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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: DOE-NRC Site Visit - Faults/Fractures near Yucca Mountain and Stratigraphy/Structure/Rock Properties along the ESF North Ramp (20-5702-425, 441, and 723 for Stirewalt; 20-5702-441 for Ferrill; 20-5702-641 and 642 for Ofoegbu)

DATE/PLACE: May 2-5, 1994 - Yucca Mountain and Vicinity

AUTHORS: Gerry L. Stirewalt and David A. Ferrill with Goodluck I. Ofoegbu

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PERSONS PRESENT:	<u>NRC</u>	<u>ACNW/Consultants</u>	<u>CNWRA</u>
	A-B. Ibrahim	K. Folland (C)	D. Ferrill
	T. Johnson	W. Hinze	G. Ofoegbu
	P. Justus		G. Stirewalt
	K. McConnell		S. Young
	J. Trapp		

Numerous staff from DOE and its subcontractors (including the Management and Operating Contractor [M&O], the U.S. Geological Survey [USGS], and the U.S. Bureau of Reclamation [USBR]) were present at this DOE-NRC site visit. In addition, participants were also present to represent the State of Nevada and concerned Counties of Nevada (i.e., Clark and Nye). An attendance list taken for the sessions on May 3 is included as Attachment 1 to this report.

BACKGROUND AND PURPOSE OF TRIP:

This DOE-NRC site visit was one of those regularly planned meetings during which DOE staff update the NRC on results of current investigative activities at the Yucca Mountain site. The purpose of this particular site visit was for NRC staff to gain from DOE up-to-date information related to characterization of faults and fractures in the vicinity of Yucca Mountain and to stratigraphy, structure, and rock properties observed along the north ramp of the exploratory studies facility (ESF). The agenda for this site visit is included as Attachment 2. All presentations were made at the Field Operations Center (FOC) unless otherwise indicated in the agenda and in this report to be a field tour stop.

SUMMARY OF PERTINENT POINTS:

Monday, May 2, 1994

1. R. Spengler (USGS) - Characterization of faults and fractures: Update on the study of structural features in the site area (Study Plan 8.3.1.4.2.2)

Mapping of the part of the repository block containing the Ghost Dance fault at a scale of 1 inch = 20 feet (i.e., 1:240) has revealed previously unrecognized structures, including the newly-discovered, northwest-trending Sundance fault. Attachment 3 illustrates the specific location of the detailed study area along the Ghost Dance. The Sundance fault has been described by Spengler and others (1994) in USGS Open-File Report 94-49, a copy of which is included with this report as Attachment 4 for any interested readers. M. Tynan (DOE) provided a hand-out summarizing significance and characteristics of the Ghost Dance and Sundance fault systems as additional information for meeting participants. This hand-out was not discussed, but is included with this report as Attachment 5. All fractures greater than 6 feet in length have been mapped, as have locations of breccia zones. Lithostratigraphy of the Tiva Canyon has been carefully established and has proven very useful in mapping offsets along faults. Attachment 6 includes a description of Tiva Canyon textures related to stratigraphic position and a map and cross section which show details of lithostratigraphy in the Tiva Canyon. During the field tour to the Ghost Dance pavement on Tuesday, May 3, it was noted by one author (GLS) that the proposed lithostratigraphic associations appeared to be quite workable for distinguishing different units of the Tiva Canyon in the field.

L. Hayes (USGS) addressed the debate which is currently going on at the USGS regarding interpretation of the Ghost Dance and Sundance faults, and indicated there was a plan to get investigators with different opinions (i.e., R. Spengler and his group versus C. Fridrich) into the field soon for open discussions. He provided a summary hand-out (Attachment 7) on status of USGS surface mapping of structural features. Questions raised include the following: How broad is the "shear zone" associated with the Ghost Dance fault? How extensive (width, length, depth) is the Sundance? What is the hydrologic significance of the Ghost Dance and Sundance faults? He quoted the recent work of Oliver and others (1994) which suggests that the Ghost Dance extends to a depth of 1 km with a width of at least 180 m.

R. Spengler raised the issue of whether the detailed mapping may reveal information which suggests a need for an alternative regional tectonic model or models. C. Johnson (Nevada) asked if the remainder of the repository block would be investigated in a detail equivalent to that being done by R. Spengler for the Ghost Dance, and questioned what priorities had been established for distribution of funds for characterization of structures. He also asked for a definition of a "minor" fault, a term which was used by L. Hayes. In response, L. Hayes stressed that a "minor" fault, however it was defined by geologists relative to amount of displacement, should not necessarily be equated with a "minor hydrologic pathway," an issue about which the USGS planned to talk with DOE.

Description of field tours and additional discussions which ensued in relation to the Ghost Dance and Sundance fault systems can be found in this trip report under Items 6 and 9 for Tuesday, May 3 and Items 3 and 4 for Wednesday, May 4.

2. D. Buesch (USGS) - Stratigraphy, structure, and stratigraphic nomenclature

The stratigraphic nomenclature established by Scott and Bonk (1984) is being re-evaluated. The divisions being developed for the new nomenclature are Age, Group, Formation, Member, Zone, Sub-zone, and Interval (Attachment 8). The Paintbrush Tuff, formerly classed as a formation with members (e.g., the Tiva Canyon Member of the Paintbrush Canyon Formation), is now classed as a group with formations (i.e., the Tiva Canyon Formation of the Paintbrush Canyon Group) in the new nomenclature. Both the Tiva Canyon and the Topopah Spring tuffs, two extensive ignimbrites, will be classed as formations in the new nomenclature which will be issued as an open-file USGS

report and reviewed by the USGS Geologic Names Committee prior to publication. Once approved and accepted, it will become the official nomenclature for naming of rock units in the Yucca Mountain Project. D. Buesch pointed out that the new nomenclature does not make void the stratigraphic relationships previously described by Scott and Bonk (1984). R. Spengler commented that some contacts have been relocated from where they had been placed by Scott and Bonk (1984), but that any changes were only minor refinements of what had been a very careful original mapping effort.

D. Buesch remarked that work was being done to tie hydrologic and thermo-mechanical units directly to the stratigraphy as closely as possible (See Attachment 8), and that efforts were being made to understand the significance of the difference in number of faults between the northern and southern parts of Yucca Mountain. Also, the USGS is still trying to resolve what is going on at and west of the Drill Hole Wash structure, which D. Buesch believes has some component of strike-slip displacement. D. Buesch reported further that the Bow Ridge fault was penetrated at a depth of about 250 feet in borehole NRG-2B, and at about 150 feet in borehole NRG-2. Attachment 9, illustrating the completed and proposed FY93-94 geophysics testing program and the proposed schedule for geophysical logging in NRG series boreholes, shows the locations of the NRG series boreholes which were located specifically for subsurface investigations along the North Ramp.

C. Johnson (Nevada) expressed some frustration because the nomenclature was being changed and faults were being found to be wider while there appeared to be no plans by DOE for preparation of a new "project-accepted" geologic map. He asked whether the USGS would re-map Yucca Mountain. L. Hayes (USGS) said all USGS mapping efforts would be issued as geologic maps. (The authors infer his statement means the maps would be published as open-file reports.) M. Tynan (DOE) stated that all recent mapping would be compiled and presented, and some additional mapping of Yucca Mountain would be done. He did not provide any specific details to clarify his statement, however. L. Hayes considered surface-based mapping a priority, but also remarked that he understood DOE may have other priorities.

3. D. Kessel/C. Brectel (Sandia) - Rock properties, North Ramp stratigraphy and structure, and Trench NRT-1

The hand-outs from D. Kessel (Attachments 10, 11, 12, 13) summarize information related to the geoenvironmental characterization of non-lithified tuffs at the North Ramp, including the in-situ tests run in Trench NRT-1. (The location of Trench NRT-1 is shown in the figure of Attachment 12.) He remarked that the bearing capacities for pre-Rainier Mesa tuffs (50 ksf) and Rainier Mesa tuffs (100 ksf) were considered high enough to support the tunnel boring machine (TBM) and its gripper pads, although he did not discount the concept that some running ground may be encountered in limited intervals that were saturated. J. Trapp (NRC) commented that cohesionless "running ground" could be encountered in fault zones as well - a condition for which they had not been able to test. Additional planned tests include saturated bearing capacity tests to evaluate soil suction and laboratory strength tests on undisturbed samples.

After C. Brectel stated that the geologic and structural logs for NRG boreholes were "available" in digital format for distribution to all project participants and were in the DOE database (i.e., ideally listed in the data catalogue and can be formally requested from DOE), C. Johnson (Nevada) remarked that these data were not in the data catalogue and asked whether the program was an open or closed one. M. Tynan (DOE) said DOE was working on getting these and all data into the data

catalogue, and T. Bjerstedt (DOE) remarked that DOE was trying to create a database architecture which would be useful in the long term. L. Hayes (USGS) said the steps for getting USGS data directly to the State of Nevada or the NRC were, at the very best, complex. M. Tynan reminded participants that this meeting was meant to show the current status of the work, so some of the data being presented were preliminary and should not be included in the database as yet.

Description of field tours and additional discussions which ensued in relation to Trench NRT-1 can be found in this trip report under Item 1 for Wednesday, May 4.

4. S. Beason/M. Fahy (USBR) - Mapping of the ESF: Status, results, plans

Mapping for the drainage channel was completed in July 1993; for the portal cut, in April 1993; and for the starter tunnel and alcove, in January 1994. Attachment 14 is a preliminary draft of the full-periphery geologic map of the starter tunnel. The report on mapping results in the starter tunnel and alcove is currently scheduled to be completed in May 1994.

Two previously unmapped faults were found in the portal cut. Large-aperture (i.e., up to 40 cm diameter) lithophysae were observed in the starter tunnel, as were smectite and altered ash fillings in fractures. The more highly fractured rock in the starter tunnel appears to have the greatest volume of lithophysae. The discontinuous nature of fractures was noted, with only a few continuous across the diameter of the tunnel.

Using photogrammetric fracture mapping methods, 2300 total fractures were measured - very few of which were thought to be blast-induced. One author (GLS) observed that orientation maxima for these fractures shown on stereonet plots were distinctly different from orientations measured on Quaternary faults in the Yucca Mountain area. S. Beason indicated there are plans to compare results from the photogrammetric method used in the starter tunnel (excavated by drill and blast techniques) with photogrammetric fracture mapping results from continuation of tunnel excavation using the tunnel boring machine (TBM). A rate of mapping of 100-feet per day is planned when the TBM starts, according to S. Beason.

FRACMAN software will apparently be used for analyzing the field data acquired on fractures. S. Beason commented that they hoped to be able to tie fracture distributions into hydrologic modeling.

5. S. Beason (USBR) - Field tour: ESF starter tunnel and test alcove

The TBM was being assembled and track was being laid for moving it into the starter tunnel at the north portal entryway. The TBM is 25 feet in diameter with 52 "cutting" heads which will crack the rock being excavated into blocks a foot or less in size. Excavated material will be extracted from the cut face by a conveyor belt passing through the TBM. Total length of the entire assembly is about 450 feet, with about 150 feet of this length allocated for accommodation of scientific workers. The machine weighs about 740 tons and is powered by engines rated at 3000 hp.

"Vapor phase partings" in the lower part of the lithophysal unit pointed out by S. Beason apparently parallel "flow foliations" in the tuff. These partings were observed in the alcove where the tuff was not yet covered with shotcrete.

6. G. Elbring (Affiliation uncertain) - North Ramp reflection/refraction studies

Three relatively short seismic lines have been run to date in the vicinity of boreholes NRG-2A, NRG-2 and NRG-2B. (See Attachment 9 for locations of these boreholes.) Lines 1 and 2 are parallel, and Line 3 is nearly perpendicular to Lines 1 and 2. Data from the lines are currently being processed, and refraction patterns appear to be complex. In Line 1, about 150 feet penetration was accomplished with a sledge hammer signal source.

7. R. Spengler (USGS)/M. Fahy (USBR) - Fracture network and fault studies at Fran Ridge and Ghost Dance and Sundance faults

A total of 10 pavements and about 100 outcrops are being used in the study of surface fracture networks. On pavements, all fractures 1 foot in length or greater are being measured. A 500-foot wide pavement exposure of the Ghost Dance fault has been created by clearing the surface of vegetation, soil and rubble.

Tuesday, May 3, 1994

1. J. Whitney (USGS) - The Windy Wash fault

Studies along the Windy Wash fault conducted in the mid-1980s provided evidence for at least 7 Quaternary faulting episodes occurring over a time period of approximately 0.5 my. Six 1100-foot long seismic refraction profiles were run to determine whether there had been any left-lateral offset of a 2.7 my old basalt along the Windy Wash fault system with inconclusive results. Offset could be all dip-slip; a maximum of 93 m apparent vertical displacement and a slip rate of 0.025-0.03 mm/yr over the last 3.7 my were interpreted from the data. J. Whitney reported an approximate orientation for the fault at the surface of N15W, 55W with dip of the fault actually varying between 60-70W. J. Whitney remarked that no rollover had been detected adjacent to the Windy Wash, so a detachment model was not supported for this fault.

The possible Quaternary slip rate along the Windy Wash, based on a 90,000 year old soil horizon which was formed in a fault wedge and had been offset, may be 0.008 mm/yr. When other age dates are considered, the slip rate may be increased to 0.016-0.017 mm/yr. Therefore, the average long-term slip rate may be 0.03 mm/yr between 3.7 my and the present while the suggested Quaternary rate is 0.01-0.02 mm/yr from Mid-Quaternary to present. J. Whitney interprets these data as indicating no real difference between Quaternary and longer-term slip rates, concluding that the rate of slip along the Windy Wash fault has been constant for the last 11 my. That is, he believes the data indicate no increase in slip rates during either the late Tertiary or the last half-million years. He commented further that 60% of the deformation occurred between 12.7-11.5 my and only 40% since deposition of the Rainier Mesa.

J. Whitney's interpretation of no increase in rates (at least) hinges on age estimates which may change as additional data come to light but represent the best interpretation which can currently be drawn using the existing ages. Suggested Quaternary slip rates presented by J. Whitney for the Windy Wash and other faults at Yucca Mountain are as follows:

Paintbrush Canyon fault	0.01 — 0.02 mm/yr
Bow Ridge fault	0.001 — 0.003 mm/yr
Solitario Canyon fault	0.01 mm/y
Stagecoach Road fault	0.005 — 0.02 mm/yr
Windy Wash fault	0.008 — 0.02 mm/yr
Bare Mountain fault	less than 0.01 mm/yr

2. C. Rautman (Sandia) - Status of the systematic drilling program (Study Plan 8.3.1.4.3.1)

The main purpose of the systematic drilling program (SDP) is to gain information on the repository block relating to engineering data, stratigraphy, lithology, rock characteristics, and in situ testing. Attachment 15 summarizes the objective, relevance and progress related to the SDP, and specifies the other SCP studies which depend upon samples and information derived from this drilling program.

Borehole SD-12, located in the figure of Attachment 9, was the first hole started in the "SD" series to investigate the repository block. Information about SD-12 is included in Attachments 15 and 16. Attachment 15 specifies location, size, and objectives for the borehole, and Attachment 16 illustrates a preliminary log of lithostratigraphy for the Tiva Canyon and Topopah Spring as revealed by borehole SD-12. SD-12 is located about 500 feet west of the Ghost Dance fault and about 100 feet west of the ESF main test drift level. It is to be continuously cored and logged to a depth of 2300 feet - a depth which should extend to about 300 feet below the water table to permit acquisition of data in the upper part of the saturated zone. SD-9 is scheduled to be the next hole drilled in this series.

3. J. Pye (M&O/TRW) - Use of site data in ESF design

The information presented by J. Pye is summarized in his hand-out, which is Attachment 17 to this report. Site data are being used by the Yucca Mountain Project in the following design and geotechnical areas: development of geological models, using mainly LYNX GMS, which integrate geological and engineering data; empirical estimates of rock mass properties (e.g., rock mass quality and rating); laboratory testing of rock core; empirical design methods; and modeling and analysis.

C. Johnson (Nevada) and R. Spengler (USGS) asked how the conditions related to poor rock quality would be handled with due consideration for allowing site characterization to properly proceed. J. Pye remarked that he expected no stress-related failure in the ESF, and that he did not anticipate a need to use chemical grouts to stabilize ground adjacent to faults or anywhere else in the ESF. However, the authors inferred that he was alluding to a plan for immediately stabilizing and supporting the Bow Ridge fault as soon as it was excavated by the TBM - possibly before anyone was allowed to approach the face from the mapping platform of the TBM.

4. C. Menges/J. Whitney (USGS) - Fault trenching activities

A new trench (A1) has been placed to investigate the Paintbrush Canyon fault at the base of Alice Ridge, and logging of this trench has just begun. There appear to be at least 2, and possibly 3 or 4, Quaternary slip events represented by offset stratigraphy in the trench, or possibly 3 or 4 events. However, the exact number of slip events is uncertain at the present time because of poor age control on the offset units. Basaltic volcanic ash has been found in a fissure along the Paintbrush Canyon

fault in this new trench. At Busted Butte where the fault is exposed in a natural gully wall, 6 to 8 slip events are interpreted on the main fault trace. Description of field tours and additional discussions which ensued in relation to the Paintbrush Canyon fault can be found in this trip report under Item 5 for Wednesday, May 4.

At Trench SCR-T3 along the Stagecoach Road fault, 2 to 4 slip events are suggested along the main fault trace. The same number of events are also indicated in Trench SCR-T1, with the youngest event having occurred around 15,000-20,000 years ago. Basaltic ash is contained in fissures associated with this fault as well, and most workers surmise it was likely produced by a volcanic eruption at Lathrop Wells cone. However, there are still no geochemical data to make it possible to correlate the ash with eruptive events from the Lathrop Wells vent. J. Whitney (USGS) believes there is a strong indication of at least a chronological connection between faulting and volcanism between 60,000-90,000 years ago.

New trenches have been added for investigation of the Solitario Canyon fault so that both fault splays and the main trace of the fault will be studied. Ash-filled fissures occur in the hanging wall of this fault, and the ash is interpreted as volcanic airfall material only at this trench. Volcanic ash associated with all other faults appears to have been reworked to some degree. The current thought is that Holocene slip may not have occurred on the Solitario Canyon fault as had been suggested earlier, with the youngest event on this fault possibly being Late Pleistocene in age. (Therefore, only the Windy Wash fault is currently interpreted as exhibiting Holocene slip.) Description of field tours and additional discussions which ensued in relation to the Solitario Canyon fault can be found in this trip report under Item 3 for Thursday, May 5.

A trench (BMT-1) at the Tarantula Canyon locale along the Bare Mountain fault has now been excavated, and results from the work done there to date are discussed in this report under the field tour to that location (Item 2 for Thursday, May 5). J. Whitney commented that the scarp at this locale is generally thought to be 50,000 to 100,000 years old. Description of field tours and additional discussions which ensued in relation to the Bare Mountain fault can be found in this trip report under Items 1 and 2 for Thursday, May 5.

C. Menges rapidly presented additional information on faulting. He reported that the Paintbrush Canyon fault is thought to exhibit between 20-85 cm of displacement per slip event and 4 to 5 events in Trench MWV-T4, and between 20-115 cm per event and 6 to 8 slip events at Busted Butte. Net slip along the Paintbrush Canyon fault is thought to be greater than 480-590 cm at Busted Butte. For the Bow Ridge fault, 5-20 cm of displacement per event is suggested with a net slip of 50-130 cm.

The following data illustrate the current thinking on recurrence interval (RI, in thousands of years, ky) and slip rate for the Paintbrush Canyon, Bow Ridge, and Stagecoach Road faults:

Paintbrush Canyon fault

- At Trench MWV-T4 - RI = 30-80ky; slip rate \leq 0.01 mm/yr
- At Busted Butte - RI = 40-100ky; slip rate = 0.01-0.02 mm/yr

Bow Ridge fault

- At Trench 14D - RI = 40-80ky; slip rate = 0.001-0.003 mm/yr

Stagecoach Road fault

- At Trench T1 - RI = 10-50ky; slip rate = 0.02-0.04 mm/yr
- At Trench T2 - RI = 10-50ky; slip rate = 0.02-0.05 mm/yr

5. J. Whitney (USGS) - Status of Midway Valley studies

The final report is being prepared for the Midway Valley fault studies.

6. C. Fridrich (USGS) - Structural model for the Yucca Mountain region

Crater Flat basin is interpreted by C. Fridrich as a half-graben, with Crater Flat as a distinct structural domain. The main pulse of extension in the basin occurred between 12.5-11.6 my ago. Therefore, he interprets faults in this area that are currently active to have been initiated about 12.5 m.y. ago. He also considers the Bare Mountain fault to be an early structure in his model. Other key elements of his model for the Yucca Mountain region include oblique (right-lateral/normal) slip on the southern Bare Mountain fault and right-lateral strike-slip on a fault separating Yucca Mountain from the Timber Mountain caldera region. He agrees with Scott (1990) that paleomagnetic data indicate 0-10 degrees of clockwise rotation in the northern part of Yucca Mountain and about 30 degrees clockwise rotation of the southern part of Yucca Mountain. The main part of the Bare Mountain fault he interprets as a releasing bend on a right-lateral strike-slip fault.

C. Fridrich interprets the Sundance fault as a minor, right-lateral strike-slip fault rather than a major structural feature as proposed by R. Spengler (USGS). Also, he does not consider the Ghost Dance fault to be offset by the Sundance feature, and believes the Ghost Dance may be a narrower zone (possibly less than 100 feet) than suggested by R. Spengler. For the steep hydraulic gradient on the northern end of Yucca Mountain, he considers a fault-related control to be a possibility. In his model for the steep hydraulic gradient, the controlling fault may be the northern boundary of a graben structure.

7. E. Majer (LBL) - Seismic reflection and VSP studies

Three holes are being used for VSP studies (Attachment 9) - UZ-16, WT-2, and NRG-6. Seismic reflection investigations (as well as gravity and ground magnetics) have been conducted across the Ghost Dance fault (Oliver and others, 1994) and are planned along other traverse lines shown in Attachment 9. Resolution of both VSP and seismic reflection methods is deemed to be as good as tens of meters and structures can be imaged using these techniques. The goal of these studies is to link mechanical properties (e.g., density of fractures) to lithology or hydrologic transport properties. The Ghost Dance fault has been traced to a depth of at least 1 km using seismic reflection data (Oliver and other, 1994). VSP results indicate fracturing in this area which E. Mejer interprets as fault-related.

8. M. Fahy (USBR) - Field tour: Large block experiment and pavement study at Fran Ridge

The pavement study at Fran Ridge is being undertaken by M. Fahy (USBR) on a surface adjacent to the large block experiment and near to borehole UE25-H1. The Topopah Spring Formation, exposed at this locale, has been divided into an upper lithophysal unit (Tsw1) and a non-lithophysal unit (Tsw2). This pavement is not located near any major fault, but does provide a good exposure

of the Topopah Spring. All fractures 1 foot or greater in length on the pavement surface are being measured and mapped.

The block for the large block experiment will be 10 x 10 x 15 feet in dimensions when excavation of the block is completed. The vertical saw cuts have been completed to a depth of 16 feet on all four sides of the block and excavation to leave a free-standing block attached only at its base are underway. A concrete slab has been poured on the top of the block to stabilize it while it is being excavated.

The plan is for the block to be loaded to 600 psi, a stress equivalent to that expected at the repository horizon. The block will be heated for a time frame of 6 to 12 months to a T of 135 °C using heaters apparently emplaced around the margins of the block. The zone of increased temperature is expected to be about 2 m wide out from the locations of the emplaced heaters. A moisture barrier will be placed atop the block during the heater test. Prior to initiation of the test, fractures in the block will be characterized and an attempt will be made to use acoustic emissions testing to map out fractures between the walls of the block and the testing boreholes which will be drilled into the block.

9. R. Spengler (USGS)/A. Braun and L. Martin (SAIC) - Field tour: Ghost Dance pavement at Antler Ridge

A. Braun and L. Martin (SAIC) have been mapping the stratigraphy in the vicinity of the pavement, and stress that they have only refined - and not drastically changed - the original stratigraphy defined by Scott and Bonk (1984). There is currently no plan to map additional areas along the Ghost Dance fault in FY94, but only to focus on "verification mapping" of the existing pavement surface.

The two main fracture trends in the pavement surface have azimuths of about 0 and 160 degrees (i.e., the Ghost Dance trends about N9E, and the northwest fracture set about N25W). The north-northeast-trending fault system includes the Ghost Dance and exhibits mainly dip-slip displacement, while the northwest-trending fault set is characterized by oblique slip. (For example, the northwest-trending Sundance fault, a fault included in the northwest fault set, has been interpreted by R. Spengler to have about 170 feet of right-lateral offset. However, there is currently strong disagreement between R. Spengler and C. Fridrich, both of the USGS, on the length, width, and importance of the Sundance feature.) The Ghost Dance fault has about 50 feet of down-to-the-west displacement along a steeply west-dipping fault surface at the pavement location, where it is bounded by faults of similar strike (i.e., N-S to N9E) but smaller displacement both east and west of its main trace. At the "west fault" in this Ghost Dance fault "package," about 15 feet of displacement has occurred along a fault trending about N8E, an orientation measured by one author (GLS). The "west fault" was observed by one author (GLS) to intersect a sheared zone with a measured strike of about N40W. C. Fridrich interprets the faults east and west of the main Ghost Dance trace to be splays off the Ghost Dance fault itself, rather than separate and distinct faults as interpreted by R. Spengler.

A 1200-foot wide monocline is associated with the Ghost Dance fault zone at this location. R. Spengler believes this is not related to rollover in association with listric faulting, and does not think that the listric/detachment fault model proposed by Scott (1990) is the best to apply. He appears to prefer a planar fault model. The authors did not obtain additional details from R. Spengler on the reasons for his planar fault model interpretation.

10. M. Tynan (DOE) - Status of the seismic investigations field program

Number of seismic lines to be run in the seismic investigations field program have been reduced from 5 to 2, and no RFP for these studies has been issued as yet. Currently it is planned to use both Vibroseis and explosive sources in the investigations. DOE has experienced some difficulty in acquiring a permit for the studies from the Bureau of Land Management (BLM).

Wednesday, May 4, 1994

1. D. Kessell/C. Brechtel (Sandia) - Field tour: Trench NRT-1 at north side of Exile Hill

Trench NRT-1, the location of which is shown on Attachment 12, was placed for engineering testing purposes to determine whether materials to be encountered in the ESF had cohesive strength adequate for supporting the TBM. NRT-1 is located on the opposite side of Exile Hill from the ESF portal which is on the east side of Exile Hill. It is near to Trench 14 which exposes the Bow Ridge fault south of Trench NRT-1. Trench 14A lies north of NRT-1 and also exposes the Bow Ridge fault. The lower section of Rainier Mesa tuff is exposed between Trench NRT-1 and Trench 14A. NRT-1 is slightly west of the main trace of the Bow Ridge fault, and reveals possible displacement in 11.5 my tuff with no displacement identified in the Quaternary materials in the trench. Net offset across the Bow Ridge has been suggested to be as large as 115-135 cm based on data obtained from recent mapping along this fault.

Four main paleosoil horizons were noted separating bedded tuff units in boreholes at the location of Trench NRT-1. Attachment 12 illustrates stratigraphy and locations of soil tests in the vicinity of this trench. Maintenance of cohesion is related to dryness of the materials, so D. Kessell cautioned that use of water during construction would need to be closely monitored. However, he did not anticipate that grout would be necessary to stabilize the walls of the ESF for use of the TBM.

2. C. Rautman (Sandia) - Field tour: Borehole SD-12

The LM-300 rig had penetrated to a depth of 620 feet with a 12.25 inch diameter finished hole after reaming. This hole diameter was necessary to accommodate the instrumentation which is planned for use in the hole. A visit was made to the core trailer, where core was being preserved for a dozen or so different types of studies.

A brief discussion of borehole UZ-14 ensued also at this stop. This is the hole in which water was encountered at a depth of 2185 feet when a fracture zone was hit in the Bullfrog Tuff, a dense and moderately welded unit. The water rose as high as 1965.09 feet depth in the borehole. At the time of this site visit, the hole extended to a depth of 2206.7 feet with a plan to drill about 20 feet deeper to final depth. As of the morning of Monday, May 2, the pH reading was 8.5.

3. R. Spengler (USGS) - Field tour: Sundance fault at the east end of Antler Ridge

Z. Peterman (USGS) gave a brief presentation on use of geochemistry for definition of stratigraphic units (Attachment 18). For the Tiva Canyon Formation, he was able to distinguish a lower high-silica rhyolite from an upper cliff unit of quartz latite and to locate the contact between these two units within a few feet using the geochemical trends for Ti, Zr, and Ba. (K, Ca, Ti, Rb, Sr, Y, Zr, Nb, La, and Ce were all analyzed by XRF.) The approach was validated in three reference section

locations. Using a multitarget, energy-dispersive XRF unit, 15 samples per day can be run rapidly so that the method should prove useful to distinguish units rock units encountered in the underground excavations. Additional work will also be done in the Topopah Spring Formation.

D. Buesch (USGS) commented that the geochemical variations described by Z. Peterman correlated with crystal content of the Tiva Canyon Formation (i.e., crystal-rich vs crystal-poor zones of the non-lithophysal zone in the Tiva Canyon). He commented further that field investigators were detecting sub-units within the quartz latite zone of the Tiva Canyon. D. Buesch stated that other criteria may also be needed in concert with the geochemistry to pick out sub-units at depth, particularly in the Topopah Spring Formation.

R. Spengler commented that it may eventually be necessary to clear a pavement at this location where the Ghost Dance and Sundance faults are thought to intersect to establish the intersection relationships and prove the proposed offset of the Ghost Dance along the Sundance fault. The general trend of the Sundance at this locale was reported by R. Spengler to be N30-37W, with 100 feet of apparent vertical displacement across the fault zone (down to the east) based on offset stratigraphy. Specifically, offset of the upper clinkstone and lower lithophysal units was used to quantify the type and amount of vertical displacement along the Sundance. Amount of horizontal displacement on the Sundance fault (i.e., about 170 feet of right-lateral offset according to R. Spengler) was based on the interpreted offset of the Ghost Dance by the Sundance. The Sundance fault zone is interpreted to be about 900 feet wide, with the location at this stop lying near the center of the fault zone.

