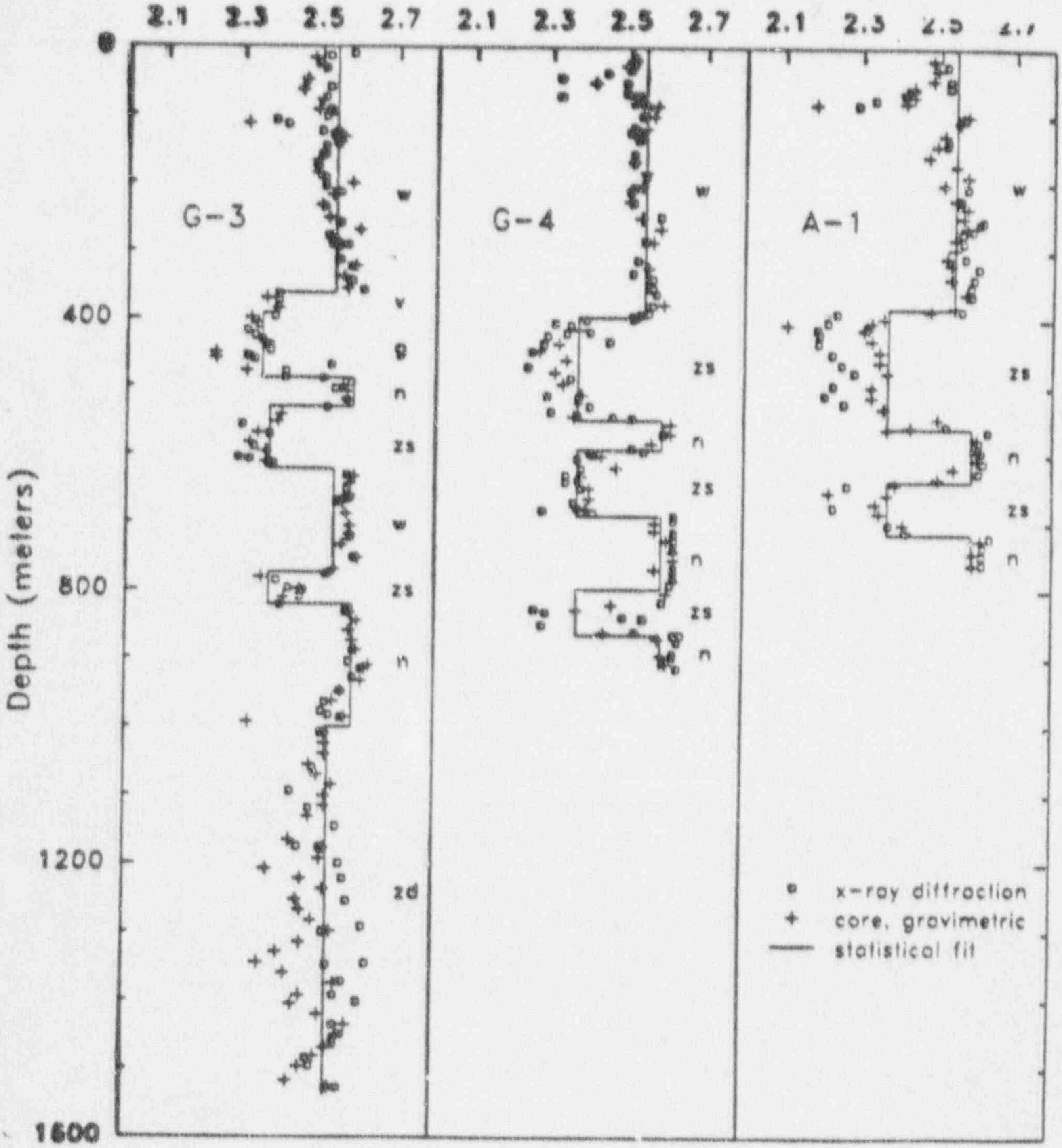


100
10
1
POROSITY (%)
10
5
2
1
0.5
SMECT
ZEOL
10^1
10^2
10^3
10^4
RESISTIVITY (ohm-meters)

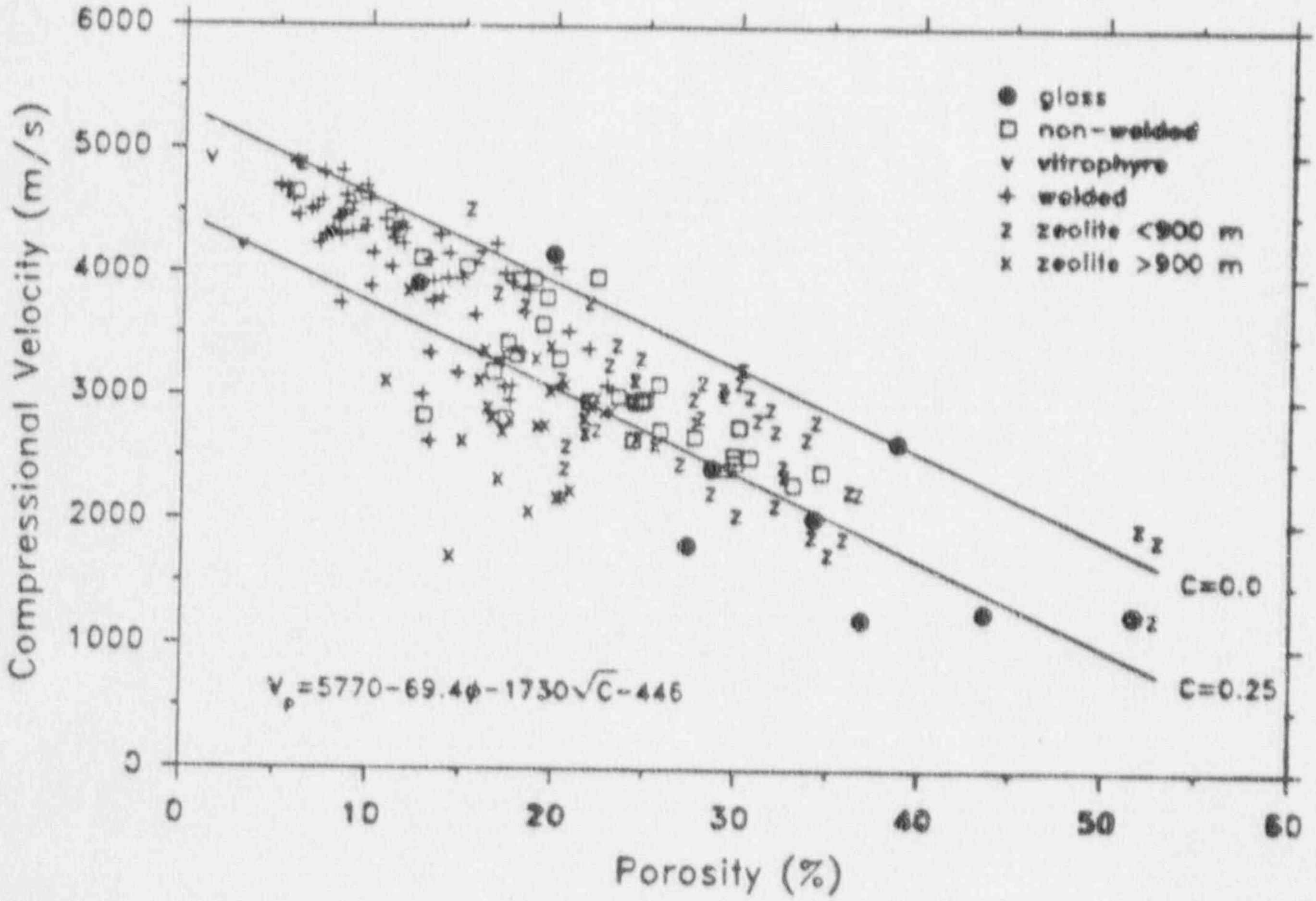


b. Zeolitic Samples





2.1 2.3 2.5 2.7 2.1 2.3 2.5 2.7 2.1 2.3 2.5 2.7
G-3
G-4
A-1
Depth (meters)
0
400
800
1200
1600
w
v
g
n
zs
w
zs
n
zd
w
zs
n
zs
n
zs
n
w
zs
n
zs
n
x-ray diffraction
core, gravimetric
statistical fit



6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Compressional Velocity (m/s)
Porosity (%)
glass
non-welded
vitrophyre
welded
zeolite <900 m
zeolite >900 m
C=0.0
C=0.25
$V_p = 5770 - 69.4\phi - 1730\sqrt{C} - 446$

fig-v2

SUMMARY - DATA ON TUFF SAMPLES

Porosity declines as degree of welding increases.
Porosity varies from 1 to 53 percent.

Density, resistivity, velocity, and permeability all depend to first order on porosity and therefore vary over a large range.

Density: 1.66 to 2.51 g/cm^3.

Resistivity: 15 to 7500 ohm-m

Velocity: 1220 to 4930 m/s

Permeability: 0.2 μdarcies to 0.2 darcies

CONCLUSIONS - TUFF SAMPLES

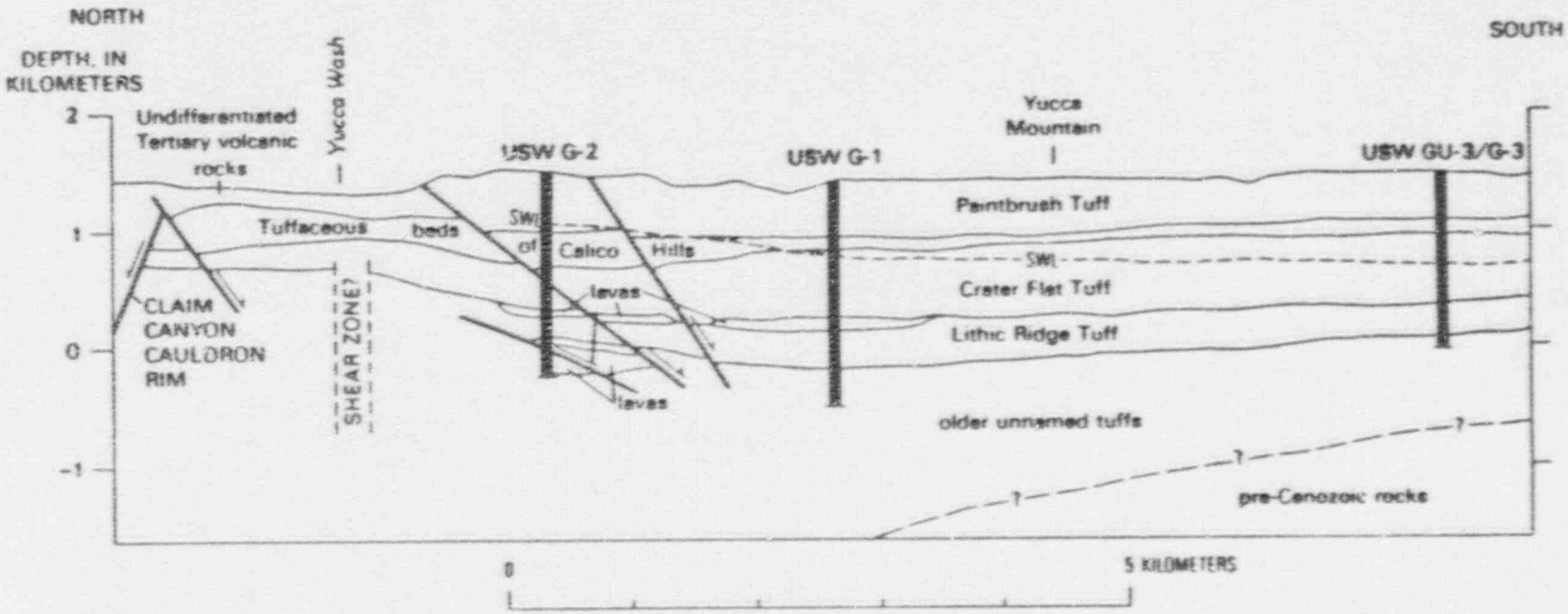
Sorting the samples into rock classes defined in terms of degree of welding and mineralogy enables us to distinguish the influence of zeolites and clays from porosity.

Empirical rock-property relationships established for sandstones can be applied to tuffs.

CONCLUSIONS - TUFF SAMPLES

The degree of welding controls primary porosity; porosity is the primary control on other measured physical properties.

Zeolites and clays are a significant secondary control on density, resistivity, velocity, and permeability.



EXPLANATION

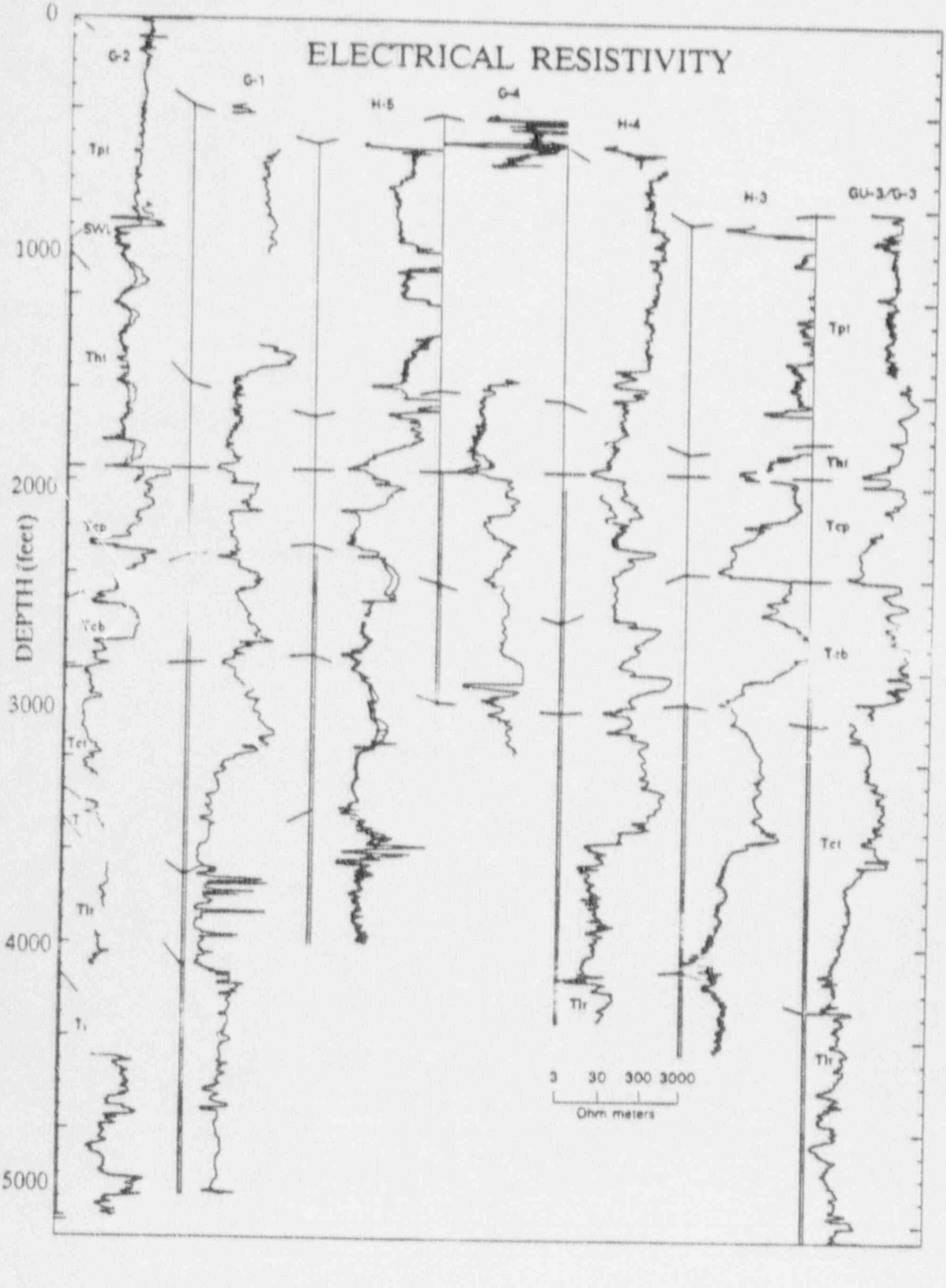
Normal fault—Arrow indicates relative motion

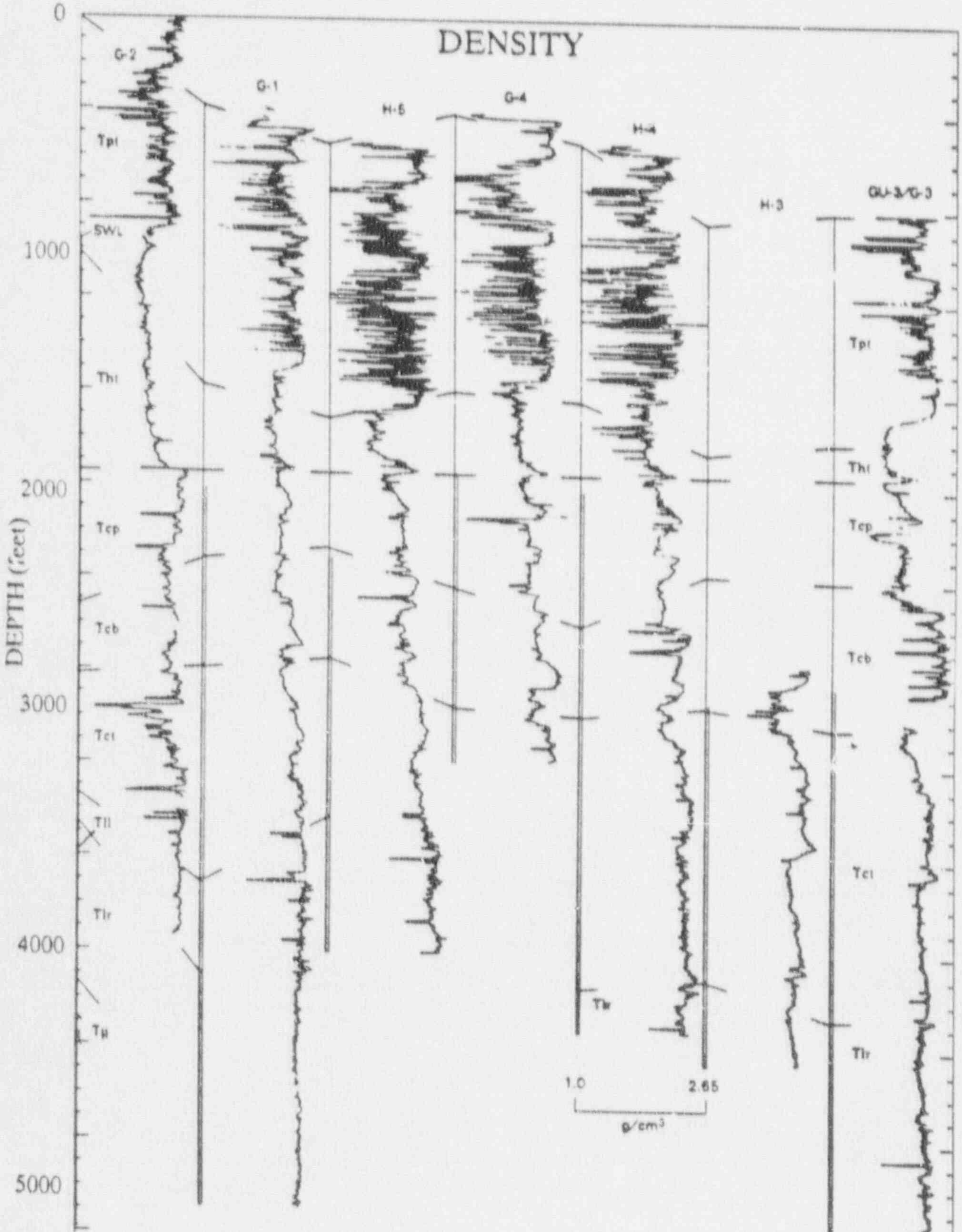
Lithologic contact—Dashed and queried where estimated

--SWL-- **Static water level**

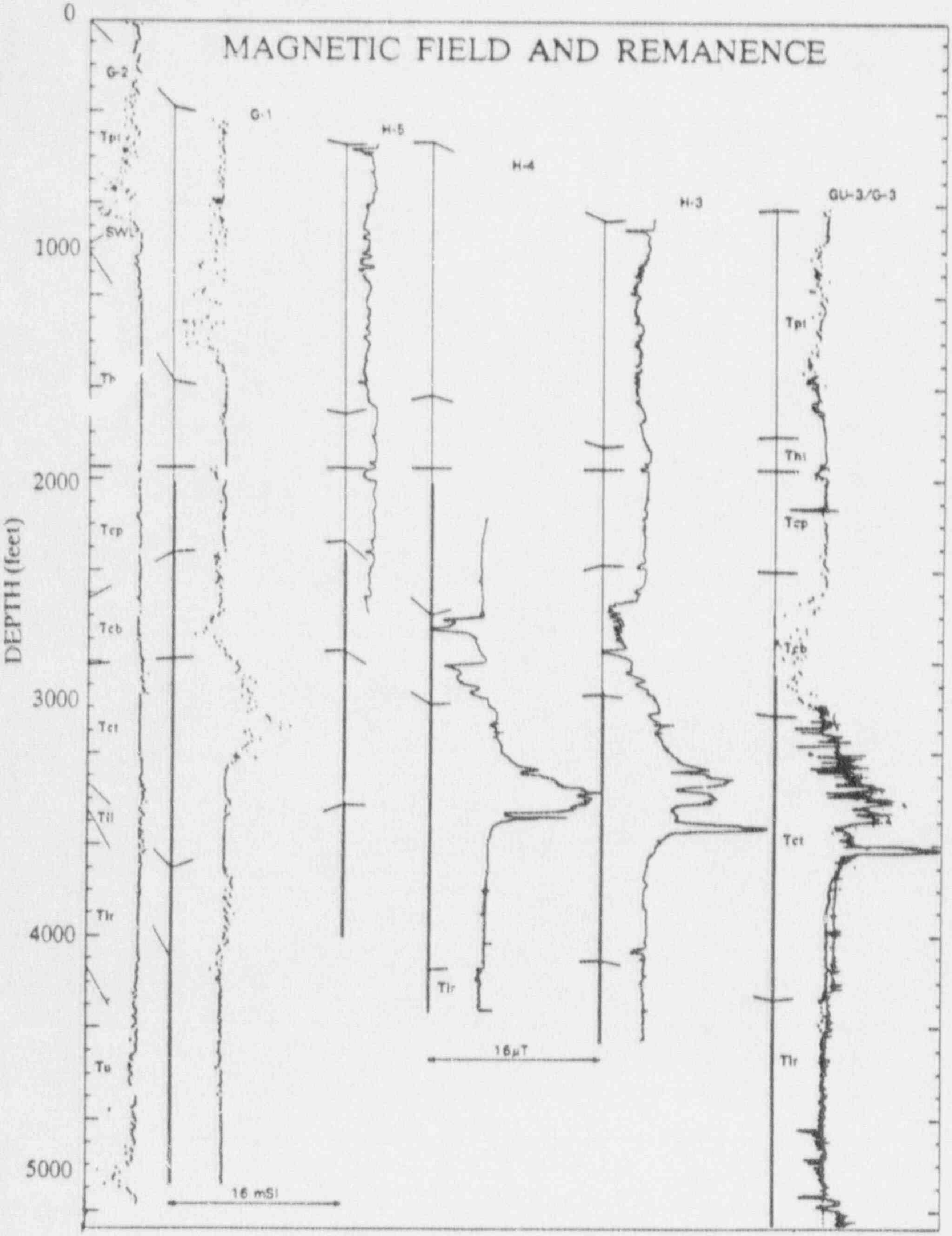
USW G-2 **Drill hole**

ELECTRICAL RESISTIVITY



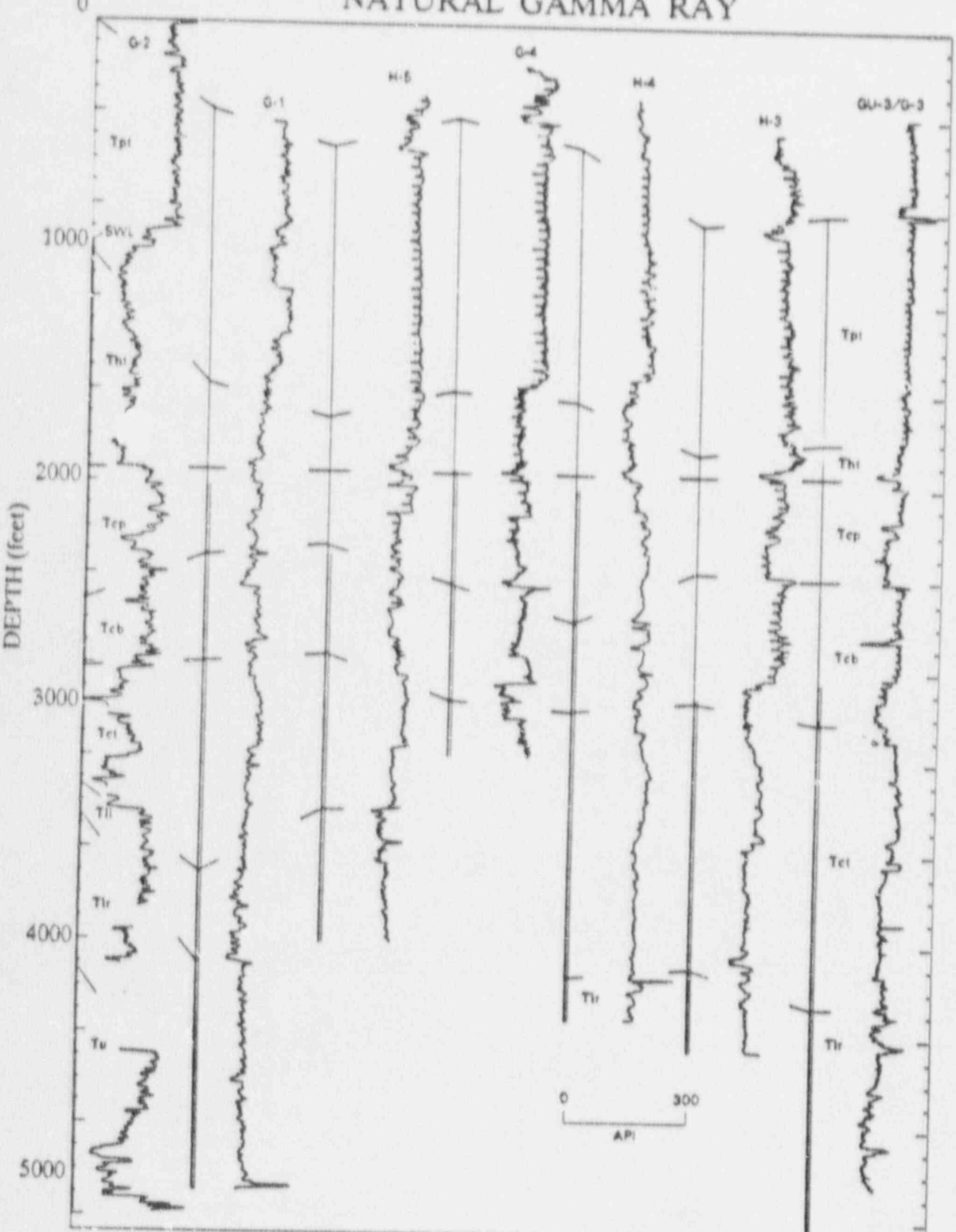


DENSITY
DEPTH (feet)
0
1000
2000
3000
4000
5000
G-2
G-1
H-5
G-4
H-4
H-3
GU-3/G-3
Tpt
SWL
Tht
Tcp
Tcb
Tct
Tll
Tlr
Tlr
Tpt
Tht
Tcp
Tcb
Tct
Tlr
1.0
2.65
g/cm³

