Earthquake Science Center Strategic Plan for 2010-2015

By the Future Directions Group

(Ross Stein, *Chair*, Bill Ellsworth, Steve Kirby, Wayne Thatcher, and David Boore)

Revised 9 September 2009

Executive Summary

The mission of the Earthquake Science Center is to collect fundamental observations of earthquakes, faults, and crustal deformation; to increase our understanding of earthquake source processes, their occurrence and effects; to synthesize this knowledge into probabilistic seismic hazard assessments and mainshock and aftershock forecasts; and to disseminate the data products and research discoveries to scientists, engineers, emergency responders, and the public. We collaboratively operate the California Integrated Seismic Network, the National Strong Motion Program, and the Pacific Northwest Regional Seismic Network, as well as continuous and campaign geodetic networks throughout the western U.S. The Center also houses renowned rock mechanics and gas hydrates laboratories, major borehole geophysics facilities, and conducts extensive paleoseismic investigations. The 156 employees are located principally in Menlo Park, Pasadena, and Seattle. We carry out research with numerous partners, which provided $3.6M in operational expenses and $1.1M in salary support in 2009.

We believe that addressing the following national needs could augment our research agenda and funding base: The risk to nuclear power plants in low-to-moderate seismicity areas; the science of seismic hazard assessment; integrated investigation of fault zone rheology, fluids, fracturing, and friction; the Southern California Multi-Hazards Demonstration project; alternative energy research; the seismic vulnerability of the Sacramento delta levee system; mining the EarthScope data stream; and more effective use of the web for map and other dissemination. We recommend that two research scientists and two technicians be hired as soon as possible in Pasadena. In Seattle, we recommend that a GPS geodesist be hired to study subduction hazards. In Menlo Park, we recommend that the Center hire at least one research scientist with broad interests and capabilities to support our *Fundamental Observations* and *Synthesis* missions. We also urge the staffing of the Center Associate Directors. Finally, with Center staff distributed among six Menlo Park buildings and two remote campuses, communication shortcomings have arisen that we believe can be reduced by creating a dedicated Menlo Park gathering spot, and by encouraging and supporting staff travel between the three offices.

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Charge from Center Director Tom Brocher, and Planning Process

1. Study the research agenda, monitoring duties, and public outreach role deemed essential for the scientific strength and public visibility of the Center.
2. Understand the needs, mission, and geographical balance among Center offices in Menlo Park, Pasadena, and Seattle.
3. Identify opportunities for growth and emerging scientific fields where the Center could initiate, expand, or strengthen its activities.
4. Propose a staffing plan that is predicated on the three foregoing elements.

Process. To answer this charge, we solicited comments from all Center staff members; about 25 people responded, all with thoughtful written comments. We met with post-Docs, young and mid-career scientists informally at several evening gatherings at our homes for an open-ended discussion over dinner. We met with senior scientists attuned to scientific opportunities and threats, and talked individually to many project chiefs. We visited the Pasadena and Seattle offices and led several-hour open discussions about their needs and concerns. We held a 90-minute conference call with David Applegate and Mike Blanpied to seek their perspective. We also reviewed the guiding documents relevant to the goals and responsibilities of the USGS, our Program, the National Earthquake Hazards Reduction

Program, and related entities. The Future Directions Group met in person about a dozen times for 1-2 hours each to discuss ideas and revise the text. This meant all members needed to come from Menlo Park, but we were acutely aware of our obligation to represent the views of the offices outside Menlo Park, and hope that we have fulfilled that duty.

Statement of Values of the Earthquake Science Center

- What unites is that:
  We want to make discoveries about how the earth works
  We want to contribute to society by lessening the earthquake toll

- In tandem with these goals:
  We want to be credited for our individual work
  We want to be part of an effort larger than what we could do on our own

- We are part of a unified national USGS earthquake program with an urban focus. The regional distinctions (Southwest, Pacific Northwest, Alaska, Central) are not important to us; we work and collaborate with others in all of these regions.