4. R. Spengler (USGS) - Field tour: Ghost Dance/Sundance faults intersection and Sundance discovery exposure in Split Wash, north side of Antler Ridge

As measured by one author (GLS) at an exposure of breccia about 1 m wide in Split Wash, the Sundance fault trends about N28W and is near vertical. The best evidence for the 170 feet of right-lateral offset along the Sundance was reported by R. Spengler to be the apparent offset of the "package" of faults associated with the Ghost Dance fault (i.e., the package of faults comprised by the main fault and the east and west faults as observed in the cleared pavement at Antler Ridge). C. Fridrich (USGS) interprets this overall fault pattern as a northward "feathering out" of the Ghost Dance fault, rather than as specific northeast (Ghost Dance) and northwest-trending (Sundance) fault systems.

C. Menges (USGS)/C. Harrington (Los Alamos) discussed the trench that had been located on the north side of Antler Ridge in an earlier attempt to investigate latest slip on the Ghost Dance fault. Fortuitously, this trench intersects the projected surface traces of both the Ghost Dance and Sundance faults. However, there is no evidence of offset of Quaternary gravel layers in this trench. Also, there is no evidence of fracturing related to faulting in the trench along either the Ghost Dance or Sundance trends, although the Ghost Dance is interpreted to have about 40 feet of vertical displacement on the hillslope south of the trench based on offset lithostratigraphic units. R. Spengler reported that displacement on the Ghost Dance fault system is interpreted to be considerably less in the ridge on the north side of the trench. Various dating methods will be applied to assess the ages of Quaternary units during investigation of potential displacements. E. Taylor (USGS) reported that at least two Quaternary units have been distinguished in this trench to date - Unit Q5 and Unit Q4. Other trenches are apparently planned along the Ghost Dance fault as well.

5. J. Whitney (USGS) - Field tour: Paintbrush Canyon fault in Trench A1, Alice Ridge

The vertical separation noted along the Paintbrush Canyon fault at this location is about 210 m with displacement increasing to the south. Slickensides show an oblique slip (possibly left-lateral) component of displacement. If a strike-slip fault does occur in Yucca Wash, it does not appear to have offset the Paintbrush Canyon fault much if at all. Basaltic ash (considered by J. Whitney to be derived from earliest Lathrop Wells or Crater Flat eruptions) does occur in the fault at this location, and a small pod of siliceous ash is found in the soil horizon. The trench has deepened and is currently being mapped. Displacement does appear to be Quaternary, but not Holocene. Trend of the fault trace is about N-S to N5W at this location.

J. Whitney commented that the listric fault model proposed by Scott (1990) for major block-bounding faults did not appear to be strongly supported by field data currently coming to light. S. Young (CNWRA) commented that fault blocks to the south may show rollover, while blocks to the north may not because of either a difference in the structural level exposed or a real difference in structural style from north to south. It is considered by two authors (DAF and GLS) that little change in fault dip to suggest a listric geometry may be expected in shallow trenches across a major block-bounding fault because of structural level being observed in the trenches. The two authors further believe that rollover should be considered more diagnostic of possible listric geometry at depth than dip of the upper parts of the fault surface as observed in shallow trenches.

Thursday, May 5, 1994

1. L. Anderson (USBR) - Field tour: Trench BMT-2 along the Bare Mountain fault

L. Anderson interpreted the Bare Mountain fault to be older and to have a longer recurrence interval than was previously thought (e.g., by Reheis, 1986). This interpretation was based on his recent studies in trenches along the fault, including conclusions drawn from a trench in Tarantula Canyon (BMT-1) along the northern extent of the fault.

Trench BMT-2 is an old mining pit first described by Reheis (1986) and re-opened for the current investigations. One author (GLS) noted vertical slickensides developed on the fault surface in the footwall block of the Bare Mountain fault at Trench BMT-2. The Bonanza King Dolomite comprised the footwall block. As measured by that author at the outcrop, the approximate orientation of the fault surface on which the slickensides occurred was N24E, 67SE.

L. Anderson does not interpret the fault to be Holocene, and believes there is evidence for only 1 late Quaternary slip event rather than 2 as Reheis (1986) suggested. J. Whitney (USGS) speculated that late Pleistocene displacement may be indicated, and suggested the possibility that as many as 3 slip events may be recorded here. J. Whitney also commented that Reheis (1986) had reported Holocene slip to be discontinuous along the Bare Mountain fault and mentioned that other workers at this location (e.g., J. Bell of UNV-Reno) believed the zone of oriented clasts and fractured alluvium likely extended all the way to the surface to suggest possible Holocene displacement at this location.

L. Anderson commented that displacement along the Bare Mountain fault appeared to decrease and die out to the north. He believes that faulting along the Bare Mountain fault in Tarantula Canyon, the location of Trench BMT-1, shows this decreased displacement to the north. He suggests that a

recurrence interval of "10,000 years or so" with 1-2 m of slip per event is typical for range-front faults of the Basin and Range like the Bare Mountain - notable exceptions being the more active Death Valley-Furnace Creek and Wasatch fault zones.

2. L. Anderson (USBR) - Field tour: Trench BMT-1 along the Bare Mountain fault at Tarantula Canyon

This trench was excavated in alluvial fan deposits in 1993 along a scarp about 1.5 m high. The scarp is considered to be older than the Beatty Scarp, a fluvial scarp with an age of around 10,000 years as reported by L. Anderson. He commented that about 1-1.5 m of displacement accompanied formation of the scarp in Tarantula Canyon - probably as a single event - sometime after Quaternary Unit 2 mapped at this locality. Four units have been mapped in total, and there are as yet no age dates although native artifacts found in Unit 4 suggest a minimum age of about 7000 years for that unit (possible Late Pleistocene-Early Holocene?) which he does not believe is offset. Unit 4 is comprised of colluvial and alluvial materials, and a K-horizon soil in the sequence may be about 100,000 years old. He also suggests that there is no evidence of late slip in the carbonate coating in the fault plane. However, questions were raised by several participants about whether Unit 4 may actually be offset and considerable controversy exists for interpretation of faulting along the Bare Mountain fault at this and other locations. For example, C. DePolo (UNV-Reno) suggested that 1.5 m of slip could have occurred at the Trench BMT-1 locale between 7,000 and 20,000 years ago in possibly 2 or 3 slip events. His interpretation yields higher slip rates and shorter recurrence intervals than the concept of 1.5 m displacement in one event occurring between 7,000 and 100,000 years ago as L. Anderson suggested.

3. J. Whitney (USGS)/A. Ramelli (UNV-Reno) - Field tour: Trenches along the Solitario Canyon fault

At Trench 8, the location with the large ash pocket in a fissure along the Solitario Canyon fault, better age controls and stratigraphic correlations are now being developed. U-series samples have been collected, and 25,000 year old rhizoliths found in the ash pocket ideally provide a minimum age estimate for faulting. Laminated carbonate in the fault zone has been dated at about 15,000 years. The ash is thought to be between 30,000-100,000 years old and from Lathrop Wells. Some workers lean towards an 80,000-100,000 year age bracket for the ash. In a small pit immediately south of Trench 8, silts in the age range of 10,000-14,000 old occur above the fault zone, and whether this silt is actually disrupted by displacement or not is uncertain although silt does occur in the fractures. The field evidence is now interpreted to not show Holocene slip along the Solitario Canyon fault. However, there appear to be 4 slip events post-dating the uppermost gravel deposits which are estimated to be "a couple hundred thousand years old." Suggested slip rate is 0.01 mm/yr, with a recurrence interval of 40,000-50,000 years.

Orientation of the fault in Trench 8 was measured by one author (GLS) as N10E,64SE. No other trenched location shows greater displacement on the Solitario Canyon, so displacement appears to decrease to the north along the fault according to J. Whitney. The increase in faulting activity on the southern end of Yucca Mountain seems to have persisted into the Quaternary.

It appears that at least two ash-producing events may have occurred at Lathrop Wells cone. However, volcanic ash occurs in fissures at Trench 8 which may be of three different ages based on field relationships for the fracturing. The number of ash deposits is important to help determine possible associations between faulting and volcanism.

Trench SCF-T3 is located south of T8 and has a story very similar to that for Trench T8. There is no definitive evidence for Holocene slip in SCF-T3. Between Trenches SCF-T3 and SCF-T1 farther south, the breccia associated with the fault has a N-S strike. During the walk between Trenches SCF-T3 and SCF-T1, C. Harrington (Los Alamos) described his efforts on scarp evolution investigations. He has attempted to use a new cosmogenic C14 technique for determining ages of scarp features and found the technique viable. A minimum age of about 20,000 years is suggested for the scarp at this location, an age that is considerably older than the Early Holocene age interpreted from analysis of the scarp trace on aerial photographs. The explanation for this difference proposed by C. Harrington was that the scarp is an eroded fault-line scarp rather than a fault scarp.

At Trench SCF-T1, J. Whitney speculated that total displacement along the Solitario Canyon fault is at least 400 m. A. Ramelli remarked that the B horizon was not offset, and displacements for the latest events noted in the trench were not yet certain. Other trenches will investigate a strand of this fault to the southeast of the main fault trace where it is thought that later displacements could have been transferred. Four U-series samples have already been collected from one trench in the fault splay area but no dates have been acquired as yet.

J. Whitney summarized the activities planned for the next fiscal year for analysis of faulting and seismicity at Yucca Mountain as follows:

- Study plans will be prepared soon for "Probabilistic Fault Displacement and Seismic Hazard Analysis" (PFD&SHA) and "Faults in the Repository Block."
- A topical report on methodology being applied in faulting investigations will be prepared and submitted to the NRC "soon."
- Few new trenches will be added during FY95, although the USGS may attempt to investigate segmentation along the Windy Wash fault and to look for other faults in Crater Flat.
- Each fault will be the subject of a separate report.
- A workshop will be conducted on PFD&SHA. Although development of a PFD&SHA methodology is expected to be iterative, the workshop will be held in time to provide preliminary information for design by FY96. The first model will be run with existing data, and later models will incorporate new data as they come to light. The EPRI methodology is apparently being adopted by the USGS for consideration of PFD&SHA, based on comments from J. Whitney.
- Preliminary tectonic models of Yucca Mountain will be out in FY94. A detachment model will be prepared by W. Hamilton, and C. Fridrich will prepare a model based on his interpretations of the Yucca Mountain region as well.

SUMMARY OF ACTIVITIES:

Activities were summarized under the discussion of "Summary of Pertinent Points."

IMPRESSION/CONCLUSIONS:

Very useful data are being collected during the field characterization of faults in the vicinity of Yucca Mountain. Information on stratigraphy and structure will be important input for formulating realistic geological models for use in performance assessment analyses. Type 5 KTUs related to development of conceptual models for tectonic deformation and volcanism can also be addressed using the information being collected.

Controversies which exist (e.g., on the significance of the Ghost Dance/Sundance fault systems and the slip history/recurrence interval for the Bare Mountain fault) will need to be resolved, or the differences in interpretation incorporated into alternative structural/tectonic and volcanic models for Yucca Mountain and vicinity. Planar fault vs listric/detachment fault geometries may both need to be considered in alternative tectonic models.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

RECOMMENDATIONS:

The controversy about significance of the Ghost Dance and Sundance fault systems should be resolved, if possible, since interpretations related to physical characteristics and interactions of these two fault systems may influence ideas formulated about structural history of Yucca Mountain and the repository block, hydrologic flow models, and selection of the area which is most useable for repository development. An attempt to resolve the Ghost Dance/Sundance controversy could be made by clearing additional pavement areas in the vicinity of the proposed intersection of the two fault systems to more closely examine the relationships between the systems, as R. Spengler (USGS) suggested during this site visit.

The controversy about slip history of the Bare Mountain fault should be resolved, if possible, because interpretation of this feature will influence concepts related to local and regional deformation rates and structural history of the Yucca Mountain area. Effort could be made to excavate and map an additional trench along the Bare Mountain fault at Sterling Canyon as a possible means of resolving the differences in opinion about number of slip events and slip recurrence intervals. During this site visit, L. Anderson (USBR) suggested this trench is potentially planned. For both of these controversies, if differences in interpretations cannot be satisfactorily resolved through additional investigations, the range of interpretations should be captured in alternative tectonic models developed for Yucca Mountain to make certain an acceptably conservative approach is taken for consideration of these structural features.

CNWRA staff must continue to participate in the site visits in order to remain up-to-date on what is being done to characterize faulting, other structural and stratigraphic relationships, and rock properties at Yucca Mountain.

REFERENCES:

The following references were cited in the discussion of "Summary of Pertinent Points":

Oliver, H.W., E.L. Mejer, and R.W. Spengler, 1994, Geophysical investigations of the Ghost Dance fault, Yucca Mountain, Nevada: Geological Society of America, GSA Abstracts with programs, Cordilleran Section, v 26, no 2, p 78.

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Scott, R.B. and J. Bonk, 1984, Preliminary geologic map of Yucca Mountain, Nye County, Nevada, with geologic sections: U.S. Geological Survey, USGS Open-File Report 84-494, Scale 1:12,000.

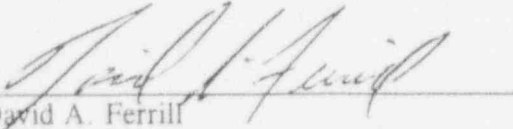
Spengler, R.W., C.A. Braun, L.G. Martin, and C.W. Weisenbery, 1994, The Sundance fault - A newly recognized shear zone at Yucca Mountain, Nevada: U.S. Geological Survey, USGS Open-File Report 94-49, 11p.

SIGNATURES AND DATE:



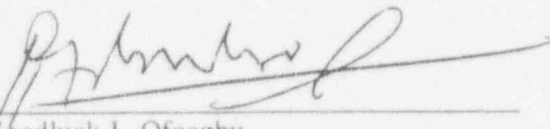
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Principal Geoscientist

27 July '94
Date



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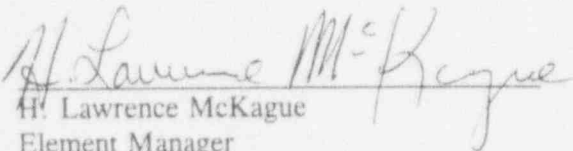
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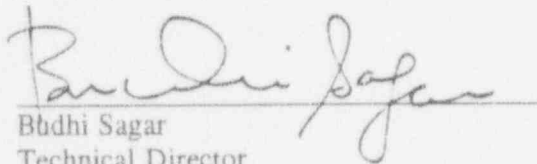
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MAY 3, 1994

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DOE-NRC SITE VISIT
 CHARACTERIZATION OF FAULTS AND FRACTURES NEAR YUCCA MOUNTAIN,
 AND STRATIGRAPHY, STRUCTURE AND ROCK PROPERTIES ALONG THE
 EXPLORATORY STUDIES FACILITY NORTH RAMP
 MAY 2-5, 1994

Monday, May 2, 1994

7:30 am	Meet at Nevada Test Site (NTS) Gate 510 for badging	
8:00	Presentations at Area 25 Field Operations Center (FOC) Introductions	DOE
8:10	Characterization of faults and fractures; update on the study; structural features in the Site Area (8.3.1.4.2.2)	R. Spengler
8:50	Stratigraphy, structure and stratigraphic nomenclature	D. Buesch
9:30	Rock properties and north ramp stratigraphy/structure; NRT-1 trench	{ D. Kessel (David) C. Brectel (Carl)
10:20	BREAK	
10:35	Mapping of the ESF: status, results, plans	{ S. Beason (Steve) Mike Fahey Jeff
11:30	ESF safety training, FOC Exhibit Room	
12:00	LUNCH	
12:45	Depart FOC for North Portal	
1:15	Arrive North Portal, tour ESF starter tunnel and test alcove	R. Spengler S. Beason N. Elkins
4:15	Depart for Field Operation Center	
4:45	North ramp reflection/refraction	G. Elbring (Greg)
5:30	Fracture network/fault studies Fran Ridge, Ghost Dance and Sundance faults	R. Spengler M. Fahey
6:30	Depart for NTS Gate 510	

DOE-NRC SITE VISIT
 CHARACTERIZATION OF FAULTS AND FRACTURES NEAR YUCCA MOUNTAIN,
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 EXPLORATORY STUDIES FACILITY NORTH RAMP
 MAY 2-5, 1994

Tuesday, May 3, 1994

7:30 am	Meet at NTS Gate 510 for badging	
8:00	Presentations at FOC Seismic refraction, Windy Wash	J. Whitney (John)
8:40	Status of systematic drilling program	C. Rautman (Chris)
9:20	Use of site data in ESF design	J. Pye (John)
9:50	BREAK	
10:05	Trenching activities; Solitario Canyon, Bare Mtn., Alice Ridge	{ J. Whitney C. Menges (Chris)
10:45	Status of Midway Valley studies	{ J. Whitney ?
11:30	Structural model of the Yucca Mountain Region, significance of northwest oriented structural features, and structural controls on the steep hydraulic gradient	C. Fridrich
12:30	LUNCH	
1:00	Depart for Fran Ridge	
1:30	Arrive at Fran Ridge. Discuss pavement study	R. Spengler, M. Fahy
2:30	Discussion of Large Block Experiment	J. Blink
3:00	Depart for Ghost Dance pavement, Antler Ridge	
3:30	Discussion of Ghost Dance and Sundance Fault	R. Spengler
6:00	Depart for NTS Gate 510	

DOE-NRC SITE VISIT
 CHARACTERIZATION OF FAULTS AND FRACTURES NEAR YUCCA MOUNTAIN,
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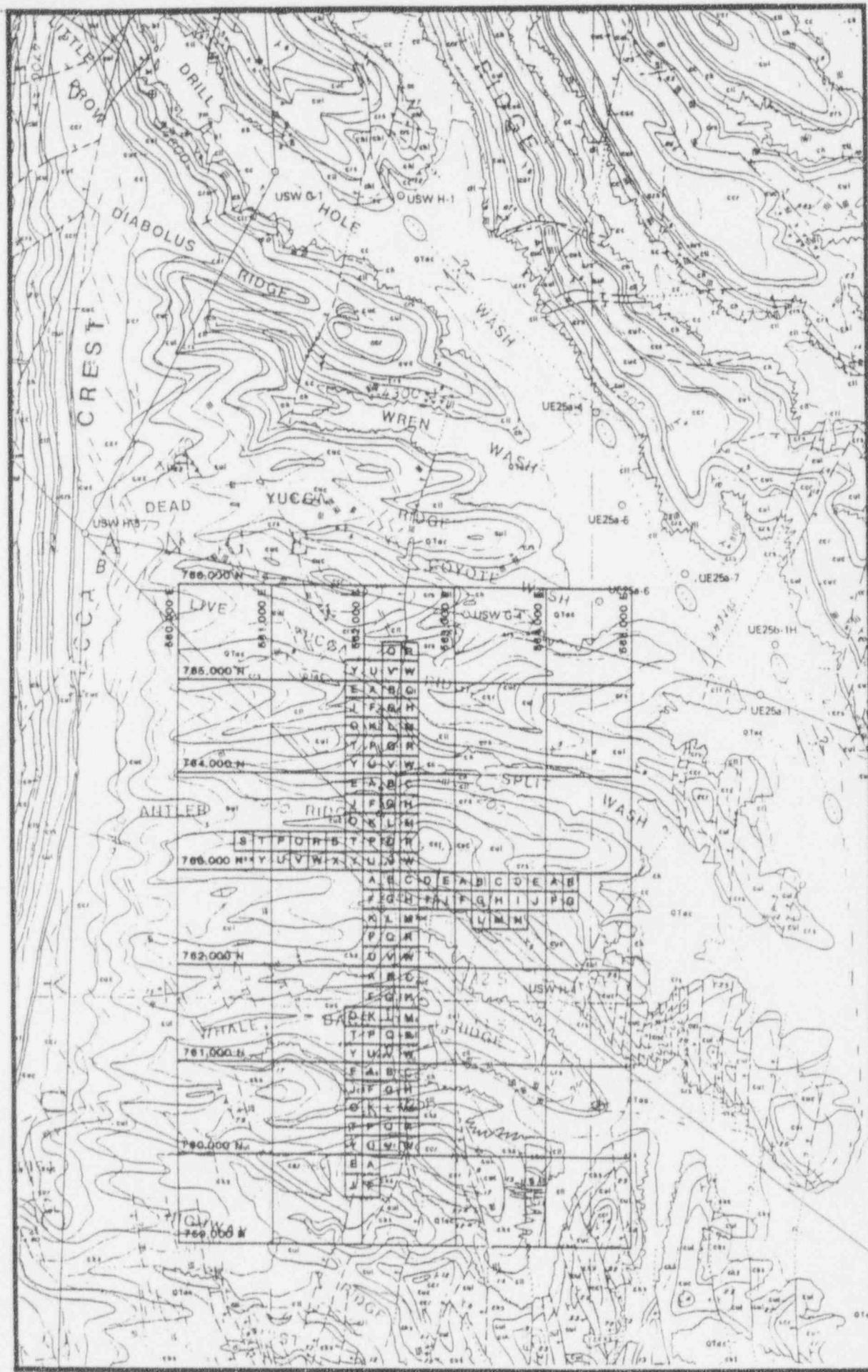
Wednesday, May 4, 1994

7:30 am	Meet at NTS Gate 510 for badging	
8:00	Depart for north side of Exile Hill, visit NRT-1 trench	
8:30	NRT-1 trench discussion	D. Kessel C. Brectel
9:30	Depart for SD-12 location	
9:45	SD-12 location; observe borehole drilling; discussion	available staff
10:15	Depart for Sundance Fault exposure, east end of Antler Ridge	
10:30	Sundance Fault, east end of Antler Ridge near UZ-16, discussion	R. Spengler
11:10	Depart for north side of Antler Ridge (eat lunch in transit)	
11:30	Arrive north side of Antler Ridge in Split Wash area for hike to location of Sundance/Ghost Dance fault systems' intersection; discussion	R. Spengler
1:00	Walk to Sundance "discovery" outcrop, Split Wash; examine outcrop and discuss Sundance fault system	R. Spengler
2:10	Depart Split Wash area for Paintbrush Canyon fault trenches, north end of Alice Ridge	
2:40	Discussion at Paintbrush Canyon trench location, Alice Ridge	J. Whitney
4:00	Depart for NTS Gate 510	

DOE-NRC SITE VISIT
CHARACTERIZATION OF FAULTS AND FRACTURES NEAR YUCCA MOUNTAIN,
AND STRATIGRAPHY, STRUCTURE AND ROCK PROPERTIES ALONG THE
EXPLORATORY STUDIES FACILITY NORTH RAMP
MAY 2-5, 1994

Thursday, May 5, 1994

7:30 am	Meet at Steve's Pass, Crater Flat	
8:00	Arrive at BMT- 2 ² trench; discussion	L. Anderson
9:00	Depart for BMT- 2 ¹ trench = <i>Tauantule Canyon</i>	
9:30	Arrive BMT- 2 ¹ trench; discussion	L. Anderson
10:30	Depart for east side of Crater Flat	
11:00	Discussions at trenches T-10, and others (lunch at trench sites)	J. Whitney
3:30	Closing remarks and questions	NRC State of Nevada AUC
4:00	Depart for Las Vegas	



LOCATION OF THE GHOST DANCE STUDY AREA SEPTEMBER 1993

ATTACHMENT #4

THE SUNDANCE FAULT: A NEWLY RECOGNIZED SHEAR ZONE AT YUCCA MOUNTAIN, NEVADA

U.S. GEOLOGICAL SURVEY

Open-File Report 94-49

Prepared in cooperation with the
U.S. Department of Energy under
Interagency Agreement DE-AI08-92NV10874



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THE SUNDANCE FAULT: A NEWLY RECOGNIZED SHEAR ZONE AT YUCCA MOUNTAIN, NEVADA

By R.W. Spengler¹, C.A. Braun², L.G. Martin², and C.W. Weisenberg²

U.S. GEOLOGICAL SURVEY

Open-File Report 94-49

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¹ U.S. Geological Survey, Denver, CO

² Scientific Applications International Corporation, Golden, CO



Denver, Colorado
1994

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M. Hirsch, Acting Director

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THE SUNDANCE FAULT: A NEWLY RECOGNIZED SHEAR ZONE AT YUCCA MOUNTAIN, NEVADA

By R. W. Spengler, C. A. Braun, L. G. Martin, and C. W. Weisenberg

ABSTRACT

Ongoing detailed mapping at a scale of 1:240 of structural features within the potential repository area indicates the presence of several previously unrecognized structural features. Minor north-trending west-side-down faults occur east and west of the Ghost Dance fault and suggest a total width of the Ghost Dance fault system of nearly 366 m (1200 ft). A zone of near-vertical N30°-40°W-trending faults, at least 274 m (900 ft) wide, has been identified in the northern part of our study area and may traverse across the proposed repository area. On the basis of a preliminary analysis of available data, we propose to name this zone the "Sundance fault system" and the dominant structure, occurring near the middle of the zone, the "Sundance fault". Some field evidence suggests left-stepping deflections of north-trending faults along a pre-existing northwest-trending structural fabric. Other field observations suggest that the "Sundance fault system" offsets the Ghost Dance fault system in an apparent right lateral sense by at least 52 m (170 ft). Additional detailed field studies, however, are needed to better understand structural complexities at Yucca Mountain.

INTRODUCTION

Yucca Mountain consists of a series of north-trending, east-tilted, 1- to 4-km (0.6 to 2.5-mi)-wide structural blocks. These blocks are bounded by north-trending westward-dipping high-angle fault zones that displace volcanic strata of Tertiary age by 100 m (330 ft), and locally to as much as 400 m (1300 ft; Scott and Bonk, 1984). The potential area for long-term storage of high-level nuclear waste is situated within the central block of Yucca Mountain, which is bounded on the west by the Solitario Canyon fault zone and on the east and southeast by numerous closely spaced northwest- and northeast-trending faults (fig. 1). From north to south, we divide the central block into three distinctive structural domains on the basis of fault intensity and orientation, topography, and attitude of volcanic strata. Strata in the northern structural domain dip 5° to 10° southeastward and are cut by a series of linear northwest-trending washes, most of which are underlain by, or coincident with, zones of right-lateral strike-slip faulting (Scott and Bonk, 1984). The southernmost strike-slip fault is suspected to underlie Drill Hole Wash, directly north of the northeastern margin of the potential repository area (fig. 1; Scott and others, 1984). In large part, the potential repository area encompasses the central structural domain, where strata commonly dip eastward from 6° to 9° and are dominantly cut by east-trending washes. Here, the Ghost Dance fault is considered the dominant structural feature, as it is the only through-going fault that offsets the exposed 12.5-m.y.-old Tiva Canyon Member of the Paintbrush Tuff. It has recently been proposed to elevate the Tiva Canyon Member to Formation status (D. A. Sawyer and others, written communications, Feb. 10, 1993), and therefore, we will provisionally refer to it as the Tiva Canyon Tuff. The southern domain is characterized by an abundance of closely spaced northwest-trending and ancillary northeast-trending faults with vertical separations on the order of several meters. As mapped by Scott and Bonk (1984), some discontinuously exposed northwest-trending

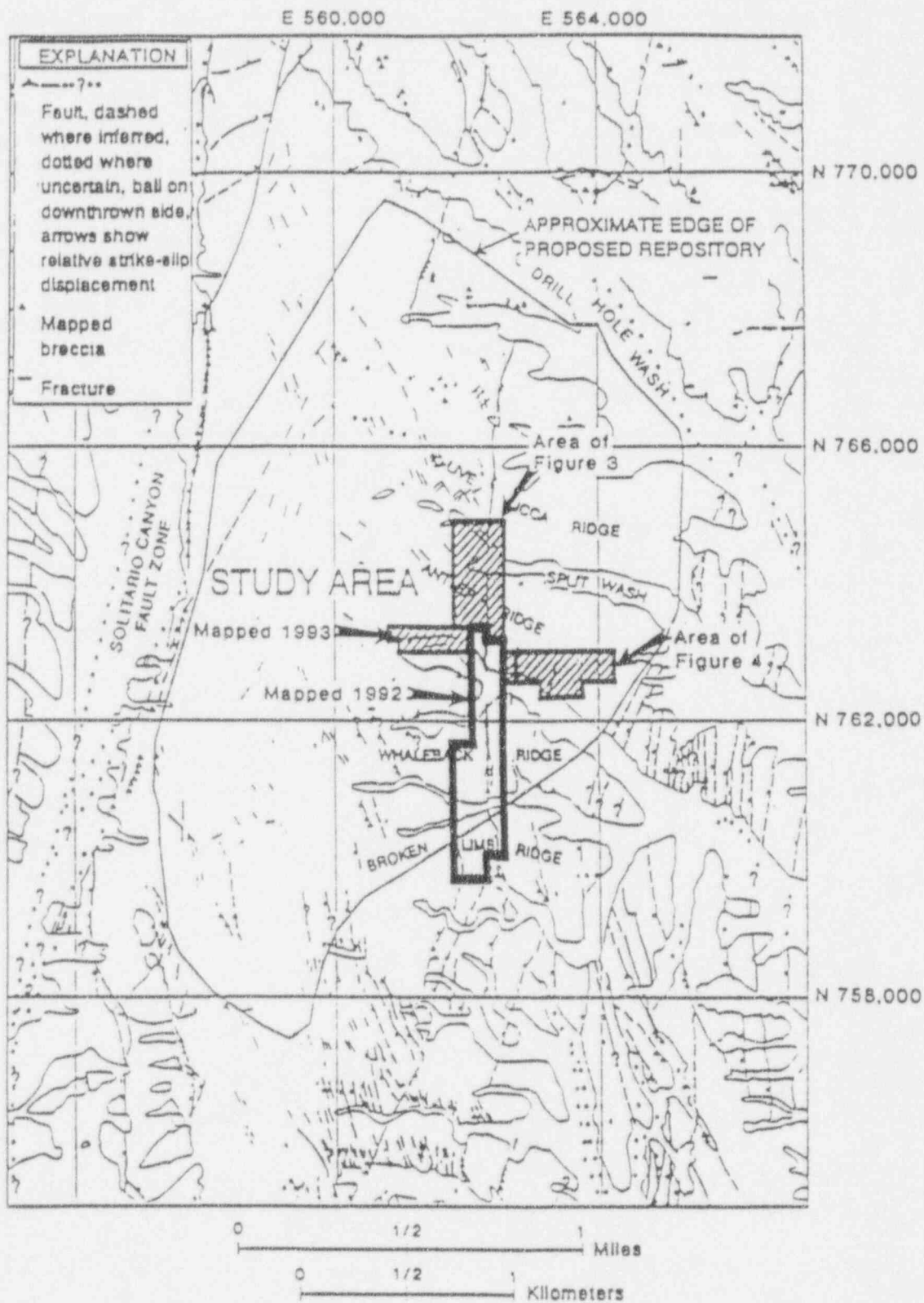


Figure 1.--Map of Yucca Mountain showing the distribution of structural features within and surrounding the proposed repository area and the location of study areas along the southern and central parts of the Ghost Dance fault (structural features from Scott and Bonk, 1984). Nevada State Coordinates are shown in feet.

faults extend northward well into the proposed repository but details of their character have not been studied (fig. 1). This paper summarizes salient structural features that have been identified from detailed field mapping of parts of the central structural domain.