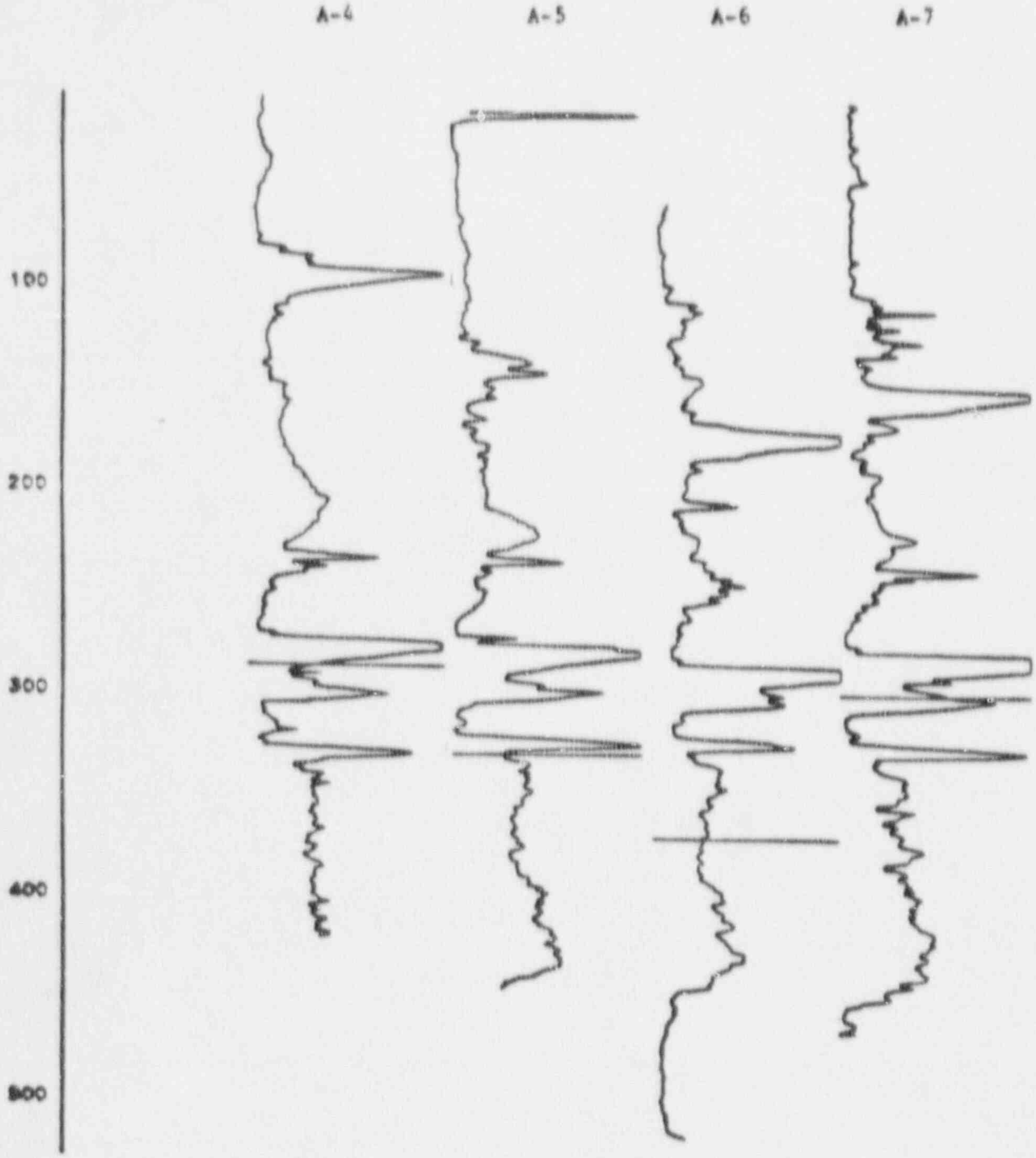


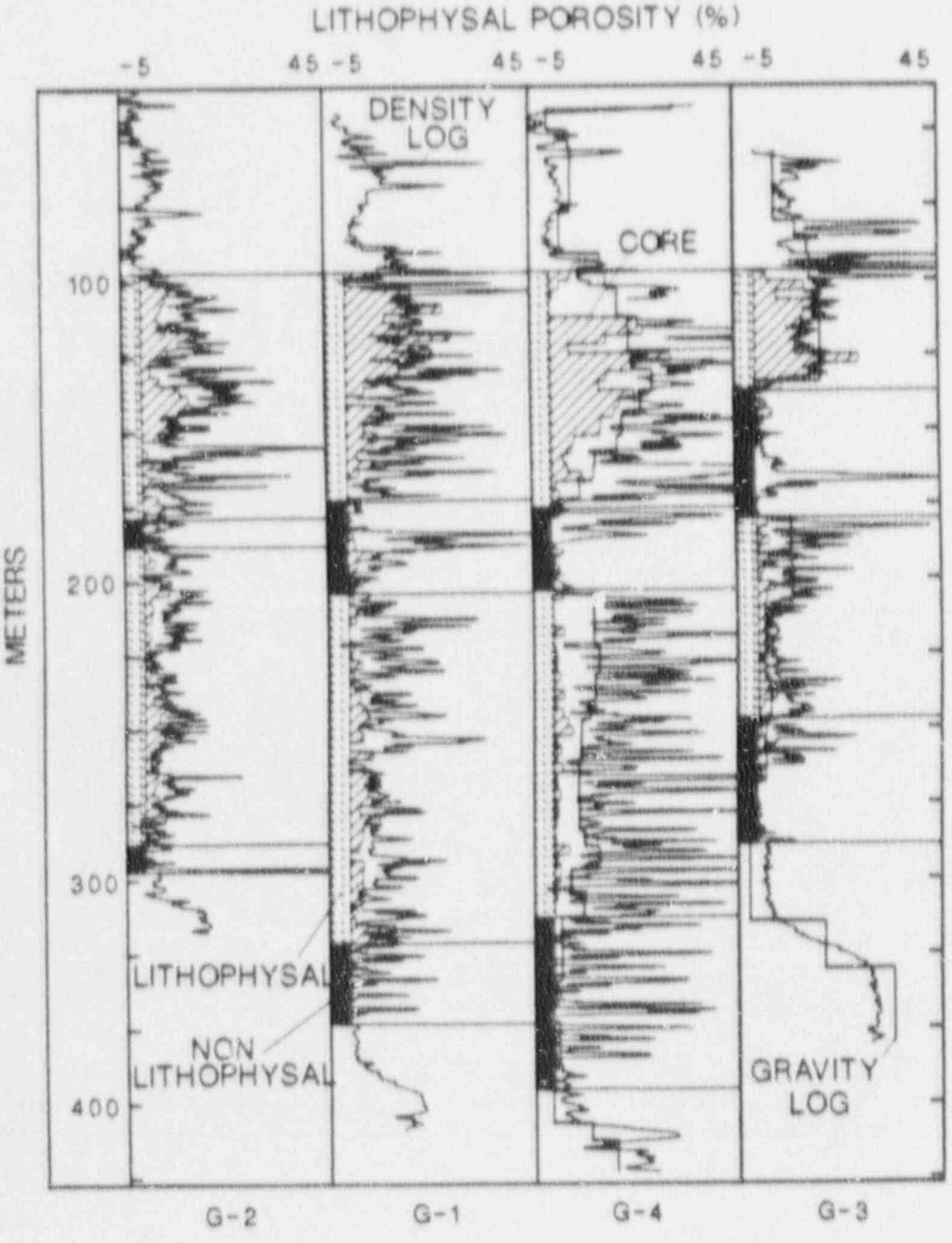
MAGNETIC FIELD AND REMANENCE
DEPTH (feet)
0
1000
2000
3000
4000
5000
G-2
G-1
H-5
H-4
H-3
GU-3/G-3
Tpt
SWL
Th
Tcp
Tcb
Tct
Tll
Tlr
Tu
Tht
16 mSI
16 µT

NATURAL GAMMA RAY



MAGNETIC SUSCEPTIBILITY





LITHOPHYSAL POROSITY (%)
-5
45
-5
45
-5
45
-5
45
DENSITY LOG
CORE
METERS
100
200
300
400
LITHOPHYSAL
NON LITHOPHYSAL
GRAVITY LOG
G-2
G-1
G-4
G-3

Phil Nelson

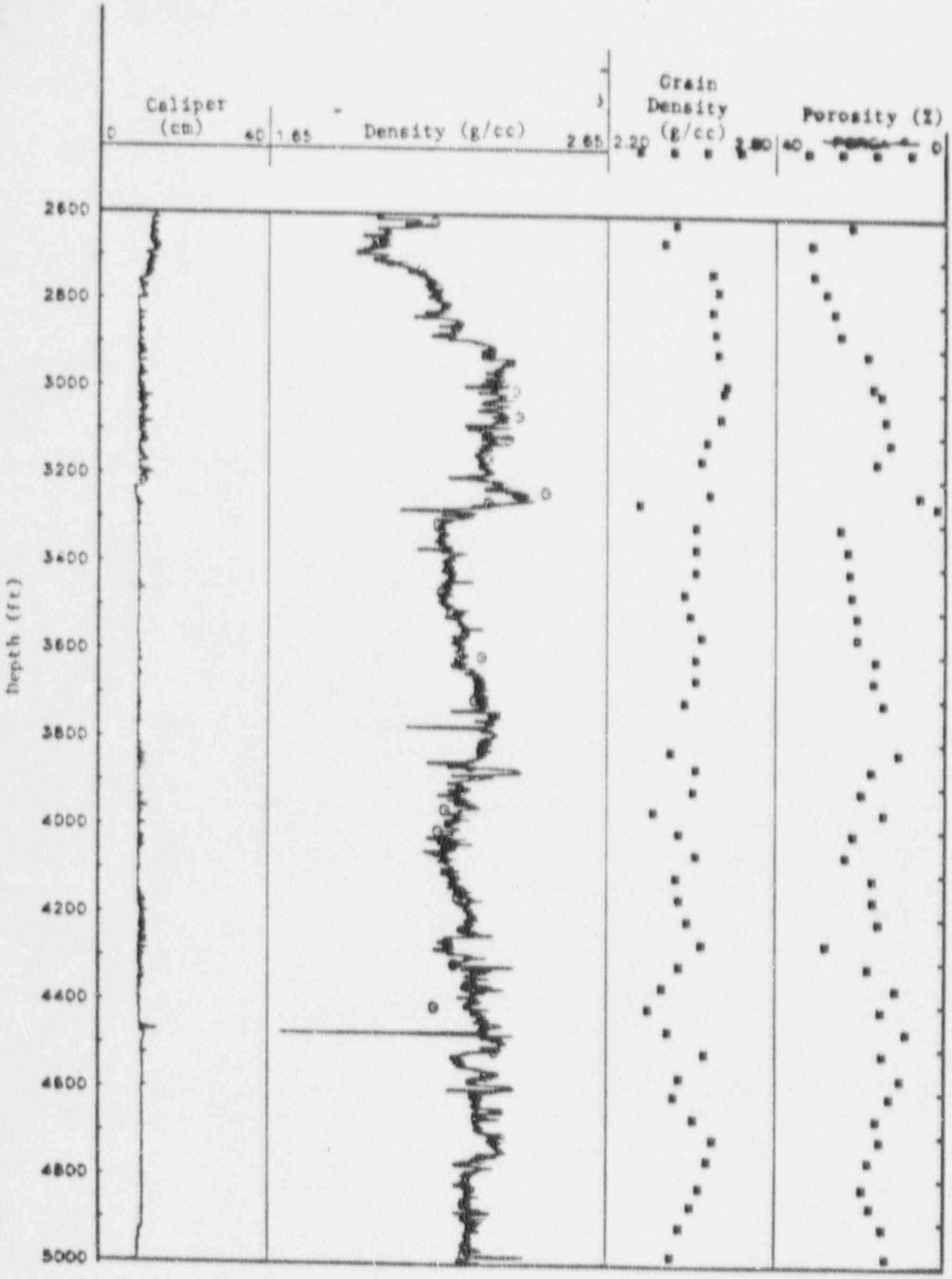
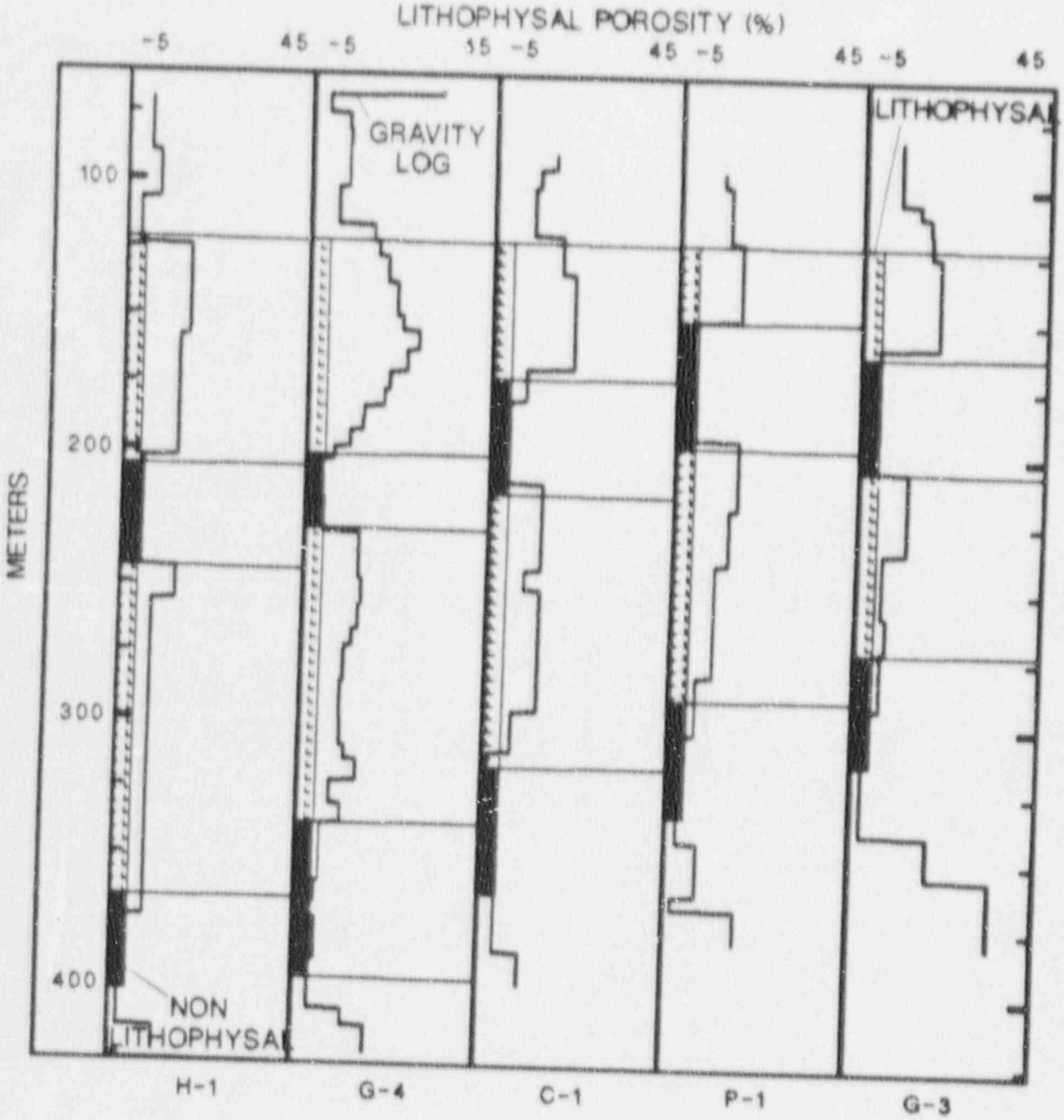


Figure 5-8. Caliper and density logs from G-3, with core measurements of saturated bulk density (open circles plotted with density log), grain density, and porosity from Anderson (1984).



LITHOPHYSAL POROSITY (%)
-5
45
-5
45
-5
45
-5
45
-5
45
GRAVITY
LOG
LITHOPHYSAL
METERS
100
200
300
400
NON
LITHOPHYSAL
H-1
G-4
C-1
P-1
G-3

Density

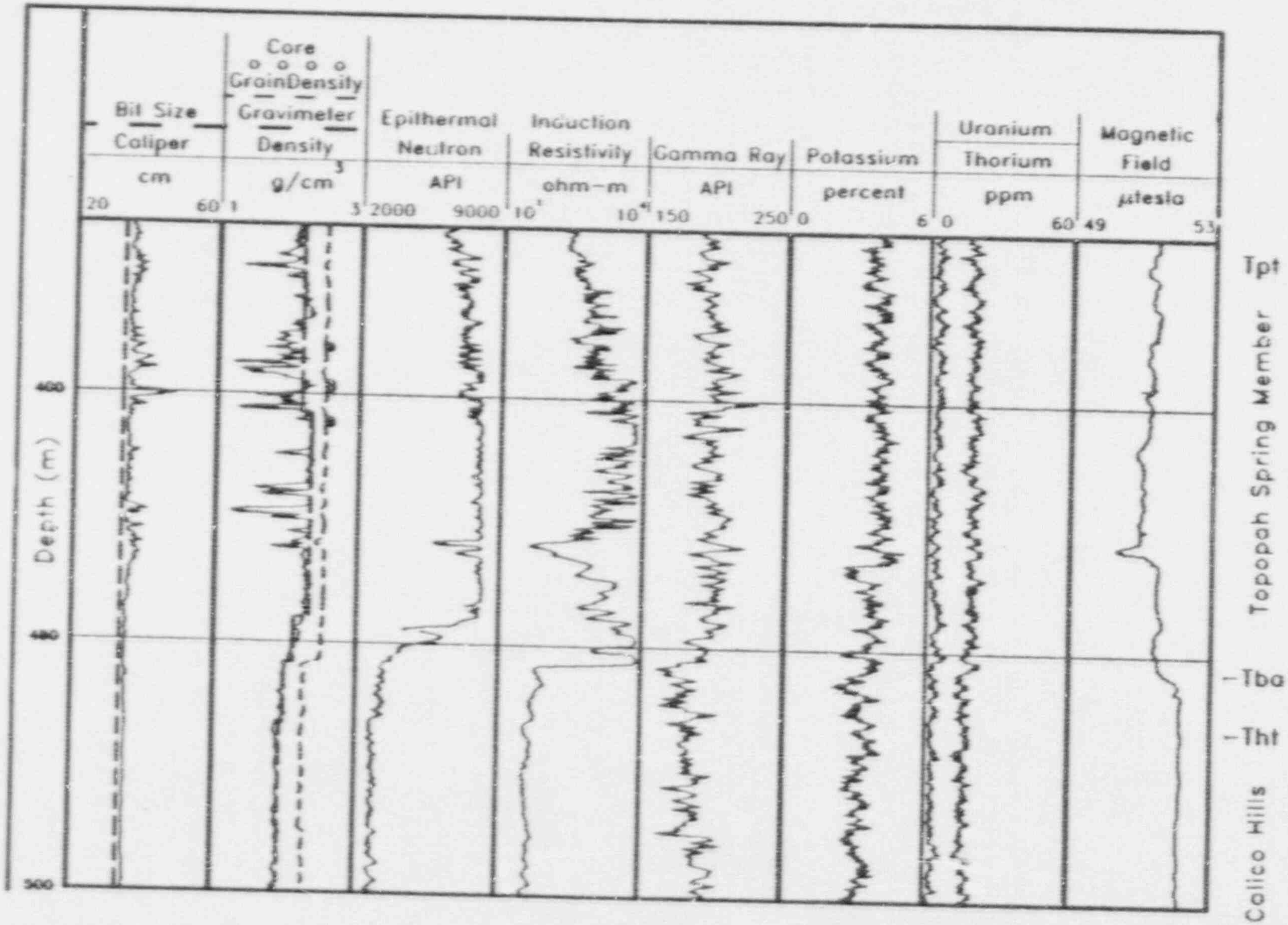
$$\rho_b = \rho_g(1-\phi) + \rho_f \phi S_w$$

Epithermal Neutron

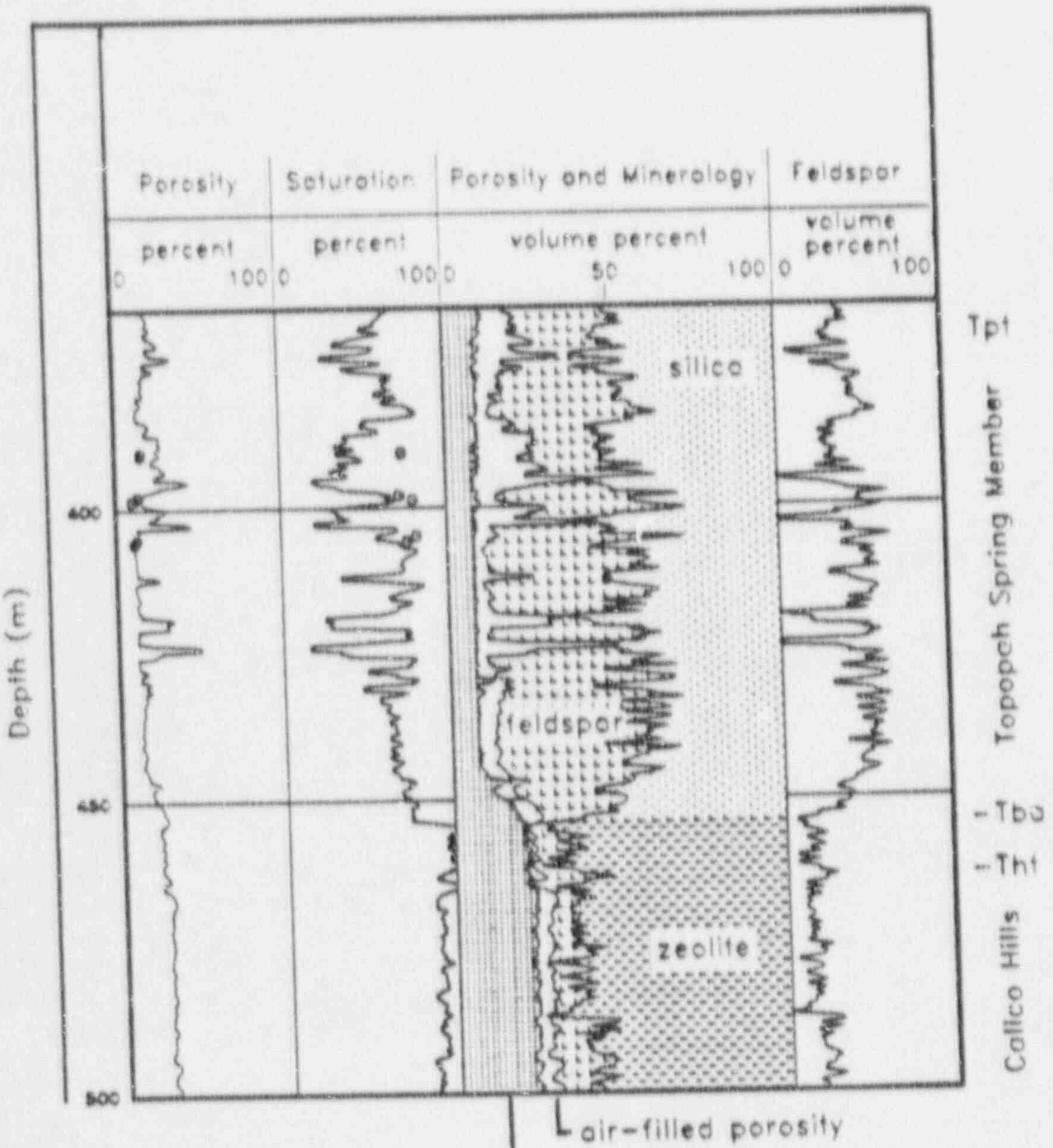
$$\log N_{epi} = b - c\,\phi S_w$$

Resistivity

$$R_t = R_w \phi^{-m} S_w^{-n}$$



Core
Grain Density
Bit Size
Caliper
cm
20 60
Gravimeter
Density
g/cm3
1 3
Epithermal
Neutron
API
2000 9000
Induction
Resistivity
ohm-m
10 10^4
Gamma Ray
API
150 250
Potassium
percent
0 6
Uranium
Thorium
ppm
0 60
Magnetic
Field
μtesla
49 53
Depth (m)
400
450
500
Tpt
Topopah Spring Member
Tba
Tht
Calico Hills



Porosity
percent
0
100
Saturation
percent
0
100
Porosity and Mineralogy
volume percent
0
50
100
Feldspar
volume percent
0
100
Depth (m)
400
450
500
silica
feldspar
zeolite
Tpt
Topopah Spring Member
-Tba
-Tht
Calico Hills
air-filled porosity
water-filled porosity

Table Uyy. Uranium content (ppm) averaged from spectral gamma-ray logs over three depth zones (feet) in each hole.				
1730-1870 5.8	1706-1820 5.7	1708-1872 8.0	1668-1796 5.7	1700-1830 6.0

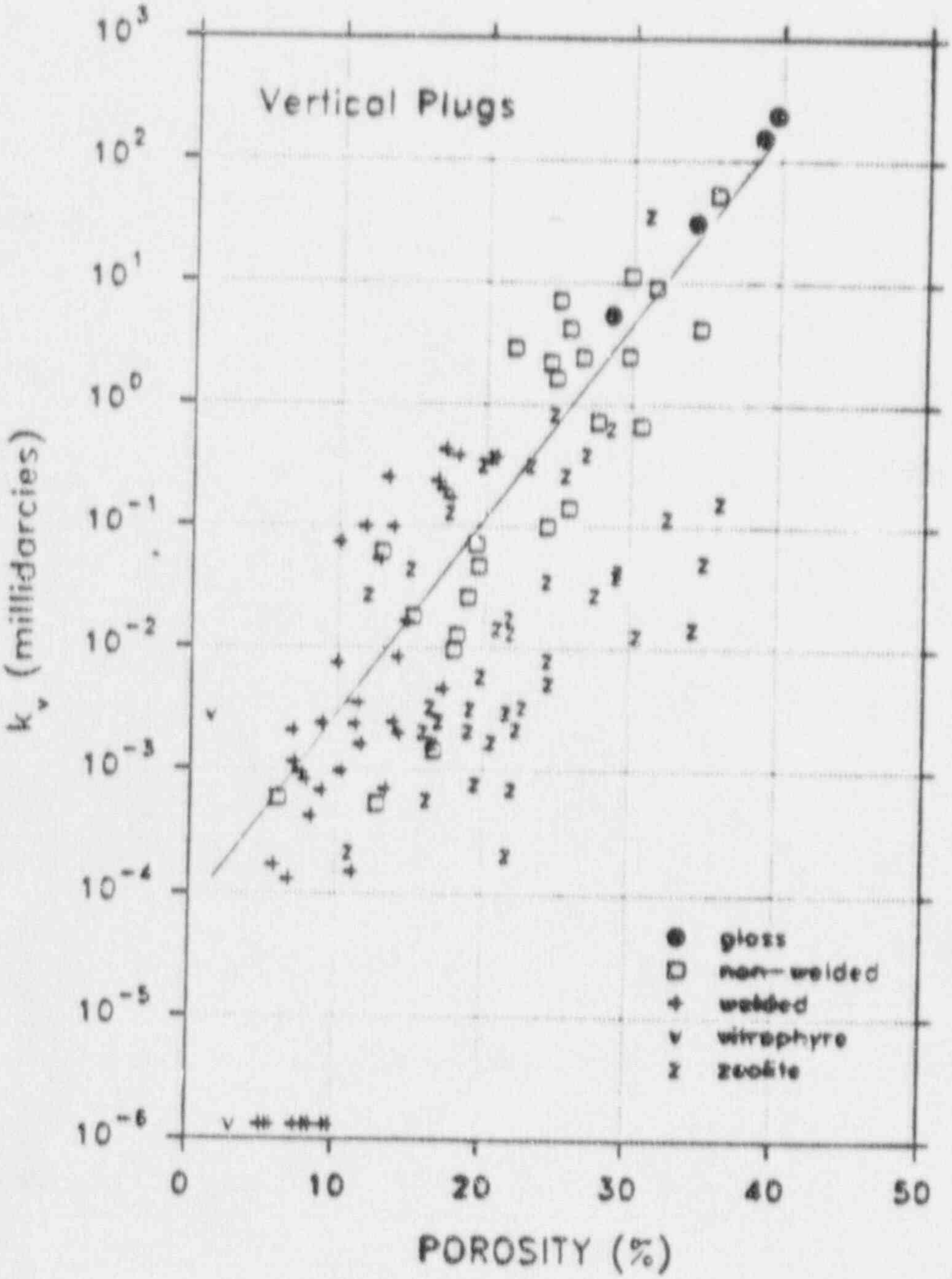
Uranium concentration in silicic igneous rocks is generally within the range 1 to 10 ppm (Clark et al., 1966). Based on a large number of samples from sites throughout the world, Clark et al. (1966) report a mean value of 4.7 ppm and a median of 3.9 ppm. Uranium can be highly mobile in oxidizing environments; its anomalous presence in fractured rock is sometimes used to infer transport and deposition by circulating groundwaters (Fertl et al. 1980, West and Laughlin, 1976). Given the excellent correlation of uranium distribution with the diabase sill and with the copper oxide distribution (figure Wp), it is quite likely that the pattern of uranium distribution in the T-holes is the result of dissolution and precipitation rather than primary distribution.