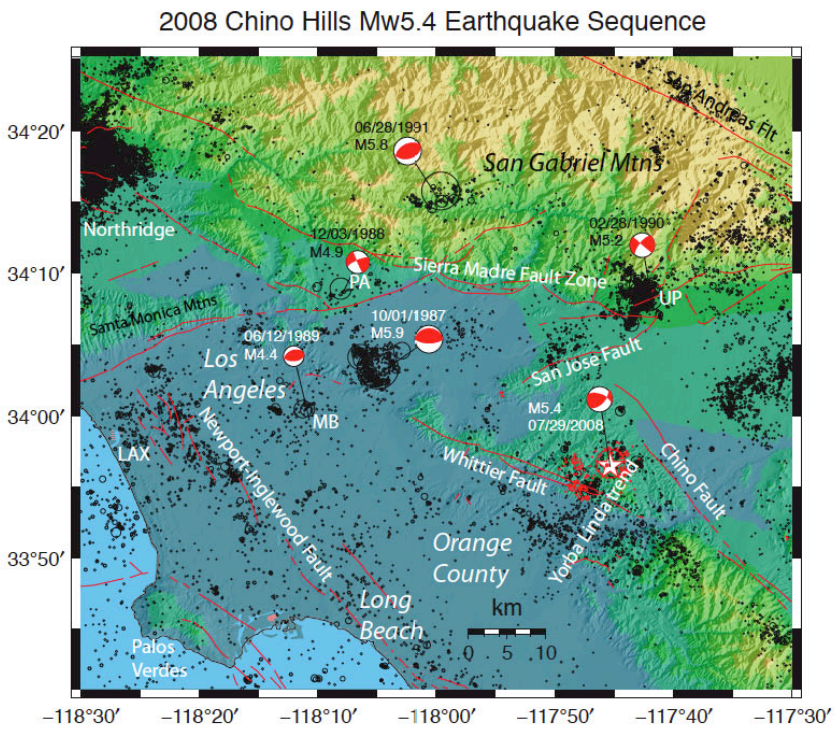
- We serve the needs of other USGS programs whenever our scientific, engineering and data management skills are needed.

Assessment of the Earthquake Science Center

Mission of the Center

I. *Fundamental Observations*: Earthquake, aftershock, fault, and strain monitoring

Seismic Data. The Center operates the California Integrated Seismic Network in cooperation with Caltech, U.C. Berkeley, and California Geological Survey; and the Pacific Northwest Seismic Network in cooperation with University of Washington. The Center also operates the National Strong Motion Program, installing sensors in the ground and in buildings to record earthquake shaking in cooperation with the California Geological Survey and Pacific Gas & Electric, U.C. San Diego, Lawrence Berkeley Laboratory, California Division of Water Resources, Veterans Administration, General Services Administration, and other partners.



Map of (1981 to 2005) seismicity recorded by the SCSN and some recent sequences in the Los Angeles basin, including lower hemisphere focal mechanisms of the moderate-sized mainshocks. The 2008 Chino Hills mainshock is shown as a red star and the aftershocks as red circles. LAX—Los Angeles Airport, MB—Montebello; PA—Pasadena; UP—Upland; WN—Whittier Narrows.

Geodetic Data. The Center operates the Northern California geodetic monitoring program in cooperation with U.C. Berkeley, and maintains and operates the Southern California GPS network in cooperation with Jet Propulsion Laboratory, the Scripps Institution of Oceanography, and the Southern California Earthquake Center. Geodetic, creep, and borehole strain monitoring is complemented by InSAR (satellite radar) imaging of rapidly deforming regions.

