

UNITED STATES OF AMERICA
U.S. NUCLEAR REGULATORY COMMISSION

SEISMIC INFORMATION WORKSHOP

DAY 1

SESSIONS 1 & 2

September 08, 2010

8:00 A.M.

TRANSCRIPT OF PROCEEDINGS

Public Meeting

San Luis Obispo, CA

APPEARANCES

Panel:

John Stamatakos
Director, Geosciences and Engineering
Southwest Research Institute

Doug Dreger
Professor of Geophysics
University of California, Berkeley

Ralph Archuleta
Professor, Earthquake Source Studies/Strong Motion
Seismology
University of California, Santa Barbara

Robb Moss
Assistant Professor, Soil Mechanics and Earthquake
Engineering
Cal Poly San Luis Obispo

Jeanne Hardebeck
Research, United States Geological Survey
Menlo Park, California

Victoria Langenheim
Research Geophysicist, United States Geological Survey
Menlo Park, California

Tim Dawson
Engineering Geologist, California Geological Survey
Menlo Park, California

NRC Staff:

William Maier
Regional State Liaison Officer, Region IV Office

William F. Burton
Chief, Rulemaking and Guidance Development Branch
Division of New Reactor Licensing
Office of New Reactors

Roy Caniano
Director of the Division of Reactor Safety

Megan Williams
Reactor Inspector

Christie Denissen
Staff Member

1 PROCEEDINGS

2 MR. MAIER: Good morning, everyone. Welcome to the Seismic
3 Information Workshop. My name is Bill Maier. I am too low? You guys got it.
4 My name is Bill Maier. I work at the Nuclear Regulatory Commission's Region IV
5 Office in Arlington, Texas. And it's my pleasure to facilitate this two day
6 workshop. Joining me in facilitation duties is Mr. Butch Burton. Butch is a
7 branch chief at the Office of New Reactors in Rockville, Maryland. And we would
8 like to introduce you to this workshop. And the purpose of this workshop, as you
9 can see from your agenda, says it's to provide a forum for members of the public
10 to gain a basic knowledge of seismic hazard and its applications for the safety
11 and operation of commercial nuclear plants, including -- tomorrow specific
12 discussions of the Diablo Canyon facility.

13 Before I introduce the welcoming remarks speaker, go over a few
14 safety and logistics items for you. In event of fire, we've got doors right behind
15 us and a door out here. Please exit through the doors to the rear, and go out into
16 the parking lot and walk away from the building. Make room for as many people
17 to get out so that everyone can have room to get away from the building in the
18 event of a fire.

19 Can I have a show of hands please of anyone in the room who is
20 certified in CPR? And keep your hands up, please. Okay, if you think you are
21 going to need chest compressions, figure out who it is that you want to do chest
22 compressions on you.

23 Restrooms were on the way in to your left. You should have seen

1 them on the way in here from the front door. Refreshments; we have two water
2 stations in the back. If you need any other type of refreshments there is a gift
3 shop on the other side of the registration desk. As you came in it was to the left
4 as you came in the front doors.

5 Today's session will be videotaped by AGP Productions. We're
6 using their sound systems; for that reason we ask that everybody put their cell
7 phones on vibrate or off. And that please do not -- refrain from any shout-outs
8 from the floor. In order to be properly recorded, we want the person who's got
9 the microphone, or who's talking into the microphone, to be the one who is
10 speaking at any one time. Only one speaker at a time.

11 On your agenda, you'll see that we have four sessions scheduled
12 for today. They are two in the morning followed by a hour and 15-minute lunch,
13 which is on your own by the way -- they asked me to say that -- and then two
14 sessions in the afternoon. Between each session there are half hour breaks.
15 And I would invite you -- if any of the speakers have set up in there, we have got
16 the Los Osos room and the Aetna room reserved for posters or any other visual
17 aids that speakers may have brought to let people take a look at. We invite you
18 to peruse those on the break. Or if you have any other personal walking around
19 time, you can try to check those out. If you don't see any in the beginning,
20 maybe some speakers haven't had the chance to set them up yet, you might
21 want to try a little later.

22 With that I think it's time to introduce Roy Caniano, who will give the
23 welcoming address. Roy is the director of the Division of Reactor Safety at the
24 NRC's Region IV Office in Arlington, Texas. Roy's division is responsible for
25 conducting inspections and reviews of engineering issues at nuclear power

1 plants. And I'll turn it over to Roy.

2 MR. CANIANO: Not yet? Oh it's on now, I can hear it. Okay, good
3 morning and welcome. I am Roy Caniano and has Bill Maier mentioned, I am the
4 Director of the Division of Reactor Safety at the Nuclear Regulatory
5 Commission's office in Region IV just in Arlington, Texas. Our core responsibility
6 at the NRC is to ensure adequate protection of public health and safety, promote
7 the common defense and the security, and protect the environment.

8 When you reflect on the workshop that we're having today, an
9 important aspect for us meeting this responsibility is to have open dialogue --
10 maintain that open communication with the public and items of issues of interest.
11 And of course, seismic we believe, is one that is extremely on the minds of
12 everybody here.

13 We want to engage all interested parties today to have constructive
14 discussion on seismic issues as they relate to safe operation of nuclear power
15 plants in the United States. We hope that today's session is going to provide
16 useful and informative information that are going to be presented by some of the
17 leading experts in the field of seismology, as you can see from the agenda. And
18 also when we go through from some introductions through the panel, I think
19 you're going to see that we really were fortunate to have a high level of
20 individuals with expertise.

21 A few administrative comments before we get started with the
22 session. This is considered to be a Category 3 public meeting. This means that
23 the public is invited to participate in the meeting by providing comments and
24 asking questions throughout the meeting. The NRC is recording this workshop,
25 as was mentioned by Bill Maier, and we're going to be making it available on our

1 NRC public website. My guess it will probably be seven to 10 days when that will
2 be available.

3 You passed the registration desk in today, and hopefully everyone
4 has signed in. We would like to have a record of attendees. I want to point out
5 that today's sessions is not going to be a decision making session. And we're
6 not here to sway or to influence everybody. It's intended to be informative, and
7 address any questions or comments that you have. There are feedback forms
8 that are available, and if you have any questions that you want to submit in that
9 way, feel free to do that. We're always interested also in seeking suggestions on
10 how we can improve on our public communications.

11 As you can see from the agenda, there are numerous panels that
12 are scheduled over the next two days; four of them are scheduled for today.
13 What we have done is scheduled, right after each panel, a question and answer
14 period. So I would appreciate it if you could hold some of your questions until
15 that Q and A session after each of the panels. In addition, the slides for today's
16 presentation are available on the table, and we're also going to post them on our
17 public website.

18 As we earlier mentioned, we have two facilitators to assist us during
19 this workshop. If anyone in the audience has questions and comments, please
20 allow time for the facilitators to get to you with a microphone. This is going to
21 make it easier for all to hear the questions and the answers. We also have note
22 cards that are available in case you would like to submit a question in writing.
23 We're going to do our best here to address, fully, your questions if we can. If we
24 don't have a complete answer, however, we're going to make a note and
25 respond to the questioner at a later time.

1 We've known for a long time that there was great interest and many
2 questions regarding seismic issues at Diablo Canyon. In an effort to adequately
3 address these questions, the NRC planned for this workshop a long time ago;
4 even before the license renewal process was implemented. We've brought
5 together, again, an extraordinary group of experts and presenters, and we're
6 excited that so many national recognized experts in the field have made their
7 time available to provide the benefit of our knowledge and experience.

8 The field of seismology has seen many changes and advancements over the
9 years. It's the goal of this workshop to provide that information to you that should
10 be of interest to all members that are in attendance today. We truly encourage
11 you to ask as many questions as you can. Again, I think that will benefit all of us.

12 It's now my pleasure and honor to introduce Dr. John Stamatakos
13 of the Rockville, Maryland Office of Southwest Research Institute. He's a
14 geologist and geophysicist currently serving as the director of the Environmental
15 Program, Geosciences, and Engineering Division of Southwest Research. He
16 holds a bachelor's degree in Geology from Franklin and Marshal College; a
17 Master's degree and Ph.D. in Geology from Lehigh University. He manages
18 several sponsored investigations that evaluate earthquake and volcanic hazards
19 at nuclear facilities. He has written or collaborated on more than 60 reports and
20 papers on structural geology, tectonics, geophysics, and has made presentations
21 at international conferences in the United States, Canada, and Europe. Prior to
22 his work at Southwest Research Institute, he taught Geology and Geophysics at
23 the University of Michigan. We are pleased to have Dr. Stamatakos here today
24 to open our workshop. John?

25 Dr. STAMATAKOS: Let's see if we can do all the stuff we need to

1 do to get a slide show.

2 [laughter]

3 Well. Right in the middle. Okay. Well, it's a real pleasure for me to
4 be here. I know that in the original agenda, the president of GSA was going to
5 give these remarks, and so I feel a little humble that because he couldn't make it
6 that NRC asked me to come and make this presentation. I think the goal of my
7 opening remarks is twofold: One, I'd like to try to set the stage and try to cover
8 some of the topics at the highest level that you're going to hear about in the
9 sessions. I'll start to introduce some of the terminology, but I'm really just hit
10 some of the high points.

11 I think the more important goal of my presentation here is to really
12 leave you with a number of questions, just to get you to start thinking about the
13 types of questions that, you know, may be important in our discussions later on
14 today and tomorrow. Now I came at geology and geophysics from the point of
15 view of tectonics and became in love with geology because of tectonics. So I'm
16 going to start this presentation with a slide of the West United States that shows
17 the topography.

18 The West United States is dominated by the tectonics that's
19 occurring along the western edge of North America, very close to us here in
20 California. It's because of these interactions of these geologic plates that we're
21 really talking about significant earthquakes and significant affects of earthquakes.
22 Those effects extend, the tectonic effects extend well inboard into the United
23 States. And it's really this interaction of these plates, the Juan de Fuca Plate,
24 and the North American Plate, and Pacific Plate that ultimately drive what's going
25 on in terms of earthquake hazards here in the Western United States.

1 And it's the understanding over the last five or six decades of plate
2 tectonics that's, in a sense, guided us on earthquake studies for a long time. It's
3 not the entire story. This is a map of the United States that shows about a
4 hundred year record of earthquakes -- the larger the red circle, the larger the
5 earthquake. And superimposed on that are yellow stars; and the yellow stars
6 show nuclear facilities. So while the West United States is dominated by
7 earthquakes, especially all the earthquakes that occur in response to the plate
8 margin along the San Andreas Faults and all the associated faults, there are
9 other parts of the United States that also have significant earthquake records --
10 the Wasatch Front that runs through the Rocky Mountains, especially in Utah.

11 The New Madrid Zone in Tennessee, and Kentucky, and Indiana,
12 Illinois, Charleston earthquake, the earthquake in the 1880s, a pretty large
13 earthquake, that are away from plate boundaries. So although tectonics does a
14 good job of helping us explain a lot of earthquakes, doesn't explain them all.

15 And the other point is that earthquakes are of concern at lots of
16 nuclear facilities across the United States. And so it's a very important and very
17 serious topic that I think keeps us all very interested in understanding them.
18 Now, earthquakes aren't all bad. From a geologist point of view, we're actually
19 pretty glad that sometimes there are earthquakes.

20 There's a picture of the Teton Mountains, beautiful mountains in
21 Wyoming. And the front of the Teton Mountains is essentially a large fault. The
22 Teton Mountains were produced over the last several million years by the
23 accumulation of many, many earthquakes. In a sense, I kind of think of
24 earthquakes as this, you know, the individual steps of a marathon, if you will. So
25 we can look at the final result, we have to study those individual steps, but from a

1 geologist's point of view, it's what gives rise to a change earth and the dynamics
2 of the earth.

3 We also know that earthquakes are dangerous and can cause
4 serious damage. Here are just some images that I pull from a talk I have to
5 admit I gave many, many years ago. This shows some of the damage of
6 earthquakes in Taiwan and in Turkey. So we know that the potential for
7 destruction, damage to property, and loss of life is significant. I think this year
8 has been especially hard in terms of casualties in Haiti, Chile, property damage
9 in Chile, New Zealand, elsewhere. So it's been a significant year for earthquake
10 damages. So I think the point that we want to make is that, yeah, we need to
11 take hazards and earthquakes extremely seriously. It's an important topic.

12 From NRC's point of view, NRC adopts a philosophy that in
13 regulating facilities for safety, they'll use something that's -- you'll hear us talk
14 about -- hear NRC talk about is risk-informed performance-based. What that
15 really means is that they want an understanding of no undue risk to public
16 healthy and safety.

17 And the questions you want to ask, the questions that I think that
18 are right to ask when you take this kind of an approach, basically are the
19 questions I think we all ask ourselves subconsciously or consciously every day,
20 and the risk triplet, you know, what can go wrong, how likely is it, and what are
21 the consequences? So as they're sitting down to breakfast this morning, and I
22 decided to have that second piece of bacon, I subconsciously asked myself that
23 same question. What can go wrong? How likely is it that it's going to go wrong?
24 And what are the consequences? So at all levels of society, I think that this is a
25 very important set of questions that we want to ask ourselves in evaluating all of

1 safety.

2 So I thought I'd put together just some obvious earthquake basics
3 as a starting point for our discussions. We know that earthquakes are
4 destructive; no question about that. We know that earthquake and earthquake-
5 related phenomenon, things like ground shaking, fault ruptures, soil liquefaction,
6 other kinds of phenomena are very complex. And we have a whole host of
7 leading experts who study all of those effects and will hopefully be able to walk
8 you through a lot of those.

9 We know we can't yet predict precisely when and where the next
10 earthquake will occur. I think most people who work in seismology, that's a
11 question that gets asked most -- when's the next big one? And I think although
12 that's an important question, I think the other question is even more important.
13 And that is, are we prepared for it? So with sufficient information, can we
14 actually predict or estimate the ground motion, the amount of shaking that an
15 earthquake will produce at a particular site, and then can we be assured that
16 structures can be designed to withstand those effects. And I think there's ample
17 evidence that with careful planning and with good engineering, that the answer to
18 that last part is, yes; structures can be designed to withstand the effects of
19 ground motion. We just need to make sure we continually evaluate what the
20 ground motion might be.

21 So in a simple sense, when we think about earthquake hazard or
22 seismic hazard assessment, we really want to look at a number of factors that
23 can influence. So and this is kind of a cheesy diagram. I apologize. It's not
24 really to scale, but on a cross section I tried to illustrate that really when we're
25 talking about the ground motion site, we want to know what's going on at the

1 source. So what happened when the earthquake occurred on the fault? You
2 know, what are the characteristics of that source? Did the energy spread out
3 equally? Did it spread in one direction? We want to know what happens along
4 the path. So how is that energy attenuated as it moves from the source towards
5 our site?

6 And also we want to know, we know from many earthquakes, that
7 the site effects are very important. So as the earthquake energy gets very near a
8 facility, the soil or the rock that's beneath the site plays an important role in how
9 much shaking, or how much vibration our facility will experience.

10 So what does it take? Well, it takes a lot. It takes a whole series of
11 different kinds of expertise in order to really do a good job in producing a reliable
12 seismic hazard assessment. So I've just tried to list a few of the topics that we're
13 going to talk about. Plate tectonic setting, we want to know as much as we can
14 about the historic and even the prehistoric earthquake records. We've been
15 measuring earthquakes since probably accurately since around the 1960s. So
16 we have a record, but is that long enough?

17 There have been tremendous strides made in paleoseismic studies;
18 studies that look at information along faults to try to discern what was going on in
19 prehistory in terms of earthquake records. We want to know about faults. We
20 want to be able to identify the faults. Often, that involves looking in the
21 subsurface. And I know that we'll have lots of discussion about geophysical
22 methods to help identify faults.

23 We want to be able to characterize those faults in terms of their
24 ability to produce earthquakes, what kind of magnitude, what's their rate of
25 activity, are they active, what style? Is it a fault that moves side-by-side? Is it a

1 fault that displaces in a normal sense? Is it a fault that displaces in a reverse
2 sense of we call a thrust fault? We want to know about how the rupture
3 propagates the rupture dynamics of that source. We want to know how the
4 attenuated energy moves through the, or how the energy moves through the
5 earth and is attenuated, and we want to know about the site effects, in particular,
6 the geotechnical conditions of the soils and rock beneath our site that can so
7 importantly influence the ground motion we ultimately see.

8 So seismic hazard really focuses on the two fundamental
9 methodologies, and I know there's some -- we'll have a panel discussion about
10 deterministic assessments and probabilistic assessments. So I thought I'd try to
11 introduce those here.

12 A deterministic assessment is one in which we try to define what
13 are likely shaking is at the site based on a single set of conditions. So a single
14 earthquake on a fault, often in NRC history, has been termed "the maximum
15 credible event." That would be the largest earthquake that could occur could on
16 the fault closest to the source, perhaps with the least amount of attenuation from
17 the source to the site. And so we can, in that sense, have a very simple
18 assessment of the likelihood of ground shaking at our site.

19 But implicit in a deterministic assessment are a lot of assumptions -
20 - you know, what's credible? How do you define credible? Is the maximum
21 credible earthquake really the maximum credible earthquake? What about
22 uncertainty and uncertainty in your assessments? So in more modern
23 assessments we now rely on probabilistic assessments rather than deterministic
24 assessments. And these are much, much more complex structures.

25 So in probabilistic assessments, we define the hazard in terms of --

1 not in terms of what a single event might do, but we might define it in terms of the
2 probability of exceeding some level of ground motion. You could think of this in
3 terms of the way that you drive. You know if -- I know that probably only about
4 five percent of you in here ever speed. But those of you who ever speed on the
5 highway, you might say, you know you have a five percent chance that you're
6 going to get caught. There's a five percent chance that you're going to exceed
7 the ability to evade a ticket. It's not really that different in terms of a probabilistic
8 assessment. And the advantage of the probabilistic assessment that we
9 explicitly try to include our uncertainty and evaluate that uncertainty in our
10 knowledge.

11 The methodology that's most often used is to construct what we call
12 logic trees, and I recognize this as a very complex. This is just a piece of a logic
13 tree of one seismic hazard study. This is from Utah from a probabilistic
14 assessment that was done in Central Utah. But I just wanted to show you that
15 the way that this is implemented in terms of uncertainty is that for each question
16 that we ask along the -- for a single fault. So for the Clover Sheeprock Fault, we
17 ask a number of questions. Is it segmented? Well, 60 percent chance that it is;
18 40 percent chance that it's not. What's the state of activity? There's a 60
19 percent chance that it's active, and a 40 percent chance that it's not. What's the
20 distribution of the likely magnitude? Well, the mostly likely magnitude in this
21 model is that it would produce a 6.6, but there's a three percent chance that it
22 could produce a seven. And so when you construct these logic trees and then
23 you run simulations, thousands and thousands of simulations, through all of
24 these, you get some sense of what the ultimate hazard might look like.

25 And so you're going to see examples of what we call probabilistic

1 seismic hazard curves. And these are essentially what I was describing in terms
2 of the speeding ticket. Basically, you can think of these as the probability of that
3 some level of shaking at your site is going to be exceeded. So 10^{-3} ,
4 that's a 1,000, chance. So in a given year, the annual frequency in a given year
5 on this curve -- oops, if I can get the mouse here -- the likelihood that you might
6 get .4 g exceeded in a 1,000 years.

7 Now, there's of course this is uncertainty around that. That
8 uncertainty is that that number could be a small .2 g and perhaps as big as .5 or
9 .6 g. So that's what these probabilistic assessments tell us. They give us some
10 idea about what's the likelihood that you might get some ground shaking at your
11 site.

12 So once you have that kind of assessment, of course, you're going
13 to have to ask the question, the next one? When it is unlikely enough, right?
14 You have to make a decision now about well, now that I know what the likelihood
15 of exceeding ground motions are, what's important to me? How unlikely am I
16 going to try? Because, you know, we can't go to infinity, right? We would live in
17 a bubble if we were not willing to take any risks at all. And I know one of the
18 issues that we're facing is as we try to do -- to go with lower and lower
19 probabilities of ground shaking, that these ground motions can get extremely
20 large.

21 I think the other question is that in terms of not only the hazard, but
22 we want to understand -- tomorrow's discussion we'll focus a little bit on how will
23 the system respond? So these are the famous train tracks that were displaced at
24 Strike-Slip Fault in Turkey. They're -- if we can design a structure so that it can
25 resist the impacts of earthquake, that's really the ultimate goal. So it's not just

1 the hazard itself that's important, we want to also understand the ability of the
2 facilities to be able to withstand the damage from earthquakes. And we can look
3 at that in a deterministic way, but we can look at how damage, how structures
4 may be damaged in a probabilistic way too. So we do that through something
5 that's called fragility.