Sulfide Distribution. Because they are electrically conductive, sulphide minerals are easily discerned on induced polarization, SP, and resistivity logs. In cored hole C-1, the induced polarization (IP) and SP logs (fig. c13) show that sulfide minerals occur at only four depths in the hole. The four excursions in IP and SP are confirmed by the observed presence of chalcocite in core (column 1 of fig. c13). Two of these appear to be in diabase and two are in granite. By way of contrast, the occurrences of oxide minerals atacamite and chrysocolla indicated in the first column tend to occur within high resistivity intervals.

Small amounts of sulphide minerals are present in all five T-holes, but are most abundant in T-1, as can be seen by comparing the resistivity logs in figures w1 through w5. The resistivity logs covering two sulphide-bearing intervals in T-1 are shown in figure S13. Note that all six resistivity curves produce a similar response across the diabase sill at 1450 feet. By comparing the details of the response to the diabase sill, it can be seen that the msfl has the greatest spatial resolution, as expected because it is a pad tool, and that the deep induction tool has the poorest resolution. Quite different results are obtained across the two sulphide zones centered at 1495 and 1575 feet. Here the two induction logs produce unrealistic data: the logs are often off-scale and show increases in resistivity in places where the other four logs do not. The induction tools are particularly susceptible to distortion in the presence of thin, highly conductive veins, which is probably the mode of occurrence here. The laterolog tool (msfl, lls, and lld) gives more realistic results where sulphide veins are present.

Fractures and Sonic Logs

The sonic slowness log overlies the mechanical strength log in cored hole C-1 (figure c1str) with remarkable fidelity, particularly when we recall that the strength log is derived from observations on core whereas the sonic log is a continuous record of sonic speed at fairly high (20 kHz) frequency. The overlap is good even in the slow, low-strength rock above 1000 feet where the rock quality designation (RQD) (column 2 of fig. c1str)



Vertical Plugs
k_v (millidarcies)
POROSITY (%)
glass
non-welded
welded
vitrophyre
zeolite

indicate that the diabase is more altered and probably has higher porosity than the host granite. That more clay minerals are present in the diabase than in the granite is substantiated by the increase in loss-on-ignition shown in figure c2elem. Where the diabase intercepts are thick, as at 1422 to 1438 feet, the gamma-ray activity is reduced. The magnetic susceptibility and thermal neutron logs appear to be the most reliable discriminators of diabase.

Diabase Sill. A near-horizontal diabase sill varying in thickness from 3 to 16 feet can be discerned in four of the T-holes. In three of the T-holes, the intercept is unambiguous with the same characteristics as seen in cored hole C-1: gamma-ray and resistivity decrease while neutron porosity increases. The depth intervals are 1446-1456 in T-1, 1436-1451 in T-2 and 1410-1426 in T-4. In T-5 the diabase is much thinner, occuring at 1416-1419 feet, and the pick is less certain; "diabase dikelets" were diagnosed from the cuttings.

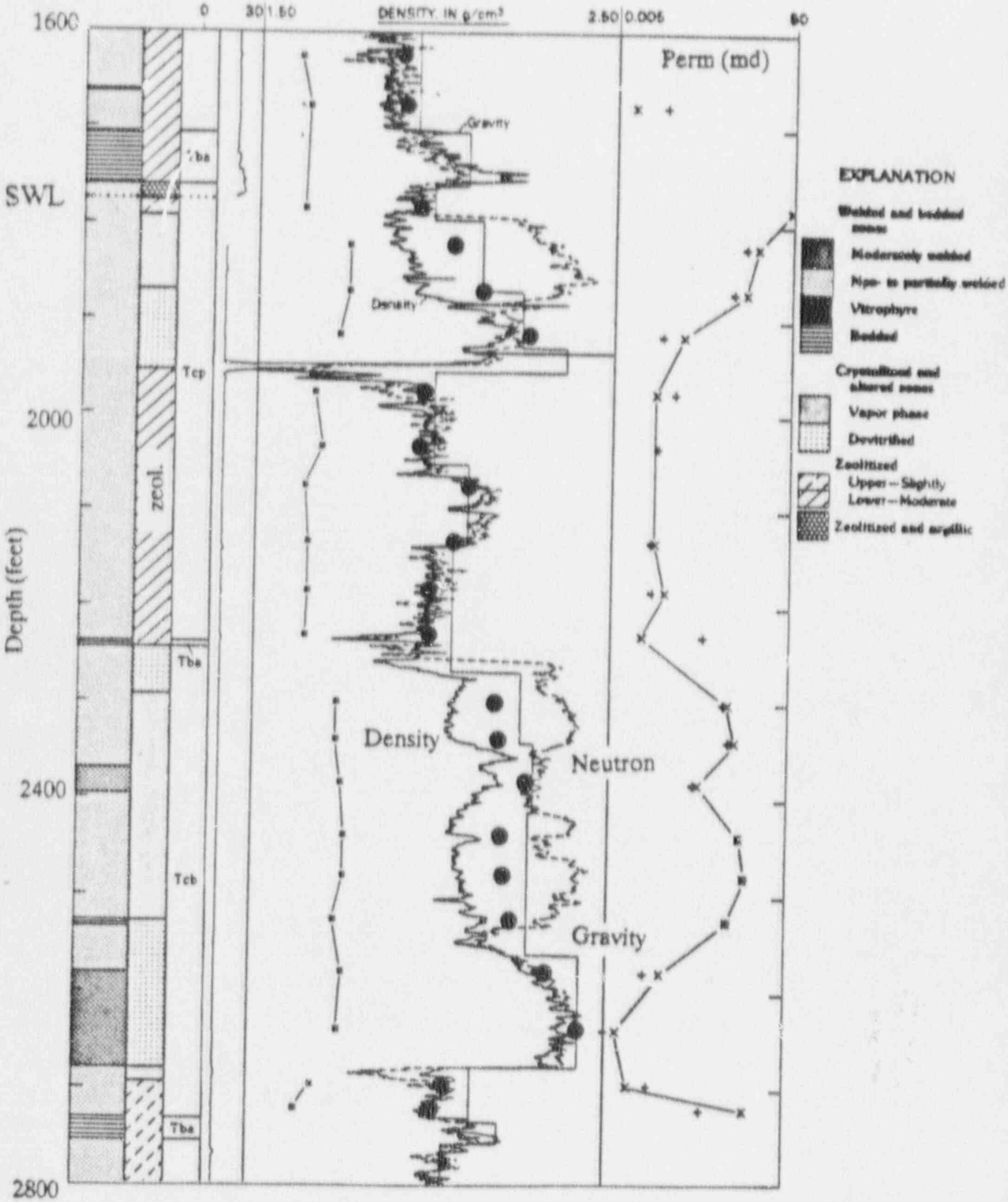
Curiously, the characteristic diabase signature is not present in the central hole T-3. Instead, over the interval 1414-1434, the gamma-ray log is high instead of low and resistivity does not change much. Neutron porosity is high. Observation of cuttings at this depth in T-5 indicated high iron oxide content and very little diabase. Better information comes from cored hole C-2 which lies within 30 feet of T-3 at this depth. The geological description for C-2 notes that diabase and diabase breccia are present from 1439 to 1449 feet within a fault zone extending from 1420 to 1472 feet, described as "strongly broken and crushed with local soft and hard gouge". Faulting within the region penetrated by T-3 and C-2 has altered the physical properties of the diabase. However, on the basis of the neutron response, we believe the diabase is present at a depth of 1414-1434 in T-3.

Uranium distribution. The Schlumberger natural gamma spectrometry log provides abundances of potassium, uranium, and thorium. Shown in figure Uxx are uranium logs in five T-holes and the location of the diabase sill. Above the sill and within a zone more or less coincident with the upper copper oxide zone, uranium content is around 10 ppm. Note that the diabase sill coincides with the lower boundary of the upper zone where uranium content is higher than below the sill. Arithmetic means are tabulated in table Uyy for three zones in each hole. Uranium content is around 2 to 4 ppm below the sill and 5 to 8 ppm near the bottom of the holes. Because of the magnitude of environmental corrections for the NGT tool, the uncertainty in uranium concentration may be several ppm. Nevertheless, Table Uyy and figure Uxx provide valid comparisons of the uranium distribution with depth.

Table Uyy. Uranium content (ppm) averaged from spectral gamma-ray logs over three depth zones (feet) in each hole.

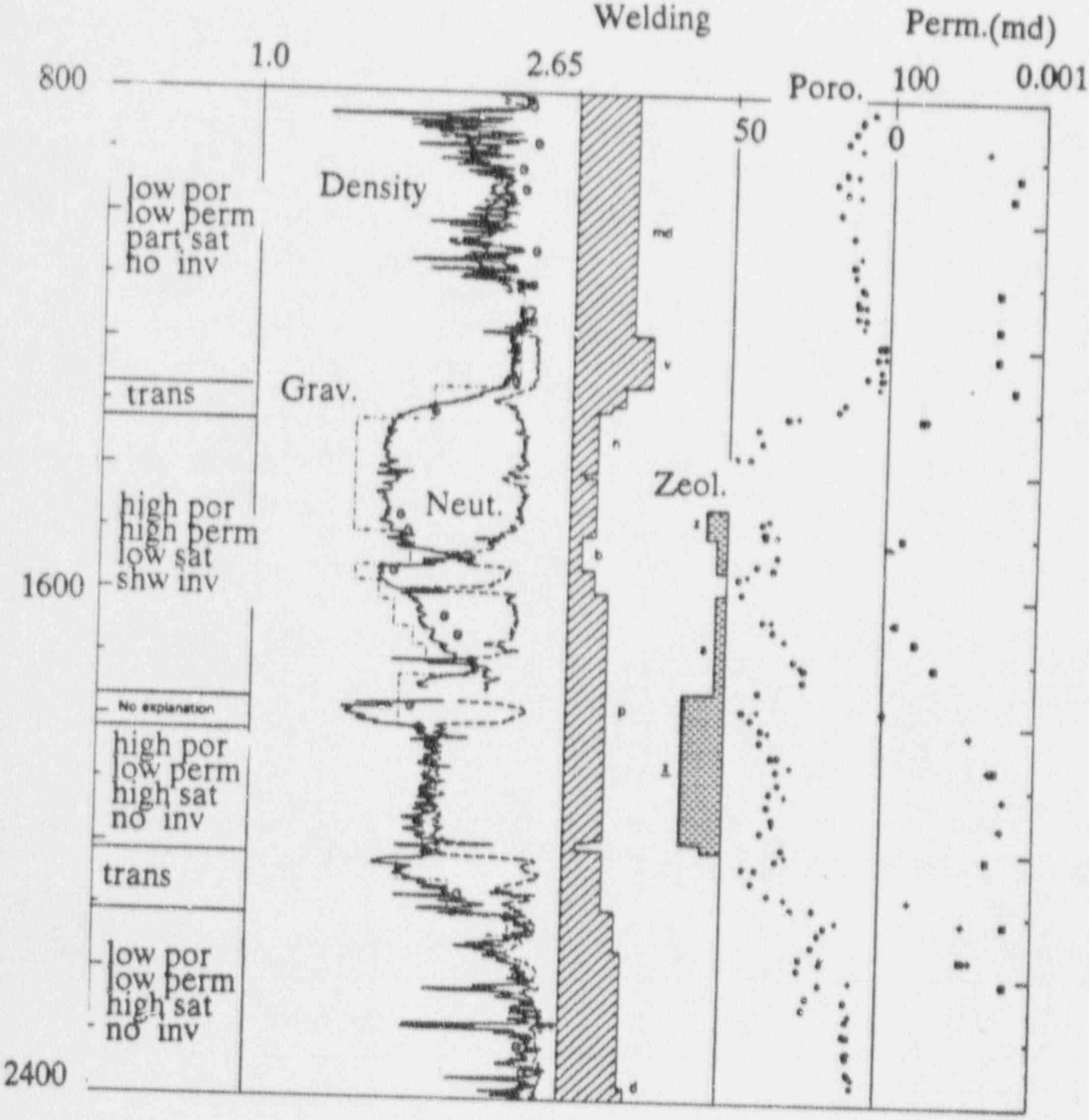
T-1	T-2	T-3	T-4	T-5
1268-1464 10.7	1255-1455 13.0	1245-1438 9.4	1220-1426 8.5	1250-1435 14.9
1464-1730 3.4	1455-1706 2.6	1438-1708 2.4	1426-1668 3.5	1435-1700 4.2

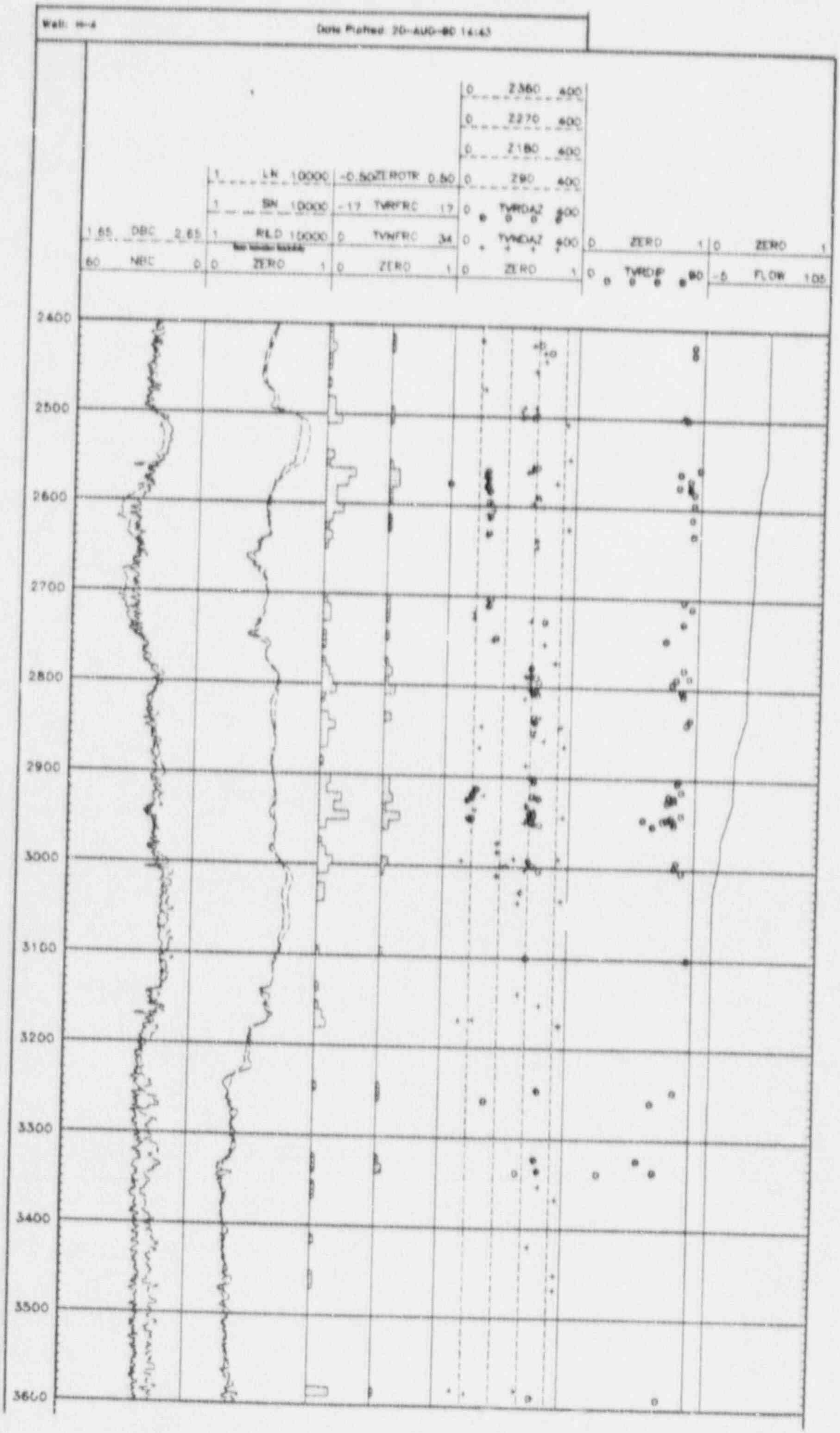
BOREHOLE G-4



1600
2000
2400
2800
Depth (feet)
SWL
zeol.
Tba
Tcp
Tcb
0
30
1.50
DENSITY, IN g/cm³
2.50
0.005
50
Perm (md)
Gravity
Density
Neutron
EXPLANATION
Welded and bedded zones
Moderately welded
Non- to partially welded
Vitrophyre
Bedded
Crystallized and altered zones
Vapor phase
Devitrified
Zeolitized
Upper—Slightly
Lower—Moderate
Zeolitized and argillic

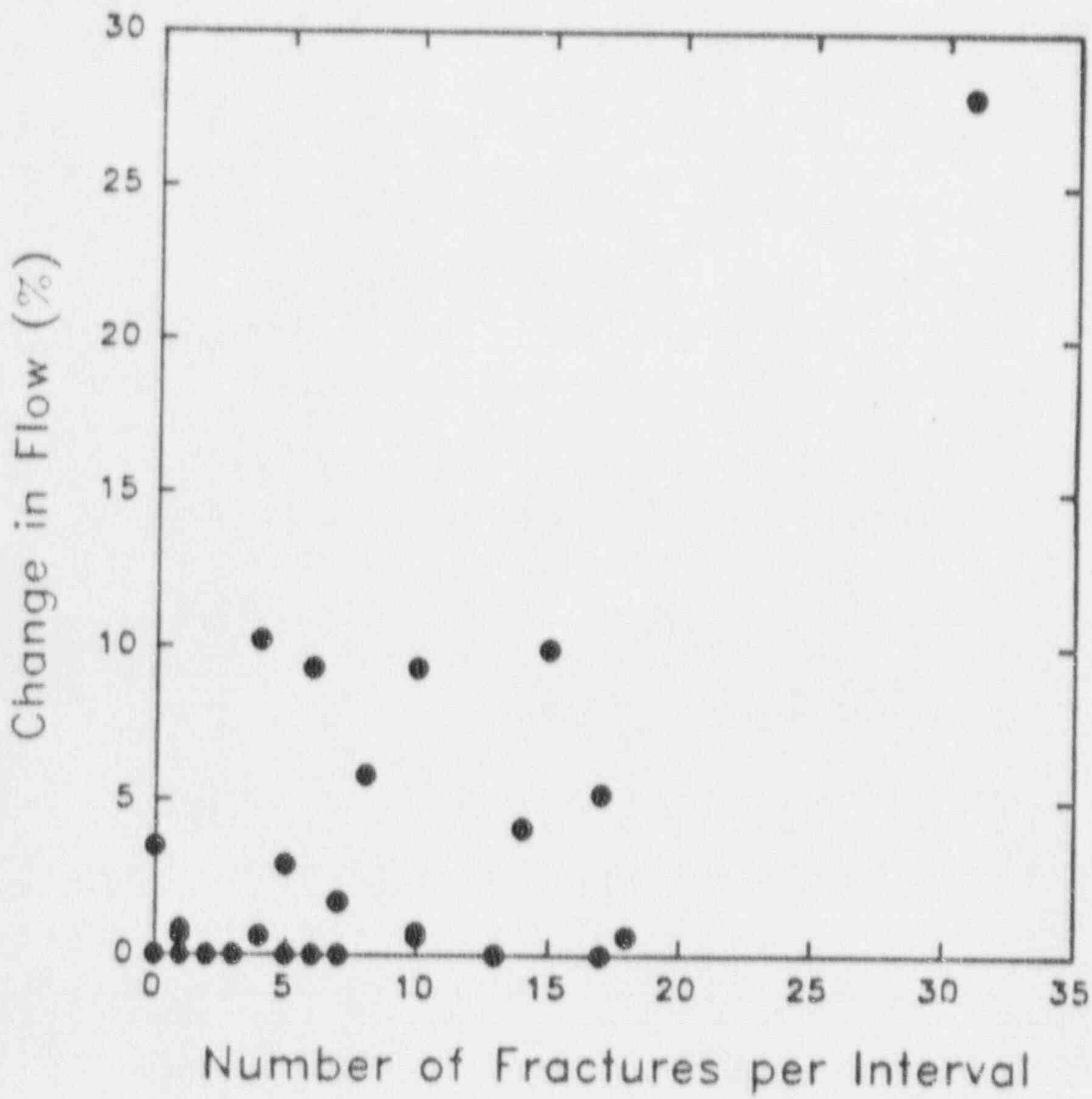
BOREHOLE GU-3/G-3



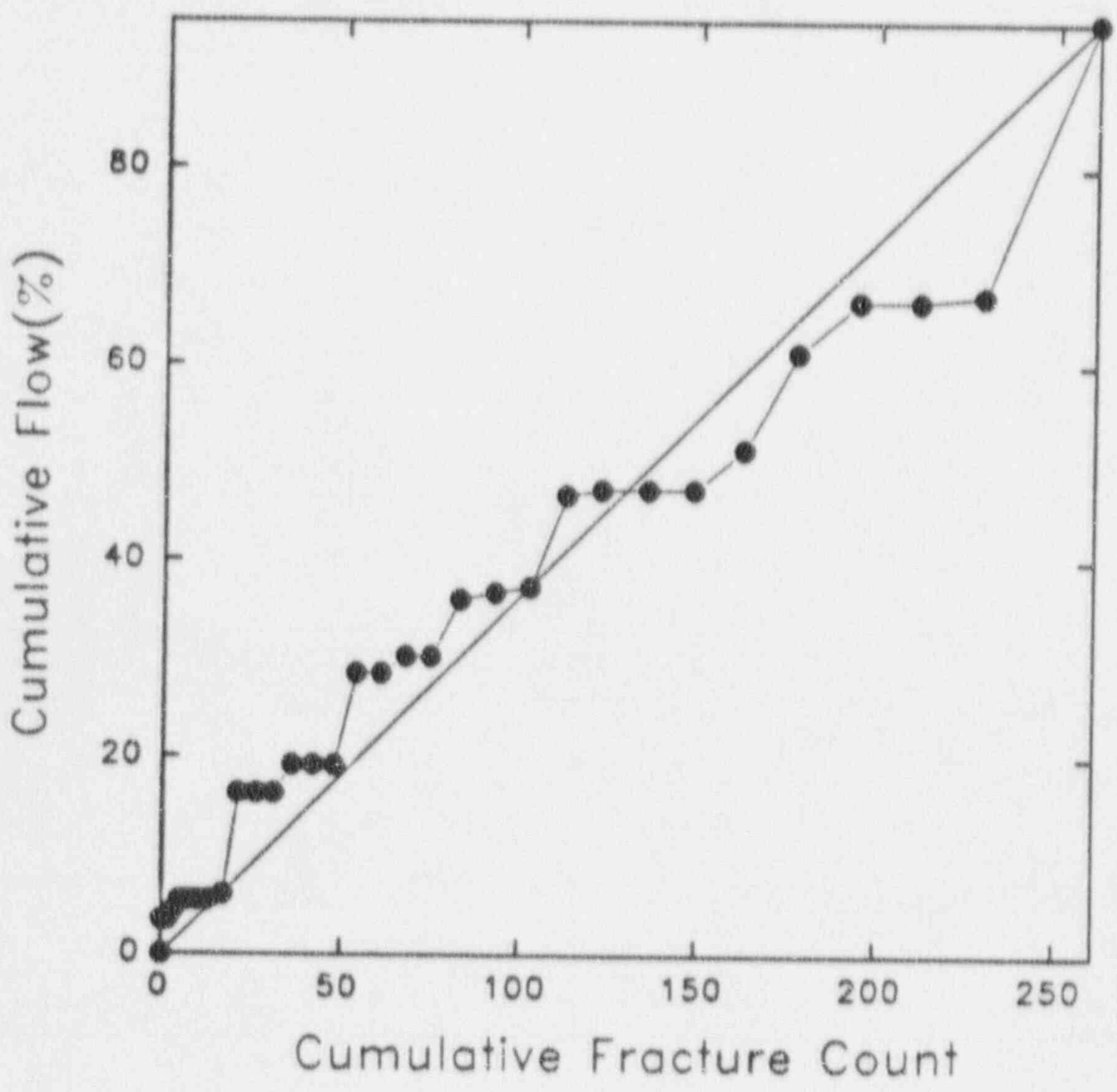


Well: H-4
Date Plotted: 20-AUG-80 14:43
1.85 DBC 2.85
60 NBC 0
1 LN 10000
1 SN 10000
1 RILD 10000
0 ZERO 1
-0.50 ZEROTR 0.50
-17 TVRFRC 17
0 TVNFRC 34
0 ZERO 1
0 2360 400
0 2270 400
0 2180 400
0 290 400
0 TVRDAZ 400
0 TVNDAZ 400
0 ZERO 1
0 ZERO 1
0 TVRDIP 90
0 ZERO 1
-5 FLOW 105
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600

H4 Data - 37 Intervals

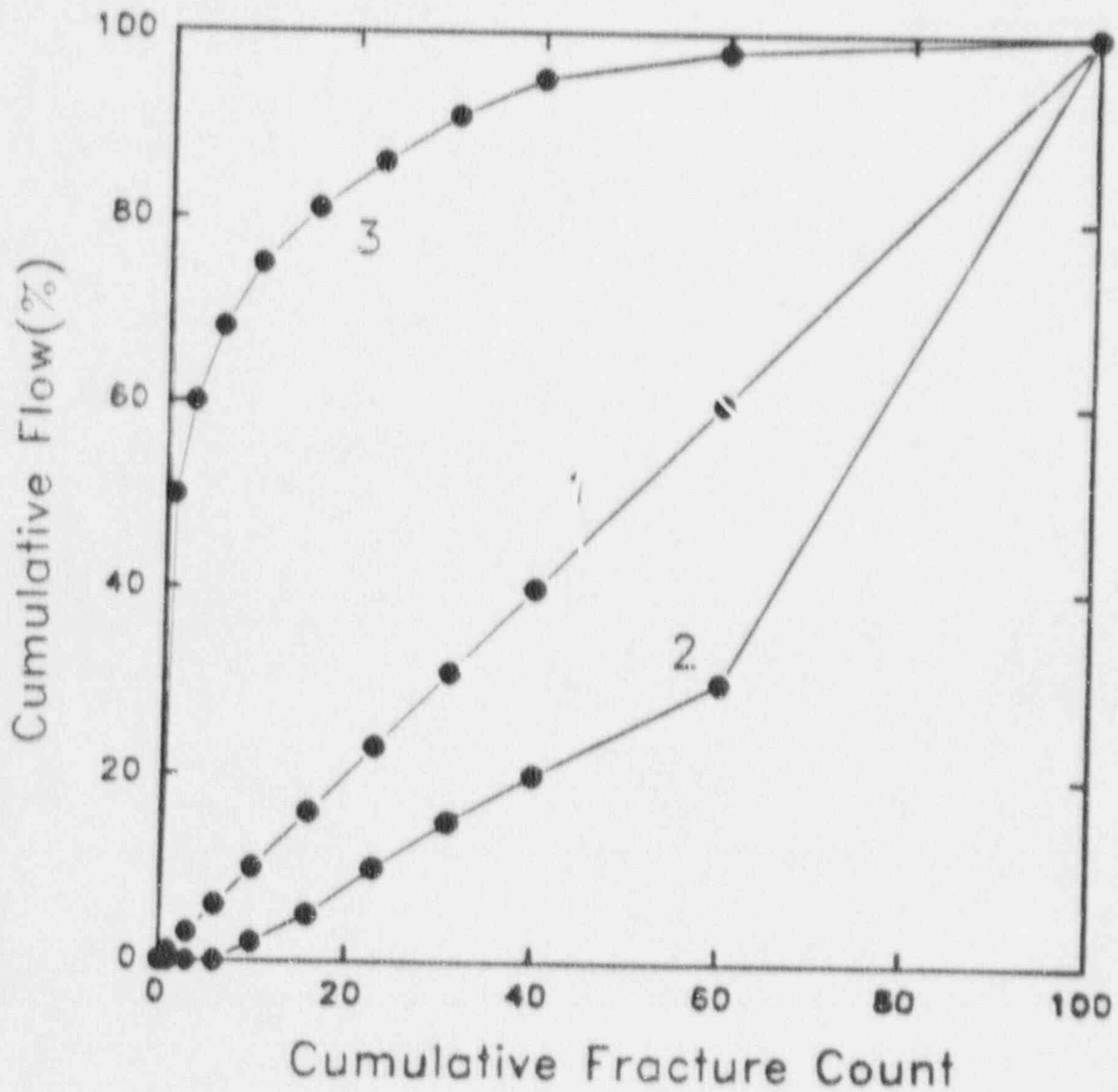


H4 Data - Ordered by no. of fractures per intervals



Artificial Example - Ordered by no. of fractures per interval

1. Flow directly proportional to no. of fractures per interval
2. Most flow occurs in highly fractured intervals.
3. Most flow (50%) occurs in an interval with one fracture.