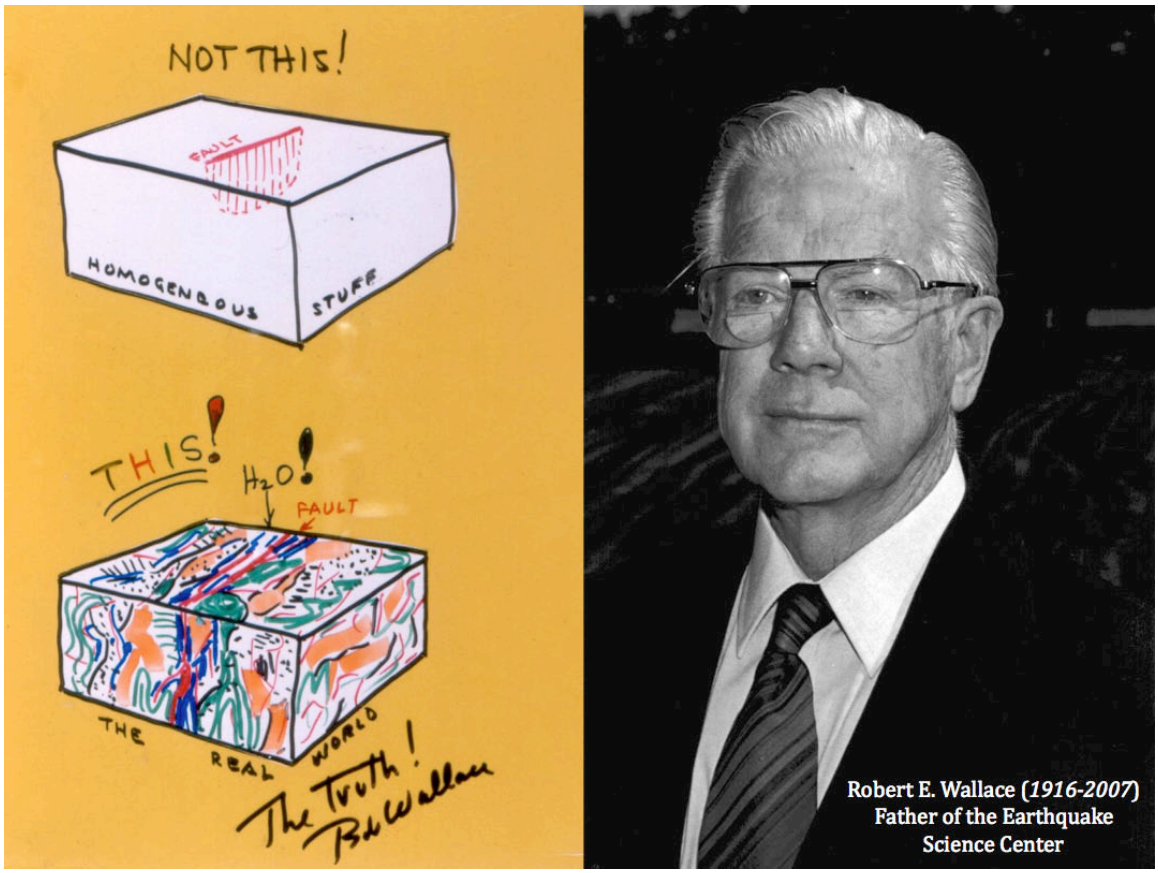
Earthquake Geology. The Center maps faults and infers their geometry, sense of slip, and slip rates, using field work, airborne and tripod LIDAR (laser ranging), satellite and aerial imagery. The Center also carries out paleoseismic investigations throughout the Western U.S. and Alaska to decipher the history of large earthquakes on major faults.

Borehole Geophysics, Seismic Imaging Surveys, Fault zone properties, and Natural Laboratories. The Center conducts borehole measurements and develops borehole instrument packages for deep fault drilling, crustal tensor strain, and heat flow. It also measures in the laboratory physical properties of fault-zone materials obtained by drilling

and carries out seismic reflection and refraction surveys to image both the shallow and deep structure of the crust and the faults and basins they often bound. Finally, the Center has established several natural laboratories that host a wide range of instruments and a broad array of studies, such as on the Parkfield-Cholame and Imperial Valley reaches of the San Andreas fault.