6 Fragility just describes the likelihood that my whatever will fail;
7 whatever I'm looking at will fail in terms of the ground motion of the input ground
8 motion. So if I have .45 g acceleration, there's an 80percent chance that I'll lose
9 off-site power. It's at 100 percent chance and an 80 percent chance. Some of
10 these other, you know, diesel generator or piping, and this example of fragility, it
11 just shows you that we, you know, it's not for certain that you'll get some kind of
12 damage, but there's a likelihood you can get some damage. And you can merge
13 the information from the hazard with the information from the fragility to really
14 understand a lot about how your system will behave under different kinds of
15 earthquakes.

16 So in summary, I think that seismic hazard assessments are based
17 on a broad spectrum of geology and geophysical data. That's really the focus of
18 a lot of what we're going to talk about in this morning's sessions. The goal of
19 seismic hazard assessments has developed reliable estimates of ground motion,
20 especially the uncertainty. It's very important that we talk about uncertainty.

21 Seismic hazard assessments are really only part of the evaluation.
22 And combining the seismic hazards and the estimates of fragility can really lead
23 to better understanding the probability of something that important will either fail
24 or last during an earthquake. That's an important question.

25 I think the really fundamental question that drives us is what are we

1 willing to do in terms of risk, huh? I always loved this picture because this is a
2 friend of mine, Chuck Connor. We used to go camping a lot together when my
3 kids were much smaller than they are now. And one time I wasn't there, and
4 Chuck took them hiking. And he had gone to the top of this rock. And my
5 youngest son, Johnny, said, "Hey, Chuck, this is great. My dad would never let
6 me do this."

7 [laughter]

8 So I think at some point, you know, the most fundamental question
9 we have is what's our ability to absorb some level of risk? Thank you, very
10 much.

11 [applause]

12 MS. WILLIAMS: Go ahead? Good morning. My name is Megan
13 Williams. I'm a reactor inspector with the Nuclear Regulatory Commission at the
14 regional office in Texas. And this morning, I have the pleasure of introducing our
15 Session 1 speakers. First, we'll have Ralph Archuleta, is a professor, as well as
16 the chair of the Department of Earth Sciences at the University of California,
17 Santa Barbara. His research interests include the dynamics of earthquake
18 source and the ground motion it creates.

19 Doug Dreger is a professor of Geophysics in the Department of
20 Earth and Planetary Science at the University of California, Berkeley. His
21 research interests include seismic wave propagation and the development of
22 automated systems for the rapid dissemination of earthquake information.
23 And Robb Moss is an assistant professor at Cal Poly, San Luis Obispo. Areas of
24 expertise include geotechnical earthquake engineering, engineering seismology,
25 and risk and reliability with respect to earthquake engineering.

1 DR. ARCHULETA: Good morning. I'm going to introduce the topic
2 of plate tectonics and sort of discuss a little bit about just how we got where we
3 are today in California. And to give some idea, a small overview and introductory
4 overview in seismology and some of the terms that you will hear with regard to
5 earthquakes; you know the type of motion they cause. And also I want to talk a
6 little bit about the ground motion that comes from earthquakes, some of their
7 general properties, without going into specifics for any given earthquake.

8 So you know, when you look at the world, it wasn't always this way.
9 We all know that but we're looking at a much longer time period. So if you go
10 back even 225 million years -- that's a little bit old -- but, nonetheless, the earth
11 has been in motion basically since about three and a half billion years. It's about
12 four billion years old, and plates are in existence from about three and a half to
13 three billion years. So the face of the earth has always been changing. So what
14 we see today is something that has evolved over time and will continue to evolve.
15 And, in fact, it's this motion between the plates, in fact, that stores the energy that
16 gives us, you know, the rise to the earthquakes that we experience.

17 And so if you look at today's present configuration of the plates,
18 what you will see then is that, you know, we've named all these plates. But these
19 plates on the surface of the earth are always jostling and juggling and trying to
20 get by each other. And what we find is that basically as they try to do this and
21 different methods of doing it, this is the place where we find earthquakes. And so
22 if you look at the plates -- and they're not always moving in the same way.
23 They're not always in -- you know, it's not always balanced in the sense that,
24 okay, this one has 3 millimeters per year, so the other one has 3 millimeters. No,
25 different plates are moving at different rates. But averaged across the surface of

1 the earth, they're in balance. And so they keep moving. And what you find then,
2 not surprisingly, is that if you look at the seismicity of the world, you find that, you
3 know, a nearly perfect outline of the plates.

4 Now as we saw earlier, not all of the earthquakes occur at plate
5 boundaries; but by far, the vast majority do. And this is the place where at least
6 we can start to understand, in part, why we're getting the earthquakes and at
7 what rate we should expect to get earthquakes if we can understand how those
8 boundaries are changing over time.

9 So if you look at global seismicity, you know, this is over a ten-year
10 period, you look at the earthquakes around the world, you can see that they are -
11 - they're associated with the -- they're associated with the boundaries of the
12 plates. The recent earthquake over here in Chile that occurred at the end of
13 February, a large magnitude, magnitude 8.8 earthquake; but then, you know,
14 we've got earthquakes over here you can hardly find New Zealand, where the
15 most recent earthquake occurred.

16 On the other hand, even if you take a snapshot of the earthquakes
17 that are occurring in the world today -- this was taken on August 24th -- you find
18 basically the same picture. So whether or not you're looking at something over
19 long periods of time or of short periods of time, basically the activity is still going
20 to be confined near the plate boundaries. And so what we're looking at then is
21 the system of where we can understand, at least in part. And again, it's in part in
22 the sense that we understand it on average. You don't always understand it on
23 detail.

24 So the other aspect about these earthquakes when you compare
25 long-term average, short-term average, there's always been the question

1 whether or not because, you know, people say, “Wow, the earth --the number of
2 earthquakes is increasing.” In fact, the long-term average of the earthquakes
3 probably is not increasing at all. As far as we can tell, it’s not doing anything
4 except staying about the average because, again, the plates which are driving
5 the occurrence of the earthquakes, they’re basically in steady state. They’re
6 generating earthquakes, they’re in balance, they’re getting by each other. And
7 so over time, the number of large earthquakes, in fact, is staying just about
8 constant. It may be slightly changing over shorter periods of time, but we don’t
9 really -- we don’t really know why or if it really does happen.

10 But as you can see from here, when people start to worry about the
11 occurrence of earthquakes, and they really worry about it because what we see
12 are the casualties that are associated with earthquakes, what we’re really seeing
13 is the influence of the fact that the population is moving into the hazardous
14 zones. In other words, the population is growing in the world, and the population
15 are in these hazardous regions. Part of which is because some of the most
16 beautiful places in the world are, in fact, due to the active tectonics, as we saw in
17 the previous slide with the Tetons, or as we all know of because those of us who
18 live in California. But the thing about it is that this active tectonics, in fact, is what
19 leads to the beautiful topography, which, in fact, attracts people to live, and, of
20 course, you present people; now you put them into greater risk.

21 So if you look then, and we’ll first start to focus in now as we come
22 in towards California, you know we’re looking then at the plate motion. The big
23 plate motion for California is the relative motion between North America and the
24 Pacific Plate. Okay. And so you can see from this slide here that we’ve got the
25 motion then of the Pacific Plate is moving into the northwest, being subducted

1 beneath the Aleutian Arc. And of course, this is reflected in the seismicity in
2 California and in the Western United States. What you see is that, yes, there are
3 earthquakes in the eastern part of the United States. But the large and the
4 greater occurrence of earthquakes is occurring in the west. And that's because
5 of this relative motion between the Pacific Plate and the North American Plate.

6 Now up here to the Northwest, we have a different plate. We have
7 the Juan de Fuca Plate, which is being subducted beneath the Oregon and
8 Washington coastline. And actually, it goes from Cape Mendocino all the way to
9 Victoria, Canada.

10 But when we talk about the boundary, the major boundary, why we
11 always talk about the San Andreas Fault, and admittedly, this is the primary fault
12 in California. Okay, it takes up most of the motion between the Pacific Plate and
13 the North American Plate. So the North American Plate relative to the Pacific
14 Plate basically is trying to move at about something on the order of five
15 centimeters per year. It's roughly the length at which your fingernails grow each
16 year. Okay. So five centimeters, about two inches, okay, per year, the North
17 American Plate is trying to slide by the Pacific Plate. And the major part of that is
18 on the San Andreas Fault. But it's not the only fault that exists. In other words,
19 when you look at the boundary, what you'll see is that the faults in California
20 come about because of a past history. And before the San Andreas, we actually
21 were the boundary of a subduction zone, very much like what we have right now
22 at the Juan de Fuca Plate going under Oregon and Washington.

23 And so what we had was the Farallon Plate. We're going to start
24 this at a 40 million years before present. This is an animation due to Tanya
25 Atwater. And what we have then is that the Farallon Plate will go underneath

1 North America. You can see how squeezed up Nevada is, and California is
2 really squeezed in here. And you'll see that basically it's only about 25 million
3 years that we start to form the basis for the San Andreas, and then it really kicks
4 off at about six million years, which I'll come back to.

5 So the Farallon Plate is being subducted beneath North America.
6 And then what happens is right about here, we're starting to see the formation of
7 the San Andreas. It's starting to form. We start seeing motion of the Pacific
8 Plate relative to North America, and we see the extension as it's pulling out
9 across California. Okay. At about six million years, we had the opening of the
10 gulf.

11 This is showing a little bit more nicely in this animation also by
12 Tanya Atwater at UCSB, in which case, we're going to see, basically, how also in
13 Southern California what we have are the Transverse Ranges, how they rotate
14 into place and why they sort of go perpendicular to the direction of the Pacific
15 Plate.

16 So we have motion here at 16 million years, and, you know, the
17 time is changing up with the upper 12. Santa Barbara is rotating into here. We
18 have the Santa Maria Basin. We're going to start to form the large Los Angeles
19 Basin. And so what'll happen is that we have then the current condition or the
20 current orientation of the plates as we have the Pacific Plate relative to North
21 America. And we've got other boundaries in here as well.

22 Well, as a result of this, we now see in California seismicity that is
23 not only here on the --basically associated with what we would say is the
24 boundary, but you know, the San Andreas Fault; we also have very complicated
25 ground motion and earthquakes in Southern California and we have those that

1 go up on the eastern side of the Sierra Nevada.

2 But when you look at the San Andreas, the San Andreas is not
3 simply one fault. In other words, it really is the San Andreas Fault system. So
4 this is taken from, if you're looking in the Bay Area, for example, and you're
5 looking up here, you have the San Andreas Fault, okay. But you also have an
6 important fault relative to where we are today, the San Gregorio Fault, which is a
7 link to the Hosgri. But you also have in the Bay Area, you also have the Hayward
8 Fault and you've also got the Calavares Fault. In other words, you have a
9 system of faults. And this is, in fact, what we generally see when we look at the
10 boundaries and the breakup. It's not like it breaks on just single plain. You have,
11 in fact, many different faults that you have to account for. And each of these are
12 taking up some of that plate motion that we're looking for.

13 Well, looking at a California geological survey activity map, you
14 know, you look then and you say well, here's the San Andreas. But they're also
15 active faults that are offshore, there are some here in Nacimiento, there are
16 some that basically you find, you know, the White Wolf, and then you find those
17 down in Southern California associated with the Transverse Ranges.

18 Then what we have then in those Transverse Ranges because the
19 San Andreas is not perfectly aligned with the plate boundary and there is this -- I
20 forgot to point it out -- it makes this bend here as you get near Bakersfield and
21 comes through Gorman and then goes across the Mojave. And so what happens
22 then is that you end up then with a compression across this region. And when
23 you're compressing two things together, what you're going to do is that you pop
24 up the mountains. And that's exactly what's happened in Southern California.

25 When you look at Southern California, what you see here are the

1 Transverse Ranges. And so what you have then are the San Gabriel's, you have
2 the San Bernardino's, you have the Santa Inez Mountain range, you have the
3 Hollywood Hills. These are all basically being popped up by this compression as
4 we come across. And this is what's generating a different style of earthquake,
5 which are the thrust earthquakes like Northridge and 1971 San Fernando. So
6 we'll talk about this just briefly.

7 You know, in those earthquakes in San Fernando, Northridge,
8 they're what's called a reverse fault. And a reverse fault, what happens is that
9 you will find that one part, the hanging wall, moves up over the foot wall. Okay.
10 And so you get this upward motion where you -- what we call a thrust or reverse,
11 and the motion is reversed in the sense it's acting in the reverse sense of gravity.

12 A normal fault in which the motion of the block over here is going to
13 act in the direction of gravity, you would see as such. Okay. And the normal
14 fault is such that basically the motion of the hanging down. It's normal in the
15 sense it acts in the direction of gravity.

16 Now for strike-slip, it's slightly different because now what we're
17 going to have is the relative motion of two sides of the fault. This is what we
18 would expect on the San Andreas. And on a strike-slip fault, what you get is
19 motion that is basically tangential; it's parallel to the free surface, slipping one
20 against the other. In fact, this is very -- this is very much the motion that we have
21 in the recent New Zealand earthquake.

22 So what's happening over time? So over time what's happening is
23 that these two plates are trying to get by each other on these boundaries, which
24 we'll identify as faults. And what will happen is that over time what you're doing
25 is that you're going to slowly build up the stresses on either side of the fault. But

1 the fault is locked due to friction. But at some point it breaks. And when it
2 breaks, we have this earthquake. And at that time is when we release the
3 seismic energy.

4 So these forces, which are applied over time basically, are
5 occurring constantly, in other words, because of the relative motion of the plates.
6 And what will happen is that you keep the fault locked due to friction. At some
7 point, it cannot stand at friction anymore and it will simply break. And we have
8 then what is an earthquake and then we get then, one side moves relative to the
9 other side, and we get the slip in the earthquake.

10 So when you look at California, Southern California, you look at all
11 the earthquakes and you see all these dots, which everybody always plots in the
12 newspaper; and they really don't give a sense of what's really happening in these
13 earthquakes. Because what they're representing is the epicenter of the
14 earthquake. They're representing a point directly above the hypocenter, the
15 point where the earthquake first got started, but they're not really giving a sense
16 of the full length of the size of that earthquake.

17 For example, the 1857 Earthquake, you would put the epicenter
18 here, near Parkfield. But this rupture went about 350 kilometers, more than 200
19 miles. It didn't stop until it got to almost Interstate 15. Over that time, it's
20 rupturing about four and a half meters a slip, you know, somewhere on the order
21 of 15 feet, one side relative to the other. So these are the differences between
22 when you look at an epicenter and when you actually say what is the fault doing.
23 And we've had some big earthquakes in California. The 1906, the 1857, and
24 we're still waiting on a repeat of this one down here, 1680, which is long overdue.

25 So I wanted to say that what does an earthquake actually look like

1 if you were to look at one rupturing, okay? So these are snapshots in time, about
2 one second a piece, showing on the fault Plain how the rupture proceeded from
3 south to north, and you see it sort of moves up the fault. But a little movie sort of
4 shows better how what happened in this earthquake. It jumps all over the place.
5 Okay. It's moving very fast, greater than basically the speed of sound at about a
6 factor of 10, so it's going mach 10. And it moves up the fault as the rupture
7 proceeds. And all during that time, it's radiating elastic waves. So elastic waves
8 are not just coming from the focus, they're coming from every point on the fault
9 that slips. And when you do that, you generate these elastic waves. This is
10 what, in fact, we feel.

11 So my voice here is generating compressional waves, okay. So
12 these are like the P-waves that arrive first. Okay. Later on you get the S-waves.
13 Now the thing to take note about the S-waves, and that you should know this for
14 your own safety, if you feel an earthquake, you better hope that it's the S-wave,
15 because then it's not too bad. But if it's the P-wave, it's simply a wakeup call that
16 the next waves coming in are going to be a lot larger and a lot more severe. So
17 when they're coming in, these S-waves are almost always basically larger. And
18 then they're going to be followed by sort of the rolling motion that you get later on
19 back in here.

20 And so when we look at this, what we've got then are the P-waves
21 coming in. We're going to get this large shearing motion. And the shearing
22 motion is, in fact, is what we know to be the most damaging motion to most
23 structures. Because when you're compressing something, if you ever tried to
24 break a pencil, nobody ever tried to break the pencil by squeezing it between
25 their hands, okay. Not unless you want a hole in your hand. So what happens is

1 that you break it, but you shear it. And so the shearing motion that's occurring
2 during an earthquake, this is the type of thing that's coming in at the base of this
3 building, it's going horizontally, and, in fact, what you're doing then is bending,
4 you know, shaking the ground horizontally. You're not compressing it, you're
5 moving the ground. The building's got to respond, or the structure, and all kinds
6 of things go haywire. And, of course, the problem is, is that the closer you are to
7 an earthquake, the more damaging the earthquake.

8 So this is Parkfield when you get in close. And the thing here, this
9 is measured in time and seconds. So if you happened to be at this station right
10 here, okay, the acceleration comes in, you have basically about two seconds of
11 warning -- that's all. Imagine at 3:00 a.m. how much time -- what you could do in
12 two seconds. You know, barely blink your eyes. Okay, so what happens is that
13 right after that, though, when you're in close, you get the large amplitude ground
14 motion over here that you can see right in here. So you get very large amplitude
15 ground motion, and then it's over. Okay, this is a small earthquake, a magnitude
16 six, but the strong shaking lasts for something on the order of four seconds.

17 A larger earthquake in Japan -- this is the purpose of this slide is
18 not to tell you much more about this other than where the earthquake occurred --
19 but to point out that it's well recorded by many, many stations around Japan.
20 And what you see is, again, the small amplitude P-waves are coming in, and the
21 very large amplitude shear waves are coming in. The total duration in this case
22 is of strong ground motion is more on the order of about 10 seconds in some
23 cases, much shorter in other cases.

24 But again, the point I want to make here, though, is that as you
25 move farther away from the fault, as you move away from the hypocenter in this

1 case, you see this decay with distance. The amplitudes of the peak amplitudes
2 are decaying with distance. So the closer you are, the larger the amplitudes, the
3 stronger the shaking. This is generally what happens -- not always, but in
4 general.

5 And we saw this with Northridge as well. If you look at the intensity
6 as a function of distance, you basically see that the intensity -- the intensity of
7 shaking is decreasing as you get away. But out to about 20 kilometers, you
8 know, which is something on the order, you know, you multiply by .6, so you're
9 about 12 miles out or something like this, you are still going to get basically about
10 the same level of shaking. It's not like you say well, I moved a kilometer. You
11 know, if you're in ground zero, you're in ground zero, okay, out until you get
12 about the depth of the fault; you're going to have basically the same amplitude.

13 And so I want to conclude with just this final slide that's taken from
14 a combination. It's from the California Geological Survey, and it is, in fact, a
15 cooperation, of course, with the USGS and other agencies, but it shows the
16 shaking in California, the anticipated shaking based on the occurrence of
17 earthquakes, the expected size, and the like.

18 And what you find is that basically, yes, as you get close to the big
19 faults, like the San Andreas, you expect a higher intensity of shaking. There are
20 other places in Southern California you cannot always identify the -- I don't know
21 what happened there -- the amplitude here in Southern California is more diffuse
22 because, again, you've got faults almost everywhere in Southern California. And
23 here we are on the coastline, you know, there's not as much amplitude as you
24 see in other places, especially in Northern California.

25 And so when you're looking around and when you're understanding

1 earthquakes, understand basically that those plates have been moving for 100,
2 200, 3 billion years. They're going to continue to move, okay. We have to just
3 be prepared basically for the consequences. But it's not like we're going to stop
4 the engine that, in fact, is driving the earthquakes. And so with that, I'll stop.
5 Thanks.

6 [applause]

7 DR. DREGER: Let's go to Session 1. I used to be PC literate, but I
8 switched to a Mac recently. I'm really happy to be able to join you here today,
9 this morning, to share some of the work that we've done at the Berkeley
10 Seismological Laboratory in terms of real-time earthquake reporting. And I'd also
11 like to take the opportunity to describe some of the monitoring technologies that
12 we have.

13 So beginning about almost two decades ago, Berkeley expanded
14 its broadband network and started developing technologies for automatically
15 analyzing signals from earthquakes, and to determine the characteristics of
16 earthquakes and to report that information in as timely a manner as possible.

17 Recently, we've partnered with other institutions from the California
18 Integrated Seismic Network, in which different organizations are pooling their
19 resources to improve network coverage throughout the state and also to develop
20 software capabilities to improve our monitoring capabilities.

21 So most of the talk is going to basically take you through a timeline
22 that illustrates what we're able to do today. And I'd like to, I guess, provide a
23 foundation for this through examples for recent central coast earthquakes. But
24 before I move onto that, I'd just like to introduce this timeline. You're going to be
25 seeing it on several different slides.

