SAN ONOFRE NUCLEAR GENERATING STATION
SEISMIC SOURCE CHARACTERIZATION SSHAC

WORKSHOP #1 PROCEEDINGS

March 2013

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Prepared for

Southern California Edison

San Onofre Nuclear Generating Station

Seismic Source Characterization SSHAC Project

TABLE OF CONTENTS

COMMON ACRONYMS

AFE	Annual Frequency of Exceedance
CEC	California Energy Commission
CFM	Community Fault Models
CGS	California Geological Survey
CHIRP	Compressed High Intensity Radar Pulse
CPT	Cone Penetrometer Test
CVM	Community Velocity Models
CPUC	California Public Utilities Commission
GIS	Geographic Information System
GMC	Ground Motion Characterization
GMPE	Ground Motion Prediction Equations
GMRS	Ground Motion Response Spectrum
GPS	Global Positioning System
HID	Hazard Input Document
HC	Hazard Calculation
Hz	Hertz
IPEEE	Individual Plant Examination of External Events
IPRG	Independent Peer Review Group
ITR	Internal Review Panel
LiDAR	Light Detection and Ranging
NI	Newport Inglewood
NI/RC	Newport Inglewood / Rose Canyon
NSHM	National Seismic Hazard Mapping
NSHMP	National Seismic Hazard Mapping Project
OBS	Ocean Bottom Seismometers
PGA	Peak Ground Acceleration
OBT	Oceanside Blind Thrust
PM	Project Manager
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis

PV	Palos Verdes
QA	Quality Assurance
QFFD	Quaternary Fault and Fold Database
RC	Rose Canyon
SCE	Southern California Edison
SCEC	Southern California Earthquake Center
SCFM	Statewide Community Fault Model
SCSN	Southern California Seismic Network
SEG-Y	Society of Exploration Geophysicists – Y file format (also SEGY)
SOPAC	Scripps Orbit and Permanent Array Center
SONGS	San Onofre Nuclear General Station
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
SWUS	Southwest United States
TI	Technical Integrator
UCERF2	Uniform California Earthquake Rupture Forecast, Version 2
UCERF3	Uniform California Earthquake Rupture Forecast, Version 3
UCSD-Scripps	University of California at San Diego—Scripps Institution of Oceanography
UNAVCO	University Navstar Consortium
USGS	United States Geological Society
U.S.NRC	U.S. Nuclear Regulatory Commission
USR	Unified Structural Representation
WGCEP	Working Group on California Earthquake Probabilities
WUS	Western United States

PURPOSE

This document serves to summarize the presentations and discussions from Workshop #1 of the San Onofre Nuclear Generating Station (SONGS) Seismic Source Characterization (SSC) Senior Seismic Hazard Analysis Committee (SSHAC) Project held on January 14-15, 2013 in Irvine, California. The SONGS SSC SSHAC Project has been undertaken to update the SSC at SONGS for input into a probabilistic seismic hazard analysis (PSHA) in response to the U.S. Nuclear Regulatory Commission's (U.S.NRC) March 12, 2012 Request for Information. This Workshop was conducted in accordance with the applicable SSHAC Level 3 guidelines (NUREG 2117 and NUREG/CR-6372) and represents the first in a series of three workshops. In accordance with these guidelines, this first Workshop was conducted to identify hazard-significant issues and available data that contribute to the ground motion hazard at SONGS. This Workshop was observed by the U.S.NRC and California Energy Commission's (CEC) Independent Peer Review Group (IPRG).

The Participatory Peer Review Panel (PPRP) for this Project held an informal closed caucus at the beginning and end of each Workshop day to review and discuss technical and procedural items with respect to the SSHAC guidelines. Similar informal caucuses were also held by the Technical Integrator (TI) Team and Project Manager (PM). The PPRP held their formal caucus on January 16, 2013, which included closed discussions and a formal debriefing with the TI Team and PM. The TI Team and PM also met separately on January 16, 2013 to review and discuss the significant issues and available data presented at the Workshop; this meeting constituted TI Team Working Meeting #2. Action items were assigned to TI Team members at Working Meeting #2 to follow up on key data, models, and methods from Workshop 1.

Workshop participants and attendees are listed in Table 1 with their roles and affiliations. The Workshop 1 agenda is appended to the end of this document. Salient points from the presentations and questions sessions are briefly summarized. The summaries serve to briefly capture the broad content of the presentations, follow-on discussions, and question and answer sessions. Specific details (e.g., quantitative values) generally are not recorded herein for the sake of brevity. Such details are provided under separate cover (in the form of presenter slideshows and personal communications) for the TI Team and PPRP for their use in the SSHAC process.

JANUARY 14, 2013 (DAY 1)

Introductions by Tom Freeman, GeoPentech, Project Manager

Mr. Freeman welcomed all participants and attendees, and noted we would spend the next two days identifying the significant issues and data available to characterize the seismic sources near SONGS. He welcomed all participants and attendees to view a poster-sized fault map on the wall during their breaks or leisure time. The fault map showed all mapped faults within a 200 mile radius of SONGS, based on the USGS Quaternary Fault and Fold Database (November 2010 version), Rivero and Shaw (2011), Rockwell (2010), and Mueller et al. (2009).

Mr. Freeman then showed the project organization chart (Figure 1) and introduced the project participants (Table 1). Following Mr. Freeman's introduction of Dr. Ralph Archuleta (University of California, Santa Barbara) as the Chair of the PPRP, Dr. Archuleta introduced the other members of the PPRP and gave a brief overview of their background and qualifications. Mr. Freeman also provided a brief overview of the day's agenda and noted the agenda would be enforced to ensure that the Workshop would remain on schedule. He then introduced the Project's sponsor.

Opening Remarks by Caroline McAndrews, Southern California Edison Company, Project Sponsor

Ms. McAndrews welcomed all participants and attendees and expressed her appreciation for their time and effort. She noted the Project was tied to the March 11, 2011 earthquake in Japan—a big day for seismic and nuclear fields, and science in general—in that the U.S.NRC formed a task force after that event to formulate recommendations for U.S. nuclear power plants. The formal U.S.NRC task force recommendations were released on March 12, 2012, in what we commonly refer to as "the March 12th letter." As a result of that letter, nuclear power plant operators were tasked with completing a seismic re-evaluation of the design basis safe shutdown earthquake by early 2015. Specifically, nuclear power plants in the Western United States were required to provide an updated, site-specific PSHA considering all relevant data, models, and methods, to be identified through a SSHAC Level 3 study. Ms. McAndrews noted that because Southern California Edison (SCE) is committed to completing this work by March 2015, the success of the these SSC SSHAC workshops is critical and depends on following the applicable procedures and ensuring that the TI Team get the data they need to complete their work. She expressed confidence in the technical strength of the team assembled. Ms. McAndrews also noted that this Workshop was being conducted in parallel with a SSHAC Level 3 Project to address GMC issues (the SWUS GMC SSHAC). Ms. Andrews closed her introductions by stating that SCE was committed to the success of this Project and participants should let her know of any needs.

SSHAC: Purposes, Products, & Procedures by Ray Weldon, University of Oregon, TI Team Lead

Dr. Weldon welcomed all participants and attendees and expressed enthusiasm about the topics being discussed in the next two days. He thanked everyone for their time and interest in this project and noted that the TI Team would follow up with presenters beyond this Workshop for more information as needed. Dr. Weldon introduced his team and provided additional details on their qualifications.

Dr. Weldon informed the group of the purpose of the SONGS SSC SSHAC Project, noting that the aim is to identify "the center, body, and range of technically defensible interpretations of the characteristics of those faults that contribute to the seismic ground motion hazard at SONGS," in accordance with the SSHAC guidelines (NUREG/CR-6372 and NUREG 2117). He noted that the SSHAC process promotes a transparent, technically defendable process that provides a venue for formal interactions through workshops, and these workshops allow models and interpretations can be "presented, debated, and defended."

Dr. Weldon then reminded the group the purpose of Workshop 1, as delineated in the SSHAC guidelines, was to identify hazard-significant issues and available data. He stated that sensitivity studies presented at the onset of this Workshop will identify the hazard-significant issues and that the Resource Experts will be providing the available data to address these issues. Dr. Weldon also reminded everyone that while Workshop 1 was focused exclusively on data and methods, a subsequent Workshop 2 would provide a venue for scientists to present and defend their models and interpretations.

Dr. Weldon noted that this Workshop 1 is geared toward identifying and acquiring the most current data. The Resource Experts gathered at this Workshop are the scientists with the data, and the job of the TI Team at this Workshop is to acquire and understand this data. Dr. Weldon stated that the TI Team is interested in any and all data that exist, and that the TI Team will consider that data and vet it in the SSHAC process. He noted that this is part of capturing the range of technically defensible interpretations and probably the most challenging task of the TI Team. They will consider everything, but ultimately include only what is technically defensible. Dr. Weldon reminded everyone that as clearly stated in the SSHAC guidelines, the product is not a consensus model, but a technically defensible model. He also reminded the group of the importance of peer review and documentation in the SSHAC guidelines, as part of developing a transparent and technically defendable product.

Dr. Weldon noted that the Workshop 1 procedures in the SSHAC guidelines were designed to give Resource Experts the opportunity to present the data to the TI Team and give the TI Team the time to ask the experts questions to understand their data. Accordingly, the TI Team would have priority in the time slots following the presentations for questions and discussion. The PPRP and other Observers were asked to make note of their questions and hold those questions for their designated time slot on the agenda.

Dr. Weldon stated that the Workshop products would consist of summaries of the presentations and discussions and copies of the slideshows, all of which would be appended to the final Project report. He noted that the TI Team would be following up with Resource Experts after the Workshop for more information and that the information then communicated would also be documented.

Dr. Weldon's Project introduction concluded with a questions session; no questions were asked.

Past SONGS Hazard Calculations & Sensitivity Analyses by Andrew Dinsick, GeoPentech, Hazard Calculation Team

Mr. Dinsick introduced himself by noting that he was a part of the GeoPentech team, and that some of the principals have been involved with evaluating the seismic hazard at SONGS since the original plant licensing in the 1970s and 1980s. He reminded everyone that the purpose of Workshop 1 was to identify the available data, much of which had been identified and synthesized in past SONGS PSHAs. The most recent effort consisted of the 2010 SONGS PSHA, and the information synthesized in the 2010 PSHA utilized data, models, and methods assembled by the leading seismic source researchers in the SONGS region (many of whom have been assembled at this SONGS SSC SSHAC Level 3 Workshop #1). Mr. Dinsick also noted that the 2010 PSHA provided an initial framework to identify the hazard-significant source parameters. Mr. Dinsick indicated that his presentation was based on the 2010 PSHA (to which the TI Team, PPRP, and several Resource Experts have contributed and/or reviewed), using an updated site shear wave velocity based on post-2010 site characterization investigations, and follow-on sensitivity analyses are presented with respect to the 2010 PSHA SSC model.

Mr. Dinsick noted that the 2010 PSHA was completed to support a reliability-level (not safety-level) study and focused on mean hazard to reflect the most current data available at that time, without making informed judgments on the parameters of each fault model. The SSC parameters and models were provided by the UCERF2 group, USGS personnel (including Holly Ryan, Dan Ponti, and Stephen Harmsen), and Dr. John Shaw.

Mr. Dinsick indicated that the 2010 PSHA considered all faults within 200 miles and focused on the primary contributors to the ground motion hazard. He noted that the 2010 PSHA revealed the OBT and NI/RC faults were the largest contributors to the ground motion hazard. Mr. Dinsick noted that these two sources were characterized as mutually exclusive (based on fault geometries and expert interpretations) and thus were treated with epistemic uncertainty in the logic tree. He provided an overview of the NI/RC source parameters, which were developed based on personal communications with the USGS (including Holly Ryan, Dan Ponti, and Stephen Harmsen) in 2009. He also provided an overview of the OBT source parameters, noted the complexity of the source, and reminded everyone that the OBT model was developed by Dr. John Shaw, who was participating in this Workshop as a Resource Expert.

Mr. Dinsick then provided details derived from the sensitivity analysis recently completed using the 2010 PSHA parameters with updated site shear wave velocity measurements. The sensitivity analyses focused on which seismic sources matter, which segments of the key sources contribute most, and which source parameters have the most significant impact on the hazard. He noted that these sensitivity analyses were completed for the annual frequencies of exceedance (AFE) of interest (10^{-4} and 10^{-6}) and for spectral accelerations of 1 Hz and PGA.

To re-emphasize the dominance of the NI/RC and OBT seismic sources, Mr. Dinsick demonstrated through deaggregation and tornado plots that the NI/RC–OBT combined source contributes over 99% of the total PGA hazard at an AFE of 10^{-4} and 100% at an AFE of 10^{-6}. Mr. Dinsick noted a similar pattern of hazard for a spectral acceleration of 1 Hz, in which the NI/RC–

OBT combined source contributes over 94% of the total hazard at an AFE of 10^{-4} and 99.9% at an AFE of 10^{-6}.

Mr. Dinsick indicated the importance of the epistemic weights assigned to the mutually exclusive fault models of the NI/RC and OBT. He noted that assigning 100% weight to the OBT resulted in approximately 40% increase in hazard vs. the case with 100% weight on the NI/RC.

Mr. Dinsick then provided insight on which segments of the NI/RC and OBT sources contribute most to the hazard. Through three-dimensional deaggregation plots, he showed that near-site events within 6 to 10 km with moment magnitudes of 6.5 to 7.6 dominate the hazard at the AFEs and frequencies evaluated. Accordingly, Mr. Dinsick noted that this indicates that ruptures that include the portion of the two key faults (NI/RC and OBT) adjacent to the site account for most of the hazard at the AFEs of interest.

Mr. Dinsick also discussed the impact of the varying NI/RC and OBT source parameters on the hazard. He showed that the total hazard was most sensitive to slip rate, closest fault distance, and magnitude recurrence relationships that characterized these faults.

Mr. Dinsick's final conclusions were that the NI/RC and OBT faults control the ground motion hazard at SONGS; the OBT model results in a significantly higher hazard than the NI/RC model; and the source characteristics of the Newport-Inglewood Offshore Segment and OBT Northern Segment are key parameters that control the hazard.

Mr. Dinsick's presentation was followed by several questions.

Questions for Andrew Dinsick

Question from TI Team: You indicated the NI/RC – OBT sources were mutually exclusive; did you consider they could both be operative?

Answer from Dinsick: Yes; the kinematic models in which the NI/RC system constituted high-angle splays off the OBT were captured in the OBT epistemic branch of the logic tree, so we effectively considered hybrid models on that branch. Note that the models used in the 2010 PSHA were those from previous published references and personal communication with active researchers; no attempt was made to modify these models, as we wanted to capture and evaluate them in their truest original form. The TI Team can and should evaluate the kinematics of these two faults in this SSHAC.

Question from TI Team: What were the fault geometries for the magnitude 7.6 events?

Answer from Dinsick: The NI/RC magnitude 7.5 event was for a rupture of the full extent of the fault system, from the ground surface to varying seismogenic depths between 10 to 12 km, depending on the specific fault segment. The OBT magnitude 7.6 event was for a blind rupture on both the modeled northern and southern segments of the fault at a seismogenic depth of 5 through 17 km. The magnitudes were estimated from the magnitude-area relationships of Hanks & Bakun and Ellsworth-b, both of which were in good agreement.

Question from TI Team: What event slips were used in these magnitudes?

Answer from Dinsick: The Hanks & Bakun and Ellsworth-b regressions are magnitude-area relationships, so event slips were not explicitly utilized.

Question from TI Team: You showed recurrence relationships matter; which models and what range did you test?

Answer from Dinsick: We looked at the combinations that produced the highest and lowest effect on the hazard to capture the range. Our goal was to test if the shape of the distribution was important to the overall model. We used the truncated Gutenberg-Richter and characteristic earthquake models with b-values of 0 and 0.8, consistent with the USGS, NSHM, and UCERF2.

Question from RE in audience: Why didn't you consider the Palos Verdes Fault?

Answer from Dinsick: We did. It's a major source close to the site, about 32 km away. We showed here that if it were given a 0% weight, the hazard would be reduced by about 1% across the AFEs and frequencies of interest. It should and will be included the overall model, but we see here that putting a significant effort into its characterization may not change the overall hazard.

Question from TI Team: What if the faults are longer and continue south into Mexico?

Answer from Dinsick: Changing the fault length did not significantly affect the hazard as it was modeled in 2010, but as you can see other parameters such as slip rate and closest distance have a greater effect. This might be because we are already considering very high magnitudes and you may need a much longer fault to get a significant impact. Additionally, understanding the fault systems to both the north and south will help constrain the uncertainty on the portion of the fault closest to the site.

Question from TI Team: You show hazard contributions from known faults; what about unknown sources?

Answer from Dinsick: We attributed seismicity to known sources when appropriate, and we considered the remaining seismicity in between the faults as background seismicity. The TI Team should look at this and consider other models for this; but in general, we found that how we treated background seismicity in 2010 did not have a significant effect on the hazard.

Question from TI Team: Do your large ruptures fill the segments, or do you have floating earthquakes?

Answer from Dinsick: The segmented scenarios are bound by the segments, and the through-going scenarios incorporate the full length. The hazard calculation is performed such that the location where a rupture occurs or begins is aleatory variability, which is basically a floating earthquake. When the program seeks a magnitude 7 event with a rupture beginning at a location, it then ruptures the length needed to obtain a magnitude 7. The program then considers the closest rupture distance.

Question from TI Team: Why was the OBT divided into two segments?

Answer from Dinsick: That's a question for the geologists that produced the source characterizations. As I understand it, for the various hazard analyses, i.e., UCERF2 and the NSHM, the NI/RC is simplified, in that you have an NI Onshore Segment, a RC Onshore Segment, and the general trace of the Offshore Segment. For the plant licensing, countless geophysical lines were completed to evaluate what was then called the Offshore Zone of Deformation; today, that's evolved into the NI/RC Offshore Segment. Dr. John Shaw is here and can give more information on the OBT model as represented in the SCEC Community Fault Model. As I understand it, there is a difference in the dip and slip rate across the two segments. These are probably interpretations that can be discussed further in Workshop 2.

Question from RE in audience: There was no mention of the San Joaquin Hills Fault; was it included in the PSHA and sensitivity studies?

Answer from Dinsick: Yes, it was included in the PSHA and sensitivity studies; that was an oversight on my part in preparing these slides. We used the characterization by Grant Ludwig, most of which is published and some of which was personal communication. The contribution to hazard from the San Joaquin Hills source was folded in the NI/RC – OBT combined source on the deaggregation plots so it didn't show up here. As you can see on the three-dimensional deaggregation plots, the ruptures that have a closest distance of 6 to 10 km dominate, and the San Joaquin Hills is located 24 km away from the site.

Question from RE in audience: Why did you change the Vs30? For which frequencies are you calculating the hazard? What about tsunami hazard?

Answer from Dinsick: Tsunami hazard analysis is outside the scope of this SSHAC Project. The Vs30 was changed based on an updated site characterization study; the Vs30 we used in 2010 was inferred, and we subsequently measured it in the field. The hazard calculation was performed for frequencies ranging from 100 Hz to 0.5 Hz, and we looked at about 11 frequencies in that range.

Question from RE in audience: You have a low shear wave velocity; have you looked at site amplification?

Answer from Dinsick: Yes, we are looking at this. The final determination of the Ground Motion Response Spectrum (GMRS) for the control point elevation at the plant involves three components. The SSC SSHAC and the GMC components are treated in a separate and concurrent SSHAC Projects. Their results will be brought together in the hazard calculation for SONGS assuming generic rock conditions for the site. This will be followed by a site specific site response analysis, which will address site amplification and the hazard curves will be modified accordingly to develop the GMRS. This process is consistent with nuclear industry methodologies and regulatory guidelines.

TI Lead Moderator: I’m jumping in here to remind everyone to focus on the task at hand, which is the source model; the ground motion response and site response are important but not the focus of this Workshop.

Question from TI Team: You showed the hazard from the OBT is higher than the hazard from the NI/RC. How much of that change is due to it being physically closer, and how much is due to it being a larger fault capable of a larger event?

Answer from Dinsick: The size and distance are significant factors, but the biggest difference between the hazard from the NI/RC and the OBT is due to the hanging wall effects on the ground motion. If we were on the footwall side of the OBT, then the hazard would probably be similar to the hazard from the NI/RC,

Question from RE in audience: In your hybrid events from John Shaw’s models, did you use the OBT slip rate or the NI/RC slip rate? If the NI/RC slip rate is driving the OBT, then that NI/RC slip rate would be the appropriate value to use, and your hazard would then increase.

Answer from Dinsick: We used the OBT slip rates in the OBT logic tree branch, regardless of whether or not the high-angle splays participated in the rupture. Again, we utilized the source characterizations developed by the experts in the 2010 PSHA.