Tim Dawson trying to log a San Andreas trench

Post-Earthquake Response. Critical to the mission of the Center are its responsibilities after a moderate to large earthquake strikes anywhere in the Western US, and particularly in California, Oregon, and Washington. The San Francisco Bay area plan is documented in the 'Special Operating Procedures for Post-Earthquake Investigations in the San Francisco Bay Region,' which pre-assigns duties to ensure that instruments and telemetry function properly, that ephemeral phenomena such as road offsets are measured, and that staffing is adequate to deal with the press. The Center has pre-existing coordination arrangements with the state and city offices of emergency services, with the Federal Emergency Management Agency, and conducts practice drills with these agencies. A similar plan is under development in Southern California, and will be coordinated with the Southern California Earthquake Center.



Bob Wallace was first to propose hundreds of kilometers of slip on the San Andreas fault, and identified groups of contemporaneously active faults in the U.S. Basin & Range province. He encouraged a balance of fundamental and targeted research, promoted the social consciousness of USGS science, and mentored many of the Center's and the nation's leading scientists. His views and ideals remain guideposts for the Center today. The 1985 figure, with its humor and insight, is typical of his efforts to encourage and challenge` us to develop more realistic fault modeling.

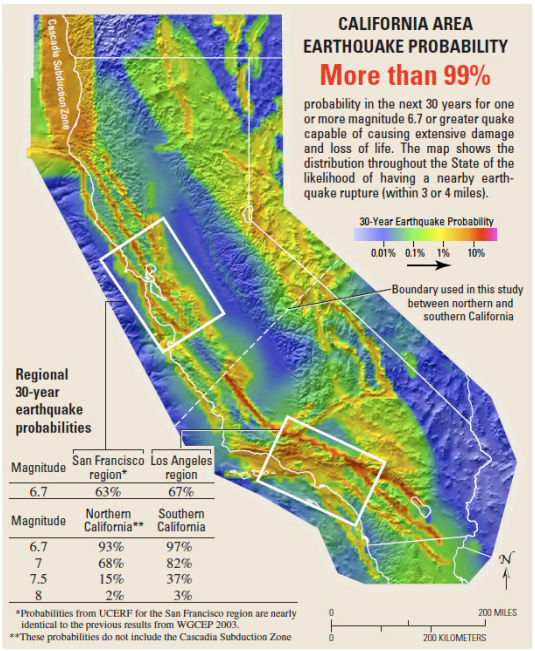
II. *Fundamental Understanding*: Research on the earthquake source, earthquake occurrence and effects

These fundamental observations serve as the springboard for making discoveries in earthquake science. The Center pursues research to probe all aspects of earthquake processes in order to advance hazard assessment methods and to improve forecasts of earthquake occurrence and effects. This includes identifying faults capable of producing moderate or larger earthquakes and determining their geometry and slip rates; understanding the role of crustal rheology, fluids in fault zones, and heat produced by fault slip through laboratory investigations; developing reliable, predictive models of earthquake

occurrence, interaction, and clustering in time and space; developing models of fault rupture dynamics capable of providing realistic, near-source seismic lip histories; developing tools for users to simulate seismograms based on models of earthquake sources and seismic wave propagation; and developing an improved understanding of ground motion and the response of buildings to earthquake shaking and fault offset.

We serve to support many federal agencies in matters pertaining to nationally and globally important issues in earth science, such as the Nuclear Regulatory Commission's reactor site assessments, the Federal Emergency Management Agency's earthquake risk assessment and mitigation programs, the Department of Energy's geothermal and gas hydrate research programs, and the National Oceanographic & Atmospheric Administration's tsunami warning system. A portion of the Center's research is carried out with international collaborators, or is focused on earthquakes or faults outside the U.S. We are frequently invited to work with foreign scientists, and we also seek to work where earthquake size or the richness of seismic records is greatest, or where the fault geometry or tectonic setting is most instructive. The majority of these studies provide insights on the U.S. seismic threat, or support hazards identification to strategic partners of the U.S.