1 This is a 10-minute timeline. Okay. So the earthquake starts at
2 zero. And there are different things that we need to do. We need to detect
3 earthquakes, we need to locate them, we need to calculate the magnitude. For
4 example, magnitude determination for this particular earthquake which occurred
5 near San Jose was about four, four and a half, to five minutes. There are things -
6 - I'll be describing shake map, which is a reporting of strong ground motions
7 through the earthquakes so that's available within five minute's time. We
8 compute things like moment tensors, which are updated, improved estimates of
9 magnitude. They can be thought of that way. We also look at finite source
10 models automatically. And the goal of all of this is to try to get as much
11 information about earthquakes as possible in as short a time as possible
12 because that might help affect the emergency response.

13 So the California Integrated Seismic Network, as I mentioned, is
14 basically a pooling of resources. The public agencies, California Geologic
15 Survey, the USGS, Cal EMA are participants. Cal Tech operates the broadband
16 strong motion that work in Southern California, and UC Berkeley is contributing
17 its broadband in strong motion stations in Northern California. So the plot on the
18 left is showing broadband and short period stations throughout the state.
19 Obviously, effort has been to concentrate the recording capabilities in the
20 urbanized areas of the San Francisco Bay Area and Southern California. Oops,
21 this is very sensitive.

22 On the right, is the strong motion instruments. And, you know,
23 clearly it's even more pooling of resources in the urban areas where there's great
24 concern. There's also improvements in recording capabilities in areas like the
25 Central Coast ranges in the last several years.

1 Red is showing stations that have communication, and blue are strong motion
2 stations that don't have communication. And the communication is really
3 important because that's the vehicle by which we get the information back to
4 processing centers where we can use the data to say something about the
5 strength of shaking, for example.

6 Faults are not only on shore. There are offshore faults as well.
7 This is really clear in the image here for the Monterey Bay, which shows offshore
8 faults. All the recording stations are on land. That really biases our recording
9 coverage. And so if we want to have a better understanding of earthquakes that
10 are occurring offshore, we need instruments located on islands, we need
11 instruments located on the sea floor. So Berkeley, in partnership with MBARI,
12 the Monterey Bay Aquarium Research Institute, deployed a broadband-
13 seismometer in one kilometer depth of water, and it successfully recorded
14 teleseisms, global earthquakes, and also local regional earthquakes. We're very
15 excited about this project.

16 I'm not going to go through all the nitty-gritty details here, but these
17 are some of the specifications of what a modern recording network must have.
18 It's broadband. Basically, what that means is that we're able today to record the
19 entire spectrum of the earthquake source process, the wave propagation
20 process. So it's a great improvement over earlier forms of instrumentation.

21 The other part of it is I've labeled here high dynamic range. But the
22 way to think about this is that it's actually digitally recorded out at the field. So
23 these recording instruments have sophisticated field computers at each site. And
24 these sites, it's like a sound card in your laptop, it digitizes the analogue signal
25 out at the site and it packages it in a way that allows for telemetry over a variety

1 of different technologies, including continuous telemetry over telephone,
2 microwave, radio and satellite networks. We use whatever technology we need
3 for the particular application.

4 And because earthquakes have damaging motions, there's a great
5 possibility that we would lose our AC power, and so all of our sites have
6 secondary sources of power. Some are solar and some are battery-powered
7 with a three-day capacity and onsite recording. So if we don't get the real-time
8 data, we can get it eventually if -- when the site comes back online.

9 So the challenge here is we have all of this seismic wave form data
10 streaming into our data center. We need to be able to identify an earthquake
11 from just background noise. The way that that's done is there's computer
12 algorithms that might scan a seismogram. Here's top seismogram, for example.
13 It's just looking at the characteristics of the amplitude and period over time,
14 maybe a moving average could be used, and so if that moving average, as the
15 data streaming in, is moving across the seismogram like this, it's actually
16 documenting what the noise level is, until finally there's some change that takes
17 place.

18 This is the arrival of a P-wave that Ralph Archuleta spoke about.
19 And that enables the first detection of an earthquake. If we have multiple
20 detections at many different stations, then there are algorithms that try to bring
21 these detections together into ways that basically tests the hypothesis that those
22 arrivals are due to an earthquake and not some telemetry glitch or some other
23 type of noise.

24 Given knowledge of earth velocity structure and P-wave and S-
25 wave times, we can use that to determine the distance. And so this is that same

1 diagram. And you can see clearly, these seismograms are aligned in absolute
2 time. So this record is occurring first. That means it's closest to the earthquake
3 source. And that station is located right here, Station C. Station E, for example,
4 is located here. And its P-wave arrival is occurring much later.

5 Well we can get these automatic P-picks ,and sometimes S-picks,
6 and we can use that to determine distance, and then we can plot the distance
7 around that station as a circle. So if we only had this record, the earthquake
8 occurred somewhere on this circle, if we're so lucky to have a station close to the
9 source. But if we only had data from Station F, for example, arriving at 18
10 seconds, then the earthquake can occur anywhere on that circle. But since we
11 have the overlapping of two circles, now there are two points where that
12 earthquake could occur. Add a third station, we triangulate into a point and we
13 can locate the earthquake. Add another station, we can start to improve our
14 locations.

15 The important thing to note here is that even -- suppose we're not
16 so lucky to have a station close into the source, even these more distant stations
17 carry enough information to locate the earthquake. So this is something that's
18 been done for -- since the beginning of observational seismology, but now it's
19 something that's automated and it's done in several seconds time.

20 The other important information, as Ralph mentioned, is the
21 amplitude of seismic waves, in particular, the amplitude of the S-waves, which
22 carries the damaging ground motions. And one way to characterize differences
23 in earthquake size is through earthquake magnitude. It's basically a measure of
24 relative size. It can be confusing. There are many different types of magnitudes
25 that can be based on shaking amplitude, duration, frequency, and wave type.

1 The one that's most common, everybody's likely heard of, is the
2 Richter magnitude. And Charles Richter developed this first magnitude scale
3 based on observations from a particular type of instrument, a Wood-Anderson
4 seismograph. This is a Magic Marker here for scale. And this is really a robust
5 instrument. It's the workhorse of seismology for many, many decades, only
6 recently being retired.

7 The way this works is that -- or the way Charles Richter developed
8 the magnitude scale is really in an ad hoc manner. What he said is okay, I have
9 a station located 10 -- 100 kilometers from this earthquake. And on this
10 particular type of instrument, the Wood-Anderson seismograph, it registered 1
11 millimeter amplitude. So that's what this line -- this blue line is showing. So this
12 is the distance curve. So the stations at 100 -- very sensitive -- 100 kilometers,
13 the amplitude is one millimeter. And then he just basically said I'm going to call
14 this a magnitude three earthquake.

15 Suppose we have that magnitude three earthquake now located a
16 distance of say seven kilometers. Well, what happens, you can see, is that the
17 amplitude would be much larger. It would be 20 times larger according to the
18 scale. So this is just another manifestation of the ground motion attenuation that
19 Ralph Archuleta mentioned.

20 Now, if we have that same 23 millimeter amplitude, which is
21 measured off the short period record here, we have the S-wave -- P -- S minus P
22 time of 24 seconds, we can plot that 24 seconds point here, corresponding to a
23 distance of 200 kilometers. The 23 millimeters amplitude on this instrument
24 indicates that it's a magnitude five. So that's how earthquake magnitude works.
25 The important point is that this is just a relative measure of size, and the actual

1 numerical value of magnitude doesn't really have very much meaning beyond
2 that.

3 [inaudible] down first motions. That information leads to a diagram,
4 which I'm not going to go into great detail. In fact, I'm not going to go into any
5 detail describing. But we affectionately call it the beach ball diagrams. And what
6 you can get here from this slide is that there are three main types of earthquakes.
7 There are strike-slip earthquakes, like those that occur on the San Andreas Fault,
8 there are normal earthquakes that might occur in the horst graben structures of
9 Nevada, reverse events like occurred in the 1994 Northridge earthquake. This
10 diagram is showing the different block motions of these three classes of
11 earthquakes. And these diagrams are just used by geologists and seismologists
12 to plot in map view to be able to quickly identify the type of fault motion. I'll show
13 you an image of why that this representation could be useful.

14 Well it's just two weeks ago, today, in fact, that there was a
15 magnitude 3.7 earthquake 20 kilometers north of San Simeon, and occurred on
16 August 25. And so this is a first-motion mechanism that the U.S. Geological
17 survey produced. And the pluses are showing up first-motions, the circles are
18 showing down first-motions. Not many observations in this quadrant. You can
19 see this quadrant's predominantly up. This one's up, that one's down, and so we
20 see that alternating pattern.

21 At Berkeley we utilize this continuous streaming wave form data.
22 We process it by low-pass filtering. We can fit these wave forms very well. The
23 computer-generated seismograms are the dotted traces in this diagram. The
24 observations are solid. We fit three orthogonal components of motion, and we're
25 mostly fitting surface waves, Love and Rayleigh waves. And by fitting these

1 types of data, we can get this beach ball diagram, which is showing
2 predominantly strike-slip faulting.

3 So the reason why this is useful is we can -- if we can do this
4 quickly, then we can say what kind of fault slipped in an earthquake. If we do this
5 over many years, then we can plot these beach ball diagrams in map view and
6 they start to reveal the underlying tectonics. We learn more about the fault
7 systems throughout California, surrounding areas.

8 Another very important data product that has been developed by
9 the US Geological survey is the Did You Feel It? map. And I have the webpage
10 at the base of this -- at this slide, so if you're not aware of it, I do encourage you
11 to surf over to this website and take a look at it. It basically provides the
12 opportunity for the public to contribute in earthquake monitoring by reporting what
13 an individual felt. I actually find it as a very useful tool as I'm responding to an
14 earthquake, because this map is updating minutes after the earthquake. I could
15 immediately see if many people felt the earthquake. I can an idea of the intensity
16 of ground shaking very quickly with this very important information that the public
17 provides.

18 If we have instruments located around the source, then we can use
19 those instruments to report ground motions, maybe accelerations or velocities, or
20 in this case, cast in terms of seismic intensity.

21 For this earthquake on August 25th, the ground motions were not
22 very severe, with a maximum of about Intensity 4 or so, which is potential
23 damage, none, light-perceived shaking. And this is just a map that's showing the
24 peak ground accelerations. And these are very low, maybe one percent g
25 maximum peak ground acceleration for this event, weak motion event.

1 So this is a cartoon that illustrates the automated processing timeline that we've
2 developed, and we're continuing to develop, through the CISN partnership. We
3 can determine a hypocenter and magnitude within 30 seconds to four minutes
4 depending on the type of method that's used. We use multiple methods. It takes
5 more time to get more robust solutions.

6 We can determine the seismic moment tensor now automatically
7 five to seven minutes. And if the earthquake's large enough, one important
8 question is which of these two possible planes actually slipped in the
9 earthquake? And so if it's above a magnitude five, we perform automated finite
10 source analysis to determine the orientation of that causative fault, and we
11 determine the slip distribution, and we try to use that information to make an
12 estimate of what the ground shaking is in the earthquake inside of a 30-minute
13 time frame.

14 Okay. So what I'd like to do is just illustrate this for, you know, what
15 transpired the day of the San Simeon earthquake, magnitude 6.5, located not too
16 far from here. On the right is showing the community internet intensity map, the
17 Did You Feel It? map for this earthquake. Intensity seven to eight over these
18 fairly large zip code regions. It seems that the intensities are asymmetrical, with
19 the largest intensity as being reported to the southeast, east, southeast of the
20 event.

21 Okay. So I'm going to go through very quickly a series of maps
22 here. This first map -- and each map is going to have a number at the bottom.
23 This is the elapsed time since the earthquake. This is the actual time. This map
24 is showing where the earthquake occurred. Now these are the recording stations
25 that were available at the time of the earthquake occurrence.

1 So 24 seconds after the earthquake occurred, the first 20 stations
2 registered P-wave detections, and a quick-look location was available. About
3 four and a half minutes later, there is an updated hypocentral location and a
4 duration magnitude of a 5.6 was determined. This was a 6.5, so the duration
5 magnitude is already saturating and underestimating in this event. Give a few
6 more seconds, 30 seconds or so, and the Richter magnitude was determined at
7 6.4 using more distance stations. You can see the location's not changing very
8 much. Just another 40 seconds after that, we have the moment tensor solution
9 that's indicating it's a moment magnitude 6.5 event, a reverse mechanism. Both
10 reverse and strike-slip earthquakes can occur in this area, and they have
11 different types of strong shaking patterns. So it's important to know this as
12 quickly as possible.

13 This is an image that it just shows the moment tensor solution, the
14 fit to the long period wave form data that's used. The first ShakeMap was
15 available at eight minutes after the earthquake. And I point out where Paso
16 Robles is here, if the arrow comes up again. There it is. It's this crossroads
17 here. And the ShakeMap prediction doesn't really have -- at the time there
18 weren't many recording stations in the area, so it's really an estimate of strong
19 shaking. And it's coming in low at about intensity five. So its potential damage is
20 very light, moderate perceived shaking. But there is actually some fairly
21 significant damage, a collapse of unreinforced masonry buildings, and some
22 damages to reinforced structures. The level of damage shown in this -- these
23 images is greater than what the initial ShakeMap would lead us to believe.

24 The ShakeMap was updated 22 minutes later. They're
25 automatically updated on a -- I guess on a schedule, and they incorporate all of

1 the newest data each time the update is done. So this one, the moment
2 magnitude 6.5 is available. It doesn't really change things very much. Well, we
3 didn't have the finite source method automated at this time, so it took about two
4 and a half hours after the earth -- within two and a half hours after the
5 earthquake. We were able to determine the finite extent of the rupture. This is
6 analogous to the movie that Ralph Archuleta showed. The earthquake
7 hypocenter is located here at zero. He showed that movie of this very
8 complicated rupture running down the fault. This is a static image that just shows
9 that slip extended about 22 kilometers away from the hypocenter, and it
10 extended 22 kilometers in the direction towards Paso Robles. So it ruptured at
11 mach 10 directly towards Paso Robles.

12 If we incorporate this information in the ShakeMap, then the effect
13 is that the intensities are increased in Paso Robles to Intensity seven to eight,
14 and those levels of motion are more consistent with the types of damage and
15 shaking that was observed or felt there.

16 Okay. So the last topic that I'm going to discuss is development by
17 Professor Richard Allen in our department in developing earthquake early
18 warning systems. The current effort is to develop a test system. This is being
19 done in partnership with PG&E and BART and other organizations. Basically,
20 what it works on is it triggers on a P-wave. I'm not going to go through the details
21 of all of these plots, but it determines the characteristic of the P-wave, notably the
22 period. Okay, so the longer the period of the P-wave, the bigger the earthquake
23 is how it works.

24 And so -- and this is a four-second time frame. So Richard tries to
25 do this analysis within four seconds. Each second, he updates the map. So at

1 the trigger time, there is no information. After one second, there's the beginning
2 of a ShakeMap. Two seconds, there's more information. Three seconds, if you
3 have a nearby station, you might even be getting S-wave information that helps
4 improve the ShakeMap. So this a -- or he calls it "AlertMaps."

5 This is a timeline that shows when the P-wave reaches -- first
6 reaches the seismometers. This is the first ElarmS detection for the Alum Rock
7 earthquake several years ago. One second later, AlertMap, two seconds, and
8 the three-second AlertMap. So 20 seconds after the earthquake. This is the
9 time when the damaging or the strong shaking S-waves reached Oakland and
10 San Francisco. This earthquake was located near San Jose. So there is a 15-
11 second telemetry delay built into this test system.

12 There's -- recently there's been updates to the monitoring
13 technologies that are available. In fact, we're updating our data loggers that
14 enable telemetry every two seconds, say several seconds' data transmission
15 latency. And so that reduces the telemetry delayed to maybe five seconds or
16 so. You get these three AlertMaps within 10 seconds. And for an earthquake
17 located in San Jose, that means you can have upwards of 10 seconds of early
18 warning before the arrival of the S-waves at Oakland and San Francisco.

19 So this is a system that is being developed and tested against
20 available data and improved, and it may, in the future, be and lead to an early-
21 warning system in California. But that's really an area of current research.
22 Okay, so to wrap up, each earthquake provides new experiences that we use to
23 improve the realtime monitoring and reporting system. In 2003, as I showed for
24 the San Simeon earthquake, the detection through finite source took two hours
25 and 38 minutes. For the 2007 Alum Rock earthquake, that whole process took

1 less than 10 seconds -- 10 minutes. I wish it was 10 seconds -- took 10 minutes.
2 And so that's a great improvement. And if we're able to do this routinely on a 10-
3 minute time basis, then we can provide information that could be very useful to
4 emergency responders dealing with an earthquake emergency. Thank you.

5 [applause]

6 DR. MOSS: Okay. Good morning. I'm going to be taking this
7 discussion towards the near surface and talk about how earthquakes can impact
8 the foundation soils and structures. And there is really not a lot of rock left to
9 build on, and so most of our structures are founded on soils. And so one of the
10 primary concerns in earthquakes is how soils respond and how that foundation
11 soil is going to react with the structure.

12 So I have a simple cartoon here showing a very simplistic
13 earthquake at depth and the ground motion's propagating up to the surface. And
14 what I want to focus on is this near surface area. And we get into the near
15 surface, and again, as was mentioned before, we're primarily talking about the
16 shear waves that are the issue. So as we get not the near surface, we have to
17 deal with different geologic layering, soil stratigraphy, topography, and other
18 effects. And my talk is divided up into site effects, soil failure, fault rupture, and
19 then I'm going to talk generically about structural response and infrastructure.

20 Now, these shear waves that are propagating to the surface are of
21 primary concern because most structures, they're built to resist gravity, but
22 they're not built to resist lateral forces. And that's why we see most of the
23 structures fail in earthquakes due to these lateral forces.

24 With site effects, we can group it into really three broad categories:
25 Near surface soil response, topographic effects, and basin and basin edge

1 effects. So how does the topography, any geologic structure, and the dynamics
2 of the soil interaction with the ground motion? And these can result in changes in
3 the amplitude of the ground motion.

4 And here, I'm showing a recording that was made after the 6.5 San
5 Simeon earthquake in 2003 right here in San Luis Obispo. And so these site
6 effects can result in changes in the amplitude. And what we're concerned about
7 is amplification, or increasing of the amplitude, can alter the duration of the
8 ground motion. So maybe we could have more significant cycles and can also
9 change the frequency content.

10 Here's kind of a busy plot that I want to break down. But the study
11 just came out. And it's looking at site effects from the 2003 San Simeon
12 earthquake. And what I've boxed in there on the top plot is the high ground
13 shaking -- high ground shaking intensity. So we're looking at measuring the
14 earthquake in terms of peak ground acceleration, usually in terms of gs. And so
15 we're looking at 30percent g or greater.

16 And what this study did is it looked at single-family homes. And we
17 can see that on the left, the primarily the damage rate for hilltops was greater
18 than it was for slopes. And this is what we would call a topographic effect. The
19 ground motions come up, and for hilltops, they can get channeled into that hilltop,
20 and so we see much stronger ground shaking at the top of the hill than we would
21 see down at the bottom of the hill.

22 The bottom plot shows how the particular geology in the soil
23 derived from those rocks can affect the ground shaking. And we've got three
24 different rock types that have weathered into different soils, and you can see that
25 they resulted in dramatically different damage rates, again for single-family

1 homes. So site effects is something that we need to be concerned about -- how
2 does the near surface geology, topography, and other features change the
3 ground motions as they get to the ground surface?

4 I want to move into soil failure here. And one of the primary
5 concerns when we talk about soil failure and earthquakes is liquefaction. This
6 cartoon shows if I take a cup of dry sand, dry loose sand, and I shake it, it will get
7 denser. Now, if I take that same cup of sand, but it's saturated, and I shake it
8 really fast, what happens is that the water doesn't have time to get out of those
9 pore spaces. It pushes out on these sand grains, making the sand grains
10 essentially buoyant. It's counter-acting the gravity forces, pulling down the sand
11 grains, and the soil becomes fluidized.

12 And what we see in the picture on the left is that when a soil is
13 fluidized, what used to be solid now tends to flow. And if we have stuff pushing
14 down on it, like here we have some soil pushing down on it from the top, well it
15 wants to get out of the way. It wants to relieve that stress, and it will come out in
16 what we call sand blows, or volcancitos, or sand boils. This is what we call
17 surface manifestation of liquefaction.

18 Now, if we have a structure sitting on there and the structure's
19 relying on the soil to support it, and the soil now liquefies, then we have a big
20 structural problem. Here is some surface manifestation from liquefaction from
21 the San Simeon earthquake, showing both the Salinas River, up near Paso
22 Robles, and Santa Maria River, further south. And what happens when you have
23 a structure sitting on it, well, it tends to tear the structure apart. This was in
24 Oceano. In the bottom left picture, the soil liquefied and then started to flow
25 downhill, creep downhill, and it essentially tore that single-family home apart.