ACKNOWLEDGMENTS

We thank D. C. Buesch of the U. S. Geological Survey and R. P. Dickerson of Science Applications International Corporation for providing thoughtful and constructive technical reviews of the paper.

PREVIOUS MAPPING

In 1992, we initiated a project to map fractures and other observable structural features such as zones of brecciation and separations of lithostratigraphic units on either side of the surface trace of the Ghost Dance fault (Spengler and others, 1993). We first established an internal grid system, composed of 61 m by 61 m (200 ft by 200 ft) areas within the framework of the Nevada State Coordinate System. Field mapping is at a scale of 1:240 and subsequently compiled at a scale of 1:600 (Spengler and others, 1993). The mapped area straddles the surface trace of the Ghost Dance fault, bounded on the north by Antler Ridge and on the south by Broken Limb Ridge (fig. 1). The length of the study area was 1158 m (3,800 ft). For the most part, the southern and northern halves of the study area were, respectively, 244 m (800 ft) and 183 m (600 ft) in width (fig. 1). Based on detailed mapping in 1992 and 1993 (fig. 1), we found that the Ghost Dance fault is the dominant fault in a previously unrecognized structural system, composed of minor north-trending faults and near-horizontal lithostratigraphic units that extend over a width of at least 213 m (700 ft). This structural system, referred to as the Ghost Dance fault system, was also found to exhibit a preferential north- to northwest-trending fracture orientation with isolated occurrences of north- to northwest-trending breccia (Spengler and others, 1993). The thickest and most intensely crushed breccia is found along the Ghost Dance fault. The character of this breccia and the significantly larger vertical separation of lithostratigraphic units are key features that are currently used to distinguish the Ghost Dance fault from other north-trending faults within the system.

STRATIGRAPHY

The uppermost 60 to 75 m (200 to 250 ft) of moderately to densely welded zones of the Tiva Canyon Tuff are moderately to poorly exposed along steep-sided east- to southeast-trending drainages. Some localities are almost completely covered with thick talus deposits. Lithostratigraphic units of the Tiva Canyon Tuff, as originally described by Scott and Bonk (1984), are based on the macroscopic variations in groundmass devitrification, degree of welding, shape of eroded slopes, texture of weathered surfaces, lithophysal cavity abundance, lithic fragment abundance, and phenocryst abundances. These zones, which include, from bottom to top, the hackly, lower lithophysal, clinkstone, upper lithophysal, and upper cliff, and locally, the upper vitrophyre, provide the detailed lithostratigraphic framework for the recognition of offsets of lithostrata on the order of a few meters at a scale of 1:12000 (Scott and Bonk, 1984).

During our detailed mapping in 1992, we increased the number of criteria for recognizing subtle contacts between units of the Tiva Canyon Tuff. These criteria include roughness coefficients of freshly broken surfaces (Barton and Choubey, 1977), working hardness (Hunt, 1984), size and shape of lithophysal cavities, orientation and abundance of foliated pumice clasts, and initial appearance of diagnostic lithic fragments and accessory minerals such as bronze-colored

biotite. Our systematic development and use of multiple criteria for each contact between units, currently allow us to recognize apparent offsets of less than a meter (fig. 2).

RESULTS OF MAPPING IN 1993

In 1993, we extended our detailed mapping north, east, and west of the our previously mapped area to include an additional 70 areas. As in previous mapping each area measures 61 m by 61 m (200 ft by 200 ft). Our 1993 mapping extended approximately 550 m (1800 ft) northward along the Ghost Dance fault to include the northern flank of Antler ridge and southern flank of Live Yucca Ridge. Two east-west strip maps were also completed. The two strip maps, for the most part, are 120 m (400 ft) wide, extending to distances of 549 m (1800 ft) east and 366 m (1200 ft) west of the mapping completed in 1992 along the southern flank of Antler Ridge (fig. 1). The primary objective for mapping the strips was to establish the full width of the area where north-trending faults could be detected along the Ghost Dance fault system.

Our detailed mapping indicates that the width of the area, containing as many as six through-going but discontinuously exposed north-trending structures, is almost 366 m (1200 ft). This width appears relatively uniform from Broken Limb Ridge northward to at least the south side of Antler Ridge; a distance of about 1 km (0.6 mi). The Ghost Dance fault, which maintains a position near the middle of the system, remains the dominant structural feature. Almost all ancillary north-trending faults indicate down-to-the-west offset that commonly range between 3 m and 6 m (10 ft and 20 ft). From Broken Limb Ridge to Live Yucca Ridge, ancillary faults maintain a fairly uniform map spacing from the Ghost Dance fault of 114 to 198 m (375 to 650 ft) for the West Hinge fault, 30 to 76 m (100 to 250 ft) for the West fault, and 24 to 69 m (80 to 225 ft) for the East fault. Within the structural system dips of lithostratigraphic units are near-horizontal.

The width of the Ghost Dance fault system is consistent with the width of the area where north- to northeast- trending faults had been previously mapped on either side of the Ghost Dance fault by Scott and Bonk (1984). These ancillary faults were previously interpreted to have northern terminations near the crest of Broken Limb Ridge at the southeastern margin of the proposed repository area (fig. 1; Scott and Bonk, 1984). In contrast to mapping at a scale of 1:12000, our mapping indicates that these faults extend northward well into the proposed repository area.

Northward progression of our structural mapping has led to the recognition of numerous northwest and northeast trending structures north of Whale Back Ridge (fig. 1). Most of these structures indicate apparent offsets of lithostratigraphic units of the Tiva Canyon Tuff by only a few meters. Geometrical relationships of many diffusely spaced northeast- and northwest-trending faults are incompletely understood.

A conspicuous variation in structural style appears to occur north of Antler Ridge and along the southeastern flank of Antler Ridge, which suggests the existence of a previously unrecognized shear zone. The existence and character of this shear zone are based on the appearance of the following structural complexities: 1) abrupt increase in northeastward dip of foliation in lithostratigraphic units, 2) closely spaced northwest-trending shears with apparent right lateral separation, 3) intensely brecciated rock in close proximity to northwest-trending fractures, 4) abrupt decrease in vertical separation along the Ghost Dance fault, and 5) apparent right lateral offset of the Ghost Dance fault system. These field observations have been documented at three critical but isolated exposures along the northern flank of Antler Ridge, along southern flank of Live Yucca Ridge, and along the southeastern flank of Antler Ridge (fig. 1, 3, 4).

Meters	Feet	Zones of Tiva Canyon Tuff	Diagnostic Minerals (Decreasing Order)	Roughness Coefficient for Fresh Surface	ISRM Hardness Classification	Texture and Fractures Features	
0	0	vitrophyre (cv)	Sandline Sphene Biotite	10 to 12	IV	Spherulites as large as 4mm in diameter and perlitic fragments up to 2cm occur in the dark portion. The groundmass varies from glassy to microcrystalline.	
	50	upper cliff (cuc)	<u>2-10% Sandline</u> + Biotite + Hornblende + Sphene	7 to 18	III	Fresh fracture surfaces vary from subconchoidal in the lower lithic zone, to a rough-blocky break in the more crystal rich upper zone.	
25	100	upper lithophysal (cul)	<u>1-3% Sandline</u> + Hornblende + Sphene	6 to 10	II	Fresh fracture surfaces have a saccharoidal (frosted) texture and are commonly subconchoidal.	
60	160						
	200	clinkstone (cks)	<u>1-3% Sandline</u> + Sphene + Hornblende	2 to 8	II to III	Prismatic breakage produces a weathered stairstep pattern at the lower contact and through the middle subzone containing minor (<1%) lithophysae. Freshly broken surfaces have microcrystalline texture and produce a distinctive conchoidal fracture.	
75	250	lower lithophysal (cli)	<u>2-3% Sandline</u> + Sphene + Hornblende + Biotite	8 to 12	I	Prismatic breakage produces a weathered stairstep pattern in outcrop. Lenticular and spherical lithophysae form lineations along foliation planes. Slight lineations of sandline phenocrysts and euhedral textures of collapsed pumice fragments also conform to these foliation planes. Fresh fractures cut directly through lithophysae and spherulitic features. Unit has diagnostic saccharoidal (frosted) texture, and subconchoidal fractures.	
	300	hackly (ch)	<u>1-3% Sandline</u> + Hornblende + Sphene + Biotite	12 to 18	III	Hackly-blocky texture. Fresh fractures break around perimeters of well-developed spherulitic features. Weathering produces a thin scree cover. Phenocrysts in matrix appear randomly oriented. Spheroidal features range from 5mm to 100mm in diameter.	
100	350	columnar (cc)	Not Exposed in Map Area				

Note: All diagnostic features are megascopic field criteria for 10X or less magnification. Visible diagnostic features are defined as being greater than 200 microns along the short dimension. All features are collected from fresh broken surfaces. Classifications of roughness coefficient and hardness are from Barton and Choubey (1977) and Hunt (1984), respectively.

* Less than 1% of whole rock volume (visible at 10X magnification);
Underline denotes relative importance of mineral for defining the unit in comparison with adjacent zones.

Figure 2 -- Stratigraphic column showing diagnostic field characteristics of the units of the Tiva Canyon Tuff (provisional) at Antler Ridge.

Northern Flank of Antler Ridge

Mapping of a 244-m (800-ft)-wide area from the southern flank to the northern flank of Antler Ridge reveals a gradual increase in structural complexity (fig. 3). Small-scale northwest- and northeast-trending faults increase in abundance. For the most part, the north-trending faults are traceable northward, maintaining a similar horizontal spacing and vertical separation as mapped to the south. From the south side of Antler Ridge to the north side of Antler Ridge, a distance of about 168 m (550 ft), vertical separation of lithostratigraphic units along the Ghost Dance fault is relatively uniform, varying from 15 to 12 m (50 to 40 ft). However, the high-angle Ghost Dance fault is offset in an apparent right lateral sense by about 15 m (50 ft) along an inferred northwest-trending shears (fig. 3).

Southern Flank of Live Yucca Ridge

North of Split Wash a conspicuous and abrupt change in structural style occurs. Along the south-facing slope of Live Yucca Ridge (fig. 1, 3), we have mapped numerous parallel N30°-40°W-striking structures, many of which are spaced 5 to 10 m (16 and 33 ft) apart and commonly show less than a few meters of right (or) east-side-down separation of lithostratigraphic contacts. Simple geometric considerations suggest that right slip on northwest-trending faults in an area of gentle eastward dips should result in left separation of contacts along south-facing slopes, which are steeper than the dips. The right separation seen along Live Yucca Ridge (and at some places to the south) may be due to local variations in attitudes of lithostratigraphic units and (or) by a vertical component of slip. Within the Ghost Dance fault system, where lithostratigraphic units are nearly horizontal, near-horizontal fault slip can produce variable outcrop patterns depending on local variations in slip line, attitudes of lithostratigraphic units and topography. Alternatively, some offsets, mapped in poorly exposed areas, may be related to slope movements or zonal variations within the Tiva Canyon Tuff.

The West Hinge, Ghost Dance, and East faults maintain a similar relative horizontal spacing on Live Yucca Ridge as seen to the south. The spacing between the West fault and Ghost Dance fault decreases slightly north of Split Wash. Some of the north-trending structures along Live Yucca Ridge appear to break into left-stepping segments connected by short northwest-trending breccia zones. These deflections from a northerly strike may be due to preexisting northwest-trending structures. However, the locations of identifiable north-trending faults within the Ghost Dance fault system along Live Yucca Ridge suggest an apparent right lateral offset of about 52 m (170 ft) relative to northern Antler Ridge (fig. 3).

The Ghost Dance fault shows a significant decrease in the amount of vertical separation of lithostratigraphic units from 12 m (40 ft) at north Antler Ridge to about 1.5 m (5 ft) near the middle of the south slope of Live Yucca Ridge, which corresponds to a map distance of about 305 m (1000 ft). North of Split Wash, the fault directly east of the Ghost Dance fault that is provisionally referred to as the East fault(?) shows the largest vertical separation of about 3 m (10 ft). If the Ghost Dance fault has been misidentified and is this easternmost fault within our mapped area, a larger amount of right separation can be inferred.

A set of the high-angle N30°W fractures, dipping 85° to 90° to the southwest, is well exposed at drainage level along Split Wash and extends northwestward for several tens of meters along the south slope of Live Yucca Ridge (fig. 3). A breccia zone, 1 m (3 ft) wide, as well as slickensides with a rake of about 2° to the northwest were also found at this exposure. Some fracture surfaces display subtle mullion structures, suggesting a smoother fracture surface in a near-horizontal direction. Internal layering within the clinkstone zone is well developed at this

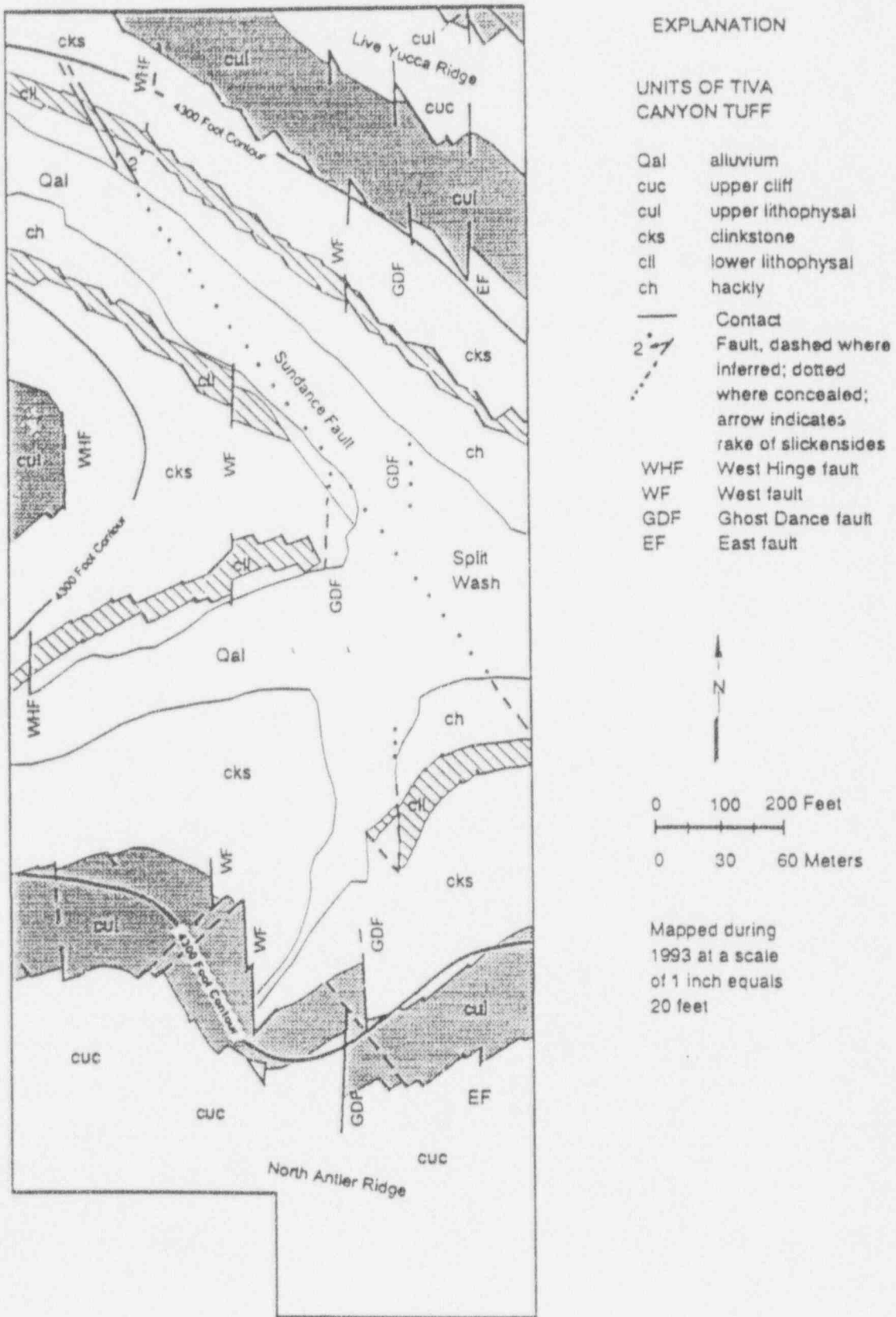


Figure 3.—Generalized geologic map of the Split Wash area showing offset of lithostratigraphic units along the Ghost Dance fault and Sundance fault systems.

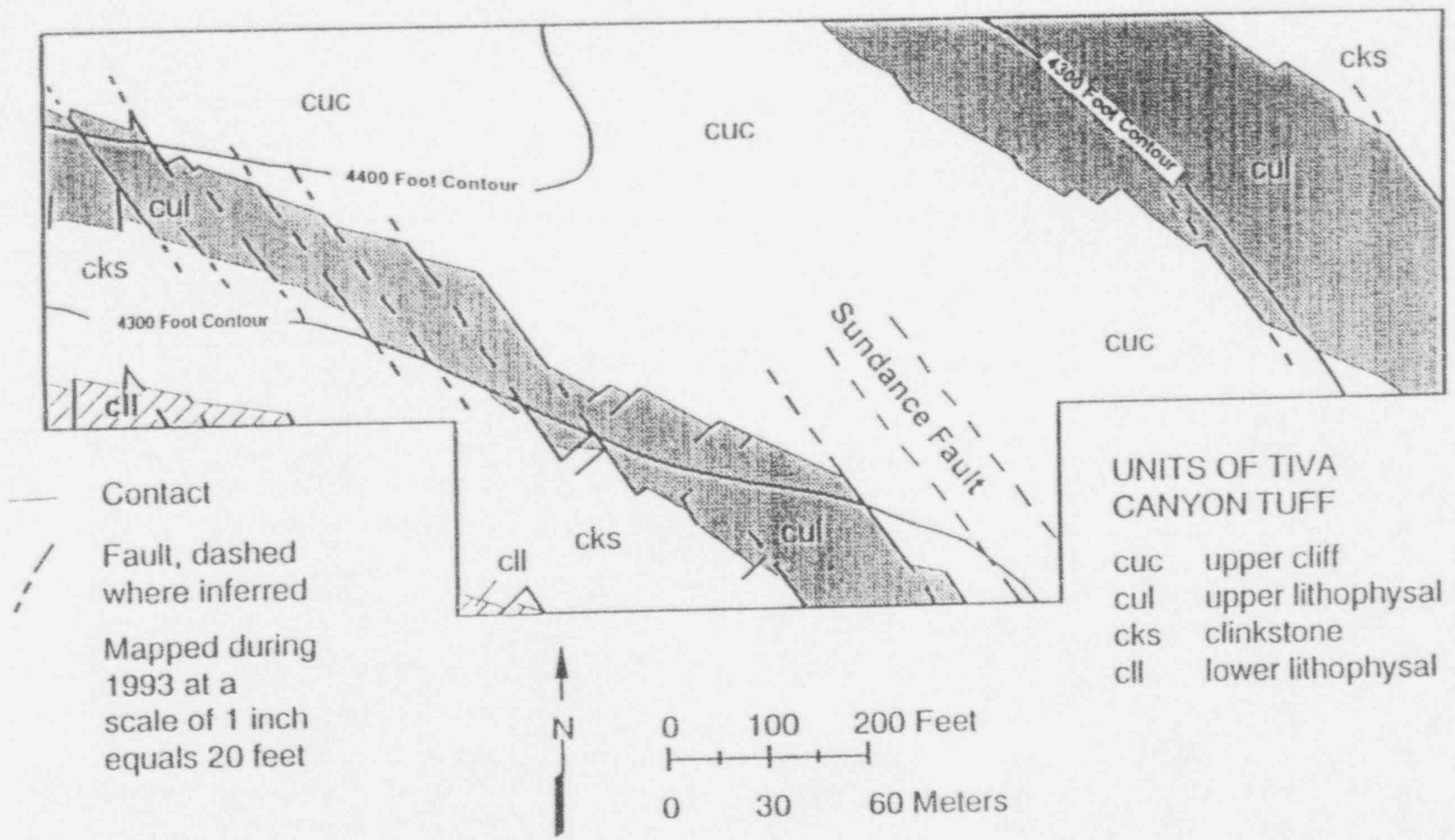


Figure 4.--Generalized geologic map of the eastern part of Antler Ridge showing offset of lithostratigraphic units along the Sundance fault.

locality, appears horizontal on the west side of the fault, dips gently eastward on the east side of the fault, but shows no recognizable vertical separation. As discussed, the inability to detect any vertical separation may be a combination of nearly vertical faults, nearly horizontal lithostratigraphic units, and horizontal slip. The fracture set can be traced northwestward across Live Yucca Ridge as a lineament on aerial photographs, where it appears to project into area of intense brecciation and into a northwest-trending lineament, depicted on Scott and Bonk (1984; fig. 1). Inferred from available preliminary data, we believe that this structure is the most conspicuous through-going feature near the middle of the shear zone and refer to it as the "Sundance fault".

Southeastern flank of Antler Ridge

The uppermost part of the upper cliff unit of the Tiva Canyon Tuff commonly forms a ridge-capping cliff several meters thick over much of Yucca Mountain. This cliff is conspicuously absent along the ridge crest of Antler Ridge directly northwest of drill hole USW UZ-16. Close examination of exposures of the upper cliff unit indicate that it is about 14 m (45 ft) thick to the west and about 23 m (75 ft) thick to the east of this geomorphic feature. Measurement of foliation attitudes in the upper cliff unit along the crest of Antler Ridge indicates an attitude of about N20° W 3°NE directly below this geomorphic feature, which increases to about N40°W 15°NE east of the feature. Mapping along the south-facing slope of Antler Ridge directly below the geomorphic anomaly indicates the presence of multiple apparent right separations of the contact between the upper cliff and the upper lithophysal units (fig. 4). Although this locality is poorly exposed and no discrete fault planes are observable, more than ten apparent right separations of contacts, commonly spaced 15 to 20 m (49 to 66 ft) apart, have been documented within a zone that is at least 274-m (900-ft) wide and trends in a N30°-40°W direction. These apparent right lateral separations in an area of anomalous northeasterly dips of foliation are consistent with right lateral slip and suggest an apparent cumulative right separation of as much as 107 m (350 ft; fig. 4). Alternatively, map patterns may suggest anomalous down-to-the-east displacements. On the basis of reconnaissance mapping, this structurally disrupted zone has been traced southeastward to the base of exposures at Antler Ridge. In the area directly south of drill hole USW UZ-16 numerous northwest-trending structures and (or) conspicuous lineaments have been mapped by Scott and Bonk (1984; fig.5).

INTERPRETATIONS

The Ghost Dance fault is the dominant fault in a structural system composed of minor north-trending west-side-down steeply dipping faults that extends over a width of nearly 366 m (1200 ft). Northward extension of our mapping at a scale of 1:240 reveals localities where closely spaced northwest-trending fractures, northwest-trending separations of lithostratigraphic units, near-horizontal slickensides, subtle mullion structures, and northwest-trending breccia appear to dominate the structural style. Preliminary analysis of the eastward extension of our mapping suggests the presence of a northwest-trending zone that shows either anomalous right lateral or anomalous east-side-down displacements, an abrupt increase in dip of foliation, and abrupt variation in the erosional thickness of the upper cliff zone. These relationships occur within a northwest-trending structural zone that is at least 274 m (900 ft) wide and is herein referred to as the "Sundance fault system". We propose to name the most conspicuous through-going structure, located near the middle of the system, the "Sundance fault" (fig 5). The "Sundance fault system" documents the presence of northwest-trending strike-slip structural features within the central structural domain of the central block. On the basis of structural lineaments and concentrations of

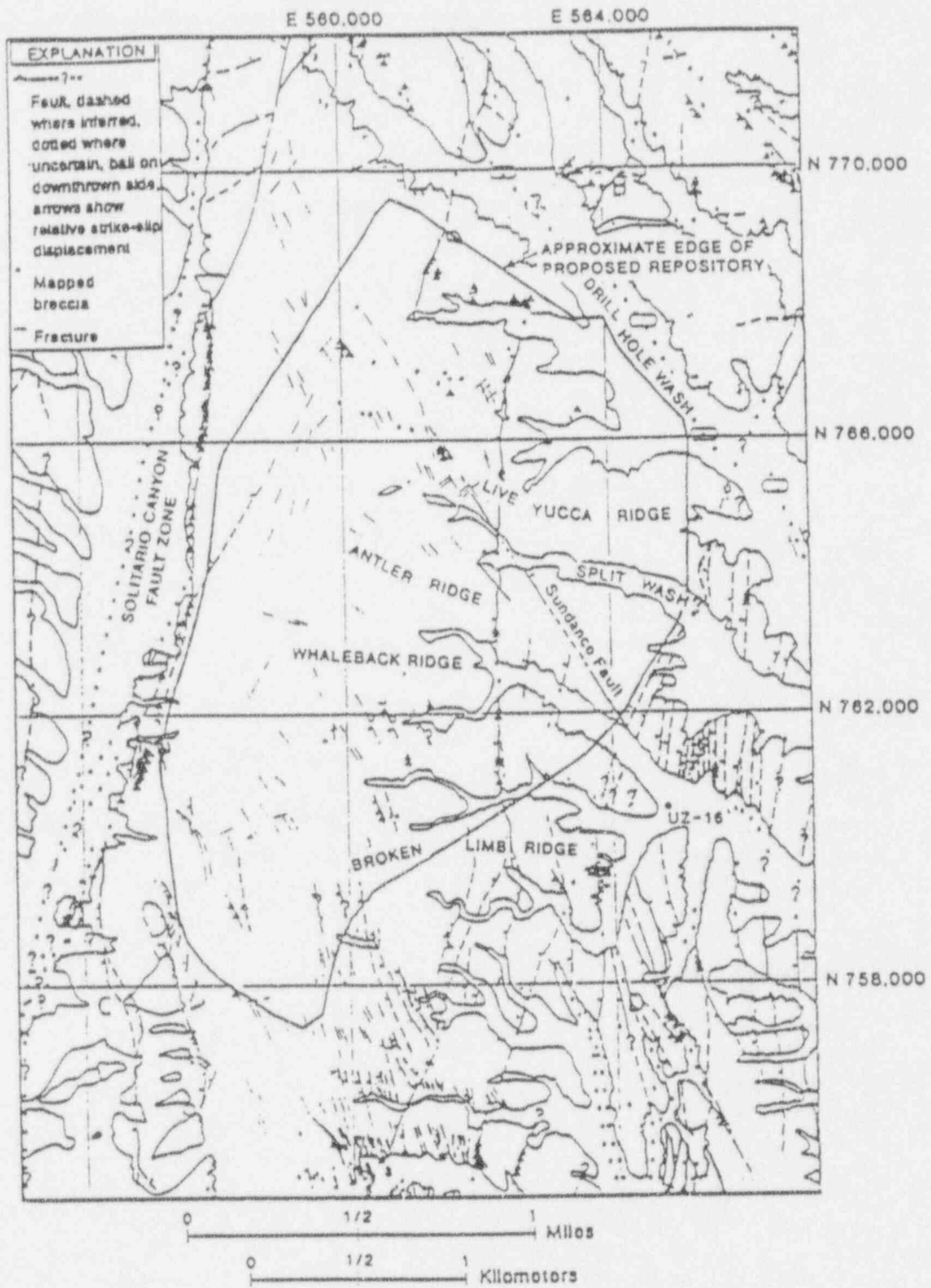


Figure 5.--Map of Yucca Mountain showing the location of the Sundance Fault relative to structural features mapped by Scott and Bonk (1984), and location of USW UZ-16 drill hole.

brecciated rock (initially identified by Scott and Bonk(1984); fig. 5), our detailed mapping, and reconnaissance observations made outside of our mapped area, this zone appears to extend northwestward across the potential repository area. To the southeast, the Sundance fault system appears to project into a conspicuous set of northwest-trending faults that occurs directly southeast of the southeastern margin of the potential repository area (fig. 5). If these previously mapped structural features are the northwestern and southeastern extensions of this same northwest-trending system, it may extend over a distance of at least 3 km (1.9 mi, fig. 5).

Geometric relations between attitudes of lithostratigraphic units, fault slips, and topography have resulted in map patterns that are incompletely understood. Relative age relations between the "Sundance fault system" and the Ghost Dance fault system also remain unresolved. Some field relations suggest that the strike of the north-trending fault system was locally influenced by a pre-existing northwest structural fabric. Other field observations suggest that steeply dipping faults of the Ghost Dance fault system may be displaced in an apparent right lateral sense by at least 52 m (170 ft).

Additional detailed mapping, particularly along east-west trending profiles, in concert with reconnaissance mapping along inferred northwest and southeast extensions will significantly help clarify map patterns, relative age relationships of fault systems, and terminations of the "Sundance fault system".