Seismic Hazard at SONGS: The 2008 USGS NSHMP and UCERF3 by Peter Powers, USGS, Resource Expert

Dr. Powers provided his own independent PSHA for SONGS based on the USGS's 2008 National Seismic Hazard Mapping Project (NSHMP) and the preliminary Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) databases and methods. He provided the geographic coordinates used in his analysis and indicated which ground motion prediction equations (GMPEs) site class he used. Dr. Powers noted that these PSHAs were completed for probabilities of exceedance of 2% and 10% in 50 years for spectral accelerations of 1 Hz and PGA. He also noted that the higher probability of exceedance, 10% in 50 years, was likely not of much interest to SONGS.

Dr. Powers identified the faults that were included in the 2008 NSHMP-based PSHA. He noted that several of the offshore faults of interest to SONGS did not have slip rate data in UCERF2 and therefore did not contribute to the UCERF2 hazard assessment. He identified the NI/RC Fault system and the background seismicity as the seismic sources with the largest contributions to the hazard.

Dr. Powers then gave a brief discussion on the structure and approach undertaken in UCERF3. He noted that while previous characterizations identified seismic sources as faults composed of discrete fault sections (which sometimes, but not always, correlate with what geologists term "fault segments"), the new UCERF3 approach entailed discretizing faults into subsections of equal seismogenic area. This approach supported the Grand Inversion model in UCERF3 and facilitated the inclusion of fault-to-fault jumps and multi-fault ruptures.

Dr. Powers also identified the faults that were included in the UCERF3-based PSHA, noting that several offshore faults that were not included in the 2008 NSHMP-based PSHA now have data and contribute to the UCERF3-based hazard. He reminded the group that these UCERF3 faults were evaluated in the Grand Inversion model as fault subsections. He also noted that the two UCERF3 deformation models (FM3.1 and FM3.2) produced hazard results at SONGS that were not appreciably different.

Dr. Powers' comparison of the 2008 NSHMP-based PSHA and the UCERF3-based PSHA showed that the hazard increased slightly in the UCERF3 PSHA at probabilities of exceedance of 2% in 50 years for both PGA and 1 Hz. Dr. Powers reminded the group that because UCERF3 faults were evaluated in the Grand Inversion model as fault subsections, discrete seismic source deaggregation were difficult. Accordingly, he identified the Newport-Inglewood, Oceanside, Carlsbad, San Joaquin Hills, Rose Canyon, Palos Verdes, Coronado Bank, and Elsinore fault subsections as the seismic sources composing the most of the top 100 contributors to the PSHA, less background sources. He also noted that the three-dimensional deaggregation plots produced in his analysis showed that the seismic sources within 20 km of SONGS dominated the ground motion hazard at SONGS for PGA and 1 Hz at a probability of exceedance of 2% in 50 years.

Dr. Powers concluded his presentation by noting that the UCERF3-based PSHA produced higher ground motions frequencies at a probability of exceedance of 2% in 50 years than the 2008 NSHMP-based PSHA. In both PSHAs, the bulk of the hazard was dominated by faults within 50 km with the greatest contributions from the NI system and the OBT, although some other faults did contribute. Dr. Powers stated when background sources were included in the UCERF3-based PSHA, these sources contributed to about 25% of the top 100 contributors to the hazard. He noted that this contribution was much less than in the 2008 NSHMP-based PSHA, in which background sources contributed close to 50% of the hazard.

Dr. Powers concluded his presentation by summing the faults contributing most to the hazard at SONGS from the UCERF3-based PSHA at probabilities of exceedance of 2% and 10% in 50 years, noting that the onshore and offshore segments of the Newport-Inglewood Fault (without the Rose Canyon Fault), the Oceanside Fault, and the Elsinore Fault had the highest participation rates.

Dr. Powers' presentation was followed by several questions.

Questions for Peter Powers

Question from TI Team: Were hanging wall effects included in your hazard calculations?

Answer from Powers: Yes, that is built into the GMPEs.

Question from TI Team: Are hanging wall effects included in the background seismicity, since some portion of those background events would be thrust earthquakes?

Answer from Powers: Yes, every background source is given a weighting for strike-slip, reverse, or normal. Here in southern California, all the background sources are 50% strike-slip and 50% reverse; for the reverse sources, hanging wall effects are included. It's actually an average hanging wall effect, since you don't know the strike of the source; but the short answer is yes, hanging wall effects are included for background reverse events.

Question from TI Team: You mentioned a scenario-based analysis?

Answer from Powers: Yes, that was an over-simplification. I understand the 2010 PSHA included very specific logic tree branches that probably captured most possible combinations. In UCERF3, the name association with the rupture sources is lost a bit since the Grand Inversion creates discrete subsection ruptures.

Comment from TI Team: We are more or less talking about the difference between a forward and inverse approach; in the past, we had forward models, now UCERF3 is an inverse model. The result is same data are included, but more variations are allowed.

Question from TI Team: Would the gridded seismicity contribute as significantly at the lower probabilities?

Answer from Powers: That is hard to say. The lower probabilities are mostly driven by large events on distinct faults. I can’t speak at this point as to whether or not the gridded seismicity contribution would be overshadowed by ruptures on the larger faults, but I expect the gridded seismicity would still contribute.

Question from TI Team: How is the maximum magnitude event handled?

Answer from Powers: There is one branch in the logic tree for balancing the maximum magnitude constraint.

Question from TI Team: How is the gridded seismicity spatially characterized?

Answer from Powers: In the 2008 NSHM, there is a 50 km radius. In UCERF3, it depends on the seismicity.

Question from TI Team: You showed much of the contribution in the UCERF3 hazard was in negative epsilon; was that also the case in UCERF2?

Answer from Powers: I don’t recall, but I agree there is a predominance of negative epsilon here in UCERF3. I think UCERF2 was a bit more of a mix.

Question from TI Team: How does UCERF3 handle potentially missing faults? How is that resolved with the geodesy? For example, that was an issue in UCERF2 where the offshore faults were identified but missing from the calculations.

Answer from Powers: I’m not sure to what degree geodesy has informed the inclusion of new faults in UCERF3; others here are better suited to comment on that. As for the potentially missing faults, the view is that they will be captured by the smoothed seismicity.

TI Lead Moderator: Other presentations today by Kaj Johnson and Tim Dawson will address to what degree geodesy has informed the inclusion of new faults in UCERF3.

Comment from Observer in audience: Just to clarify, the 2008 Working Group that produced UCERF2 knew the multi-fault ruptures were important and that many faults were just defined by segments. There was a combined option in UCERF2 with a characteristic earthquake on the whole length of NI/RC Fault Zone. The changes in UCERF3 just allow for more diversity in the structures.

Comment from Powers: Yes, that is seen in the magnitude-frequency distributions used in UCERF3. We still have the same amount of moment released in a region and now we allow it to snake around a number of different faults.

Comment from TI Team: Another big improvement from UCERF2 to UCERF3 is the update to the offshore faults database. In UCERF2, those gray faults offshore were given a zero slip rate and not included in the calculations. Our big step forward in UCERF3 is that we now have slip rates for these faults. It's a bit problematic in that it increases total moment, but it is fundamentally correct.

Evidence for and against Gutenberg-Richter Scaling on Faults by Morgan Page, USGS, Resource Expert

Dr. Page presented earthquake data and discussed how those data may be interpreted to support either of the UCERF3 Gutenberg-Richter and Characteristic earthquake distribution models. She began with a brief introduction of the Characteristic model, in which the rate of the largest earthquakes is higher than the Gutenberg-Richter model would predict. She noted that Schwartz and Coppersmith (1984) proposed a Characteristic model for the southern San Andreas Fault. Using their data, combined with new data, Dr. Page showed that for the southern San Andreas Fault, the rate of instrumental, historical, and pre-historical (paleo) earthquakes does not agree with a strict Gutenberg-Richter distribution. She noted that a Gutenberg-Richter distribution could be fit to the southern San Andreas seismicity database (instrumental, historical, and pre-historical events) by adjusting the a-value, such as if the rate of seismicity changes throughout time; or, alternatively, relaxing the b-value could also fit the observed (instrumental) seismicity to the Gutenberg-Richter distribution model. Dr. Page showed magnitude frequency distribution plots to illustrate that there is evidence that b-values are lower near faults. She noted that alternatively, a Characteristic model could better fit the recorded seismicity and paleoseismic data by accepting a Gutenberg-Richter distribution at low magnitudes but including a breaking point (bulge) at some higher magnitude to capture paleoseismic data.

Dr. Page emphasized that resolving the paleoseismicity data on the southern San Andreas Fault with either model is difficult. Our short-term seismicity catalogs are not expected to capture long-term seismicity rates evidenced in paleoseismic records. Furthermore, she noted trends in short-term catalogs are often driven by aftershocks, and aftershocks of aftershocks, even though there is some evidence supporting a Poisson (random) earthquake distribution in background seismicity. She emphasized that if there is a scaling break or a rate change, the current seismicity catalogs are not long enough to capture either.

Dr. Page indicated that in the UCERF3 project, the total target Gutenberg-Richter distribution estimated from the California's on-fault and off-fault Gutenberg-Richter distribution datasets and models overestimate the total seismicity rate, as compared to historic statewide seismicity catalog. Dr. Page postulated that this apparent discrepancy may be related to current catalog limitations, incorrect fault connectivity models, or overestimated b-values. She noted that because of these issues, the Gutenberg-Richter distribution model has not yet been implemented in UCERF3.

Dr. Page then provided more discussion on Characteristic slip models, noting that recent studies in the Carrizo Plain have shown that the previously estimated large, characteristic slip events on the Southern San Andreas Fault were actually the result of multiple events, indicating that not all surface rupturing events are readily discernible in the paleoseismic record. She provided covariance estimates of the probability of seeing multiple events in the paleoseismic record using Weldon et al.'s (2008) tapered-slip distribution model and noted high covariances for both Characteristic and Gutenberg-Richter distribution models. She noted that neither model matched the available data.

Dr. Page then commented on the influence of aftershock statistics in Gutenberg-Richter scaling relationships, noting that the distribution of aftershocks seemed to support a Gutenberg-Richter distribution. She indicated that if the Gutenberg-Richter distribution model is wrong, explaining how well global aftershock statistics support a Gutenberg-Richter distribution would be difficult. Dr. Page also noted the difficulty in getting time-dependent aftershocks that are in agreement with global aftershock statistics out of the Characteristic model.

Lastly, Dr. Page provided a couple comments on the UCERF3 methodology. She identified all the fault subsections in UCERF3 that could rupture with some part of the offshore Newport-Inglewood Fault, but did not discuss alternative subsection linkages. She noted that the Grand Inversion methodology of UCERF3 could be employed at a smaller scale, although discretization parameters would have to be adjusted and connectivity scenarios would need to be closely evaluated to ensure a proper magnitude frequency distribution.

Dr. Page's presentation was followed by several questions.

Questions for Morgan Page

Question from TI Team: You showed a slide at the end that illustrated the network of faults that could be linked with the NI/RC. Are these likely linkages, or are these the pretty rare events? Are there any constraints on the linkages? We know that when we look at the same thing for the San Andreas Fault that some of those are very rare.

Answer from Page: Those are probably low probability events that are below the water level (i.e., 1% of the total moment). I'd have to look at it more; we can look at my computer over the break.

Question from TI Team: The Gutenberg-Richter b-value variability is interesting. How likely is it that this is the answer?

Answer from Page: I think it's definitely part of the answer, and I think the data are convincing. It may look like a small change, going from a b-value of 1.0 to 0.9, but when extrapolated out to a magnitude 7, it is very significant and the problem goes away. Yet the data don't support a b-value of 0.9. So the b-value is probably part of the solution, but not all of it.

Earthquake Scaling and Depth Dependence by Glenn Biasi, University of Nevada, Reno, Resource Expert

Dr. Biasi began by providing a summary of the available magnitude-area scaling relationships by Wells and Coppersmith (1994), Ellsworth (model B, Ellsworth, 2003), Hanks and Bakun (2002, 2008), and [Bruce] Shaw (2009). He identified the basic parameters in these different models, datasets used to develop the models, their applicable magnitude range, and the fact that these models were based on limited, physical and/or empirical data from different tectonic settings throughout the world leading to considerable uncertainty in these models. Dr. Biasi also commented that uncertainties in these models, in particular whether California's tectonics are similar enough to other parts of the world where some of the data driving these models were derived, has led to the technical community's motivation to develop more recent models. Dr. Biasi expressed his opinion that a large amount of this uncertainty may be due to the fact that 'stress drop' is not accommodated in these existing models, briefly referencing King and Wesnousky (2007), which suggested constant stress drop could be accommodated with tapered-slip as a function of depth by allowing the down-dip fault width to extend below the seismogenic depth and thereby allowing more slip to be accommodated at depth.

Dr. Biasi plotted the combined datasets against the different magnitude-area scaling models, noting that all models have weaknesses, and commented on some of those weaknesses. Dr. Biasi observed that in general, none of the models fit the data well. He noted that the datasets used to develop these different models could be updated to include recent earthquakes, although consideration of the spatial extent of the data should be considered, as there is some evidence that the crust and heat flow regimes vary in different parts of California. In his summary of the magnitude-area relationships, Dr. Biasi also noted that the available magnitude-area scaling models are decent for magnitudes up to about 6.7; above this magnitude, the models yield different predictions. Dr. Biasi supported Mai and Beroza's (2000) conclusion that no single magnitude-area scaling model fit the data.

Dr. Biasi briefly discussed other magnitude regressions, noting that other researchers have published average displacement-surface rupture length scaling relationships (namely, Wells and Coppersmith [1994] and Wesnousky [2008]) and magnitude-length scaling relationships (Romanowicz and Ruff [2002]). He noted that average displacement-surface rupture length scaling relationships are difficult to use when modeling complex ruptures like the 1992 Landers earthquake. More specifically, he noted that the scaling relationships for entire ruptures do not scale down to fault subsections, even though they fit for the total rupture, so the scaling is a function of the rupture, not the individual fault sections that participate in a rupture. Dr. Biasi also indicated that the location of SONGS relative to the fault's length is important, as the distribution of slip along the fault length is generally not uniform. There is also a wide spread in the available data on fault length-slip distributions.

Dr. Biasi then discussed the dependence of magnitude on hypocentral depth and noted regional variations in seismogenic depths in California. He indicated that a study by Mori and Abercrombie (1997) showed a trend of decreasing b-values with increasing depth, particularly in southern California. Dr. Biasi further noted that although there is a general belief that the largest earthquakes nucleate at deeper depths (largely based on Das and Scholz [1983]), there are too few data points to test this hypothesis robustly and some data may even conflict with it.

Lastly, Dr. Biasi closed his presentation by commenting on the potential for developing California-specific magnitude regressions. He noted that this may be appropriate and that mixing datasets from different parts of the earth's crust can be problematic, particularly if crustal conditions are dissimilar. Dr. Biasi emphasized that based on observations, average displacement and rupture length do not scale well and global observations for strike-slip earthquakes may suggest a systematic slip-saturation with length. Toward understanding these issues, Dr. Biasi recommending compiled a California-specific dataset.

Dr. Biasi's presentation was followed by several questions.

Questions for Glenn Biasi

Question from RE in audience: When you showed event data from the California ruptures, did you show LiDAR ruptures?

Answer from Biasi: I skipped over those details in the interest of time, but yes, those were identified as San Andreas Fault ruptures with likely dates of about 1690 AD.

Question from RE in audience: So that is an interpretation, not data?

Answer from Biasi: It's a consistent observation, and most people would come to the same interpretation. The details of the observation and interpretations are written up better in the UCERF3 documentation. One example to think about is the 1918 San Jacinto earthquake; is that really hard data? It's certainly the best data we have. You can be the judge.

Question from RE in audience: But those are paleoseismic interpretations. How much of the dataset you showed contains paleoseismic interpretations as data?

Answer from Biasi: I'm not sure, probably four or five.

Comment from TI Team: Just to clarify, these aren't purely interpretative; these are measurements of discrete earthquakes. Tim Dawson may touch on this in his presentation. One example would be the Owens Valley earthquake: it's an early historic or immediately prehistoric event. We think it's one offset in that displacement, but we can supplement that observation with LiDAR data.

Comment from Biasi: Yes, Owens Valley is an example of a cleaned-up observation dataset. We know there is no way the average slip was 6 meters, and when we look at the LiDAR data, we see it's about 2.5 meters.

Question from RE in audience: Yes, Owens Valley is still interpretive.

Question from TI Team: You showed plots of fault length versus displacement for California earthquakes. Which ones were anomalously low for the fault length?

Answer from Biasi: The 1857 and 1906 ruptures were. It seems there are different slip estimates.

Comment from TI Team: Some plots like this show the uncertainties; I'm not sure if those plots did. In general, those data and that flattening trend are really due to the historic events. We are not relying on fuzzy prehistoric data there.

Comment from Biasi: Yes, in the middle portion of this graph there are no observations that correspond with the Wells and Coppersmith (1984) regression.

Question from RE in audience: The Wells and Coppersmith (1984) regressions use worldwide data. How reliable are those data? For example, in China, they show many magnitude 8 events, like the 1556 event, but they are short faults. Is there a cultural dimension that is getting lost?

Answer from Biasi: In 1994, getting data out of China was tough. These events were known, but the literature was incomplete. There probably were not enough reliable records then for slip and rupture length measurements on the China events since there were not enough boots on the ground.

Comment from RE in audience: There seems to be a fundamental difference in that part of the world. Some of those events have been revisited, and the magnitudes still hold.

Answer from Biasi: Some of these issues come from folks guessing at fault width and fault length; that's not an observation at that point, it's an interpreted magnitude.

Question from RE in audience: How were the fault areas determined? If you had a perfect, magical way to measure the fault areas, would the correlations improve?

Answer from Biasi: I think the noise is intrinsic by and large, so the correlations could probably be improved, but there are other issues, like stress drop.

Question from TI Team: Did you show the Denali strike-slip earthquake? When you have rupture length and surface displacement measurements, you should be able to get an idea of the fault width.

Answer from Biasi: The Denali earthquake is in the dataset. The fault width (by way of depth of rupture) is the "Achilles heel" of this data set. The real question is, how thick is the seismogenic crust?

UCERF3 Fault Databases by Tim Dawson, USGS, Resource Expert

Mr. Dawson introduced himself as representing the UCERF3 Working Group on the development of the fault database and noted that Ray Weldon was also a member of the same Working Group. He gave a brief overview of the history of the UCERF project and the general structure of UCERF products in a systems-level science framework. Mr. Dawson noted that UCERF3 fault models served as the initial system inputs that identify the spatial geometry of source faults. Deformation models are second-level inputs that identify fault slip rates that are used for statewide moment balancing.

Mr. Dawson noted the UCERF3 effort constituted a robust update to the fault database used in UCERF2. This update included adding additional faults and re-evaluating the faults that were in the UCERF2 database. Fault endpoints were also more closely evaluated for use in fault linkage/fault-to-fault jumps scenarios. Mr. Dawson noted that the geologic data were used to develop a geologically-based block geodetic deformation models. Fault zones polygons were also developed to delineate distributed zones of deformation around a discrete fault. He also noted the UCERF3 fault models are consistent with the rectilinear versions of the Statewide Community Fault Model (SCFM). Mr. Dawson presented a map comparing the faults fully included in the UCERF2 and UCERF3 databases, and noted the addition of several faults offshore SONGS to the UCERF3 database.

Mr. Dawson commented on the inclusion of alternative fault models in the UCERF3 database. He stated that UCERF3 will include the alternative models developed in UCERF2 (FM2.1 and FM2.2, to become FM3.2), as well as alternative models developed for UCERF3 for offshore faults (within FM3.1). These new alternative fault models for the San Diego Trough – San Pedro Basin Fault System, Palos Verdes – Coronado Bank Fault Zone, and Oceanside Blind Thrust Fault may be of interest to SONGS. He indicated that most of the data for the new offshore alternative fault models were provided by recently-completed offshore geophysical surveys by the USGS, which were discussed by Dr. Jamie Conrad on Day 2 of this workshop.

Mr. Dawson also briefly discussed the role of fault zone polygons in UCERF3. He noted that the zones served to distinguish discrete fault traces versus braided systems and provide an area over which deformation model rates apply. He noted the inclusion of fault zone polygons made it easier to moment balance and calculate elastic-rebound based conditional probabilities and may help better define background seismicity.

Mr. Dawson then provided information bearing on the data sources for the UCERF3 fault slip rates. He noted that slip rate estimates in the literature were evaluated and given qualitative reliability rankings and that the final UCERF3 slip rates for each fault were the best geologic estimates. For sources lacking fault-specific data, slip rates were estimated using the USGS Quaternary Fault and Fold Database (QFFD) slip rate categories. Mr. Dawson noted that the slip rate dataset is relatively sparse and several best estimate slip rates were based on the USGS QFFD. He also stated that a subset of the best estimate slip rates for key faults were used to bound the geologically-based block geodetic deformation models.

Mr. Dawson then briefly commented on the UCERF3 creep database, developed by Ray Weldon and others. He noted the inclusion of new data and the development of a model to estimate moment release accommodated by creep.

