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SUBJECT: Trip rept of 961016-18 & 970106-08 visits to Salt Lake City, UT and 961118-21 visit to Amagosa Valley,NV re Seismic Source Characterization Workshops (20-5708-471).

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TRIP REPORT

SUBJECT: Yucca Mountain (YM) Seismic Source Characterization (SSC) Workshops; Workshops #2, #3, and #4. (20-5708-471)

DATE/PLACE: SSC Workshop #2 - October 16-18, 1996: Salt Lake City, Utah
SSC Workshop #3 - November 18-21, 1996: Amargosa Valley, Nevada
SSC Workshop #4 - January 6-8, 1997: Salt Lake City, Utah

AUTHOR: John Stamatakos

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BACKGROUND AND PURPOSE OF TRIP:

As part of the analyses of structural deformation and seismicity of the Yucca Mountain (YM) region, the United States Geologic Survey (USGS) (under contract to the Department of Energy (DOE)) is developing new probabilistic seismic hazard and probabilistic fault displacement hazard analyses (PSHA and PFDHA, respectively). The goals of the PSHA and PFDHA are to provide DOE with a basis for seismic design inputs (preclosure) and performance assessment studies (post-closure).

The PSHA and PFDHA are being produced by two expert panels, one to assess seismic source characterization (SSC) and one to assess vibratory ground motions (GM). There is also a seismic design basis (SDB) team, but, it is not part of the expert elicitation. The panels will interact through a series of structured workshops (schedule given in Appendix 1) and ultimately develop PSHA and PFDHA hazard curves through an expert elicitation. Each panel of experts is aided by a facilitation team and the work is being reviewed by an independent four-member review team. Tim Sullivan is the DOE representative for all three panels and Carl Stepp is the project director. Kevin Coppersmith leads the SSC facilitation team. Norm Abrahamson leads the GM facilitation team. Robin McGuire leads the SDB team. The workshops are being organized through Woodward Clyde Federal Services headed by Ivan Wong. A complete list of the teams, experts, and panels is given in Table 1 of Appendix 2 (Summary of Seismic Source Characterization Hazard Methodologies Workshop). An interesting twist to the SSC expert elicitation is that the eighteen panel members are grouped into six expert teams, each consisting of three so-called specialists (a seismologist, a geologist, and a paleoseismologist).

SSC Workshop 2:

Workshop 2 was intended to focus on methodologies for characterizing seismic and fault displacement hazards, although because more than one year passed since the initial SSC workshop on data needs (convened in April, 1995), this second workshop also included a lot of discussion on relevant data, especially the plethora of new structural and tectonic data that had been gathered, analyzed, and published since 1995.

Workshop 2 was divided into three topics for discussion: (i) seismic sources (locations and geometries), (ii) maximum magnitude earthquake, and (iii) earthquake recurrence assessment. The experts were also divided into their respective teams-of-three at this meeting. Participants and their affiliations are given

in Appendix 2. A detailed summary of the presentations are is given in Appendix 2. A copy of the handouts for the meeting is organized and stored in a white binder in room A228, marked "Seismic Source Characterization Workshop 2." As Kevin Coppersmith had to keep reminding the participants, the intent of the workshop was presentation of the amount, types and references for relevant SSC data. Discussions of interpretations with proponent positions was put off until workshop # 3.

At workshop 2, I made two presentations (Appendix 3). In the first talk, I summarized much of our recent geological and geophysical investigations at Bare Mountain and in Crater Flat (much of which is summarized in Ferrill et al., 1995). This included our analyses of Bare Mountain and Crater Flat paleomagnetism, apatite and zircon fission track geochronometry and thermochronology, calcite deformation-twin geothermometry, tectonic sedimentology, detailed structural geology, ground magnetic surveys, slip and dilation tendency analyses, finite element modeling, and "sandbox" analog modeling. The second presentation reviewed the geodetic data from the NRC-CalTech-CNWRA GPS surveys. These presentations highlighted what we consider a fundamental difference between the Center and the DOE on seismicity and faulting. DOE studies typically yield low slip and recurrence rates for faults in the YM region. Their rates are based entirely on paleoseismic results gleaned from trenching studies. Our analyses indicate up to an order of magnitude greater slip and recurrence rates. This discrepancy is most pronounced for the Bare Mountain fault (where we have concentrated our efforts). Substantial differences also exist between the DOE Global Positioning System (GPS) survey results of Savage (1994) and the CalTech-NRC results (Ferrill et al., 1995), especially with regard to surface displacement associated with the 1992 Little Skull Mountain earthquake.