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ATTACHMENT #5

**SIGNIFICANCE AND CHARACTERISTICS
OF THE GHOST DANCE AND SUNDANCE
FAULT SYSTEMS AT YUCCA MOUNTAIN**

**Mark C. Tynan
U. S. Department of Energy
May 2, 1994**

SIGNIFICANCE OF THE GHOST DANCE AND SUNDANCE FAULTS, SITE CHARACTERIZATION

**GHOST DANCE FAULT AND ASSOCIATED FRACTURE
FEATURES RECOGNIZED FOR 10 YEARS; DETAILED
MAPPING IN SMALL AREA DURING LAST TWO YEARS**

**SUNDANCE FAULT : ZONE OF FAULTING AND
FRACTURING APPARENTLY COINCIDING WITH
FRACTURE/FAULT TRENDS MAPPED 10 YEARS AGO;
DETAILED MAPPING IN RESTRICTED AREA WITHIN LAST 6
MONTHS (SCALE = 1": 20')**

**ESF N/S MAIN DRIFT WILL INTERSECT BOTH
FEATURES**

**SURFACE AND SUBSURFACE TESTING
PROGRAMS ESTABLISHED FOR EXAMINATION OF THESE
AND OTHER SIMILAR FEATURES**

**SITE SUITABILITY ISSUE: TOO EARLY IN SITE
CHARACTERIZATION TO DETERMINE IMPACT; LIKELY
SIMILAR FEATURES WILL BE FOUND WITH CONTINUED
SBT AND ESF PROGRAMS**

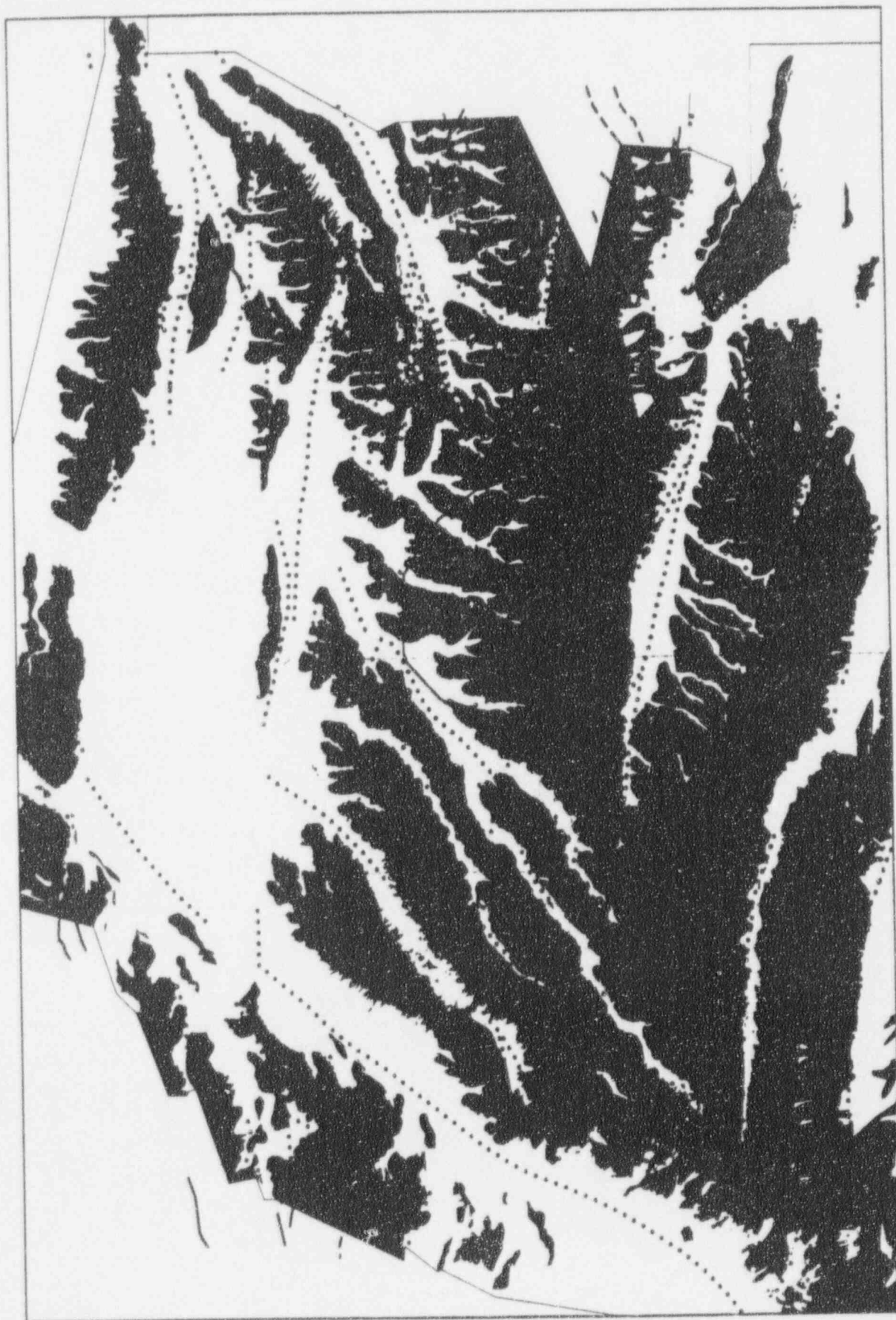
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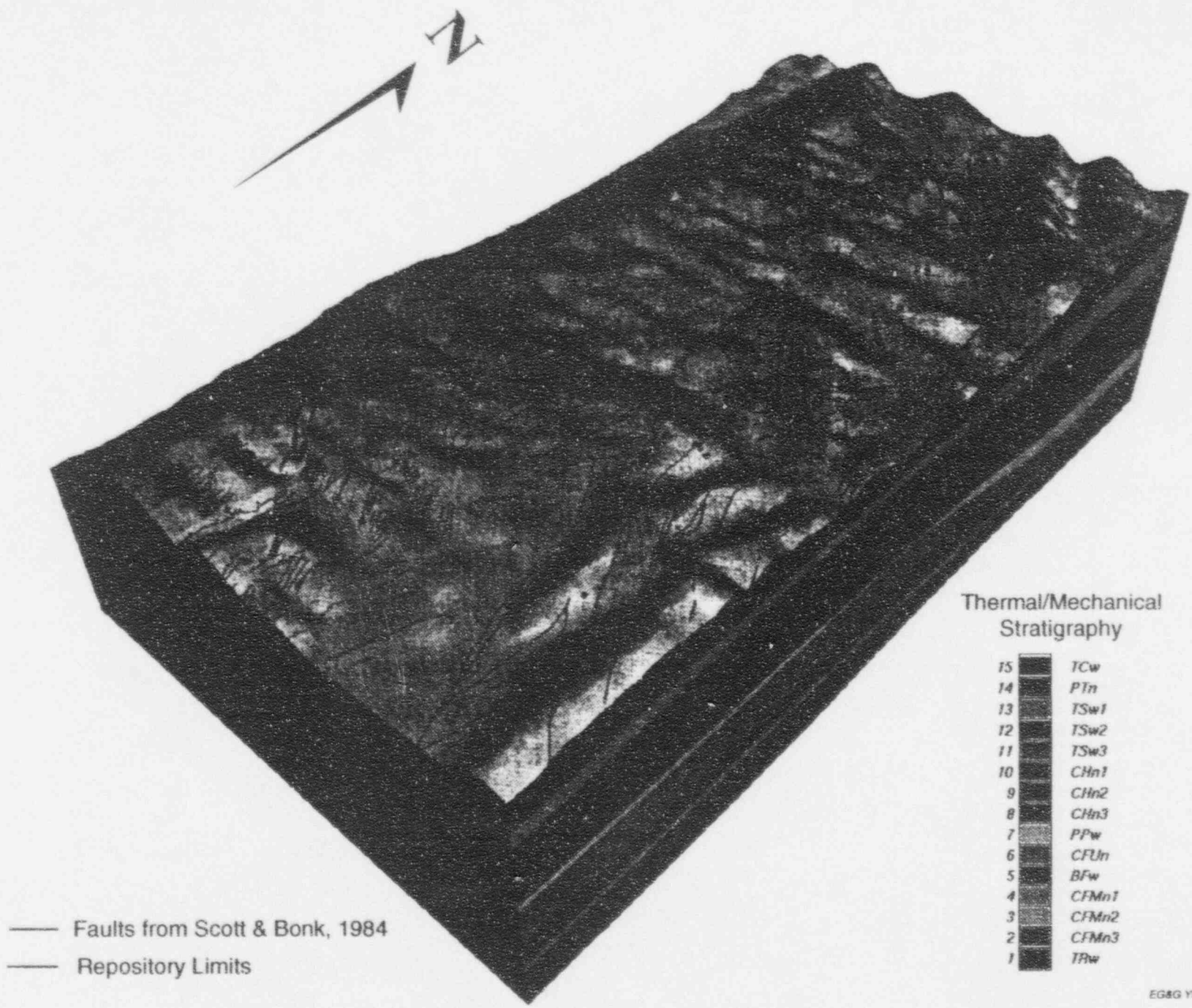
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SIGNIFICANCE

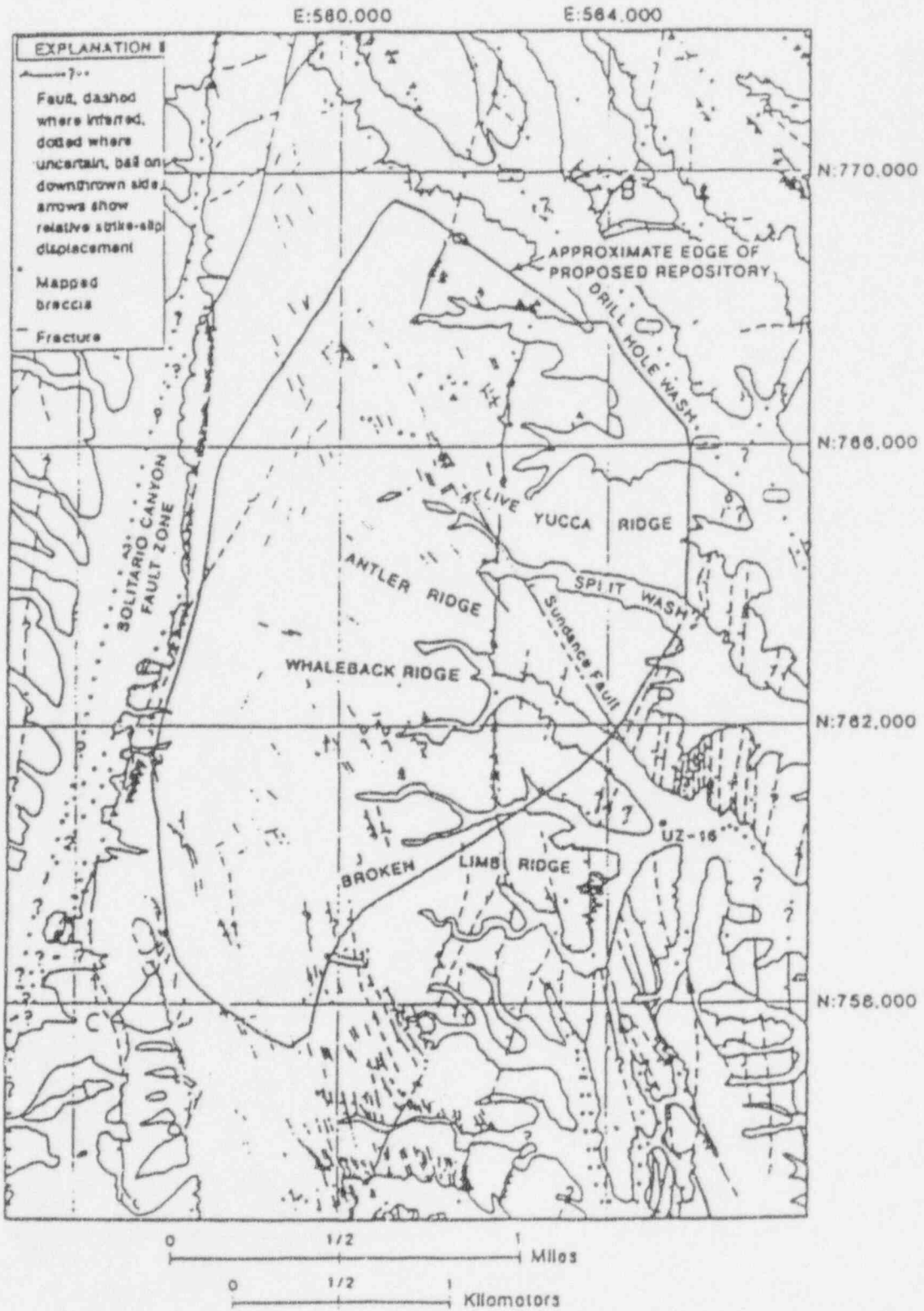
SITE SUITABILITY CONTINUED

- REPOSITORY AREA OR SIZE/CAPACITY MAY BECOME AN ISSUE IF PROBLEMS ARE ENCOUNTERED WITH PERFORMANCE OF THE NATURAL BARRIER SYSTEM.
- TESTING OF THE PERFORMANCE OF THE NATURAL BARRIERS, FAULTS, ETC., WILL REQUIRE SUBSURFACE EXPOSURES AND TESTING IN THE ESF.
- PERFORMANCE EVALUATION VIA TSPA WOULD FOLLOW TESTING AND EVALUATION OF THE NATURAL SYSTEM IN THE ESF
- THUS, IT IS TOO EARLY TO ADDRESS SUITABILITY ISSUE





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Map of Yucca Mountain showing the location of the Sundance Fault relative to structural features mapped by Scott and Bonk, and location of USW UZ-16 drill hole.

INFORMATION COPY

CHARACTERISTICS OF THE GHOST DANCE - SUNDANCE FAULT / FRACTURE SYSTEMS

SOME GENERAL COMMENTS AND OBSERVATIONS CONCERNING STRUCTURE OF THE YUCCA MOUNTAIN AREA

- REGIONAL SETTING
- 3-D GEOLOGIC MODELS
- SCOTT AND BONK
- SE PLUNGING SYNCLINAL CHARACTER OF YM
- TOPOGRAPHIC EXPRESSIONS OF KEY STRUCTURAL FEATURES: WATCH THE HORIZON NEXT TIME
- NW/SE FAULTS, N/S ORIENTED FAULTS, E/W ORIENTED FEATURES, SURFACE DRAINAGE PATTERNS

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CHARACTERISTICS OF THE GHOST DANCE FAULT AND FRACTURE SYSTEM

FIELD MAPPING PROGRAM

- USGS/SAIC SCALE = 1":20'(240")
- FIELD MAPPING 1992, 1993, SEE ATTACHED MAP
- MAPPING FOR FY'94, FOCUS ON COMPLETION OF '93
MAPS AND PAVEMENT STUDY
- PAVEMENT STUDY AT GDF, MAP AT 2 SCALES
a) 1" : 20' BY SAIC, b) 1" : 5' BY BUR. REC.
- MAPPING FOR OUTYEARS: ASSESSMENT OF MAPPING
STRATEGY IN PROGRESS
 - » MAY MAP AT COARSER SCALE DURING FY'94 AS
TEST TO DETERMINE EFFICACY OF SCALE
CHANGE.

HOPE TO CONDUCT FIELD RECON, HIGH-GRADE MAPPING
TARGETS, IDENTIFY AND MAP ADDITIONAL FEATURES

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**SUNDANCE/GHOST DANCE
MAPPING EXERCISE**

CONDUCTED UNDER

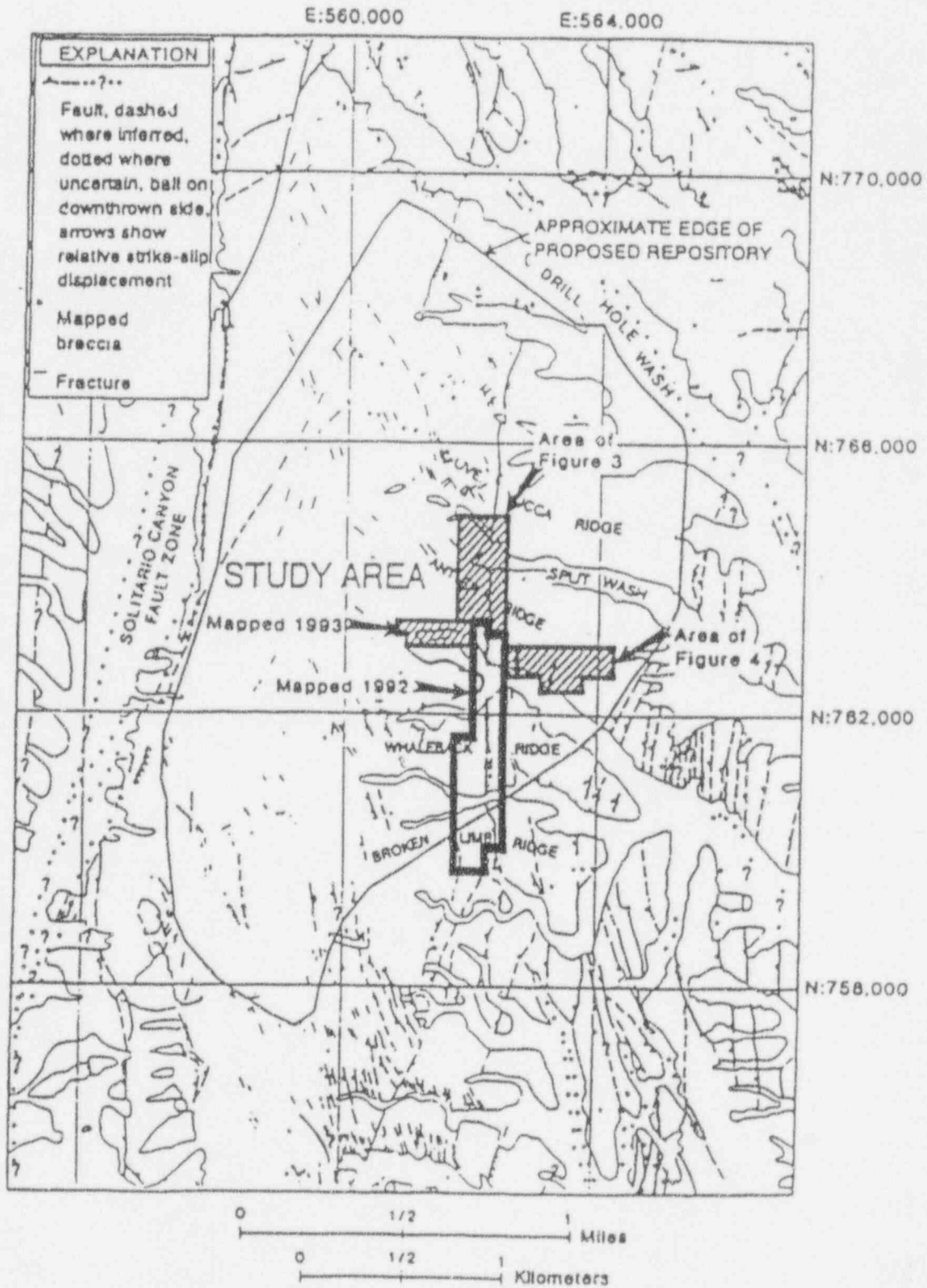
**STUDY 8.3.1.4.2.2,
Structural Features in the Site Area**

**Richard Spengler, group leader/section chief for
the Rock Characteristics Program,
United States Geological Survey**

These presentation materials constitute synthesis of preliminary data generated by R. Spengler and coworkers. Any misrepresentation or misinterpretation of these data is the responsibility of M. C. Tynan.

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Map of Yucca Mountain showing the distribution of structural features within and surrounding the proposed repository area and the location of study areas along the southern and central parts of the Ghost Dance fault (structural features from Scott and BonR).

CHARACTERISTICS OF THE GHOST DANCE FAULT AND FRACTURE SYSTEM

RECOGNITION CRITERIA/CHARACTERISTICS

- SERIES OF MINOR NORTH TRENDING PARALLEL TO SUBPARALLEL FAULTS WITH SMALL OFFSETS FLANKING MAIN GHOST DANCE FAULT
- CONSTITUTES 360m (1200') WIDE SYSTEM
- SURFACE LINEAMENTS ON AIR PHOTOS
- TOPOGRAPHIC EXPRESSION EVIDENT
- BRECCIA AND FRACTURE EXPOSURES
- APPARENT VERTICAL OFFSET, MAIN GHOST DANCE 10s OF METERS; MINOR FAULTS WITH FEW METER RANGE OFFSETS

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CHARACTERISTICS OF THE SUNDANCE FAULT AND FRACTURE SYSTEM

RECOGNITION BASED UPON

- ABRUPT BEDDING DIP CHANGES
- CLOSELY SPACED NW SHEARS , SMALL OFFSETS
- BRECCIATION ASSOCIATED WITH NW SHEARS
- DECREASE IN APPARENT VERTICAL OFFSET ON GDF
- APPARENT R LATERAL OFFSET OF GDF, ANTLER RIDGE
- EVIDENCE OF NE-SIDE-DOWN OFFSETS

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CHARACTERISTICS OF THE SUNDANCE FAULT AND FRACTURE SYSTEM

274m (900') WIDE SYSTEM

NEAR VERTICAL DIP

N30-40W TRENDING

OFFSETS GDF, APPARENT RIGHT LATERAL
BY 50m+ ON N SIDE ANTLER RIDGE

RECOGNIZED IN SURFACE MAPPING WITHIN
EXPOSED TIVA CANYON TUFF

TRENCHING DEMONSTRATES NO OFFSET
IN LATEST PLEISTOCENE TO HOLOCENE AGE
UNITS

DRAFT

"INFORMATION COPY"

SITE CHARACTERIZATION PLANS: KNOWN, NEWLY RECOGNIZED, AND YET-TO-BE- RECOGNIZED FAULT SYSTEMS

TECTONICS

- PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA, I.E., THE LIKELYHOOD OF OCCURRENCE OF AN EVENT) WILL ADDRESS DISPLACEMENT AND GROUND MOTION HAZARDS FOR FEATURES AT ALL SCALES**

- PLANNING TO ASSESS QUATERNARY ACTIVITY**
 - » APPEARS SUITABLE AGE QUATERNARY DEPOSITS ARE LACKING WITHIN THE REPOSITORY AREA FOR DEFINITIVE ASSESSMENT**
 - » ASSESSMENT MUST BE BASED ON HISTORICAL EQ DATA, MODELING, AND ANALOG DATA FROM SITE AREA**

- EXAMPLE: PROBABILITY OF EVENT (EARTHQUAKE) OCCURRING ON SOLITARIO OR PAINTBRUSH FAULT = 1/10,000 TO 1/100,000 ANNUAL PROB.**
 - » GDF AND SDF MUCH SMALLER FEATURES, EXPECTED MUCH LOWER PROBABILITIES OF OCCURRENCE**

TECTONICS (CONTINUED)

DOE maintains :

- Reasonably available technology allows for design of tunnels to accommodate fault displacement**
- Will avoid significant (Type I) faults in placing of waste containers**
- Presence of Type I fault (subject to displacement; may affect design/performance structures systems components) is not a disqualifier**
- Investigations are to be conducted to determine if GDF or SDF are Type I features; will map and determine length, etc.; will encounter and test, if present, in ESF**
- Robust MPC concept; identify design concerns; perform design analysis**
- PA process model to be developed to determine effects, if any**
- Develop fault length screen**

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SITE CHARACTERIZATION PLANS: KNOWN, NEWLY RECOGNIZED, AND YET-TO-BE- RECOGNIZED FAULT SYSTEMS

HYDROLOGY

- SURFACE AND SUBSURFACE TESTING PROGRAM ESTABLISHED TO UNDERSTAND HYDROLOGIC CHARACTERISTICS OF FAULTS ENCOUNTERED AT THE SITE
- FRACTURE DATA BEING COLLECTED FROM
 - » SURFACE MAPPING EXERCISES
 - » ESF MAPPING STUDY
 - » BOREHOLE CORE DATA
- FRACTURE INFORMATION AND HYDROLOGIC CHARACTERISTICS WILL BE INCORPORATED INTO
 - » HYDROLOGIC MODELS
 - » DESIGN OF ESF
 - » ROLL INTO PA ANALYSIS

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SITE CHARACTERIZATION PLANS: KNOWN, NEWLY RECOGNIZED, AND YET-TO-BE- RECOGNIZED FAULT SYSTEMS

DESIGN OF ESF AND REPOSITORY

- ENHANCED ESF DESIGN IS FLEXIBLE AND ALLOWS FOR UTILIZATION OF RAIL DELIVERY SYSTEM IN THE POTENTIAL REPOSITORY**
- ROCK QUALITY INFORMATION WILL BE INCORPORATED INTO ESF DESIGN ANALYSIS IN DEVELOPMENT OF TUNNEL CONSTRUCTION SUPPORT SYSTEMS**
- SUNDANCE AND GHOST DANCE BOTH WILL BE EXAMINED WITH CURRENT DESIGN PLAN FOR EXPLORATORY STUDIES; HYDROLOGY AND OTHER CHARACTERIZATION STUDIES WILL BE PERMITTED BY ESF LOCATION FOR BOTH FEATURES**
- NO REGULATORY REQUIREMENT EXISTS FOR STANDOFF DISTANCES IN DESIGN OF THE ESF OR REPOSITORY; STANDOFF IS A DOE ASSURANCE**
- NO MAJOR IMPACT ENVISIONED FOR ESF**

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"INFORMATION COPY"

TOTAL SYSTEM PERFORMANCE ASSESSMENT: FAULTS AND SITE CHARACTERIZATION PLANS

TSPA WILL TREAT ALL ELEMENTS OF THE SYSTEM

- TOO EARLY IN SITE CHARACTERIZATION PROGRAM TO DETERMINE IMPACT ON PA ISSUES, GIVEN GDF AND SDF SYSTEMS. ADDITIONAL SIMILAR FEATURES LIKELY.**
- AWAIT CHARACTERIZATION OF FAULT FEATURES ON INDIVIDUAL BASIS, MODEL DEVELOPMENT AT SUBSYSTEM AND PROCESS LEVELS, AND ULTIMATELY, TSPA FOR DETERMINATION OF SITE SUITABILITY**

"PRELIMINARY DRAFT"

SIGNIFICANCE OF THE GHOST DANCE AND SUNDANCE FAULTS, SITE CHARACTERIZATION

SUMMARY:

- These fracture and fault trends have been recognized for ten years; detailed mapping began in 1992
- Additional features may be encountered
- Hydrology testing program well established
- Tectonic implications: low probability of significant earthquake on these minor faults
- No Design impact expected for ESF
- North/South main drift will intersect both features; surface and ESF testing expected
- Determination of site suitability will follow rigorous planned testing program, and Total System Performance Assessment (TSPA)

“PRELIMINARY DRAFT”

CURRENT ACTIVITIES

o SITE CHARACTERIZATION FOR THE ESF

The current site characterization effort for the ESF uses boreholes, trenches, and geophysics to characterize the rocks that the ESF will be excavated in. The effort considers known faults and recognizes that unknown faults may exist. Where faults may pose a particular problem in design and construction, such as the Bow Ridge Fault, special efforts are made in characterization. Site characterization for the ESF will continue as the ESF is excavated, with special attention paid to faults. Some activities have already taken place in the Starter Tunnel, including mapping and construction monitoring. Geophysical methods may prove to be useful in finding some of the heretofore undiscovered/unknown faults.

o DESIGN & CONSTRUCTION OF THE ESF

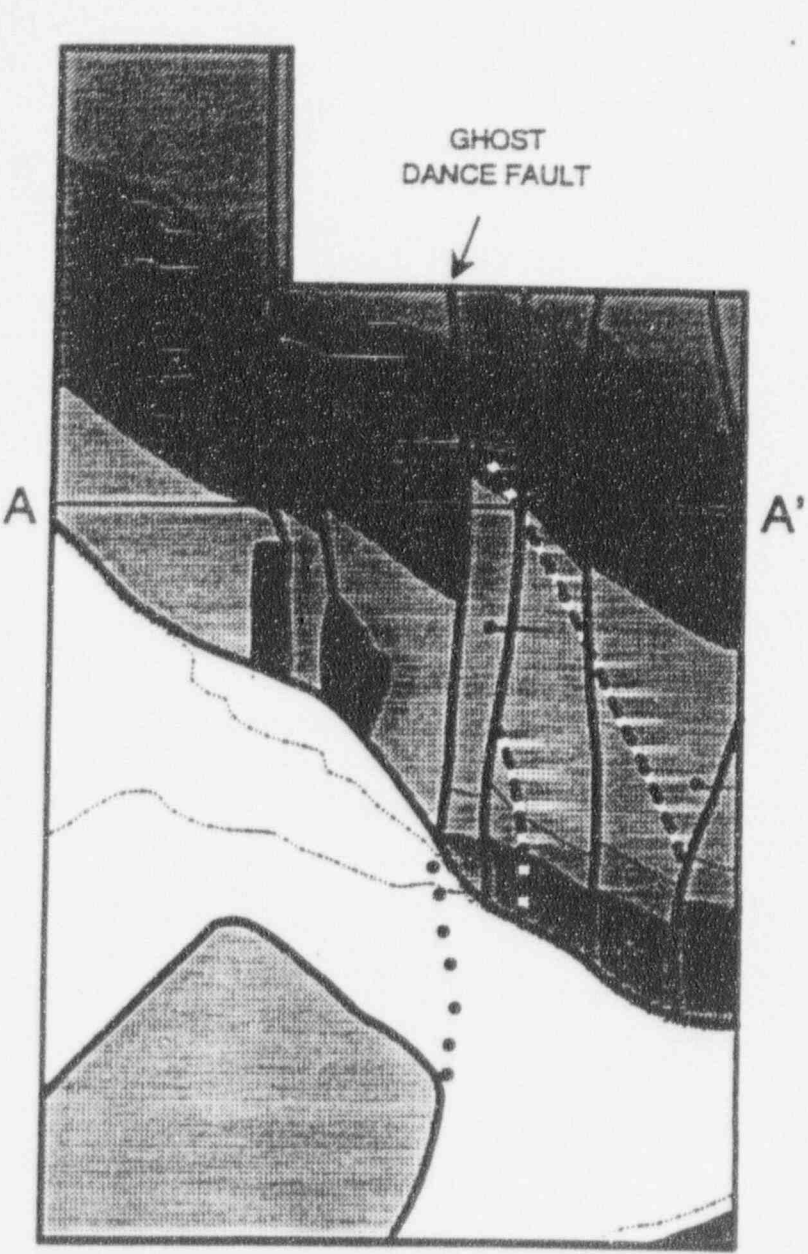
The design & construction efforts for the ESF also consider known and unknown faults. Again, the Bow Ridge Fault serves as an example. There is more tunnel support designed for this zone, and special consideration is being given to the excavation methods in this zone.

o SITE CHARACTERIZATION IN THE ESF








The site characterization efforts to be conducted in the ESF always recognized that faults would be encountered, and that some of these faults would be unexpected. Many activities in the ESF will concentrate on faults because of the potential impact of faults on the performance of the proposed repository. One specific activity is 8.3.1.2.2.4.10, *Hydrologic Properties of Major Faults Encountered in the ESF*. Nine faults that are expected to be to be intersected by the ESF are listed in the planning document for this activity, as well as a tenth item "All major faults not previously identified". In addition, activities already started in the Starter Tunnel, such as mapping and construction monitoring, will continue in the ESF with special attention paid to faults.