Lastly, Mr. Dawson noted the inclusion of a historic/paleoseismic database that documented compilations of most recent and penultimate event data, including historical rupture measurements, geomorphic measurements, LiDAR interpretations, event slips, and paleoseismic trench data. He noted that while these data served to better constrain slip distributions, the smallest offsets cannot be discerned and paleoslip estimates can be controversial. Nevertheless, Mr. Dawson emphasized the benefit of having an expanded dataset compiled into one document. Mr. Dawson closed his presentation by noting several UCERF3 products that may be of interest to SONGS, with emphasis on the historical seismicity catalogs.

Mr. Dawson's presentation was followed by several questions.

Questions for Tim Dawson

Question from TI Team:	In the Borderlands area offshore SONGS, UCERF3 has a couple alternative fault models offshore. What's the quality of database?
Answer from Dawson:	The data come from recently published work and personal communications with Jamie Conrad's group for the Palos Verdes, Coronado Bank, and San Diego Trough faults. We used data from Carlos Rivero and John Shaw for the OBT and personal communications with Tom Rockwell for the Rose Canyon and offshore Newport-Inglewood faults.

Question from TI Team: Is this a surface rupture map, or are some of these faults defined from seismicity trends?

Answer from Dawson: We used all datasets; it's a synthesis of the data.

Question from TI Team: Where do the slip rate data come from, and how well constrained are those data?

Answer from Dawson: The slip rates come from a variety of researchers and a variety of observations. Some data are well constrained, others less so.

Question from TI Team: Is there one, single preferred value for slip rate in UCERF3?

Answer from Dawson: There are four deformation models in UCERF3. Geologic and geodetic slip rates are used in those models.

Comment from Observer in audience: The 2008 Working Group had consensus model-based slip rates that considered geologic and geodetic data in UCERF2. In UCERF3, there are geologic data tables with slip rates and best-fit, modeled slip rates; so there are two types of slip rate datasets coming out of UCERF3.

Question from RE in audience: I think slip rate you showed on the Coronado Bank Fault came from Palos Verdes Fault. We now think those faults are not connected, so what's the best slip rate estimate for the Coronado Bank Fault?

Answer from Dawson: I'd have to look at that.

SCEC Unified Structural Representation (USR) of southern California by John Shaw, Harvard University, Resource Expert

Dr. Shaw stated that his goal was to ensure everyone understood the many components of the SCEC USR to better understand how it could be used for the SONGS seismic hazard assessment. He identified the two main components of the SCEC USR: the Community Fault Models (CFMs) and the Community Velocity Models (CVMs).

Dr. Shaw elaborated on the datasets used to develop the CVMs. He noted two models: the SCEC model, CVM-S, and the Harvard model, CVM-H. Dr. Shaw indicated that both models were developed from seismic reflection, subsurface boring, and well data with tens of thousands of direct velocity measurements. He emphasized the challenging task of integrating meter-scale site measurements across kilometer-scale areas, and noted a concentrated effort to produce internally consistent models, not "Frankenstein models." Dr. Shaw noted that the CVMs contained descriptions of wave speeds and sedimentary structures for geotechnical depths (Vs30), crustal depths, and the upper mantle, as well as refined Moho locations. He noted the geotechnical layer within the CVM-H was based on Vs30 measurements and that velocities are smoothed using a

Boore-Joyner type interpolation. Dr. Shaw also reminded the group the CVMs are internally consistent with the CFMs.

Dr. Shaw then discussed the volumetric descriptions of basin sediments throughout the model area, emphasizing the importance of deep basins to structural geology in onshore and offshore southern California. He noted the CVMs contain topographic and bathymetric data and basement contact depths (between sediments and crystalline rock); most basement depths were derived from seismic reflection data and some were supplemented with boring logs. Dr. Shaw highlighted the importance of faulting on the velocity structure, noting the need for internal consistency between the CFMs and CVMs. Dr. Shaw also noted that datasets can be sparse or irregularly distributed and that data quality is variable. He reminded everyone that metadata constrain how fault surfaces and velocity boundaries are drawn and/or interpolated.

Dr. Shaw briefly noted that SCEC incorporated alternative fault models to capture the multiple potential subsurface geometries that are mutually exclusive. He also noted that these SCEC models are regularly updated and improved, and that the group is working toward a Statewide Community Fault Model (SCFM) that integrates data from the USGS, CGS, and SCEC databases.

Dr. Shaw then commented on how the CVMs and CFMs represented a unified structural model for southern California. He noted that the data sets are internally consistent, such that major faults that offset basement rocks are reflected by changes in the velocity structure across the fault. Accordingly, inactive faults are included as they produce velocity discontinuities at depth. He also noted that first-order stratigraphy is represented in the CVMs, as the internal velocity structure in the models is derived from direct measurements. The direct measurements are also used to define uncertainties within the models.

Dr. Shaw noted that the basin structures within the CVM-H, combined with teleseismic data, have supported regional tomographic models. These models have been tested and iteratively revised through wavefield simulations, producing a self-consistent CVM-H. Dr. Shaw noted that the models are being continuously evaluated and validated by simulations through work led by Dr. Kim Olsen.

Dr. Shaw then commented on what the USR showed in the SONGS region. He showed maps of the basement surface depths in the area, as well as maps of P-wave velocities at various depths and P-wave velocity cross sections. He noted that SONGS is at boundary between the deep Los Angeles sedimentary basin and coastal basins, and that while there is a lot of variability in the velocity structure, it appears to be most similar to that of the Los Angeles Basin. He emphasized that the tectonic complexities of the area precluded the use of a one-dimensional velocity model near SONGS. Dr. Shaw noted that the preferred fault description in the USR showed a through-going Oceanside Blind Thrust Fault with the Carlsbad Thrust Fault as a splay off the Oceanside; he also indicated that there were many possible geometries for Oceanside fault and Newport-Inglewood Fault interactions that cannot be resolved with the currently available data.

Dr. Shaw concluded his presentation by identifying potential uses of the USR/CVMs for this SSC SSHAC. He noted that the CVMs could be used to refine earthquake locations and seismic reflection data processing, and that the USR could provide a regional structural/tectonic context for evaluating data and models to produce self-consistent hazard assessments.

Dr. Shaw's presentation was followed by several questions.

Questions for John Shaw

Question from TI Team:	Is there significant improvement that can be done to the CFM around SONGS, or is this a limitation of data?
Answer from Shaw:	In the CVM, we can benefit from just a little bit of new data. There are not many data near SONGS, so just a bit will help. For CFM, that's probably an issue for tomorrow's talks and Workshop #2; really, the key is the offshore geophysics. Ultimately, we need earthquakes on these sources to really assess them.
Question from TI Team:	Looking at the Los Angeles Basin and how it extends into Orange County: what you call "basement", could someone else be talking about older Miocene volcanics?
Answer from Shaw:	Good question. What we call "top of basement" is not a geologic observation, it's a geophysical observation. Regardless of whether it is granitic or Catalina schist, we're looking at velocity increases and contrasts. Surely the quality of these data could improve, but the scale of the structure has high confidence. Of course, we do have these Miocene volcanics. We see those in well logs and have those in some of the sedimentary structures. We think they are captured as velocity inversions.
Question from TI Team:	Are there any modern datasets, or are they mostly 1970s vintage?
Answer from Shaw:	There are very few newer datasets.
Question from TI Team:	In the bigger picture, what do basin boundaries represent?
Answer from Shaw:	There is a transition zone between the deep trough of the Los Angeles Basin and the basins in the Borderlands. In the latter, the basins are dissected. We know, roughly, that the transition occurs, and some bedrock geology guides it, but there is a paucity of data. SONGS is actually in a critical area, not because of the facility, but because it's in a structural transition zone that is not well understood.

Passive Seismic Deployment for SONGS by Luciana Astiz, University of California, San Diego, Resource Expert

Dr. Astiz began her presentation with a map of the existing seismic stations in southern California and noted the gap in coverage near SONGS onshore and the regional absence of stations offshore. She noted that fewer stations resulted in lower quality earthquake data. She compared a map of an older earthquake catalog to a new catalog, which showed improved event locations that better delineate the distribution of seismicity. Dr. Astiz reminded the group that more seismic stations are needed to better constrain earthquake hypocenters and seismic velocities, and more earthquake are also needed to constrain the seismic velocities, resulting in an iterative process to develop velocity models. She noted that John Shaw's offshore models are largely based on extended and interpolated data due to the paucity of offshore seismic stations.

Dr. Astiz then presented the results of her post-doctoral work with Peter Shearer (Astiz and Shearer, 2000) in which they relocated several events and clusters offshore. She noted that the relocations were highly dependent on the velocity models and that a better model was needed to further refine the earthquake hypocenters. Dr. Astiz provided some comments on the distribution of relocated seismicity for the Oceanside cluster and Coronado Banks events, emphasizing that the locations could be improved with better station coverage and a better velocity model.

Dr. Astiz briefly presented the current plans for a passive seismic station deployment near SONGS, in which 12 seismometers would be deployed on land and 15 ocean bottom seismometers (OBS) would be deployed offshore SONGS. The OBS instruments would be deployed for three years and data would be collected annually. She noted that the OBS deployment is scheduled to be done in conjunction with the seismic reflection surveys, although permitting complications are significantly delaying the process. Dr. Astiz reported that some onshore stations will be co-located with new geodetic stations installed by UNAVCO, as presented by Chris Walls in a subsequent presentation.

Dr. Astiz's presentation was followed by several questions.

Questions for Luciana Astiz

Question from TI Team:	Can you clarify when the results will come out of the deployments?
Answer from Astiz:	For the land-based data, we need to acquire the permits. We hope to get that done in next two to three months. We will then order equipment, and that takes about three months. So, best-case scenario, we could have all the land stations up by April. In the worst-case scenario, we never get the permits. We don't know when the OBS instruments will be deployed. Maybe we'll hear from Neal Driscoll on that? Once they are deployed, we won't get that data for a year.

Question from TI Team: So this offshore data will be close to not making the SSHAC "new data cutoff" deadline?

Answer from Astiz: Yes, very close. If they were deployed next month, we would have it. It's difficult, but maybe not impossible.

Question from RE in audience: Could you get any data from Monica Koehler's offshore array from 2010?

Answer from Astiz: I think their data was from farther south.

Question from RE in audience: Are you sure?

Answer from Astiz: We'll check.

Question from TI Team: You showed a cross section across Coronado Banks Fault. We talked about hybrid models with low-angle thrusts and high-angle strike-slip splays. Can you comment on that cross section and such hybrid models?

Answer from Astiz: These earthquakes occurred in one of the best locations because we are closer to the land stations. The locations are decent. I don't remember the locations errors, but they are less than 1 km for sure, maybe even 0.5 km. What we have shown here are the relative locations.

Comment from RE in audience: There is more to notice on that Coronado Banks seismicity figure. That cluster has a northeast trend. There are other northeast trends offshore, but the CFM doesn't have any NE trending faults. So what is that?

SONGS: Seismicity Datasets by Egill Hauksson, California Institute of Technology, Resource Expert

Dr. Hauksson began his presentation by identifying the types of data, models and modeling methods relevant to SONGS. He identified primary earthquake catalogs, relocated catalogs, focal mechanism catalogs, moment tensor catalogs, and finite source models for historic earthquakes as key datasets. Dr. Hauksson commented on the applicability of three-dimensional velocity, state of stress, and style of faulting models. Lastly, he identified key modeling methods as consisting of hypocenter relocations, velocity modeling, and stress inversion.

Dr. Hauksson briefly commented on the distribution of seismic stations throughout space and time. He reminded the group that SCE currently hosts about 30 stations at their facilities throughout southern California and that an instrument was installed at SONGS around September 2012. The equipment was purchased by SCE, and the data are being managed by the USGS in Pasadena. Dr. Hauksson noted that installing new stations on Camp Pendleton is difficult for logistical reasons.

Dr. Hauksson then presented a map of relocated seismicity based on his recently relocated catalog spanning 1981 through June 2011 (Hauksson et al., 2012) and seismicity cross sections through SONGS, parallel (NW – SE) and orthogonal (SW – NE) to the coast. In the coast-parallel, NW – SE cross section, Dr. Hauksson drew attention to seismicity onshore near the NI Fault and the 1933 earthquake and noted the paucity of seismicity near SONGS and to southeast. On his coast-orthogonal, SW – NE section, Dr. Hauksson noted the general absence of seismicity immediately offshore SONGS, less known earthquake clusters farther southwest. He noted depths of seismicity to the east, in the Peninsular Ranges, could be quite deep. Dr. Hauksson then overlaid his seismicity cross sections with P-wave velocity cross sections from his work in 2000 (viz. Hauksson, 2000).

Dr. Hauksson discussed the variability of seismogenic depths throughout southern California and potential reasons for the variability (Nazareth and Hauksson, 2004). Dr. Hauksson drew attention to the variable Moho depth throughout southern California and noted an apparent correlation between deeper focal depths and regions where the Moho was deeper. Dr. Hauksson's concluding remarks on the depth of seismicity were that crustal thickness controls the depths of crustal isotherms and thus the depths of earthquakes. He noted mineral composition of the crust was less important.

Dr. Hauksson then discussed earthquake focal mechanisms from the 1981-2010 Southern California Seismic Network (SCSN) catalog (Yang et al., 2012) and presented a map of focal mechanisms in the area around SONGS. He also presented data derived from inverted focal mechanisms that show state of stress in southern California.

Dr. Hauksson concluded his talk by noting the sparse seismicity in the area around SONGS and distributed dip-slip and strike-slip focal mechanisms in the broad area around SONGS. He also emphasized the importance of understanding the crustal structure at SONGS and the transition between Borderland structure, which has shallower focal depths in the 10 to 12 km range, and Peninsular Ranges structure, which has focal depths on the order of 20 km.

Several questions followed Dr. Hauksson's presentation.

Questions for Egill Hauksson

Question from TI Team: Can you comment on any depth dependency on earthquake magnitude?

Answer from Hauksson: If you look at the Landers earthquake, the hypocenter was fairly shallow at about 6 km, but the slip extended deeper. I'm not convinced that for big earthquakes, the initiation is near bottom of seismogenic zone. I would need time to think more about the data.

Question from TI Team: There are areas with thicker crust in thrust zones where there are deeper earthquakes. Is this a "chicken or egg" question?

Answer from Hauksson: Yes, you are right. That depends on whether you are in a zone of thick-skinned or thin-skinned tectonics. For example, on the Elsinore Fault, we see seismicity at a depth of 22 km, so we know earthquakes there can be deep. I think it has more to do with crustal structure and heat flow rather than style of faulting.

Question from TI Team: Near SONGS, did you show a southern boundary offshore with more reverse faults?

Answer from Hauksson: We have data that shows reverse faults there, but there is no data south of that. So it is not a boundary; it is just the extent of the dataset.

Question from TI Team: Can you comment on seismicity on the Newport-Inglewood Fault?

Answer from Hauksson: In my opinion, the Newport-Inglewood is a weak fault, so it rotates in the stress field in the area around the fault. There are very few data to constrain it.

Question from TI Team: Can you comment on seismicity on the Rose Canyon Fault?

Answer from Hauksson: The data are better, and there is some contrast for sure.

Question from RE in audience: You mentioned mineral composition is not significant. So whether or not the basement is schist or granitic doesn't matter?

Answer from Hauksson: I didn't directly compare mineral composition, but if you look at the depth versus thickness plot, we would expect that to show up there, and it doesn't.

Question from RE in audience: This is all so dependent on the data we have. For example, if we didn't have the instrumentation, would we see a hole in the area of the 1986 Oceanside sequence? We're only looking at 30 years of data.

Answer from Hauksson: Yes that's true.

Question from HA in audience: You mentioned you rated the focal mechanisms with a quality ranking. What was the quality of the focal mechanisms near SONGS?

Answer from Hauksson: I didn't look at this, but with the lack of station coverage in the area, I would guess probably low quality.

Question from TI Team: You mentioned a mixture of mechanisms. Are there any patterns? Do the depth distributions show fault mechanisms that can hint at truncation?

Answer from Hauksson: Perhaps, would have to do detailed study.

Question from TI Team: Would this be one way to get at the truncation problem, or is that too simple?

Answer from Hauksson: It leads you to make assumptions. What if earthquakes are above and below the OBT? That doesn't tell you anything about the mechanics then.

Question from TI Team: Maybe we could look at a depth dependence on the style of faulting?

Answer from Hauksson: Yes, we see that in the eastern Los Angeles Basin. The thrust mechanisms are deeper, and the strike-slip mechanisms are shallower; so we see strain partitioning with depth.

Question from TI Team: There aren't many earthquakes in our area of interest, but there's more than one. We're struggling for this type of data. Would it be possible to focus in on this area? Would you learn anything?

Answer from Hauksson: I think you might. It's a question of getting a local velocity model and combing through the data.

Comment from RE in audience: Your dataset only goes through June 2011. There were some more recent earthquakes in the San Joaquin Hills area, like the September 15, 2011, May 2012, and April 23, 2012 events with magnitudes up to 3.9.

Comment from Hauksson: I have not extended catalog to the present, but that could be done.

Comment from TI Team: Yes, for focusing on what's important, it would be worthwhile to extract as much information as possible out of this type of data.

Permanent GPS in the Vicinity of SONGS by Chris Walls, UNAVCO, Resource Expert

Mr. Walls briefly acknowledged SCE's funding of new GPS stations and noted that these new data sources were very helpful to the geodetic community. He showed a map of the existing GPS station near SONGS, noting a dearth of stations in the area prior to the installation of new stations by SCE since 2011. Mr. Walls noted up to three additional new GPS stations are planned on Camp Pendleton, pending logistics. He also reported recently receiving permission to install one new station offshore Long Beach on the Elly oil rig. Mr. Walls stated these recently installed and planned stations have the best available instrumentation. Mr. Walls then discussed potential sources of error in GPS datasets and ways to mitigate the error sources.

Mr. Walls concluded his presentation with a discussion on uncertainties in vertical deformation rates derived from geodesy. He drew attention to the recently completed study by Hammond et al. (2012) that assessed uplift in the Sierra Nevada with accuracies on the order of 1 mm/yr. He noted various studies by Hammond and Blewitt have suggested vertical rates can be obtained from datasets spanning as low as 2.5 to 3 years from older instrumentation. Mr. Walls noted that some stations near SONGS should produce good vertical data, such as the recently installed Laguna Woods site and the older Saddleback Community College site. He also reported that preliminary analyses by Dr. Adrian Borsa at Scripps suggest vertical errors may be less than 1 mm/yr for the stations near SONGS.

Mr. Walls' presentation was followed by a question on the reference frame used in the time series presented.

Questions for Chris Walls

Question from TI Team: Is there a systematic subsidence in the data you showed?

Answer from Walls: Those data are plotted relative to the WGS84 ellipsoid. So, they are not plotted with respect to things nearby. But yes, there is some hint of that.

Present-day Surface Motions in the California Borderland by Kaj Johnson, Indiana University, Resource Expert

Dr. Johnson began his presentation by showing a visual inspection of horizontal GPS data. He noted that velocity vectors relative to Catalina Island suggested lateral slip rates on the order of 5 mm/yr, and vectors relative to a rigid coastal block were on the order of 5 to 7 mm/yr. Dr. Johnson noted that although velocity gradients were clear, he cautioned against making slip rate inferences across any particular fault as the velocities reflect interseismic deformation. He also reminded the group that the data shown only cover a portion of the Pacific – North American plate boundary motion, and there are some uncertainties in the total plate boundary motion. Dr. Johnson also showed the normal component of the velocity vectors orthogonal to the coast and noted contraction on the order of 2 mm/yr.

Dr. Johnson then presented two velocity profiles across the Borderland and southern California to estimate velocity changes across fault zones. He reiterated that determining slip rates across the Borderland faults is difficult because the faults are closely spaced. He presented slip rate estimates for some of the offshore faults and groups of faults across two profiles perpendicular to the coast in the form of probability density functions. He noted that although there were large uncertainties in the slip rate estimates, the data generally agreed with the slip rates presented by Meade and Hager (2005) and McCaffrey (2005). Dr. Johnson stated the data were better suited to estimate the combined slip across structures, particularly for the Palos Verdes and NI fault zones. Dr. Johnson then presented fault-normal velocity profiles. He noted shortening on the order of 2 mm/yr was more clearly expressed in the southern profile near the international border and less evident in the northern profile. He indicated this degree of shortening was consistent with the values presented by Meade and Hager (2005) and McCaffrey (2005).

Dr. Johnson then briefly summarized the three geodetic models used in UCERF3, noting that there is a fair amount of variability in the slip rates assigned to the offshore faults across the three models. He also identified slip rate estimates for the offshore faults in his work in review for publication.