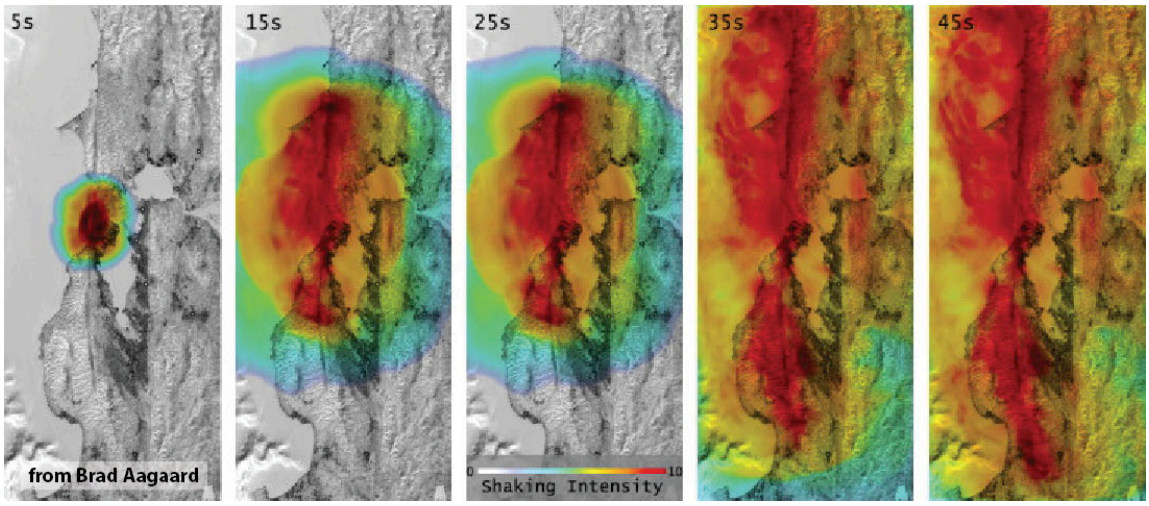
Laboratory experiments, field investigations, and numerical modeling occupy equal footing in the work of the Center, and many individual studies draw upon all three sources of inquiry. All of our research is rigorously peer-reviewed, and published in widely-distributed U.S. and international Earth science journals.



III. *Synthesis*: Seismic hazard assessments, mainshock and aftershock forecasts, and evaluation of early warning systems

Probabilistic seismic hazard assessments bring all of the Center's tools, understanding, and findings to bear in comprehensive hazards reports. They are multi-disciplinary in character, and undertaken with great scrutiny both within and outside of the USGS—these are very visible projects. An example is the recent Uniform California Earthquake Rupture Forecast report by the Working Group for California Earthquake Probabilities (WGCEP). In each successive WGCEP, we strive to capture more of the earthquake physics (such as time-dependence and clustering), and to highlight the key unresolved problems where we will need to increase our efforts (such as modeling earthquake ruptures that jump from fault to fault). These assessments are also used by the National Seismic Hazard Mapping Project of the Geologic Hazards Center to produce probabilistic shaking maps for the entire nation that are used to set building construction codes.

Another synthesis example are dynamic shaking animations produced for events like the Great 1857 and 1906 San Andreas and scenario Hayward fault earthquakes, which incorporate our understanding of the fault rupture process, the excitation of seismic waves, and their amplification in sedimentary basins. In addition, after every moderate or larger earthquake, the Center must provide aftershock likelihood statistics and shaking distributions. In collaboration with U.C. Berkeley, Caltech, and University of Southern California, we are also assessing the feasibility, desirability, and operational challenges of a California earthquake early warning system.