1 And the picture on the right shows the ground pushing out on the curb.

2 So these are some fairly contained examples of liquefaction from a
3 local earthquake. An earthquake that I visited this spring, the Chilean
4 earthquake, much larger earthquake, much stronger ground shaking, longer
5 duration. We see more exacerbated liquefaction effects. The lower left, you can
6 see evidence of lateral spreading over that entire site. In the upper right is when
7 we bury things in liquefiable soil and it liquefies, if it's less dense than that
8 liquefied soil, then it becomes buoyant. And we see this with pipelines, we see
9 this with tanks. Anything that's less dense than the liquefied soil pops out of the
10 ground.

11 Another type of soil failure is seismic induced landslides. And here
12 I have a cartoon showing a slope, and there's some mass that could potentially
13 slide. And the earthquake kind of affected it in a couple of ways. One is, it
14 provides a big kick, a lateral kick to it, and that can destabilize the slide mass.
15 And the ground shaking can also result in strength the loss at the base of that
16 slide mass. And the primary variables that we're dealing with is the resonance --
17 do we see the slide mass resonating with the particular frequency content of the
18 ground motion, and how many cycles of that earthquake are going to kick the
19 slide mass?

20 What does that look like? San Simeon, it was fairly contained.
21 Again, that was a 6.5 earthquake, some good peak ground acceleration, but not
22 a lot of duration. On the right, you see surficial sliding. And not really an
23 engineering issue, you just scrape the dirt off the road and you keep going. On
24 the lower left, a larger existing slide that reactivated. Lower left larger, deep-
25 seated slide. You can see the ground cracking there in the foreground. And out

1 on the coast, we see destabilized coastal bluffs due to the ground shaking there.

2 Again, bigger earthquakes, more effects. This was Chile this
3 spring. A large land mass that moved -- no strength lost here, just the kick from
4 the ground motion destabilizing that slide mass. What other near surface effects
5 do we see from earthquakes? Well, we can see fault rupture propagating to the
6 ground surface we call the "surface fault rupture." And I don't need to go through
7 the different types of faults. We've been through that before. But the length of
8 surface fault rupture is strongly correlated with the magnitude of the earthquake.
9 And that's what that busy plot on the lower left shows. Surface rupture length
10 versus moment magnitude.

11 So again, an earthquake is a rupture at depth in some seismogenic
12 rock and does that displacement propagating to the surface. [inaudible] frozen
13 turf and the fault ruptured right here and essentially toward [unintelligible]. The
14 same response we see with structures. It was a rupture to a structure that is not
15 properly enforced did a lot of damage, essentially tears it apart. Okay. Let's get
16 to talking about generic structural response and infrastructure relating to
17 earthquakes.

18 You've seen this picture before. San Simeon, we had this awful
19 occurrence where the Acorn building collapsed and [unintelligible]. And if some
20 of you have been following in the press, there's been a lot of litigation, and it's
21 really effecting how building owners deal with retrofits. This was primarily the
22 only structure that failed, and it was an unreinforced masonry structure, which
23 meant that it was either brick or masonry that was stacked up, resisting gravity
24 forces, but not shear forces, and it collapsed.

25 I want to juxtapose this with an earthquake that occurred essentially

1 three days later in Iran. The entire city was built out of unreinforced masonry.
2 It's a very old city. And you can see it looks like a bomb hit the place. San
3 Simeon, two people died in unreinforced masonry collapse. Here, we're talking
4 about tens of thousands of people that died in unreinforced masonry collapse.
5 I'm not showing this to be catastrophic, I'm showing this to make a point that why
6 didn't we have more deaths in San Simeon?

7 The mechanisms are a little bit different. The magnitudes are about
8 the same. The ground shaking in Iran was a little bit stronger. The fault actually
9 ruptured right through the town. But the primary difference is that we have
10 seismic codes here; and there's no seismic codes there. And we can talk about
11 the same effect with the Chilean earthquake and the Haiti earthquake.

12 The Chilean earthquake, much larger, longer duration, stronger
13 amplitude ground motions. Haiti, hundreds of thousands of people died. Chile,
14 we're talking about hundreds of people died, and that was primarily due to the
15 Tsunami. So seismic codes work. If we design structures to resist these lateral
16 forces, it shows that it works. We save lives. Here we show some structural
17 failure in Chile. And again, unreinforced masonry. Typical residential adobe
18 construction on the left, older, poorly reinforced construction on the right.

19 And this picture -- these pictures are particularly interesting. The
20 single-family home there is a modern home. It was probably designed well. And
21 let me preface this a bit by saying that Chile has very good seismic codes
22 equivalent to our seismic codes in California. So this home was probably
23 designed adequately for ground shaking but not for the liquefaction and lateral
24 spreading that it experienced there. That's very hard to design against.

25 However, the apartment complex that's below it was on the same

1 lateral spread and performed very well. So it had a very beefy mat foundation.
2 It went for a ride, but it survived. I mean, it's essentially -- the people could move
3 right back in. The problem is that a lot of damage surrounding the structure, and
4 you can see the sidewalks are collapsed and the fences fell down. They might
5 have a little trouble opening the doors.

6 The picture on the lower left is a very interesting picture. You can
7 see the building that fell down there. That was recently completed. And then
8 there's the building on the upper left of that picture that's almost completed.
9 Now, they had essentially the exact same ground motions, they have the exact
10 same foundation conditions, and the only difference here is that the one on the
11 lower right somehow did not follow the seismic codes as carefully as they should
12 have. This building is now in a lot of litigation. When we flew over, you can see
13 the cranes are tearing it apart. The next day, the cranes were halted because
14 they were doing some forensic analysis on it. But basically, there was something
15 that went on where the codes were not followed and that building fell down. And
16 the bigger building up behind it, and it's almost finished, no damage. So, again,
17 seismic codes work.

18 Let's talk about infrastructure because this is one of my primary
19 interests and it has a wide region effect in terms of earthquakes. The bridge you
20 see in the upper picture, that should look -- the type of damage that look familiar
21 to you from people that saw the '89 earthquake and the Bay Bridge dropping one
22 of its decks. Same type of issue here, that this bridge deck was not designed to
23 handle those types of ground motions. The Chilean government knew that. This
24 bridge was closed to traffic, and rightly so. It performed poorly. It dropped the
25 bridge deck.

1 The pictures along the bottom of this slide show liquefaction. And
2 particularly, the middle picture here, the ground liquefied and then flowed this
3 direction and then sheared this column. And you can see that this older bridge
4 sustained a significant amount of damage. Here, our colleague's standing in one
5 of these sand boils where there was some liquefaction and ground loss.

6 This was an older bridge, was not designed very well, and the
7 ground deformations due to liquefaction hammered it pretty good. Here was a
8 bridge that was built in 2008. A very rigorous seismic codes. The bridge
9 performed very well, even though you can see essentially the same effect --
10 liquefaction, lateral spreading, ground pushing on the foundation of the bridge.
11 The bridge did well. The bridge was perfectly fine after the earthquake. They
12 had to deal with the abutment a little bit. There was some abutment deformation,
13 but no reconstruction needed on this bridge.

14 Here we have a soil failure along, essentially, the main highway in
15 Chile, the Pan-American Highway. And most of the failures that we saw were in
16 engineered fills, soils that had been compacted to support something, and there
17 were some issues with either the soil underneath the compacted fill or that the fill
18 settled. Here, we see large failures. Again, same type of stuff we saw in the
19 Northridge earthquake, lots of fill settlement. We saw that in the San Simeon
20 earthquake on the highway that goes from Paso Robles to Cambria. Lots of
21 compacted earth fill did not perform very well. It's not catastrophic failure, but it
22 costs a lot to go back and fix this. On the Pan-American Highway, every 10
23 kilometers, there was some type of ground failure like this.

24 Port facilities tend to take the brunt of earthquakes. In the '89
25 earthquake, Loma Prieta, Port of Oakland, Port of San Francisco, they got hit

1 really hard. We were talking about poor soils -- we're talking about saturated,
2 soft, weak soils -- amplified ground motions liquefy fail. And so here you can see
3 evidence of that. Lots of ground damage, lots of damage to the piers and wharfs
4 and the supporting foundations.

5 What other types of impacts do we see from earthquakes? This
6 was an interesting one from the San Simeon earthquake is that Paso Robles
7 used to be known, the turn of the last century, known for its warm springs. And
8 essentially that fell out of favor and they capped a lot of these or diverted them.
9 Well, they came back with a vengeance. The picture on the right shows city hall,
10 and that's the parking lot of the city hall. And it used to be -- they used to have a
11 bathhouse there. And this warm spring decided to re-emerge and essentially
12 eroded out a huge hole, and they were throwing everything they had in there to
13 plug the hole. And the lower left picture shows a new spring that came out of
14 the, ironically, Spring Street exit in Paso Robles. [laughter] Coming right out of
15 the embankment there. As an engineering issue, not a problem. Kind of a pain
16 in the neck to deal with.

17 Again, other impacts, larger earthquakes, bigger stuff. The lower
18 left shows what tsunami damage looks like. And, essentially, there used to be a
19 town there, and the town's gone. Tsunami damages -- dealing with tsunamis is
20 at the forefront of our engineering issues right now. It's a very big problem.

21 In the upper right, why are all those ships sitting on dry ground?
22 Well, it used to be a port there, the town of Lebu. And the ground that that
23 person is standing on used to be one to two meters below what it is now. That's
24 wholesale tectonic shift. And so we had within the time frame that the
25 earthquake occurred, that entire section of the crust rose up one to two meters,

1 essentially, leaving the port facility high and dry.

2 So just to briefly summarize what I've run through. I'm talking
3 about impacts of earthquakes on soils and structures. The hazards that we're
4 dealing with -- ground shaking, soil failure, fault rupture, and structural failure.
5 And I've been very broad with structural failure and just talking about hey, lateral
6 forces we need to design for.

7 I think there's no argument about that seismic design codes work
8 well. And that's why we have performance issues here in -- or in developed
9 countries, we have performance issues. Well, we've got to deal with the
10 highways, and we have to deal with, you know, minor issues, and people
11 avoiding the code. In developing countries, we need to get the codes in place.

12 There is a lot of infrastructure issues that remain. Highways I
13 showed, bridges, whatnot, but some of the other peripheral issues -- power
14 continuity, water transmission, telecommunication. A lot of the hazard planners
15 talk about being on your own for 72 hours, and that was true in Chile. Even the
16 big city of Santiago that was far away from the epicenter, they were without
17 electricity for a couple of days, without water for a couple of days, and
18 telecommunication took about a week to get back online.

19 And critical -- the critical path forward is mitigating these hazards
20 and then having a proper emergency response. So that's all I have for you
21 today.

22 [applause]

23 MR. MAIER: If you notice the waves traveling across the screens
24 and how could you not --

25 [laughter]

1 -- I apologize to the presenters and to you for their existence.
2 We're going to see what we can do to try to get those -- get rid of those during
3 the break.

4 This brings us to the first question and answer session. And I'd like
5 to go over a little bit of the protocol or ground rules for conducting questions and
6 answers. We finished up each session with a 15 minute question and answer
7 session. As you heard me mention earlier, the entire proceedings are being
8 videotaped by AGP for inclusion on the NRC's website. For that reason, once
9 again, we ask that only one person speak at a time and wait for Butch or I to
10 come around and hold the microphone for you while you speak. I hope you won't
11 be insulted if we hold the microphone. That's the first -- that's the -- that's the
12 prime directive of facilitating, right, Butch? You never surrender the mic.

13 Okay. We ask you to raise your hand, and Butch and I will
14 alternate between opposite sides of the room. I invite you to stand and identify
15 yourself if you want to. Direct the question to whichever panel member you want
16 to direct it to. Please bear in mind that we -- in the interest of brevity, we would
17 like folks to kind of keep their questions as focused as possible so that the
18 maximum number of people who have questions can be included in the question-
19 answer session. And I'd also like to ask the answerers to try to keep your
20 answers as focused as possible, also in the interest of time.

21 If you don't have an opportunity to get your question asked during
22 the question-answer session, Butch and I have 3x5 cards that we'll carry around.
23 And if you've picked up any on the way in, there's some outside, I believe. Write
24 your question down on the card, put some contact information for yourself on it,
25 either an e-mail address or telephone, and please write legibly. And if we don't

1 get a chance to your questions, then if you hand that question back to Butch or to
2 me, we'll make sure that an answer gets back to you in some fashion.

3 Also, we would ask that you -- we only have the folks who just
4 presented up here, so we would ask you to focus your questions on the topics
5 that these gentlemen just presented. If you have a topic on another issue that's
6 not related to what they just presented on, we ask you to look at your agenda,
7 figure out which session would be the best one to ask that question in, and then
8 hold your question for that session. Tomorrow will be all day Diablo, so what
9 we're looking at today is the basics of the sciences.

10 If you won't be at a session that you think that your question should
11 be asked in, put it on a card, get it to Butch or to me, and we'll make sure that an
12 answer comes back to you somehow. Anything I forgot to mention, Butch?

13 MR. BURTON: No, I think you covered it.

14 MR. MAIER: Okay. And if anybody has any questions, please raise
15 your hand.

16 MR. WARDELL: Ferman Wardell, Diablo Canyon Independent
17 Safety Committee. My question's directed to Dr. Dreger of Berkeley. And on the
18 handouts, I don't think you showed this slide, but it's the -- looks like the last one.
19 It says if a San Simeon earthquake was a strike-slip, the extent of damaging
20 ground motions would have been larger. And I guess my question's twofold, is
21 one, how well can we characterize the faults as to where they're strike-slip or
22 what else? And in general, how much larger could it be or could -- in this
23 particular earthquake if it were strike-slip as opposed to what we characterize it
24 as?

25 DR. DREGER: To answer the first question, we can characterize

1 the type of faulting very well. There's many different techniques that we employ
2 to get that information. In regards to the second question, what that slide
3 addresses is if you take the model that was determined for the actual San
4 Simeon earthquake and change it from a dipping fault to a vertical fault, and
5 changing it from one where it's a reverse fault where the hanging block moves --
6 is thrust up over the footwall block to one where the motion is side-by-side, all
7 other parameters being identical, the area of strong shaking is larger. It's about
8 three times larger. In this model, and it's important for me to state that this is a
9 model, the peak ground motion is about the same. It's just that the area of
10 elevated motions is larger.

11 MR. MAIER: Other questions?

12 MR. BARD: My name is Geof Bard, Upland Research Science
13 Action. My question is directed to Dr. Moss regarding the phenomenon of soil
14 liquefaction. I would appreciate it if you could please expand a bit and tell us
15 about the variables, topographic and soil composition variables, hilltop versus
16 slope, the effect of pitch, and also the depth of the aquifer or proximity to bodies
17 of waters, such as creeks, and streams, and lakes in the ocean. And also, how
18 well-mapped is all of that type of data?

19 DR. MOSS: Liquefaction is a phenomena of loose granular soils
20 that are saturated. So any time you have a -- is this working okay? Yeah?
21 Okay. Any time you have a loose granular soil to it, a sand that's saturated, so
22 below the water table, and you apply strong enough ground shaking, then you
23 could have liquefaction.

24 Now, you mention a number of other things that aren't necessarily
25 related to liquefaction. Usually, we find these loose sandy soils in some type of

1 river deposit or some type of beach deposit. And are they mapped well? The
2 CGS provides liquefaction hazard maps, but the coverage is usually restricted to
3 the areas that have been studied. The state does require a liquefaction analysis
4 for every, essentially, every development. Does that answer your question?

5 MR. MAIER: Other questions?

6 MS. COCHRAN: June Cochran, Shell Beach. The Japanese plant
7 shut down -- and this is to mainly Professor Moss -- the Japanese plant shut
8 down by an earthquake in 2007 was to designed to withstand short, intense
9 tremors. The builders had studied and designed the plant based on these
10 studies, not the broad, horizontal swaying that occurred with the 2007
11 earthquake. This caused water to slosh out of storage pools, with around 1200
12 liters, contaminated with radioactive material reaching the Sea of Japan. At least
13 63 other problems were reported, including burst pipes, water leaks, and
14 radioactive waste spillage.

15 In five of the reactors, major exhaust pipes were knocked out of the
16 place, as Professor Moss demonstrated in pictures from Chile. About 100 drums
17 containing radioactive water fell over. I'm almost done. Some of them were
18 found with their lids open, cobalt and chromium 51 leaked into the atmosphere.
19 Given that the Japanese regulators were incorrect in their calculations about
20 earthquake movement and the design of the plant, can the NRC rely totally on
21 the seismic studies being performed for Diablo to be totally accurate, especially
22 when there are strike-slip movements in California?

23 DR. MOSS: Wow --

24 [laughter]

25 -- I don't have any specific knowledge about the shutdown of that

1 plant in Japan. What I presented was a generic description of the hazards that
2 we're dealing with. Now, there has been a lot of study of that plant, and we can
3 dig that up, but that's not my background is how earthquakes have affected
4 particular power plants and why they've been shut down.

5 Now, generically, we do a very good job with seismic codes and
6 seismic containment. Now, are we learning? Yeah, we're always learning.
7 Every earthquake provides us with new information. Can we deal with every
8 contingency? Well, we can do our best, but it doesn't necessarily have to do with
9 nuclear power plants, it has to do with anything -- highways, tall buildings, sewer
10 systems. And so we're always improving the seismic design.

11 MR. CANIANO: And I think in Session 4 later this afternoon, that
12 session is titled "Nuclear Power Plants and Seismic Hazard." Maybe you might
13 want to ask one of those folks.

14 MR. MAIER: Other questions? Anybody from Butch's side of the
15 room?

16 MR. BURTON: Yeah, my side's kind of quiet.

17 [laughter]

18 Ah, we got one.

19 MS. HUNT: My name is Gail Hunt, and I would like to have you
20 review just one more time how you determine moment magnitude.

21 DR. DREGER: There are actually many ways to do it. But the way
22 that we do it is we process the data in a way that highlights the long periods.
23 And as earthquakes get larger, they radiate more and more energy at longer
24 periods. And the precise way that we actually determine moment magnitude at
25 Berkeley, is to fit three component long-period seismograms with computer-

1 generated seismograms that were computed for a specific velocity structure
2 that's appropriate for the region. So it's a model fit.

3 You can kind of liken it to if you have a distribution of points and
4 you fit a straight line through those points. You know, maybe you just take a
5 ruler and fit a straight line through those points. We're doing the same thing,
6 except instead of a straight line, we have these wiggly lines, which are the
7 seismograms, the computer-generated seismograms.

8 DR. MOSS: Doug, can I add one thing to that? If we have a good
9 measure of default area and how much displacement occurred on that fault area,
10 that's directly proportional to the moment magnitude. So if we have, if we can --
11 and what Doug's talking about is defining that fault area. And that's not easy.
12 Defining the fault area and then how much displacement occurred on that fault
13 area at depth, and that's directly proportional to the moment magnitude. So it's a
14 measure of, essentially, the moment, the moment alarm that occurred at depth
15 and how much energy that took.

16 MR. MAIER: Okay. We have another question here.

17 MS. EVERED: I'm Judith Evered from Goleta, Santa Barbara
18 County. And I'd like to ask a question of Mr. Doug Dreger. It's the relationship
19 between the P and the S waves. For instance, I felt the Northridge earthquake in
20 Santa Barbara. And I immediately identified it as an S-wave; it was a waiving
21 kind of motion --and I thought -- it's not close and it's fairly distance. Is it north or
22 south? I always think that when I feel an earthquake in Santa Barbara. And it
23 turned out, when I phoned LA, no answer. I phoned San Diego, oh, yes, it
24 happened in LA. But now you've mentioned that a P wave turns into an S wave,
25 and I'm wondering if I didn't just feel the P wave that night or whether S waves

1 can be by themselves. And usually I thought they were the end of an earthquake
2 effect, the farthest from the epicenter, for instance.

3 DR. DREGER: Well, they're P and S waves, and there are actually
4 many other waves. So for that swaying motion, you might have actually felt a
5 surface wave. That's a possibility. And those arrive after the S waves.
6 Sometimes you'll only feel the S wave, but that would be for small earthquakes
7 because the P wave -- the P waves are much lower amplitude, so they're not
8 perceived. A large earthquake like Northridge -- how far is Goleta from
9 Northridge? A hundred miles? So you may have felt the P wave in that event.
10 I felt the Landers earthquake when I was in Pasadena. That was 100 and --
11 about 100 miles away, and I felt the P wave, and responded to that and got in the
12 door jamb before the S wave arrived. You're not supposed to do that now, but
13 that's that's what I did back then. One thing that you can do next time if you feel
14 a P wave, just start counting off, you know, 1/1000, 2/1000, until you feel the
15 larger amplitude waves. And if you multiply that number, that number of seconds
16 by eight -- I call it the "rule of eights," then you can get the distance of the
17 earthquake.