V.J. MURPHY

SITE CHARACTERIZATION

SHALLOW DEPTH RANGE

0 - 100$^+$ m

(0 - 1,000m)

SEISMIC REFRACTION

SEISMIC REFLECTION

VERTICAL SEISMIC PROFILING (VSP)

Tomographic Imaging
Vertical & Wide Angle
Vertically &
"Horizontally"
Drilled Holes

CROSS-HOLE

V.J. MURPHY

PRINCIPAL OBJECTIVES

1. VELOCITY → MODULI → STRENGTH

2. PROFILING

3. 3D VELOCITY CHARACTERIZATION

   "p" WAVE VALUES

   & "S" WAVE VALUES

4. FAULT & FRACTURE ZONE

   DETECTION & DELINEATION

5. FRACTURE DENSITY

   P/S IN SITU

   VS P/S LAB/SOLID SAMPLES

V.J. MURPHY

ADDITIONAL OBJECTIVES

A. INTEGRATION (CROSS-REFERENCE)

BORINGS

GEOLOGY

OTHER GEOPHYSICS

B. PERFORMANCE

IN-SITU MEASUREMENTS

a) "DAMAGED" ZONE

b) STRESS RELIEVED ZONE

c) GROUTING

(ADITS, SHAFTS,

FULL SCALE OPENINGS)

Overall Objective

Establish geohydrologic /engineering integrity

of

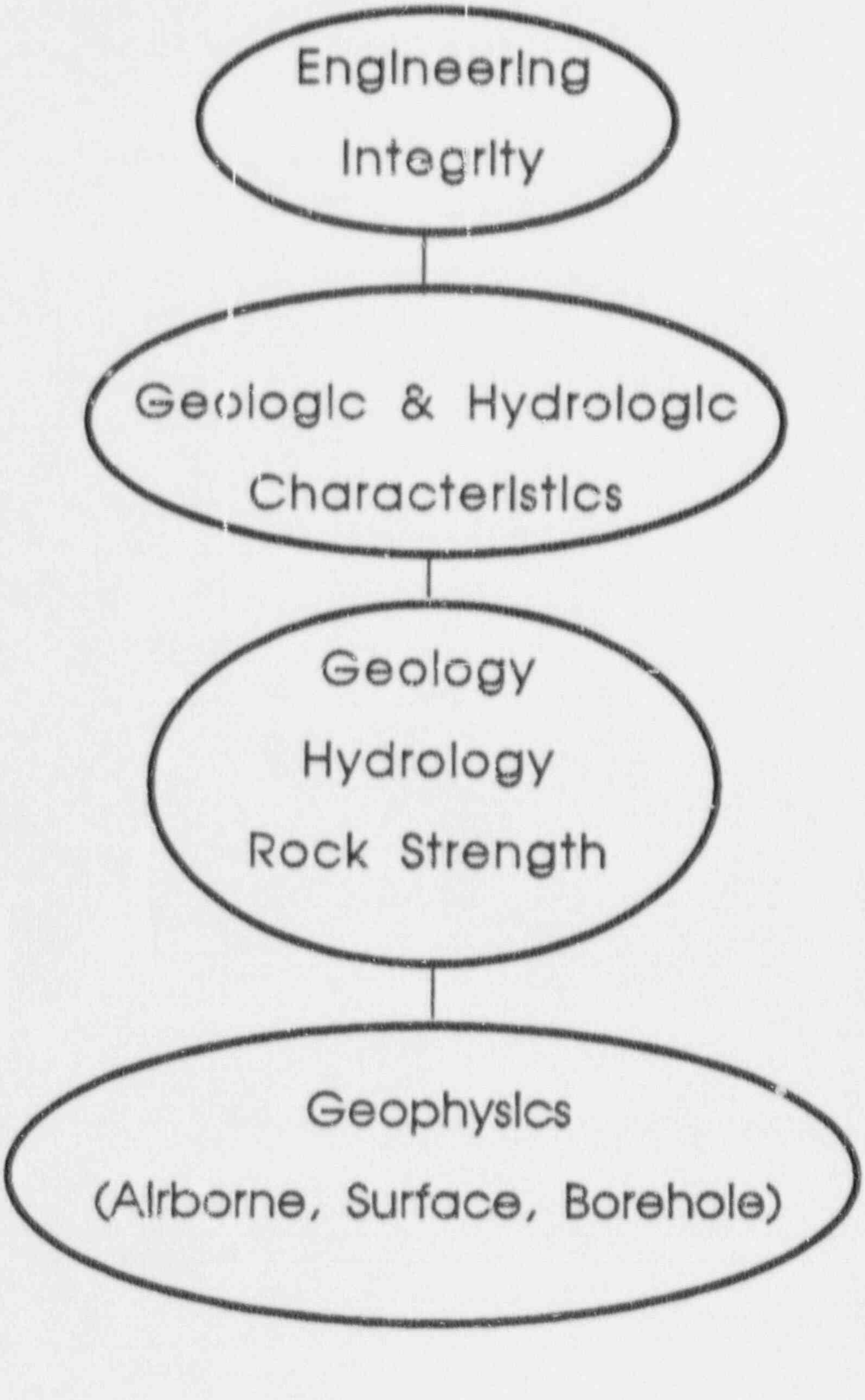
Waste Repository

by

Geologic Studies

Hydrology Studies

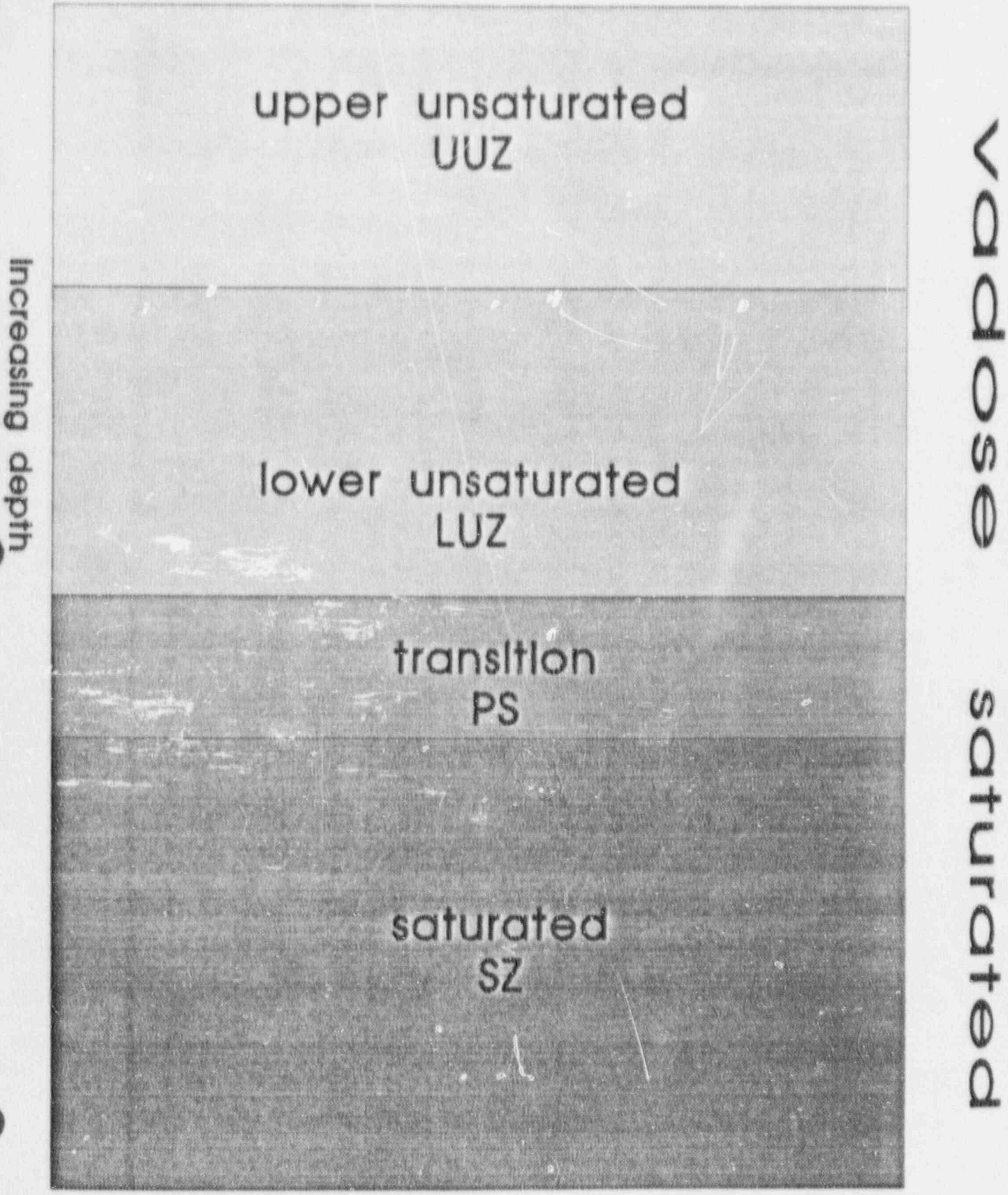
Engineering Testing


Engineering
Integrity
Geologic & Hydrologic
Characteristics
Geology
Hydrology
Rock Strength
Geophysics
(Airborne, Surface, Borehole)

Borehole Geophysics Objectives

Geophysical Well Logging

* Characterize Geology
  - lithology / mineralogy
  - stratigraphy / correlation
* Determine fracturing
* Insitu Physical Properties
  - density
  - porosity
  - acoustic properties
* Geophysical parameters


upper unsaturated
UUZ
lower unsaturated
LUZ
transition
PS
saturated
SZ
vadose
saturated
increasing depth
------->

Vadose & Saturated Zone Effects on Geophysical Well Logs

Geophysical Well Log	upper unsaturated	lower unsaturated	partially saturated	saturated
gamma ray	X	X	X	X
resistivity				X
conductivity	?	?	?	?
neutron-neutron	?	?	?	?
density (g-g)	?	?	?	X
acoustic vel.				X
acoustic-full wave				X
acoustic TV				X
Video TV	X	X	?	X
magnetic susc.	X	X	X	X
IP / NLCR				X
dipmeter				X
electric scanner				X
dielectric	X	X	X	X
flowmeter				X

? - restricted use X - application O.K.

Log Response to Hydrogeologic Parameters

Geophysical Well Log	lithology	stratigraphy	porosity	rock strength	fractures
gamma ray	X	?			
resistivity	?	?	?		
conductivity	?	?	?		
neutron-neutron	?	?	?		
density (g-g)	?	?	?	X	
acoustic vel.	?	?	?	?	X
acoustic-full wave			?	X	+
acoustic TV	?				+
Video TV	X	X			+
magnetic susc.	X	+			
IP / NLCR	?	?			
dipmeter		+			X
electric scanner					
dielectric	X	X	?		X
flowmeter			X		X
NMR			?		?
nuclear activation	X				

? - restricted use   X - application O.K.   + - application good

Borehole Geophysics Objectives

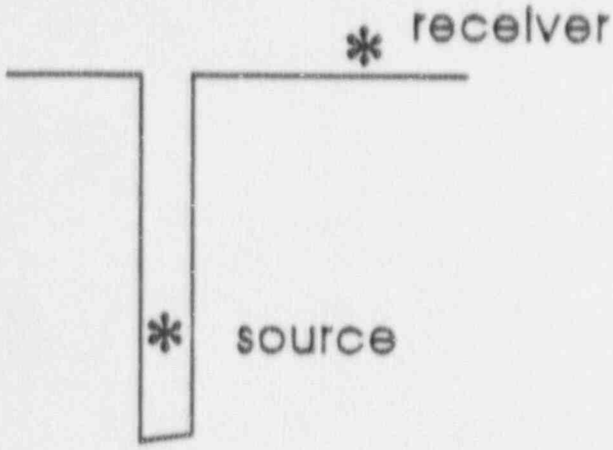
Borehole Geophysics

* characterize geology

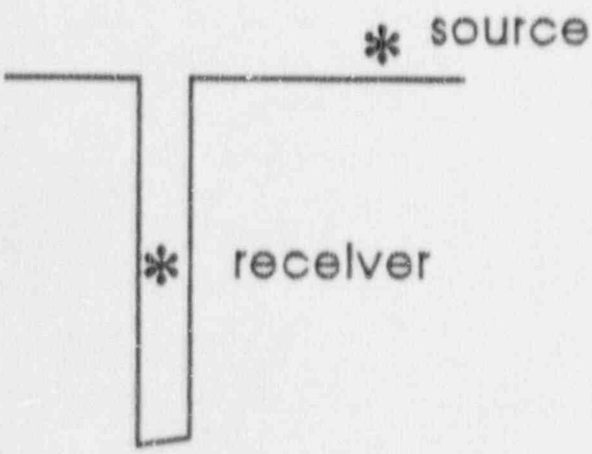
* Provide a subsurface image

* Integrate physical properties with surface geology/geophysics

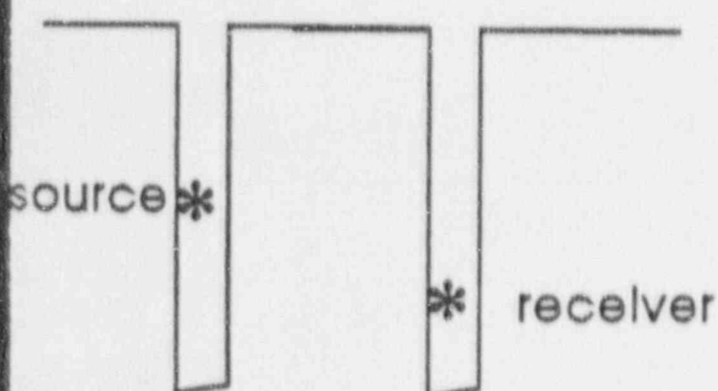
Borehole Geophysics



Hole-to-surface



Surface-to-hole



Hole-to-hole

Vadose & Saturated Zone Effects on Borehole Geophysics

Borehole Geophysical Method	upper unsaturated	lower unsaturated	partially saturated	saturated
Resistivity				X
Low frequency EM	X	X	X	X
VHF Electromagnetic	X	X	X	X
RADAR (GPR)	X	X	X	X
Seismic	?	?	?	X
Gravity	?	?	?	X
Magnetics	X	X	X	X

? - restricted use X - application O.K.

Response of Borehole Geophysics to Hydrogeologic Parameters

Borehole Geophysical Method	lithology	stratigraphy	porosity	rock strength	fractures
Resistivity	?	?	?		X
Low frequency EM	?	?	?		X
VHF Electromagnetic	?	?	X		X
RADAR (GPR)	X ?	X ?	X ?		X
Seismic	?	?	?		X
Gravity	?	?	?		X
Magnetics					

? - restricted use X - application O.K.

RRR (rough, relative resolution) of Borehole Geophysical Techniques

LOW Gravity

Magnetics, Resistivity

Low Frequency EM , Seismic

VHF Electromagnetics

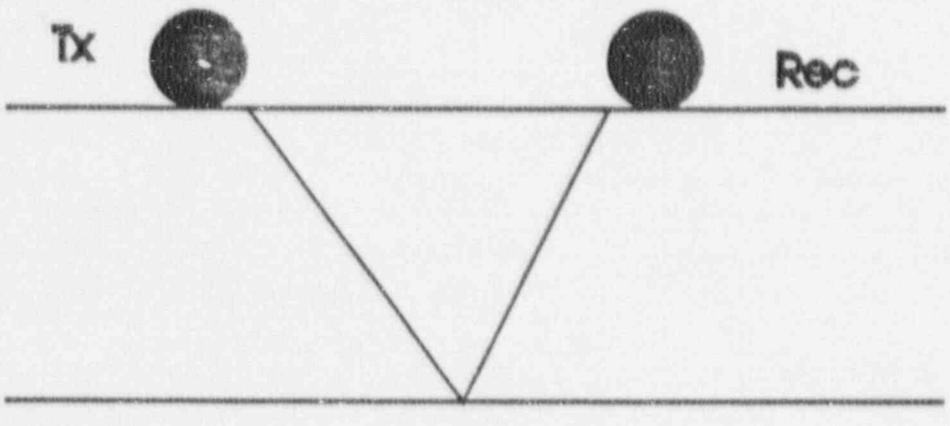
RADAR

HIGH

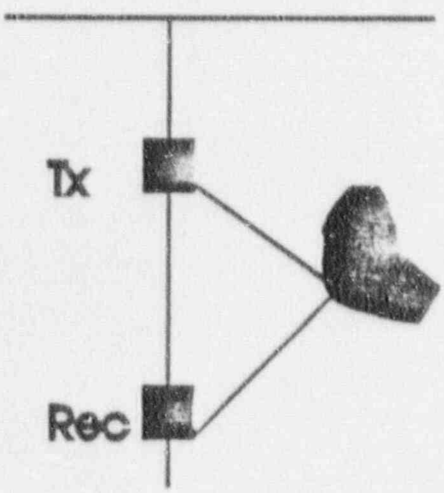
11

Surface and Borehole GPR

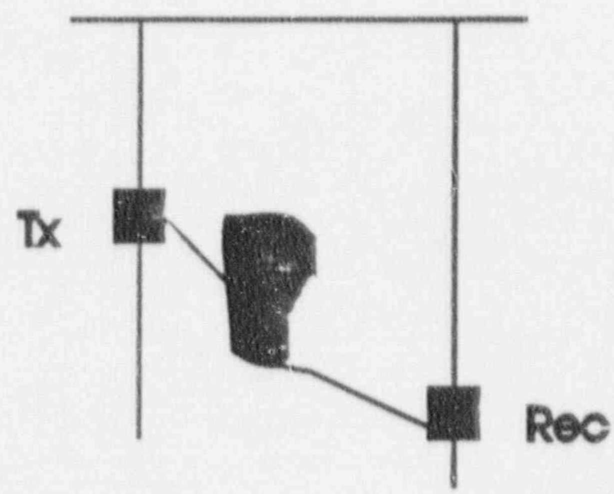
- Surface reflection



- Single hole reflection

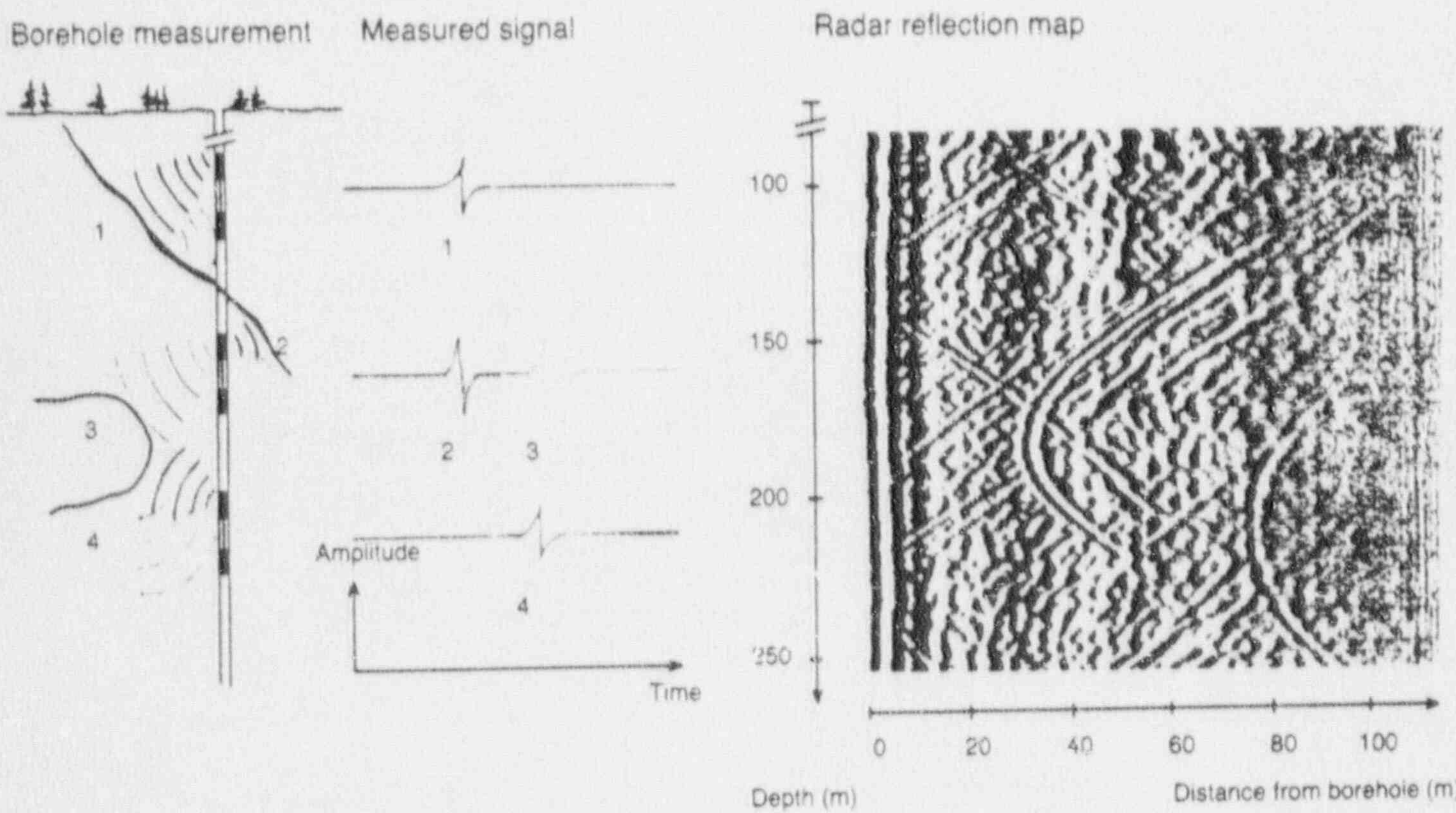


Hole-to-hole Reflection



-

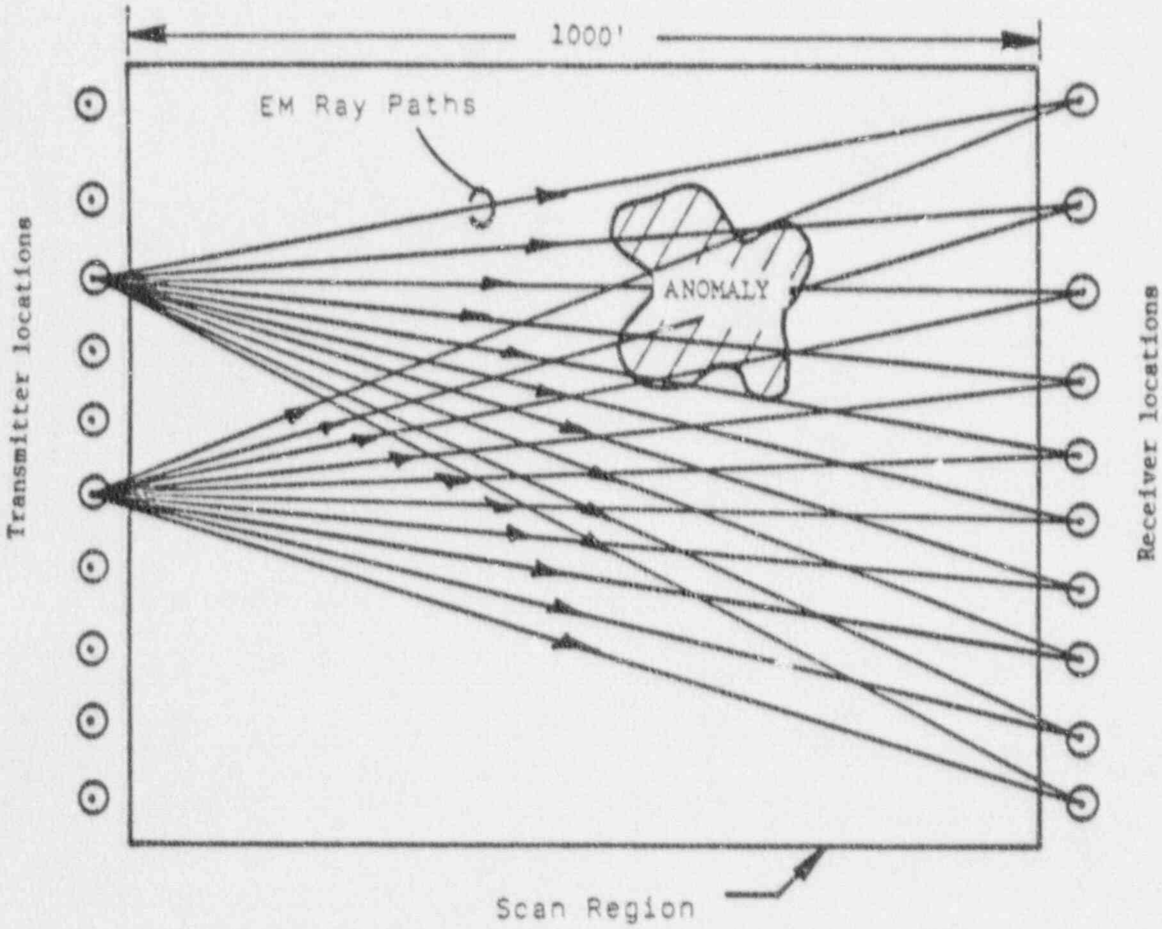
Single-hole reflection measurements



(from Swedish Geological Co. Ad.)