Simulated ground motion for the Great 1906 San Francisco earthquake

IV. *Dissemination:* Science data and public information

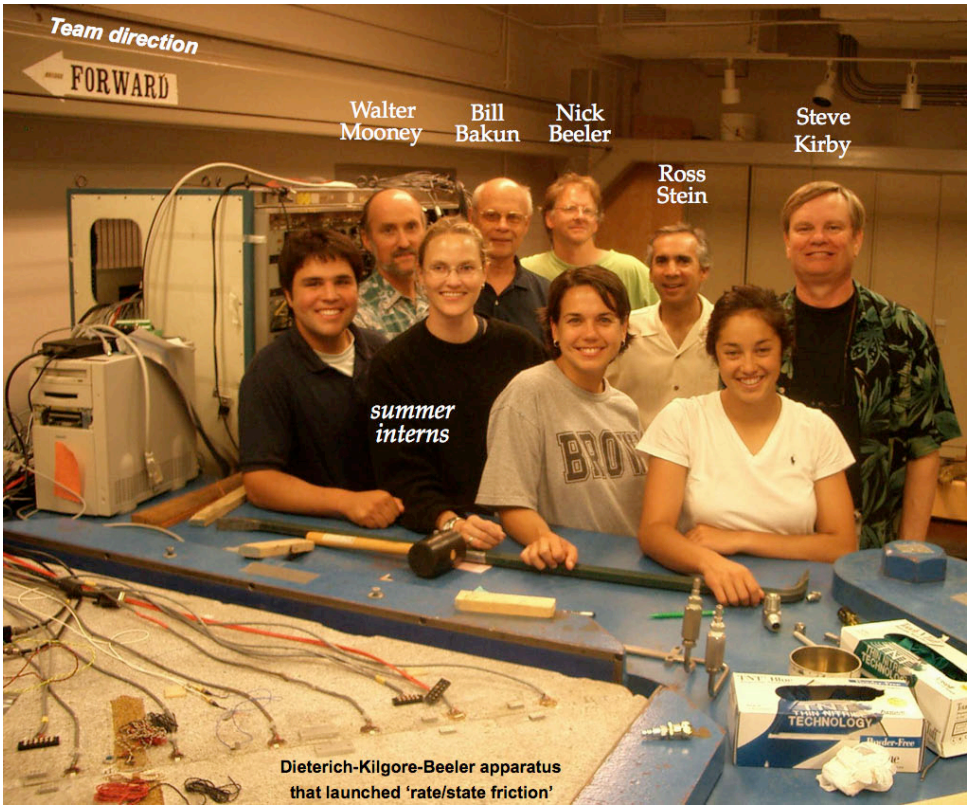
We strive to make all of our seismic, strong motion and geodetic data publicly available online in near-real time to scientists, emergency responders, engineers, public officials, and the press. We work closely with many elements of the engineering community.

In addition to our publications, many members of the Center provide plain English summaries of their studies for the public on the web. We also produce and make freely available software for use by scientists, students, and engineers. These are just some of the ways in which the Center transmits knowledge and provides tools for others to use.

The Menlo Park, Pasadena, and Seattle offices of the Center respond to a continuous stream of requests by the press to explain the earthquake threat. We have a twin compact with the public: We must tell them what we know, and we tell them what we don't know. This is how we maintain their trust.

Current Center Capabilities and those Needed for our Future

In addition to its 156 employees, the Center includes 12 emeritus scientists, 11 contractors, 6 volunteers and numerous visiting scientists and students engaged in a very broad spectrum of activities related to earthquake hazards, earthquake and volcano monitoring and basic research on the deformation of the solid Earth. The staff includes 67 scientists in research positions, 8 in equipment development (EDGE) position, 64 operational scientist and technicians, 13 administrative personnel, 4 in management positions, and the rotational position of Science Center Director.



National leadership. The stature of the staff has been widely recognized by the scientific community. Some 13 current and emeritus scientists are Fellows of the American Geophysical Union, 4 are Fellows of the Geological Society of America, and 6 are Fellows of both. Two are Honorary Members of the Seismological Society of America and one is an Honorary Member of the Earthquake Engineering Research Institute. One current and one emeritus scientist are members of the National Academy of Sciences, as are two Chief Scientists of the former Earthquake Hazards Team. Numerous Center members have been elected to national offices in these scientific societies, been awarded medals and awards, and been chosen to serve as senior editors of their leading scientific journals. Of note, in just the past two years, three Center researchers have been recognized by major early-career awards, including the AGU Macelwane Medal, AGU Aki Award, and the SSA Richter Award. Thus, there is reason to be optimistic about the future, provided opportunities for hiring scientists of this caliber continues and grows.