18 MS. WILLIAMS: Can you take one more, Bill?

19 MR. MAIER: Anyone from the other side? Nope? I got another
20 question here. I guess I'm going to get most of the exercise during this
21 workshop, I think.

22 FEMALE SPEAKER: This is not a question. This is a statement to
23 the NRC staff.

24 MR. MAIER: We really wanted to make sure that it was questions
25 for the folks who were here. Maybe you could hold it for a better session if it's a

1 better session tomorrow?

2 FEMALE SPEAKER: Unfortunately, the reason I'm -- I want to
3 make this statement today is because tomorrow is Rosh Hashanah, a Jewish
4 New Year, and I won't be able to be here, as will many of the people who would
5 like to be here tomorrow. And that's the reason for my statement because the
6 NRC staff chose today, September 8, and tomorrow, September 9, the eve of
7 Rosh Hashanah and Rosh Hashanah day, the beginning of the holiest time of the
8 year for the Jewish people to hold these workshops in San Luis Obispo. To me,
9 it indicates a gross insensitivity, to say the least, and a lack of planning. And I'm
10 just wondering how well we can trust the staff of the NRC to reassure us about
11 the safety of an -- of a nuclear power plant with 2,000 metric tons of highly
12 radioactive waste stored 11 miles from here if they can't even plan to make these
13 meetings on a date when people can attend? Thank you.

14 MR. MAIER: Thank you for your statement. Questions from the
15 other side?

16 FEMALE SPEAKER: [unintelligible]

17 MR. BURTON: We're running a little late, but we can take a little bit
18 out of the break, I think. This lady over here. Stand?

19 FEMALE SPEAKER: I'm wondering if individual faults have
20 characteristic geometry or if any -- am I in it? Do individual faults have
21 characteristic geometry or is any type of movement possible on any fault?

22 MR. MAIER: Is that direct to any panel member in particular?

23 FEMALE SPEAKER: Dr. Dreger.

24 DR. DREGER: You can answer this question with different layers.
25 I would say that, you know, for the most part, a fault, once it's identified as being

1 reverse or normal or strike-slip, that's the predominant sense of motion. When
2 we look at earthquake ruptures in detail, we can see some deviation from that.
3 Sometimes there are earthquakes that have compound ruptures. The Denali
4 earthquake in Alaska was one that started as a reverse event and then ended up
5 as a big strike-slip earthquake.

6 FEMALE SPEAKER: Thank you.

7 MR. CANIANO: Megan, if it's all right, let's do one more. I see
8 these two young ladies here who have raised their hand several times. And if
9 anyone else isn't able to get their question in, again, we have index cards. You
10 can leave your question and your contact information on the card and we'll make
11 sure we get back to you. Hi Jane.

12 MS. SWANSON: Hi, my name is Jane Swanson. I have a two-part
13 question about those S waves, and I think you'll know who wants to answer.
14 One is very simple. The "S," I think that stands for the word "shear"? I'd like that
15 clarified. Very simple. And the other one is I'd like one of you to expound on the
16 effects of those S waves, the difference between their effects on a low-thick wall
17 versus a very tall, skinny structure, a pipe or anything, a tower, or something tall
18 and vertical and skinny -- the difference between the effects on those types of
19 structures.

20 MR. MAIER: I think Dr. Moss is going to jump on that one.

21 DR. MOSS: "S" stands for "secondary" or "shear" wave. We use
22 both. It's generally shear in nature by the time it reaches the ground surface, so
23 it's this lateral movement. And it was primarily called the secondary wave
24 because it was the second one that came in when people started recording
25 earthquakes. Now your question about how the S waves affect -- I think you're

1 talking about different structures, but you used the example of a short, thick wall
2 and a tall, slender pipe. It's a little more complex than that. It has to do with the -
3 - at what frequency that structure's going to resonate at with the frequency
4 content of the motion. And you just think about a tuning fork. A tuning fork
5 resonates at a particular frequency, and structures do the same thing. And if you
6 hit that frequency, then you're going to get resonance and you're going to get a
7 large displacement of the structure or large response of the structure. Now you
8 take that response and you say well, how well built is it? So if we're talking about
9 an unreinforced brick wall versus a steel pipe, well, it's kind of a no-brainer there.
10 The unreinforced brick wall is probably going to fall apart due to the shear waves,
11 and the steel pipe is not. It's a very simplistic answer. I hopefully -- that gets to
12 what you were asking.

13 MR. MAIER: And Sherry, we have time for one more? Sherry,
14 you want to ask a question?

15 MS. LEWIS: I'm Sherry Lewis. Do you have liquefaction under the
16 sea?

17 DR. MOSS: Yes. We can have liquefaction under the sea. Any
18 loose, saturated soil, whether it's below the ground surface and below the water
19 table, or if it's below the ground surface beneath the ocean, you can get
20 liquefaction.

21 MR. MAIER: All right. Well, that -- I want to thank our presenters,
22 and thank you for the questions. We're going to take a break now until about
23 10:30. I urge you to check out the Los Osos in the Aetna rooms. I don't know if
24 there are any posters or any displays up for those, but if there are, you might find
25 them useful. And we'll be back here at 10:30 for Session No. 2.

1 [break]

2 MS. DENISSEN: My name is Christie Denissen. I'm with the NRC,
3 and I'm here to introduce Session No. 2, which is Seismic Source
4 Characterization. And we have brought three specialists from the U.S.
5 Geological Survey and California Geological Survey to talk about how faults are
6 characterized. So first we have Vicki Langenheim, who's a research
7 geophysicist with the U.S. Geological Survey in Menlo Park, California,
8 specializing in the application of gravity and magnetic methods to assessment of
9 seismic hazards. And then Jeanne Hardebeck is also with the U.S. Geological
10 Survey in Menlo Park. Her research interests include the strength of faults,
11 earthquake stress triggering, and imaging fault structures using microseismicity.
12 And finally, Tim Dawson is an engineering geologist at the California Geological
13 Survey, also in Menlo Park, California. His research has focus on developing
14 paleoseismic earthquake records along the Hayward and San Andreas Faults in
15 California and the Denali Faults in Alaska. And with that, I'll let Vicki take it away.

16 MS. LANGENHEIM: Okay. Well, thank you for this opportunity for
17 me to talk to you about how we use geophysics to characterize faults. And in
18 particular, I'm going to be talking about the gravity, magnetic, and seismic
19 reflection methods. Because this workshop is focused on the Central California
20 Coast ranges, I thought I would introduce these methods with the geology and
21 geophysics of this region in mind. But before we get on to geophysics, I thought I
22 would just show you what an actual fault looks like at the surface, because this is
23 what we're trying to characterize at depth, indirectly mapping them using these
24 geophysical techniques. So here's a photo of a fault, which is a fracture or
25 fracture zone, along which there has been displacement of the sides relative to

1 one another. And the displacement could be really quite minor on the order of
2 inches, or it could be really significant, like hundreds of miles like our friend, the
3 San Andreas Fault. Note that this definition doesn't say anything about when the
4 fault last moved. So a fault could have last moved seven years ago, like in San
5 Simeon, or it might have moved thousands to hundreds of thousands to millions
6 of years ago.

7 Okay. So looking at this photo, we see a zone of shearing, which
8 separates rocks of different ages. And on the left side, we have the Monterey
9 Formation and we have the Pancho Rico Formation on the right side. We can
10 get information on how the fault moved, in that the Monterey Formation is older
11 than the Pancho Rico, so it must have moved up. And looking in the sheared
12 zone, we have indicators that indicate that the fault also moved such that the
13 rocks on the left moved away from us relative to the rocks on the right. We can
14 also look -- get some information on when this fault might have last moved,
15 because, obviously, the fault must post-date the rocks that it displaces. And the
16 youngest rocks that look like they may have been displaced are these river
17 terrace deposits up here, which are between about 10 to 100,000 years ago.
18 Sounds like a lot of time to us, but geologically, this is a fairly young fault. So
19 what I'm going to be doing is trying to show you how we map these features and
20 extend them into the subsurface where earthquakes actually occur, and this is
21 using gravity, magnetic, and seismic reflection methods. So let me first show you
22 something about the geology of the area because these geophysical methods
23 are indirect ways of mapping these rock types through their physical properties.

24 Okay. So this is a topographic map of the area. For reference,
25 here's Monterey, Paso Robles. Here we are in San Luis Obispo, the beautiful

1 town of Lompoc, and Santa Barbara. And that photo in that last slide was taken
2 here. The red lines on this map are quaternary faults. These are geologically
3 young faults. And we see that that fault actually extends to the North, forming
4 the eastern margin of the San Lucia Mountains, and then it extends oh, about
5 100 kilometers to the South. So this is a fairly significant fault. This is called the
6 Rinconada-Reliz Fault. And it's now overlaid the geology on top of this
7 topography. And I've simplified this geologic map to kind of reflect the physical
8 properties that these geophysical methods we'll be looking at. And we're just
9 going to go through this map from youngest to oldest. So the youngest deposits
10 are those sands, gravels, clays that are deposited in the valley, sometimes
11 mantle the hill slopes. Beneath them, we have older sedimentary rocks, such as
12 the Monterey Formation, which is about 17 to 7 million years old. It's a
13 widespread marine sedimentary unit. Locally, we have volcanic rocks that are
14 inner-layered with these older tertiary rocks in places we have them intruding,
15 such as this line of volcanic necks here, culminating with Morro rock.

16 The next package of rocks we have are cretaceous sedimentary
17 rock, such as the Atascadero formation. This is along Highway 41. Again, it's
18 very well bedded, but we'll see it's denser, more consolidated. So somewhat
19 different properties. To a geophysicist, these sedimentary rocks, these younger
20 rocks, we call them "cover." And what we're -- what that's covering are the
21 basement rocks. And we have three basic basement types. We have the
22 Mesozoic granitic and metamorphic rocks that are exposed in, for example, the
23 Gabilan, Santa Lucia, and here in the La Panza range. Then we have a very
24 characteristic basement rock, the Franciscan Complex. These are basically
25 mostly oceanic sedimentary rocks that were scraped off the edge of North

1 America when we had a sub-duction zone here. And the result of this is that it's
2 kind of a *mélange*, a mixture. It's very heterogeneous, very disrupted. It also
3 incorporates things that geologists call "knockers," such as this. I don't know why
4 they call that, but that's what they call it. And then the third basement type are
5 bits of oceanic crust and mantle that are interleaved within these basement
6 rocks. So, for example, we have here at Port San Luis, these are pillow basalts.
7 These are basalt flows that extruded onto the ocean floor, forming these pillow-
8 like structures that have then been tilted upward.

9 All right. Now that I've introduced the geology, let's talk about
10 some geophysics. So the first method I'm going to talk about is gravity. And this
11 exploits very small variations in the earth's gravitational field force to map
12 subsurface density. And so you might thought -- you think that gravity is a
13 constant. It is not on the surface of the earth. It varies. According to our
14 famous equation describing gravity by Newton, it varies with your distance from
15 the center of the earth, so are, and it also varies as the mass. So if you have
16 denser rocks in there, you'll actually feel a little bit heavier -- well, maybe not you
17 but some of our very sensitive instruments can sense this.

18 So here we can make these measurements at various locations on
19 the earth's surface and be able to map and figure out where we have different
20 density rocks. And this is kind of schematically shown in these cartoons. The
21 slide -- the cartoon on the left shows what you might expect if you had a buried
22 dense body. You would see that the satellite is more increasingly pulled towards
23 that dense body. If you have a fault that juxtaposes rocks that are dense verses
24 less dense, you would see that the satellite would become increasingly more
25 pulled as you got over those dense rocks, forming this gradient in gravity. Well

1 how do we measure these variations? These are very small variations. We're
2 talking about one part in a million of the earth's gravitational field or less. And we
3 do it, well mostly on land with something that we creatively called a gravity meter.
4 It's basically a weight on the end of a spring, and that weight is pulled more
5 strongly over dense rocks, less so over less dense rocks.

6 We can lower this kind of instrument onto the ocean bottom, level it
7 like we would on land and measure the earth's density there, or we can also
8 measure it from a ship, which is a bit more complicated. This is on a gyroscopic
9 platform. And you also have to isolate the accelerations that the ship is
10 experiencing. Well, in the Central California Coast ranges, we have all of these
11 various kinds of measurements. And the blue dots are the measurements that
12 we have. You can see we have tens of thousands of these measurements. We
13 are very grateful to the Defense Mapping Agency, which is responsible for this
14 grid of gravity data. They collected that data in order to better constrain the
15 paths of missiles launched from Vandenberg Air Force Base, but we're using it to
16 look at geology. So we take these measurements, we process them so that we
17 remove kind of the gross earth mass so that we're really focusing on the mass or
18 densities in the upper, let's say, 10 to 15 miles. We processing them, we grid
19 them, and we produce a gravity map.

20 So for orientation, here's Monterey, Paso Robles, San Luis Obispo,
21 Lompoc. And the warm colors on this map are gravity highs where we have
22 higher density rocks exposed or voluminous in the crust. And the gravity lows
23 are the cooler colors. This is where we have lower density rocks. So going back
24 to the geologic map. The less dense rocks, we have a really good density
25 contrast between the sedimentary rocks and the basement rocks. So we would

1 expect gravity highs over the basement rocks. So where the pinks and dark
2 greens are, we would expect gravity lows over the more beige and blue areas.
3 And for the most part, that's what we see. We see a good gravity lows over the
4 Salinas Valley, the Santa Maria Basin, San Joaquin Valley, Santa Barbara. But
5 we can also see that there are these linear gravity gradients that coincide at least
6 locally with our major faults, such as the San Andreas, the Rinconada-Reliz, and
7 the Hosgri Fault.

8 Now I'm just going to give you an example of how we use gravity to
9 extend faults into the subsurface. Let's focus in on this area. This is a gravity
10 map. Here's Morro Bay. Here's the coastline. And here's the Hosgri Fault.
11 Note that the Hosgri Fault lies near the base of this rather significant gravity
12 gradient where we have a gravity high, and therefore, denser rocks on the east
13 side of the fault. By looking at where the fault lies relative to that gradient, we
14 can say something about how that fault dips into the subsurface. So if the fault
15 lies in the middle of the gradient, it's going to be a vertical fault, typically a strike-
16 slip fault. If the fault is located near the top, it will be more of a fault dipping off to
17 the west. And if it's located at the base, it's dipping off to the east. So just by
18 looking at where the Hosgri Fault lies relative to this gradient, we can tell that the
19 fault dips to the east, it's not a vertical fault, and it's a rather steeply-dipping fault
20 because this gradient is rather narrow.

21 Let's go on to our second method, the magnetic method. And it
22 works a bit like the gravity method, except we're looking at very small variations
23 in the earth's magnetic field to look at magnetic rock types beneath our feet. So
24 here's an example of a magnetic anomaly or variation that would be produced by
25 a fault offsetting these concealed magnetic rocks. And we can also -- oops --

1 measure these variations by either walking a magnetometer, which means that
2 we take a really long time to map the Central California Coast ranges and I don't
3 have that much time in my life I don't think. So what we often do is we mount it
4 on an airplane, such as this, or on a helicopter, and you can cover a lot of ground
5 that way. We can also tow it behind a boat so we get marine magnet. So let's
6 see. We can get a feel for how deeply buried those magnetic rocks by looking at
7 the wave length of the anomaly. So in general, the shallower that magnetic
8 source is, the more high wave length -- short wave length we get. As it gets
9 deeper, the variation becomes more broader and low amplitude. So you can
10 think of this as another way.

11 If you collected the data from an airplane -- of course, you have to
12 fly somewhat over the ground -- you'll get a broader anomaly than if you
13 collected that over the same ground with a magnetometer on the back of your
14 backpack. So this is a map collected from an airplane flown about 1,000 feet
15 above terrain as safely as one could. And what I want you to do is focus on the
16 offshore area and this area here. I'm going to merge in data collected from a
17 boat and from a helicopter, and you'll see just the increased amount of
18 resolution. Let me just do that again. You can see a lot of these anomalies are
19 being cut off. This is the Hosgri Fault running down through here. All right. This
20 is an aeromagnetic map of the whole region -- again, Monterey, Paso Robles,
21 San Luis Obispo, Lompoc. And this is a map made of merging several different
22 surveys all flown at about the same height. So this is a consistent data set in that
23 the broader anomalies that we see over here really are more deeply buried
24 magnetic rocks than the more high frequency short wavelength anomalies over
25 here.

1 Going back to the geologic map. What are the magnetic rock
2 types? Well, the most important rock type for producing magnetic anomalies is
3 oceanic crust and mantle. In fact, it's a rock called Serpentinite. It's your state
4 rock, at least for now. And it's a very prominent magnetic anomaly producer.
5 We also can get magnetic anomalies from some of the granitic rock types and
6 locally from some of those tertiary volcanic rocks. So going back to the magnetic
7 map -- oh, let me go back here one sec [spelled phonetically]. For example, we
8 can map faults here because if you have sedimentary rocks, which you'll notice
9 are not magnetic, up against these magnetic rock types, you can look at the fault
10 geometry that way. You can also map buried faults where they're concealed
11 beneath the sedimentary cover. Because, again, the sedimentary cover is not
12 very magnetic. So an example here at Point Sow [spelled phonetically], we have
13 a little bit of oceanic crust and mantle exposed. If we look at the magnetic map,
14 we can trace these magnetic rocks beneath the sedimentary cover of the Santa
15 Maria Basin. And if that magnetic property contrast is a major fault, we might
16 want to rethink where this poorly-known quaternary fault is located based on the
17 magnetic data. We can also gain some insight into the total displacement on
18 some of these faults. For example here, this is the La Panza Range. And we
19 see that this prominent magnetic anomaly is truncated on its west side by the
20 Rinconada-Reliz Fault. If we look along the fault, we can see an equivalent
21 anomaly off to the Northwest. And so this is suggesting that the long term
22 displacement of this fault is about 38 kilometers. Oops, it went back. We can tell
23 that this was mostly right lateral strike-slip, but there's also some vertical
24 component in that the granitic rocks are exposed here but are concealed beneath
25 the sedimentary cover here.

1 Okay, the next thing I'm going to show you are a couple of profiles
2 that we modeled to extend the geometry of the San Gregorio Fault, the Hosgri
3 Fault and the Rinconada Fault. So this northern panel is across the San
4 Gregorio Fault zone, which is offshore, and the black dots here are the observed
5 magnetic and gravity variations. The red and blue lines are the predicted
6 magnetic and gravity responses, given this geologic cross section and attributing
7 densities and magnetic susceptibilities to it. The feature we're trying to fit is this
8 magnetic gradient along here, which we do a very good job with having magnetic
9 rocks off to the west, extending at a moderate dip to the east down to 10
10 kilometers. We can also fit that gradient if we extend it down to 15 kilometers,
11 but we can't fit it if the fault is vertical. Along that southern profile, here is the
12 Hosgri Fault. And we see that there is significant magnetic and gravity gradient
13 associated with that. Modeling these data together tells us that in the upper two
14 to three kilometers, which is constrained by the gravity, the Hosgri is dipping
15 steeply off to the east. But we can extend that fault near vertically using the
16 magnetic data down to depths of about 12 kilometers. For the Rinconada Fault,
17 we can fit this gradient quite well with magnetic granitic rocks on the east side of
18 the fault. If we introduce a dip to that fault of 60 degrees, we no longer fit the
19 position of that gradient. We're significantly mismatching the location of that
20 gradient. And I just wanted to show you a couple of these examples so you have
21 an idea of how sensitive these methods are to sensing faults at depth.

22 Okay. So let's now go on to our third method. This is the seismic
23 reflection method. This is used extensively in oil and gas exploration, and it uses
24 sound waves induced by explosives, vibrating devices, or percussive equipment,
25 such as hammers or shotguns. And the reflections of these sound waves, you

1 can get at the subsurface structure by looking at how the energy bounces off
2 rocks of different types. Reflection of transmitted energy will occur when there's
3 a good contrast in acoustic impedance, which is a function of the density of the
4 rocks, but also how fast that energy can travel through the rocks. So this is a
5 really good method for mapping, especially bedded rock, such as sedimentary
6 rocks. So let me just show you a couple of examples of how we've collected that
7 data in the Central California Coast ranges. This is a fibrosis truck. And you'll
8 see that its wheels are not on the ground. All the weight is on this platform,
9 which then vibrates at a whole sequence of different frequencies. That energy is
10 transmitted into the ground, and then it is picked up by these geophones. These
11 are essentially microphones placed into the ground that record those vibrations
12 and the time at which they occur. Offshore, we use something called a mini-
13 sparker. It's basically sending out an electrical impulse in the water, sending out
14 energy. And then in this cable here, we have hydrophones. These are listening
15 devices to pick up that energy. We can also use an air gun, which releases a
16 blast of compressed air in the water, sending out energy. The advantage of hang
17 these two different sources, is that this is a higher frequency source than this.
18 And I'm going to highlight that in the next slide.