Table 1
Tiva Canyon Textures related to Stratigraphic Position
(South Flank of Antler Range, Yucca Mountain, Nevada)
by F.R. Singer and F.M. Byers, Jr.


Zone	Shard Morphology	Devitrification Textures		Notes: (including pumice)
		Shard Wall	Shard Body	
Upper Cliff	- Slightly curved to straight	- Indistinct (similar to clinkstone)	- Microgranular	- Coarse granophyre and vapor-phase minerals line pumice cavities - First appearance of biotite and plagioclase - Moderately to densely welded - Phenocryst content increases upward to 10%
Upper Lithophysal	- Slightly curved to straight	- Indistinct (similar to clinkstone)	- Mottled light and dark gray microgranular - Light areas are microcrystalline, axiolic, and coarsely microgranular. These areas also contain abundant tridymite-filled vesicles - Dark areas are charged with opaque oxides	- Pumice contains coarse granophyre, tridymite and alkali feldspar - First appearance of clinopyroxene - Moderately welded - Phenocryst content increases upward to 5%
Clinkstone	- Slightly curved to straight	- Indistinct, thick jackets of cryptocrystalline and dark, grainy aggregates outline former shard boundaries	- Microgranular and coarsely axiolic - Decrease in brown, finely fibrous axiolic devitrification	- Increase in disseminated fine-grained opaque oxides - Groundmass has a grainy or dirty appearance - Destruction of primary shard boundaries - Moderately welded - Phenocryst content 1.0 - 2.0%
Lower Lithophysal	- Slightly curved to straight - Y-shaped with acute intrashard angle (~60°)	- Distinct, ranging from thick opaque cryptocrystalline to thin filamentous walls (these contrasting thin and thick-walled shards impart a patchy [mottled] aspect to the groundmass)	- Finely microcrystalline to coarsely axiolic - Increase in brown, finely fibrous axiolic devitrification	- Marked flattening of shards (moderately welded) - Dense, dark brown, microcrystalline clots are scattered throughout the groundmass - First appearance of tridymite-filled microvesicles - Phenocryst content 1.0 - 2.0%
Heckly	- Curved - Irregular - Y-shaped with large intrashard angle (>60°)	- Distinct, thin, cryptocrystalline, filamentous walls	- Finely microcrystalline to coarsely axiolic (devitrification is contained within shard walls) - Brown, finely fibrous axiolic (devitrification cross-cut shard walls)	- Weak to moderate compaction (welding) with slight preferred orientation of shards - Phenocryst content 1.0 - 2.0%




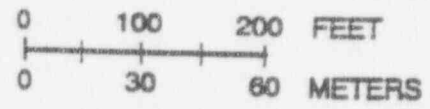
TIVA CANYON MEMBER

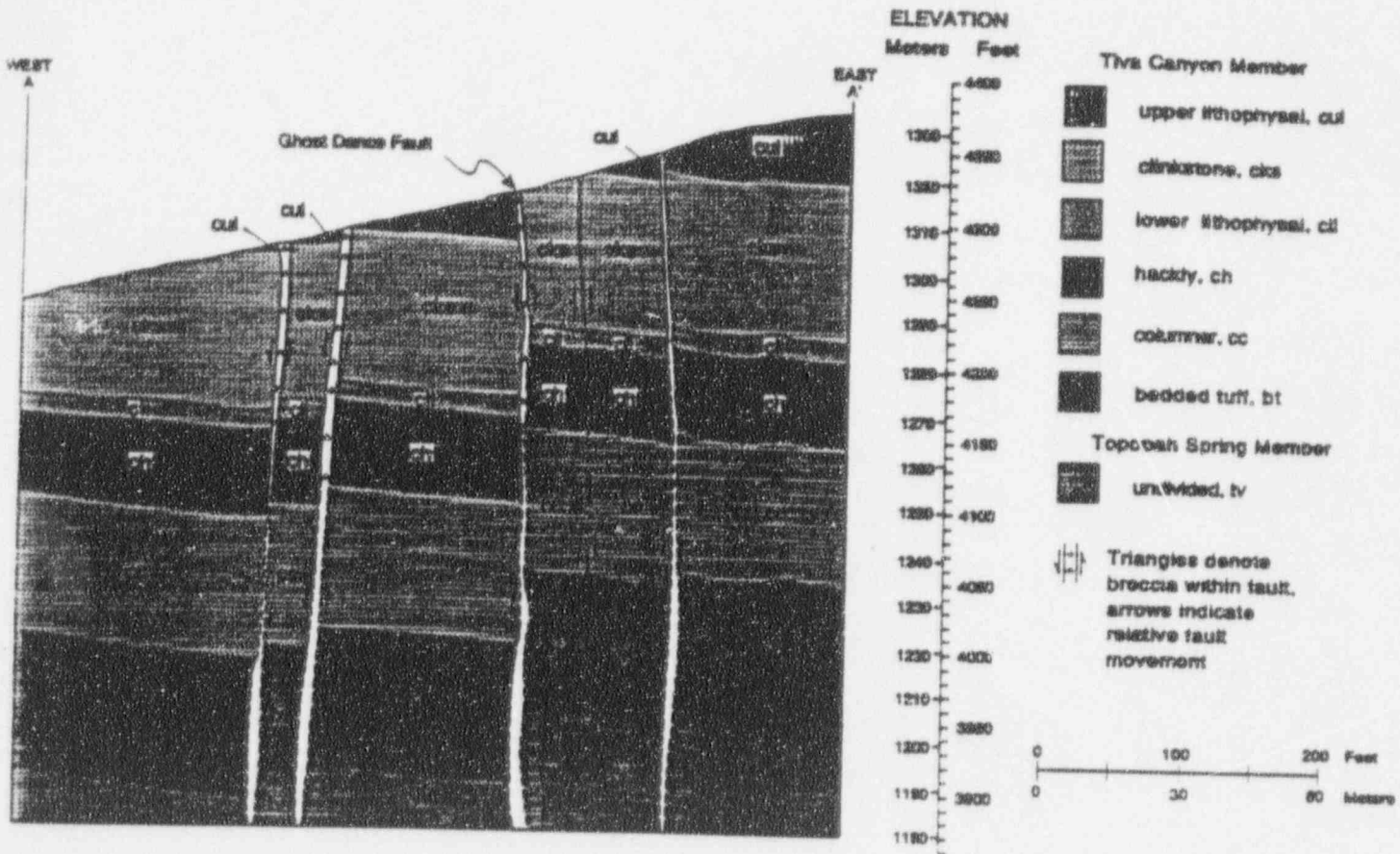
-  alluvium
-  rockslides
(Upper cliff lithology)
-  upper cliff
-  upper lithophysal
-  clinkstone
-  lower lithophysal
-  hackly

Fault, ball and bar on  down-thrown side; dashed where breccia occurs, but no offset identified; dotted where concealed

Dip of layering 

Major drainage 





ATTACHMENT # 7

STATUS OF U.S. GEOLOGICAL SURVEY GEOLOGIC SURFACE MAPPING OF STRUCTURAL FEATURES

The Rock Characteristics Section of the U.S. Geological Survey - Yucca Mountain Project Branch (USGS-YMPB) has completed the first stage of review of detailed surface geologic mapping at Yucca Mountain. Some preliminary conclusions can now be finalized; others have been identified as needing further work.

The completed technical review confirms that the detailed mapping is very precise. The location of outcrops and other features can be confirmed independently within a meter.

The review confirms that the Ghost Dance fault zone consists of a main fault, as shown by Scott and Bonk (1984), and several small subparallel faults of minor displacement. The latter were previously unrecognized. The fault zone can locally be shown to be at least 120m wide and locally may be as wide as 400m.

The review confirms the existence of a previously unrecognized northwest trending fault (the Sundance Fault). And the review confirmed that a microstratigraphy exists within the Tiva Canyon tuff that can be used to define structural features.

Several important questions, however, remain to be resolved. How does the current microstratigraphy compare to that of Scott and Bonk (1984), and is it parallel to bedding? What is the actual length, width and offset of the Sundance Fault or fault zone? Are all of the small discontinuities shown on the detailed map properly interpreted? Can the width of the Ghost Dance Fault zone be defined or is it a matter of semantics? That is, are minor north-trending faults a common feature of the mountain such that the west edge of the Ghost Dance zone grades into the east edge of the Solitario Canyon zone?

The final conclusions drawn from the reviewed work ^{to date} do not suggest major new seismic or tectonic findings. The findings may have, however, significance for fluid flow (both gaseous and liquid) into or out of the potential repository and Exploratory Studies Facility (ESF) design/construction. The USGS-YMPB would like to meet sometime in June with hydrogeologic modeling, performance assessment and ESF design/construction staff to discuss potential significance to site suitability of confirmed results and unconfirmed- but-likely results (based on converging lines of evidence from surface mapping, surface geophysics and vertical seismic profiles.) At this time the unconfirmed results suggest that the minor faults being mapped at the surface do extend to depth.

From L. Hayes...

2 May 94
-9-

Table 1. Hierarchy of stratigraphic and symbol nomenclature (Sawyer and others, in press).

<u>Previous Nomenclature</u>	<u>Revised Nomenclature</u>
Paintbrush Tuff (Formation)	Paintbrush Tuff Group
Tiva Canyon Member	Tiva Canyon Tuff (Formation)
Yucca Mountain Member	Yucca Mountain Tuff (Formation)
Pah Canyon Member	Pah Canyon Tuff (Formation)
Topopah Spring Member	Topopah Spring Tuff (Formation)

Stratigraphic and symbol hierarchy

- | | |
|---|--|
| <ul style="list-style-type: none"> <u>1</u> Age <u>2</u> Group <u>3</u> Formation <u>4</u> member (informal)^a
change in magma chemistry
or eruption dynamics <u>5-6</u> zone <u>6-7</u> subzone <u>7-8</u> interval | <ul style="list-style-type: none"> <u>T</u> Tertiary <u>p</u> Paintbrush Group <u>t</u> Topopah Spring Tuff <u>r</u> crystal-rich member
 <u>v</u> vitric <u>l</u> vitrophyre subzone |
|---|--|

Example: Tpcplnc2- Tiva Canyon Tuff, crystal-poor (member), lower nonlithophysal (zone), columnar (subzone), clay-altered pumice (interval)

^a Age to member hierarchy are proposed by Warren and others (1989a) and Sawyer and others (in press); zone, subzone, and interval proposed in this report.

PRELIMINARY DRAFT

From D. Buesch's presentation... 2 May 94

Zones of welding (W)

- Moderately to Densely (o-lithophysae)
- Partially to moderately
- Partially
- Nonwelded

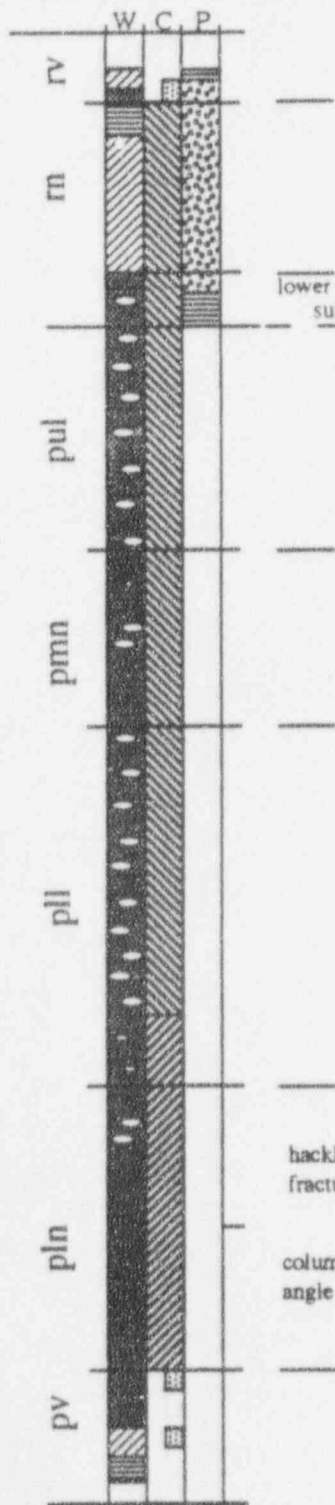
Zones of crystallization (C)

- Devitrified / Devit. + vapor-phase mins.
- Vitric / Vitric + vapor-phase mins.

Phenocryst content (P)

- > 10 percent
- 5 - 10 percent
- < 5 percent

Tiva Canyon Tuff (Tpc)
(100 - 150 m thick)



Crystal-rich member
vitric zone

nonlithophysal zone

lithophysal zone

Crystal-poor member

upper lithophysal zone

mostly low-angle fractures with rough fractures

middle nonlithophysal zone

mostly high-angle fractures with very smooth surfaces

lower lithophysal zone

mostly low-angle fractures with rough fractures

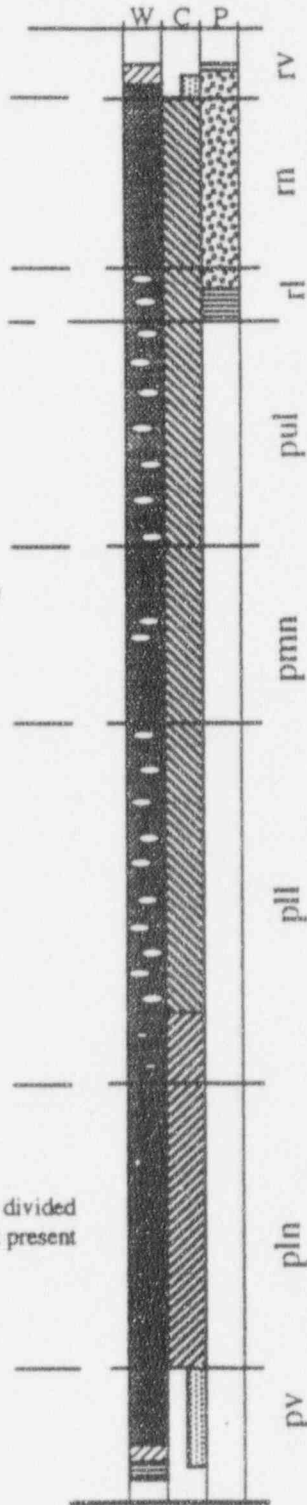
lower nonlithophysal zone

hackly subzone - mostly low-angle fractures with very rough surfaces

columnar subzone - mostly high-angle fractures with smooth surfaces

vitric zone

Topopah Spring Tuff (Tpt)
(250 - 350 m thick)



PRELIMINARY DRAFT

PRELIMINARY DRAFT

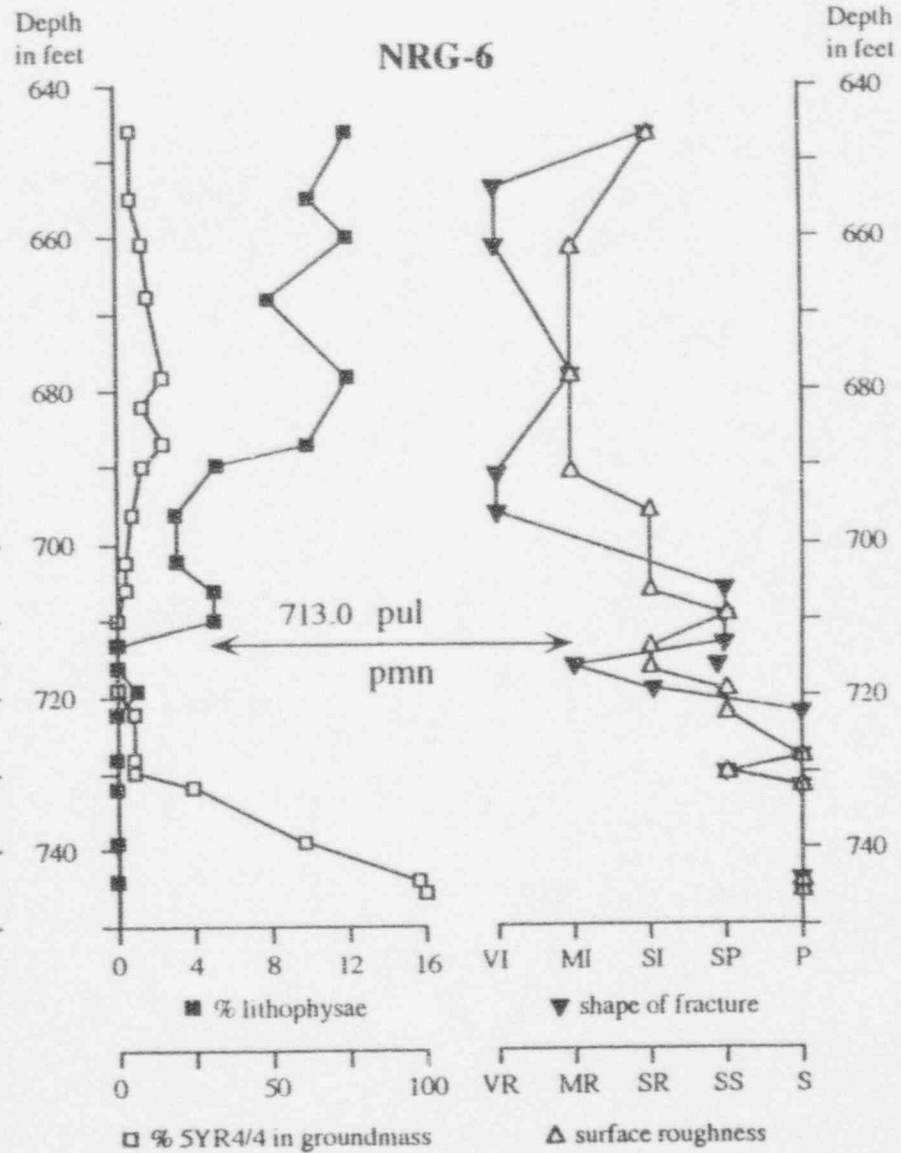
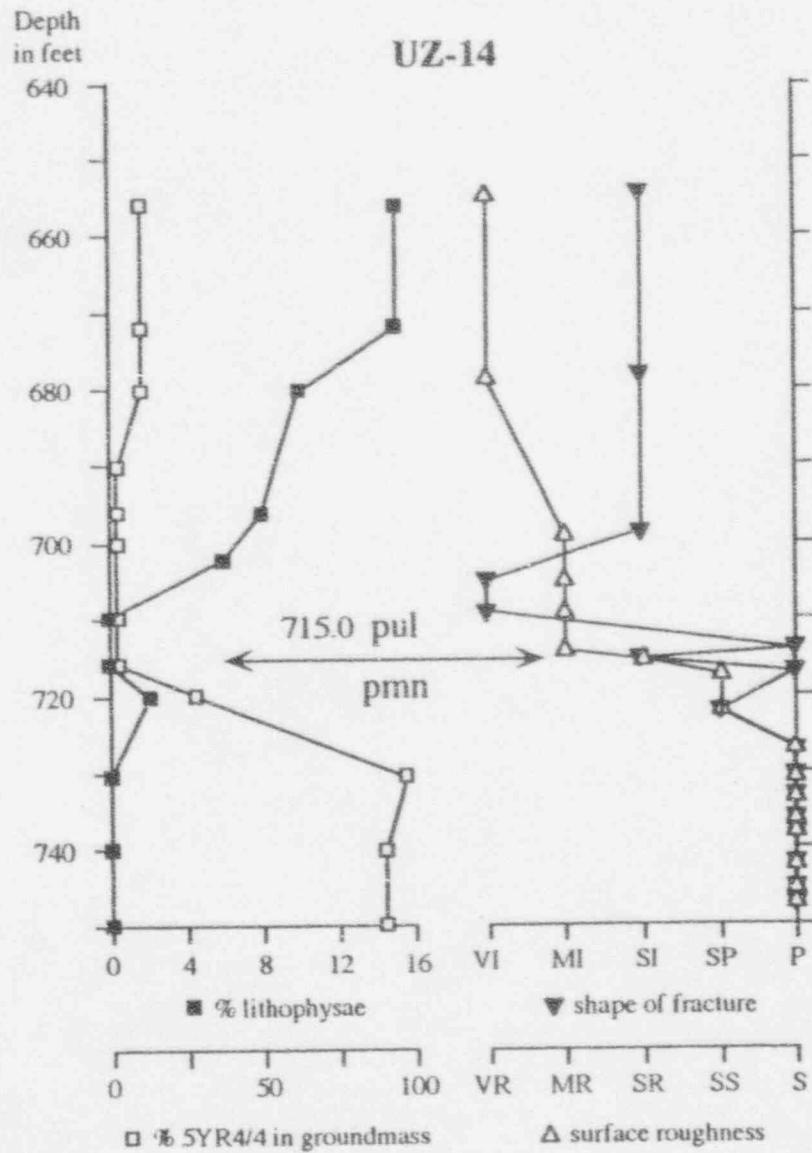


Table 5. Correlation of lithologic, thermal-mechanical, and hydrogeologic units on the basis of the revised lithostratigraphy.

Lithologic units	Thermal-mechanical units	Hydrogeologic units
PAINTBRUSH GROUP Tiva Canyon Tuff (Tpc) crystal-rich vitric nonwelded (rv3) moderately (rv2)	Undifferentiated overburden (UO)	Unconsolidated Surficial Materials (UO)
vitrophyre (rv1) nonlithophysal crystal-poor upper lithophysal middle nonlithophysal lower lithophysal lower nonlithophysal hackly columnar	Tiva Canyon welded unit (TCw)	Tiva Canyon Unit welded hydrogeologic unit (TCw)
vitric vitrophyre (pv3) ¹ moderately welded, devitrified (pv2) partially welded to nonwelded, vitric (pv1)	Upper Paintbrush nonwelded unit (PTn)	Paintbrush unit nonwelded hydrogeologic unit (PTn)
pre-Tpc bedded tuff Yucca Mountain Tuff (Tpy) pre-Tpy bedded tuffs Pah Canyon Tuff (Tpp) pre-Tpp bedded tuffs		
Topopah Spring Tuff (Tpt) crystal-rich vitric nonwelded welded (rv3) moderately welded (rv2) incipient devitrified		
vitrophyre (rv1) nonlithophysal lithophysal	Topopah Spring welded unit lithophysae-rich (TSw1) ²	Topopah Spring welded hydrogeologic unit (TSw)
crystal-poor upper lithophysal		
middle nonlithophysal lower lithophysal lower nonlithophysal	Topopah Spring welded unit lithophysae-poor (TSw2)	
vitric vitrophyre (pv3)	Topopah Spring welded unit vitrophyre (TSw3)	
moderately welded (pv2) nonwelded (pv1)	Calico Hills and Lower Paintbrush nonwelded unit (CHn1)	Calico Hills nonwelded hydrogeologic unit (CHn)
CALICO HILLS FORMATION		

PRELIMINARY DRAFT

Notes:

- Where preserved, the base of the vitrophyre subzone forms the base of the TCw thermal-mechanical and hydrogeologic units.
- The TSw1-TSw2 contact is where the amount of lithophysae changes from greater than to less than 10 percent of the total rock volume (Ortiz and others, 1985). This change in the amount of lithophysae occurs up to 30 meters above the upper lithophysal-middle nonlithophysal zone contact as identified by multiple criteria.

PRELIMINARY DRAFT

Field units (Spengler and others, in press)

Field units (Scott and Bonk, 1984)

Surface and subsurface units (this report)

caprock zone: (ccr)
not mapped in study area
15 % phenocrysts
(S > P > Q) (B > CP ≈ H) (Sp)
nonwelded to densely welded
vitric, but base is devitrified
red brown color: (5YR5/2)
mixed pumice

upper cliff zone: (cuc)
thickness: 10 - 35 m
(S > P) (B > H) (Sp)
euhedral oxy-biotite in matrix
mixed pumice: ≤ 15 - 20 cm diameter
light gray (N8-9)
medium gray (N6)
very dark yellowish orange (10YR6/8)
ISRM Hardness: I
Subzones: (subzones not mapped)
7 - 15 % phenocrysts
Roughness coefficient: 7 - 18
subvitrophyre pumice-rich subzone
pumice-poor subzone
pumice-rich subzone
subzone not specified
Transition subzone:
6-10 m above contact
5 - 7 % phenocrysts
Roughness coefficient: 3 - 6
lithic clasts: light gray (N7) to moderate
red (5R5/4) (≤ 1 % of rock)
pumice: smaller and fewer than above
lithophysae: long axis = 3 - 100 cm
aspect ratio 1:1 - 3:1

caprock zone: (ccr)
thickness: 25+ m
15 % phenocrysts
(S > P > Q) (B > CP ≈ H) (Sp)
mixed pumice:
"more" mafic: medium light gray (N6)
(≤ 5 cm diameter)
"more" silicic: light gray to white (N8-9)
(≤ 30 cm diameter)

Subzones:
nonwelded subzone
includes partially welded
vitric, abundant mafic pumice
moderately welded devitrified base
vitrophyre subzone
abundant mafic pumice
brown devitrified subzone (5YR5/2)
abundant mafic pumice
yellow-brown devit. subzone (10YR6/2)
minor mafic pumice
brown-gray devit. subzone (5YR6/1)
minor mafic pumice
≤ 15 % lithophysae, ≤ 5 cm

upper cliff zone: (cuc)
thickness: 0 - 11 m
moderately to densely welded
rhyolitic: 12 - 15 % phenocrysts
(S > P) (B s) (Sp)
cognate pumice, 0.1 - 2 cm
5 - 10 % lithophysae, 10 - 50 cm

upper lithophysal zone: (cul)
thickness: 15 - 25 m
2 - 5 % phenocrysts
(S) (B > H) (Sp)
H in matrix, but not B
Roughness coefficient: 6-10
ISRM Hardness: II
pumice: mostly light gray (N8)
6 - 10 m from top, minor amounts of
very dark yellow brown (10YR6/8)
lithophysae: 30-50 %
0.5 - 30 cm, aspect ratio 1:1 - 3:1
subzone:
spherulites, 1mm dia., well developed
≈ 2 - 4 m-thick near base

upper lithophysal zone: (cul)
thickness: 5 - 35 m
rhyolitic: 10-12 % phenocrysts
(S) (B s) (Sp)
cognate pumice, 0.2 - 2.5 cm
10-20 % lithophysae, 10 - 30 cm
convolute with gray (N8) rims

crystal-rich unit: (cr...)
10-15 % phenocrysts
(S > P > Q) (B > CP ≈ H) (Sp)
B in matrix
mixed pumice: light gray (N8-9)
medium gray (N6)
very dark yellowish orange
(10YR6/8)

vitric zone: (crv...)
nonwelded to densely welded
Subzones:
non-welded to partially welded (v3)
moderately to densely welded (v2)
locally devitrified
vitrophyre (v1)

nonlithophysal zone: (crn...)
densely to partially welded
devitrified with vapor-phase minerals
small (≤ 3 mm) cavities in pumice and
matrix, these are not lithophysae
Subzones:
subvitrophyre transition (n4) (2.5YR5/2)
pumice-poor (n3) (10R4/2)
mixed pumice (n2) (10R6/1)
upper lithoph. transition (n1) (10R7/1)
8 - 12 % phenocrysts
minor lithophysae
≤ 10 % white pumice
very rare, very dark yellowish orange
(10YR6/8)

crystal-poor zones: (cp...)
≤ 5 % phenocrysts (S) (H > B) (Sp)
pumice: light gray (N8-9)
rare, very dark yellowish orange
(10YR6/8)

upper lithophysal zone: (cpul)
moderately to densely welded
devitrified with vapor-phase minerals
pumice: light gray (N8-9)
very rare, very dark yellowish orange
(10YR6/8)
lithophysae: 5 - 40 % of rock
10 - 30 cm diameter
1 - 5 mm-thick light-gray (N8) rims
high-angle fractures are rare
moderately rough surface fractures
Subzones:
spherulite-rich subzone (u1)
spherulites are well defined and
1 - 3 mm diameter
relatively smooth surface fractures
rare lithophysae
subzone is 2 - 4 m-thick and
1 - 3 m above base of cpul
lower transition interval of few small
lithophysae ≈ 1 - 3 m thick

clinkstone zone: (cks)
thickness: 20 - 30 m
2 - 5 % phenocrysts: (S)
Roughness coefficient:
2 - 4 near top, 2 - 8 near base
concoidal fracture
ISRM Hardness: II-III
lithic clasts, 0 - 6 m above base
light gray (N8) to moderate red
(5R5/4), and 2 - 30 mm diameter
rare lithophysae ($\leq 1\%$)
locally, middle lithophysal subzone
1 - 20 cm, aspect ratio $\leq 4:1$

lower lithophysal zone: (cli)
thickness: 5 - 10 m
2 - 5 % phenocrysts
(S)
Roughness coefficient: 8-12
fractures break through groundmass
textures and lithophysae
ISRM Hardness: I
2 - 10 % lithophysae
maximum size = 8x15 cm
0.5x4 cm (ave), aspect ratio $\leq 2-8:1$

hackly zone: (ch)
thickness: > 20 m
2 - 5 % phenocrysts: (S) (B) (Sp)
Roughness coefficient: 12-18
ISRM Hardness: III
lithophysae occur locally, near the top

columnar zone:
not included in the study

clinkstone zone: (cks)
locally rounded step (crs)
thickness: 0 - 55 m
rhyolitic; 8-12 % phenocrysts
(S) (B tr) (Sp)
cognate pumice, 0.2 - 2 cm
concoidal fracture
no lithophysae, but locally a
middle lithophysal subzone

lower lithophysal zone: (cli)
thickness: 0 - 25 m
rhyolitic; 6 - 8 % phenocrysts
(S) (B tr) (Sp)
cognate pumice, 0.2 - 1.5 cm
10 - 15 % lithophysae, 1 - 5 cm
spherical to oblate
pinkish-gray (5YR 8/1) margins
around lithophysae
hackly fracture near base

hackly zone: (ch)
thickness: 2 - 26 m
rhyolitic; 6 - 8 % phenocrysts
(S) (B tr) (Sp)
cognate pumice, 0.2 - 2 cm
irregular hackly fracture
breaks into pieces 1 - 5 cm diameter

columnar zone: (cc)
thickness: 11 - 31 m
rhyolitic; 5 - 8 % phenocrysts
(S) (B, Sp rare)
partially glassy
cognate pumice, 0.2 - 1.5 cm
Subzones:
vitrophyre subzone (local)
flattened pumice subzone
devitrified (not stated)
nonwelded subzone
vitric

middle nonlithophysal zone: (pmn)
moderately to densely welded
devitrified with minor amounts of vapor
phase minerals along fractures
high-angle fractures common
smooth surface fractures
pumice: light gray (N8-9), but very
difficult to recognize because of
crystallization in groundmass
lithophysae: trace amounts
locally $\leq 2\%$ in lower 4 m
Subzones:
lower and upper (mn1 and 3)
lithophysae bearing (mn2)
lower transition interval (≈ 3 m thick) of
small scale poorly developed hackly
fractures and $\leq 2\%$ lithophysae

lower lithophysal zone: (pli)
moderately to densely welded
devitrified with vapor-phase minerals
minor high-angle fractures
slightly rough surface fractures
pumice: light gray (N8-9), but difficult
to recognize due to crystallization in
groundmass
lithophysae: $\approx 2\%$ in upper 12 m
5 - 10 % in most of unit
up to 6 cm, commonly ≤ 2 cm
light gray (N7) rims, 1 - 4 mm wide

lower nonlithophysal zone: (pln...)
moderately to densely welded
devitrified with minor amounts of vapor
phase minerals along fractures
no lithophysae, except locally near top
Subzones:
hackly subzone: (plnh)
minor high-angle fractures
rough "hackly" surface fractures
pumice: light gray (N8-9)
lithophysae: $\leq 2\%$ in upper 6 m
columnar subzone: (plnc...)
high-angle planar fractures
are common
smooth surface fractures
subzones, based on pumice:
devitrified, grayish brown
(5YR3/1) (c3)
clay-altered, pink (5R6/2) (c2)
vitric, black (N3) (c1)

vitric zone: (cpv...)
nonwelded to densely welded
Subzones:
vitrophyre (v3) (local)
matrix, shards and pumice are fused
fractures across grain boundaries
moderately to densely welded (v2)
locally devitrified with v-p minerals
matrix, shards, and pumice are
mostly fused, but identifiable
fractures across most boundaries
non-welded to partially welded (v1)
fractures along grain boundaries