Dr. Johnson concluded his presentation with a summary table showing slip rate and fault-normal rate estimates from his two-dimensional cross sections presented here, block models by other authors in 2005, the UCERF3 geodetic models, and his publication in review. Dr. Johnson noted that all the data were in good general agreement. He drew attention to the observations that the Palos Verdes system seems to accommodate more slip than the NI Fault and that there seems to be consensus that there is a couple mm/yr of shortening, relative to the rigid coastal block, across the Borderland area, although the data are insufficient to resolve the shorten across specific faults.

Dr. Johnson's presentation was followed by several questions.

Questions for Kaj Johnson

Question from TI Team: Did you use the newest GPS stations in your analyses?

Answer from Johnson: No, it will be nice to have these new ones. Look at this big hole here in station coverage where SONGS is located. That's something we need to do; it would be very valuable.

Question from RE in audience: You showed the interseismic strain for a strike-slip system. What would we expect to see for thrust?

Answer from Johnson: That's tricky to do with simple elastic models. I avoided that because it's tricky to handle in the model. It's a model, so it's very sensitive to how you choose to model what goes on below the locked part and where that locked part is. I'm bumbling around here because I don't want to answer that, really we don't have the data to look at that.

Question from RE in audience: So one of the issues is how the slip is modeled at depth. Is it like a box car?

Answer from Johnson: Yes, it's tricky. For example, if you have slip abutting along a decollement, you have to be careful. For a strike-slip fault, your assumptions are easier.

Question from RE in audience: This morning we heard talks focusing on the Newport-Inglewood because it's so close to site. Now we see the Newport-Inglewood is moving slower and Palos Verdes is moving faster. Why aren't we paying more attention to the Palos Verdes Fault?

Answer from Johnson: As we saw from the hazard sensitivity, the Newport-Inglewood is what is important. I can't really say much about the Newport-Inglewood on its own from the geodetic data.

Question from TI Team: For Andrew Dinsick, what slip rates were used on these faults in the 2010 PSHA and the sensitivity analyses?

Answer from Dinsick: We used a slip rate on the Newport-Inglewood Fault of 1.5 mm/yr, which was consistent with UCERF2 and personal communications with USGS experts. We put the emphasis on it in our talks because it is 8 km away and contributes much more the total ground motion hazed. The Palos Verdes/Coronado Bank Fault System is 32 km away from the site. We used a 3 mm/yr slip rate on Palos Verdes Fault, so that's consistent with what we see here.

Question from TI Team: Could we incorporate the new GPS stations Chris Walls discussed, and would it improve the resolution on your conclusions?

Answer from Johnson: Yes, I think it would be worth it. They fill in a data gap, especially if you are trying to look at three-dimensional models and rotation rates. Who would do that, I'm not sure. I could talk to Tom Herring about getting the data into a consistent reference frame. It may not be a big deal, but I need to look into that more.

Question from TI Team: In a zone of strike-slip faults, is it possible the whole system is rotating? Like a bookshelf-shutter effect? Could rotations be misinterpreted as crustal shortening?

Answer from Johnson: Yes, that is a good point. We would need to look at it more. We would need to think about what it would look like without block rotations in three-dimensions, and what it would look like with the rotations maximized? You won't have one answer, but you can look at the extremes and figure out where we fit in.

Question from TI Team: Looking at your maps with just your eyes, are the motions parallel to PACNOAM on the islands?

Answer from Johnson: Yes, they are fairly parallel. There is room for deviation, maybe on the order of 1 mm/yr. There's some noise, but there is not a whole lot of relative motion between the islands.

Question from TI Team: Could the 2 mm/yr of contraction be concentrated in the Inner Borderland?

Answer from Johnson: This is where data near SONGS would be valuable. If there's coupling down along the coast, that could explain some of these observations. It's hard to say right now.

Question from TI Team: There are many papers the plate boundary slip rates, and they all vary by few mm/yr. Which rates are you looking at here?

Answer from Johnson: We're looking at the extreme ranges of the geodetically estimated plate boundary motion. The level of uncertainty in those rates is a couple mm/yr, and that's the potential amount of shortening we see.

Question from RE in audience: If your vectors here are parallel, which they look like they are, then how can you get shortening?

Answer from Johnson: If you remove the rigid block motion and just look at normal vectors, you see some arrows pointing both ways. Is this strain accumulation? Is it noise? Some of these are campaign sites. I'm not showing error ellipses either.

Question from RE in audience: If you found out later there was not any contraction across this area, would that be within the errors?

Answer from Johnson: Maybe.

End-of-Day PPRP Questions Session by Ralph Archuleta, University of California, Santa Barbara, PPRP Chair

The SONGS SSC SSHAC Workshop 1, Day 1 presentations were followed by a PPRP questions session; several questions were directed to specific presenters.

PPRP Questions Session

Question for Dinsick: If your maximum earthquake magnitudes were determined from the fault area, where did you get your area estimates?

Answer from Dinsick: Yes, the maximum earthquake magnitudes were determined from the fault area. We used the fault geometries through the top and bottom of the seismogenic depths with the length of the surface trace to get the fault areas.

Question for Dinsick: Where did you get the geometry data?

Answer from Dinsick: The geometries came from the modelers or experts. Our intent was to capture the true modeler's model, not our judgments. Our geometries came from the published sources and interaction with the researchers.

Question for Dinsick: Who gave you the OBT geometry?

Answer from Dinsick: John Shaw, Carlos Rivero, and Andreas Plesch.

Question for Dinsick: You indicated you have new borehole data at the SONGS site that warranted an update of the site Vs30. Will this data be available to the TI Team and PPRP?

Answer from Dinsick: The report is being finalized right now. To offer a quick summary, we drilled three boreholes on site and collected downhole geophysics measurements in all borings. Two boreholes were drilled to a depth of about 300 feet, and the third boring was drilled to an 1100-ft depth.

Question for Powers: Who decided on the OBT geometry you showed?

Answer from Powers: That's beyond my role; you would need to ask the fault geometry folks.

Answer from Shaw: The geometry is published in journals.

Question for Shaw: Why is SONGS not in the hanging wall in the new UCERF3 maps that were shown? *Editor's note: this exchange was based on a misconception due to an oblique map view shown in an earlier presentation and was resolved after the Workshop ended.*

Answer from Shaw: That has to do with the base of seismicity surface used to clip the down dip extension of all faults. It was truncated at a shallower depth in UCERF3 because the depth of seismicity is expected to be shallower in crustal Borderland region, as Egill Hauksson discussed. It was extended deeper by GeoPentech.

Question for Shaw: Is the OBT location and geometry defined by seismicity?

Answer from Shaw: There are some data; we'll talk about this tomorrow.

Question for Dawson: Can you elaborate on the slip rate data for the NI/RC and OBT faults?

Answer from Dawson: The NI/RC slip rates were adopted from UCERF2. The best estimate for the OBT slip rate is about 1 mm/yr.

Question for Dawson: Are those slip rates data-driven or data-plus-model-driven?

Answer from Dawson: Both, for the Newport-Inglewood Offshore Segment, the slip rate is extrapolated from the Newport-Inglewood onshore and Rose Canyon slip rates.

Answer from Shaw: The OBT slip rate is a long-term slip rate that incorporates late Pliocene to present shortening on the OBT.

Question for Shaw: Can crustal velocity model resolve the predicted crustal shortening or thickening on the OBT?

Answer from Shaw: The crust thickens eastward, dipping toward the shore. I don't believe we have data to resolve thickening with only one fault, the OBT or any other.

Question for Page: Can we get probabilities that the OBT & NI/RC faults would be operating together, in concert?

Answer from Page: Yes, I can show you the Grand Inversion results, but keep in mind it's model-driven based on slip rate differences.

Question for Biasi: Which recurrence models are used in UCERF3?

Answer from Biasi: I think all three: Hanks & Bakun (2008), Ellsworth model B (2003), and Bruce Shaw (2009).

Answer from Weldon: There has been some discussion on Hanks & Bakun (2008).

Question for Hauksson: There didn't seem to be seismicity associated with the OBT; as well, strike-slip focal mechanisms seemed to dominate the style of faulting offshore. What evidence is there for a thrust environment from seismicity?

Answer from Hauksson: As you saw, not a lot; but it's worth going through with a "fine-tooth comb."

Question for Johnson: Where is the 2 mm/yr of convergence concentrated? Is it between the Elsinore Fault and San Clemente Island?

Answer from Johnson: It's too difficult to tell right now. There is a possibility to address this, in that we may be able to tease this out of the stations with the best data. We could find out what's onshore, and then the leftover would be offshore.

Comment from Powers: Referring back to the hanging wall effect, there is a term that measures the normal distance from the fault trace. The fault doesn't have to come to surface, it's a binary term.

Reply from PPRP: The point was that in the map you showed, SONGS was beyond seismogenic depth of the OBT and thus beyond the reach of the hanging wall effects.

Comment from Shaw: The CFM and UCERF use different bases of seismicity. The GeoPentech 2010 PSHA used our published work, which had deeper base of seismicity.

Reply from PPRP: Based on what Egill Hauksson showed, it seems the depth of seismicity is around 17 km.

Reply from Shaw: Yes, that would put it below SONGS.

Moderator: This is a critical issue, but it's important to note that we're talking about different models here. There are variations in the depth of seismicity, potentially radical changes; this is known from the earthquake catalogs. The UCERF model smooths a regional model to get the depth of rupture, and that's probably not fully right either. Clearly this has been identified as a critical issue.

Comment from Legg: You should look at the older earthquakes. Shawn Biehler evaluated seismicity along the projected trace of the Cristianitos Fault.

Observer Questions Session

Day 1 of the SONGS SSC SSHAC Workshop 1 closed with an open questions session for the Observers.

Observers/Open Questions Session

Question for TI Team: You mentioned that unknown faults are covered in the background seismicity. In light of the Northridge earthquake, and considering we have this OBT Fault, how are earthquakes on previously unknown faults covered by background seismicity?

Answer from RE in audience: The planned geophysical work offshore through the CPUC funds will help with that.

Answer from PM: Tom Rockwell's marine terrace research will also help.

Answer from RE in audience: In past UCERF versions, we had C Zones that were known areas of moment release lacking discrete faults, and these were treated as a gridded source. I could imagine you'd have a constrained gridded source model at SONGS.

Question for TI Team: So it's being looked at?

Answer from TI Team: Yes. For example, in UCERF3 we have geodetically-driven models, where strain is turned into earthquakes; these effectively replace the C Zones. So, all the available strain is being used in the model. The current geodetic models capture these areas of strain accumulation.

Question from TI Team: At these latitudes, could we could make a transect from the outermost island across the San Andreas to get an idea of the strain budget?

Answer from Johnson: You wouldn't get the full picture; you'd be missing a few mm/yr. But we do have most of it.

Answer from PPRP: That's correct, you wouldn't be capturing the full strain. For example, we know the Whipple Mountains (on the California and Arizona border) are moving at about 3 mm/yr.

Question from RE in audience: Could we look again at Egill Hauksson's focal mechanism distribution slide? It looks like there are both strike-slip and oblique-slip mechanisms offshore. If you look at the Oceanside sequence, it is oblique-right-reverse, so it's unfair to characterize that area as strike-slip.

Answer from Hauksson: Yes, that is true.

Question from Observer in audience: To follow up on the IRPG's earlier question, the Working Group has been looking at relatively minor faults mapped geologically and with geophysics, like the new studies at Diablo Canyon Power Plant. Are there any plans to do shallow three-dimensional seismic surveys on land? This is a GeoPentech or Edison question.

Answer from Sponsor: Just by way of collecting data, perhaps. But right now, we will have to deal with unknowns by adding uncertainties. This is a SSHAC project; it represents a snapshot point in time of the data that's available. Of course we will use the data are available.

Question from RE in audience: How well-known is the trace of the Newport-Inglewood Fault?

Answer from Legg: The UCERF models are simplified. It's called a "fault zone" for a reason. That is, it's complex. It has step-overs, like across the Carlsbad structure. There a lot of good surveys, and we are getting better locations on it. But it's a complex zone that we need to simplify for modeling purposes. The biggest issue will be getting better data closer to shore. That is hard to impossible with the permitting required.

Question from PPRP: How does the dip vary on the OBT? The crustal velocity structure is not well known, so it is difficult to estimate the dip. How did you do it?

Answer from Shaw: The OBT is mapped based on its ramp. It's a geometric feature. There is uncertainty on the dip, but there are coarse, although somewhat informal, uncertainties in the CFM. I would say in the shallow portion, the uncertainty is modest, maybe five degrees. But don't quote me; I'll check on that. At depth, it is not imaged, so it is projected.

Question from TI Team: Does the lateral ramp distinguish the north and south OBT segments?

Answer from Shaw: The lateral ramp is in the part that's imaged. I would add that the lateral ramp does obviously produce an offset at depth.

Question from TI Team: Could it become more listric? Or could the ramp "peter out"?

Answer from Shaw: Absolutely.

Question from PPRP: So it's projected at about 5 km depth, where you last see it in the sediments?

Answer from Shaw: At the plant location, it's probably more than 5 km; I'll check.

Comment from RE in audience: Tomorrow we will talk about and look at an old Chevron line reprocessed by Geotrace. We can talk more about this tomorrow, but this OBT feature isn't like most reflections you think of, it's a curious feature and hard to image.

Project Sponsor's Closing Remarks by Caroline McAndrews, Southern California Edison Company

Ms. McAndrews thanked the group for their participation and active engagement.

JANUARY 15, 2013 (DAY 2)

Opening Remarks

Ms. McAndrews thanked all participants and attendees for their time yesterday. She noted that great questions were asked on how data was developed and how it could be used going forward.

Dr. Weldon thanked the group for their hard work and reminded everyone that questions and discussion would follow the same structure, with the primary objective to be for the TI Team to query the Resource Experts. He reiterated the rules of conduct discussed previously. Dr. Weldon also noted that the TI Team would engage the Resource Experts beyond this Workshop.

Tectonics of Los Angeles Basin: Inherited Structure & Strain Partitioning by Bob Yeats, Earth Consultants International, Resource Expert

Dr. Yeats began his presentation with two points that he felt were key to tectonics based on observations of the data in the Los Angeles Basin. First, he noted that the orientation of today's major faults follow normal faults formed during Miocene extension and volcanism. Second, he noted that there is evidence for strain partitioning along the Whittier, Newport-Inglewood (NI), and Palos Verdes (PV) faults, meaning that these sources were capable of strike-slip and reverse earthquakes. Dr. Yeats reminded the group that the 2010 Haiti earthquake was a major reverse-motion earthquake along a strike-slip zone.

Dr. Yeats then gave an overview of Miocene tectonics in the Los Angeles Basin. He identified key faults and sedimentary units related to the Miocene evolution of the area. Dr. Yeats noted that the NI Fault was generally considered to be the basement boundary between the Catalina schist and Peninsular Ranges terranes. He reported that this is not true north of Seal Beach in the Los Angeles Basin, where oil field data show the actual boundary is west of the Anaheim Nose. South of Seal Beach, the contact between the terranes closely follows the trend of the NI Fault.

Dr. Yeats also indicated that oil field data helped constrain the distribution and style of secondary faults. He stated that these data indicated faulting the Los Angeles Basin was largely a function of the northwest/southeast-directed strain field, in that north/south-trending faults were extensional, east/west-trending faults were compressive, and other orientations were dominantly strike-slip.

Dr. Yeats then presented isopach maps for the Los Angeles Basin. He showed that the development of a trough in the Los Angeles area began in Delmontian time, at around 8 Ma. The trough was oriented northeast/southwest, perpendicular to the modern Los Angeles Basin. He noted that the modern orientation of the basin (northwest/southeast) developed in the Lower Pliocene, about 3-4 Ma. His time-slice isopach maps identify depocenters and uplifts throughout the Miocene and Pliocene, but no evidence for strike-slip displacements on the Whittier and NI faults was discernible. Dr. Yeats noted that the absence of strike-slip evidence did not mean strike-slip faults were not active, only that the data resolution was insufficient to detect their level of activity. He reminded the group that Freeman et al.'s (1992) work correlating electric log (e-log) data across the NI showed increasing horizontal offsets with increasing age, suggesting active strike-slip faulting during the deposition of those units. Post-Repetto (0-3 Ma) isopach maps showed relief along the NI indicating reverse displacements.

Next, Dr. Yeats presented evidence for modern strain partitioning in the Los Angeles Basin. He noted the geomorphology, distribution and style of earthquakes, and distribution of oil fields along the Whittier Fault support strain partitioning along this fault in the Puente Hills.

Dr. Yeats reported a study recently completed by Earth Consultants International (ECI; Yeats et al., 2011) suggested complex strain partitioning along the NI Fault, particularly in the northern Los Angeles Basin. The study purported the Compton-Los Alamitos Fault System was complexly linked with the NI Fault, not the Puente Hills. Dr. Yeats also referenced early work by [U.S.] Grant IV (Gilluly and Grant, 1949) that documented vertical deformation (subsidence) in the Central Uplift immediately after the 1933 Long Beach earthquake. Recent studies have shown the main 1933 event was followed by reverse sub-event, which would explain vertical deformation in the Central Uplift. Dr. Yeats noted that this constituted evidence that the NI Fault System was capable of strain partitioning and producing both strike-slip and reverse-slip earthquakes. He also noted that subsurface structural interpretations derived from industry seismic and well/oil log data supported strain partitioning models.

Lastly, Dr. Yeats noted that strain partitioning was also evident across the Palos Verdes Fault, based on work recently completed by John Shaw and a graduate student (Brankman and Shaw, 2009). He summarized the complex tectonic history across the fault, noting that structural and stratigraphic relations suggested it was an extensional feature in Miocene time, reactivated today as an oblique-reverse fault. Dr. Yeats indicated the data suggest the oblique-reverse motion is partitioned into purely strike-slip and purely dip-slip components at shallow depths. Constraints on the cumulative right-lateral slip and horizontal to vertical slip ratios were mentioned, as well as fault segmentation, slip rates, and estimated earthquake magnitudes.

Dr. Yeats' presentation was followed by several questions.

Questions for Bob Yeats

Question from TI Team: In this transpressional regime, you see a lot of thickening. As we leave the thick sedimentary cover, south of the basin, would the style of faulting change?

Answer from Yeats: Well, the Newport-Inglewood Fault occurs in the basin facies; so you're looking at strike-slip displacement when deposition is taking place; I don't see a problem with that.

Question from TI Team: To ask differently, would you expect the fault to simplify at depth below sediments, in basement? Maybe you would see fewer secondary structures?

Answer from Yeats: That is probably the case. In the basin, the near-surface is more complex, and not what you see at depth.

Question from TI Team: The Palos Verdes Fault seems to be more active in the LA Harbor area than the Newport-Inglewood Fault. How have the relative activities developed through time? Is it possible the Palos Verdes Fault is taking over, and the Newport-Inglewood Fault was more important in the past?

Answer from Yeats: That's a good question. The two faults are geographically close together, and the Palos Verdes has four to five times the slip rate of the Newport-Inglewood. You guys talk about the Newport-Inglewood Fault being the driver for SONGS, but it's really a lazy fault. Kaj Johnson's talk yesterday demonstrated this. Maybe we need a focus shift; but there's not a lot of seismicity on these faults.

Question from TI Team: Could the Newport-Inglewood and Palos Verdes faults be meeting and buttressing against the Transverse Ranges? Or is this a wrench faulting environment with step-overs, etc. What's the role of the Santa Monica Mountains buttress?

Answer from Yeats: Most of these faults don't make it up there, that far north, into the Santa Monica Mountains. The Whittier Fault doesn't even make it to Interstate 10; the slip rate dies out. Something, same trend, from the Newport-Inglewood gets up there, but there is no evidence it's a right lateral fault there.

Question from TI Team: Based on Kaj Johnson's talk, one would predict the broad right step along the Palos Verdes Fault to have thrust component, correct?

Answer from Yeats: There are a couple things going on. There is a compressional component on the strike of the Palos Verdes Fault; it is strictly a reverse fault north of Redondo Canyon, and the seismicity supports this. So this is a transpressional situation. The best documentation of such a setting is on the Whittier Fault. If you look at the trace of the fault, the northern part is really off trend; why the bend? Well, it's probably because it's sitting on big rift valley with diabase, and that deflects the Whittier Fault more westerly. The transpressional component here, along the Whittier Fault, is because it's freeloading on Miocene volcanics. There's probably something like this going on for Palos Verdes Fault.

Question from TI Team: Both the Newport-Inglewood Fault and the Palos Verdes Fault look relatively young; they have many steps, discontinuous traces, etc. What can you say about age of initiation of these as strike-slip faults?

Answer from Yeats: John Shaw has done some of that. He shows about 1.5 Ma of strike-slip motion along the Palos Verdes Fault. You can do this for the Whittier Fault, where you have Paleogene piercing points. It would be harder on the Newport-Inglewood Fault; the basement boundary is parallel, and it is harder to do this when structures are parallel. You can get a hint of the age of the fault in the Los Angeles Basin from Tom Freeman's 1992 work on facies correlations.

Comment from RE in audience: The most important thing Bob Yeats is pointing out is that you must remember all of this structure is inherited from the Miocene. You have to understand that system in context of what's driving the tectonics today.