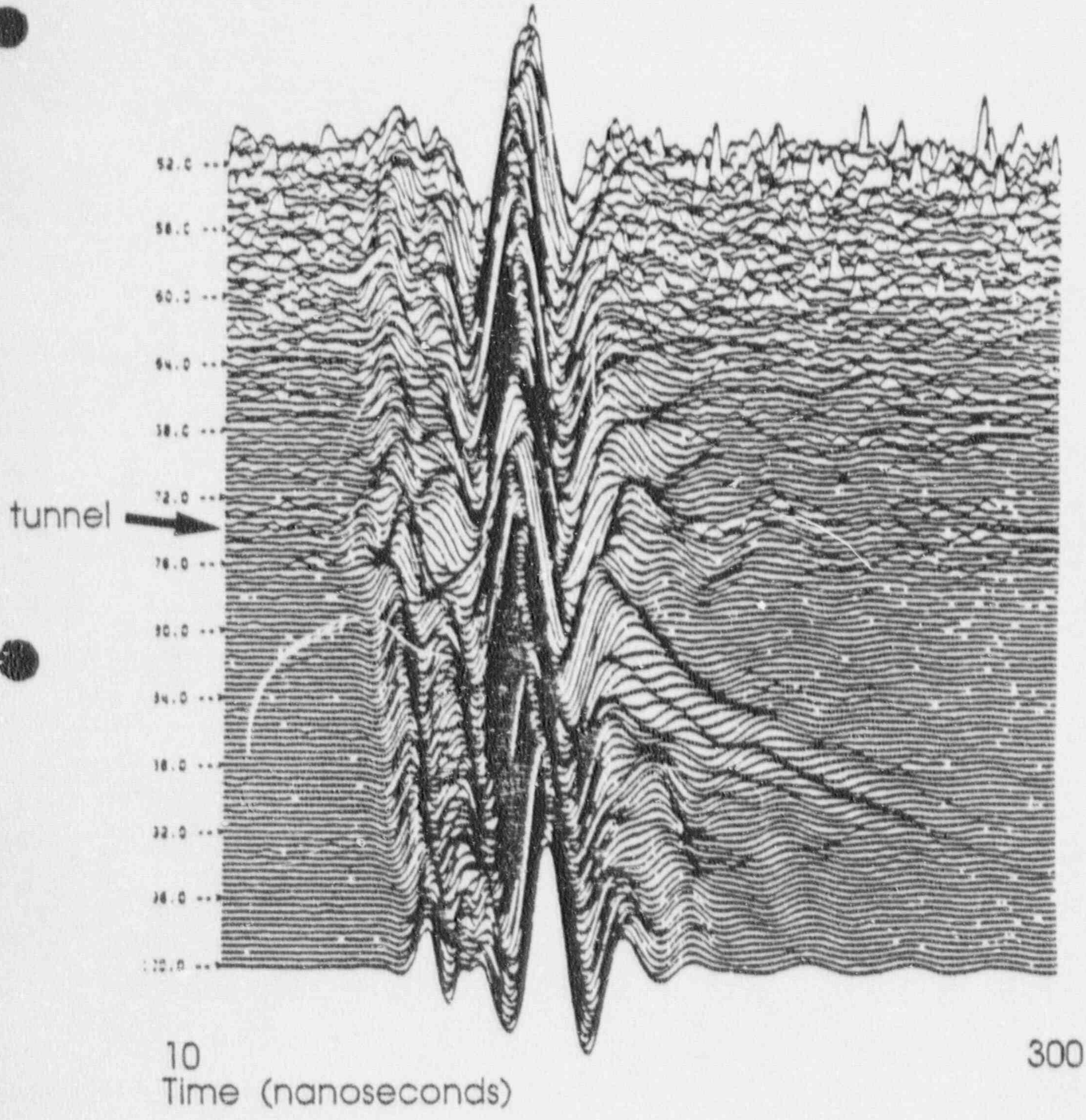
Pulse Radar

tomography arrays



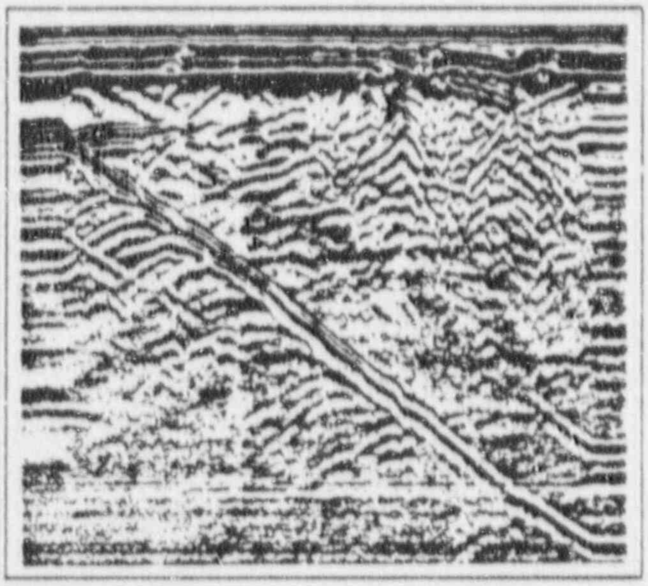
Greenfield, 88

Pulse Radar



normalized/pulse compression
pulse compression filtering

DIPPING REFLECTOR



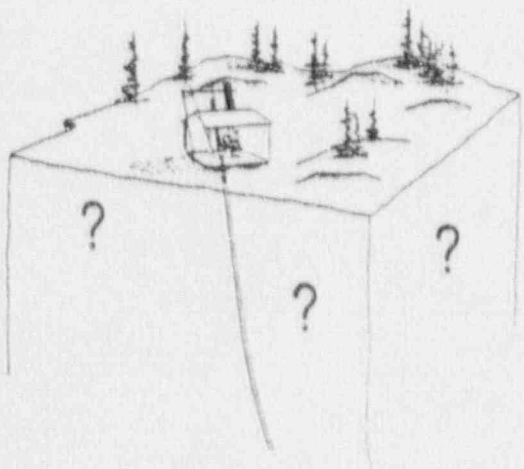
Ground Penetrating Radar at NTS

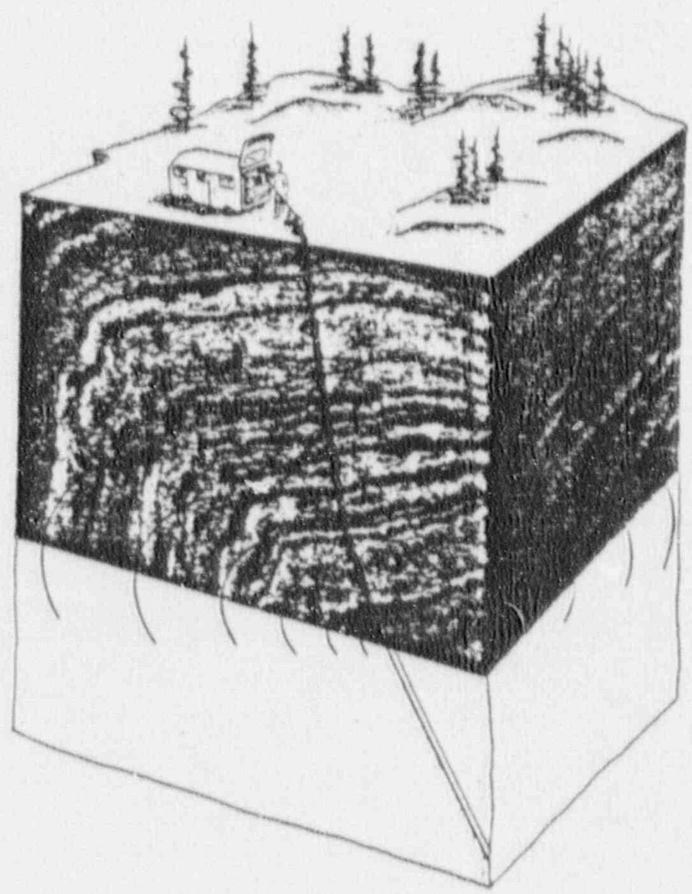
* Surface Depth Penetration 15 m ?
* Interference from Microwave transmissions

Possible Solutions for microwave noise

* Shielding
* Field Processing (Antenna design, ensamble averaging)
* Data Processing and Filtering

Would you like to see through rock?





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of

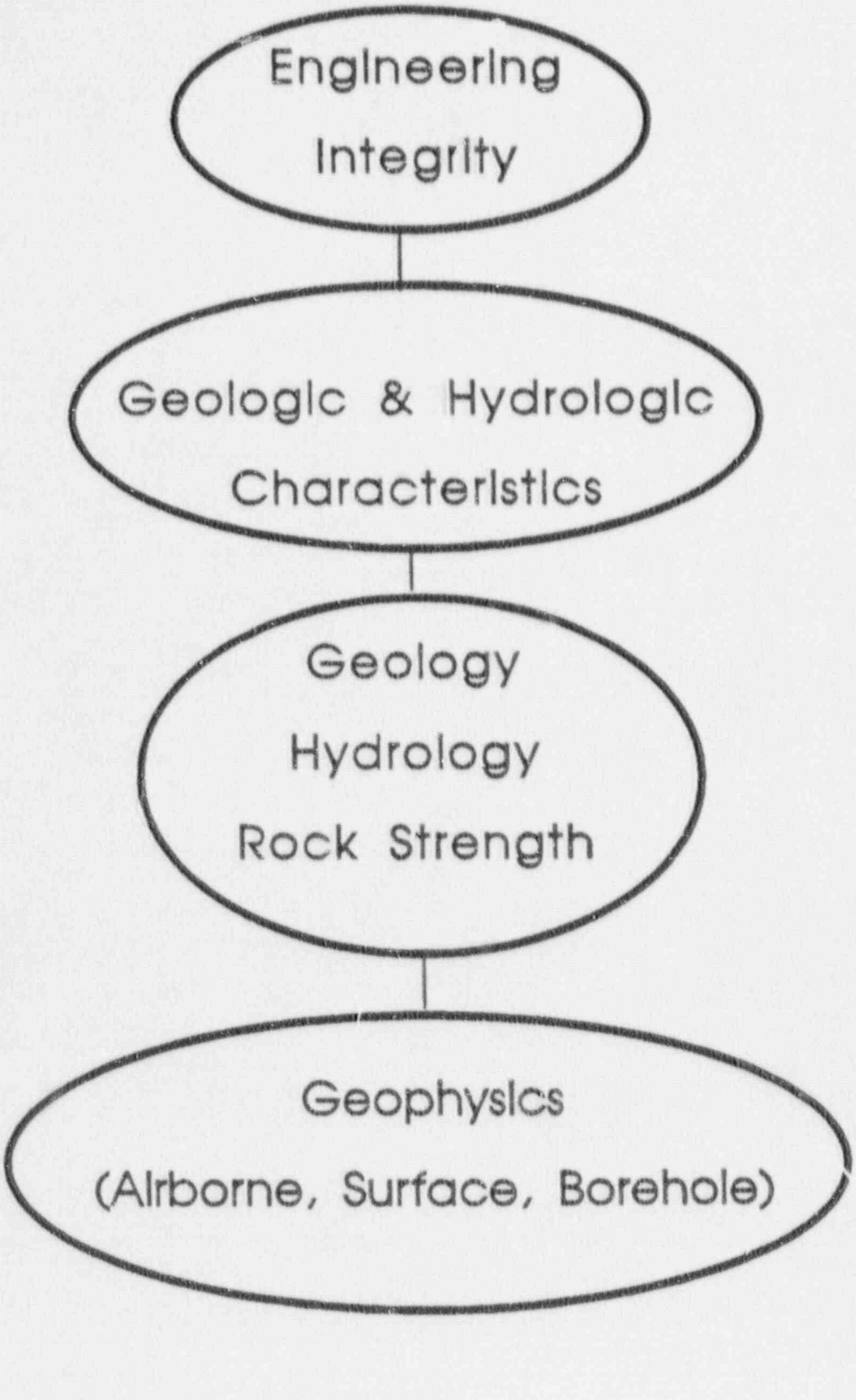
Waste Repository

by

Geologic Studies

Hydrology Studies

Engineering Testing


Engineering Integrity
Geologic & Hydrologic Characteristics
Geology
Hydrology
Rock Strength
Geophysics
(Airborne, Surface, Borehole)

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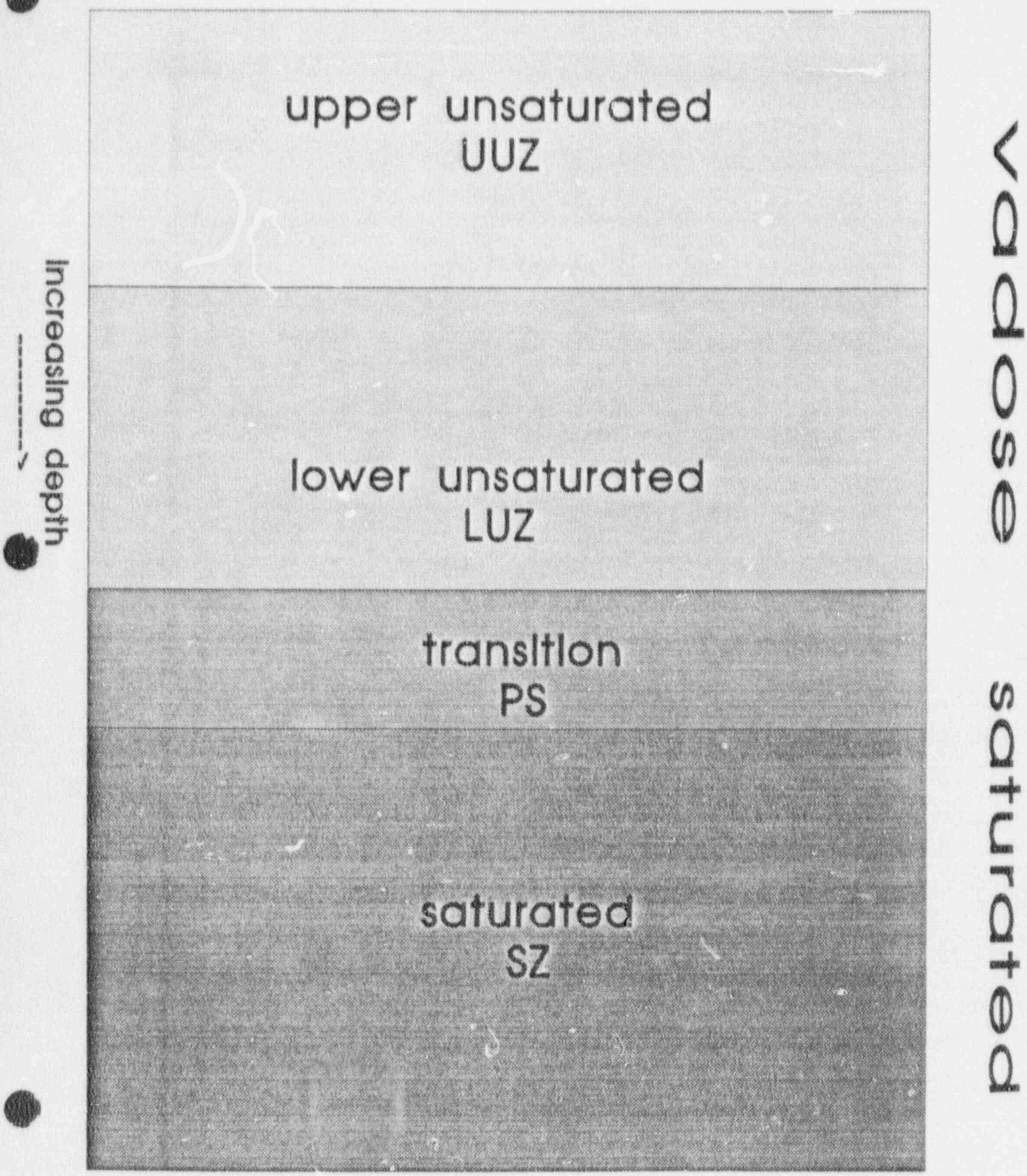
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increasing depth

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resistivity				X
conductivity	?	?	?	?
neutron-neutron	?	?	?	?
density (g-g)	?	?	?	X
acoustic vel.				X
acoustic-full wave				X
acoustic TV				X
Video TV	X	X	?	X
magnetic susc.	X	X	X	X
IP / NLCR				X
dipmeter				X
electric scanner				X
dielectric	X	X	X	X
flowmeter				X

? - restricted use X - application O.K.

Log Response to Hydrogeologic Parameters

Geophysical Well Log	lithology	stratigraphy	porosity	rock strength	fractures
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conductivity	?	?	?		
neutron-neutron	?	?	?		
density (g-g)	?	?	?	X	
acoustic vel.	?	?	?	?	X
acoustic-full wave			?	X	+
acoustic TV	?				+
Video TV	X	X			+
magnetic susc.	X	+			
IP / NLCR	?	?			
dipmeter		+			X
electric scanner					
dielectric	X	X	?		X
flowmeter			X		X
NMR			?		?
nuclear activation	X				

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Borehole Geophysics Objectives

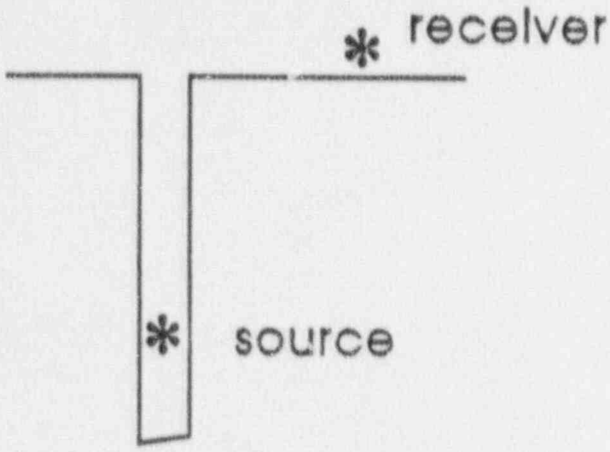
Borehole Geophysics

* characterize geology

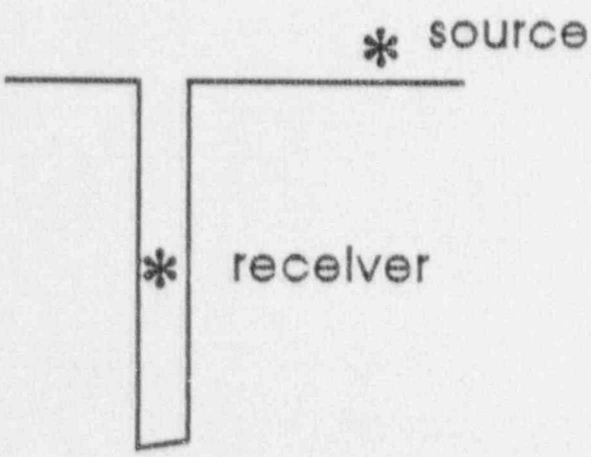
* Provide a subsurface image

* Integrate physical properties with surface geology/geophysics

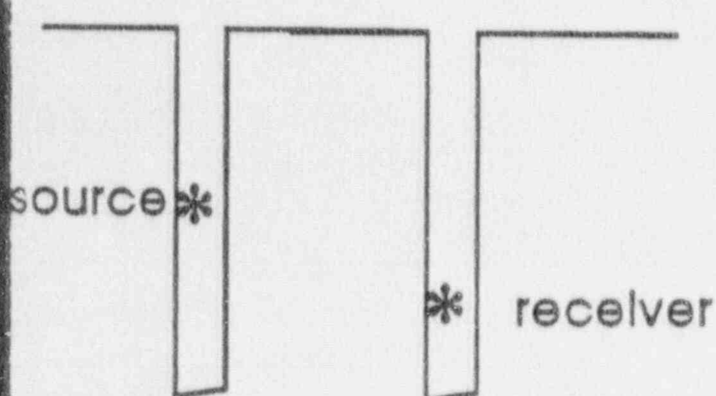
Borehole Geophysics



Hole-to-surface



Surface-to-hole



Hole-to-hole

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HIGH

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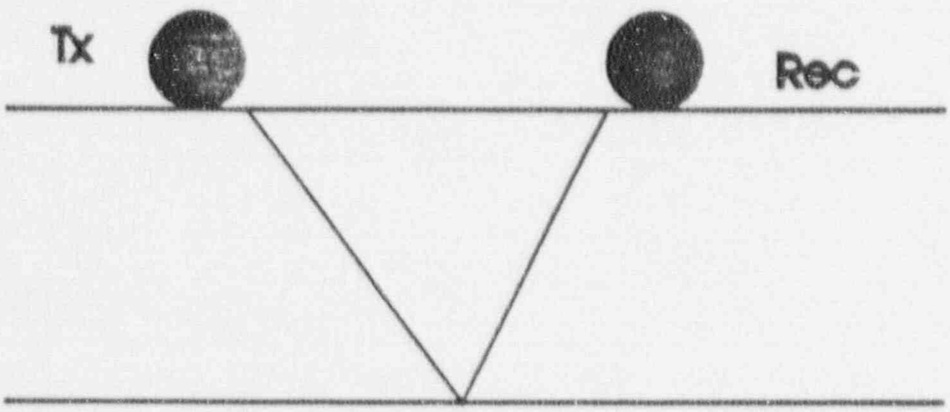
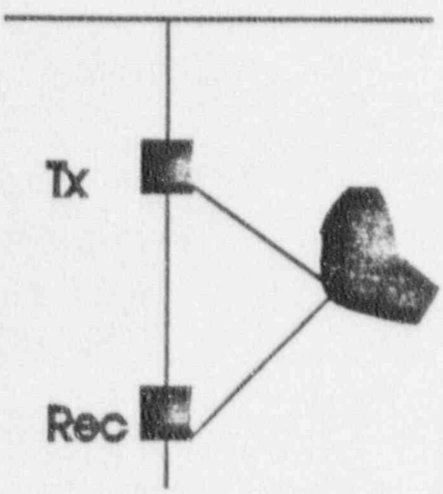
Surface and Borehole GPR