PRELIMINARY DRAFT

Note: Old nomenclature

Formal Geologic Stratigraphy		Microstratigraphic Units ¹	Thermal/Mechanical Units ²
Paintbrush Tuff	Tiva Canyon Member	ccr - caprock	TCw
		cuc - upper cliff	
		cul - upper lithophysal	
		cks - cinkstone	
		cli - lower lithophysal	
		ch - hackdy	
		cc - columnar	
	ocs - shardy base	PTn	
	Yucca Mtn. Mbr.		
	Pah Cyn. Mbr.		
Topopah Spring Member <i>(Formation in new nomenclature)</i>	tc - caprock	TSw1	
	tr - rounded		
	tul - upper lithophysal		
	tn - nonlithophysal		
	tl - lower lithophysal	TSw2	
	tm - mottled		
	tv - basal vitrophyre	TSw3	
	nonwelded base		
Tuffaceous Beds of Calico Hills			CHn
Crater Flat Tuff	Prow Pass Member	not subdivided	PPw
	Bullfrog Member		CFUn
	Tram Member		BFw
			CFMn
		TRw	

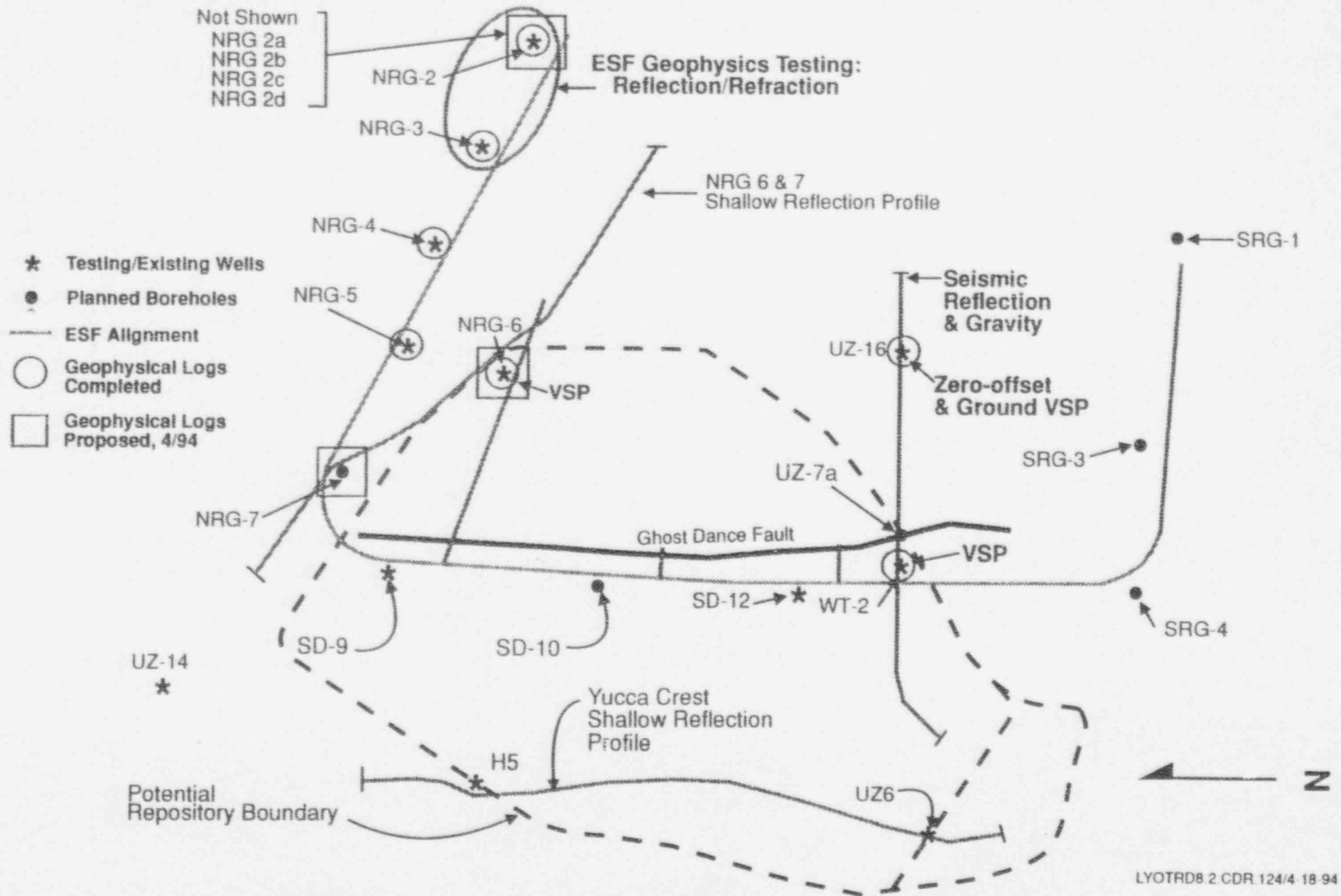


Water Table Occurs in This Interval in Vicinity of the Potentia Repository

Figure 1.2 Comparative stratigraphic terminology in common usage at Yucca Mountain. ¹modified after Scott and Bonk (1984) for the immediate repository vicinity; ²from Ortiz and others, 1985. Thicknesses and "weathering profile" are highly schematic; character varies with location.

ATTACHMENT #9

Completed and Proposed FY93/94 Geophysics Testing Program



ATTACHMENT #10

Geoen지니어ing Characterization of the Nonlithified Tuffs to be Encountered by the North Ramp

David Kessel



Sandia National Laboratories

Study Plan 8.3.1.14.2 Studies to Provide Soil and Rock Properties

8.3.1.14.2.1 Exploration Program Study

8.3.1.14.2.2 Laboratory Tests and Material Property Measurement

8.3.1.14.2.3 Field Tests and Characterization Measurements Study

Soil and Rock Properties Studies Objectives

Geological and Geotechnical Data - Provides Input to ESF Design

- . Stratigraphic Cross Sections**
- . Rock Mass Quality (RQD, Q, RMR)**
- . Rock Mechanical and Thermal Properties**
- . Detailed Characterization of Localized Conditions as Required**

Background

**Six boreholes planned to support North Ramp
Design (NRG-1 - NRG-6)**

**NRG-2 indicated potentially incompetent material
(above North Ramp)**

**NRG-2A drilled to provide stratigraphic control
between NRG-2 and NRG-3**

Grade of the North Ramp was reduced

**NRG-2B drilled to investigate potentially
incompetent material (lost core in NRG-2)**

Background

Core recovery in NRG-2B successful - material appeared to be nonlithified and cohesionless

Possible that tuff does have some cohesion and was disaggregated by the drilling process

Characterization activities planned and NRT-1 excavated and NRG-2C and -2D drilled

Issues to be Addressed by Study

**Define stratigraphy and tunnel length of the
nonlithified tuff**

Define the engineering properties of the tuff

Evaluate the bearing capacity of the tuff

Demonstrate stand up time

Characterization Activities

- **Mapping and Geologic logs**
- **Bearing Capacity of Soil for Static Load**
- **Sand Cone Density and Nuclear Density**
- **Specific Gravity**
- **Moisture Content**
- **Particle Size Gradation**
- **Liquid Limit**
- **Soil Permeability**
- **Empirical Stand up Tests**

Conclusions

**Stratigraphy of Pre-Rainier Mesa Bedded Tuff and
Rainier Mesa Tuffs defined**

**Tunnel length of 74 m in Pre-Rainier and Rainier
Mesa Tuff**

Pre-Tuff-X also nonlithified - tunnel length of 2-5 m

**Pre-Rainier and Rainier Mesa material behave like
a lightly cemented sand with apparent cohesion**

PRELIMINARY

Apparent Cohesion due to soil suction is significant component of strength - saturating the soil will eliminate apparent cohesion

Material properties defined (soil stress-strain-strength properties)

Lateral continuity of material properties can be inferred from geologic continuity and SPT data

Bearing capacity is 50 ksf for Pre-Rainier Mesa and 100 ksf for Rainier Mesa — *Should be high enough to support TBM & grappes pads...*

Unlikely that cohesionless running ground will be encountered - except possibly in limited intervals that are saturated

local moisture contents 5/30%

PRELIMINARY

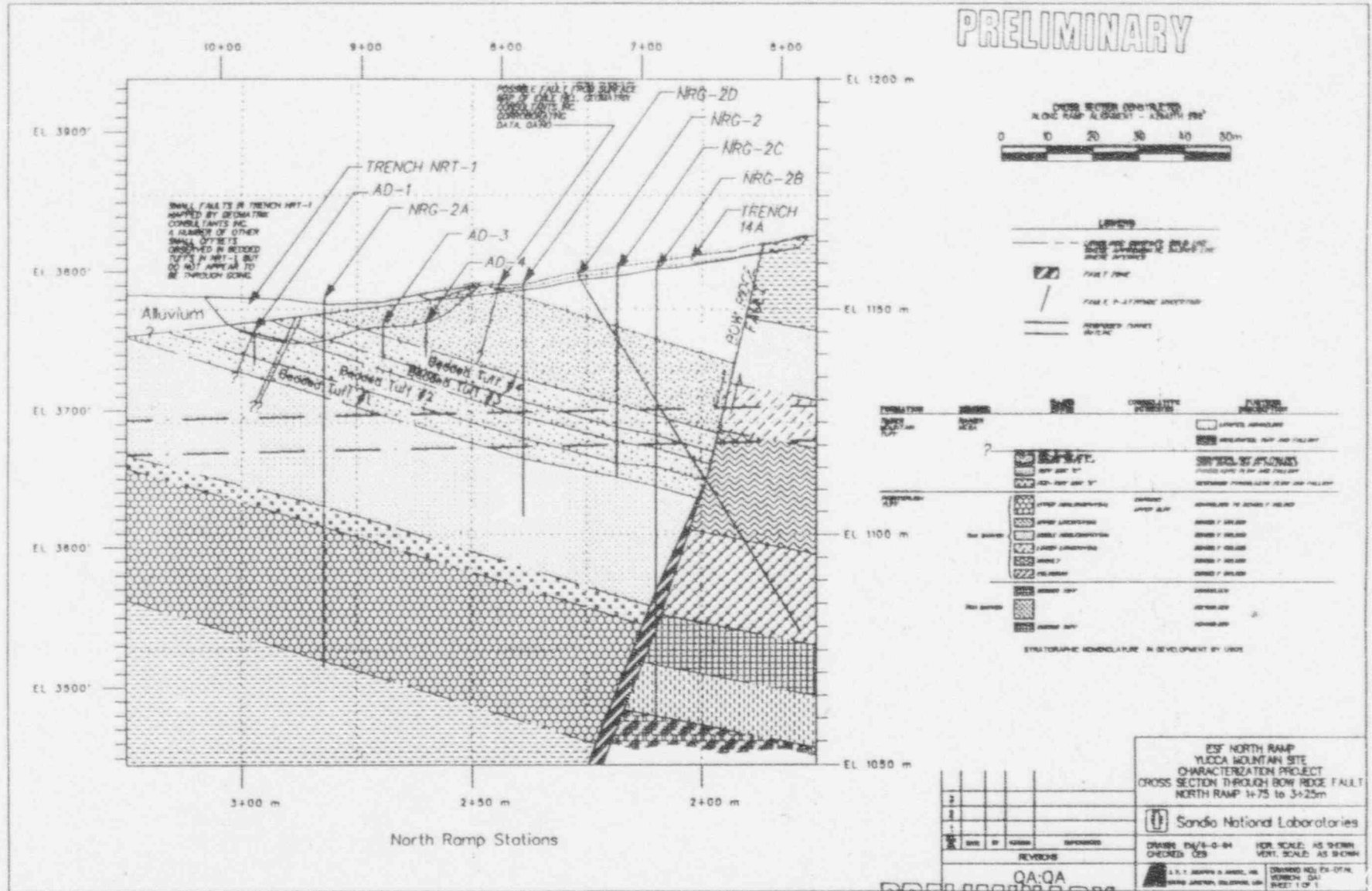
7-day test period

Stand up tests were inconclusive - no failures were observed in 4 test pockets

Results of grain size distributions and permeability tests indicate structural chemical grout could be used to enhance ground stability

Will grouting cause any problems for site characterization?

PRELIMINARY



PRELIMINARY

Additional Tests

**Saturated bearing capacity tests to evaluate
magnitude of soil suction**

Lab strength tests on undisturbed samples

Engineering Characterization of the pre-Rainier Mesa and Rainier Mesa Tuffs

The following tests were performed:

- Bearing Capacity of Soil for Static Load
- Standard Penetration Tests
- Sand Cone Density
- Nuclear Density
- Specific Gravity
- Moisture Content
- Particle Size Gradation
- Liquid and Plastic Limits, and
- Soil Permeability

In addition the trench NRT-1 which was excavated to a depth of approximately 7 m, served as a demonstration of the capacity of the materials to stand in relatively high vertical walls. An undercut stand up demonstration test was performed in the bottom the trench.

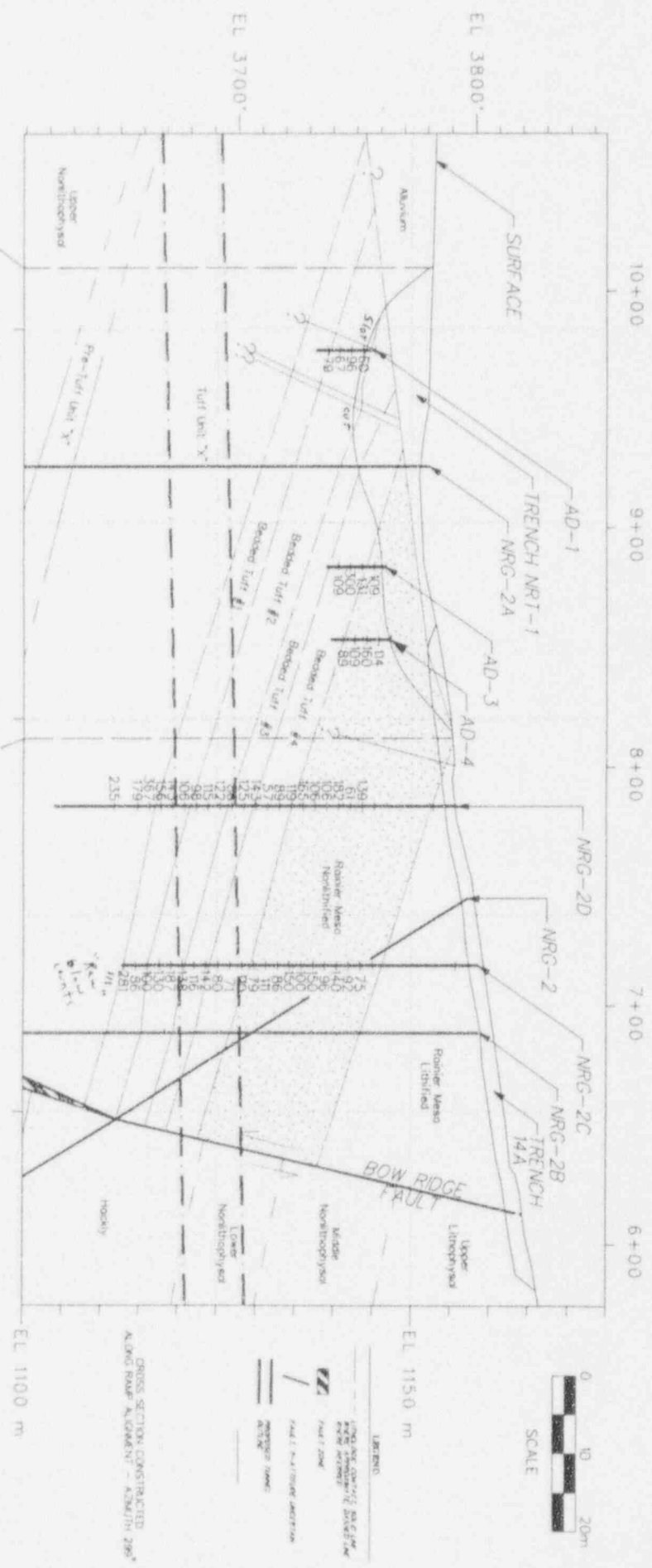
PRELIMINARY DRAFT

Conclusions from Engineering Properties Tests

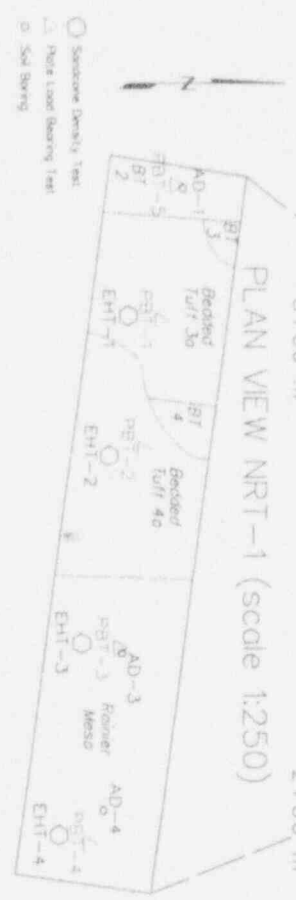
- The Stress-Strain-Strength properties of the pre-Rainier Mesa and Rainier Mesa Tuffs were defined in sufficient detail to allow the design of tunnel support systems for these materials
- The bearing capacity of the nonlithified pre-Rainier Mesa Tuff and the Rainier Mesa Tuff is sufficiently high to support TBM operation through these materials. (50 ksf).
- Apparent cohesion is derived from the capillary tension resulting from partial saturation ($w=8.5\%$). Some intervals may be saturated and exhibit lower bearing capacity and may be cohesionless.
- Structural chemical grout may be used to support local zones of very low cohesion but an overall ground stability enhancement with structural chemical grout does not appear feasible or necessary.
- Standup demonstration tests did not result in failures.

PRELIMINARY DRAFT

SECTION VIEW (scale 1:500)



PLAN VIEW NRT-1 (scale 1:250)



REV		DATE	BY	CHKD	APP'D
1					
2					
3					

DATE: 04/14/2014
 DRAWN: J. L. L. / J. L. L.
 CHECKED: J. L. L.
 APP'D: J. L. L.
 SCALE: AS SHOWN

PROJECT: Sarafid National Laboratories
 SHEET: 12 OF 12

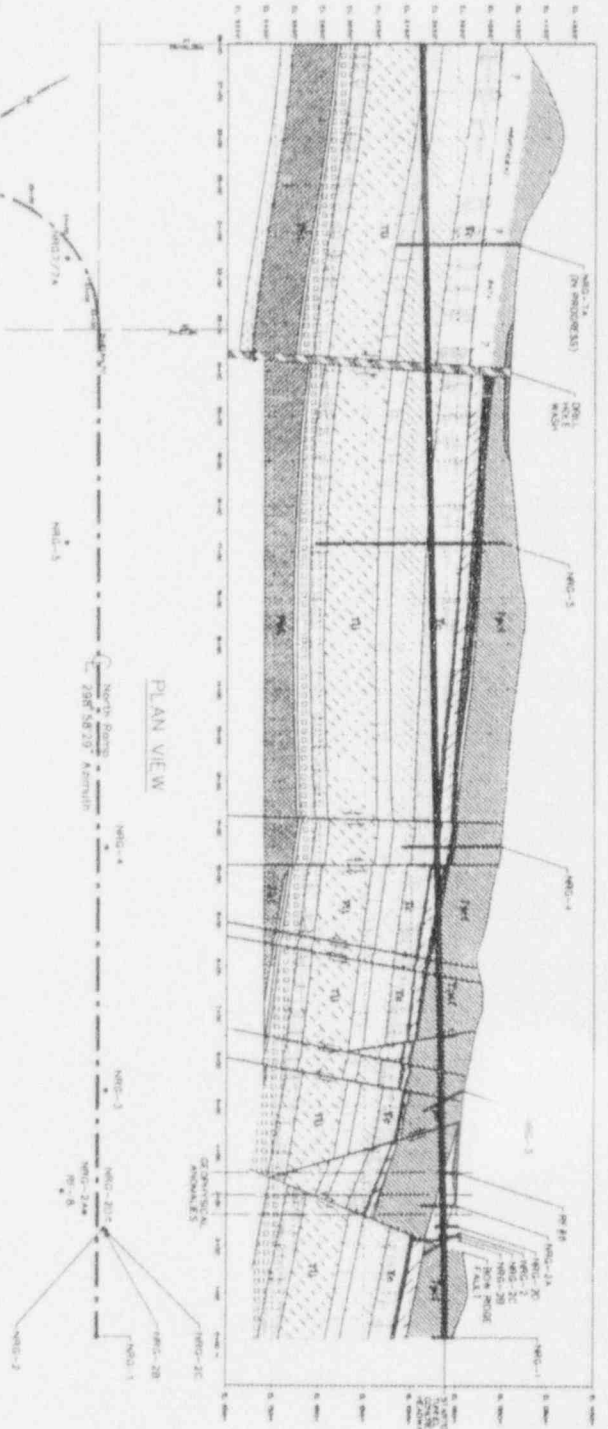
PRELIMINARY

ES NORTH PLAIN
 GROSS SECTION THROUGH
 BOW RIDGE FAULT
 SHOWING LOCATION OF SOIL TESTS

CROSS SECTION CONSTRUCTED
 ALONG RAIL ALIGNMENT - AZIMUTH 288°

LEGEND:
 Lithology
 Fault
 Trench

SECTION VIEW



PLAN VIEW



PRELIMINARY RAMP DATA

Station	Grade (%)	Length (ft)	Notes
1+00	1.5	100	
2+00	2.0	100	
3+00	1.8	100	
4+00	2.2	100	
5+00	1.9	100	
6+00	2.1	100	
7+00	1.7	100	
8+00	2.3	100	
9+00	1.6	100	
10+00	2.0	100	
11+00	1.8	100	
12+00	2.1	100	
13+00	1.9	100	
14+00	2.2	100	
15+00	1.7	100	
16+00	2.3	100	
17+00	1.6	100	
18+00	2.0	100	
19+00	1.8	100	
20+00	2.1	100	
21+00	1.9	100	
22+00	2.2	100	
23+00	1.7	100	
24+00	2.3	100	
25+00	1.6	100	
26+00	2.0	100	
27+00	1.8	100	
28+00	2.1	100	
29+00	1.9	100	
30+00	2.2	100	
31+00	1.7	100	
32+00	2.3	100	
33+00	1.6	100	
34+00	2.0	100	
35+00	1.8	100	
36+00	2.1	100	
37+00	1.9	100	
38+00	2.2	100	
39+00	1.7	100	
40+00	2.3	100	
41+00	1.6	100	
42+00	2.0	100	
43+00	1.8	100	
44+00	2.1	100	
45+00	1.9	100	
46+00	2.2	100	
47+00	1.7	100	
48+00	2.3	100	
49+00	1.6	100	
50+00	2.0	100	

BORCHOLE PROJECTIONS

Station	Grade (%)	Length (ft)	Notes
1+00	1.5	100	
2+00	2.0	100	
3+00	1.8	100	
4+00	2.2	100	
5+00	1.9	100	
6+00	2.1	100	
7+00	1.7	100	
8+00	2.3	100	
9+00	1.6	100	
10+00	2.0	100	
11+00	1.8	100	
12+00	2.1	100	
13+00	1.9	100	
14+00	2.2	100	
15+00	1.7	100	
16+00	2.3	100	
17+00	1.6	100	
18+00	2.0	100	
19+00	1.8	100	
20+00	2.1	100	
21+00	1.9	100	
22+00	2.2	100	
23+00	1.7	100	
24+00	2.3	100	
25+00	1.6	100	
26+00	2.0	100	
27+00	1.8	100	
28+00	2.1	100	
29+00	1.9	100	
30+00	2.2	100	
31+00	1.7	100	
32+00	2.3	100	
33+00	1.6	100	
34+00	2.0	100	
35+00	1.8	100	
36+00	2.1	100	
37+00	1.9	100	
38+00	2.2	100	
39+00	1.7	100	
40+00	2.3	100	
41+00	1.6	100	
42+00	2.0	100	
43+00	1.8	100	
44+00	2.1	100	
45+00	1.9	100	
46+00	2.2	100	
47+00	1.7	100	
48+00	2.3	100	
49+00	1.6	100	
50+00	2.0	100	

LEGEND

Symbol	Description
[Symbol]	Topography
[Symbol]	Proposed Right-of-Way
[Symbol]	Proposed Road
[Symbol]	Proposed Bridge
[Symbol]	Proposed Structure
[Symbol]	Proposed Utility
[Symbol]	Proposed Fencing
[Symbol]	Proposed Signage
[Symbol]	Proposed Lighting
[Symbol]	Proposed Stormwater Management
[Symbol]	Proposed Landscaping
[Symbol]	Proposed Security
[Symbol]	Proposed Other

PROPOSAL

FOR THE
 DESIGN AND CONSTRUCTION OF
 THE
 PROJECT
 AT THE
 LOCATION
 OF THE
 PROJECT
 IN THE
 CITY OF
 LOS ANGELES
 COUNTY OF
 LOS ANGELES
 STATE OF
 CALIFORNIA

DATE: 10/20/2011

SCALE: AS SHOWN

PROJECT NO: 1011111111

DATE: 10/20/2011

SCALE: AS SHOWN

PROJECT NO: 1011111111

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gk

ATTACHMENT # 15

NAME: Chris Rautman	AFFILIATION: Sandia National Laboratories, Dept. 6115 Phone: 505-848-0707 FAX: 505-848-0789
OBJECTIVE	To collect basic geologic descriptions, rock samples, and laboratory measurements of "framework" material properties in a systematic and statistically valid manner from the subsurface within the immediate repository block.
RELEVANCE	A basic geologic and material properties description of the repository block is fundamental to (1) locating and designing the workings of the ESF within the Topopah Spring Member, (2) designing the workings of the potential repository, (3) ensuring that pre-closure performance requirements will be met, (4) assessing the likelihood that the post-closure performance objectives will be met, and (5) preparing the License Application and supporting documents related to the design and operation of the potential repository.
TECHNICAL PROGRESS	<ul style="list-style-type: none"> • Completed 4 phases of a major outcrop sampling effort designed to identify spatial correlation patterns; measured basic hydrologic properties from 5 vertical and 4 horizontal large-scale transects, plus 26 closely spaced vertical transects through a major lithologic transition overlying the potential repository horizon (shardy base of Tiva Canyon Member); quantified vertical and horizontal correlation scales in welded, nonwelded, and zeolitic rocks. • Identified significant control of hydrologic properties by "microstratigraphic" zonation of major ash-flow sequences. • Demonstrated correlation of important hydrologic properties (Ksat, Sorptivity) with matrix porosity across a variety of degrees of welding --> use of porosity as "soft" data to improve modeling of other properties. • Conducted successful hypothesis test of deterministic predictions of hydrologic properties as a function of stratigraphic position within a lithologic transition zone. • Started drilling first SD hole Jan 28 1994
REMAINING TECHNICAL ACTIVITIES	<ul style="list-style-type: none"> • Drilling, sampling, testing, and other activities related to the program of drilling proposed in the Study Plan (SD-1 through SD-12) as may be modified to reflect evolving Project design and PA requirements. • Sampling of critical units (Topopah Spring Member, tuffs of Calico Hills) at close-spaced intervals in the underground facilities of the ESF to refine estimates of spatial correlation of framework material properties in the horizontal dimension.
TECHNICAL ISSUES	<ul style="list-style-type: none"> • Current drilling schedules do not mesh with design-driven demands for data; fundamental design decisions must be made before the necessary drilling, laboratory testing, and release of data can occur. • Inadequate drilling resources are available to conduct this and other drilling programs necessary for site characterization; long lead-times related to equipment availability are an additional problem.

From C. Rautman

Systematic Drilling Program (SCP Study 8.3.1.4.3.1)

The Systematic Drilling Program is ...

