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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: DOE-NRC Site Visit - Surface Based and Underground Site Characterization Activities 20-5702-441

DATE/PLACE: May 17 and 18, 1995 - Yucca Mountain, Crater Flat and vicinity

AUTHORS: John Stamatakos and Rui Chen with Larry McKague, David Ferrill, and Gerry Stirewalt

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David Ferrill
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John Stamatakos
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BACKGROUND:

NRC representatives and members of the ACNW and NWTRB were also present as well as DOE staff and their sub contractors (including the Management and Operating Contractor, the U. S. Geological Survey, and the Bureau of Reclamation), representatives of the State of Nevada and representatives of Clark and Nye counties. Attendance was taken on May 17 and is included as Attachment 1.

BACKGROUND AND PURPOSE OF TRIP:

The DOE-NRC visit was a regularly planned meeting designed to provide a format for the DOE staff and their sub contractors to update the NRC on results of current investigations at the Yucca Mountain site. The purpose of this trip was to apprise the NRC and related personnel of the DOE's progress in the characterization of faults and fractures at Yucca Mountain, including stratigraphic and structural mapping of the ESF North Ramp tunnel. The agenda for this site visit is included as Attachment 2. Presentations were made either at the DOE's Field Operation Center (FOC) or as field-tour stops (FTS), and are denoted as such in this report. Specific information distributed as hand-outs during the presentations or tour stops are available from John Stamatakos or David Ferrill at the CNWRA in San Antonio, Texas or Gerry Stirewalt in the Rockville, Maryland office of CNWRA upon request.

SUMMARY OF PERTINENT POINTS:

<u>Wednesday, May 17, 1995</u>

FOC-1. Protocols and Introductions (M. Tynan - DOE)

Mark Tynan presented an overview of the current project status, including current ESF studies, ESF construction and design, stratigraphic investigations, surface mapping activities, geophysical

investigations, trenching activities, borehole activities, and 3D modeling. He noted that surface mapping activities were now being conducted under the supervision of Warren Day from the USGS.

FOC-2 Main Drift Stratigraphy and Cross Sections (D. Kessel, SNL)

David Kessel presented current stratigraphic and structural cross-sections of the North Ramp based upon data from 11 boreholes (USW SD-9, USW NRG-7/7A, UE 25 NRG-1, 2, 2a, 2c, 2b, 2d, 3, 4 and 5) and mapping results from the ESF North Ramp. The geotechnical report (SAND-95-0488/1) which includes cross sections, geologic and geotechnical data is complete.

Stratigraphic and structural cross-sections for the ESF Main Drift based upon data from two boreholes (USW SD-9 and USW SD-12) are "work in progress". The main drift geotechnical report will be available by the end of May, 1995.

The rock mass classification based upon the Norwegian Geotechnical Institute (NGI) quality index (Q) was discussed. Actual Q values are higher in the ESF than the predicted Q values from borehole data. As a result, the recommended ground support for the North Ramp is 85 percent higher than category 3 and partly category 4 and the recommended ground support for the Main Drift is 70 percent higher than category 3. It was noted that the estimated Q values were not used in selecting ground supports for tunnel construction. The limited number of boreholes was cited as a reason for the difference between predicted and actual Q values.

A question was raised about correlation of faults mapped in the ESF and the imbricate fault zone of Scott and Bonk (1984). Warren Day noted that re-mapping at the surface did not find all of Scott and Bonk's imbricate faults, but some of the imbricate faults were confirmed. Warren Day noted that future mapping by the USGS at a more detailed map scale (1:6000) should resolve any remaining discrepancies.

FOC-3 ESF mapping update - Structural features and fracture characteristics in the ESF (S. Beason, USGS/USBR)

Steve Beason presented preliminary cross-sections of the north ramp and main drift sections. Mapping includes full periphery mapping (after steel sets are installed), line surveys on the right spike wall, analysis of fracture/fault geometry, photographic documentation, construction monitoring, and estimation of rock quality indices. As of May 17, 1995, the ESF reached station 7+62 (m) within the lower non-lithophysal unit of the Tiva Canyon Tuff.