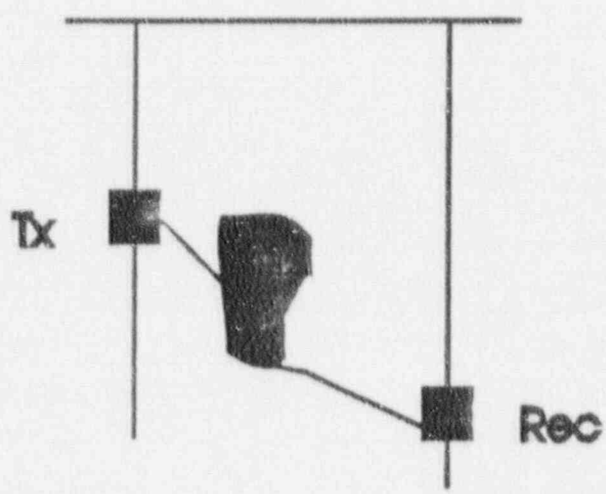
Surface reflection



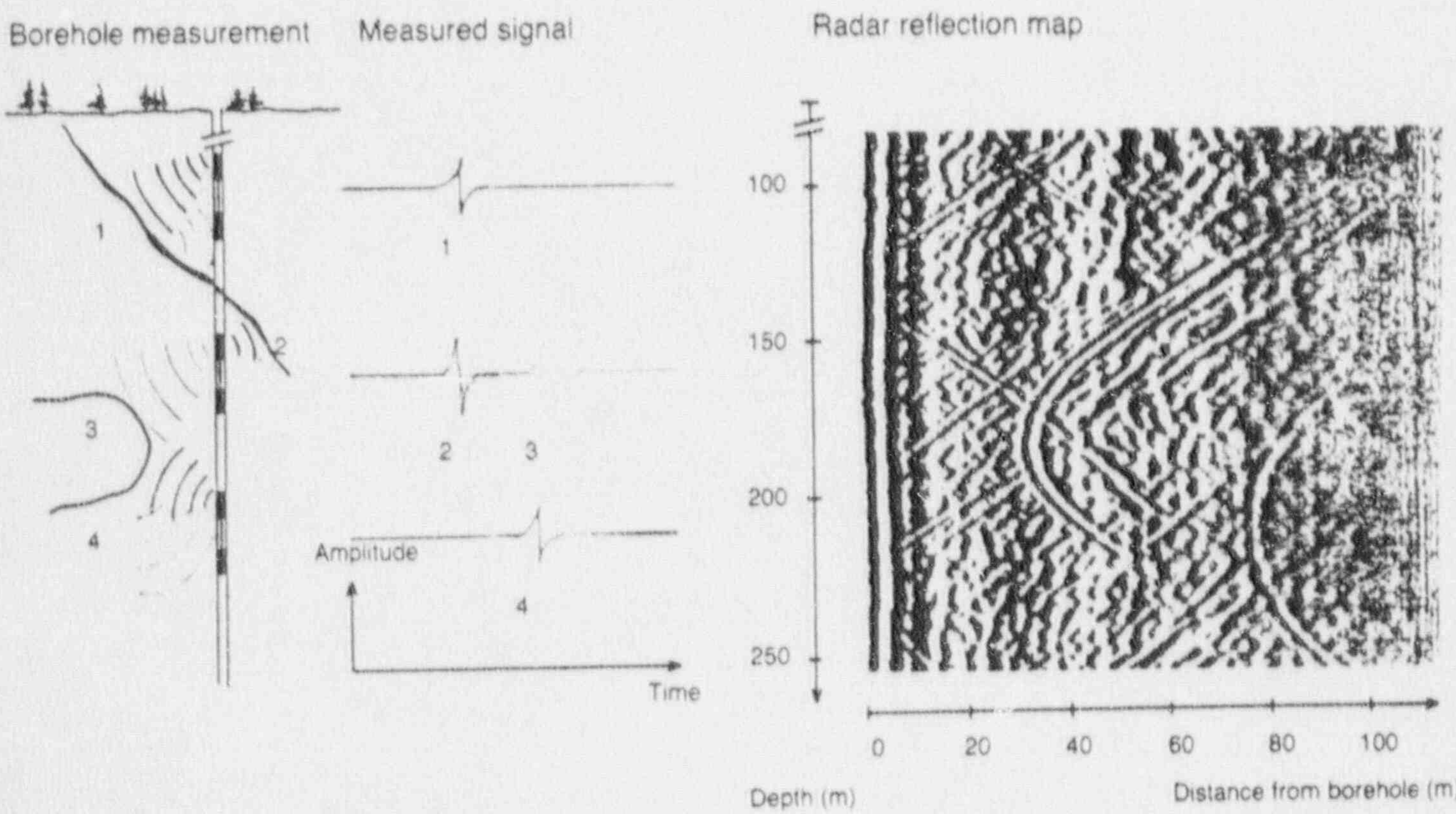
Single hole reflection



Hole-to-hole Reflection



Single-hole reflection measurements



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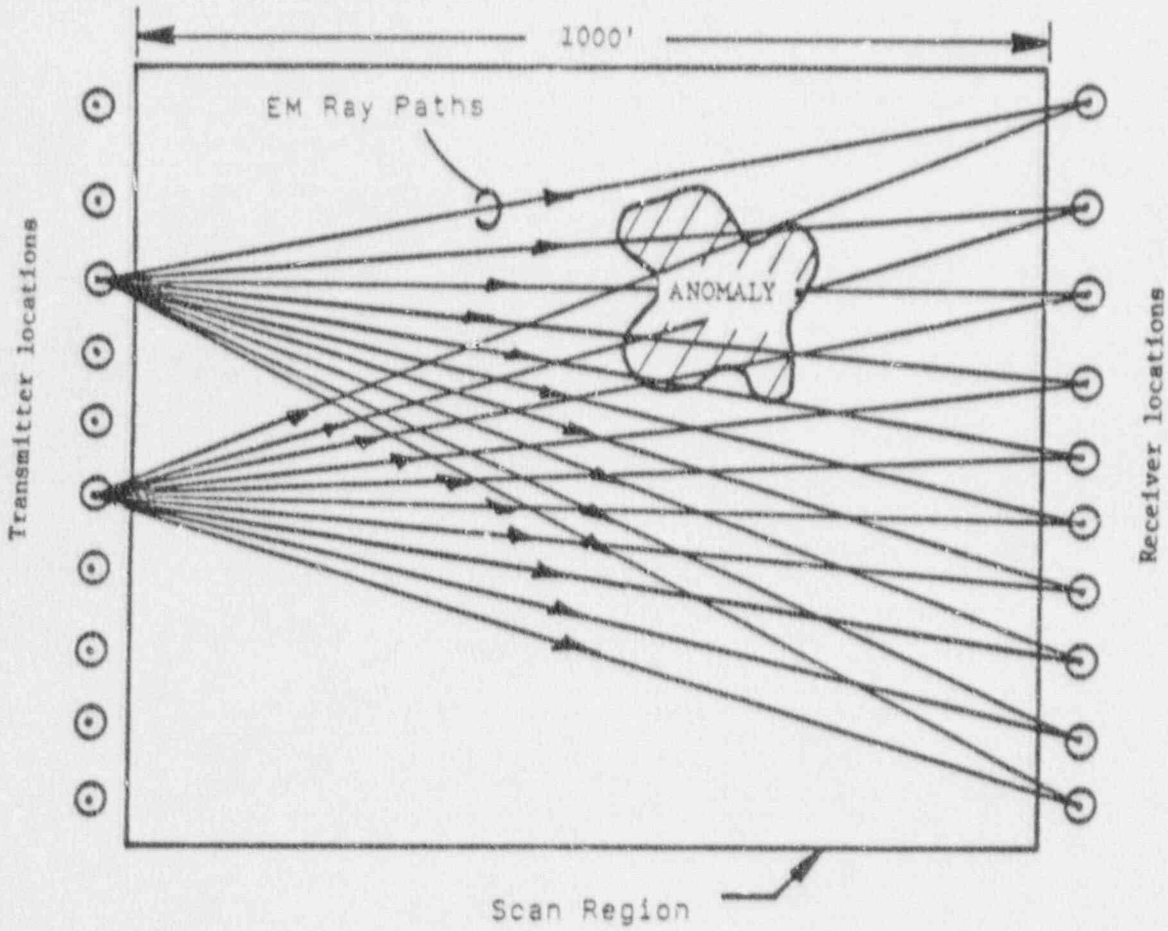
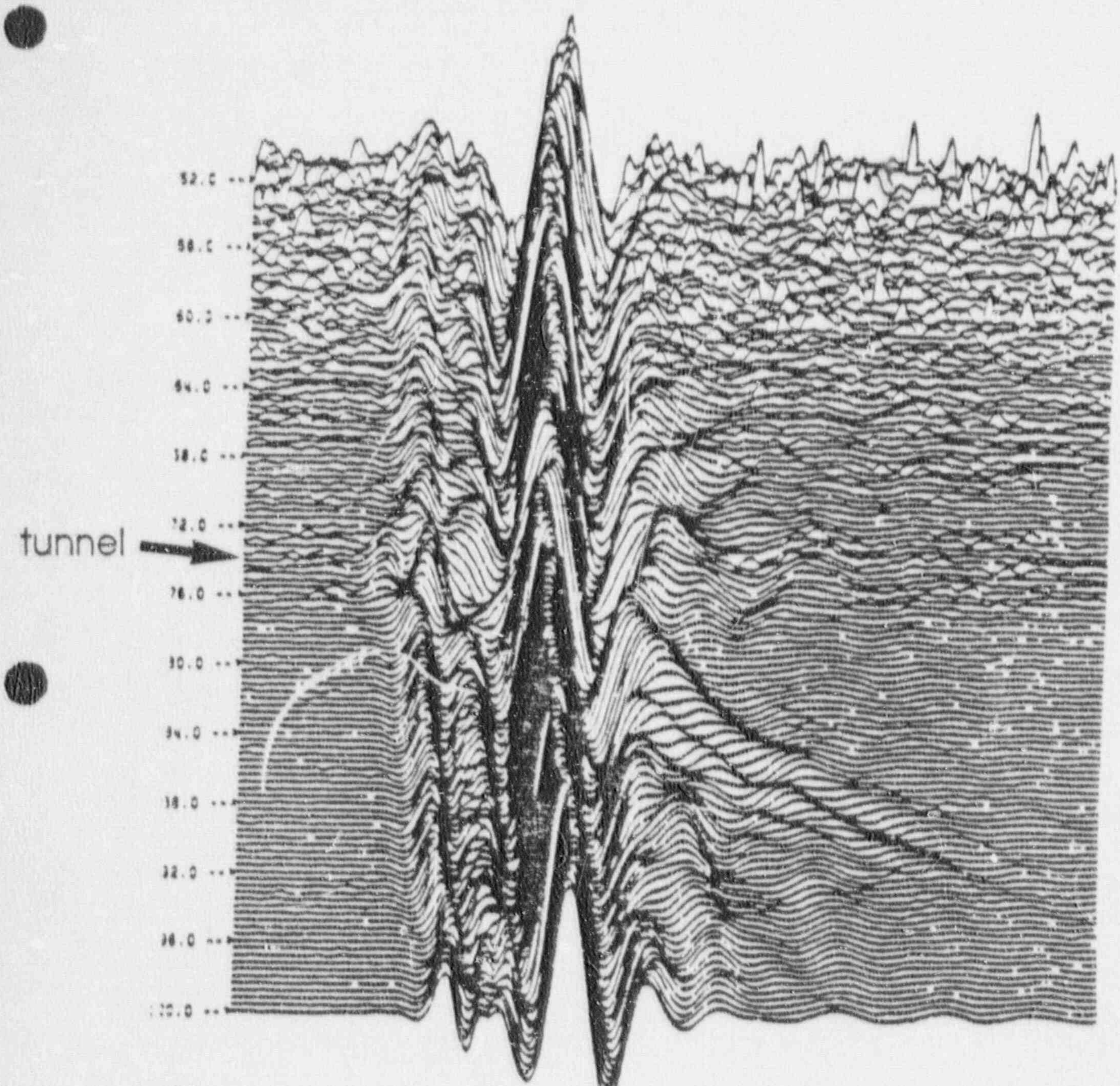
Pulse Radar

tomography arrays



Greenfield, 88

Pulse Radar



normalized/pulse compression
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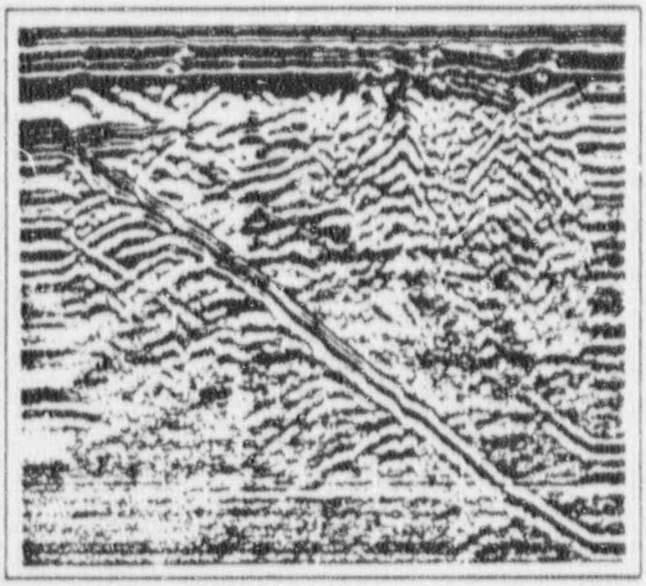
DIPPING REFLECTOR



Ground Penetrating Radar at NTS

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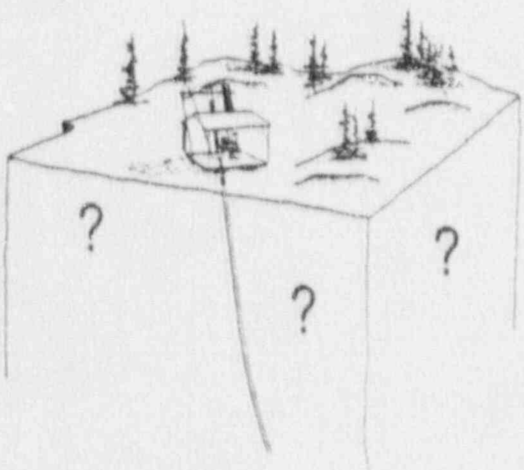
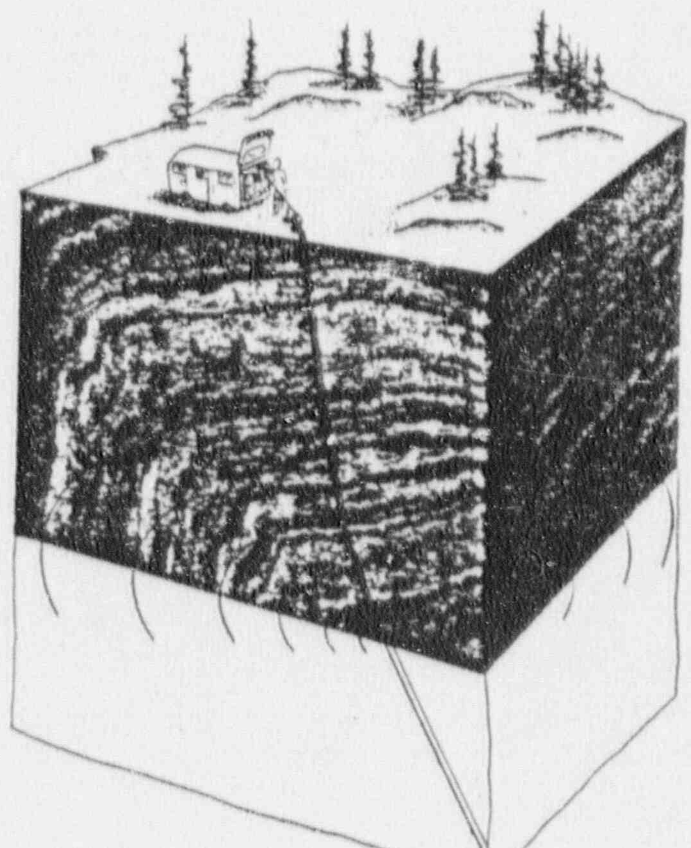




	Advantage	Limitation
VLF	fast; inexpensive	limited depth
air EM	fast; good coverage	limited depth
DC resis / IP	chargeability	galvanic (S/N) resolution EM coupling
loop-loop	fast; efficient	limited depth
Schlumberger	DC	galvanic; lateral var; length of line
TEM	low f; no topo	loop size logistics interpretation modelling
CSAMT	depth	near surface effects interpretation modelling

Site Characterization

A

0 – ±4000'

DC Resistivity
(E-Skan)

TEM

CSAMT

· shallow faulting
· economic resources
· shallow aquitards
· hydrologic grad.
· depth to Pz surface
· geothermal

B

0 – ± 2000'

VLF

Airborne EM

loop-loop/Slingram

DC – Resistivity
IP/ spec. IP

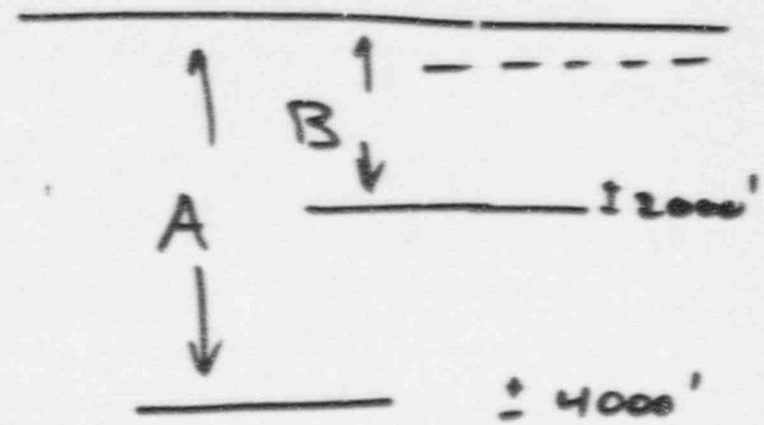
Schlumberger S.

TEM

CSAMT

Regional Evaluation

Site Characterization



structure

tectonics

magma chambers

shallow faulting

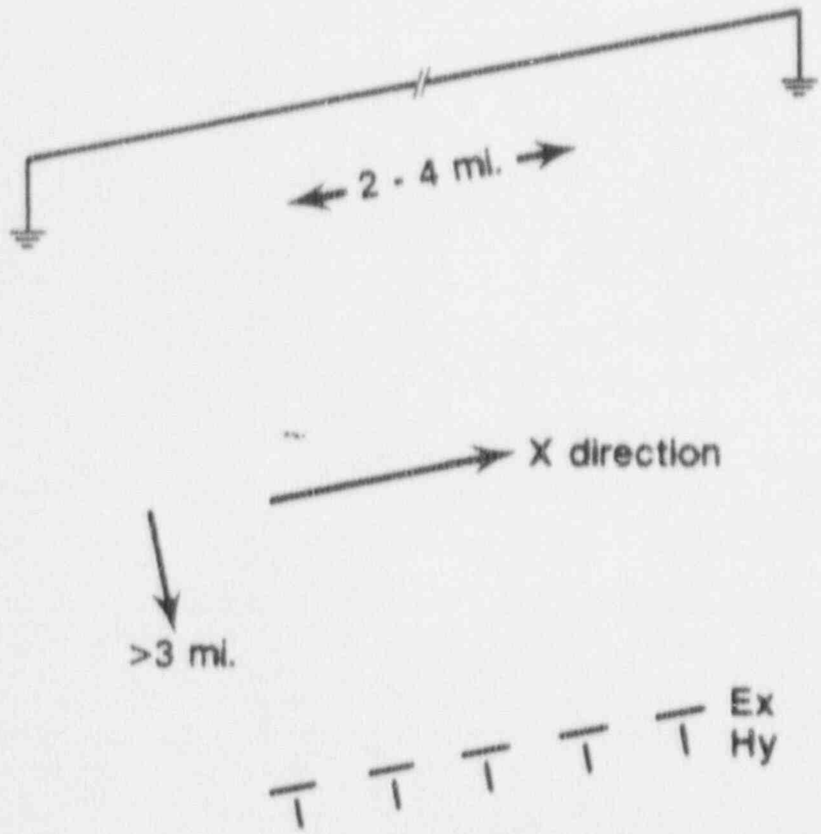
economic resources

shallow aquitards

hydrologic gradient

geothermal

CSAMT ARRAY

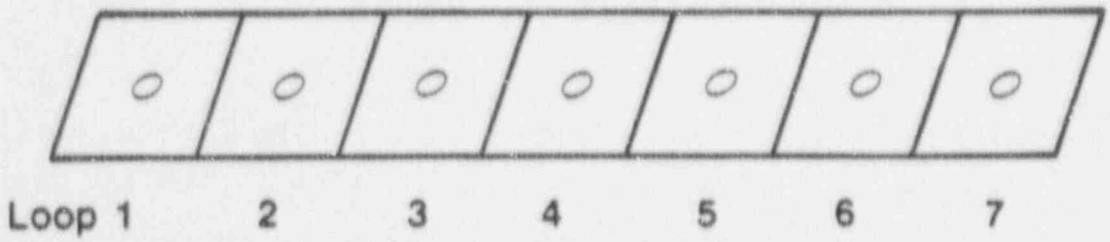


Measurement of electric field Ex and magnetic field Hy at 0.1 to 8000 Hz

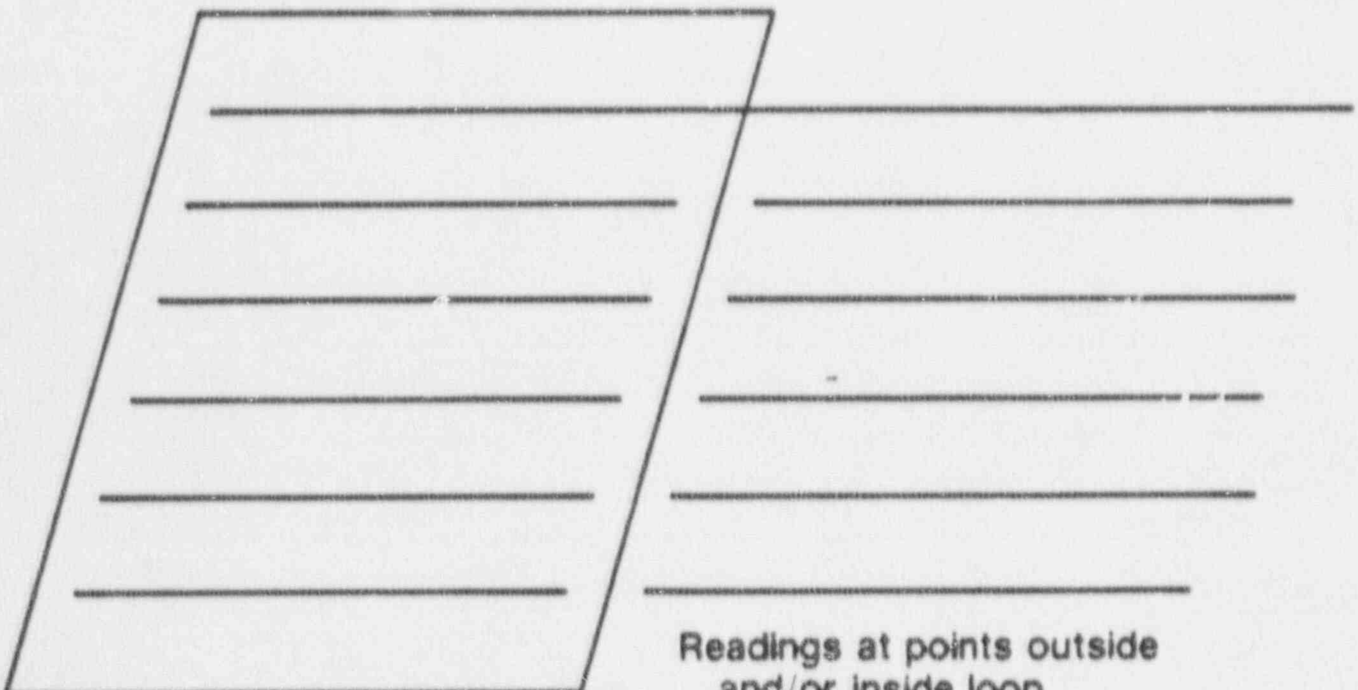
$$\text{Cagniard Resistivity} = \frac{1}{5f}\left|\frac{Ex}{Hy}\right|$$

$$\phi = \frac{E}{H}$$

TEM ARRAYS



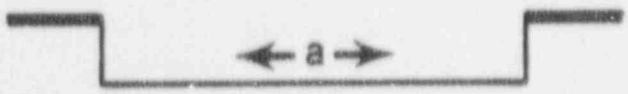
Loop size: 100 - 1500 ft.
Readings at center of each loop



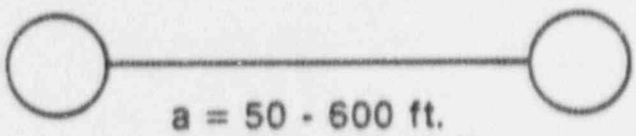
Readings at points outside
and/or inside loop

Loop size >2000 ft. on
any side to >1 x 2 mi.

FREQUENCY DOMAIN EM SYSTEMS

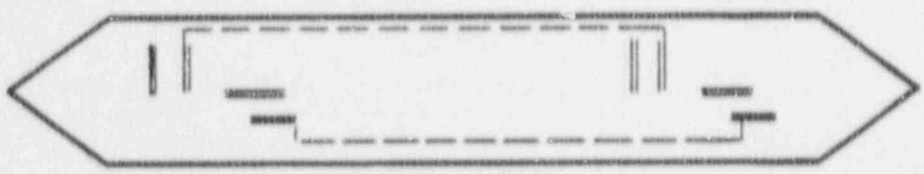


Slingram or
Horizontal Loop



Plan View

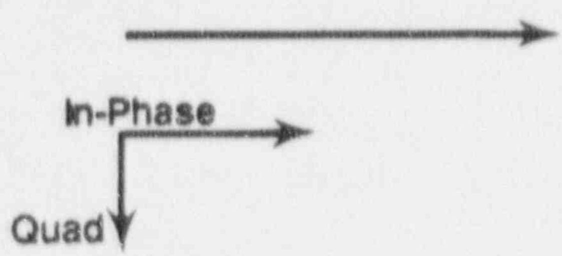
a = 50 - 600 ft.
f = 220 - 5000 Hz



Airborne
Configuration

a = 20 - 30 ft.
f = 500 - 35 KHz

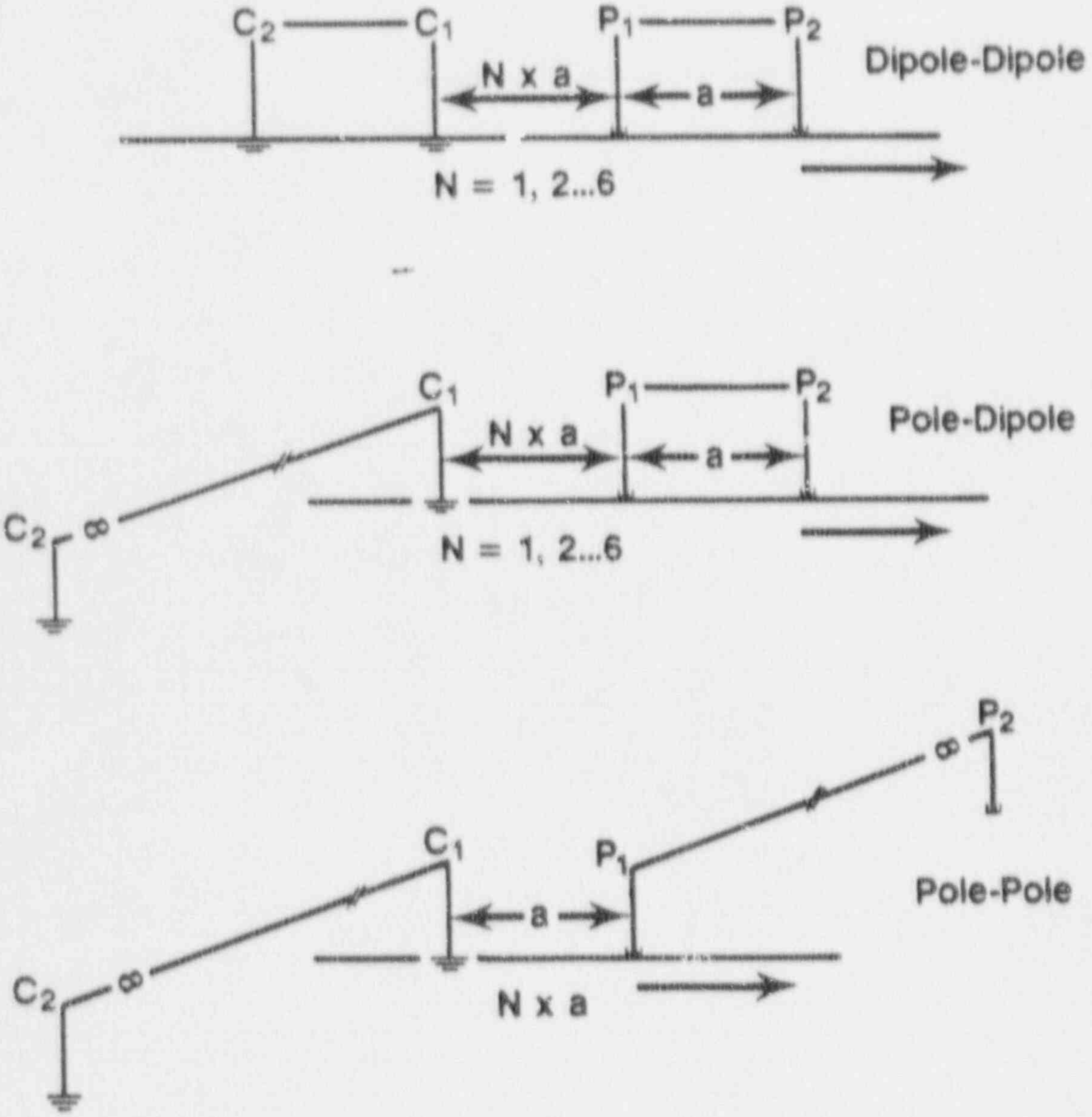
Primary & Secondary Field Relationships



Primary Hp

Secondary Hs
in percent (%) or
parts per million
(ppm)

ELECTRICAL ARRAYS - 1



U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN
SITE CHARACTERIZATION
PROJECT

INTEGRATION OF GEOPHYSICS WITH TECHNICAL PROGRAMS FOR CHARACTERIZATION OF A HLW SITE

PRESENTED TO

ACNW WORKING GROUP ON GEOPHYSICS

PRESENTED BY

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SCOPE OF PRESENTATION

- GEOPHYSICS PROGRAM – PAST, PRESENT, FUTURE
- HOW PROGRAM USES GEOPHYSICAL DATA
- TWO EXAMPLES

CURRENT STATUS OF GEOPHYSICS PROGRAM:

1. DATA ALREADY COLLECTED: DISCUSSION.
2. RECOGNITION OF FUTURE NEEDS: SCP
3. STATUS OF PLANNING AND COORDINATION
4. ONGOING: STUDY PLANS AND WORKING PAPERS
5. PRIORITIZATION AND FEASIBILITY TESTING
6. TWO EXAMPLES OF FOCUSED STUDIES:
   (1) ESF INVESTIGATIONS
   (2) CAUSE OF THE LARGE HYDRAULIC GRADIENT

Study Plan 8.3.1.X.X.X	Seismic: Reflection: Deep (Regional)	Seismic: Reflection: Intermediate	Seismic: Reflection: Shallow	Seismic: Refr.: Upper Crustal	Seismic: Refr.: Shallow	Seismic: VSP & Crosshole	Potential Field: Aeromagnetics	Potential Field: Detailed Mag.	Potential Field: Detailed Gravity	Paleomagnetics	Geoelectric Methods	Ground Penetrating Radar	Remote Sensing: LANDSAT	Remote Sensing: SLAR	Remote Sensing: Radiometric	Borehole Geophysics: Crosshole Gamma	Borehole Geophysics: Neutron Logging	Borehole Geophysics: TV & BATV	Borehole Geophysics: BH EM & VHF	Borehole Geophysics: Gravity & Magnetics	Borehole Geophysics: Other BH Methods	Related SB Drilling Program
.2.1.3 Regional Flow (Czarnecki)	a b	a b	b				a b	b	b		b	d	b				b	b		b	B	WT- holes; UZN-holes
.2.2.1 UZ Infiltration (Flint)			d		D							d	d			D	B	d	B		d	UZN-holes
.2.2.3 UZ Percolation SB (Rousseau)						D										D	d	d	D		d	UZ-holes; SD-holes
.2.2.4 UZ Percolation ESF (Yang et al.)						c											C	C			C	MPBH activity
.2.3.1 SZ Flow (USGS)		b		b			b	b	b		b							b			B	WT-holes
.2.3.2 SZ Hydrochem. (Steinkampf)																				d	d	WT-holes
5.2.1 Quatern. Reg. Hydro. (Stuckless)											b		b	b				b			B	WT-holes
.4.2.1 3-D Strat. (Spengler)				b						b							B D	b d	B D	B D	B D	G-holes, & others
.4.2.2 3-D Structure (Spengler)		b				D				a b								b	b d	b	d	G-holes, & others
.4.3.1 Systematic Drilling (Rautmann)										d							d	d		d	B D	UZ-holes; SD-holes
.8.1.1 Prob. Volcanic Eruption (Crowe)	a	a b		a b			a				b											
8.5.1 Volcanic Features (Crowe)							b	b	b	A B										b		V-holes
9.2.1 Natural Resources (USGS)	d	d					d	d			d		d		d						d	G-holes; SD-holes
.14.2.3 Geotechnical (SNL)			c		c			c				c						c			C	
.15.1.5 Excavation Invest. (SNL)						c																
.17.4.2 Faulting, Surf. Fac. (Shephard)			c									C										
.17.4.3 Quat. Faults w/in 100 km (Fox)	A	A	b	A B			a	A	A	A B	A		a								b	
.17.4.4 Proximal Faulting (Yount)			B		B						B											
.17.4.7 Subsurface Faulting (Fox)	a	B	B	b			B	A BC	B	a b	b		b		B							
8.3.4.2.4.4 Engr. Barrier Tests (LLNL)																			C			

NOTES:

(1) a = Regional, b = Yucca Mtn & vicinity, c = Surface facilities, d = Repository block & vicinity.