19 So this is a profile, offshore Port San Luis here. The upper panel is
20 the sparker, and this is the air gun. And one thing about the frequency of the
21 energy, the higher frequency means you get higher resolution, but it doesn't
22 always mean that it propagates very deeply. In fact, usually it doesn't. And this
23 is a really good example. The sparker here, the time thing here, is about two --
24 about .45 seconds. We can actually see structure really only to about here. Two
25 seconds, it's about 200 meters, dots. You can see that there's very folded

1 sediments in here that are truncated here by the various strands of the Hosgri
2 Fault. The bottom panel, this green line, corresponds to the depth of penetration
3 of the sparker. So you can see that the air gun is seeing much deeper down to
4 about three seconds or about 3 kilometers. It's also mapping the strands of the
5 Hosgri Faults of where these well-bedded reflections are terminated. But you
6 can't really see much close to the ocean floor. In fact, it's overwhelmed by these
7 multiples here. So you can't really tell how close this fault comes to the surface.
8 And this is important because, especially in bedded rocks, the closer that fault
9 gets to the surface, that means the younger that fault must be.

10 Okay. So let me just show you another example of two para-lines
11 [spelled phonetically] here, this time off of Morro Bay. And I just want you to see
12 that these disruptions here, especially here, go all the way as close to the
13 seafloor as you can. So this is a very young fault. Since this is an environment
14 where you have kind of a steady rain of detritus falling down. I also want to point
15 out that if you go to the northeast part of the profile, you see that it's fairly
16 transparent. There aren't a whole lot of reflections, except for these things,
17 which are multiples. These are echoes bouncing off the seafloor interface. This
18 doesn't mean that we don't have bedded rocks in here, but in this technique, if
19 the rocks dip more than 20 to 30 degrees; this has a real difficult time seeing
20 those reflections. And the other thing is, the bedrock, the basement rocks, like
21 the Franciscan, it's all disrupted. It does not lend itself to producing nice layered
22 reflection. So this is a place where this technique doesn't work as well, but if you
23 use it in conjunction with gravity, magnetic, and geology, you can get a hope of
24 trying to characterize these faults in the subsurface. Just a couple of examples
25 from online profiles, again, illustrating that, for example, along here, along SJ6,

1 well-bedded reflections. These are from the young tertiary sedimentary rocks.
2 But the granite beneath it is fairly transparent until you get down to depths of
3 about 10 to 15 kilometers, which is seen on some adjacent profiles here. This
4 package of reflections may be reflecting sediments that were under-thrust
5 beneath California when the sub-duction zone was active before the San
6 Andreas was born. And there's some question about whether -- this is a way to
7 tie the faults that are active here in the Coast Ranges with the San Andreas.
8 This is certainly an area that warrants future research.

9 So in conclusion, we can use these really small variations in the
10 gravity and magnetic fields to provide horizontal and down-dip constraints on
11 locations of density and magnetization contrasts, which, in turn, can reflect faults.
12 Seismic reflection data are great because they can tell us about folding and
13 faulting within the sedimentary rocks, and this information can tell us about the
14 latest movement on a fault. But really, this is just one part of the puzzle of trying
15 to characterize these faults. And so, in order to determine if a fault is seismically
16 active or likely to be seismically active, or whether it's going to produce a
17 magnitude 7 or 3 earthquake, other information is needed, such as dating the
18 layers that are offset or not offset, measuring how the ground is deforming, and
19 seismic monitoring -- seeing where these little earthquakes occur. And that's
20 really what Jeanne and Tim are going to talk about next. So thank you.

21 [applause]

22 DR. HARDEBECK: That's not the beginning of the talk. Okay.

23 Can I just slide this slider back? No, that's the size [chuckles].

24 FEMALE SPEAKER: [unintelligible] Go, go to here.

25 DR. HARDEBECK: Go to slide show?

1 FEMALE SPEAKER: Go to slide show.

2 DR. HARDEBECK: From the beginning. I'm glad somebody here
3 is a PC person who knows how to do this. Okay, so as Vicki said, I'm going to
4 sort of take it from here on how we find out about active faults, faults that are
5 currently moving and currently having earthquakes.

6 So first I'm going to talk about how we use seismicity or how we
7 use the locations of small earthquakes to image active faults in 3D. And I just
8 want to start this off with a reminder that we tend to look at faults as a line on a
9 map, and we tend to look at earthquakes as a dot on a map. And we have to
10 remember that faults are actually 3D, that is, when an earthquake -- when a large
11 earthquake occurs on a fault, two 3D chunks of rock move relative to each other
12 in this earthquake along some surface that is the fault. And where this fault hits
13 the surface, that you might refer to as a fault line, or the more technical term
14 would be the surface trace of the fault, this is really just a small part of the fault
15 where it happened to reach the earth's surface.

16 The faults can extend more than 10 miles down into the earth, and,
17 in fact, it's this deeper part of the fault that's often where the large earthquake
18 starts. So we need to be able to see, not just where faults are near the surface
19 or at the surface, we need to be able to see where faults are deep below the
20 surface of the earth. So one way we can do this is that some of these larger
21 faults have small earthquakes or seismicity occurring on them all the time. And if
22 we can get a good idea of where these small earthquakes are happening below
23 the surface of the earth, we can use them to image where that fault is beneath
24 the surface.

25 So sometimes the situation of a fault is very simple. And an

1 example near here that's quite simple is the Parkfield segment of the San
2 Andreas Fault. This is a vertical strike-slip fault, meaning that the two blocks of
3 crust on either side of this fault are moving horizontally relative to each other.

4 And you can see in this little inset map here that the surface trace
5 of the fault is in red, and the small earthquakes happening on this fault are in
6 black. And the small earthquakes in map view look like they're basically
7 happening right along the fault, because this is a nice, simple vertical fault.
8 There are a lot of faults that are not nearly this simple. And an example from
9 around here is the San Simeon earthquake.

10 So San Simeon earthquake, to remind you, is a thrust-type
11 earthquake where the fault isn't vertical like the San Andreas. It has a dip. And
12 one of the -- one of the blocks of rock is moving up and over the other block of
13 rock. So this creates a much more complicated situation than the simple vertical
14 strike-slip faults. So to give you an idea, this map here just has the surface
15 traces of the map faults in the vicinity of where the San Simeon earthquake
16 occurred.

17 And if you look in the Santa Lucia Range, you see, well, there's a
18 map fault on one side of the range and there's a map fault in the other. But then
19 if we see where the earthquakes happen, if we plot them in map view, this star is
20 the hypocenter of the San Simeon earthquake, and all of these dots here are its
21 aftershocks. And you can see that these faults aren't limited in map view to the
22 places where the surface trace of the fault was, that they're occurring deep in the
23 earth, down to 10 miles deep into the earth, and they're occurring, first of all, on
24 dipping planes. Oh, this is very sensitive, isn't it? They're occurring on dipping
25 planes. Therefore, the earthquake at depth aren't right under the surface trace of

1 the fault. And there's also a very complicated fault geometry here at depth that
2 isn't reflected in the surface.

3 So why is it important to see what's happening at depth for seismic
4 hazard estimation? This is an example from the southern part of the San
5 Francisco Bay area. And this is, this little blob here, is the southern end of the
6 Bay, and north is this direction. So here are the surface traces of the Calaveres
7 Fault and the Hayward Fault. And like the San Andreas Fault, these are vertical
8 strike-slip faults that the two sides, the crust on either side of these faults are
9 moving horizontally relative to each other. And the faults are pretty much vertical
10 for most of their length.

11 So looking at this map of the fault traces, you would say, okay, well
12 these faults come close together in this area, but they don't actually connect, so if
13 we're going to be doing some seismic hazard analysis here, we're not going to
14 consider earthquakes that would connect these faults, we just consider some
15 earthquakes in the Calaveres Fault and some earthquakes on the Hayward
16 Fault.

17 However, if we look at what's going on below the surface, if we plot
18 in the earthquakes, we can see that these two faults are actually very clearly
19 connected at four miles and deeper in the crust. And these are, of course, the
20 depths where the major earthquakes are occurring. So the realization that these
21 two faults are connected is actually changing the way that we're thinking about
22 potential earthquakes that could occur on the Hayward and Calaveres Fault.

23 And it's interesting to note that this chain of seismicity here at four
24 miles to eight miles depth in the crust isn't actually another fault that's connecting
25 the Hayward and the Calaveres, this actually appears to be a dip in the Hayward

1 Fault as it merges towards the Calavares. And we can see this dip in this
2 seismic image here on the Hayward Fault, that the Hayward Fault is dipping
3 toward the east. And if we can continue that dip down to the depth to where the
4 seismicity is occurring, we see it matches up very nicely. So it actually appears
5 that these earthquakes here are not following the surface trace of the Hayward
6 Fault any more, are deviating from the Hayward Fault and are matching up with
7 the earthquakes on the Calavares Fault. So as I said, this has changed the way
8 that we've been thinking about the potential hazard of these two faults.

9 So clearly, it's very important to be using seismicity to map faults at
10 depth. So let me walk you through a little bit what we do to locate these
11 earthquakes to image them.

12 So Doug Dreger talked earlier this morning about how we locate
13 earthquakes, that is, the basic idea is that if we have three or more stations and
14 we have an idea of the distance from each of these stations to the earthquake,
15 we can just draw a circle around each of these stations at the appropriate
16 distance, and the location where these three circles intersect is the location of the
17 earthquake.

18 So as Doug talked about, one of the ways that you figure out the
19 distance from the station to the earthquake is that you look at how long it took
20 seismic waves to arrive at the station. So how long it takes seismic waves to
21 arrive at a station depends on how fast these seismic waves can move through
22 the earth's crust. And how fast these seismic waves can move depends on the
23 geology. So when we're locating earthquakes, if we want to locate these
24 earthquakes very precisely, we either have to know something about the geology
25 at depth where these seismic waves are propagating or we have to assume

1 something about the geology.

2 And most of the time when we locate earthquakes, we just
3 approximate the real geology in the earth with what we refer to as a one-
4 dimensional velocity model, basically assuming that the geology in the earth is
5 just these simple flat layers. So in some circumstances, this works pretty well, in
6 some circumstances, this does not.

7 So just to give you an example of what earthquake locations look
8 like using a 1D velocity model, this is this region. Here we are in San Luis
9 Obispo. And these are the earthquakes of this region located using a simple 1D
10 velocity model. And all these earthquakes up here, these are the aftershocks of
11 the San Simeon earthquake. And if you look at the rest of the earthquakes, they
12 look pretty scattered. They don't look like they're very precisely delineating any
13 faults. Some of this could be because there is complex geology here that's not
14 getting modeled in the simple 1D model.

15 So, for instance, if there was some block of rock here that didn't fit
16 this layered 1D model and seismic waves could travel through this rock really
17 fast, if we were recording this earthquake at that station under the trees, we
18 might say oh, the waves from this earthquake reached the station under the trees
19 pretty fast, so this earthquake must be close to the station under the trees. And
20 we might move our earthquake location to be closer to that station. And now,
21 unfortunately, we've moved that earthquake location from its true location and
22 we've moved it off the fault, and we're not doing a good job of imaging that fault.

23 So one of the ways that we can improve the locations of small
24 earthquakes is try to do a better job of modeling the 3D changes in geology and
25 the 3D changes in seismic wave speed in the earth.

1 So this is something we've attempted to do for this region. And this
2 is just a little slice through a 3D model that we've made of the seismic wave
3 speed in this region. This is at four miles depth. Then you can see that these
4 yellow patches are places where it appears that the seismic waves are moving
5 relatively slowly and the darker patches are regions where we think the waves
6 are moving relatively quickly. And we can use this to relocate these
7 earthquakes.

8 So just as a reminder, here's what the earthquake locations look
9 like when we use a simple 1D model, and here's what they look like when we use
10 a 3D model. And you can see, if you compare these, there's a couple of
11 differences.

12 First of all, a lot of the offshore earthquakes have shifted sort of
13 nearer to the shore. And if you focus on some regions -- regions, you can see
14 that we can start seeing some fault structures more sharply. For instance, if you
15 focus out here in the 1D model, this just looks like a big cloud of earthquakes.
16 But when we use a 3D model, it starts looking like there might be a fault structure
17 there. So this is moving us a little bit closer to imaging some of the faults.

18 So we want to image these faults even more sharply. And one of
19 the things that we can do to image the faults more sharply is to get a better idea
20 of the relative locations of two earthquakes relative to each other. So for
21 instance, if we had these two earthquakes here, the blue one and the red one
22 and they might be on the same fault, they might not be, and we want to see what
23 their -- what the structures are that they might be defining, we're really interested
24 not so much in where these earthquakes are exactly in space, but we're
25 interested in how close together they are. And, in fact, how close together they

1 are in space is directly related to how much time there is between when the
2 seismic waves arrive at a station from one earthquake and the other. So this
3 blue earthquake is a little farther away from the station, so the seismic waves
4 arrive a little bit later.

5 And, actually, it doesn't really matter if there's some geology that
6 we don't know about along the path of the waves from these earthquakes to the
7 station, because it's going to speed up or slow down the waves from -- okay, I'm
8 really getting ahead of myself -- it's going to speed up or slow down the waves
9 from both of these earthquakes just about the same.

10 So looking back to this region around here again, these are the
11 earthquake locations with the 3D model. And then on top of that, I apply this
12 relative location technique to try to better constrain the relative locations between
13 every pair of earthquakes in this -- in this region now. And you can see that this
14 has definitely caused us to sharpen our view of some of the earthquake -- some
15 of the fault structures.

16 For instance, if you look at the Hosgri Fault offshore here, in the 3D
17 model, these earthquakes, again, look kind of scattered. But once we looked at
18 their relative locations, you see that they sharpen up in a line following the strike
19 at the Hosgri Fault. And you can see a number of other places along the Hosgri
20 Fault off here in the bay. And, of course, the Shoreline Fault have really
21 sharpened up in this analysis also.

22 So this is -- just going to quickly draw these -- there are all these
23 faults on here. If you're interested in looking at the earthquakes in this region in
24 a little bit more detail, I have a poster in the other room that you can kind of stare
25 at for a while.

1 But the one thing I want to remind you of this slide is to go back to
2 how I started, when I was talking about how faults are really three dimensional.
3 So I'm drawing lines on a map here, and I'm looking at faults in terms of
4 earthquakes that appear to line up in map view, and we're even calling one of
5 these faults the Shoreline Fault. But we have to remember that these faults are
6 really in 3D. And even when we look at what looks like a line of faults along this -
7 - a line of earthquakes along the surface, we have to remember some of these
8 earthquakes are occurring in shallows two miles depth -- whoa -- and some of
9 these earthquakes are occurring as deep as almost 10 miles of depth. So this --
10 all of these faults, the Hosgri Fault, Shoreline, all of the faults, I show 3D faults
11 separating 3D blocks of crust that move relative to one another.

12 So the sorts of ways that these blocks of crust can move relative to
13 one another has been covered a couple of times already in this workshop. But
14 just as a reminder, the two types of faults that are important in this area: One
15 type is the strike-slip fault, where the two blocks of crust are moving horizontally
16 relative to each other, and the other important type is the reverse or thrust fault,
17 where one chunk of rock is moving up and over the other.

18 So I'm glad Doug Dreger took a stab at explaining these beach ball
19 plots to you earlier. The basic idea here is just the beach ball, this slip -- the slip
20 on the fault is in the direction of the filled part of the circle. So a strike-slip fault
21 looks like these sort of quadrants and the slip is towards the filled quadrant. And
22 if you have a thrust fault, which means that the slip -- that the fault motion is
23 pushing something up, it's the symbol where we have the filled part of -- the filled
24 part of the circle is up.

25 So to look now at -- we can get -- use that micro-seismicity to small

1 earthquakes that are occurring all the time to get a sense of what the faulting
2 style -- for the faults around here are.

3 And these beach balls are not now individual earthquakes, like
4 Doug was showing you. These are average motion over a lot of small
5 earthquakes. And you can see that there's a lot of strike-slip motion offshore on
6 the Hosgri Fault. Let's see if I drew the faults on --yeah. Offshore, for instance,
7 the Hosgri Fault, Shoreline Fault, and the bay here, there's strike-slip.

8 There's uplift in the region of this -- of the San Simeon earthquake,
9 which makes a lot of sense because it's these earthquakes that are raising the
10 Santa Lucia Mountains, and that's why they're such high mountains there. We
11 also see some uplift just west of San Luis Obispo.

12 Okay, my talk really wants to move ahead, so let's move ahead.
13 I'm also going to talk about how we use geodesy to watch faults move. And the
14 word "geodesy" really just means "measuring the shape of the earth or
15 measuring the shape of the surface of the earth." And for studying earthquakes,
16 we're mostly interested in changes of the shape of the earth.

17 So this little benchmark here, that I'm showing a picture of, is a
18 benchmark that was installed in 1932 by the U.S. Coast and Geodetic Survey.
19 And the sort of geodesy they would have been doing back then would have been
20 using very standard surveying techniques to look at the movements of these
21 benchmarks relative to each other.

22 So I'm going to talk today more about modern techniques that we
23 can use to watch the surface of the earth move, modern techniques based on
24 satellite data.

25 So the first technique that we use is GPS, Global Positioning

1 System, which is exactly the same satellites and basically the same technology
2 as is in navigation systems in cars and in cell phones and in other consumer
3 electronics. The only difference on how we use GPS for scientific studies is that
4 we need much higher precision to watch plates that are moving, you know, the
5 rate that your fingernail grows. We need much higher precision than we need
6 just for, you know, navigating your car on the street. And so the way we do that
7 is by leaving a GPS receiver in its position for a longer period of time, like a day
8 or so, so that it can talk to the satellites for a pretty long period of time and get a
9 very precise measurement of the location of the receiver.

10 And the way the GPS location works is actually pretty much the
11 same way as earthquake location works. If we know the distance between the
12 stations and the earthquake and we draw these circles at the appropriate
13 distance from the station, it gives you a location of the earthquake. Now we're
14 just looking at your distance between your receiver and the satellites orbiting the
15 earth. And so that's what the spheres are in this drawing -- is equal distance
16 away from one of these satellites. And if you can see at least three or four
17 satellites and you can draw these spheres around each satellite, the place where
18 the spheres intersects is where you are.

19 So we can use GPS in sort of the same mode as standard
20 surveying; that we can go to one of these benchmarks and set up a GPS
21 receiver. And this is just a GPS on top of a tripod to keep it very stable for a long
22 enough period of time to get a very precise measurement of where it is, and then
23 we can come back a few months later, a year later as such. And that -- and, for
24 instance, for this station, we can see, you know, if we've measured this over
25 time, then we can see it's moving a little bit to the north and a little bit to the west.

1 And, so this is what we would call campaign or survey-mode GPS, where we just
2 come out and visit these stations occasionally.

3 The other thing we can do is install these GPS stations
4 permanently. And, so this is an example of a continuous GPS station near the
5 San Andreas near Parkfield. And this station is permanently installed there and
6 is constantly recording data. And you can see from this example here that you
7 get very detailed -- very detailed information about the movement of this location,
8 much more detailed than you would get if you just visited this every year or so.
9 And these are some maps of continuous GPS stations installed in the western
10 U.S., and you can see that there's been quite an investment in installing GPS
11 stations.

12 So these are -- this is just sort of zooming into this area now. And
13 the arrows here represent the velocity of each of these GPS stations relative to
14 somewhere way out in the east coast that's considered to be the stable North
15 American Plate.

16 So what GPS really tells us that's useful for seismic hazard
17 assessment is it tells us what is the relative velocity of the blocks of rock on
18 either side of a particular fault. And in this example, if you look at -- if you look at
19 arrows on either side of the San Andreas Fault -- for instance, if you look at these
20 arrows on either side of the San Andreas Fault, that can give you an idea of what
21 the rate is of slip on the San Andreas Fault. And if you look at the arrows near
22 the San Andreas Fault and compare those to the arrows near the coastline, you
23 can see that those stations at the coastline are actually moving a bit faster than
24 the stations near the San Andreas Fault.

25 And this difference -- [coughs] excuse me. And this difference in

1 motion is reflecting the slip rates of all of the smaller faults that are west of the
2 San Andreas here. So this has the potential to give us a lot of information about
3 the slip rates on all of the various faults.