Mapped faults are in good agreement with their predicted location to station 5+00. However, there is an apparent mismatch between 5+00 and 6+00. Stratigraphic contacts are located in the tunnel nearly as predicted. Only faults with displacements greater than 0.5 m are shown on cross-sections. Smaller displacement faults (defined as fractures longer than 10 cm with more than 10 cm of offset) and shears (fractures longer than 10 cm with less than 10 cm of offset) were noted but not included in the cross-sections. On the right wall, 28 faults with displacements greater than 10 cm have been mapped.

Fault and fracture characteristics within the ESF were summarized by Steve Beason as follows:

(i) The Bow Ridge fault exposed on right wall is about 2 m thick and filled with "fault rubble"

(ii) Low-angle slickenlines indicate a component of strike-slip displacement in addition to the mapped dip-slip offsets.

(iii) Most faults and fractures have northwest trends. Northeast trending structures, prevalent in surface outcrops, are rarely observed in the ESF.

(iv) Faults and fractures have discontinuous apertures with varying thicknesses (up to 8 cm). Opal fracture fillings are common, although some "spotty" calcite fillings suggest torturous fluid pathways. Very few fractures show continuous fracture fillings.

(v) The only evidence of water in the tunnel was "moist" clay in a fracture east of the Bow Ridge fault and in a heavily disturbed zone at station 5+30. Steve Beason indicated that this water smells of ammonia and was probably introduced during drilling. It was not considered evidence for perched ground water.

FTS-1 UZ-7a drill pad - Ghost Dance fault and fracture patterns (W. Day, S. Williams-Stroud, USGS; E. L. Majer, LBL).

Warren Day gave an overview of the important features of the UZ-7a drill pad. At this outcrop, about 50 m horizontal section of Tiva Canyon Tuff is exposed in the Ghost Dance fault zone. The outcrop contains two fault gouge zones (the Ghost dance fault proper and a secondary unnamed fault within the Ghost Dance fault zone to the west). The Ghost Dance fault trends north-south (or slightly northwest-southeast) and dips steeply to the west between 60° and 70°. According to the USGS, offset across the fault is between 60 ft and 70 ft, based upon the offset boundary between the crystal rich and crystal poor members of the Tiva Canyon Tuff. The USGS mappers found no evidence for strike-slip displacement of the Ghost Dance fault. Mapping of the exposure by Sherilyn Williams-Stroud (USGS) shows intense brittle deformation in the hanging wall rocks, while foot wall rocks appear relatively undeformed. She defined the following four deformation-style subzones based upon the fracture patterns in the hanging wall (moving progressively away from the exposed Ghost Dance fault) :

I. conjugate fracture sets and radial fracture splays;
II. high-angle fractures, refracted across horizontal joints and radial fracture splays;
III. breakage predominantly into small blocks (about 10 cm);
IV. radial fracture splays, but with lower incidence of open fractures.

Warren Day noted that there are three pre-existing joints sets in the Tiva Canyon rocks (N-S, NW-SE, and NE-SW). The N-S and NW-SE sets are interpreted as primary cooling joints in the tuffs. He stressed that deformation reactivated these primary cooling joints as faults (i.e. that fault orientations are strongly influenced by the cooling fabric).

Ernie Majer presented new VSP seismic results. His interpretation of that data shows that the Ghost Dance fault is planar to at least 2500 ft, well below the water table (based upon linear features observed in the 0.5 second frequency seismic survey). Reflectors appear more continuous below the water table. The seismic data have an apparent problem with velocity pull down, possibly caused by decreased seismic velocities associated with extensive fracturing within the Ghost Dance fault zone.