(2) **CAPITALIZED** indicates actual data collection activities, vs. studies where geophysical data are used.

Figure 3.2-1. Matrix correlating categories of geophysical methods, with SCP studies wherein geophysical data will be collected and used.

HOW GEOPHYSICS WILL BE USED IN SITE CHARACTERIZATION AT YUCCA MOUNTAIN:

HYDROLOGY:	GEOPHYSICS PART OF PROGRAM:
UNSATURATED ZONE:	
Fracture Characterization:	Vertical Seismic Profiling (VSP) at ESF, UZ-9 Borehole Logs: borehole television (BHTV) logs
Percolation Tests:	Well logs: neutron and dielectric logs Cross-hole tools: Gamma, seismic, VHF, EM and ER logs, Remote Sensing: infrared moisture detection
SATURATED ZONE:	
Large Hydraulic Gradient:	Gravity, Magnetics, Magnetotelluric, Seismic reflection and refraction, Borehole acoustic televiewer (BATV)
Recharge in Washes:	Seismic, Gravity, Resistivity, Neutron Moisture Logs
Fracture Characterization:	BHTV, BATV, VSP, ER and EM logs, VHF tomography
Regional 3-D hydrogeology:	Deep Seismic reflection and refraction, Magnetics, Gravity, Resistivity
NATURAL RESOURCES:	
Mineral Resources:	Remote Sensing: gamma ray spectometry, Induced Polarization, indirectly: 3-D geological-geophysical studies
Energy Resources:	Deep Seismic reflection and refraction, 3-D geological-geophysical studies
GEOLOGY AND TECTONICS:	
Regional-Scale Studies:	Deep Seismic: reflection and refraction, Gravity, Magnetic, Magnetotelluric, Landsat Paleomagnetic studies of rotations
Site Structure and Stratigraphy:	Well-logging of nearly all types for stratigraphy, and for surface faulting: Remote Sensing, Gamma-ray surveys, Shallow Seismic for faults, Gravity, inc. borehole gravity, Magnetics, Geoelectric methods, Remote Sensing, Gamma-ray surveys, Intermediate depth Seismic reflection amd refraction, EM Tomography, VSP.
VOLCANIC GEOLOGY:	
Detect Buried Basalts:	Aeromagnetic surveys, Gravity, Paleomagnetics
Detect Magma Chambers:	Seismic refraction and deep reflection, gravity, magnetics - esp. Curie isotherm, magneto-tellurics, teleseismic tomography
ENGINEERING APPLICATIONS:	
Surface Facilities Siting:	Shallow Seismic, VSP, Ground Penetrating Radar
Repository Characterization:	Borehole logs of many kinds to characterize the repository horizon, cross-hole techniques. Investigate extent of damaged zone

Summary of High-Priority Geophysical Activities

Action	Timing and Prerequisites	Responsibility	Study Plan 8.3.1.X.X.X	Prioritization Concern
A. (1) Peer Review Notice, for review of the applicability of regional geophysical traverses to site characterization (2) Peer review (SCP Activity 8.3.1.17.4.3.1)	ASAP, per QMP-03-01 Approval of Peer Review Plan	Project Office Project Office to initiate and support; USGS participation in review functions	N/A N/A	Applicability of regional gephysical traverses such as those identified in SCP Activity 8.3.1.17.4.3.1.
B. (1) Peer Review Notice, for review of Seismic Methods for Characterizing Yucca Mountain and Vicinity (2) Peer review (SCP Activity 8.3.1.17.4.7.1)	ASAP, per QMP-03-01 Approval of Peer Review Plan	Project Office Project Office to initiate and support; USGS participation in review functions	N/A N/A	Successful seismic reflection methodology; structural profile across YM, Crater Flat, and Jackass Flat; characterize volcanic deposits in Amargosa Desert
C. VSP feasibility test (Activity 8.3.1.4.2.2.5)	ASAP (Site access)	USGS (LBL)	N/A	Application to seismic reflection methodology; fracture/fault char. in repository block; plan ESF VSP; plan VSP in surface boreholes.
D. Seismic refraction line (Activity 8.3.1.4.2.1.2)	Peer Review of Seismic Methods	USGS	N/A	Structure of northern YM; structural cause for large hydraulic gradient.
E. Teleseismic data collection and inversion (associated with SCP Activities 8.3.1.8.1.1.3 and 8.3.1.17.4.1.2)	Study Plan 8.3.1.8.1.1 and 8.3.1.17.4.1	USGS	TBD	Structural reconnaissance; correlate mid- and lower crust features with surface structure incl. volcanic deposits.
F. Geoelectric data interpretation and scoping analyses.	Feasibility test plan	USGS	N/A	Applicability of existing data and available techniques to investigation of large hydraulic gradient area; natural resource assessment.

Summary of High-Priority Geophysical Activities

Action	Timing and Prerequisites	Responsibility	Study Plan 8.3.1.X.X.X	Prioritization Concern
G. Feasibility test for detection and delineation of volcanic deposits by geophysical methods.	Feasibility test plan	USGS, with input from LANL	N/A	Volcanic hazard assessment.
H. Feasibility test of borehole and related methods for fracture/fault zone characterization in the UZ and SZ.	Feasibility test plan	USGS	N/A	Resolve applicability of geophysics to characterization of the repository block; requirements on boreholes penetrating the block.
I. Detailed aeromagnetic survey (Activity 8.3.1.17.4.7.4)	Study Plan 8.3.1.17.4.7; feasibility testing	USGS, input from LANL	.17.4.7	Distribution of volcanic deposits; reconnaissance of large hydraulic gradient area; mineral resource assessment; detailed Curie isotherm analysis.
J. Feasibility test of the use of MT traverses for exploration of the large hydraulic gradient area	Feasibility test plan	USGS	N/A	Structure of northern Yucca Mountain, as a possible cause for the large hydraulic gradient.
K. Feasibility test of seismic reflection for structural profiling across Yucca Mountain and vicinity.	VSP test; Peer Review of Seismic Methods; Feasibility test plan	USGS	N/A	Demonstrate applicability of seismic reflection for site characterization; structural profile across Yucca Mountain, Crater Flat, and part of Jackass Flat.
L. Feasibility test of the Mini-Sosie method for fault detection and characterization in the vicinity of Yucca Mountain.	Feasibility test plan	USGS	N/A	Determine extent to which method can be relied upon in site characterization.
M. Preparation and review of plan for geophysics integration and feasibility testing, corresponding to SCP Section 8.3.1.4.1.2.	TBD	TBD	N/A	Structure the integration activity; produce a single integrated geophysical feasibility test plan to facilitate review, approval, and implementation.

GEOPHYSICAL TECHNIQUES ARE NOT STAND-ALONE TOOLS, BUT THEN NEITHER ARE THE OTHER TECHNIQUES THAT WE USE IN SITE CHARACTERIZATION

GEOLOGIC TOOLS:	PROS:	CONS:
FIELD MAPPING	LOCAL CONTINUOUS CONTROL GROUND TRUTH RELATIONS CAN BE EXAMINED AS WITH NO OTHER TECHNIQUE	LARGE DATA GAPS SURFICIAL INFORMATION - VERY LIMITED 3-D CONTROL 3-D INTERPRETATION NEEDS TO BE VERIFIED WITH GEOPHYSICS, DRILLING
DRILL CORE, & CUTTINGS	GROUND TRUTH IN SUBSURFACE	MISSING SECTIONS, STRICTLY 1-D SUBSURFACE CONTROL
ANALYTICAL TOOLS (GEOCHRONOLOGY, CHEM & MINERAL ANALYSIS)	ABSOLUTE AGES COMPOSITIONAL FINGERPRINTS	UNCERTAINTIES CAN BE LARGE COMMONLY NEEDS VERIFICATION

GEOPHYSICAL TOOLS:		
WELL LOGS	CONTINUOUS - NO MISSING SECTIONS & CAN SEE EFFECTS BEYOND THE BOREHOLE	MUST BE CALIBRATED USING PETROPHYSICAL DATA
LINEAR SURVEYS: (GEOELECTRIC, SEISMIC, ETC.	2-D SUBSURFACE CONTROL	GEOLOGIC CONTROL NEEDED TO INTERPRET - NOT GROUND TRUTH
AREAL SURVEYS: (MAGNETICS, GRAVITY, ETC)	INTEGRATES EVERYTHING THERE IN 3-D	NO UNIQUE SOLUTION - GEOLOGIC DATA NEEDED TO INTERPRET
PALEOMAGNETICS	CORRELATIVE AGE CONTROL & GROUND TRUTH ON ROTATIONS	CAN'T TELL ABSOLUTE AGE GEOLOGIC CONTROL NEEDED TO INTERPRET

THE LEVELS OF CERTAINTY NEEDED AT YUCCA MOUNTAIN CANNOT BE ACHIEVED USING GEOLOGY ALONE - WE NEED THE POWERFUL EXTENSION THAT GEOPHYSICS PROVIDES.

EXAMPLES

1. CAUSE OF LARGE HYDRAULIC GRADIENT – EXAMPLE OF INTEGRATION OF DATA AND RETHINKING OF PLANS

2. SITING EXPLORATORY STUDIES FACILITY (ESF) – EXAMPLE OF IDENTIFICATION OF INFORMATION NEEDS

GEOPHYSICAL PROGRAM FOR PROVIDING DESIGN DATA FOR THE ESF ACCESS RAMPS AND PORTALS

- ONE OR MORE SEISMIC LINES ARE PLANNED ALONG THE AXIS OF THE PROPOSED PORTALS AND EXCAVATIONS LEADING TO THE PORTALS

  - MEASURE COMPRESSIONAL AND SHEAR WAVE VELOCITIES OF ALLUVIAL AND BEDROCK MATERIALS
  - DETERMINE SEISMIC STRUCTURE IN THE VICINITY OF THE RAMP PORTAL

GEOPHYSICAL PROGRAM
(CONTINUED)

- ONE OR MORE OF THE BOREHOLES DRILLED AT THE RAMP PORTALS AND ALONG THE RAMP ALIGNMENT WILL BE LOGGED

  - MEASURE COMPRESSIONAL AND SHEAR WAVE VELOCITIES OF BEDROCK AND POSSIBLY ALLUVIUM
  - DETERMINE SEISMIC STRUCTURE IN THE VICINITY OF THE RAMP PORTALS
  - MEASURE PHYSICAL PROPERTIES
  - CORRELATE STRATA BETWEEN BOREHOLES AND LOCATE STRATA TRANSITIONS OR CONTACTS

GEOPHYSICS FOR THE SITING OF THE EXPLORATORY FACILITIES ACCESS RAMPS AND PORTALS

- PRESENT STUDIES ARE TO EVALUATE EXISTING GEOPHYSICAL INFORMATION TO DETERMINE IF ANY UNFAVORABLE CONDITIONS ARE KNOWN OR SUSPECTED, ESPECIALLY FAULTS

- ALL OF THE PROPOSED RAMP ALIGNMENTS WILL PROBABLY CROSS FAULTS; THEREFORE FAULTS ALONE ARE NOT A CRITERIA FOR REJECTING A PARTICULAR ALIGNMENT

- FAULTING IN THE VICINITY OF A PROPOSED PORTAL LOCATION, OR FAULTS WHICH COINCIDE WITH A RAMP ALIGNMENT, WOULD PROBABLY RESULT IN MOVING THAT FACILITY

GEOPHYSICS FOR SITING

(CONTINUED)

- PRESENT COVERAGE OF GEOPHYSICAL WORK IS OUTLINED IN:

  - GEOPHYSICS "WHITE PAPER"

  - TECHNICAL ASSESSMENT REVIEW (TAR) FOR THE PROPOSED EXPLORATORY SHAFT (COVERS MOST OF THE AREA BEING CONSIDERED FOR THE NORTHERN RAMP LOCATION)

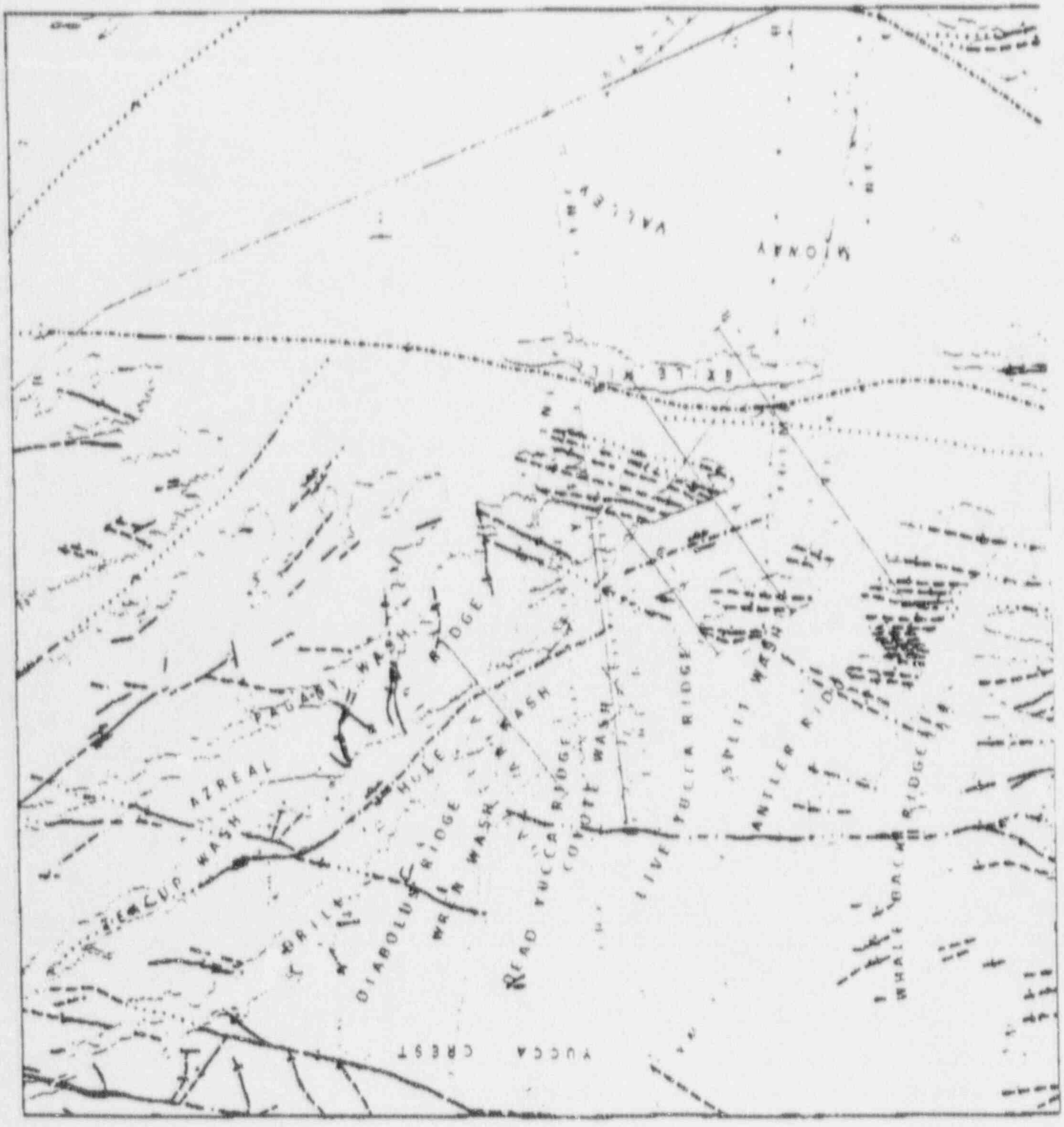
  - SNL DRAFT REPORT FOR THE EVALUATION OF GEOLOGIC AND GEOPHYSICAL DATA FOR THE AREA OF PROSPECTIVE SURFACE FACILITIES ASSOCIATED WITH THE PROPOSED REPOSITORY (COVERS THE REST OF THE AREA BEING CONSIDERED FOR THE NORTHERN RAMP LOCATION)

GEOPHYSICS FOR SITING

(CONTINUED)

- THE AREA BEING CONSIDERED FOR THE SOUTHERN RAMP IS GENERALLY COVERED BY THE GEOPHYSICS "WHITE PAPER", BUT NO DETAILED LITERATURE/ INFORMATION SEARCHES FOR THIS SOUTHERN AREA HAVE BEEN MADE

- THE GEOPHYSICAL AND GEOLOGICAL INFORMATION WILL BE EVALUATED IN THE SITING STUDIES NOW UNDERWAY FOR THE RAMP AND PORTAL LOCATIONS. BASED ON THIS EVALUATION, ADDITIONAL GEOPHYSICAL AND/ OR GEOLOGICAL WORK MAY BE RECOMMENDED FOR THE SITING OF THESE FACILITIES



AZREAL
WASH
PAGANY WASH
RIDGE
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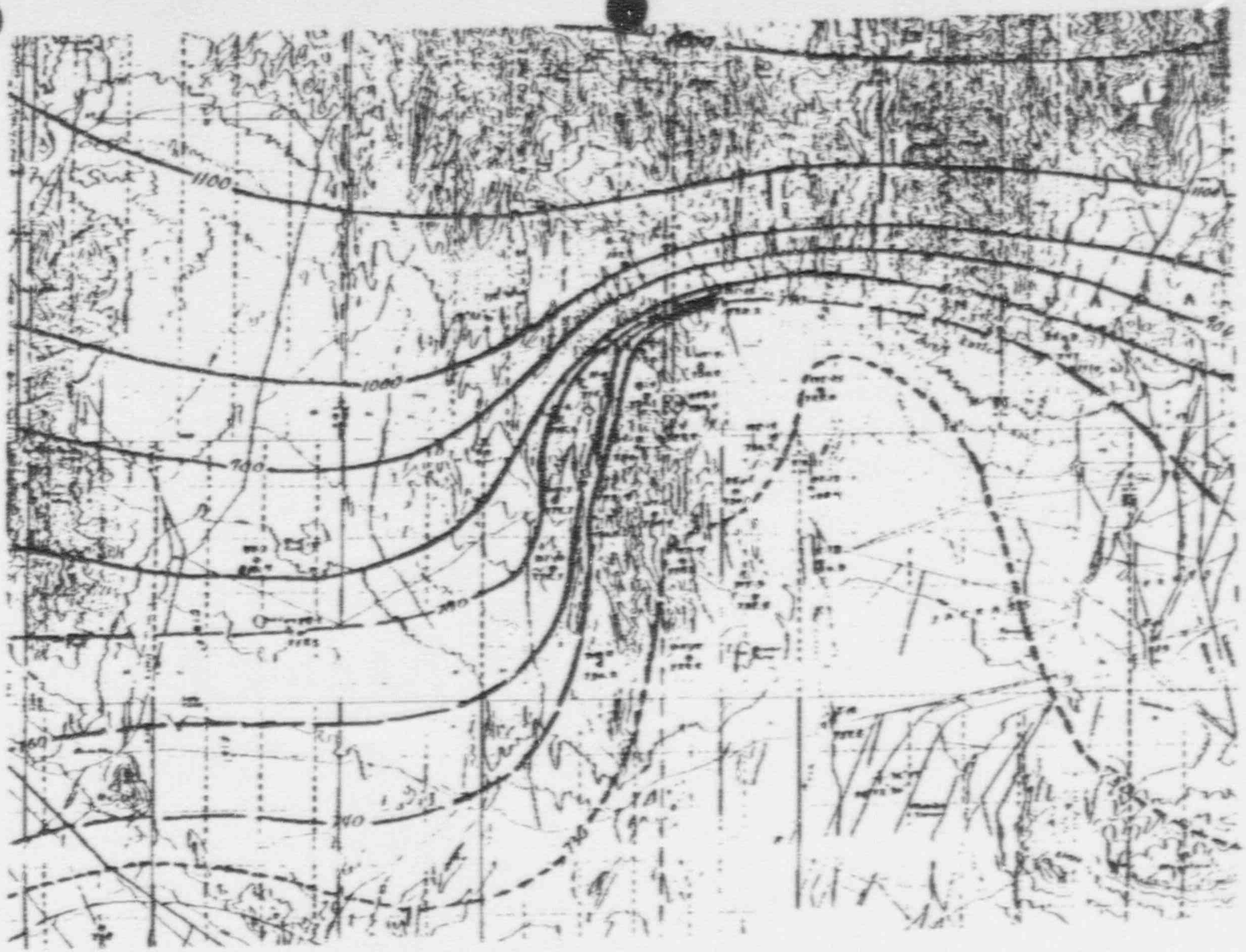
RIDGE
YUCCA CREST



Potentiometric surface map for Yucca Mountain and vicinity

EXAMPLE: CAUSE OF LARGE HYDRAULIC GRADIENT UNDER YUCCA MOUNTAIN

APPROACH TAKEN:

(1) FORGET ALL PREVIOUS IDEAS FOR NOW

(2) REVIEW ALL TYPES OF EXISTING DATA

(3) SEE WHAT ACTUALLY CORRELATES WITH LHG

(4) DECIDE WHAT ELSE NEEDS EXPLAINING

(5) REVIEW REGIONAL CONTEXT

(6) LET THE DATA DRIVE THE INTERPRETATION

(7) FORMULATE HYPOTHESIS USING OCCAM'S RAZOR

(8) COMPARE AGAINST PREVIOUS HYPOTHESES

(9) DEVELOP TESTING STRATEGY APPLICABLE TO ALL THE HYPOTHESES

WHAT DOES/DOESN'T CORRELATE WITH THE LHG?

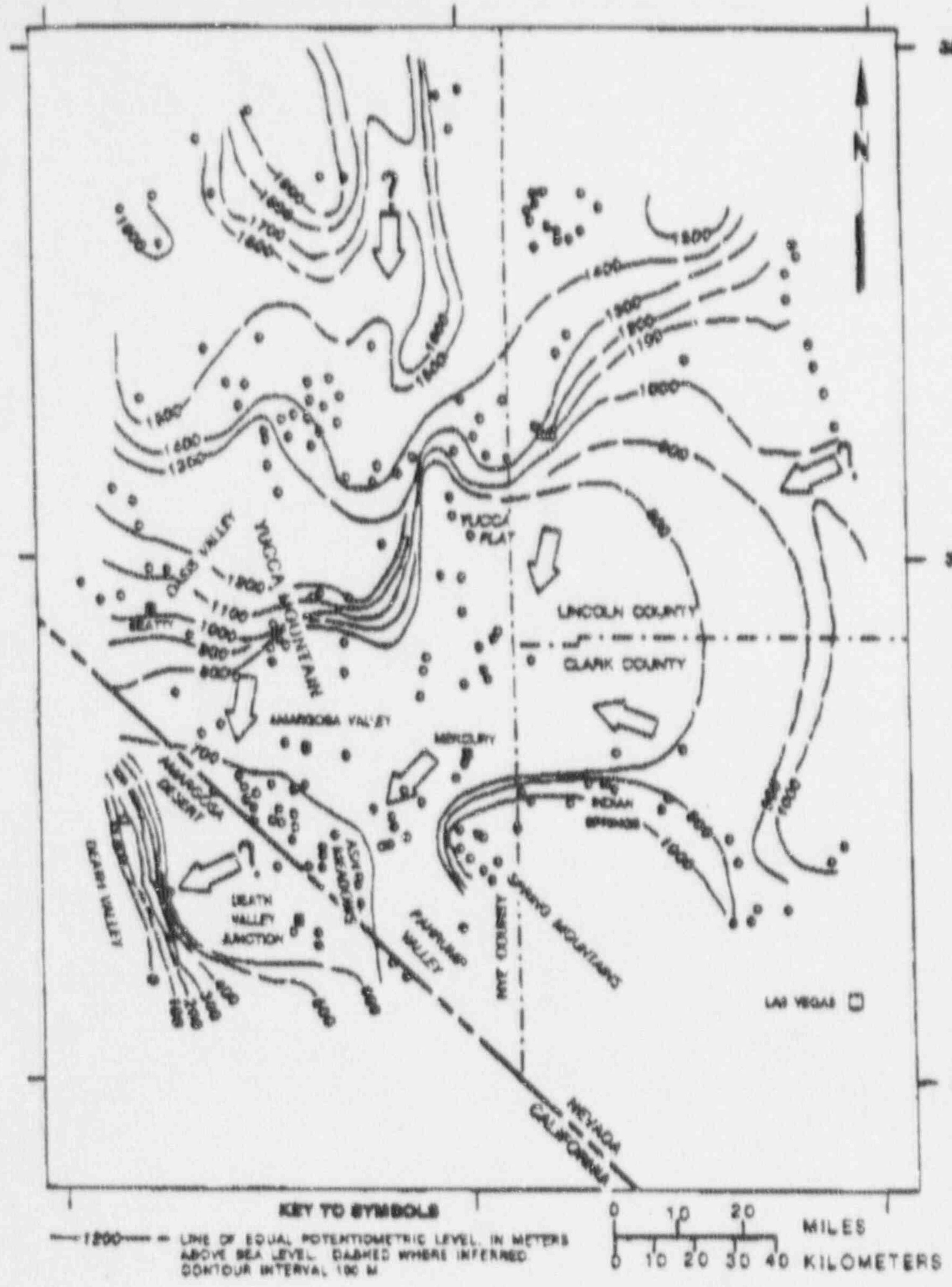
#1 LHG DOES NOT CORRELATE WITH ANY KNOWN FEATURE IN THE UPPER 1 KM OF YUCCA MOUNTAIN

#2 FEATURES THAT DO CORRELATE WITH THE LHG:

(1) AEROMAGNETIC ANOMALY
(2) HEAT FLOW ANOMALY
(3) GRAVITY ANOMALY
(4) DEEP STRATIGRAPHIC CHANGES

#3 ADDITION FEATURES TO EXPLAIN IN SZ MODEL:

(5) LINEAR THERMAL ANOMALIES SOUTH OF LHG
(6) HYDROCHEMICAL VARIATIONS
(7) CALICO HILLS AQUITARD AT WT
(8) CONTINUITY WITH REGIONAL LHG <—



Potentiometric surface contour map of Ash Meadows regional groundwater basin.