4 Although you can see in this picture one of the downsides of using
5 GPS is that we can only install these stations on land or on islands. So we're not
6 going to be able to use GPS, or at least land-base GPS, to get an idea of slip
7 rates of faults offshore.

8 So the other technique that -- satellite based geodesy technique
9 that I want to discuss is called Interferometric Synthetic Aperture Radar, or just
10 simply InSAR. And what happens here is a satellite passes over some spot on
11 the earth, and it sends a radar signal down, which bounces off the earth, and
12 comes back to the satellite. The satellite then is going to come back later some
13 time after there's been some ground deformation, such as an earthquake. It's
14 going to send this radar signal, the radar's signal's going to bounce back again,
15 but this time, it took the radar signal longer to bounce back. So that gives us a
16 measurement of how much the earth moved. And the difference in the time it
17 took is actually measured as a phase difference of a wave, so that's going to
18 affect kind of how these -- how these patterns look. But the basic idea is it's
19 really just measuring the difference in time it took a wave to hit the surface and
20 come back.

21 So over on the right there is an example of what we would see just
22 if this little -- if just a little circular hill popped up. So you can see the advantage
23 right away of this over GPS, which is that GPS gives you the movement at one
24 point in space, whereas an InSAR image gives you the movement over a whole
25 region so you can see the details of this hill popping up. And it looks like,

1 because it's a very symmetrical little hill, you get these symmetrical little set of
2 rings.

3 So in the real earth, it can be quite more complicated. This is an
4 example from the San Simeon earthquake. This is some deformation continuing
5 after the San Simeon earthquake. And you can see again that there are these
6 rings of color outlining the region that's being uplifted. But because the San
7 Simeon earthquake was such a complicated earthquake, this is actually a very
8 complicated diagram. And we can draw some cross sections across it, and on
9 the right here, just some cross sections across this image showing this very
10 complicated pattern of continuing uplift following the San Simeon earthquake.

11 So both of these -- both of these space-based techniques -- GPS
12 and InSAR -- are showing us the movement of the surface of the earth. And as I
13 kind of keep coming back to, faults are 3D, faults are extending into the earth by
14 10 miles or more. So what we really need to do is translate these observations
15 we see at the surface to tell us something about what's going on on these 3D
16 fault structures at depth.

17 So we have to use models then. We have to move from the data at
18 the surface and use that to come up with a model for what's going on on the fault
19 that it can explain the data we see at the surface. So this is just an example of a
20 few GPS stations near the San Andreas Fault near the Parkfield earthquake, and
21 all the arrows just indicate the direction and the amount of movement during this
22 fault.

23 And on the right, we've translated that to a model of the slip on the
24 fault that best explains those set of GPS observations. And interestingly, we can
25 see that although the earthquake started here where this red star is, most of the

1 movement in the earth -- most of the motion in the earthquake that we can see
2 using GPS actually happened to the north. And we can also see that motion in
3 the fault continued for more than a couple of months after the earthquake.

4 So this is an example of using GPS just to look at one fault and
5 over a short period of time. But what we'd really like to know for seismic hazard
6 assessment is what are the long term slip rates on all of these faults. And if you
7 can get -- if you can use geodesy to see the long term relative rate of motion of
8 the two blocks on either side of a particular fault, that can give you long term slip
9 rate of the fault, which then can give you the rate of earthquakes on that fault.

10 So this can also be done through modeling. On the left is GPS
11 observations covering all of Southern California, and on the right is an attempt to
12 fit that data with a model of the slip rate of all of the important faults.

13 And you can see, for instance, that the San Andreas fault has a
14 very high slip rate, so it's there in red and it's very thick, but you can also get an
15 idea of the slip rate of some of the other faults. For instance, the Hosgri Fault
16 has a slip rate in this model, and it has some detail to it. For instance, this model
17 says that the slip rate of the northern part of the Hosgri Fault is higher than the
18 southern part of the Hosgri Fault. And there's also quite a bit of detail about the
19 other faults in Southern California in this model as well.

20 So this is the sort of model where you would have the slip rates --
21 where you would have the slip rates on all of the -- the long term slip rates on all
22 of the faults to give you an idea of the long term earthquake rate, that then it's the
23 sort of thing that you would put into a seismic hazard assessment for the area.
24 And Tim is going to talk to you a little bit more about how we do seismic hazard
25 assessment. Thank you.

1 [applause]

2 MR. DAWSON: Okay. Let's get this. Okay. Good morning,
3 everyone. Thanks for wading through all these talks -- wading through all these
4 talks and all this information. There's a lot to be presented still.

5 My talk today is in two parts. First of all, I'm going to explain how
6 we use geology to characterize active faults. I'm a geologist, and so that's sort of
7 my area of expertise. And then the second part of this is going to provide a flavor
8 of what some of the future sessions are going to be talking about in the site
9 [spelled phonetically]. What do we do if all this geologic, seismic, and geodesy
10 data, and geophysical data, and how do we use it to construct an earthquake
11 rupture forecast or how do we use it to come up with the probabilities of future
12 earthquakes on this fault system?

13 So we've seen this before a little bit, this geologic map of California.
14 Simply, the geologic map just shows the distribution of rock types throughout the
15 state, as well as geologic structures such as folds and the location of faults. And
16 from this, a geologist can piece together the geologic history of the region.
17 That's important because we want to know what happened in the past, how did
18 the rocks get to be where they are? It provides context for what we're looking at
19 today, and it also can help us look into the future and see what might happen.

20 For seismic hazards, geology can also be used to help predict
21 potential shaking. On the lower or on the left side here is the geologic you just
22 saw in the previous slide converted to a shear wave velocity map of the upper 30
23 meters. And what this map shows is that in the most red colors, those are the
24 fastest shear wave velocity rocks in the state that's mostly, you will notice, it's in
25 the mountains. It's where the bedrock is generally hard. The more yellow colors

1 and, kind of getting down to the pinker colors, which are kind of hard to see on
2 this figure, are the types of rocks and unconsolidated sediment where shear
3 wave velocity is sort of low, and where it can be kind of used as approximately
4 where shear wave velocity is, is a little bit slower, it tends to amplify the shaking.

5 So what we do if this kind of -- this type of geologic map, is when
6 we -- oops, this is sensitive -- when we combine it with the fault locations, as
7 shown here in the upper right, we can start making these shaking potential maps.
8 And all it does is it shows -- it's a combination that shows the influence of
9 geologic materials, as well as the location of faults on shaking potential. And in
10 general, you can see that most of the expected shaking within the State of
11 California, it's generally along the major faults that are in the upper right-hand
12 corner or the upper right-hand part of the map. But there are some basins and
13 areas of the state which will shake just because of the nature of their geologic
14 materials that are underlying the surface.

15 So how do we find these faults? Well, what we're mostly
16 concerned with are the active faults. Those are the faults that have moved in
17 general within the quaternary [spelled phonetically] that last about two -- 1.8 to
18 two million years. In this example here, this is a blocked diagram that shows
19 some of the features that a geologist looks for when looking for an active fault,
20 especially in this case, which is an active strike-slip fault. Typically, you'll see
21 things like scarps, sag ponds, ridges, alignments, drainages. In this case, this is
22 a right lateral fault. You can see this stream right here being offset down here.
23 This is the idealized example.

24 Here's a more realistic example. This is taken -- it's a photo of the
25 San Andreas Fault at Wallace Creek, California, which is just south of Highway

1 58, I believe, in the Carrizo Plain. You can actually go out here and visit this site.
2 There's a nature's trail that the Southern California Earthquake Center and
3 Caltech and the Bureau of Land Management have set up at this site.

4 But as in the previous figure, you can see things like alignments of
5 drain -- of troughs along the faults, scarps. This creek here, Wallace Creek, has
6 been offset along the faults. And you can even see evidence of past offsets.
7 This feature right here, which we call beheaded channel, actually is the kind of
8 ancestral Wallace Creek, and thousands of years ago it actually was connected
9 to Wallace Creek, the upper parts of Wallace Creek, and it's been offset, it's
10 been abandoned. This newer channel of Wallace Creek has formed and also
11 been offset. If you look really closely, there's even smaller offsets, like this
12 channel is offset from here and here. And all these offsets occur from multiple
13 earthquakes. You know this -- and I'll talk about this in a little bit, but this one
14 offset from here to here occurred over the past, about, 3,800 years. So that's
15 hundreds of earthquakes.

16 In the past, geologists have typically mapped the active faults on
17 the ground. We go out there, we look at the faults themselves, we map the rock
18 types. We use aerial photographs as well. Within the last, you know, 10 or 15
19 years, we had one new technology, which is really exciting to us. It's called the
20 LiDAR. It stands for Light Detection and Ranging. And essentially what this is,
21 it's an airborne mountain laser system. This laser is mounted on the bottom of
22 the aircraft. It shoots out tens of thousands of points per second. And each one
23 of these points will hit the ground. A number of them will be reflected back up to
24 the sensors within the aircraft. That time difference is used to map the surface of
25 the earth.

1 The advantage of this process is just the sheer number of points.
2 There's, you know, probably multiple -- they call them returns -- for every square
3 meter that these lasers hit on the surface of the earth.

4 The other advantage of this is because this system is tied to GPS
5 satellites, as well as base stations on the ground, there's stunning accuracy, both
6 horizontally and vertically. And so what we can do with that is make some very
7 positionally accurate maps of the earth's surface.

8 And here's an example of some LiDAR data. Actually, before we
9 get -- describe that, on the very far left here is just what you would see is in an
10 aerial photograph of this region. Notice that there's a lot of vegetation. This site
11 right here is actually from the north coast of Northern California on the San
12 Andreas Fault. And even to an experienced geologist, we would have a hard
13 time defining where all -- oops -- all the active faults are. We might map
14 something like this right through here where you can see this gap in the trees.
15 There's some other erliniments [spelled phonetically] that you might see up here
16 on the screen, but it would be very difficult to get out there, use this photograph
17 to map where the faults are. It's also, because the density of the vegetation,
18 extremely difficult to get out there on the ground and locate yourself.

19 With LiDAR, we kind of call this our virtual lawnmower. What the
20 LiDAR data does is when you process it, you can filter out the trees. It'll take
21 only the very last laser returns from the very -- the bare earth of the ground. And
22 what we've done here is processed all the trees away, and now you can see
23 where the faults actually are on the ground. Here's some nice scarps right
24 through here, right through here. And in general, some of this does line up with
25 where we saw -- we thought we saw faults before on this aerial photograph, but

1 there's a lot more detail, and it's a lot more accurate than anything we'd be able
2 to do just off of an aerial photograph. On the far right here, is interpretation of the
3 faulting for this image that you're seeing.

4 Why is the location of these faults important? Well, for us at CGS,
5 one of the things we do is we're actively involved with mapping faults for the
6 Alquist-Priolo Act. And what that is, is that the state requires us to map where
7 there's a potential for earthquake surface rupture. That's where the earthquake
8 fault, when it ruptures, as an earthquake, it actually reaches the ground and has
9 the potential to destroy structures and roads and things that are located on the
10 top of the fault or that cross the fault.

11 In the upper left here is -- you can see the fault crossing the figure
12 right through about the middle of it. This is from the 1992 Landers earthquake. It
13 actually nicked this home right here. It kind of goes through this trailer that's
14 parked out back and continues on its way. If that home was located even closer
15 on top of the fault, it would have been completely destroyed. I think, as it were, it
16 had to be abandoned.

17 The right-hand side here is an example of the Chi-Chi Earthquake
18 in Taiwan in 1999. This waterfall, actually, was not there before the earthquake.
19 This is caused by a thrust fault that ruptured the ground surface. This waterfall is
20 formed as a result of that fault movement. And this highway bridge was actually
21 built across the fault, and that's why it eventually -- it collapsed during the
22 earthquake.

23 The Alquist-Priolo Act is designed to address surface fault rupture
24 through avoidance. And so in California, what we do is the CGS goes out, they
25 map these faults using some of these techniques, mostly on aerial photographs,

1 geologic mapping, and lately, even using some of the LiDAR data, and by law,
2 we're required to create these setback zones.

3 So on this figure right here, the lines in black are the actual fault
4 traces that we've mapped. And then the shaded area, buffered by this -- these
5 red lines, are what we've defined as our earthquake fault zone. And under AP
6 Law in the State of California, it requires if you want to build a structure within
7 one of these earthquake fault zones, it requires certain geologic investigations to
8 make sure that you're not going to build on top of one of these fault traces
9 because there's fully fit -- there could be other fault traces that we're not able to
10 see within this zone. And typically, this is done through geologic investigations
11 such as trenching. If they happen to find a fault, any structures that are going to
12 be built on that property need to be set back from that.

13 And just to clarify, the criteria for AP Law in the State of California is
14 Holocene-active. That's about the last 11,000 years. And I just want to make the
15 point that for other structures regulated by other government agencies such as
16 dams, critical infrastructure, the term "active fault" may even be longer than that.
17 It could be tens, hundreds of thousands of years that make it an active fault.
18 That's movement within that time period.

19 In some cases, structures might require mitigation to survive
20 earthquake surface rupture. For a thing, something like a pipeline, you can't
21 avoid crossing a fault. This is an example of the Trans-Alaska Pipeline in Alaska.
22 And back in the '70s, when they were designing this pipeline, they realized that
23 this pipeline would be crossing the Denali Fault. They knew the Denali Fault was
24 potentially active at the time. And so they sent a team of geologists up there.
25 They did some careful geologic studies that mapped out the fault trace as best as

1 they could at the time. And the one thing they did in this case is that the pipeline
2 crossing -- here's the proposed pipeline through here -- crosses through this
3 valley here where it was really difficult to see the fault. And so through this
4 careful geologic mapping, the geologists defined this zone where they thought
5 the fault would be that could impact the pipeline should there be an earthquake.
6 And the geologists also provided some estimates of how much displacement to
7 expect if there was a large earthquake on this fault.

8 They gave this information to the engineers, and the engineers
9 were able to design a system to accommodate this fault movement. What they
10 essentially did was they put the pipeline on these slider rails, and so when the
11 fault moved in a right lateral sense, the pipeline was allowed to flex with that fault
12 movement.

13 The one really interesting thing about this earthquake is they built
14 this for -- they built this pipeline before an earthquake happened on the Denali,
15 and in 2002, this design was actually tested and survived nearly 20 feet of right
16 lateral displacement during a magnitude 7.9 earthquake on that fault. So a
17 magnitude 7.9, that's about what we have in California on the San Andreas Fault.
18 The 1906 earthquake, 1857, were both about that size.

19 Other things geologists do is paleoseismology. That's the study of
20 ancient or prehistoric earthquakes. These are the questions we like to address
21 when we're doing these paleoseismic studies. How often do the large
22 earthquakes occur? When did they happen? How large were these
23 earthquakes? And how fast is the fault moving?

24 So how often do the large earthquakes occur? How do we do
25 this? Typically, we do this through subsurface investigations. The photo you

1 see here is an example of a trenching investigation on the Hayward Fault across
2 a golf course in El Cerrito, California. The reason why the geologists who were
3 involved with the study picked this site is because through mapping and analysis
4 of aerial photos before this golf course was built, they could see a nice fault scarp
5 crossing through here where these dash lines are. There's -- you can see the
6 inflection in the surface here. That's typical of what an active strike-slip fault
7 looks like.

8 Also, through the aerial photos, there was a sag pond at this site,
9 marshy area that was created by fault movement, kind of down-dropping the
10 earth's surface at this location. These types of features, like a sag pond, are very
11 conducive for preserving evidence of past earthquakes. So that's one of the
12 reasons why the geologists picked this location.

13 In the subsurface, what are we looking for? Well, as I showed in
14 some of the past -- previous slides, when an earthquake ruptures to the ground,
15 it'll displace the earth's surface, it displaces the geologic strata below the earth's
16 surface, and that's shown in this first diagram right here. This is -- we can call
17 this Times -- Time One or Time Zero, when the earthquake just happened. It
18 creates the faults, they reach the earth's surface, they displace the ground, they
19 displace everything below that. Well, with time, especially in one of these sag
20 pond environments, there will be subsequent deposition after the earthquake,
21 and it'll cover up this evidence of past faulting. So you can see here, this was the
22 first geologic unit to be deposited after that earthquake. There's some other units
23 that are unbroken until the next earthquake.

24 And this is what the geologists are looking for, is independent
25 evidence of different earthquakes occurring in the subsurface. So if I dug a

1 trench right here and saw this in an exposure, I would identify an earthquake that
2 one, reached the surface. That would be the most recent earthquake. And then
3 somewhere down here, I would see that evidence for the first earthquake that
4 had occurred.

5 Here's an example of what we really see in the trenches. It's
6 actually -- this is a good example. Typically, it's not quite as nice. In this figure,
7 this is taken from the Tule Pond site, also on the Hayward Fault. And what the
8 geologists who worked on this did was we excavated a trench across the fault,
9 carefully logged both the features, such as the geologic units in the trench. We
10 logged -- and the faulting relations. And each one of these blue dash lines
11 represents an earthquake horizon. So when an earthquake occurred, we've
12 identified evidence, such as upward terminations, and increasing amounts of
13 deformation that indicate that an earthquake occurred at one of these horizons,
14 sort of like in the previous figure.

15 In fact, you can see here that this orange unit and everything above
16 it, about to this blue line, is a lot more disturbed than everything above it. And it's
17 interesting to note that this orange unit was originally deposited relatively flat, and
18 it's been deformed by about four earthquakes in this trench.

19 So what do we do with that information? Well, if we want to
20 answer the question of how often these earthquakes occur and over what period
21 of time, well, we're going to need some dating for this. And typically, in one of
22 these trenches what we have are radiocarbon samples. It can come in the form
23 of charcoal preserved, plant matter, bone. That's another example. Those
24 things can be dated through radiometric dating techniques. And we can develop
25 a model of the ages of each of those units that were deformed and when the

1 earthquakes occurred.

2 This example, we actually have a lot of different types of
3 information that helped us develop this earthquake record. We have historical
4 records. The most recent earthquake we know on the Hayward Fault there was
5 in 1868. And so we use that to pin our record. And that's represented by the
6 spike right here.

7 And then we also used a combination of radiocarbon dating of
8 plants and seeds, as well as pollen analysis, to develop this chronologic model of
9 the earthquake -- the earthquake timing at this site. And so each one of these
10 curves in the gray represents the radiocarbon age derived from a piece of
11 charcoal or a plant fiber. Those are from the individual units in the trench,
12 whereas these black probability density functions, such as this one, this one, and
13 this one, represent the timing of an earthquake in calendar years.

14 So what we have here is we saw about four earthquakes in the last
15 400 years. That's three intervals between earthquakes. And what you might
16 hear a lot about are average recurrence intervals for a fault. Well, there's three
17 intervals, and you take the 400 years, you do some simple division, even a
18 geologist can do it, you come up with an average recurrence interval of about
19 130 years.

20 The one thing to note is that each one of these probability density
21 functions for an earthquake age, it's not just one single date, it's kind of a range.
22 And so they don't always happen periodically. And within the uncertainties of the
23 dating, the individual intervals between earthquakes should be less than 100
24 years or could be as much as 150 years.

25 The other thing geologists try to do is they try to measure how fast

1 the fault is moving through geologic time. Jeanne here talked about GPS trying
2 to measure how fast faults are moving. Well, GPS has only been around for the
3 last, you know, 30 or 40 years. That's a very short interval of time to measure
4 how fast the fault's moving, and it's not really averaged over a lot of earthquakes.
5 And so what we're doing is getting how fast the faults are moving in geologic
6 time. So hundreds, thousands, tens of thousands years, that's what we're
7 looking for to average out the, you know, tens or hundreds of earthquakes that
8 have occurred along a fault.

9 Here's an example in map view of a stream that's been
10 progressively offset. I showed an example of this a little bit earlier, which we'll
11 revisit in a second. Initially, the stream crossed the fault relatively perpendicular
12 to the fault strike here. During one earthquake, or several earthquakes, it was
13 offset along this fault. Sometimes these channels will be abandoned. We'll call
14 this Offset 1 from where the stream, the upper part of the stream is to this
15 abandoned channel. And then it's offset yet again. So what we want to measure
16 is the cumulative offset through time. So that's all a slip rate is. You'll hear a lot
17 about slip rates. But when we're talking about geologic slip rates, it's basically
18 the total offset of a feature, such as a stream. It can be any feature that really --
19 that crosses a fault. It could be a marine terrace, it could be a stream terrace, it
20 can even be a street curve -- curb. And so the total offset, take that, divide it by
21 the time it took for that offset to accumulate, and it's usually expressed in
22 millimeters per year.

23 Here is the real-life example from Wallace Creek. I think you've
24 seen this figure already, but this is how the calculation goes. It's fairly simple.
25 We know that we can measure this at the earth's surface. This channel has

1 been offset to about here. That's about 130 meters or 130,000 millimeters.