The Earthquake Science Center possesses very broad, interdisciplinary capabilities and programmatic responsibilities. Although most appropriated funding comes from the

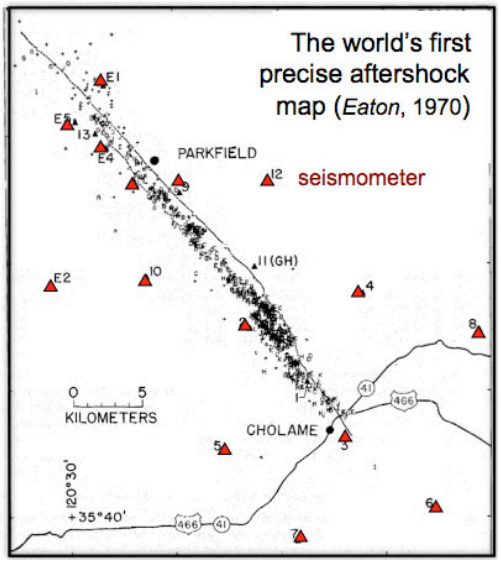
Earthquake Hazards Program, earthquake science has application to many allied problems and they are also part of the Center's core mission. This currently includes significant effort for the Volcano Hazards and Energy Resources Programs, and Dept. of Energy, NASA, the Nuclear Regulatory Agency, and Dept. of Defense, and from state and private organizations.

Operational capabilities. The principal operational activities of the Earthquake Science Center include the California Integrated Seismic Network (with Caltech, UC Berkeley and the California Geological Survey), the National Strong Motion Program and the Pacific Northwest Regional Seismic Network (with the University of Washington). The Center also operates major continuous and campaign geodetic networks throughout the western U.S.

Jim Byerlee's first big rig in 1970

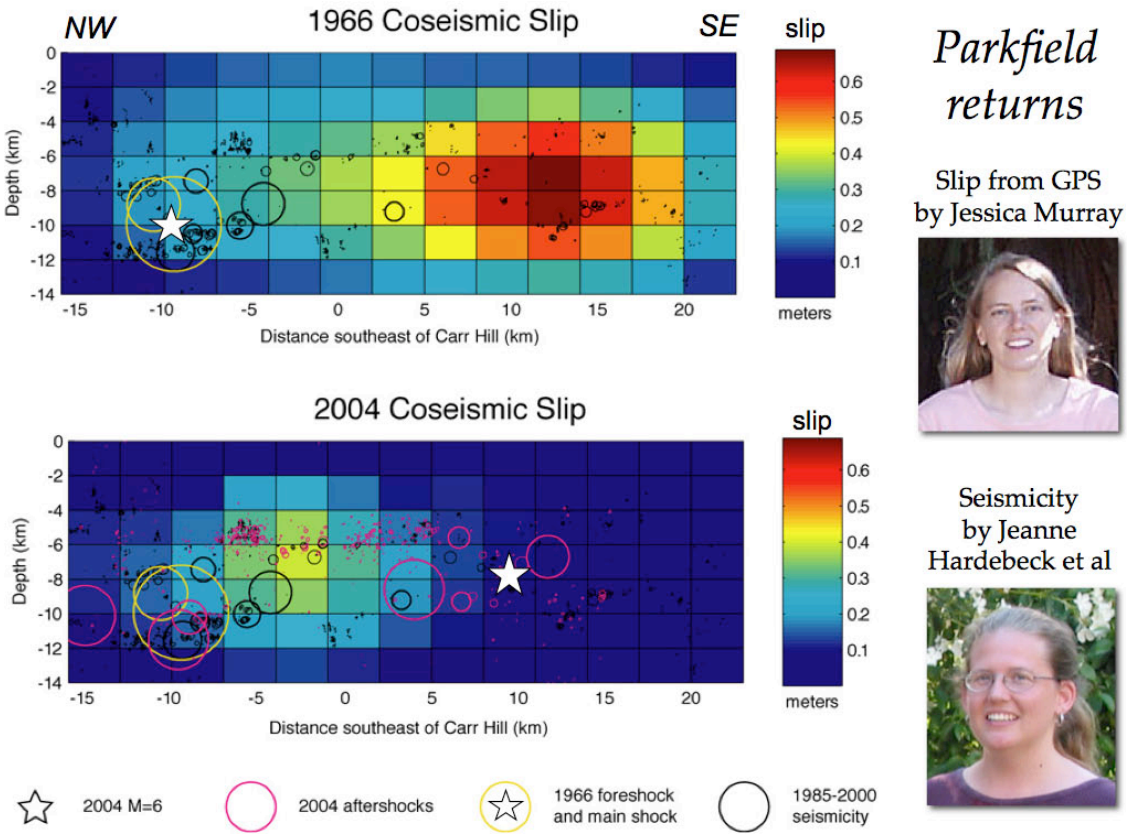
The successor rig can subject a granite cylinder to the 2,000-ton force needed to create a new fault