FTS-2 Ghost Dance Trench at Whale Back Ridge (R. Spengler, Warren Day, Emily Taylor, D. Buesch, USGS)

Atop Whaleback Ridge, detailed USGS mapping constrains the width of the Ghost Dance fault zone to approximately 250 ft and the offset to about 90 ft of offset. Warren Day pointed out that there is

considerable lateral variations in both fault displacement (45-90 ft) and fault-zone thickness (100-250 ft) along the fault zone. He asserted that geological movement along the Ghost Dance fault is limited, citing the lack of a significant Holocene fault scarp. However, several points were raised by members of the field tour which argue against this assertion. The trace of the main fault surface cuts across the middle of the slope near the saddle making it easily eroded. The fault zone is wide (250 ft), which allows for distributed displacement. Moreover, as seen in the refraction seismic surveys (see FOC-06), displacement along the Ghost Dance fault at depth may exceed 1 km. This issue of strain incompatibility (between fault displacements mapped at the surface and displacement estimated from seismic data at depth) is a major source of uncertainty in evaluating slip-rates and recurrence intervals of these faults.

There is remaining disagreement among the USGS mappers about the relationship between the Ghost Dance and Sundance faults. According to Spengler (1994), the NW-SE trending Sundance fault offsets the Ghost Dance Fault zone by up to 52 m (in a right lateral sense). However, the possibility that Ghost Dance displacement is partitioned onto several widely-spaced, parallel faults that extend north of Split Wash remains a distinct possibility (see last 1994 trip report for details of this discussion). Resolution of this issue is important because, in Spengler's model, Sundance NW-SE displacement would post-date motion on the Ghost Dance fault.

New maps also show that at Antler Ridge, the Ghost Dance fault is offset about 45 ft by a second NW-SE trending fault. This newly mapped fault is subparallel with the Sundance fault. The fault does not appear to offset stratigraphy so perhaps it is simply a step-out on the Ghost Dance fault. Currently, a 1500 ft wide strip map is being produced along the Sundance trend, from Antler Ridge to a point 1000 ft beyond the proposed intersection between the Sundance and Solitario Canyon faults in order to resolve these issues.

Within the trench itself, colluvium horizons are not offset along the fault trace. U-series ages (of apparent low quality) indicate that youngest horizons are 80,000-90,0000 years old or older. Based upon calcification of the colluvium, the USGS (mainly Emily Taylor) argued that there is no Holocene slip on this fault and possibly no Quaternary offset (although no clear constraints on Quaternary slip were presented and future dating is clearly needed to establish this interpretation). A wedge of welded tuff preserved only in the hanging wall also suggests that displacement are old (> 1 Ma). Los Alamos National Lab is currently looking at cosmogenic radio nuclide Be^{10} as a way to constrain the age of fault motion.

FOC-4 ESF and Repository design models, borehole geophysical applications, fractures and design (R. Elayer, MK/M&O)

Robert Elayer discussed the constraints on repository area and volume. Aerial constraints include setbacks from the Solitario Canyon, Sundance and Ghost Dance faults, minimum depth criteria, and depth above the water table. These repository design models still rely upon the USGS Lynx model (YMP.R2.0) and the nomenclature defined by Ortiz et al., (1985). There was some discussion of how to update design models to more recently adopted by DOE's EARTHVISION format.

FOC-5 Consolidated lithologic/structural logging soil and rock North Ramp stratigraphy (D. Kessel, SNL)

David Kessel discussed the core logging procedures and data handling routines for the North Ramp tunnel. Software used by SNL includes COMPLOG (self-developed) for core logging, Microsoft Office

Application (including Excel) for data manipulation, and CorelDraw for plotting. David Kessel emphasized the versatility and portability of storing and manipulating the data in these software formats.

FOC-6 Preliminary results of USGS regional seismic profiles (Tom Brocher, USGS)

Tom Brocher presented new seismic reflection surveys across Yucca Mountain and Crater Flat Valley (using dynamite and Vibroseis sources). The final report on these new data is due in October, 1995. Preliminary results follow:

(i) Strong, west-dipping reflectors beneath Crater Flat. These reflectors are truncated by an east-dipping reflector (Bare Mountain Fault).