2 And through careful dating that a person -- a professor at Caltech
3 did back in the '80s, his name was Carrie Si [spelled phonetically], he was able to
4 conclude that this offset took about 3,800 years to accumulate, so that's
5 hundreds of earthquakes on the San Andreas Fault. So that's hundreds of
6 earthquakes on the San Andreas Fault. So by doing the division here, 130
7 millimeters or 130,000 millimeters, divided by 3,800 years, comes up with 34
8 millimeters a year. So that's the slip rate for the San Andreas Fault. A good
9 chunk of that 50 millimeters for the total plate rate that's been tossed out in a
10 couple of talks this meeting.

11 I'm going to move onto the second part of my talk here. That's
12 forecasting earthquakes. How do we come up with the probability of
13 earthquakes? And the most recent study of this that's been done for this state
14 was called UCERF, the Uniform California Earthquake Rupture Forecast. It's a
15 joint project between the USGS, the Southern California Earthquake Center, the
16 California Geological Survey. In part, it was sponsored by the California
17 Earthquake Authority, which administers a good chunk of the earthquake
18 insurance within the State of California.

19 So this process takes place under the umbrella of what's called the
20 Working Group on California Earthquake Probabilities. And they've met
21 periodically over the last 20 years to calculate the probabilities of earthquakes.
22 And when they first started out, they were concerned mainly with the largest
23 faults within California, San Andreas, the Hayward Fault back in 1988. [coughs]
24 Excuse me.

25 MALE SPEAKER: Want to grab some water?

1 MR. DAWSON: They've shifted their focus through time to different
2 regions of the state. In 1990, they focused mostly on the northern San Andreas
3 Fault and Hayward Fault system. 1995 was when the first big regional studies
4 focusing on Southern California. 2003 was the second of the big regional studies
5 focusing on the Bay Area. And most recently, in 2007 was the first statewide
6 earthquake probability forecast.

7 The process is really designed to develop a consensus model for
8 the probability of earthquakes within California. It has participants from
9 academia, industry, and government working on this, each tapping into their
10 various strengths as to what they're experts in. And this is used as a model that
11 finds its way into public policy. So the earthquake probabilities that are
12 developed by these working groups are used to building codes, earthquake
13 insurance rates, and hazard mitigation.

14 As I mentioned, 2007 was the first statewide application of the
15 working group, and it was sponsored in part by the California Earthquake
16 Authority, who is interested in a kind of -- a consistent treatment throughout the
17 state.

18 So what is an earthquake rupture forecast? Well I think this figure
19 really illustrates what we're getting at when we're trying to find the balance of
20 what goes into the system and what's released in the system in earthquakes.
21 And so the forecast seeks to use all the available data that we can get our hands
22 on; the geology, the geophysics, the seismology, geodesy, to assess the number
23 of earthquakes and the sizes of these earthquakes.

24 What we do know and have a good handle on is like what's going
25 into the system. This plate rate of about 50 millimeters a year or two inches, it's

1 about two inches a year that goes in across this system of faults throughout
2 California. What we are trying to get at is how that energy that's going into the
3 system is being released, and this scale kind of illustrates that. You can see that
4 as you dump more of this plate motion on this side of the scale, your earthquake
5 odds will start going up unless they're released by earthquakes, which are
6 represented by these balls. And you can see here that if you took one of these
7 big balls like a magnitude 7.8 earthquake, your earthquake odds will go down a
8 lot more significantly than if you just dumped one or two of these little 6.5
9 earthquakes into the system.

10 Okay. Almost done. So here are some of the ingredients, going to
11 try to bring all this together. Default models specifies the spatial geometry of the
12 large active faults within the system. This is done through geology and mapping
13 these fault systems at the surface, as well as some of the other things we
14 touched on today like the geophysical data that specifies the geometry, and the
15 seismicity data, which also gives us a handle on how these faults look in the
16 subsurface, as well as the depth of seismicity.

17 The deformation models. It takes all these slip rates, the geologic
18 slip rates, the geodesy and puts it onto these faults like I mentioned for the net
19 tectonic movement that goes into the system that's defined by geodesy. And
20 geodesy can also help constrain the fault slip rates as well.

21 Seismology, it's important both for the fault geometries, but it also
22 helps us figure out the rate of earthquakes located off of the larger faults.
23 Because not all of the earthquakes in the state happen on the largest known
24 faults. There's a whole spectrum of earthquakes that either occur on faults we
25 don't yet know about, or that just occur randomly throughout the state and we

1 use the rate of seismicity to define that in our analysis here.

2 Earthquake rate models. There's different ways of looking at how
3 the energy's released. This example just shows a magnitude -- two different
4 magnitude area relationships. These are different models to explain what we
5 observe in the data. And since we don't really know which model is right, we try
6 to incorporate both of them into our analysis.

7 Same with the probability models. I think Ralph earlier in the first
8 talk of the session; he talked about Reid's Elastic Rebound Theory. There's
9 been some thinking in one model, one in-member model, is that earthquakes
10 along a fault or maybe certain faults are more or less perfectly periodic.
11 However, there's other people who think that maybe earthquakes aren't perfectly
12 periodic and there's a range of different earthquake sizes that occur in fault.
13 These are represented by the saw-tooth diagrams. The top one is more or less
14 perfectly periodic; whereas, say a fault with a range of earthquakes and a
15 variation in the time of the largest earthquakes is represented by this kind of
16 noisy figure that you see down here at the bottom.

17 So all this is put together into the composite forecast. This is the 30
18 year earthquake probability for the State of California, magnitude 6.7 or larger.
19 I'm sure you're curious about some of the actual numbers, so I'll get to them and
20 wrap up the talk here.

21 But as you can see that for the smaller earthquakes are much more
22 frequent throughout the State of California, and they can happen with some
23 probability almost anywhere. This is for a magnitude greater than a magnitude
24 five. As you get up to the highest magnitude earthquakes, most of those
25 probabilities are located on the largest faults in the system. So here we have the

1 Southern San Andreas Fault, the Garlock Fault, the Northern San Andreas
2 Faults, faults that we know are active, have been active in the past, and are the
3 largest faults in the system and capable of producing some of the largest faults
4 we expect to see.

5 Here's just a summary of the highlights of the study. Southern San
6 Andreas Fault has the highest probability in the next 30 year of a magnitude 6.7
7 earthquake or larger at 59 percent, and it goes down from there. The Hayward-
8 Rogers Creek, which is probably the most dangerous fault in the Bay Area, has a
9 31 percent probability of earthquake -- a large earthquake.

10 Just to wrap up here, we just started the UCERF3 study. It's the
11 next generation of this earthquake rupture forecast. And what we're trying to do
12 is we're trying to improve the deformation model, incorporate more of this new
13 GPS data that's been coming in. We're going to include a wider arrange of fault
14 behaviors not addressed in previous models. I think someone in the first session
15 mentioned how the Denali earthquake actually started on a thrust fault before it
16 turned into a strike-slip faulting earthquake. That really has been looked at in
17 detail in past earthquake probability studies for California, and we're going to look
18 at that.

19 And finally, something that I'm not really involved with, but will
20 hopefully happen with this next generation of study, is real-time forecasting; and
21 that if an earthquake happens somewhere in the state of significance, they'll be
22 able to adjust the probability model as it happens to forecast areas where there's
23 a higher likelihood of seismicity, large earthquakes occurring because of that
24 adjustment and the stress from that earthquake that had just occurred.

25 And I think that's it. We go on to the question session. Thank you.

1 [applause]

2 MR. BURTON: Victoria, Jeanne, Tim, thank you. Great
3 presentations. We are running a little bit behind schedule, but we do want to
4 allow time for some questions related to the session. After that, we're going to
5 be going to lunch, so I'll go on and open it up. Now, I will say just before we get
6 started, Bill offered to switch places with me, but I told him I'm invested on this
7 side of the room --

8 [laughter]

9 -- and I am very confident that my side will come roaring back with
10 a lot of questions. So if you don't mind, we'll start on this side, and we do have a
11 question. And give us your name. You can stand.

12 MR. PECK: My name is Michael Peck -- oh, you're not supposed
13 to give up your microphone -- my name is Michael Peck. I have a question for
14 Dr. Hardebeck. Thank you. You had put a picture up here of earthquakes in the
15 San Luis Obispo area and superimposed both the Hosgri and the Shoreline Fault
16 using the 3D velocity model. And in that slide, you show data points of -- on the
17 northern part of the Shoreline Fault intersecting all the way up through the
18 Hosgri. My question is, based on that data, would you say that the northern part
19 of the Shoreline Fault as it integrates with the Hosgri is active?

20 DR. HARDEBECK: Okay that -- is my mic on? No, my mic's not
21 on.

22 FEMALE SPEAKER: It's [unintelligible].

23 DR. HARDEBECK: Okay now, is it on now?

24 MALE SPEAKER: It's no -- here.

25 DR. HARDEBECK: Does this one -- here. Does this one work?

1 Oh, that one really works. What you've just asked is an incredibly important
2 question, and I hope this is something that we will get into tomorrow when there's
3 more discussion specifically of the Shoreline Fault and hazard in this area.

4 I first want to say that when I drew those lines on the map, that is
5 interpretation from seismicity locations. So there is certainly seismicity going
6 from sort of the central Shoreline Fault up all the way to the Hosgri Fault. There -
7 - that suggests that there is some sort of active faulting going all the way to the
8 Hosgri Fault. And we're currently in the process of trying to get even better
9 locations for those earthquakes to better understand whether that's really a
10 single active fault, whether that's a zone of deformation, or what exactly that is.

11 But there are certainly small earthquakes on that northern most part
12 of the Shoreline Fault, but I think it's really too early to say what that says in
13 terms of what could actually happen in a larger earthquake, whether a large
14 earthquake could rupture through there, or whether that zone could actually
15 connect an earthquake from the Hosgri Fault to the Shoreline Fault. I think that's
16 something that's an incredibly important question, and I think that's something
17 that's still kind of unanswered.

18 MR. MAIER: Question over here?

19 MS. EVERED: Yeah, I'm still from Santa Barbara. And we've been
20 continually in the last, as I remember, 30 years, been warned we're in for "the big
21 one" in Santa Barbara because in the last 700 years there's been on an average
22 a big earthquake every 100 years until this period. And we're probably 85 years
23 now overdue for "the big one." And I'd like to get anybody on the panel their
24 opinion of this. Is it just an aberration of some kind, and how might it play out in
25 San Luis Obispo?

1 MR. DAWSON: Of the last figures I showed, showed that basically
2 anywhere in this state, you could have a large earthquake, a damaging
3 earthquake. You know the probabilities for statewide are almost certain for one
4 of those earthquakes to occur. Specific to region, it's a little bit harder to address
5 without cutting up the study in even finer detail. But for the San Andreas -- you
6 know when people talk about "the big one," they usually refer to the San
7 Andreas, both the largest earthquakes within the state's history, have occurred
8 on the San Andreas -- the 1906 in Northern California, 1857 in Southern
9 California. Some of the figures that we showed in the first session looks like the
10 southernmost part of the San Andreas from the Salton Sea up to San Bernardino
11 is what people, you know, might hear them say is overdue. It's past its average
12 recurrence is what they mean.

13 I think a few weeks ago there was a newspaper article in the LA
14 Times saying that the earthquake recurrence on the San Andreas Fault, in the
15 Carrizo Plain in some of the slides I just showed, was a lot more frequent than
16 geologists thought in the past, perhaps every hundred years. And so I think if
17 you -- if you're going to live in California, you just need to be prepared for one of
18 these earthquakes no matter where you are. And in some areas, it's a lot more
19 likely than others. And certainly, Santa Barbara has a number of active faults
20 surround it. And the truth is, some of those faults, we don't really know that
21 much about, but we know they're active. And so the best bet is to be prepared
22 for these earthquakes and expect them at some time in the future.

23 MR. MAIER: Okay. Very good. I have one here. Take a stand.
24 Give your name.

25 MS. BECKER: Okay, hold my mic. My name is Rochelle Becker,

1 and I'm with -- is that on? The Alliance for Nuclear Responsibility. And you
2 talked about the complexity of the San Simeon Fault. And I was just wondering -
3 - we've also heard about a lot of the faults that are offshore are slip-strike faults,
4 that a lot of the faults that are onshore are thrust faults -- and I was wondering
5 what happens when your thrust fault onshore may meet an 1800 feet away
6 offshore fault at the shoreline. And have you had incidents of onshore faults
7 triggering offshore faults that are going in different directions?

8 MR. MAIER: Anybody want to take that one?

9 MR. DAWSON: I think -- the one thing I should clarify is that there
10 probably is really no difference in behavior of onshore and offshore faults. We
11 probably don't know as much about the offshore faults as we'd like to just
12 because they are harder to get at. It's like the paleoseismic studies that I
13 showed in my talk. They're really difficult, if not impossible, to do offshore with
14 current technology.

15 As far as faults going together, you know, we have seen instances
16 worldwide of different faults triggering other faults -- the Landers rupture is
17 commonly cited as one of those examples of one fault jumping to another fault as
18 it was mapped. The Denali Fault earthquake in Alaska started out on a thrust
19 fault and then connected with a strike-slip fault. And, you know, it's a big
20 question. And that's one of those things that we may not have such a good
21 handle on, but we're working on trying to find the range of fault behaviors and
22 how these things work together.

23 MR. BURTON: Question from Sherry.

24 MS. LEWIS: Yes. So in answer to the very first question about the
25 Hosgri and the Shoreline Fault, would then it be a great help to have more 3D

1 mapping in order to find all that stuff out? You need more research is what
2 you're saying, and does the 3D mapping help with that?

3 DR. HARDEBECK: Can I just ask for a quick clarification of your
4 question? Are you talking about the 3D seismic imaging?

5 MS. LEWIS: I was addressing primarily your answer to the very
6 first question, which is whether the two faults can connect, as I recall. The
7 Shoreline and the Hosgri can connect. Apparently, there's not quite enough
8 research yet to know whether they really are connected, if they affect each other,
9 and so to find that out, you need more research, is that true? And a sub little
10 question, does 3D mapping come into that kind of research to understand that?

11 MALE SPEAKER: Is your question would the 3D seismic imaging
12 get you that answer more or likely?

13 MS. LEWIS: That's part of the question. The first question is -- the
14 first question is, apparently, you need more research, right? And the second is
15 does 3D imaging, is that part of that research?

16 MS. LANGENHEIM: Okay. Well I'll take a stab at this. We don't
17 really have any information on timing of events on the Hosgri versus the
18 Shoreline for some of the reasons that Tim alluded to. So if we could come up
19 with a way of doing that, that might help address that question.

20 I think also you can do some theoretical modeling of faults that
21 intersect with each other; how likely they are to propagate one pathway versus
22 another? But in terms of hard data, we don't have the answer to that question
23 right now.

24 And 3D mapping would help maybe, but I think you really need to
25 get some age control on it as to whether they really are linked. Yeah, more

1 research, of course.

2 [laughter]

3 MR. BURTON: Anybody on this side? Don't fail me, guys. No?

4 Nothing? Okay. Over there.

5 MS. COCHRAN: Cochran. I have a quick question for Timothy

6 Dawson. Would you consider the land Diablo is on an earthquake fault zone

7 since there's -- since there's like 13 faults there?

8 MR. DAWSON: Well in some ways, all of California is an

9 earthquake fault zone. You know we're spreading this plate motion from one

10 side -- the western part of the state all the way over to Nevada. And so there's

11 really nowhere within California that you can go to which doesn't have some of

12 this plate deformation distributed on it. I'm not sure if that really answers your

13 question but [laughter] it's part of a fault system. There's faults, you know, that

14 accommodate all this fault motion, and how that's partitioned is -- it's a good

15 question. Most of it's partitioned on the large faults, and then there's a number of

16 less active faults where some of that motion is as well.

17 MR. MAIER: June, we may also be able to get better information

18 tomorrow during the session on Diablo. If you -- if you'd like to leave your

19 question on a card, we can maybe get an answer back to you.

20 MS. COCHRAN: But that slide that you have --

21 MR. MAIER: Wait.

22 MS. COCHRAN: -- that slide that you have --

23 MR. BURTON: Wait, need your mic. Need your mic.

24 MS. COCHRAN: -- earthquake fault zone. Remember the slide

25 that you had that had an earthquake fault zone?

1 MR. DAWSON: [assent]

2 MS. COCHRAN: Okay.

3 MR. DAWSON: The photo or the --

4 MS. COCHRAN: The photo. Okay.

5 MR. DAWSON: Okay, yes.

6 MS. COCHRAN: Okay. So would you consider then the Diablo
7 site a fault zone similar to that one?

8 MR. DAWSON: I don't think I can really answer that question
9 because I haven't looked at the Diablo Canyon site itself. That fault zone that's
10 drawn on the AP maps, that's a regulatory fault zone and that's -- in some ways,
11 it's rather arbitrary. It's done as kind of a safety buffer zone that when the
12 geologists -- when they map defaults, depending on how distributed they think
13 that fault zone is within that area, they'll draw wider regulatory zone around it
14 where they think that geologic investigations are required. And that -- the width
15 of that zone, you know, it will vary depending on how complex the fault is at the
16 earth's surface. And so without knowing what the faults around Diablo Canyon
17 look like, it would be really hard for me to decide whether I think it's in a fault
18 zone or not. And --

19 MR. BURTON: Uh --

20 MR. DAWSON: -- just because it's in that box doesn't -- at least
21 the figure that you saw, just because it's in that box, doesn't actually mean it's a
22 fault zone as much as that's what the state has mandated specific fault
23 investigations need to occur in.

24 MR. BURTON: And let me just say, as you can see, some of the
25 question specifically on Diablo Canyon, we don't really have the experts here up

1 at the panel who can ask -- who could answer those specific questions. That's
2 why we had asked folks to save those questions for tomorrow when we're going
3 to be focusing on Diablo Canyon. If you're not going to be here tomorrow but
4 you have those questions, please write them down with your contact information.
5 We will raise them tomorrow, and we'll make sure that we get them answered
6 and you get that answer.

7 It's almost 10 after 12. We're cutting into the lunchtime. So maybe
8 we can take two more questions and then we can -- we can break for lunch. Any
9 questions on this side?

10 MR. MAIER: I've got one here.

11 MR. BLECHA: Jim Blecha of Port San Luis Harbor District.
12 Curiosity, there's been a seismic vessel off of Port San Luis, three, four miles out
13 for the last two or three days. Out of curiosity, is that seismic or oil? Do we
14 know?

15 DR. LANGENHEIM: I'm not aware of a USGS vessel offshore port
16 in San Luis right now, so. They were doing surveying a year ago off of Port San
17 Luis, but I don't think they're doing it right now.

18 MALE SPEAKER: [unintelligible] now.

19 DR. LANGENHEIM: Oh, okay. [laughs] Might not be our boat.

20 MR. BURTON: What? Time for one more? Anyone?

21 MR. MAIER: This lady wanted to ask a follow-up question.

22 MS. COCHRAN: Just one quick question for Jim Dawson? Tim.
23 Has the ground underneath Diablo Canyon ever been seismically mapped? I
24 mean, do you have a seismic map of that area? Does anybody?

25 MR. MAIER: I think we have people that will be able to answer that

1 --

2 MR. DAWSON: Yeah, that's -- that's --

3 MR. MAIER: -- later.

4 MR. DAWSON: -- that's something that I can't answer. I really
5 don't know all the details of what's been studied at Diablo Canyon.

6 MR. BURTON: Barbara, would you like to ask a question?

7 MS. BYRON: [assent]

8 MALE SPEAKER: Oh, excuse me, sir.

9 MS. BYRON: I'm sorry, I just had a follow-up question for Dr.
10 Langenheim. You mentioned that 3D mapping would be helpful but that you
11 needed some age control along with that. I was just wondering if you could
12 elaborate on what that would -- what that means.

13 MS. LANGENHEIM: Well, if we could get Tim in a scuba tank --
14 [laughter]

15 -- dig a, you know -- take a backhoe, and if we could first locate
16 where the strand comes closest to the surface -- and I think they'll probably talk
17 about that tomorrow because there's some bathymetric maps that have been
18 done -- to go there and dig a trench across it and try and look at the layers like
19 they do on land, try and do it under the water, which I don't think they've done a
20 whole lot of that. But then try to get samples of carbon, or something to date, so
21 that you could actually maybe get an earthquake history for those structures
22 offshore. Does that answer your question?

23 MR. BURTON: I think that will probably do it for this Q & A. That
24 still leaves us about an hour for lunch. We're going to meet back here about 1:15
25 for Session 3. And as Bill mentioned, you're kind of on your own for lunch.

1 There are a lot of good places to eat. And we'll see you back at 1:15

2

3 [Whereupon, the proceedings were concluded]