- A primary source of subsurface data within the repository block
 - Engineering information: ESF and repository
 - Geometry of stratigraphic units
 - Lithology
 - Rock characteristics via sampling and testing
 - *In-situ* test facilities
- Closely integrated with PA and design analyses through 3-D models of the site
 - Evaluation of data adequacy/geologic uncertainty
 - Quantitative numerical models of material properties to support performance and design analyses

Ties to Underground Exploration Program

- Necessary precursor to location of ESF facilities
- Areal coverage versus intensive detail
- Vertical coverage versus repository-horizon detail
- Exploration of deeper units and transport pathways
 - Tuffs of Calico Hills: "primary barrier" to waste migration
 - Crater Flat Tuff units: saturated zone
- SDP study plan contains plans for closely spaced sampling in ESF main test level and Calico Hills test level
 - Issue of range of spatial correlation and drill hole spacings
 - Required input for 3-D material properties models for design and PA analyses

Ties to Other Surface-Based Testing Programs

- Site focus versus process focus
- "Systematic" complement to feature-of-interest based drilling programs
 - Drill hole pattern optimized to provide coherent areal coverage and statistically valid (unbiased) sampling
- Window-of-opportunity for other studies

Other SCP Studies Depending Upon SDP for Samples and Information

- UZ Percolation
- UZ Hydrochemistry
- Mineralogy, Petrology and Chemistry of Transport Pathways
- Site Ambient Stress
- Seal Material Properties
- Laboratory Thermal Properties
- Laboratory Thermal Expansion
- Laboratory Mechanical Properties, intact rock
- Laboratory Mechanical Properties, fractures
- Geomechanical waste package
- 3-D Geologic Model
- 3-D Rock Characteristics Models

Specifics for Drill Hole USW SD-12

- Location: about 100 ft west of ESF main test level drift
about 500 ft west of Ghost Dance Fault
along ESF main test level drift, about 2/3 from N to S
- Planned TD: 2,300 ft (300 ft into saturated zone)
- Hole Diameter: 12-1/4 inch reamed hole; PQ and HQ core
- Specific Objectives:
 - Collect stratigraphic and rock properties data relevant to ESF design
 - Collect geologic and matrix properties data within main repository block
 - Provide instrumented borehole for establishing a "predisturbance" understanding of in-situ hydrologic conditions in the unsaturated zone and monitor disturbance of these conditions as ESF drift is excavated
- Depth as of 29 April 1994: 589 ft, upper lithophysal zone of Topopah Spring Member, Paintbrush Tuff

ATTACHMENT #16

Preliminary SD-12 Stratigraphy

INTERVAL	UNIT	MEMBER
0 - 12.9	alluvium	
12.9 - 100.6	non-lithophysal	
100.6 - 134.8	lower lithophysal	Tiva Canyon
134.8 - 192.2	hackly	
192.2 - 238.2	columnar	
238.2 - 263.7	shardy base	
263.7 - 266.4	airfall	
266.4 - 272.0	bedded tuff unit	
	yucca mountain (missing)	
272.0 - 278.3	bedded tuff unit	
278.3 - 291.5	pah canyon	
291.5 - 295.9	bedded tuff unit	
295.9 - 324.6	N-PW caprock	Topopah Spring
324.6 - 437.1	caprock	
437.1 - 560+	upper lithophysal	

Preliminary UZ-14 Stratigraphy

UNIT	MEMBER
0.0 - 8.0 drill pad fill	
8.0 - 39.7 Alluvium	ALLUVIUM
39.7 - 78.2 Yucca Mountain	YUCCA MOUNTAIN
78.2 - 102.2 Bedded Tuff	
102.2 - 240.5 Pah Canyon	PAH CANYON
240.5 - 265.3 Bedded Tuff	
265.3 - 281.5 non-partially welded	
281.5 - 436.5 Caprock	
436.5 - 680 Upper Lithophysal	TOPOPAH SPRING
680 - 779.5 Middle nonlithophysal (gradational contact)	
779.5 - 1015.0 Lower lithophysal	
1015. - 1278.0 Lower nonlithophysal	
1278.0 - 1361.8 Basal vitrophyre	
1361.3 - 1403. partially welded	Topopah Spring
1403 - 1418 Bedded Unit	
1418 - 1744 Tuffs of Calico Hills	CALICO HILLS
1744 - 2047 Prow Pass	CRATER FLAT
2047 - 2197.27 Bullfrog	

DRAFT

-gls-

(ATTACHMENT #17)

Civilian Radioactive Waste
Management System

Management & Operating
Contractor

TRW

TRW Environmental Safety
Systems Inc.

DOE/NRC Visit

May 2 - 5, 1994

USE OF SITE DATA IN ESF DESIGN

John H. Pye
May 3, 1994

B&W Fuel Company
Duke Engineering & Services, Inc.
Fluor Daniel, Inc.
INTERA Inc.

JK Research Associates, Inc.
E. R. Johnson Associates, Inc.
Logicon RDA

Morrison Knudsen Corporation
TRW Environmental Safety Systems Inc.
Winston & Strawn
Woodward-Clyde Federal Services

DOE/NRC Visit - May 2 - 5, 1994

Use of Site Data in ESF Design

- **Site Data Used in the Following Design & Geotechnical Areas:**
 - **Geological Models** *- i.e. LYNX GMS mainly, he said*
 - **Empirical Estimates Rock Mass Properties**
 - **Laboratory Testing of Core Specimens**
 - **Empirical Design Methods**
 - **Modeling & Analysis**

DOE/NRC Visit - May 2 - 5, 1994

Use of Site Data in ESF Design

- **Geological Modeling (LYNX System)**
 - **Volume Model of ESF Site & ESF Tunnel Alignments**
 - **Produce Profiles & Sections of Site Geology ESF Tunnels**
 - **Display Lithostratigraphic or Thermo-Mechanical Units**

DOE/NRC Visit - May 2 - 5, 1994

Use of Site Data in ESF Design

- **Geological Modeling (LYNX System)**
(continued)
 - **Engineering Data**
 - » **3D Coordinate System**
 - » **Database - Geotechnical**
 - » **Geostatistical Information**

Used to Develop 10 Key Cross-Sections

Civilian Radioactive Waste
Management System
Management & Operating
Contractor

LV.ESSB.JHP.5/94-632

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DOE/NRC Visit - May 2 - 5, 1994

Use of Site Data in ESF Design

- **Geological Modeling (LYNX System) (continued)**

Used to Determine Line & Grade of North Ramp

Used to Locate Test Alcoves

Define Physical Extent of the Thermo-Mechanical Units on TS North Ramp Alignment

Civilian Radioactive Waste
Management System

Management & Operating
Contractor

LV.ESSB.JHP.5/94-632

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DOE/NRC Visit - May 2 - 5, 1994

Use of Site Data in ESF Design

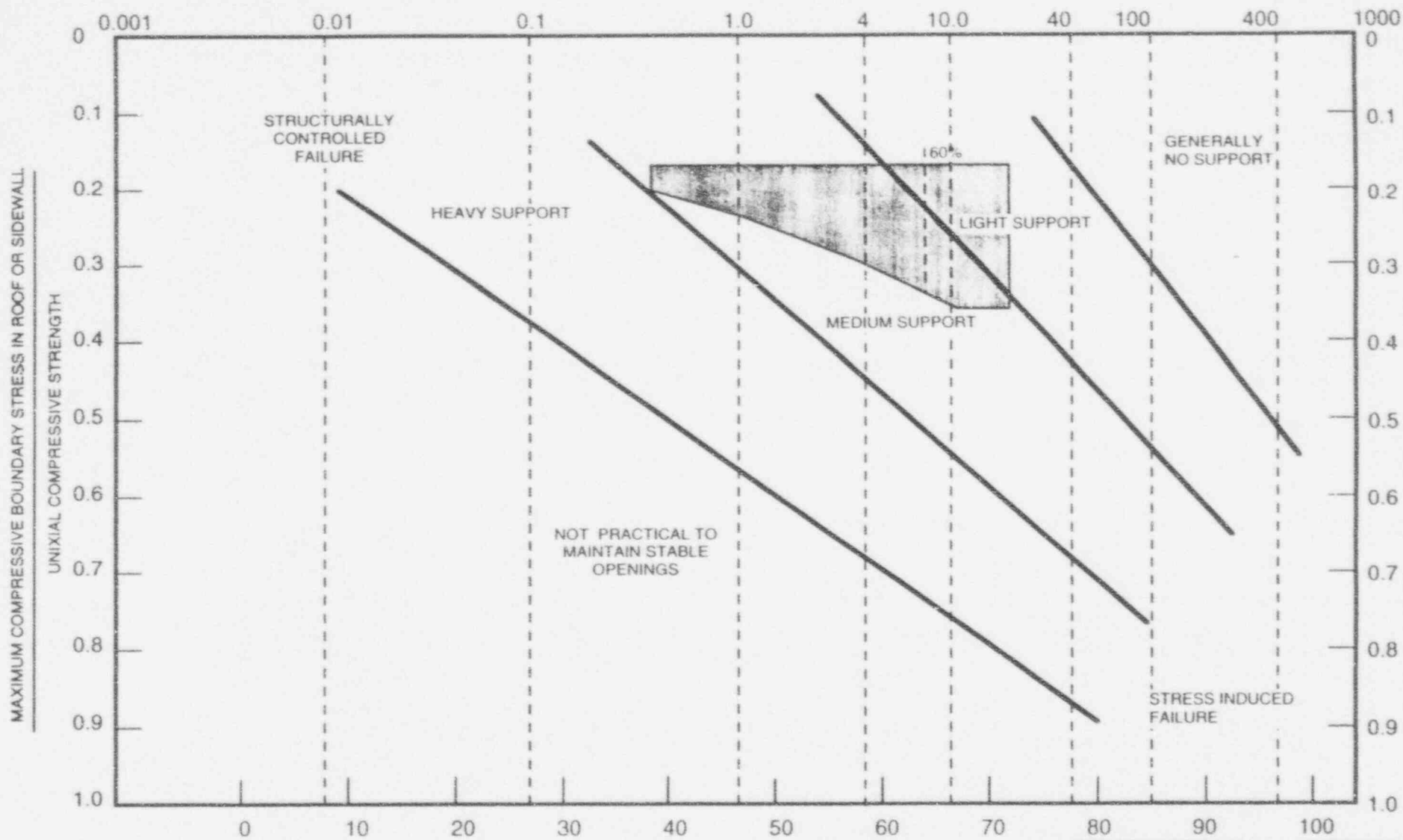
- **Empirical Design Methods**

- Rock Mass Quality “Q” (NGI)
- Rock Mass Rating (RMR)

Used to Determine Range of Anticipated Tunneling Conditions

- Rock Support Recommendations
- Develop Site Specific Ground Support Categories

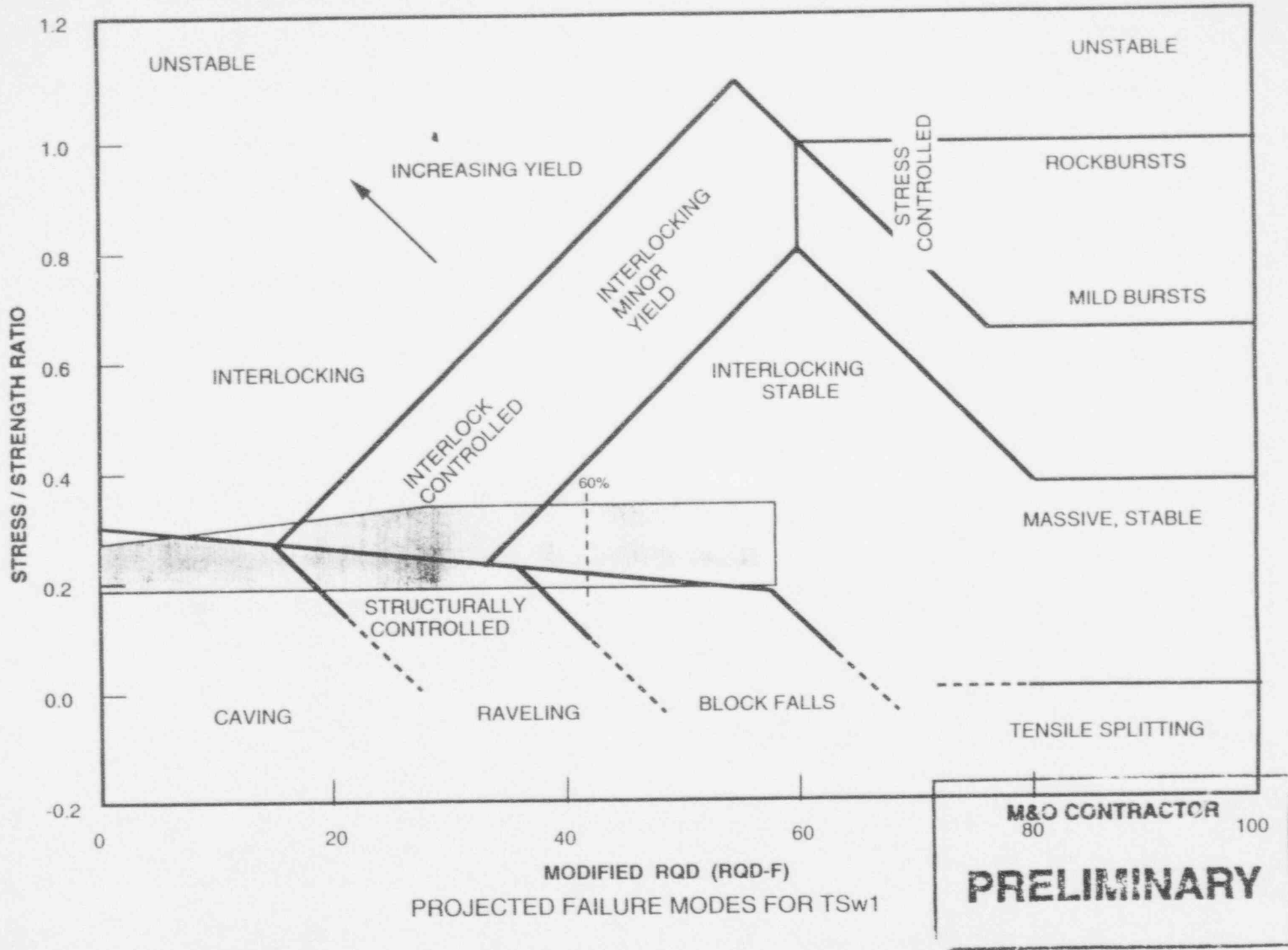
TUNNELING QUALITY INDEX Q



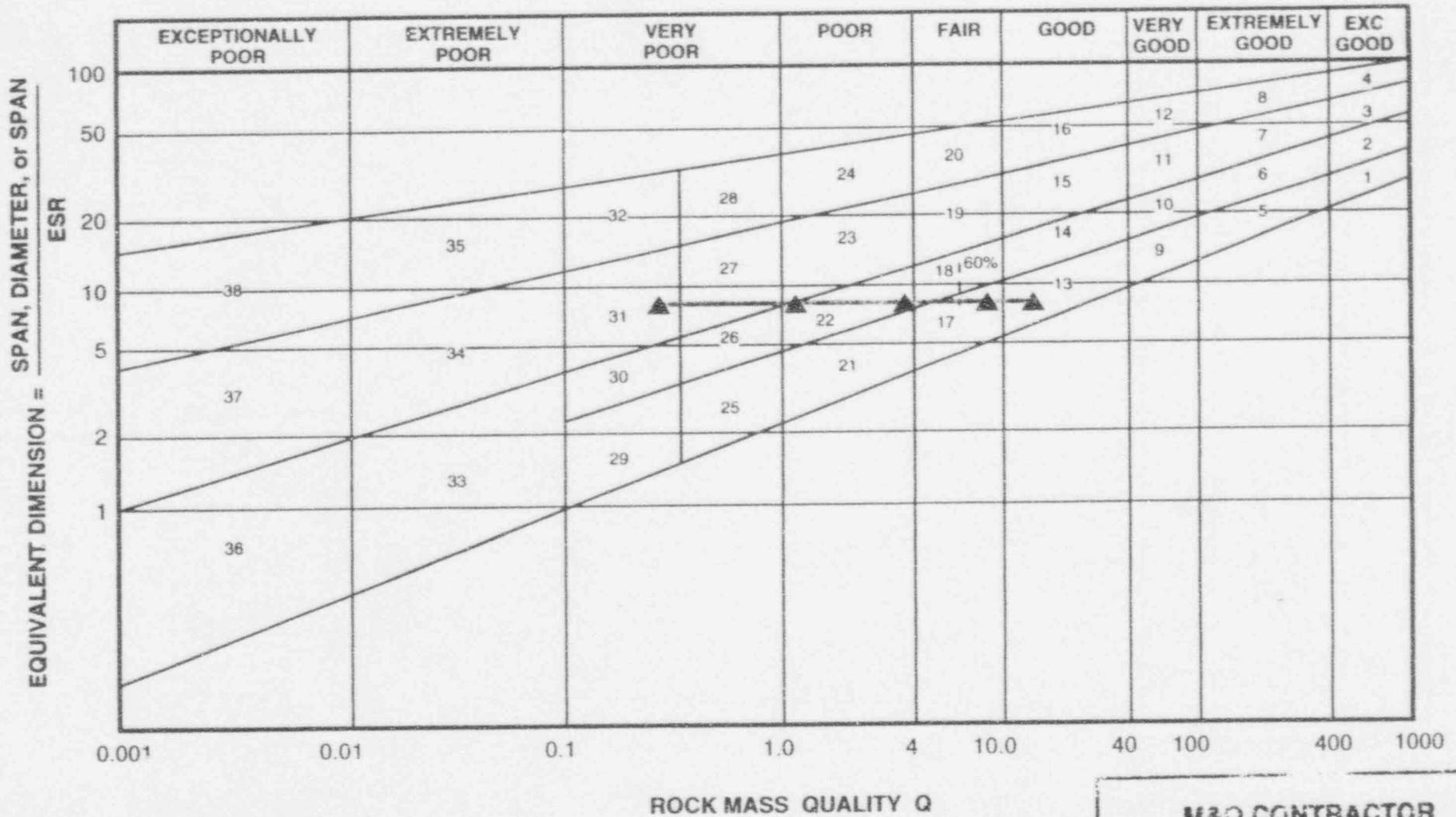
VERY POOR POOR FAIR GOOD **VERY GOOD CONTRACTOR**

ROCK MASS RATINGS RMR
PROJECTED RANGE OF SUPPORT FOR TS_{w1}

PRELIMINARY



TUNNELING QUALITY INDEX Q



PROJECTED CATEGORIES OF GROUND SUPPORT FOR TSW1

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PRELIMINARY

JOB TITLE : TS NORTH RAMP MOHR-COULOMB MODEL STATION 18+00 M (H/V=1) GROUND SUPPORT

FLAC (Version 3.22)

LEGEND

5/02/1994 14:28

step 4100

-1.000E+01 <x< 1.000E+01

-1.000E+01 <y< 1.000E+01

Boundary plot



Principal stresses

Max. Value = 7.256E+06



(*10^1)

900

700

500

300

100

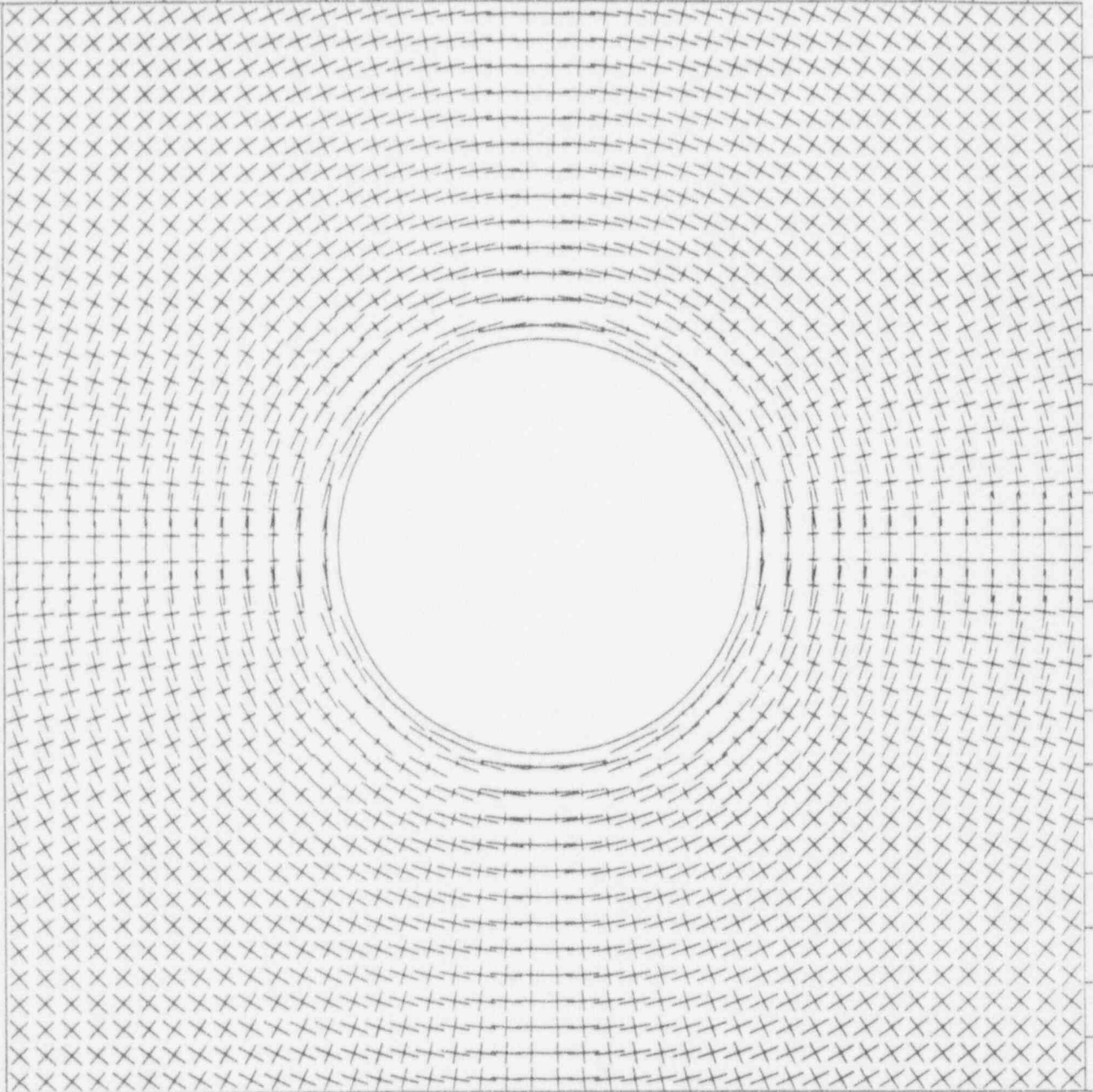
-100

-300

-500

-700

-900



900

700

500

300

100

-100

-300

-500

-700

-900

(*10^1)

Y

CRWMS M & O

JOB TITLE : TS NORTH RAMP MOHR-COULOMB MODEL STATION 18+00 M (H/V=1) GROUND SUPPORT

(*10^1)

FLAC (Version 3.22)

LEGEND

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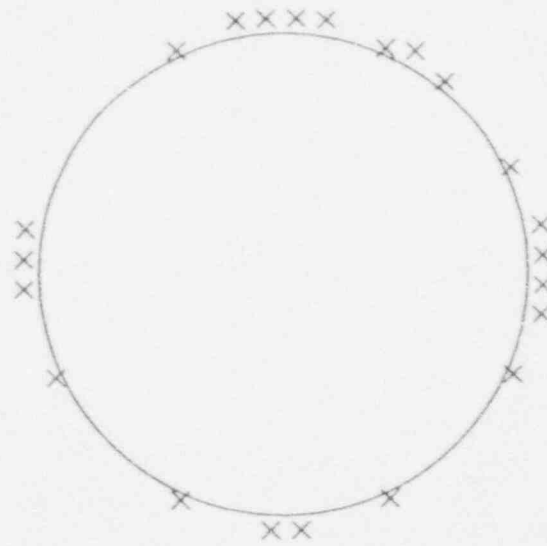
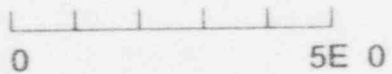
-1.000E+01 <x< 1.000E+01

-1.000E+01 <y< 1.000E+01

Plasticity Indicator

X elastic, at yield in past

Boundary plot



900

700

500

300

100

-100

-300

-500

-700

-900

-900 -700 -500 -300 -100 100 300 500 700 900

(*10^1)

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PRELIMINARY

JOB TITLE : TS NORTH RAMP MOHR-COULOMB MODEL STATION 18+00 M (H/V=1) GROUND SUPPORT

(*10^1)

FLAC (Version 3.22)

LEGEND

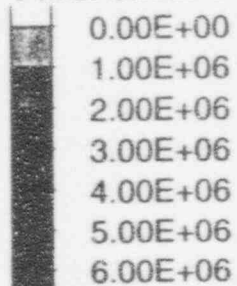
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step 4100

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-1.000E+01 <y< 1.000E+01

Princ. Stress Dif. contours



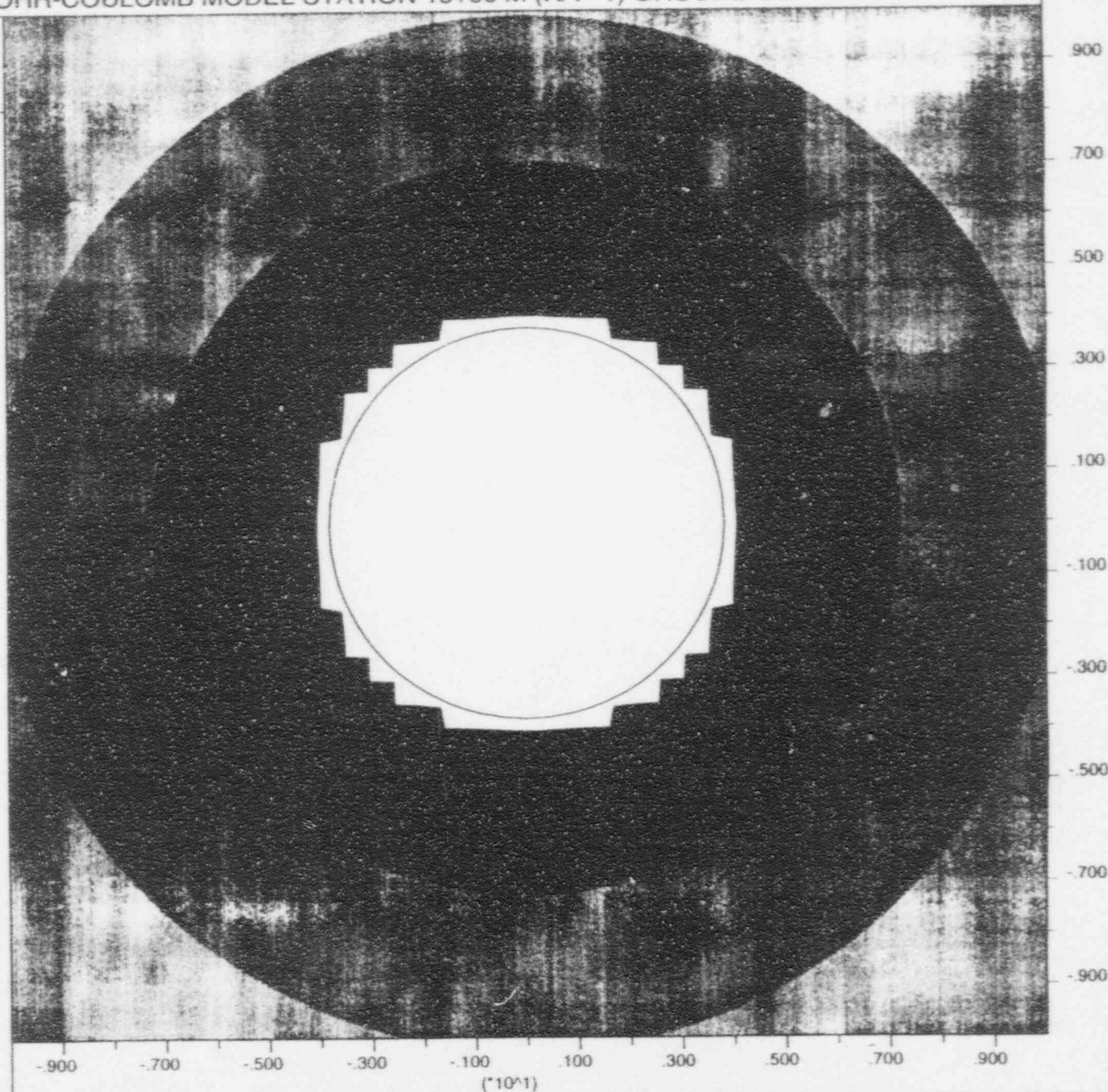
Contour interval= 1.00E+06

Boundary plot



M&O CONTRACTOR

PRELIMINARY



JOB TITLE : TS NORTH RAMP MOHR-COULOMB MODEL STATION 18+00 M (H/V=1) GROUND SUPPORT

(*10^1)

FLAC (Version 3.22)