(ii) Significant displacement across both the Ghost Dance and Solitario Canyon faults (> 1-2 km). This raises the question as to why less than 100 ft of this displacement is observed in the surface exposures. Balancing this displacement gradient (from 1-2 km at depth to less than 50 m at the surface) along the Ghost Dance fault would require considerable growth of the Tertiary tuff section across the fault.

(iii) West-dipping normal faults (like the Ghost Dance fault) sole into an east-dipping master listric fault below approximately 3 km.

FOC-7 Preliminary results of LBL repository seismic (E. L. Majer, LBL)

Ernie Majer presented preliminary results from high resolution, shallow seismic reflection, micro-gravity, and geoelectric surveys in the repository area. These surveys suggest that there is greater displacement along the Ghost Dance Fault near the repository depth (> 150 ft) than at the surface.

FOC-8 USGS Rock Characteristics Team- Structural Studies Project (W. Day, R. Dickerson, C. Potter, D. Sweetkind, C. Weisenberg, S. Williams-Stroud, and J. Ziegler)

Warren Day summarized the current mapping efforts of the USGS which includes (1) enhanced surface geologic maps/verification of Scott and Bonk (1984), (2) detailed mapping of the Sundance fault to better constrain the geometry, continuity, and character of the Sundance fault, and (3) fracture studies (vertical continuity of fractures in PTn, pavement mapping at Fran Ridge, and fracture mapping at the UZ-7a drillpad). Specific observations and conclusions from these projects were presented at the individual field tour stops.

FOC-9 Trenching activities at Ghost Dance Fault (E. Taylor, C. Menges, and J. Whitney, USGS)

Emily Taylor gave a very brief presentation summarizing the current trenching activities. Many of the conclusions discussed here were also presented at the trenches visited during the second day of the field tour.

FOC-10 and 11 Geologic Framework & Integrated 3-D Site Model (M. Tynan, DOE,; D. Jefferis, EG&G)

David Jeffries summarized the progress of the geologic framework and integrated 3-D site models. Some important points include:

(i) Qualification of EARTHVISION to be completed by June, 1995.

(ii) Methods to convert USGS models from Lynx GMS to EARTHVISION are under review (YMP.R1.1 and YMP.R2.0)

(iii) Access of the numerical models or model data via the internet. Access would come through Mosaic implementing the Numerical Model Warehouse Data Access home page.

FOC-12 Finite Element Analysis/Hanging Wall Deformation (D. Ferrill, NRC/CNWRA)

David Ferrill presented results of finite element modeling (static and dynamic) of listric normal faulting models. The purpose of this modeling experiment is to test mechanical viability of listric normal faults within a brittle upper crust. The models treats the host rock as a linear-elastic medium with discrete elastic-plastic fault zones. Output from the models show theoretical strains and strain rates associated with various initial geometries of listric-normal faults. One significant observation of the models is that slip rates are high for the steeper portions of the faults and low along the detachments. This is consistent with seismic data from Basin and Range faults, in which only the steeper portions of the faults appear to be seismically active.

Wednesday, May 18, 1995

FTS-03 Rock Valley trenches - Rock Valley fault zone (NE) (D. W. O'Leary, J, Yount, USGS)

New trenches were dug in Rock Valley to better constrain motion along the Rock Valley fault. Fault scarps seen on air photos were used to site the new trenches.