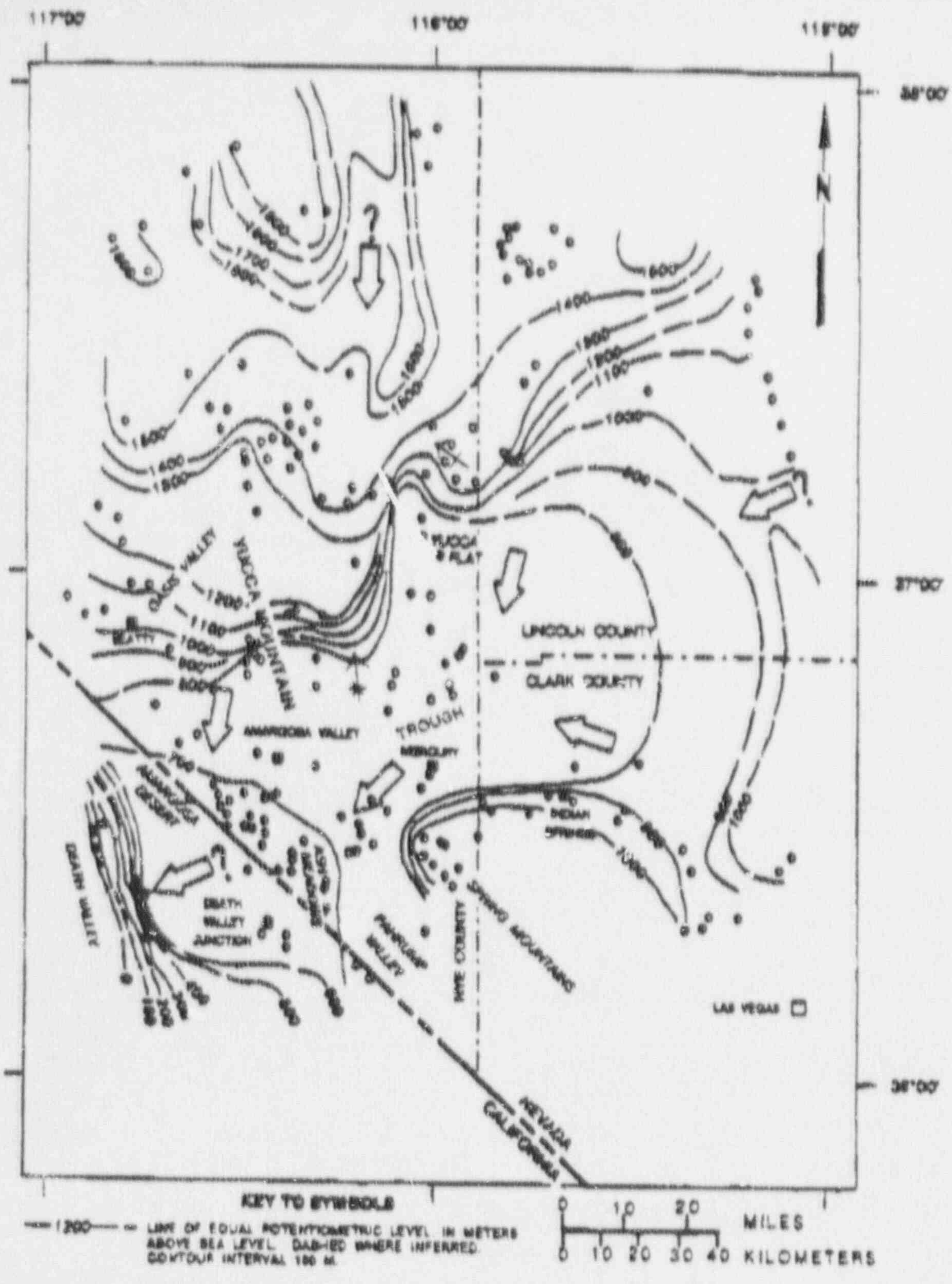


Figure 1. Potentiometric surface contour map of the Ash Meadows regional groundwater basin with superposed distribution of the clastic aquitard.

- Eleana Argillite, surface exposures
- Eleana Argillite, present at depth, usually <1 km based on surface relations
- Lower Clastic Aquitard, surface
- Lower Clastic Aquitard, at depth

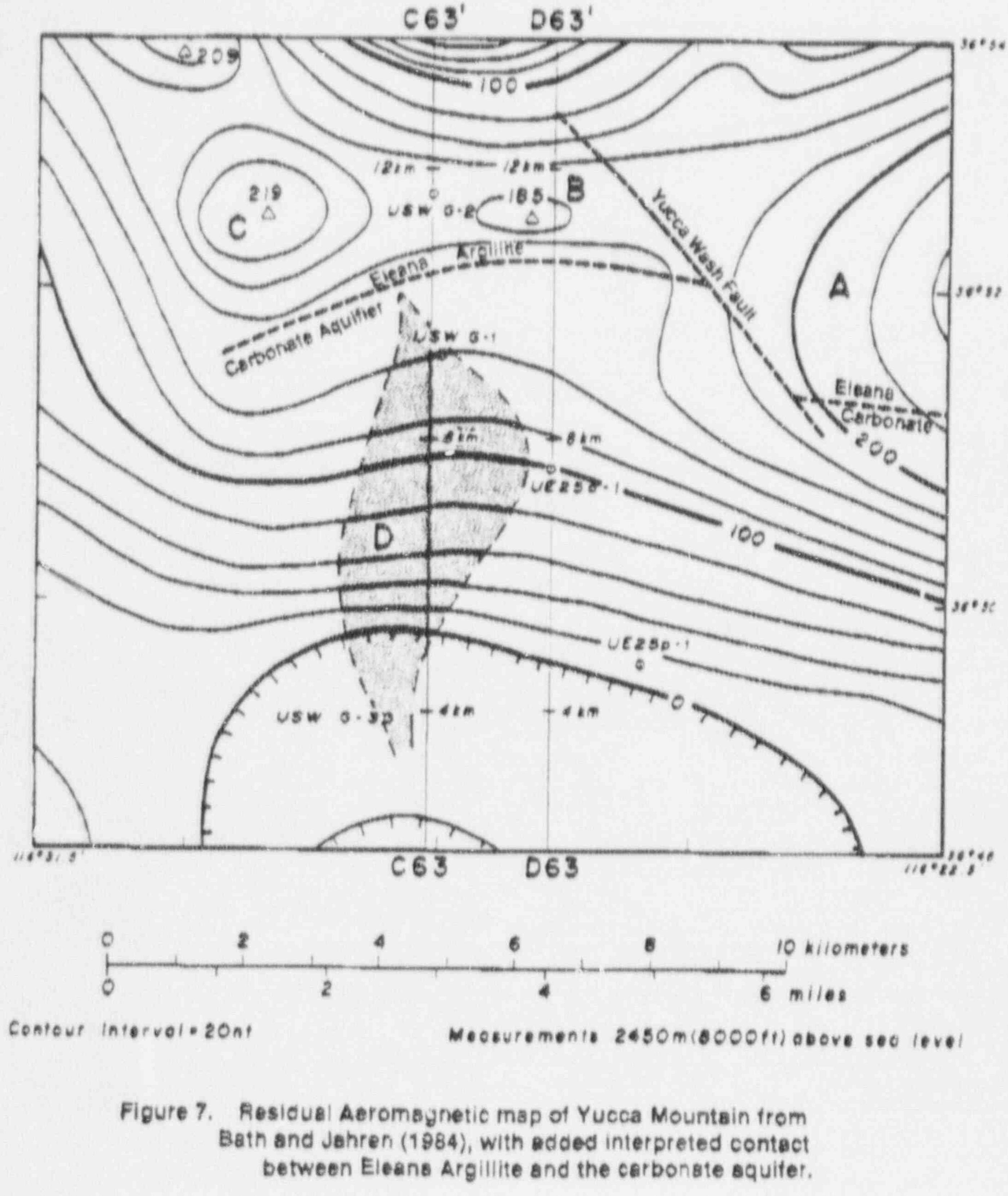


Figure 7. Residual Aeromagnetic map of Yucca Mountain from Bath and Jahren (1984), with added interpreted contact between Eleana Argillite and the carbonate aquifer.

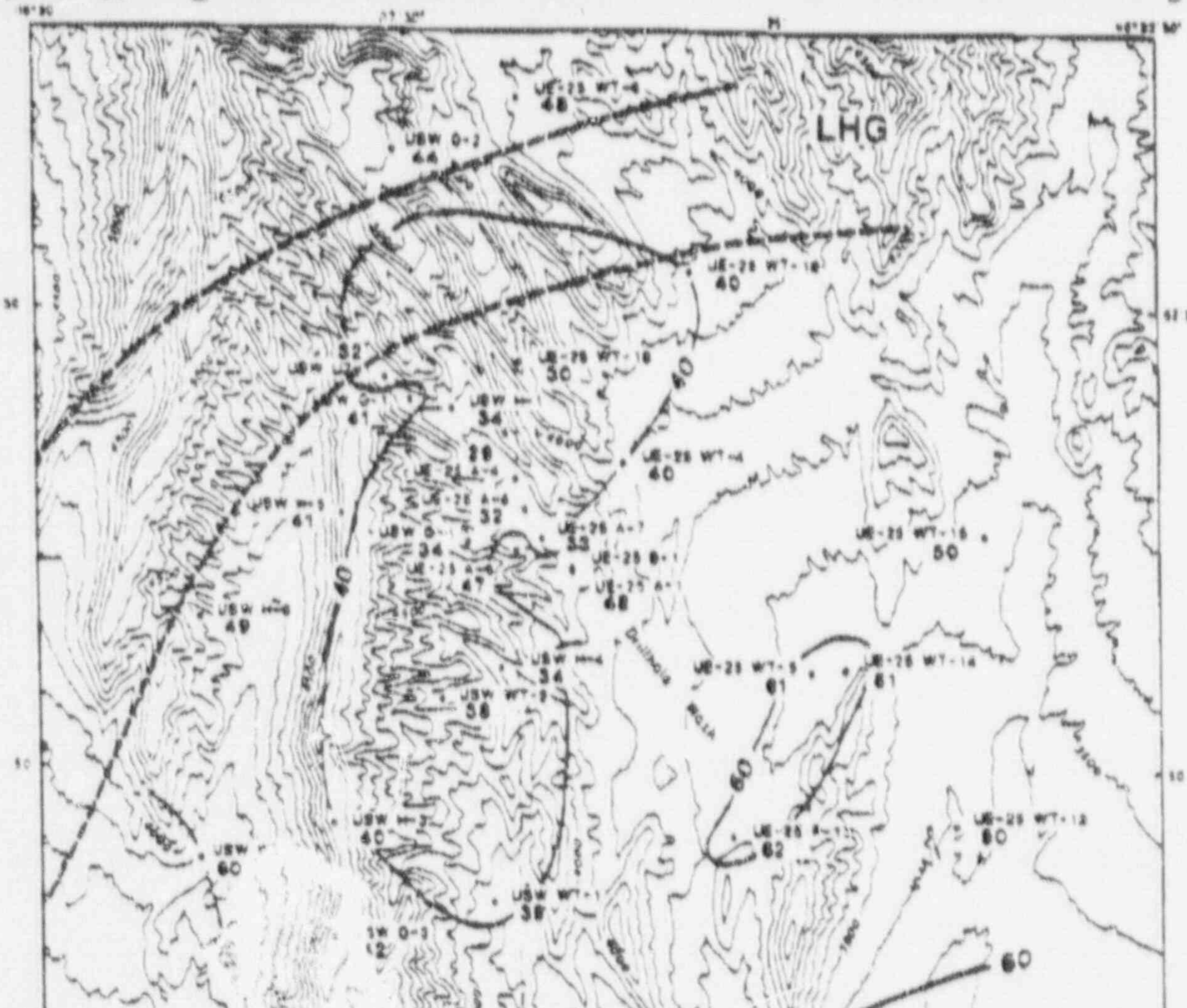


Figure 8. Heat Flow in the Unsaturated Zone under Yucca Mountain.

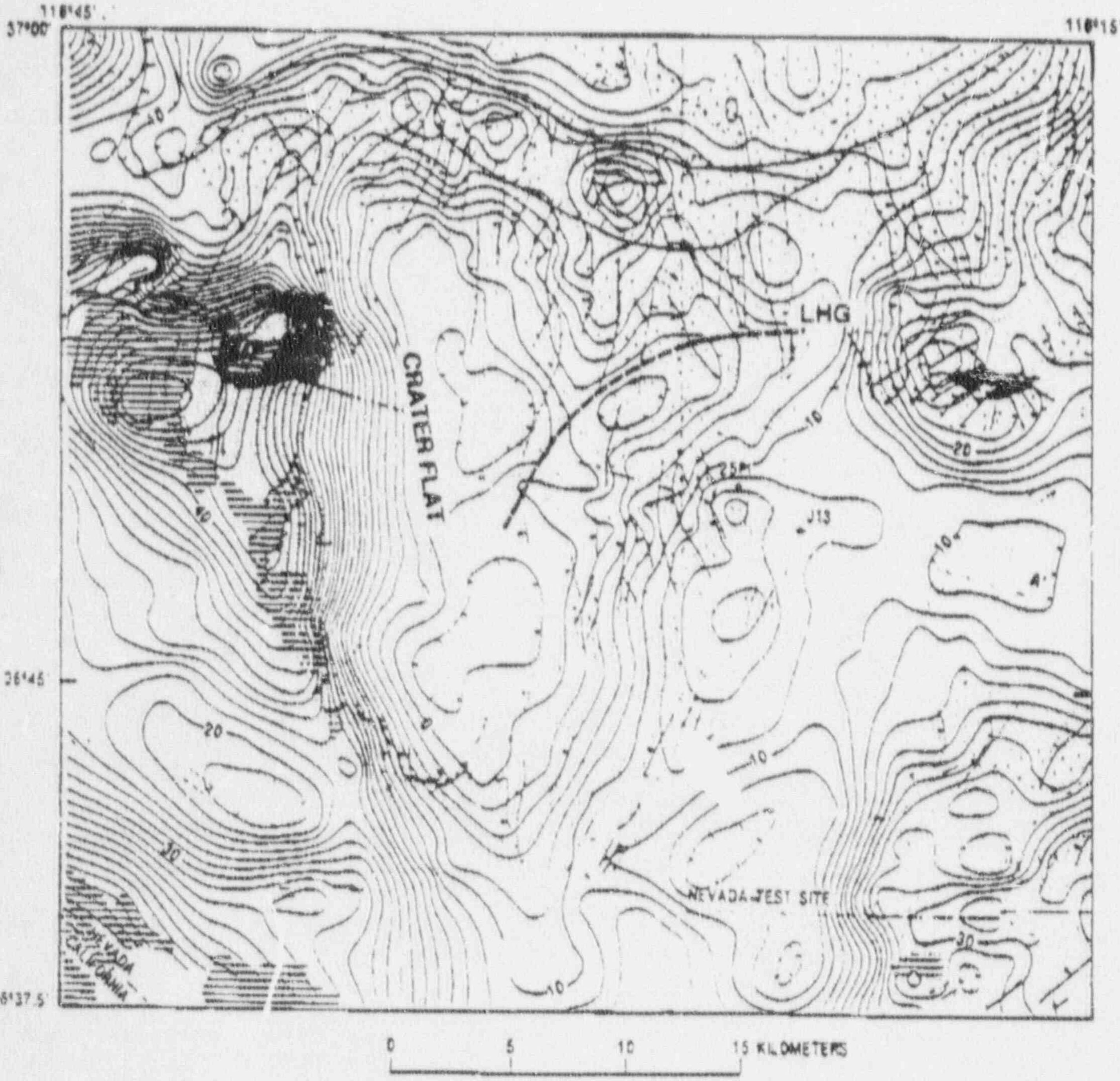


Figure 9. Residual Gravity Map of Yucca Mountain and vicinity.

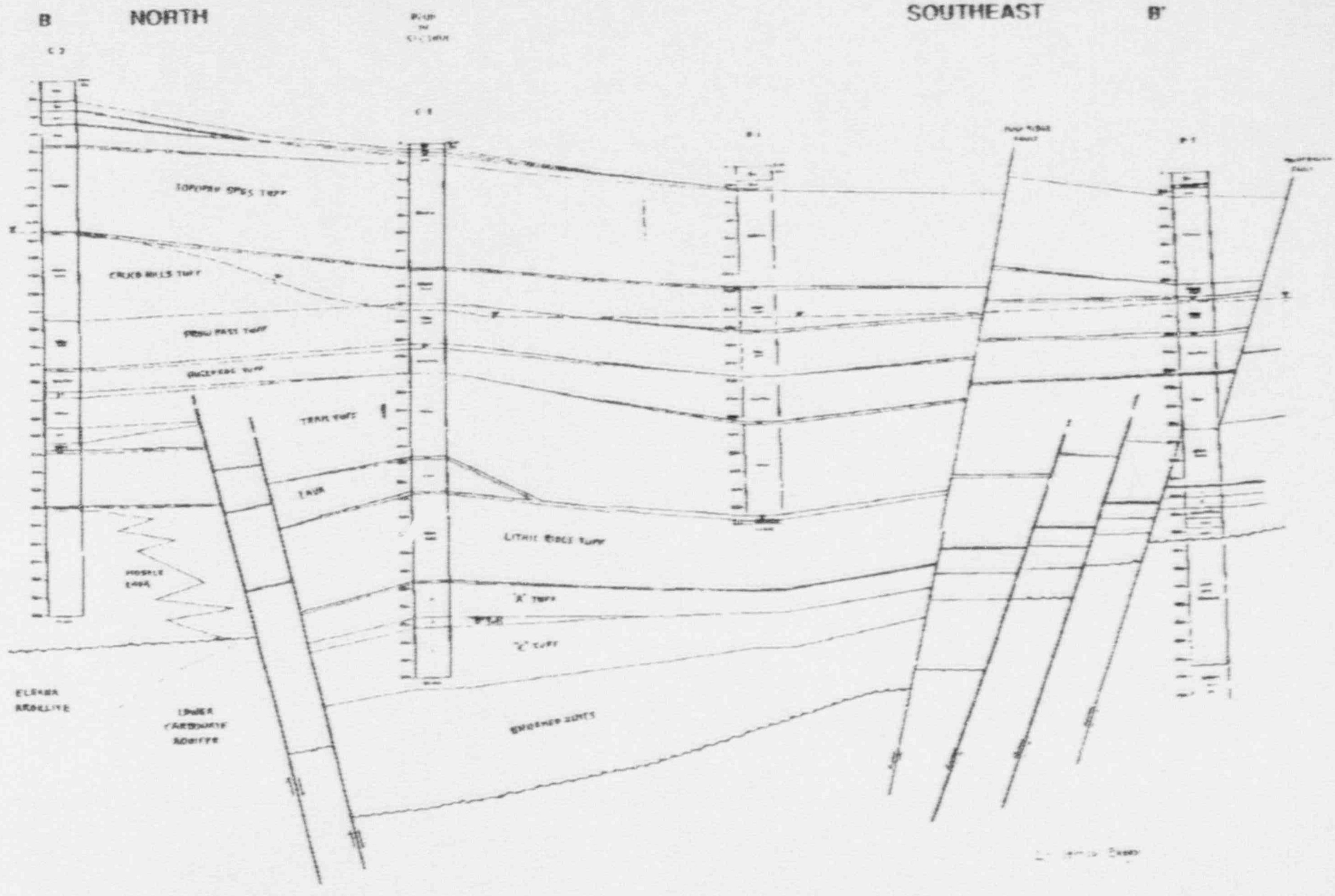


Figure 11. North-Southeast cross-section through Yucca Mountain.

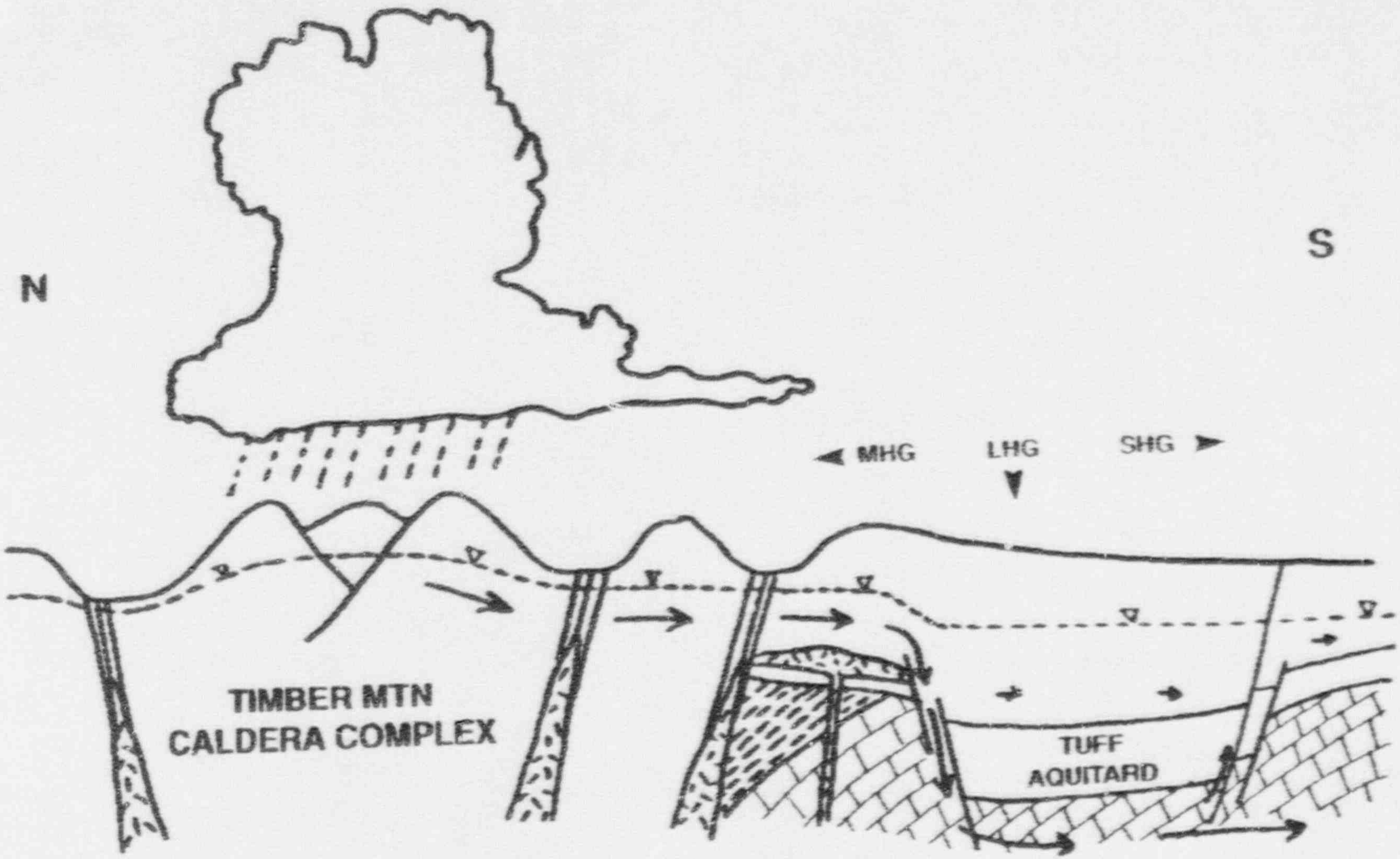


Figure 22. Cartoon representation of the hydrogeologic model.

Table 1. Proposed models for the large hydraulic gradient (LHG) under Yucca Mountain, with expected features in proposed test well.

TECTONIC-CONTROL MODELS:	EXPECTED FEATURES IN A TEST WELL IN CENTER OF LHG:
(1) Seismic-pumping: LASIIP* at LHG due to southward increase in shear stress. High WT north of LHG caused by seismic pumping and thermal convection. Calcite veins in surface rocks are spring deposits formed when the WT rose to the surface in past seismic events (Szymanski, 1989).	(1) WT unstable; level varies through time. Strong upward hydraulic gradient and large increase in temperature with depth. Abundant Quaternary calcite veins, resembling those on surface, filling fractures in the saturated tuffs and Paleozoic rocks.
(2) Seismic-refreshing: LHG marks a LASIIP due to "refreshing" of fracture zones by Quaternary seismic activity (Fox, et al., 1991).	(2) Similar to above on fracture fillings. WT intermediate between levels above and below decline. Small decline in head with depth is probable.
(3) Stress-control: LASIIP at LHG caused by change in direction of regional stress field across boundary between a N-trending normal fault zone and a NW-trending strike-slip fault zone (Czarnecki, 1989).	(3) None. Hypothesis conflicts with existing information (see text).
DAM MODELS:	
(4) Alteration-front: Alteration front causes a LASIIP and abrupt downward extension of permeability of tuffs at LHG (oral comm., Czarnecki, 1991).	(4) WT at intermediate level, with possible small decline with depth. All but uppermost Crater Flat Tuff aquifer highly impermeable due to Miocene alteration.
(5) Tertiary-dam: The LHG marks a LASIIP that coincides with a concealed dike or nontransmissive fault that forms the dam across the tuff aquifer (Czarnecki, 1988; Haws and Brikowski, 1989).	(5) WT at level of top or bottom of decline, but not intermediate. If borehole goes through the dam, ~300 m change in head across it.
(6) Recharge-Mound: LASIIP invoked without explanation; high WT north of LHG is relict recharge mound from the last pluvial (Czarnecki, ?).	(6) Not an adequate explanation by itself, as no hydrogeologic features invoked. Works as an adjunct to models (4) or (5), but untestable.
DRAIN MODEL:	
(7) Fault-drain: LHG underlain by buried fault that acts as a drain, providing a pathway along which the deep carbonate aquifer captures flow from the tuff aquifer to the north. LASIIP results from addition of deep aquifer to system, instead of a change in the tuffs (proposed here).	(7) WT level initially intermediate; drops steadily to >75 m lower by the base of the Crater Flat Tuffs, and >100 m lower in the Paleozoics. Highly conductive fault zone with rapid flow near base of the tuff aquifer. Very small temperature gradient above the conductive fault. If Eleana Argillite encountered, it is underlain by carbonate aquifer bearing water that is chemically out of equilibrium with its host rocks.

* LASIIP = large abrupt southward increase in permeability

WT = water table