SSC Workshop 3:

Workshop 3 focused on alternative conceptual models and interpretations including proponent positions. This meeting was held in the Amargosa Desert and included two and a one half days of field trips, including a half day trip into the Exploratory Studies Facility (ESF). A detailed review of the workshop is given in Appendix 3. Handouts from the presentations and field trip stops are stored in A228, and marked as "Seismic Source Characterization, Workshop 3." Appendix 4 also includes a list of the meeting participants and their affiliations as well as a meeting schedule and map of the field trip routes. The main controversies of the proponent positions centered on the geophysical results (especially alternative interpretations of the seismic reflection data), fault-scarp trenching methodologies and Quaternary stratigraphy, and the underling tectonic models that control the structural in the region.

At workshop 3, I made two presentations (Appendix 5 and Appendix 6). The first presentation was one of four invited discussions that focused on conceptual tectonic models of the YM region. These conceptual models are critical to seismic source characterization because they help define the maximum capable earthquake that a single fault can generate (this depends essentially on the length and down-dip extent of the fault). Moreover, tectonic models constrain interpretations of the nature and frequency of seismicity on blind or buried faults. This was by far the liveliest exchange of all the workshops.

In my second presentation I presented a review of the Center's work on balanced cross-sections across Bare Mountain, Crater Flat and YM (mainly from the work of Young et al., 1992). Our interpretations of fault geometries differ substantially with those of the USGS and DOE. We view all the faults as curved or listric (with convex upward shapes). The DOE views all faults as planar to depths ($\sim$ 15 km) where they intersect more ductile regions of the crust. These differences have important implications for fault displacement and seismic hazard analyses, most notably in the location, size and frequency of earthquakes and how faults may interact at depth.

I also made two short presentations during the field trips. The first one was part of a discussion of slip along the Bare Mountain fault. In the two trenches along the Bare Mountain fault, Larry Anderson, of the Bureau of Reclamation, deduced a constant slip rate of 0.01 mm/yr (a low rate) from his interpretations of the offset stratigraphy in the trenches. Our work, including the burial of the Little Cones by Quaternary alluvium (Stamatakos et al., 1997) and by the change in the morphology of the alluvial fans (Ferrill et al., 1996) along the eastern flank of Bare Mountain fault suggest that much greater fault slip (perhaps as much as an order of magnitude) on the southern end of the Bare Mountain fault. Our work raises questions about the accuracy and reliability of the trenching data in the YM region. This disagreement has been formalized in a discussion and reply recently published in Geology (Anderson et al., 1997; Ferrill et al., 1997).

The second field stop discussion was on the exposure of normal faults at the Gold Ace Mine outcrop on the western flank of Bare Mountain. These normal faults cut the older Precambrian and Paleozoic strata of Bare Mountain within the hangingwall of the Gold Ace Mine fault. The most important aspect of these older faults is that they probably represent the nature of faulting in the basement rocks beneath YM and appear to be faults capable of earthquakes in the deep crust (e.g., the 1992 Little Skull Mountain earthquake may have been triggered by slip on such a fault). I also pointed out the structural complexity of the Precambrian and Paleozoic sections (chiefly that the rocks are now essentially standing on end and tilted to the northeast) and that this style of complex geometry (minus the tilting to the northeast) probably exits beneath Crater Flat. Recognition of this complexity goes a long way to explain the chaotic seismic reflections observed below the tuff sections in recent seismic reflection profiles across Crater Flat (e.g., Brocher, 1994).

SSC Workshop 4:

Workshop 4 gave the experts their first chance to present their preliminary interpretations of the seismic and fault displacement sources and to ask for supplemental discussions of controversial results. For example, the experts invited Brain Wernicke (one of our consultants) to discuss his interpretation for the potential of large magnitude earthquakes on shallow dipping listric normal faults (Wernicke et al., 1995) and to review our most recent GPS data. Ernie Majer was also asked to discuss the seismic data as an alternative to Tom Brocher's interpretations. A detailed summary of all the presentations is given in Appendix 7. Handouts from the presentations are stored in room A228, titled "Seismic Source Characterization Workshop 4", along with the preceding workshop material.