LEGEND

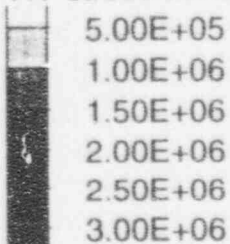
5/02/1994 14:31

step 4100

-1.000E+01 <x< 1.000E+01

-1.000E+01 <y< 1.000E+01

XY-stress contours



Contour interval= 5.00E+05

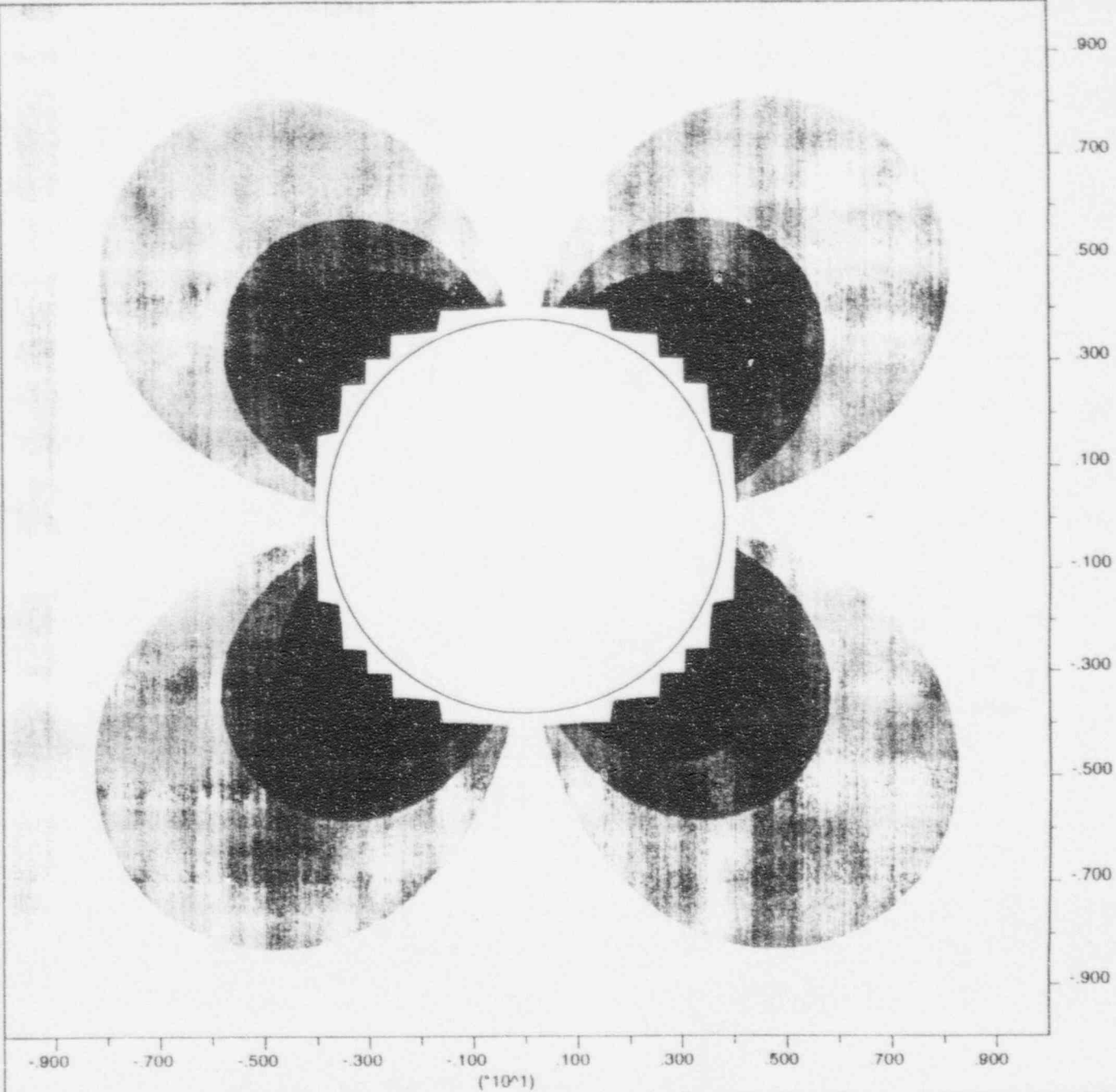
(zero contour omitted)

Boundary plot



M&O CONTRACTOR

PRELIMINARY



JOB TITLE : TS NORTH RAMP MOHR-COULOMB MODEL STATION 18+00 M (H/V=1) GROUND SUPPORT

FLAC (Version 3.22)

LEGEND

5/02/1994 14:27

step 4100

-1.000E+01 <x< 1.000E+01

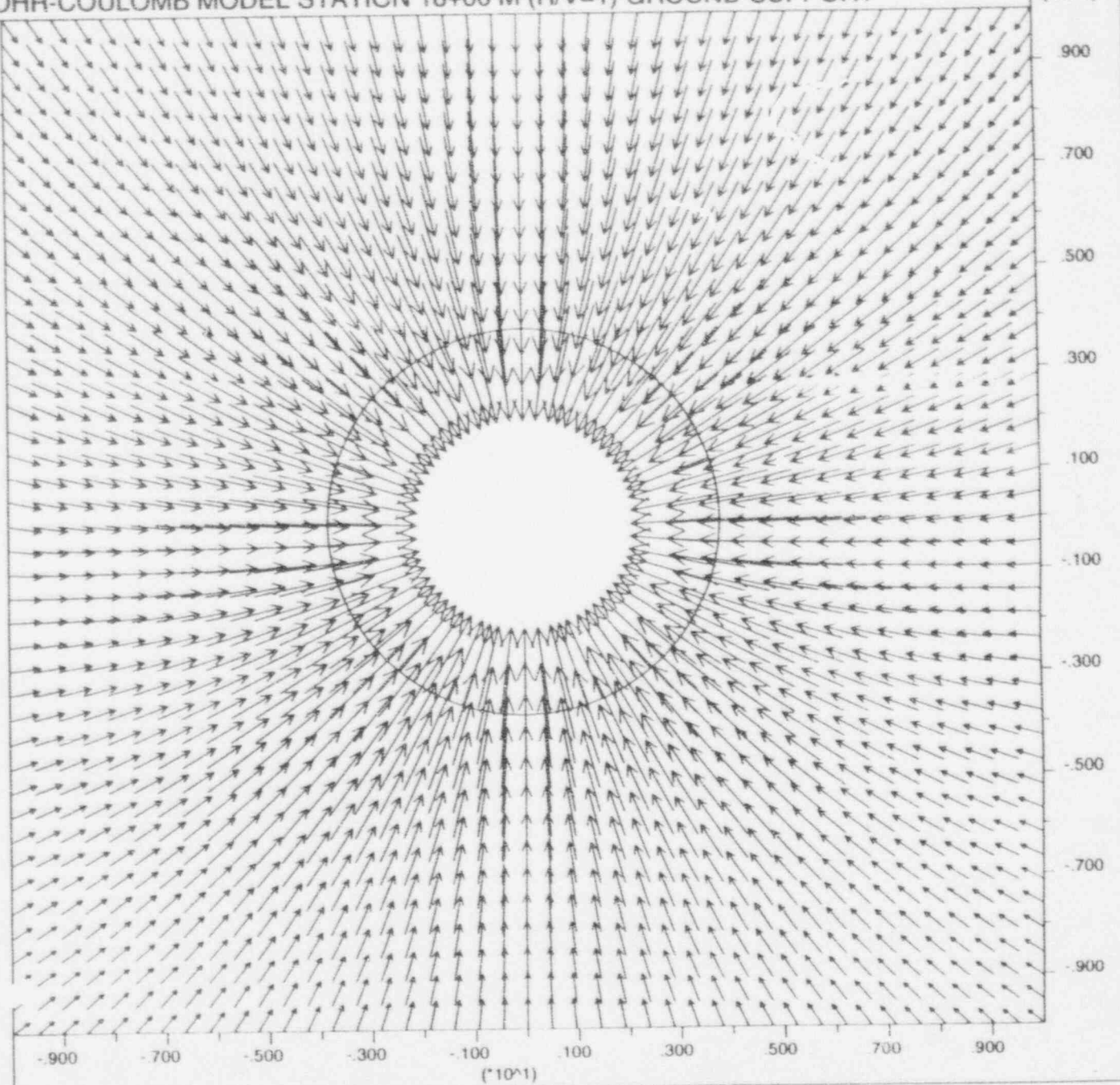
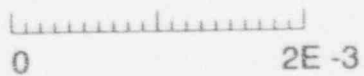
-1.000E+01 <y< 1.000E+01

Boundary plot



Displacement vectors

Max Vector = 7.956E-04



M&C CONTRACTOR

PRELIMINARY

JOB TITLE : TS NORTH RAMP MOHR-COULOMB MODEL STATION 18+00 M (H/V=1) GROUND SUPPORT

(*10^1)

FLAC (Version 3.22)

LEGEND

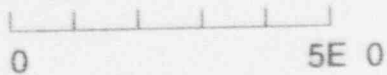
5/02/1994 14:34

step 4100

-1.000E+01 <x< 1.000E+01

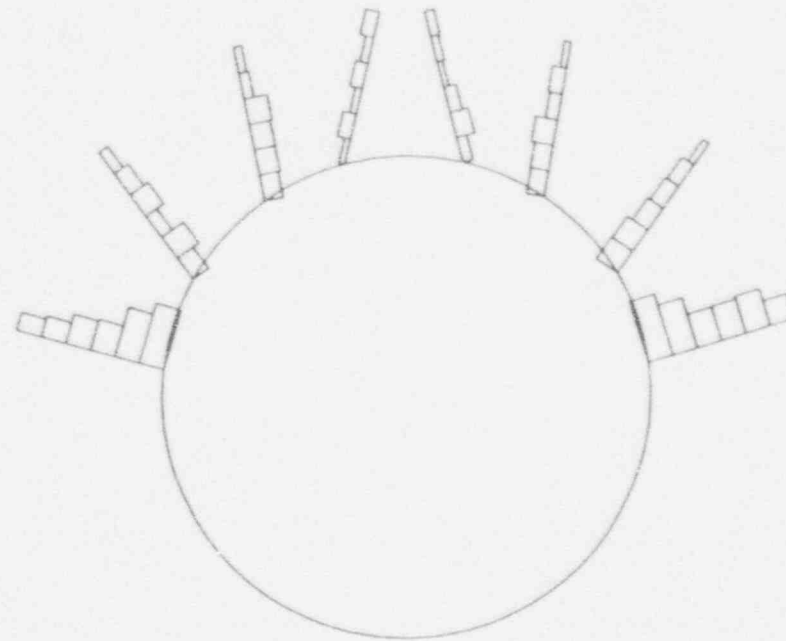
-1.000E+01 <y< 1.000E+01

Boundary plot



Axial Force on

Structure	Max. Value
Cable # 1	-7.351E+02
Cable # 2	-3.126E+02
Cable # 3	-2.748E+02
Cable # 4	-1.629E+02
Cable # 5	-7.522E+02
Cable # 6	-3.051E+02
Cable # 7	-2.567E+02
Cable # 8	-2.191E+02



M&O CONTRACTOR

PRELIMINARY

-900 -700 -500 -300 -100 100 300 500 700 900 (*10^1)

JOB TITLE : TS NORTH RAMP STATION 18+00 M (H/V=1) SEISMIC ANALYSIS

(*10^1)

FLAC (Version 3.22)

LEGEND

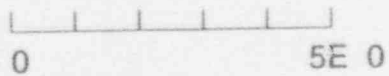
5/02/1994 14:48

step 10100

-1.000E+01 <x< 1.000E+01

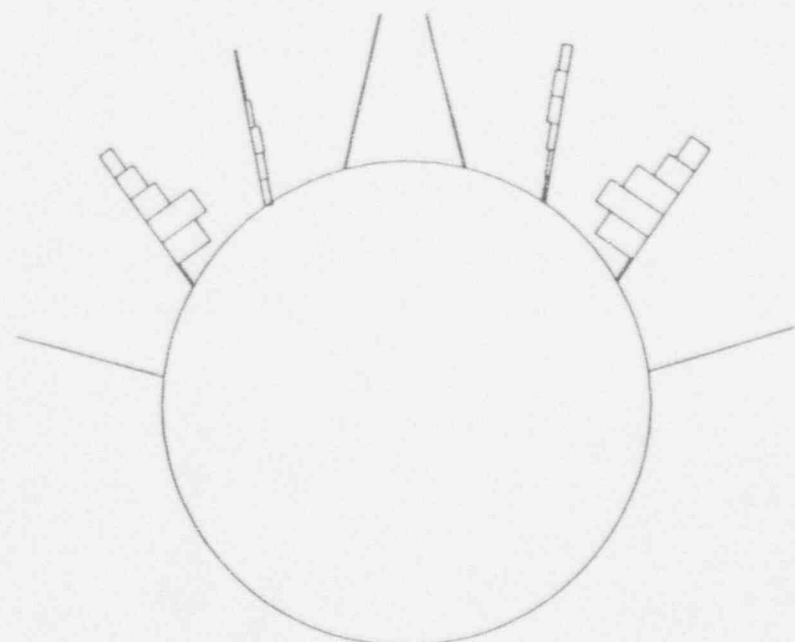
-1.000E+01 <y< 1.000E+01

Boundary ,



Axial Force on

Structure	Max. Value
Cable # 1	-1.426E+03
Cable # 2	-1.308E+05
Cable # 3	-2.303E+04
Cable # 4	-2.340E+03
Cable # 5	-1.423E+03
Cable # 6	-1.523E+05
Cable # 7	-2.925E+04
Cable # 8	-3.294E+03



M&C CONTRACTOR

PRELIMINARY

-900 -700 -500 -300 -100 .100 .300 .500 .700 900
(*10^1)

JOB TITLE : TS North Ramp Stability Analysis Station 18+00 m - Excavated & Unsupported

UDEC (Version 2.00)

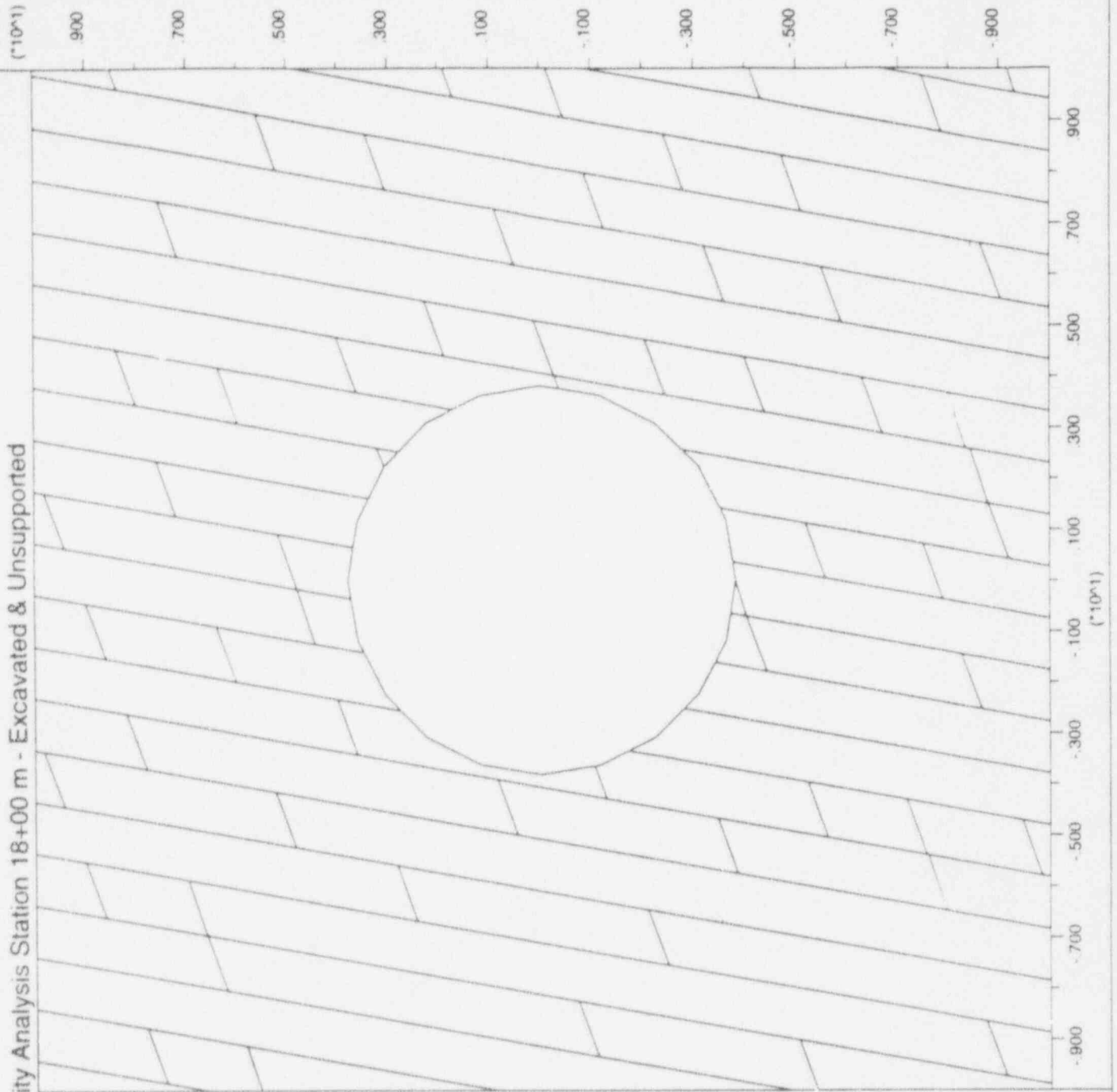
LEGEND

5/02/1994 14:53

cycle 6000

time 1.280E+00 sec

block plot



M&O CONTRACTOR

PRELIMINARY

JOB TITLE : TS North Ramp Stability Analysis Station 18+00 m - Excavated & Unsupported

($\times 10^1$)

UDEC (Version 2.00)

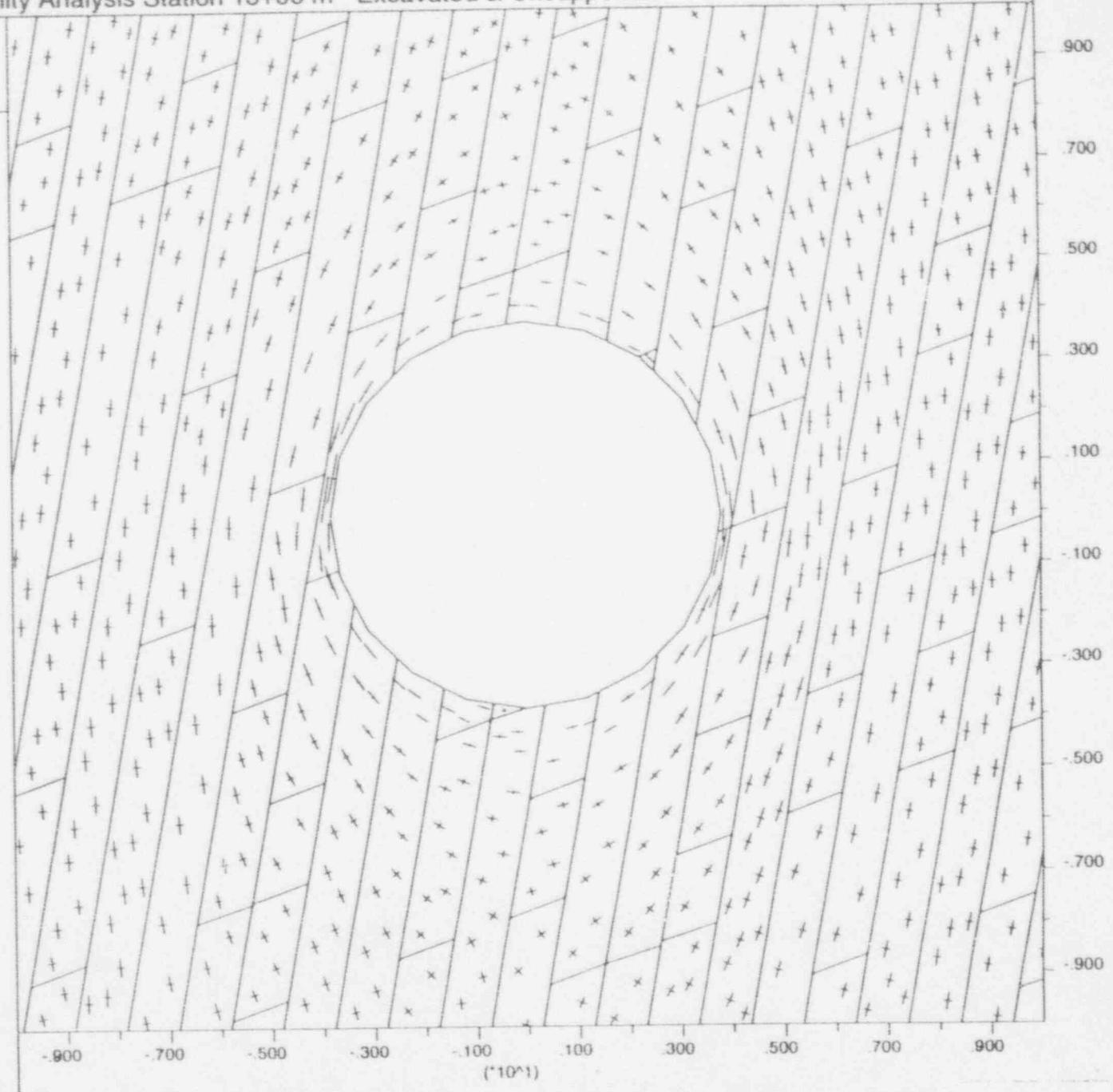
LEGEND

5/02/1994 14:57
cycle 6000
time 1.280E+00 sec

block plot
principal stresses
minimum = $-1.135E+07$
maximum = $5.845E+05$



M&O CONTRACTOR
PRELIMINARY



JOB TITLE : TS North Ramp Stability Analysis Station 18+00 m - Excavated & Unsupported

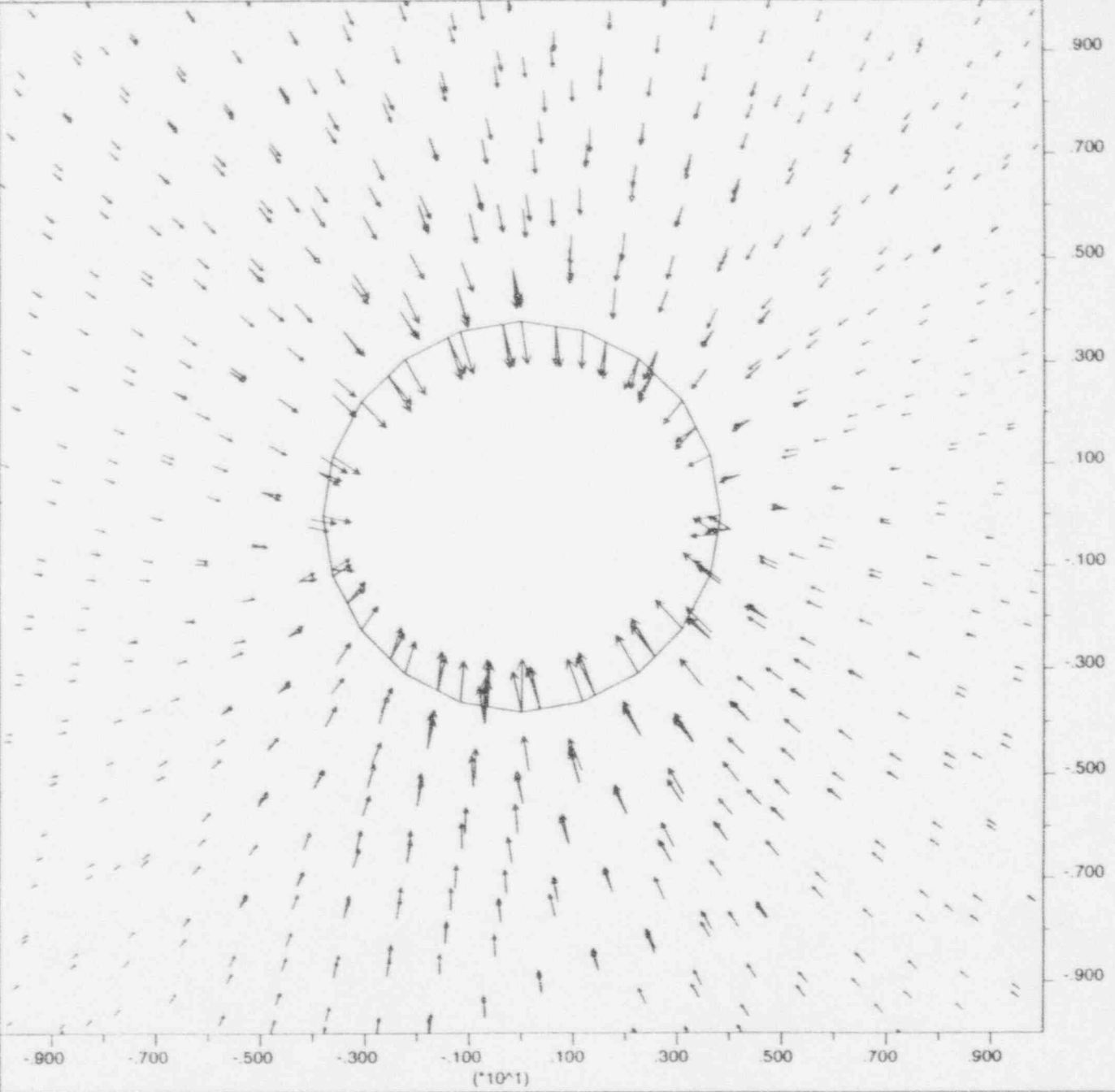
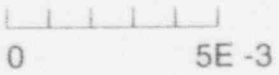
(*10^1)

UDEC (Version 2.00)

LEGEND

5/02/1994 14:58
cycle 6000
time 1.280E+00 sec

boundary plot
displacement vectors
maximum = 1.519E-03



M&O CONTRACTOR

PRELIMINARY

JOB TITLE : TS North Ramp Stability Analysis Station 18+00 m - Excavated & Unsupported

(*10^1)

UDEC (Version 2.00)

LEGEND

5/02/1994 14:58
cycle 6000
time 1.280E+00 sec

boundary plot
shear displacements on joints
max shear disp = 3.611E-04
each line thick = 7.222E-05



M&O CONTRACTOR

PRELIMINARY

-900 -700 -500 -300 -100 .100 .300 .500 .700 900

(*10^1)

From Z Petermann
4 May 94
-g-

ATTACHMENT #18

-yls-

Geochemical Stratigraphy
(Handout, NRC Field Trip, May 4, 1994)

Isotope and Geochemistry Support Group
Yucca Mountain Project Branch
U.S. Geological Survey
MS 963 Box 25046 DFC, Denver CO 80225

Introduction

The intrinsic mineralogic, chemical, and isotopic variations within large felsic ash flows such as the Topopah Spring and Tiva Canyon Tuffs provide a wealth of information for reconstructing the petrogenetic evolution of the source magmas and the fluid dynamics of magma-chamber evacuation. The distinctive and laterally extensive compositional variations within the tuffs reflect eruption from zoned magma chambers; the vertical arrangement of the compositional zones in the tuffs are inverted from those that existed in the magmas. Although fractional crystallization and crystal settling were important processes in establishing some of the compositional stratification in the magmas, assimilation was also important as shown by significant isotopic (Sr, Nb, and Pb) variations within individual tuff units, and by inherited Precambrian zircons in Tertiary ash-flow tuffs from other areas.

From a practical stratigraphic standpoint, these systematic variations can be used to subdivide the units into stratiform zones that aid in mapping structural features. In both the Topopah Spring and Tiva Canyon Tuffs, monotonously uniform, crystal-poor, high-silica rhyolite is overlain, through a gradational transition, with crystal- and pumice-rich quartz latite.

Geochemistry

Numerous published reports present detailed geochemical and isotopic studies of the Topopah Spring and Tiva Canyon Tuffs aimed at deciphering their petrogenetic and eruptive histories. For the stratigraphic approach described here, we have developed a rapid method for determining distinctive geochemical zonation of bulk-rock samples that can be used as an aid in mapping and structural interpretation. Samples obtained from outcrop or drill core are subsampled with a one-half inch diamond drill to minimize the effects of alteration and surficial calcite. The samples are pulverized to 200 mesh powders and analyzed for K, Ca, Ti, Rb, Sr, Y, Zr, Nb, Ba, La, and Ce on a multitarget, energy-dispersive XRF unit. Detection limits are a few parts per million and analytical uncertainties are typically less than 10 percent of the values reported.

The remarkably uniform composition of the Tiva Canyon high-silica rhyolite is shown by mean compositions (Attachment 1) and by the smooth vertical trends in Ti, Zr, and Ba for an outcrop reference section and for drill core from NRG-3

(Attachments 2 and 3). The change from compositionally uniform high-silica rhyolite to quartz latite occurs as an abrupt inflection point in the curves followed by a dramatic rise in Ti, Zr, and Ba. Although not shown, K, Ca, Sr, La, and Ce also increase systematically through the quartz latite whereas Rb and Nb decrease and Y remains virtually constant through both rock types. Rb/Sr ratios are nearly constant in the high-silica rhyolite but decrease by more than a factor of 10 through the quartz latite. Similarly, K/Rb ratios are amazingly uniform in the high-silica rhyolite but increase by a factor of four through the quartz latite. The uppermost part of the Tiva Canyon Tuff was intersected by NRG-2A. Within the upper five feet of the quartz latite and immediately below the superjacent bedded tuffs, the concentrations of Zr, Ba, and Ti decrease rapidly as shown in Attachment 4.

The contact between the high-silica rhyolite and the transitional quartz latite can easily be located by the geochemical trends shown on Attachments 2 and 3. For example in the five-foot interval between samples that bound this contact in NRG-3, the lowest quartz latite is enriched by the following over the subjacent high-silica rhyolite sample: Ti, 12 percent; Zr, 11 percent; and Ba, 82 percent. These changes are substantially greater than experimental error suggesting a potential resolution of less than five feet. The changes are illustrated graphically in Attachment 5 where selected samples of the quartz latite are normalized to the mean high-silica rhyolite composition and referenced to their stratigraphic position above the contact.

This geochemical method for identifying the high-silica rhyolite/quartz latite contact has been used on the north side of Antler Ridge in a structurally complex area to verify the mapping of zonal features where displaced by faulting. We anticipate that this technique will be especially useful underground where many of the physical attributes of the zonal features that are enhanced by weathering in outcrop will not be present. We will be able to identify the high-silica rhyolite/quartz latite in both the Tiva Canyon and Topopah Springs Tuff within a few feet (Attachment 5), and reliable estimates of position in the quartz latite can be made on the basis of the rapid stratigraphic changes in many of the elements (Attachments 2, 3, and 4).

Mean Values for High-Silica Rhyolite of the Tiva Canyon Tuff

Number	Whaleback		Antler Ridge		NRG-3 (Drill Hole)	
	Mean	Stdev.	Mean	Stdev.	Mean	Stdev.
	26		25		29	
K (%)	3.56	0.04	3.63	0.08	3.60	0.05
Ca (%)	0.50	0.26	0.66	0.26	0.18	0.02
Ti (ppm)	863	17.8	853	16.0	872	16.6
Rb	188	3.9	188	5.6	191	3.3
Sr	19	5.1	19	4.2	24	5.7
Y	42	4.7	44	3.4	41	5.2
Zr	202	4.5	201	5.5	204	5.8
Nb	32	1.1	31	1.0	32	1.5
Ba	51	9.9	48	8.1	30	9.4
La	43	5.3	43	5.5	42	6.7
Cc	73	6.8	74	6.5	71	9.4