Trench RV-4 - southern strand of the Rock Valley fault - Dennis O'Leary interprets Holocene slip on the Rock Valley fault exposed in this trench. It appears that 40,000 - 100,000 year old paleosols were disturbed by the fault. The USGS interprets multiple slip events, recorded in the alluvium, although only one event is clearly discernible in RV-4. The fault shows significant vertical offset (> 1 m) and evidence for even greater strike-slip displacement (e.g. mismatch of features on opposite walls of the trench or low angle slickenlines on fault surfaces). Dennis O'Leary suggested that orientation of the slikenlines and the amount of dip-slip offsets could be used to constrain strike-slip displacement. However, this method seems uncertain because it requires exact knowledge of the fault plane orientation. Small changes in fault plane orientation would result in significant differences in the amount estimated horizontal slip.

Trench RV-4b (test pit #2) - Jim Yount interprets multiple slip events in this trench. The faults and fractures exposed in this trench clearly cut the well calcified alluvium, which he suggest may be 250,000 years old. New U-series ages are being run to better constrain the age of faulting.

Trench RV-3 - north strand of the Rock Valley fault - The fault is clearly exposed here. The fault offsets colluvium wedges and overlying units up to 1 m. Jim Yount guesses that the youngest units offset are about 100,000 years old. Several samples were collected here for thermoluminescence (TL) and U-series dating. As before, there is no direct observation of strike-slip faulting, yet, sections exposed on opposite walls do not match suggesting some strike-slip displacement.

FTS-04 Fracture mapping at the Fran Ridge Pavement (D. Sweetkind, W. Day, Alan Flint, USGS)

The pavement exposes the middle part of the Topoah Springs Tuff (a similar unit was mapped in detail by Chris Barton south of Fran Ridge). Apparently, the fracture intensity is greater at the southern end

of Fran Ridge because of its closer proximity to major faults. The pavement has been remapped since last year's tour.

Three sets of primary cooling joints were mapped, two vertical sets oriented NE-SW and NW-SE and a sub-horizontal set. The cooling joints are then overprinted by N-S and NW-SE tectonic joints, with reactivation of the cooling joints during deformation of the tuffs. The multiple sets suggest rotation of stress with time. Don Sweetkind hopes to use the relationships between joint sets to constrain the stress history of Yucca Mountain and to help evaluate the regional extensional strain.

Alan Flint is evaluating fracture conductivity and using the results of the joint mapping as input parameters in the hydrologic models. Preliminary results show that fractures in the middle nonlithophysal zone are large and well connected while fractures in the upper lithophysal zone are short and poorly connected. Alan Flint suggested that the fractures adjacent to the faults and not the faults themselves may be the most important pathways for ground water flow.

Much of the discussion here centered on the hydrologic models. According to Alan Flint, the present hydrologic models are based upon a dual permeability - dual porosity assumption with discrete fractures. The model does not incorporate a fractal description of joints, fractures, or faults. FRACMAN is used to transform structural data on joints, faults, and fractures to the hydrologic models.

FTS-05 Little Prow area - Yucca Mountain Crest (Chris Potter, USGS)

Chris Potter discussed the detailed mapping of the Little Prow Area. This more detailed mapping (1:240) was specifically designed to answer uncertainties about the relationship between the Solitario Canyon and Sundance faults. New mapping has not found evidence of the Sundance fault intersecting the Solitario Canyon fault at Yucca Crest. However, a complex fault pattern near the Yucca Crest was discovered, including some small-displacement NW trending faults. These faults are interpreted by Chris Potter to be splays off the Solitario Canyon fault. These splays do not extend beyond Solitario Canyon and, therefore, cannot be linked the Sundance fault.

The Solitario Canyon fault is exposed within an unnamed and unlogged trench near the Yucca Crest. Within the fault zone are 10 m.y. brecciated basalt fragments. The basalt can be traced down slope to the south for about 100 meters along the Solitario Canyon fault, and along the fault it is intermittently brecciated and unbrecciated. Recently, the basalt has been extensively cored for either geochemical or paleomagnetic analyses (unknown who actually drilled the rocks).

According to the USGS mapping, offsets along Solitario Canyon fault decreases toward the south (40 ft at ridge north of little Prow, 50 ft at little Prow, and 400 ft at Yucca Crest).