Comment from Yeats: There's a controversy over how much rifting has occurred in the Borderland, and one area of controversy is the location of the basement boundary offshore SONGS.

Comment from Yeats: I hope you will all use the well log data. It can be used for a lot of things, and there are more well datasets than any other types of data.

Question from TI Team: Do you feel there is more to be gained from the well data?

Answer from Yeats: I think we have just barely scratched the surface. The question of when this all started—the ages of initiation on these faults—the answers are probably there.

Industry Geophysical Datasets and Their Use in Source Characterization by John Shaw, Harvard University, Resource Expert

Dr. Shaw began his presentation by reiterating the potential usefulness of oil industry data to SONGS. He noted that the oil industry has collected ample data in the last 30 years to identify oil traps controlled by faults and that these datasets were thus aptly suited for assessing tectonic activity. Dr. Shaw showed a map of the seismic data coverage off the southern California coast, noting more than 10,000 km of two-dimensional survey lines have been completed, along with two three-dimensional surveys. He stated data near SONGS was collected along dip lines perpendicular to the coast and orthogonal strike lines. Dr. Shaw emphasized that the survey line coverage was fairly dense at about 2 to 5 km spacing. He then provided a list of two-dimensional seismic datasets, and noted that these data were available to GeoPentech for their 2010 PSHA.

Dr. Shaw then showed examples of the two-dimensional seismic reflection surveys near SONGS to illustrate data quality, strengths, and weaknesses. He noted that most two-dimensional lines were of moderate to high quality and capable of resolving major fold and thrust systems, although some datasets contained spurious reflections, multiples, sideswipes, or improperly migrated features.

Dr. Shaw provided a list of fault systems and structure features over which seismic data were available; these included the NI/RC, San Diego Trough, Palos Verdes, Oceanside, San Mateo, Carlsbad, and Thirty Mile Bank.

Dr. Shaw then showed examples of how faults are identified in seismic reflection data and how the rate and style of deformation of these faults are constrained in the data. He reminded the group that the depth of imaging was generally limited to the basin depth. He noted strike-slip faults could be identified in the seismic profiles by lateral terminations of reflectors in basin fill and sometimes bathymetric expression. He emphasized that in many cases, the recency of deformation was obvious when faults extended to the near-surface of the seafloor. Dr. Shaw noted that in areas of high structural complexity, strike-slip faults were not always clearly imaged. He noted that the data nevertheless were able to identify the faults, constrain their position, and constrain the dips. Dr. Shaw showed examples from the San Diego Trough Fault and RC Fault to illustrate these concepts.

Dr. Shaw then discussed seismic stratigraphy techniques for identifying thrust and reverse faults. He noted that these faults could be identified in the seismic profiles by lateral terminations of reflectors against hanging wall/footwall cutoffs, downward terminations of folds, abrupt truncations of prominent reflectors, bathymetric expression, duplicated reflectors, or sometimes by reflections of the fault plane itself. Dr. Shaw also indicated that structural and stratigraphic relations across some thrust faults suggested reactivation, such as those that were extensional features in Miocene time reactivated today as compressive structures. He showed seismic reflection profiles from the San Onofre anticline, Carlsbad thrust, and Wilmington anticline to illustrate these concepts.

Dr. Shaw identified the importance of understanding how thrust and strike-slip faults interact at depth. He noted that this was challenging, largely due to imaging depth constraints, but still feasible. As an example of a seismic reflection line that imaged strike-slip and thrust fault interactions at depth, Dr. Shaw showed a line offshore the San Joaquin Hills in which the NI fault was imaged and possibly truncated by a west-dipping back limb/back-thrust. He noted that some thrusts may be partly guided by stratigraphy and that in this example, it was possible the back-thrust soled into the San Onofre breccia unconformity.

Dr. Shaw then discussed some of the limitations associated with characterizing fault systems with seismic reflection data. He noted that depth constraints due to impedance contrasts and emphasized that these data do not image basement rocks juxtaposed against basement rocks. Dr. Shaw showed an example seismic line for the Oceanside thrust, and emphasized that the detachment surface was imaged due to the impedance contrast across sedimentary units thrust atop basement rocks. He noted that further east and down-dip, the detachment juxtaposed basement rocks and that the impedance contrast was insufficient to resolve a fault plane. Dr. Shaw showed a similar example from the Thirty Mile Bank Blind Thrust Fault and San Diego Trough Fault.

Dr. Shaw noted that seismic reflection data provided important constraints on regional velocity structure, particularly when combined with well log data. He indicated that the near-surface sediments in the Borderland region had slower than average velocities, possible due to fluid entrapment and unconsolidated character, and that deeper depths showed more variability. Dr. Shaw indicated that velocity inversions in the deep basins were not uncommon and may identify Miocene volcanic units.

Dr. Shaw closed his presentation by noting that well log data provided stratigraphic tops and thus age control for the seismic reflection surveys and regional velocity models.

Dr. Shaw's presentation was followed by several questions.

Questions for John Shaw

Question from TI Team: It seems like you see a lot of dramatic thickness changes across the faults that have presumably occurred during Miocene extension. Can we isopach that and maybe get strike-slip slip rate?

Answer from Shaw: Yes, we did that for the Palos Verdes Fault. When the data are sufficient, that's one of the best ways to do it. But to constrain the oblique component, we tend to look at structural relief, so, post-rift topography. There are often stratigraphic units deposited in periods of quiescence with no thickness changes across the fault that are helpful to constrain age of initiation.

Question from TI Team: Is there potential for someone to look more carefully through the data and map sediment thicknesses along the Newport-Inglewood Offshore Segment? Are there data available there?

Answer from Shaw: What I showed here were data subsets. The data density is high, but one of the challenges is that the Newport-Inglewood Offshore Segment is in a structurally complex zone and at the limits of some of the geophysical imagery. It's complex; that's probably why it hasn't been done already. I agree with what others here have said, that the Newport-Inglewood offshore is not a single fault but a zone; so that would make it difficult. But I think it's possible; not all the data have been mined. It will take work and synthesis of old and new data. In sum, it would be doable but challenging.

Question from TI Team: I understand your argument for the Thirty Mile Bank Blind Thrust Fault; but why are the sediments over basement rock clear in some places but not others?

Answer from Shaw: I interpret this as a rifting area, a rift shoulder that has been down-dropped and rotated. The sediments have been deposited and reworked. Where the contact is clearly imaged, it's just a cleaner contact. To the east, the impedance contrast is not as sharp.

Comment from RE in audience: The block on the right is the Coronado Bank block, and it's tilted up to 35 degrees, so imaging it is hard. This is important to recognize: steeply-dipping layers are difficult to image.

Question from TI Team: Why is the clarity of the San Diego Trough Fault trace lost at about two to three seconds?

Answer from Shaw: This is typical; it's the limitation of lower resolution. This is also a more complex area.

Question from TI Team: Are there ways to get the down-dip geometry?

Answer from Shaw: When you have a listric component, then you rotate this in the upper block. If such features exist in these fault systems, there should be hints of it up-dip. In the Thirty Mile Bank Blind Thrust Fault, the apparent listric character is not a true shallowing; it's just distortion.

Comment from RE in audience: We may disagree here. This stuff has a different character. On Chevron line 4520, it's not really an impedance contrast; it's energy being shed off a gradient that's producing this plane. Gradients are harder to put in space and time. You really need to look at the data and how it was collected.

Comment from Shaw: Yes, we differ in opinion. I'm convinced it's a detachment system.

Comment from RE in audience: Yes, the question is whether it's an active feature. You would expect some strain localization, like we see elsewhere.

Comment from Shaw: The best way to determine if it's active is if it deforms younger strata; and we see that it does in the San Diego Trough.

Question from TI Team: You've looked at many lines and seen what are clearly faults and folds above the detachment surface. Do the clearest faults and folds in the upper couple of seconds link to the OBT?

Answer from Shaw: We can say with a degree of confidence that these features don't continue below the detachment.

Exploration Industry Geophysical Data and Recent High-Resolution Surveys by Mark Legg, Consultant, Resource Expert

Dr. Legg presented information bearing on the available geophysical datasets and proper processing techniques. He acknowledged contributions from Drs. Chris Sorlien and Peter Fischer. Dr. Legg identified older, deep and intermediate penetration seismic data available, as well as recently collected or planned new high-resolution datasets. He then noted that stratigraphic correlations to the offshore seismic reflection data were weak due to the paucity of wells/boreholes offshore SONGS. He indicated that most offshore wells were within or near the Los Angeles Basin. The few well logs offshore SONGS were only located on the east side of the NI Fault, making stratigraphic correlation across the fault zone difficult.

Dr. Legg then presented a high-resolution shaded relief map (from Dr. Jason Chaytor) showing the locations of seismic reflection lines offshore southern California. He drew attention to the absence of lines near-shore, noting that this area was difficult to survey for physical reasons (shallow water) and, more importantly, for political reasons. He noted that some deep multi-channel seismic datasets near SONGS are of good quality, but there is no such data within the three-mile coastline limit. Dr. Legg stated that there are datasets that have not been reprocessed that may be of interest to SONGS. He also noted that some datasets available from the MMS, such as the Exxon data, have not been evaluated and are of an unknown vintage (i.e., analog versus digital). Dr. Legg indicated that some single-channel data available only as images could be digitized and converted into SEGY data.

Dr. Legg provided a brief technical overview of the data processing behind the seismic reflection profiles, with emphasis on data collection techniques conducive to minimizing processing limitations. He noted that much of his career has focused on understanding and minimizing coherent noise in seismic data processing. He emphasized the importance of selecting the appropriate parameters for each line to ensure maximum vertical and horizontal resolution for the types of structures expected. Dr. Legg reminded the group that detailed planning (acquisition design) of these parameters would minimize aliasing and make the coherent noise in any dataset more manageable. He noted the importance of minimizing water-bottom multiples to obtain the best resolution possible in the upper strata. He also stated that although steeply dipping structures are difficult to image, closer spacing can provide better constraints on these structures. Dr. Legg then provided a brief summary of the main technical considerations in multi-channel seismic data processing.

Dr. Legg reminded the group of the advantages of three-dimensional data collection, noting that the oil industry has had great success with three-dimensional data despite its costs. He also noted that the multi-component collection technique is the new state-of-the-art, minimizing water-bottom multiples.

Dr. Legg then showed examples of various interpreted seismic reflection profiles. He emphasized the lack of resolution at depth, multiples throughout the profiles, and difficulties imaging steeply dipping structures. Dr. Legg commented on the quality and limitations of these various older datasets and some of the collection parameters. He also noted the “catch-22” of data collection: we need more information on the velocity structure at depth, but lengthening the surveys or increasing the signal strength creates more coherent noise in the data. Dr. Legg re-emphasized the importance of understanding and minimizing coherent noise and the challenges in removing multiples from the data.

Dr. Legg emphasized the importance of stratigraphic control when interpreting seismic data and reminded the group that interpretations in the absence of stratigraphic control could be severely wrong. He noted that near SONGS, some stratigraphic control was available from outcrops and well control, and he suggested that some of the well logs may be available. Dr. Legg indicated that one of the best oil well records came from the San Clemente Oil Rig #1, located within the NI offshore Fault Zone. Although this location makes stratigraphic correlation on either side of the fault difficult, it is one of the only datasets available. A USGS multi-channel seismic line from their 1990 survey also crosses the well, so there is seismic data to calibrate against.

Dr. Legg reminded the group that the Miocene tectonic and depositional history of the area was important in understanding the stratigraphy. He referenced the elusive basement contact offshore between crystalline and granitic bedrock, noting that it was probably along the NI Fault. He also identified seismic data with stratigraphic control available offshore near the Los Angeles Basin (by Sorlien et al., 2008 and Legg, 2011) and across the San Mateo/Carlsbad structures (by Bennett, 2012).

Dr. Legg noted that some wells/boreholes on land near San Clemente, completed for the construction of a water desalination plant, may provide some data, but that correlating these data to the offshore area and across the NI Fault would be difficult.

In summation, Dr. Legg identified wells and boreholes of which he was aware and limitations of those datasets. He also reminded the group that Dr. Vicki Langenheim has collected aeromagnetic data across the Borderland and coastal area.

Dr. Legg's presentation was followed by several questions.

Questions for Mark Legg

Question from TI Team:	Has the onshore geology been adequately mapped, and have the geology logs been correlated correctly? Do we need additional onshore mapping?
Answer from Legg:	If it hasn't been done already, all the onshore and offshore well logs need to be compiled and correlated. The onshore area has probably been mapped well; for example, fossil work has been done to confirm Monterey versus Capistrano formations, etc. There are least two new well logs for desalination plant that probably haven't been evaluated here.
Question from TI Team:	I haven't seen a lot of cross sections that combine the offshore and onshore. What's the barrier?
Answer from Legg:	I think this issue is that the Newport-Inglewood Fault is on the slope offshore, a major structural boundary breakaway from 110 Ma, and there's no easy way to correlate strata across the fault. It's a structural barrier, and we don't have boreholes west of it. We had plans in the 1960s to do cores in the Borderland; they were eventually completed, but they have not been publicly released. It's a political thing— something like 22 companies own the data

and all need to agree to release it, but 19 of those companies don't exist anymore, or something like that.

Comment from RE in audience: The USGS actually does have that data; the question is what we can do with it since we can't release it.

Question from TI Team: Has there been any dredging or recovery of samples offshore?

Answer from Legg: The USGS did a lot, and Vedder did a lot too.

Question from TI Team: Is it worth the effort to get more?

Answer from Legg: We have to be practical. Yes, it'd be great, but we have limited budget and time, so we would need to get them in the right place. That would require planning.

Question from RE in audience: A question on the detachment; Sorlien and Seeber (2009) interpreted those detachments as Miocene features. How do you know which are Miocene features and which are active today?

Answer from Legg: This is a four-dimensional problem. We have an evolving plate boundary. How do you know these aren't Mesozoic subduction thrusts? Gary Atkinson says sometimes they are and sometimes they aren't. That is, some features are, and some are not.

Question from RE in audience: I couldn't tell why they aren't just buttress unconformities. How do you know these are a seismic hazard?

Answer from Legg: Well, we see all this deformation above the detachment; it's a major lithologic discontinuity. I think we can image them at depth because of the fluids. Also, there's another detachment underneath. So you have layers of detachments, as we saw near San Diego on Luciana Astiz's cross section, and I think that lower detachment is seismogenic.

Comment from RE in audience: You can't just assume they are active.

TI Lead Moderator: We're drifting into interpretation here, let's get back to the data.

Question from TI Team: You said earlier that we can't see folding below there, below the detachment, so how do we know if it's there? Yes, there is obvious folding in the shallow portions, but could there be folding down there that we can't see?

Answer from Legg: That's why we need new data. I think we have the technology to do this, the three-dimensional high-resolutions surveys, but it's hard to do politically.

Comment from TI Team: But that's not going to happen by our "new data cutoff" in 2014.

New Offshore Geophysics Data: USGS Earthquake Hazard Studies Offshore San Diego and Orange Counties, 2006-2012 by Jamie Conrad, USGS, Resource Expert

Mr. Conrad began his presentation by noting that he would be discussing near-surface, high resolution data collected by the USGS in the last 6 years or so, and that one of the goals of the effort was to produce data that could be used to inform regional seismic hazard assessments like UCERF.

Mr. Conrad presented the offshore active fault map from Ryan et al. (2009), noting it was the most recent compilation of offshore faults. He identified interpretations pertaining to the structure of the Palos Verdes, Coronado Banks, and San Diego Trough faults.

Mr. Conrad then discussed specific datasets recently collected by the USGS. He noted the vertical resolution and spatial distribution of high-resolution multi-channel seismic data collected in 1999-2000. He also indicated that the data from this dataset near SONGS do not extend far enough west to image the Palos Verdes and San Diego Trough faults. He showed example seismic reflection profiles derived from these data and noted that although the faults were nicely imaged, it was not always clear if the faults were deforming the seafloor.

Mr. Conrad also commented on the Huntec and Geopulse datasets collected in 1998-2000. He noted that data were collected offshore SONGS to fill in the clear data gap in the area, but unfortunately most of the best the data were lost due to technical complications.

Mr. Conrad then discussed the mini-sparker, CHIRP, and AUV surveys that began in 2006. He noted coverage from Laguna Beach to Oceanside. Some surveys targeted specific structures, such as the trend of the Palos Verdes and Coronado Bank faults and the San Diego Trough Fault near Mexico. He showed example seismic reflection profiles from track lines across the Palos Verdes Fault that imaged fault strands and seafloor deformation. Mr. Conrad also noted a number of gravity cores collected offshore in 2009 to obtain radiocarbon age-dates of the sediments. Unfortunately, the cores sampled near SONGS had no recovery. Mr. Conrad noted that these cores contained sandy material that fell out of the sampler.

Dr. Conrad presented an interpretation a seismic line across the San Diego Trough Fault correlated with borehole data. He noted that the borehole penetrated to sufficient depths to capture sediments spanning the Holocene, as confirmed by radiocarbon age-dating. Mr. Conrad stated that these age dates allowed their group to date deformation inferred to be due to transpression within the San Diego Trough Fault. He also referenced more detailed surveys along this fault aimed to acquire high-resolution bathymetry and more detailed stratigraphic data using AUVs and ROVs. The data acquired allowed his group to calculate sedimentation rates and derive a slip rate estimate for the San Diego Trough Fault, as published in Ryan et al. (2012).

Mr. Conrad then presented similar data collected across the Palos Verdes Fault. He noted that his group has estimated a slip rate of about 4-5 mm/yr on the Palos Verdes Fault, although this data is not yet published.

Mr. Conrad discussed some data available offshore San Mateo Point that imaged the Oceanside detachment (also referred to as the Oceanside Blind Thrust Fault), NI Fault zone, and folded sediments east and west of the NI Fault Zone. He identified the vertical resolution afforded by the datasets presented, which ranged from a couple kilometers to tens of meters. Mr. Conrad emphasized that in theory, if fault splays were demonstrably active and could be shown to sole into the detachment, then this would constitute evidence that the detachment was reactivated. He noted that some sections showed and increasing dip with depth, suggesting activity, but he cautioned that the data were insufficient to resolve key questions at depth.

Mr. Conrad then discussed some of the interpretations and conclusions in his recently published work on the San Diego Trough Fault (Ryan et al., 2012), including slip rate estimates, relation to the San Pedro Bay Fault Zone, and re-interpretations of the structures involved in the 1986 Oceanside earthquake.

Mr. Conrad commented on the multibeam bathymetry recently collected offshore southern California, noting that the USGS has high-resolution bathymetry for the entire slope area between the three-mile limit and ocean depths of about 800 meters. He presented a map showing the distribution of high-resolution bathymetry data in the Borderland region. Mr. Conrad indicated that the data showed areas of deep gullying and, near SONGS, a series of west/northwest-striking folds and reverse faults. He stated that his group was nearly complete analyzing the backscatter data from these bathymetric surveys, and that this data would help locate offset streams/channels and other features of structural interest.

Mr. Conrad then presented a new active fault map, based on the data and interpretations available to his group at the USGS. He noted the continuation of the San Diego Trough Fault into the San Pedro Basin, that the Palos Verdes and Coronado Banks faults were not connected, and some small, northeast-striking normal faults near La Jolla.

Mr. Conrad concluded his presentation with maps showing the depth distribution of Quaternary sediments in the greater offshore area. He noted that these data were from old CalDrill borehole logs available to the USGS but not the general public. Mr. Conrad drew attention to the depocenters delineated by the distribution of Quaternary sediments. He also showed these data plotted along the Oceanside detachment surface within the seafloor traces of the San Mateo thrust belts.

Mr. Conrad's presentation was followed by several questions.

Questions for Jamie Conrad

Question from TI Team: Some of the profiles you showed were highly, vertically exaggerated. Would we be impressed seeing this at a 1:1 scale? How do you distinguish folding from draping?

Answer from Conrad: Yes, you'd be impressed; you can see these folds in the bathymetry.

Question from TI Team: Are there any plans to get this great, high-resolution data on the Newport-Inglewood Fault offshore? It seems it should be a high priority for the Federal government.

Answer from Conrad: Yes, but the problem is the shallow area along the shelf. We'd like to do a high-resolution survey using CHIRP.

Question from TI Team: You showed high-resolution bathymetry near SONGS with backscatter data and the distribution of Quaternary sediments. Are there any publications on this data?

Answer from Conrad: The bathymetry data can be released almost any day now; the paper is written. The backscatter work will be coming soon, probably in a couple months.

Question from TI Team: What about the Quaternary maps?

Answer from Conrad: This is sort of a teaser of what we can do with the existing data. This map took about one month of Holly Ryan's time.

Question from TI Team: Question about the CalDrill wells—they are not publicly accessible? I thought you were public agency?

Answer from Conrad: Yes, we can't publish it or use variations of it. I'm not sure what this means. The data isn't that great in some places. The paleontology calls are very general: Pleistocene, Holocene, Miocene, etc. But it still would be nice and useful in places.