A significant outcome of the discussions was the recognition by many that fault slip and recurrence rates do not balance across Crater Flat as expected (a point that reinforces our concern about the paleoseismic data from trenches). Based on the trenching data, there appears to be relatively large cumulative displacement and frequent recurrence of large magnitude earthquakes at YM compared to Bare Mountain. Yet, the actively subsiding and deepest portion of the Basin, including where nearly all the latest Quaternary and Holocene deposits have been deposited, is the southwestern corner of Crater Flat, adjacent to the Bare Mountain fault. Tom Hanks, from the USGS and on the facilitation team, was particularly concerned that this incongruity represents an important problem that needs resolution before an accurate probabilistic seismic hazard curve can be developed. Others like Kevin Coppersmith, however, suggest that the logic tree approach of the expert elicitation can handle such uncertainties.

Also included in the workshop was a training exercise on probability assessment, given by Peter Morris of Applied Decisions Analysis Inc. The training was marginally useful. Because the speaker did not appear to possess the indepth competence in the fundamentals and the case-study examples used to

reinforce critical aspects of the training were not well chosen with respect to questions on the probability of faulting or seismicity.

The ground Motion workshop focused on theoretical approaches to generating a unique ground motion attenuation relationship that would best fit the Yucca Mountain region. Handouts from the presentations are stored in a white binder on A228 and marked "Ground Motion Characterization Workshop 2."

At the workshop, David Ferrill made a presentation summarizing our recent results from finite element modeling. Handouts form the presentation are given in Appendix 8 (Contact author if a copy of an Appendix is desired). Our modeling was carried with Goodluck Ofoegbu, using ABAQUS, in a simulation of a master listric Bare Mountain fault with a series of subordinate antithetic Yucca Mountain faults. The modeling shows that fault geometry, in addition to the distance between earthquake and site, strongly governs peak ground motions. The effect is that simple attenuation functions, which typically use the surface distance between earthquake source (epicenter) and the site, will systematically underpredict peak ground motions, especially for faults relatively close to the site (within ~ 15 km).

IMPRESSIONS/CONCLUSIONS:

Final conclusions regarding the expert elicitation await a detailed review of the DOE PSHA and PFDHA (due sometime next fall). My initial impression is that the workshops were very informative with impressively detailed discussions of the seismic and faulting data and interpretations. In addition, I think Kevin Coppersmith and Woodward-Clyde are doing a good job of keeping the experts on task and the process well organized. However, I have two initial concerns about the process.

First, it is not clear whether the expert panel represents a broad diversity of opinion with regard to seismic sources. Although there are a number of well qualified independent geoscientists on the panel, such as Robert Smith and Ron Bruhn (of the University of Utah), the panel is clearly dominated by geoscientists (especially USGS personnel) who have long-standing ties to the project. Moreover, many of the geologists of the three-member teams are specialists in paleoseismology (for example Jim Yount was one of the USGS paleoseismologists to work on many of the trenches at Yucca Mountain). The heavy representation of paleoseismologists may lead to trenching studies being given a higher weighting in the overall hazard calculation than would otherwise occur if more broadly trained geologists were on the panel. Paleoseismic results from trenches are considered to represent minimum values of seismicity and faulting, which may minimize the hazard. In light of this by SDS KTI staff potential bias, careful scrutiny of the final PSHA and PFDHA results is highly recommended.

A second potentially significant problem has to do with the aforementioned incongruity of slip rate and cumulative fault displacements across Crater Flat. The potential for an order of magnitude difference in slip rate on the Bare Mountain fault, for example, will certainly affect the hazard calculations. The Bare Mountain fault problem remains a subissue that deserves continued focused technical analyses by Center staff.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

The NRC and Center will continue to interact with the DOE and the expert panels as the seismic and fault displacement hazard curves are developed. This will include an upcoming workshop in April, 1997 in which the experts will present their preliminary results and receive feedback from the other members of the panel. Final PSHA and PFDHA calculations are expected to be completed this summer and should be available to the NRC and Center sometime early next fall.

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