FTS-06 Crater Flat Trenches (J. Whitney, Jeff Coe, Emily Taylor, USGS)

New trenches have been dug in northern and southern Crater Flat to look for evidence of Holocene faulting along the Crater Flat Fault.

<u>Trench CFF-T2A - northern end of Crater Flat</u> - This new trench cuts across the Crater Flat fault. It is about 6.5 km west of the repository edge and just north of Black Cone. The trench was located across a fault scarp in the alluvium gravel. Jeff Coe (USGS) interprets three slip events, the youngest of which offsets a thin silt layer no younger than 500,000 years. These results suggest a low recurrence interval.

New U-series dating on silica rinds of pebbles within the offset horizons should better constrain the age of faulting here.

CFFT-1A - southern end of Crater Flat - This is very new trench (just a few days old) that exposes either the southern end of the Crater Flat fault or part of the Windy Wash fault. At the time of the field tour, it had not been mapped in detail. "Off the cuff" interpretations by several USGS geologists suggest that there may be three or four seismic events recorded here.

SUMMARY OF ACTIVITIES:

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

IMPRESSIONS/CONCLUSIONS:

The current focus of much of the geologic work at Yucca mountains centers on paleoseismic investigations from trenching studies. These data are very useful, especially for regional and tectonic models of structural deformation and to the hyrogeologic models. However, the issue of discrepancies between fault displacements estimated from trenching studies and those from other data (specifically seismic surveys or uplift rates from fission tracks) need to be resolved before all uncertainties about paleoseimicity can be clearly examined. Analysis of this issue naturally requires better processing of the recent reflection seismic data, but, it also requires better structural controls, namely construction of balanced cross-sections across the region. Balanced cross-sections may also provide insights into regional tectonic models, especially with regard to the geometry of faults at depth (planer vs. listric/detachment geometry). Integration of the other geophysical data (gravity and magnetics) into the regional structural model should also improve uncertainties in the tectonic models.

A related source of uncertainty centers on questions of subsurface and surface rupture. Trenching studies assume that all significant seismic events result in surface offsets that can be mapped in trenchs cut normal to the active faults. Yet, the Little Skull Mountain (5.4) and even the larger Northridge (6.9) earthquakes did not produce recognizable surface ruptures. This lack of surface rupture for these relatively large earthquakes suggests that trenching studies underestimate paleoseismic activity. Future work needs to address this uncertainty.

The controversy about the nature and significance of the Sundance fault needs to be resolved. The more detailed mapping currently underway at Yucca Mountain should help to clear up some of the remaining controversies about the Sundance fault.

Fracture mapping at the pavement sites is important to the hydrogeologic models. However, questions of how those patterns apply at a regional scale needs to be carefully addressed. Specifically, how do the joints and fractures change with depth, why are the NW-SE fractures more prevalent in the ESF, and how are the joint and fracture patterns different at the southern end of Yucca mountain where paleomagnetic evidence suggests up to 20° of clockwise rotation. Relevant to this last questions is how reactivation of joints as faults change at the southern end of Yucca Mountain. Resolution of these issues is important to both the hydrogologic and tectonic models.

PROBLEMS ENCOUNTERED:

None

PENDING ACTION:

None

RECOMMENDATIONS:

Specific recommendations are listed in the "Impressions/Conclusions" section. CNWRA staff must continue to participate in the site visits in order to remain informed on current fault and fracture characterization, other structural and stratigraphic relationships, rock properties and tectonic, structural and hydrologic modeling at Yucca Mountain.

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SIGNATURES:

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David A. Ferrill Research Scientist	6/27/95 Date
H. L. McKague FOR GERRY STIREWALT Gerry L. Stirewalt Principal Scientist	6/27/95 Date
H. Lawrence McKague Manager, Geologic Setting	6/27/95 Date
Budhi Sagar Technical Director	6/27/95 Date