Question from Observer in audience: Has the area adjacent to Camp Pendleton been mapped?

Answer from Conrad: Yes.

Question from RE in audience: Can we get some of this data?

TI Lead Moderator: We need to move on to maintain schedule, but we can come back to this at the end of the day.

Offshore Geophysics—Limitations in the Old and New (old) Data by Graham Kent, University of Nevada, Reno, Resource Expert

Dr. Kent opened his presentation by stating he would offer a summary on the completed re-evaluation of the 1979 Chevron multi-channel seismic reflection line #4520 data. He noted he had presented some of this work in the 2011 Seismic Source Topical Meeting (SCE, 2011). He showed a map locating this line near SONGS. Dr. Kent noted that this line has been reprocessed and that he had confidence in the results. He also indicated that he expects to have about 30 other lines reprocessed by April 2013.

Dr. Kent then elaborated on the goals of the line #4520 study, with the primary intent being to establish if modern processing techniques could enhance the existing vintage data. He noted that this line was chosen because of its unique geological features that could be correlated to ensure the reprocessing was done correctly (i.e., defining quality control). Dr. Kent discussed some of the technical challenges associated with “untangling” the older dataset and geometry. He concluded that these older datasets were usable and expressed a high level of confidence that the necessary parameters could be identified and reprocessed, with some limitations. He then showed examples of the original data and reprocessed data to illustrate improvements in the imaging quality and also some inherent limitations.

Dr. Kent noted that he was working with geophysicists at Geotrace for the reprocessing effort. He presented a detailed description of the workflow associated with Geotrace’s reprocessing effort.

Dr. Kent then discussed the conclusions of his study on line #4520. He noted that although the data were of good quality, some data filters intrinsic to the data may have caused some of the low frequency data to wash out at depth. He also found that determining the velocity gradients under three seconds was difficult due to the acquisition parameters. Dr. Kent noted that despite these limitations, the overall final product was improved with the modern processing techniques, particularly with respect to removing multiples.

Dr. Kent concluded his presentation by flipping back and forth between the original data and reprocessed data. He identified areas within the seismic profile where the imaging was improved, such as the potential detachment surface and the structure within the antiform to the east. He noted that a portion of the RC Fault was well imaged as dipping about 60° to the east. Dr. Kent stated his optimism for the data and observations that would be derived from the reprocessing of the other seismic lines in this dataset.

Dr. Kent’s presentation was followed by a few questions.

Questions for Graham Kent

Question from TI Team: When you and Geotrace are done with the reprocessing, could we have a follow-on process where you, John Shaw, and Mark Legg independently sit down to turn these into interpretations? Can we do this before Workshop #2 in August?

Answer from Kent: I suspect we’ll send the data to Geotrace in about 10 days, and they’ll send it back in March or April; then I, Neal Driscoll, and Steve Wesnousky will look at it and send it back to the GeoPentech database. We’ll want to know what this OBT surface is—an acoustic surface, a gradient, etc. We’ll look at it regionally.

I expect we'll make significant strides before August and folks in here will have it well before then.

Question from RE in audience: Are you going to look for fluid incursions?

Answer from Kent: Ideally, we will have a full waveform inversion that is essentially two-dimensional, where we can downward extract all receivers and shots on the seafloor. This hasn't been done before; it's basically a new experiment. We can tell the results are spectacular, but we will need a new dataset. I'll keep doing this with a rough cut.

New Offshore Geophysics Data Collection Plans by Jamie Conrad, USGS, Resource Expert

Mr. Conrad stated he would present the USGS's current plans for new offshore geophysical studies on behalf of Dr. Danny Brothers, who could not attend. He noted the USGS intends to extend their high-resolution Quaternary stratigraphy data from the San Pedro shelf to the area offshore SONGS. He noted that correlating stratigraphy along the coast using surveys obtained perpendicular to the coast is challenging due to copious underwater channels. They plan to combine new data with the existing mini-sparker surveys. Mr. Conrad noted that Ms. Holly Ryan of the USGS has identified the area offshore Costa Mesa as likely to provide good data.

Mr. Conrad also indicated that his group hopes to identify and date channels offset by the NI/RC Fault Zone with CHIRP and borehole data. He also indicated high-resolution geophysical surveys are planned offshore SONGS.

Mr. Conrad's presentation was followed by a few questions.

Questions for Jamie Conrad

Question from TI Team: What's the time frame for these new surveys?

Answer from Conrad: There are some things coming through the pipeline now, things in progress, but those mostly are along the Palos Verdes and San Diego Trough faults.

Comment from RE in audience: There are a lot of high-resolution surveys planned for the late summer or early fall of this year. The USGS will be a part of these.

Question from TI Team: Would these be processed and interpreted by March 2014?

Answer from Kent: Yes, certainly processed, and you can do what you need with it.

TI Lead Moderator: We need to move on.

Quaternary Stratigraphic Framework of the Los Angeles Basin by Dan Ponti, USGS, Resource Expert

Dr. Ponti opened his presentation by noting he would be focusing on a Quaternary chronostratigraphic database and model developed for the Los Angeles County portion of the Los Angeles Basin through his work with water agencies in the area. He indicated Version 3 of the three-dimensional model was currently under review. Dr. Ponti noted that the model utilized sequence stratigraphy concepts and incorporated ten sequences spanning latest Pliocene time through the Holocene. He noted the stratigraphic sequences in the model were climatically controlled genetic successions of facies correlated across the basin; that is, primarily high stand tract units deposited in response to eustatic sea level changes.

Dr. Ponti then gave a brief overview of the history and concept of sequence stratigraphy. He emphasized that his approach in the Los Angeles Basin correlated genetically related facies of chronostratigraphically significant surfaces and that the dataset provided a high-resolution correlation of time and facies. This dataset thus allows the timing of deformation to be constrained.

Dr. Ponti provided details on the data types and sources in the model database. He noted several boreholes were drilled and sampled throughout the basin. He identified multiple field and laboratory tests that were completed in the borehole and on the samples, including several borehole geophysical measurements, age-dating of the samples with multiple techniques, and other geophysical and chemical tests on the samples. Dr. Ponti also commented on the strengths and limitations of the field and laboratory tests and data. He noted that the cores are still preserved in refrigerated storage. At present, 54 holes have been drilled, including primary reference wells with continuous core sampling and confirmatory geophysical wells with targeted core sampling. Dr. Ponti noted that the program is still ongoing, with about two to three wells/boreholes drilled per year. He also reported that he expects to receive funding soon to drill a deep 3,000-foot hole in the basin.

Dr. Ponti reminded the group that the Los Angeles Basin model has implications for assessments at SONGS. He noted that some sequence boundaries could probably be traced south into the SONGS area to provide constraints on timing and rates of deformation. He also noted that his data provide information bearing on the history and character of the NI Fault and related structures.

Dr. Ponti commented on the feasibility of extending his dataset into the SONGS area. He identified seismic reflection data in his dataset in the offshore area of the Los Angeles Basin and stratigraphic sequence boundaries were generally discernible in the data. Dr. Ponti indicated that with the available confidential CalDrill well log data, one or two mid-Pleistocene surfaces might be able to be correlated south of San Pedro Bay and into the SONGS area. He noted that most surfaces older than mid-Pleistocene were located below the depth of high-resolution seismic reflection penetration offshore. He also indicated that the existing lower-resolution seismic data could not readily resolve upper Pleistocene surfaces. In sum, he noted that it would be difficult to extend most of the surfaces in his Los Angeles Basin model south into the offshore SONGS region with the existing available data.

Dr. Ponti then discussed the NI Fault in the Los Angeles Basin. He noted that using constraints from his dataset, fault surfaces from the CFM, and bedrock structural control, several faults in the basin appear to be related to deformation on the NI Fault. Dr. Ponti summarized structural, stratigraphic, and seismic evidence for late Quaternary activity on the Charnock Fault, Pacific Coast Highway, and Los Alamitos/Compton faults. He indicated the data suggest these faults may be bleeding slip off the NI Fault as it dies out northward toward the Transverse Ranges. Dr. Ponti presented cross sections and seismic profiles to illustrate the complex geometries of these fault systems, and noted that the Compton ramp was somewhat analogous to the OBT, in that it appears to be a blind ramp that cuts the NI Fault.

In summation, Dr. Ponti noted that the sequence-based framework he applied to the Los Angeles Basin was successful and could be extended throughout coastal southern California with expanded data collection efforts. He noted that some horizons could be carried south off San Pedro Bay into the San Mateo Point area with the available data, although additional high-resolution data would be needed to have confidence in those interpretations. Lastly, he emphasized the complexity of the NI Fault Zone and the role of high-angle faults that consume slip at the northern reach of the NI Fault.

Dr. Ponti's presentation was followed by several questions.

Questions for Dan Ponti

Question from TI Team:	Do you see any evidence of initiation for the modern Newport-Inglewood Fault? Or any variations in activity?
Answer from Ponti:	There really is not much we can tell about Newport-Inglewood Fault right now. We just have some vertical separations, which aren't consistent, as you'd expect for a strike-slip fault. Our next phase of work will look at things that can answer that. We can say something about initiation on related structures like the PCH Fault. Tom Wright thought these were older rift structures, but we see some evidence they are potentially active in late Quaternary time.
Question from TI Team:	This 500,000-year-old surface can be traced south, out of Los Angeles Harbor, and it was above Holly Ryan's base of Quaternary; so it's in stratigraphic order. Could we extend that into the whole volume, down to the international border?
Answer from Ponti:	I haven't looked at it, but probably. I don't think we can get the other surface picks. But that's one we could work with, with this existing data set. This 500,000-year-old is traceable throughout entire basin; it pinches out to north.
Question from TI Team:	Is this effort going on in Orange County?

Answer from Ponti: Not yet. They have some data, although no cores. We are trying to get some collaborative efforts underway, but these wells are expensive to drill.

The Rose Canyon–Newport Inglewood Fault by Tom Rockwell, San Diego State University, Resource Expert

Dr. Rockwell opened his presentation by noting that he would provide an overview of the tectonic framework relative to the plate boundary motion, late Quaternary slip rate and earthquake history constrains on the NI and RC faults, and a comparison of the timing of surface ruptures on these two faults.

Dr. Rockwell noted strain accumulation across the Pacific-North American plate boundary on the order of 50 mm/yr and indicated about 10 to 15% of that strain is accumulated offshore. He then identified the distribution of slip along key faults that bifurcate northward from the Agua Blanca Fault in Mexico, noting that the slip accommodated on this fault feeds northward into the Borderland and is distributed across the offshore strike-slip fault zones. Furthermore, he indicated that the kinematics of the Agua Blanca Fault suggest a transtensional setting in the Borderland.

Dr. Rockwell commented on the geomorphic expression and paleoseismic history of both the Agua Blanca Fault and the San Miguel Fault. He stated that although the geomorphology and paleoseismicity on these faults suggest the Agua Blanca Fault is accommodating much more long-term slip than the San Miguel Fault (5-6 mm/yr versus 0.2 mm/yr), some geodetic models in UCERF3 suggest the slip rates on these faults are more similar at 3-4 mm/yr. Dr. Rockwell suggested this might indicate a change from the long-term rate and reminded the group that understanding these faults is important because they feed some slip into the RC Fault.

Dr. Rockwell discussed the geomorphic and paleoseismic history of the Salsipuedes Fault. He noted the Descanso Fault accommodates at least 1.5 mm/yr from the Agua Blanca Fault and feeds that slip north into San Diego and the RC Fault. Dr. Rockwell also drew attention to the La Nacion Fault east of San Diego Bay, which accommodates extension across the RC/Descanso transition.

Dr. Rockwell then discussed the geomorphic expression of the RC Fault. He noted the Mount Soledad uplift was the result of the compressional left bend in the fault trace. He also presented annotation air photos, geomorphic maps, and Quaternary maps of parts of the fault.

Next, Dr. Rockwell presented data and observations bearing on the slip rate on the RC Fault. He referenced his earliest study in 1990 that showed the RC Fault was Holocene-active with a surface rupture that post-dated 8-9 ka Indian middens and offset an argillic soil horizon. Dr. Rockwell noted that this three-dimensional excavation across one strand of the RC Fault Zone recorded a slip rate of 1 mm/yr, providing a minimum constraint on the total slip accommodated across the full RC Fault Zone. He also indicated that stream deflections and incisions within terrace deposits suggested a slip rate of 2 mm/yr on the RC Fault, and that this rate agrees with the notion slip being fed north into the RC Fault through the Descanso and San Miguel faults.

Dr. Rockwell noted that farther north, there are no well-constrained late Quaternary slip rates for the NI Fault. He referenced the Freeman et al. (1992) study that derived a Plio-Quaternary slip rate estimate of about 0.5 mm/yr for the NI Fault, based on e-log correlations across the fault. With respect to the age of initiation of the NI Fault, Dr. Rockwell noted evidence of Miocene slip across the fault in Long Beach and Huntington Beach, and late Pliocene slip in the Inglewood oil field. These data suggest the fault is younger to the north. Dr. Rockwell noted the slip rate on the NI Fault is probably on the order 0.5 mm/yr and likely not greater than 1 mm/yr, unless the fault is very young. He also postulated that as slip decreases to the north through the RC/NI Fault System, some of the slip may be transferred west to the Palos Verdes Fault across the San Mateo Thrust, and/or to other structures in the Los Angeles Basin (as Dan Ponti discussed). Dr. Rockwell emphasized that regardless of interpretations of how the NI slip is distributed, the observations show the slip rate on the NI Fault is less than the rate on the RC Fault.

Dr. Rockwell then provided an overview of the earthquake history of the RC Fault. He noted that his previous studies found evidence for two to three events in the last 8-9 ka, with a lengthy hiatus between the most recent and penultimate events (based on a well-developed soil offset in the most recent event). He stated that prior to his trenching in November 2012, the data suggested ruptures of the RC Fault in downtown San Diego and La Jolla more or less around 1650 AD, based on radiocarbon age dates and historical records. He also noted evidence for a rupture on the Agua Blanca Fault and uplift in the San Joaquin Hills around 1650 AD as well. Dr. Rockwell thus indicated that the data suggested closely spaced ruptures of the coastal fault system, followed by the 1933 Long Beach earthquake.

Dr. Rockwell next discussed his recently completed RC Fault trench study for Southern California Edison. He noted that the aim of that study was to identify the youngest events on the RC Fault, and so he targeted sites with late Holocene sediments. He commented on the logistical difficulties of excavating trenches in populated and built-up areas. He was able to acquire permission to push two CPT lines and excavate one trench on the Presidio Hills Golf Course in Old Town, San Diego. Dr. Rockwell noted the trench was sited near a previous study that identified 9.8 ka gravels. He reported that the excavation uncovered a Spanish/Mexican era villa floor at the western end of the trench and that a strand of the RC Fault was found in the center of the trench, near the bottom of the initial excavation. His team hand-dug the trench down to the water table to map the south and north walls of the trench in more detail in the fault zone. He briefly commented on the stratigraphy in the trench and described the fault zone with annotated photomosaics. Dr. Rockwell noted that over a dozen radiocarbon age dates were obtained from the trench. All ages were in stratigraphic order and only four samples showed signs of inherited age.

Dr. Rockwell then presented the Ox Cal model based on the radiocarbon samples collected from the November 2012 Presidio Hills Golf Course (Old Town) trench, noting that the age dates and stratigraphic relations in the trench indicated the most recent event occurred at about 800 AD. He emphasized that the previously determined most recent event for the fault system in downtown San Diego and La Jolla was about 1650 AD, and that this trench thus did not capture that event.

Dr. Rockwell provided a discussion on the possible reasons for the disagreement on the age of the most recent rupture along the RC Fault. He stated that while it was possible these recently obtained ages had a significant amount of age inheritance, it was unlikely for such a large number of samples, especially because the dates were in stratigraphic order. He then noted that while it was possible the La Jolla and downtown San Diego sites were contaminated by young carbon, this would also be an unlikely coincidence. Dr. Rockwell thus concluded that the most likely explanation for the apparent discrepancy was that the Presidio Hills Golf Course (Old Town) trench did not cross the RC Fault strand that ruptured in the most recent earthquake.

Dr. Rockwell then commented on the recurrence interval for surface-rupturing earthquakes on the RC Fault. He noted that the most recent study has confirmed at least two, and possibly three, ruptures in late Holocene time. He also reported that the two earthquakes identified in the Presidio Hills Golf Course (Old Town) trench could be interpreted as a mainshock with afterslip, depending on the depositional history of the site. Alternatively, the two earthquakes could represent slip during the mainshock and triggered slip from an adjacent strand. He concluded that these details could not be discerned with the available data and that additional trenching would be needed. Dr. Rockwell emphasized that if there have been three events in the last 1.5 ka, then that implies a surface-rupturing event recurrence on the order of 500 years. He also importantly noted that a recurrence interval of 500 years for a slip rate of 1.5-2 mm/yr implied an average displacement of one meter or less and thus earthquakes less than magnitude 7.

Dr. Rockwell closed his presentation with a comparison of the timing of surface ruptures on the RC and NI Faults. He noted there is very little data available on paleoseismicity on the NI Fault. A 1997 study by Grant et al. interpreted an earthquake history on the NI in Bolsa Chica from CPT stratigraphy and radiocarbon age dates obtained from core samples. Dr. Rockwell also referenced a study by Leon et al. (2009) that evaluated the Holocene earthquake history on the Compton Fault. He showed through a spatio-temporal plot that some paleoearthquakes along the coast (through the Compton, NI, San Joaquin Hills, RC, Descanso, and Agua Blanca faults) do not appear to have correlations, but some are permissible. He noted there seems to be evidence that would support a hard linkage between the NI and Compton faults. He concluded that the data available today do not suggest the NI and RC faults have ruptured together in the Holocene, although this is still an open question.

Dr. Rockwell’s presentation was followed by several questions.

Questions for Tom Rockwell

Question from TI Team:	Do you see evidence for high strike-slip slip rates offshore?
Answer from Rockwell:	I think through San Diego the slip rate is about 1.5 to 2 mm/yr, and I don’t see how you could change that. But there is slip west of the NI/RC, in the ocean.
Question from TI Team:	What sort of vertical slip rates do you see? There’s a transpressive step in the Rose Canyon Fault.

Answer from Rockwell: Yes, the Rose Canyon Fault bends at Mount Soledad. We have marine terraces there to tell us these things, the uplift rates. Away from the fault, the terraces are at the same elevation, and Mount Soledad is capped by the Claremont terrace.

Question from TI Team: Given the Rose Canyon Fault geometry and vertical rates you see in the terraces, could you put some limits on the uplift? Do the uplift rates seem to be consistent with lateral rates?

Answer from Rockwell: I haven't thought about that; we can talk about it.

Question from TI Team: What studies are planned in the next year, and what can we incorporate into this SSHAC?

Answer from Rockwell: Well, we need to do the other trench at the golf course, along the other CPT alignment.

Question from RE in audience: You say you seem to be missing an event in your recent Old Town/golf course trench. There was a large flood event of the San Diego River around 1862; could that flood have washed away the stratigraphic evidence for your missing earthquake?

Answer from Rockwell: Nope; the ages still don't work out unless you have a consistent and large age inheritance in the charcoal dates.

Developing the Database to Test Mechanisms Producing Coastal Uplift: Marine Terraces from Palos Verdes to Punta Banda, with an emphasis near SONGS by Tom Rockwell, San Diego State University, Resource Expert

Dr. Rockwell opened his presentation by noting he would identify what was known, inferred, and unknown about the marine terraces along the coast of southern California and Baja California, and why these data were important.

Dr. Rockwell began with a brief comment on the two leading models for coastal uplift and emphasized that marine terrace data could test those models. He identified the Rivero et al. (2000) model for the OBT Fault and noted that this model required differential coastal uplift that should be manifest in the marine terrace elevations. He also noted an alternative model of rift shoulder uplift by Mueller et al. (2009) that would produce less coastal uplift than the Rivero et al. (2000) model in a more uniform fashion. Dr. Rockwell re-emphasized that marine terraces are an absolute, data-based framework of vertical deformation through which various deformation models could be tested.

Dr. Rockwell then identified the study area as spanning the coastal region between the Palos Verdes Peninsula and Punta Banda. He gave a brief overview on how marine terraces are formed and which features are of interest in field mapping (namely the shoreline angle). He noted marine terraces record sea level high stands, and that the ages of these high stands were well dated globally (e.g., the MIS 9 occurred about 300-320 ka; 5e about 120 ka; 5a about 80 ka; etc.). He emphasized marine terraces are well preserved along the southern California and northern Baja coast.

Dr. Rockwell reminded the group that modern studies on these marine terraces for Southern California Edison were initiated in 2011. He identified hundreds of pertinent references pertaining to the distribution of marine terraces and age control sites (fossil and coral localities) along the coast that have been reviewed by his group. Dr. Rockwell showed maps locating known fossil localities, coral localities, and shoreline angle projections along the coast.

Dr. Rockwell then discussed the available data. He noted that marine terrace shoreline angle elevations and ages were well recorded in Punta Banda. He stated that *Balanophyllia elegans* corals in Punta Banda yielded the most reliable age dates. Dr. Rockwell referenced his 1992 work (Kern and Rockwell) that mapped the distribution and elevations of several terraces in San Diego from Point Loma to Arroyo Canyon (north of the Santa Margarita River). He reported that these terraces appeared to be flat along the coast. He also noted that the elevations of the terraces were derived from maps, and that the vertical datum in these maps (i.e., which maps were used) is not known; but nevertheless, he emphasized that the terraces in the study area were flat. In the San Joaquin Hills, Dr. Rockwell identified some terrace mapping with elevation data, and noted that some terraces have also been dated by uranium-series analyses on corals. He noted a data gap in the existing marine terrace literature between the San Joaquin Hills and the northern reach of his 1992 San Diego study. Dr. Rockwell indicated that marine terraces in the Palos Verdes Hills were well studied, although some older data were missing or incorrect. He identified recent work by Drs. Daniel Muhs and Dan Ponti that provided better age control for some platforms.

Dr. Rockwell then presented a plot showing the elevations of the marine terraces along the coast, based on the data compiled in 2011 for Southern California Edison. He drew attention to the uplift in the San Joaquin Hills, the data gap near SONGS, and the generally flat terraces south of the Santa Margarita River. He emphasized the location of the hinge point between the San Joaquin Hills uplift and flat terraces to the south was not known. Dr. Rockwell also noted that the few terrace elevations in the SONGS area were projected shoreline angles, rather than true field measurements. He noted the absence of more modern marine terrace data to resolve uplift models near SONGS prompted Southern California Edison to support a field mapping and age dating program on Camp Pendleton and in Orange County in 2012.

Dr. Rockwell then provided a discussion on his group's ongoing marine terrace study. He showed an oblique photograph of the San Onofre Mountains range front, delineating an upper terrace set, palisade slope, middle terrace set, and buried lower terrace set. He noted the upper terraces and palisade slope were traceable to San Diego. Dr. Rockwell commented on the importance of vertical datums, identified the datum used in his study, vertical errors and their sources, and quality assurance/quality control measures. He also noted that during field mapping, some shoreline angles had to be projected a few tens of feet at some sites due to land disturbance restrictions.

Dr. Rockwell stated that his group surveyed terraces up to 300 meters (the highest terrace at the top of the mountain). He noted that samples from this terrace have been submitted for beryllium age dating, and that he expects the surface to be Pliocene in age. He noted that his group hiked up and down every canyon, and that they also looked for faults. Dr. Rockwell reported that the only fault they found was the Target Canyon Fault that had been previously identified and evaluated by Dr. Roy Shlemon.

Dr. Rockwell then presented example and summary figures from his group's recent work. He noted that they completed transects up every ridge line (for which they had access) to construct high-resolution GPS profiles, as the thin marine terrace deposits and platforms would not show up well on the typical 20- to 40-ft contour maps. Dr. Rockwell showed a summary plot of the new terrace elevation data from Stuart Mesa to San Onofre State Beach. He stated that these terrace elevations were horizontal/flat across Camp Pendleton and that these terraces could be correlated very well with the Kern and Rockwell (1992) terraces through the Mexican border. Dr. Rockwell also presented a hillshade map with marine terraces constructed from a high-resolution DEM of the coastal region. He emphasized that for this SSHAC process, the TI Team would need to develop a model that could explain the flat uplift along the coast reflected in these data.

Dr. Rockwell closed his presentation with a brief discussion on Dr. Reed Burgette's recent analysis of historical tidal gauge data along the coast from Newport Bay to the Mexican border. He noted that the processed data showed a mostly flat trend along the coast, with perhaps some subsidence between La Jolla and Newport; however, he indicated that the apparent subsidence was within the errors, and a 0 mm/yr uplift rate along the coast would fit the tidal gauge data.

Dr. Rockwell's presentation was followed by several questions.

Questions for Tom Rockwell

Question from TI Team: Is there any chance you could find corals for age dating across the Rose Canyon Fault?

Answer from Rockwell: I think there are museum specimens, but they don't want to give up their sample. They may be open to new, non-destructive techniques. We're hoping to find our own coral, though. It took a long time to get the permits, but George Kennedy sampled some localities. Hopefully we will find coral in what we collected. We intend to nail down those ages.

Question from TI Team: You mentioned terraces that look like they are rising to the hills, to the east? The ones Roy Shlemon measured?

Answer from Rockwell: I think Roy Shlemon inferred they were all 5a (and 5e) terraces and just projected them. We've already shown that gradient is wrong;

it's flat. We haven't been able to survey in San Clemente. The bottom line is, you see no deformation from the San Diego River to San Clemente, aside from flat uplift.

Comment from TI Team: That could be clarified in the report.

Question from TI Team: I'm interested in the beach ridges. In Oregon, the ridges aren't at the same elevations as the shoreline angles.

Answer from Rockwell: Yes, that's a good question. So these represent the projection of the shorelines underneath the beach ridges. The beach ridges are there because the step was present. We can document the step; that's in our 1992 paper. We're using the elevation of the platform.

Question from TI Team: You say sand; are they gravels or sands?

Answer from Rockwell: These appear to be high stand beach ridges.

Question from TI Team: Like a beach dune along a step?

Answer from Rockwell: We used the elevations of the abrasion platforms, not the beach ridges.

Question from TI Team: You made a case for constant elevations over long distances. What's uplift rate? Does it change if you go back into the oldest terraces?

Answer from Rockwell: At that point, we're introducing sea level models. If you believe the current sea level models (which I'm not sure I do), then the uplift rate may be about 0.3 mm/yr. If you use different models, the uplift rate may by 0.15 mm/yr. Everything back to 1 Ma shows dead-flat uplift. The highest terraces in San Diego are at an elevation of 225 meters. In Pendleton, we have terraces at elevations over 300 meters, but that's when and where the Cristianitos Fault was active. Maybe the older terraces show something else, but we were focusing on the younger ones.

Question from TI Team: Do the 5e terraces match the high stands?

Answer from Rockwell: We published the ages based on the model, so I can fit data to the model.

Question from TI Team: What about the recent ones? It's more than a model; it's a consistency check. It would be nice to see a figure like this in the report.

Answer from Rockwell: Yes, but that is hard to do beyond MIS 9.

Question from TI Team: Just back to MIS 7 would be good; we would encourage you to do it.

Question from RE in audience: You say the terraces are dead flat. Is there a seaward dip, and does it change?

Answer from Rockwell: There is always a seaward dip. The highest terraces dip about 9 degrees seaward. The lower ones dip about 5 degrees seaward. So, there is some tilting in oldest terraces probably.

Question from RE in audience: Are the terraces and the OBT related?

TI Lead Moderator: That's interpretation, so we'll come back to that in Workshop #2 in August.

San Joaquin Hills Marine Terraces and Faulting by Lisa Grant Ludwig, University of California, Irvine, Resource Expert

Dr. Grant Ludwig opened her presentation by stating she would discuss published and unpublished data bearing on the late Quaternary uplift of the San Joaquin Hills, anomalous coastal notches in the San Joaquin Hills, late Quaternary faults in the San Joaquin Hills, and recent earthquakes in Irvine and Laguna Niguel.

Dr. Grant Ludwig gave a brief overview of the physiographic setting of the San Joaquin Hills and identified geomorphic and tectonic features controlled and/or influenced by the San Joaquin Hills. She noted Rivero (2004) mapped the San Joaquin Hills as an antiformal structure, and she emphasized a potentially complex relationship between the San Joaquin Hills Blind Thrust faults, the OBT, and the NI Fault.

Dr. Grant Ludwig also discussed the distribution of marine terraces in the San Joaquin Hills and noted the absence of marine terraces on the inland (east) flank of the mountains. She noted that this indicated a drainage must have been incised somewhere to let the back (east) area drain and preclude the development of terrace platforms. She reported that the distribution and ages of the marine terraces were well constrained along the northwest reach of the San Joaquin Hills and that the axial trace of the uplift was constrained on the coastal (west) flank by her terrace mapping. Dr. Grant Ludwig referenced her 1999 work (Grant et al.) that published a post 122 ka uplift rate, and she reminded the group that this uplift rate did not take into consideration any deformation caused by late Quaternary faults in the San Joaquin Hills, such as the UCI Campus, Pelican Hill, and Shady Canyon faults.

Dr. Grant Ludwig then presented data bearing on late Holocene coastal uplift. She emphasized recent uplift of Newport Bay, manifest by a raised preserved marine platform, an escarpment along the east face of the platform, and incised drainages adjacent to the uplift. She noted age-dating of the platform yielded a young age, on the order of 1635 to 1797 AD, and postulated an earthquake on the order of magnitude 7 could have uplifted the terrace to its current elevation (Grant et al., 2002). Dr. Grant Ludwig also indicated an analysis of leveling surveys across Newport Bay were generally consistent with the antiformal structure of the San Joaquin Hills.

Dr. Grant Ludwig next identified anomalous elevated shorelines and notches that could not be readily correlated with known marine terraces. She noted that assuming which high stand these notches correlated with had significant impact on local uplift rate calculations.

Dr. Grant Ludwig then commented on the recency of faulting in the San Joaquin Hills. She identified known faults with robust topographic expressions. Dr. Grant Ludwig discussed the UCI Campus Fault, noting that while university records of studies on the fault were sparse, presumably in-depth investigations were completed on the fault as the university developed around the fault. She was, however, able to locate sections of some early consultant reports and logs for trenches excavated across the fault. Dr. Grant Ludwig noted that the logs reflected thrust displacement of Topanga bedrock over undifferentiated Quaternary terrace materials. She emphasized that undocumented fault offsets in the San Joaquin Hills would have a significant impact on uplift rates assumed from the marine terrace elevations.

Dr. Grant Ludwig closed her presentation by reporting recent seismicity in the San Joaquin Hills. She discussed the 15 September 2001 M3.5 Irvine earthquake, commented on the depth and focal mechanism of the event and noted the earthquake might be correlated with either the UCI Campus Fault or the San Joaquin Hills Blind Thrust Fault, pending further detailed studies. She also identified the shallow 21 May 2012 M2.4 Irvine earthquake as one that should be evaluated by a seismologist, noting that it might be spatially associated with the UCI Campus or Shady Canyon faults. Lastly, she referenced initial, publicly available USGS data for the 23 April 2012 Laguna Hills earthquake, noting that the depth and one possible fault plane orientation were consistent with movement on both the OBT and San Joaquin Hills Blind Thrust faults. Dr. Grant Ludwig briefly noted that 2012 Laguna Hills earthquake could be consistent with one of the San Joaquin Blind Thrust/NI fault models in Grant and Runnerstrom (2001).

Dr. Grant Ludwig's presentation was followed by several questions.

Questions for Lisa Grant Ludwig

Question from TI Team: You showed a figure with an anticline in the San Joaquin Hills. Does this structure fit the geology?

Answer from Lisa Grant Ludwig: That antiform is for Quaternary sediments and is largely constrained by the elevations of terrace platforms and shorelines. It's also considered by the broader distribution of Quaternary sediments. Of course, these Quaternary sediments are on older structures. What's the relation between the Quaternary sediments and the older structures? That's what I wonder.

Question from TI Team: What is the bedrock in the San Joaquin Hills?

Answer from Lisa Grant Ludwig: There are not many cross sections through the San Joaquin Hills. Tom Wright has some. There are some wells drilled there, but I haven't been able to find the logs. There's no oil and no water there, so there hasn't been a reason to obtain a lot of subsurface data. In general, my focus has been on the Quaternary uplift rate and thus Quaternary sediments.

Question from TI Team: You mentioned coral age dates?

Answer from Lisa Grant Ludwig: Yes, those are presented in Grant et al., 1999. The terraces in southern part of the San Joaquin Hills appear to be a different sequence, but they are built up with homes now. I'm not sure if the data exist to be able to compile those terraces.

Question from TI Team: Could you continue this terrace work down to Dana Point and SONGS?

Answer from Lisa Grant Ludwig: We had the 105 ka and 120 ka terraces, and another one, but they were weathered and had huge error bars. We had three terraces at the north nose of the San Joaquin Hills. The 5e terrace was prominent. There was another notch, but we couldn't tell if it was 5a or 5c. We assumed it was 5c. There are no age dates on the terraces at Dana Point, but may be possible to sample there. Chuck Powell had a publication in which he had 5a terrace age dates.

Question from RE in audience: I didn't know about this anticline parallel to the Newport-Inglewood Fault. This looks like strain partitioning.

Answer from Lisa Grant Ludwig: That was addressed bit in the published comment-response by Bender.

Comment from RE in audience: If it's correct, that's the best evidence I've seen.

Moderator: Let's follow up on that in Workshop #2 in August; this is interesting.

Exploration Industry Geophysical Data and Recent High-Resolution Surveys by Mark Legg, Consultant, Resource Expert

Dr. Legg opened his presentation by noting he would be presenting data largely collected by Dr. Gerry Kuhn. He stated he would identify specific field evidence of paleoliquefaction in north San Diego County and comment on general field expressions of paleoliquefaction. He also noted he would not discussed paleotsunami deposits, contrary to his outline presentation slide.

Dr. Legg then gave a general overview of the types of features that have been interpreted as paleoliquefaction. He identified mima mounds, sand blows, sand injections, lateral spreads, and polygonal fissure patterns as such features, and noted common environments that preserve these features.

Dr. Legg showed examples of paleoliquified materials throughout coastal San Diego County, visible in regional air photos. The examples included mima mounds/sand blows in an estuarine south of Carlsbad, sand blows near the Santa Margarita River mouth, and sand blows on the marine terraces near SONGS, south of San Onofre Creek. He indicated these features may have been observed during plant construction.

Dr. Legg also presented site (ground-level) photographs of several locations near Carlsbad. These paleoliquefaction features included lateral spreads, sand dikes, sand injection craterlets, and sand injection dikes in polygonal fissure patterns. He also commented on a photograph of Holocene-aged paleoliquefaction at an archaeological burial site.

Dr. Legg noted that most of the sites he discussed recorded Holocene liquefaction of Pleistocene-aged sediments. He emphasized that Pleistocene-aged sediments should not liquefy in theory under normal ground shaking conditions; thus, the occurrence of Holocene liquefaction of Pleistocene-aged sediments was suggestive of extremely strong ground shaking. He also noted that coastal areas in the hanging wall of east-dipping thrust faults would be subjected to extremely strong ground shaking.

Dr. Legg's presentation was followed by a few questions.

Questions for Mark Legg

Question from TI Team: In Oregon, for example, you see bedding plane parallel features. Do you see that here?

Answer from Legg: These are high angle faults.

Question from TI Team: Can you see the bedding?

Answer from Legg: You can see these faults in the sea cliffs, like at La Costa Avenue.

Question from TI Team: Do the faults cut bedding?

Answer from Legg: I don't know.

Question from TI Team: You mention uplifted estuaries. Did they liquefy when they were estuaries? Don't you think liquefaction most likely occurred when they were at water level?

Answer from Legg: Well the archaeology site is above MIS stage 5e, so we have Pleistocene sediments that have liquefied in Holocene time there.

Question from TI Team: Was there liquefaction from 1933 Long Beach earthquake?

Answer from Legg: Yes.

Question from RE in audience: What is the scale of the sand blows?

Answer from Legg: Some are a meter.

Question from RE in audience: You have a picture of a submerged shoreline. Is it a high or low stand?

Answer from Legg: You would be more likely to expect the low stand to be preserved under the water, but not for long.

Comment from RE in audience: High stands are better.

Comment from TI Team: The underwater terraces are beginning to be imaged, and that will be beneficial.

Vertical deformation of the southern California coast from relative sea level and leveling by Reed Burgette, GeoPentech and University of Oregon, Resource Expert

Dr. Burgette opened his presentation by identifying coastal southern California tidal gauge records as his primary data source. He provided a schematic illustration of a typical tidal gauge station. Dr. Burgette noted that tidal gauges are anchored and record both sea level rise and deformation of the crust in which they are anchored. He noted that eustatic sea level rises could be subtracted from the tidal gauge measurements to estimate crustal deformation.

Dr. Burgette stated the assumptions used in his preliminary leveling analysis and gave a brief overview of the analysis process. He also identified systematic errors in the dataset in 1933, 1978, and 1988, showing trends in the data that highlighted these errors. He noted that he had corrected for the 1933 and 1988 errors, and that he would be correcting for the 1978 errors in his final report.

Dr. Burgette noted that the tidal gauge measurements were similar to eustatic sea level rise in La Jolla and San Diego, suggesting little to no uplift there, but that the Newport Beach area appeared to be uplifting relative to the gauges to the south. He also reported the data show a hint of subsidence near SONGS, but that the error on that trend overlaps with no vertical deformation.

In summation, Dr. Burgette reported that the data suggest no vertical deformation in San Diego and La Jolla, broad subsidence in the area between La Jolla and SONGS, and uplift in the San Joaquin Hills through Newport Beach. He noted that the vertical deformation rates are small and no vertical deformation is within the errors of the data.

No questions were asked at the end of Dr. Burgette’s presentation.

End-of-Day PPRP Questions Session by Ralph Archuleta, University of California, Santa Barbara, PPRP Chair

The SONGS SSC SSHAC Workshop 1, Day 2 presentations were followed by a PPRP questions session; several questions were directed to specific presenters.

PPRP Questions Session

Question for Kent:	Do you see any slip rates in your marine geophysical datasets?
Answer from Kent:	The reprocessing effort is focusing on structural and stratigraphic relations. With the resolution we have, it's not the best tool for looking at slip rates. We're really looking at the architecture.
Question for Kent:	Are you reprocessing all the Chevron lines?
Answer from Kent:	Not all, but we are doing a lot. We're focusing on the ones in areas targeted for potential new geophysical surveys.
Question for Kent:	Do the lines that are planned for reprocessing cross the Newport-Inglewood Fault offshore?
Answer from Kent:	There are about 10 lines north of SONGS and about 14 lines south of SONGS we are planning to reprocess. About 50% of those will cross the Newport-Inglewood Fault.
Question for Kent:	Will these constrain some SSC parameters?
Answer from Kent:	Sure, a good example is how we see the Newport-Inglewood Fault dipping 60 degrees toward the plant in the line we have already reprocessed. We can debate about the OBT, but we're getting a better image of the architecture.
Question for Yeats & Legg:	Are there any aerogravity or aeromagnetic datasets available?
Answer from Legg:	Yes, there are aeromagnetic data. It has an impressive pattern that we could interpret. Vicki Langenheim at the USGS is the expert on that.
Comment from PPRP:	This is additional data that we didn't see at this workshop, so it needs to be brought in.
Answer from Yeats:	Both data types are available in the Los Angeles Basin. Vicki Langenheim has been involved with that, too. But what we have seen is too coarse. Of course we'd like to refine it.
Question for Shaw:	Can we get slip rates out of the seismic reflection profiles?

Answer from Shaw: There is potential for using the profiles in conjunction with boreholes or seafloor sampling; but you need both.

Question for Shaw: Do those data exist now?

Answer from Shaw: The existing data are poorly suited. My bias is that you want targeted new work.

Question for Shaw: What can be done within the existing in the time frame of this SSC SSHAC?

Answer from Shaw: The reprocessing and reinterpretation efforts are great. A reanalysis of existing datasets is worthwhile and can give broad constraints.

Question for Shaw: What data are available for the Oceanside and San Clemente wells offshore?

Answer from Shaw: Top records for Pliocene and Miocene tops. We don't have actual logs. They may exist, but we would have to request them. There are logs available for some wells in THUMBS/Huntington Beach. The boundaries are unconformities, but they haven't been looked at the way Dan Ponti has done in the Los Angeles Basin.

Question for Shaw: What's lithology in the upper two seconds of most of the offshore seismic lines?

Answer from Shaw: Sands and shales. The depositional environment isn't clear, and I'm not qualified to answer.

Question for Shaw: Did you assume they were initially deposited horizontally?

Answer from Shaw: No, most units have a seaward tilt. When we look at uplift rates, we are looking at the hinge.

Comment from Legg: The San Mateo formation dips to the west, and the San Onofre Breccia dips to the east. We need to correlate the onshore and offshore geology.

Question for Legg: During your liquefaction talk, you showed evidence for liquefaction occurring as recently as 6 ka and as old as 10 ka. Can you say you see liquefaction evidence younger than that?

Answer from Legg: There are very little data on that. This work was done without funding.

Question for Legg:	You say Pleistocene-aged sediments shouldn't liquefy; why?
Answer from Legg:	The engineering literature says sediments older than 15 ka should not liquefy.
Question for Conrad:	Which datasets are available to the TI Team?
Answer from Conrad:	The JebCo data are available. No CHIRP or mini-sparker surveys are available to the public.
Question for Conrad:	Do those datasets include facies? Which lithostratigraphic datasets are available?
Answer from Conrad:	I need to check on which datasets are public. I'm not sure how we can use non-public data.
Question for Ponti:	Has anyone correlated the Los Angeles Basin stratigraphy with deep water sediments outside the basin, anywhere?
Answer from Ponti:	At spot locations, yes, but there has not been a rigorous effort as far as I know.
Question for Rockwell:	What is the slip rate of the Newport-Inglewood Fault near SONGS?
Answer from Rockwell:	Somewhere between 0.5 to 2.0 mm/yr, based on onshore slip rates to the north and south.
Question for Rockwell:	What is the structure of the Newport-Inglewood Fault near SONGS?
Answer from Rockwell:	It's a zone with splays, like the Carlsbad thrust. But these are modeling talking points. We don't have much data out there, offshore.
Question for Rockwell:	Is the structure of the Newport-Inglewood offshore SONGS unknown? Is it through-going?
Answer from Rockwell:	It's a through-going zone of deformation, and it looks transpressive, which is what you would expect.
Question for Rockwell:	Do you see evidence for strain partitioning?
Answer from Rockwell:	If you have shortening across step-overs, then that's a different type of strain partitioning. But we'll discuss these ideas when we talk about models at Workshop #2 in August.

Question for Rockwell: If the flank rifting model of Mueller is right, why don't the uplift rates decrease south to north?

Answer from Rockwell: This is same latitude of the Salton Trough, so maybe this is the end of the system.

Question for Grant Ludwig: We saw the uplift rate in the San Joaquin Hills is about twice that of Rockwell's to south, all based on marine terraces. Is there an explanation for the difference?

Answer from Grant Ludwig: Well, I've gone on record saying I think this is tectonic and local to tectonism in the San Joaquin Hills. If I stick to the data, I don't know what the structure is underneath. There is of course very little data on structures at depth. I do think the uplift rates are good, that is, I think the ages and measurements are good.

Question for Grant Ludwig: You mentioned the Cristianitos Fault. Is it active?

Answer from Grant Ludwig: Robert Speed found exposures in the foothills of the Santa Ana Mountains, and he was convinced there was youthful strike-slip activity. Unfortunately he passed away before we were supposed to meet to go out there.

Answer from Rockwell: The main Cristianitos Fault is exposed in the sea cliff next to SONGS. It's buried by the marine terrace. Based on the geology, there's got to be another fault mixed in there that is not exposed. The Cristianitos is interpreted as a normal fault. You can speculate all you want, but there is absolutely no evidence it has been active. Activity on this fault was tied to the development of the Capistrano Embayment, in which the San Mateo formation was deposited. No one is speculating the Cristianitos Fault is active that I know of. There is a fault that is on trend with the Cristianitos Fault for which there was some evidence of activity buried deeply in consultant reports.

Answer from Legg: There were NRC hearings in 1980s that focused on the activity of the Cristianitos Fault. Some folks thought it was active offshore. Personally, I think it is a strike-slip fault; it's only considered a normal fault because of the exposure at the sea cliff. You have examples of listric faulting and horsts and grabens, so they think it's a normal fault. But remember, it is curving to west, offshore, so it is listric in character. There was also a Shawn Biehler report that assessed instrumental seismicity on Cristianitos Fault.

Observer Questions Session

Day 2 of the SONGS SSC SSHAC Workshop 1 closed with an open questions session for the other Observers; several questions were asked.

Observers/Open Questions Session

Comment from TI Team: Just to follow up, the evidence is compelling for uplift in the San Joaquin Hills, but we are lacking evidence as to how far south it extends.

Answer from Grant Ludwig: In the 2002 paper, we looked at the Holocene uplift down to Dana Point. The shoreline from Dana Point into San Clemente has been modified, and the rock type not conducive to record this. I can confirm Holocene uplift north of Dana Point, but I have no way of dating it there. The sequence of Quaternary marine terraces was mapped in the south San Joaquin Hills before that area was developed. I've tried to correlate them, but there is no way to correlate. The uplift rate looks about the same to me, to the extent that I can tell with the limited data. I don't think it's possible to get the data.

Question for Rockwell: Have folks drilled through the Quaternary cover in these critical data gap areas?

Answer from Rockwell: Yes, it's possible. We've proposed to gain access to a large amount of information that we believe exists in geotechnical consultant reports. All we need is top of bedrock elevations from the geotechnical borings. If we can get these, I think we can extend this mapping through San Clemente.

Answer from PM: There's only one area that isn't developed yet, just north of Pico Road and west of Interstate-5. We tried to get the people to let us in, but they wouldn't let us.

Comment from Rockwell: Yes, anyone who lives on the beach doesn't want surfers walking through their land, geologists included. They are protective of their property.

Question for TI Team: Reed Burgette showed data that suggested the Newport Beach area may be uplifting at twice the rate Lisa presented. So you have a hint that today's uplift may be different than the long term uplift rate. How are you going to resolve that?

Answer from TI Team: I'm not sure with the uncertainty they are that different. The tidal gauge uplift has errors of about 0.2 mm/yr. There are a number of lines of evidence that the Newport Beach area is uplifting faster than San Diego and La Jolla, so that is solid. The gradient from north to south is probably real, so it's a question of where it ends and becomes that flat surface Tom Rockwell talked about. It's also important to remember this is interseismic data, and it's always risky to compare long term uplift rates to interseismic rates. Reed Burgette isn't done yet with his analysis, so hopefully he can tease out more information in the errors. Some models will need to be made and presented in August at Workshop #2. That's the appropriate setting, so that's really where that will be addressed.

Comment from Observer in audience: There are probably hundreds of such geotechnical reports in our Coastal Commission archives for Tom Rockwell and others to evaluate.

Comment from TI Team: Yes, this seems to be important to pursue, especially if we want to constrain seaward tilt.

Question from Observer in audience: Are there any LiDAR datasets available? Would that would be good for assessing the Cristianitos Fault?

Answer from Observer in audience: The Coastal Commission has some LiDAR datasets.

Question for Grant Ludwig: Could LiDAR tell you something about the faults in the San Joaquin Hills? Could you write a proposal to do a study on this?

Answer from Grant Ludwig: It certainly would tell you something about the UCI Campus Fault. But there are not very many places it would be useful. Maybe some data could be compiled. Strands of the Pelican Hill Fault have been identified in geotechnical reports, but those reports have not been compiled. I'd have to think about whether or not LiDAR would work.

Question from RE in audience: There are a number of drainages that come off the hills and drain into the coast. Has any morphometric mapping completed?

Answer from Rockwell: Well, there are river terraces. You're thinking of doing this for assessing the Cristianitos Fault? Yes, there was some mapping done by a USGS geologist, but I forgot his name. The terraces end where his mapping ends; that is, work hasn't been done beyond his mapping. So yes, some work could be done.

Question for Rockwell: There have been hints that the older marine terraces are tilted to the west. With the rift flank model, some terraces might be old enough to be tilted. Has anyone looked at that?

Answer from Rockwell: The highest terraces on Camp Pendleton, near SONGS, are at an elevation of 285 meters and are exposed in a road cut. There, the platform slopes at 9 degrees to the west. The lower terraces slope at 5 degrees or lower. So there's a hint that above the palisade (major) slope paleo-sea cliff, the Pliocene terraces show tilting deformation. The marine terraces younger than 1 Ma are flat. So, there's a hint of older deformation.

Question for Rockwell: If the whole area has been tilted due to the rift flank uplift, are there data that could test that, and what the tilt would have to be?

Answer from Rockwell: You don't need much tilt at all. It would be less than a degree. It's over 100 km or so. So, one degree over 100 km is in the noise. The work in east San Diego County and south of the Mexico border, in the regional high altiplano, has Eocene, Cretaceous, and Miocene stable surfaces with Eocene cobbles from Sonora. All the topography in the Peninsular Ranges is post-Miocene.

Question for Rockwell: Some of Roland's work is in Quaternary sediments, commonly called "the old red alluvium"; is there any marker like this to test the rift flank uplift model?

Answer from Rockwell: In a geomorphic way, yes. Closer to coast, you would get deeper incisions that would disappear inland. The tilting we think we see can't be attributed to the rift shoulder uplift. As you come north into San Diego County, you have flat lying Eocene rocks, then you see folded and faulted Tertiary units. You see this on both sides of the Peninsular Ranges. The terraces suggest this is an older feature, since we don't see it in the terraces younger than 1 Ma.

Question for Rockwell: If those Miocene volcanics are flat, shouldn't they be titled by the rift flank uplift?

Answer from Rockwell: Those Miocene volcanics were flowing down paleovalleys, and we expect less than a degree of tilt from the rift flank uplift.

Comment from RE in audience: We see a progressive tilt of the San Mateo formation offshore, and the San Onofre Breccia has been tilted the other direction.

Project Sponsor's Closing Remarks by Caroline McAndrews, Southern California Edison Company

Ms. McAndrews thanked the group for their participation and active engagement. She reminded the Workshop participants and attendees that although a number of potentially valuable new studies were identified, such studies would need to provide data within the SSHAC timeframe.

Ms. McAndrews re-iterated SCE's commitment to supporting the needs of the SSC SSHAC project and thanked the group again.

Closing Remarks by Ray Weldon, University of Oregon, TI Team Lead

Dr. Weldon thanked the Workshop participants and attendees for their efforts. He noted the TI Team would follow up with the Resource Experts as needed and reminded them to expect email correspondence soon.

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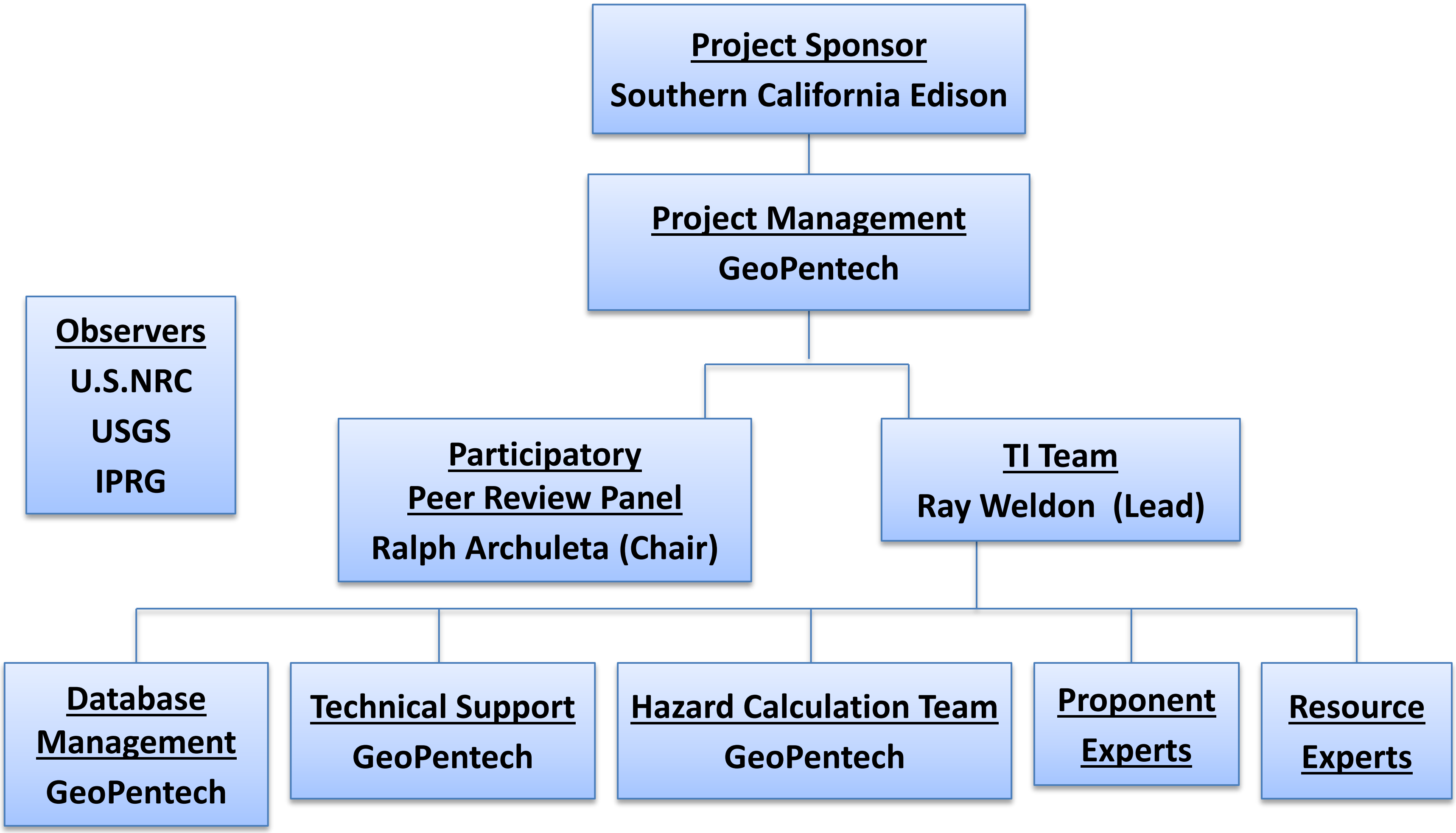
TABLE 1
SONGS SSC SSHAC WORKSHOP #1 PARTICIPANTS

Role	Personnel	Affiliation	Present Jan. 14, 2013	Present Jan. 15, 2013
PPRP	Ralph Archuleta	Univ. California, Santa Barbara	Yes	Yes
	Jan Rietman	Private Consultant / Fugro	Yes	Yes
	Peter Bird	Univ. California, Los Angeles (ret.)	Yes	Yes
	Neal Driscoll	Univ. California, San Diego / Scripps	Yes	Yes
TI Team	Ray Weldon	Univ. Oregon	Yes	Yes
	Matthew Muto	SCE	Yes	Yes
	Paul Umhoefer	Northern Arizona Univ.	Yes	Yes
	Peter Shearer	Univ. California, San Diego / Scripps	Yes	Yes
	Yoshi Moriwaki	GeoPentech	Yes	Yes
Experts	John Shaw	Harvard Univ.	Yes	Yes
	Lisa Grant	Univ. California, Irvine	Yes	Yes
	Mark Legg	Private Consultant	Yes	Yes
	Tom Rockwell	San Diego State Univ.	Yes	Yes
	Luciana Astiz	Univ. California, San Diego	Yes	Yes
	Tim Dawson	California Geological Survey	Yes	Yes
	Chris Walls	UNAVCO	Yes	Yes
	Dan Ponti	USGS	Yes	No
	Jamie Conrad	USGS	Yes	Yes
	Peter Powers	USGS	Yes	No
	Graham Kent	Univ. Nevada, Reno	Yes	Yes
	Kaj Johnson	Indiana Univ.	Yes	Yes
	Morgan Page	USGS	Yes	No
	Egill Hauksson	CalTech	Yes	Yes
	Glenn Biasi	Univ. Nevada - Reno	Yes	Yes
	Danny Brothers	USGS	No	No
	Bob Yeats	Oregon State Univ. (ret.) / Earth Consultants Intl.	Yes	Yes
Hazard Calcuations	Phalkun Tan	GeoPentech	Yes	Yes
	Andrew Dinsick	GeoPentech	Yes	Yes
Regulatory Observers	Walter Barnhardt	USGS	No	No
	Cliff Munson	NRC	No	No
	Jon Ake	NRC	Yes	Yes
	John Stamatakos	NRC	Yes	Yes
	Gerry Stirewalt	NRC	Yes	Yes
	Christie Hale	NRC	Yes	Yes
	Megan Williams	NRC	Yes	Yes
	Chris Wills	California Geological Survey	Yes	Yes
	Eric Greene	California Public Utilities Commission	No	No
	Bob Anderson	California Public Utilities Commission	Yes	Yes
	Dick McCarthy	California Public Utilities Commission	No	No
	Casey Weaver	California Energy Commission	Yes	Yes
	Joan Walter	California Energy Commission	No	No
	Mark Johnsson	California Coastal Commission	Yes	Yes
	Johanna Fenton	California Emergency Management Agency	Yes	Yes
Other Observers	Steve Thompson	Lettis Consultants International (PG&E SSC)	Yes	Yes
Project Sponsors	Caroline McAndrews	SCE	Yes	Yes
	Mark Malzahn	SCE	Yes	Yes
	Florin Arsene	SCE	Yes	Yes
	Joseph Wambold	SCE	Yes	Yes
Project Management and Technical Support	Tom Freeman	GeoPentech	Yes	Yes
	John Barneich	GeoPentech	Yes	Yes
	Alexandra Sarmiento	GeoPentech	Yes	Yes
	Carola Di Alessandro	GeoPentech	Yes	Yes
	Reed Burgette	GeoPentech / Univ. Oregon	Yes	Yes



SONGS SSC SSHAC PROJECT PERSONNEL/ROLES FLOWCHART

PROJECT #: 12024A	DATE: JAN 2013	PROJECT: SONGS SSC SSHAC	Figure: 1

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ATTACHMENT A

Workshop Agenda

San Onofre Nuclear Generating Station
Seismic Source Characterization
Senior Seismic Hazard Analysis Committee
Workshop #1 Agenda

	Time	Topic	Speaker
Day 1 – Jan.14 2013	0900 – 0915	Introductions	T. Freeman
	0915 – 0930	Project Sponsor's Opening Remarks	C. McAndrews
	0930 – 1000	SSC SSHAC Purposes, Procedures & Products	R. Weldon
	1000 – 1015	TI Team, PPRP and Resource Experts Questions about Purposes, Products and Procedures; Observer Questions Time Permitting	
	1015 – 1045	Past SONGS Hazard Calculations & Sensitivity Analyses	A. Dinsick
	1045 – 1100	*Break*	
	1100 – 1130	Seismic Hazard at SONGS: The 2008 USGS NSHMP and UCERF3	P. Powers
	1130 – 1145	TI Team & Resource Experts Questions Session	
	1145 – 1245	*Lunch*	
	1245 – 1315	Earthquake Recurrence – Gutenberg-Richter and Characteristic Models	M. Page
	1315 – 1345	Earthquake Scaling and Depth Dependence	G. Biasi
	1345 – 1415	UCERF3 Fault Databases	T. Dawson
	1415 – 1430	*Break*	
	1430 – 1500	SCEC Unified Structural Representation (USR) of Southern California	J. Shaw
	1500 – 1515	Passive Seismic Deployment for SONGS	L. Astiz
	1515 - 1545	Local Seismicity & Focal Mechanisms	E. Hauksson
	1545 – 1600	TI Team & Resource Experts Questions Session	
	1600 – 1615	*Break*	
	1615 – 1630	Permanent GPS in the Vicinity of SONGS	C. Walls
	1630 – 1700	Present-Day Surface Motions in the California Borderland	K. Johnson
	1700 – 1715	TI Team & Resource Experts Questions Session	
	1710 – 1745	PPRP Questions Session	
	1745 – 1815	Observers Questions Session	
	1815 – 1830	Tomorrow's Agenda	T. Freeman

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San Onofre Nuclear Generating Station
Seismic Source Characterization
Senior Seismic Hazard Analysis Committee
Workshop #1 Agenda (cont.)

	Time	**Topic**	**Speaker**
Day 2 – Jan.15 2013	0830 – 0840	Project Sponsor's Opening Remarks	C. McAndrews
	0840 – 0850	SSHAC: Reminder on Rules of Conduct & Procedures	R. Weldon
	0850 – 0900	Agenda	R. Weldon
	0900 – 0930	Tectonics of Los Angeles Basin: Inherited Structure & Strain Partitioning	R. Yeats
	0930 – 1000	Industry Geophysical Datasets and Their Use in Source Characterization	J. Shaw
	1000 – 1030	*Break*	
	1030 – 1100	Offshore Geophysics – Reinterpretations of Old Data	M. Legg
	1100 – 1115	USGS Earthquake Hazard Studies Offshore San Diego and Orange Counties, 2006-2012	J. Conrad
	1115 – 1130	TI Team & Resource Experts Questions Session	
	1130 – 1215	*Lunch*	
	1215 – 1245	Offshore Geophysics – Limitations in Old and New Data	G. Kent
	1245 – 1315	New Offshore Geophysics Data Collection Plans	D. Brothers
	1315 – 1345	TI Team & Resource Experts Questions Session	
	1345 – 1415	LA Basin & Nearby Area – Structure & Stratigraphy	D. Ponti
	1415 – 1430	*Break*	
	1430 – 1510	NI/RC Paleoseismology, Earthquake Recurrence and Slip Rate	T. Rockwell
	1510 – 1530	Local Marine Terraces/Geomorphology	T. Rockwell
	1530 – 1555	San Joaquin Hills Marine Terraces/Faulting	L. Grant Ludwig
	1555 – 1605	Summary of Paleoliquefaction Data	M. Legg
	1605 – 1630	TI Team & Resource Experts Questions Session	
	1630 – 1645	*Break*	
	1645 – 1715	PPRP Questions Session	
	1715 – 1745	Observers Questions Session	
	1745 – 1800	Closing	R. Weldon

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