The Center also has major laboratory facilities that deform rocks under crustal pressure, temperature, and fluid conditions; simulate earthquake nucleation and rupture; synthesize gas hydrates; and explore mineral mobility by pressure solution and deposition. The Center has extensive, global expertise in explosion (refraction and reflection) seismology, earthquake networks, site response arrays, borehole strain, geodesy, active fault mapping, paleoseismology, and hazard analysis. The Center also operates major field experimental facilities for near-surface measurements of geotechnical properties (shear strength, liquefaction potential, etc.), and deep borehole measurement of stress and heat flow.



A balance of fundamental and targeted research. Every major operational activity or major research facility of the Center has its roots in the basic research and developmental work of the group that reaches back to its establishment in 1965. When the earthquake research program in the USGS was created at that time, there were no modern seismic or geodetic networks, few laboratory facilities, scant knowledge about the behavior of faults and little in the way of field experimental or computational capabilities to address these questions. The guiding principle for building the scientific and technical staff was then and continues today to be to hire the best and most promising people, encourage their intellectual growth, and give them the freedom to pursue new fields and lines of inquiry. The results of this policy are self-evident. The geodetic research program pioneered the application of terrestrial and space geodesy for the study of crustal deformation and earthquake source mechanics. Many of the seminal results on rock friction (e.g., Jim Byerlee's rock friction law, and Jim Dieterich's rate- and state-dependent friction) came out of the unique experimental apparatus designed and constructed in the lab. Essentially all of the software and many of the hardware systems used to detect, transmit, record, analyze, report and archive earthquakes in the U.S. have been developed by the Center staff. By combining a rigorous approach to data analysis with sound theory, the Center has made major contributions to the understanding of strong motion in earthquakes and to earthquake hazard assessment. Pioneering studies of past earthquakes in the Pacific Northwest by Center scientists in collaboration with those at the University of Washington and in Japan has transformed our understanding of the hazard for Washington, Oregon and northern California.

Today, the scientific and technical breadth of the Earthquake Science Center enables it to tackle a very wide range of key scientific problems in the solid Earth sciences. Core activities will likely remain focused on seismotectonics, crustal structure, earthquake geology and paleoseismology, laboratory investigations, seismicity, rupture mechanics, computational seismology, strong motion, site effects, soil-structure interaction, earthquake hazard assessment, probabilistic forecasting and rapid reporting of earthquakes to emergency managers and the general public. There is also a need to continue work with colleagues in the Volcano Science Center, as well as continue fundamental work on geothermal resources and enhanced production. The recent development of a Multi-Hazards Demonstration Project in southern California is showing great promise for unifying hazards research operations, and educating the public through earthquake exercises.



The Future. Looking to the future, there will be an ongoing need to renew the research, development and operational staffs if the Center is to continue to thrive and to provide national leadership in earthquake hazards. Open, national searches to fill scientific

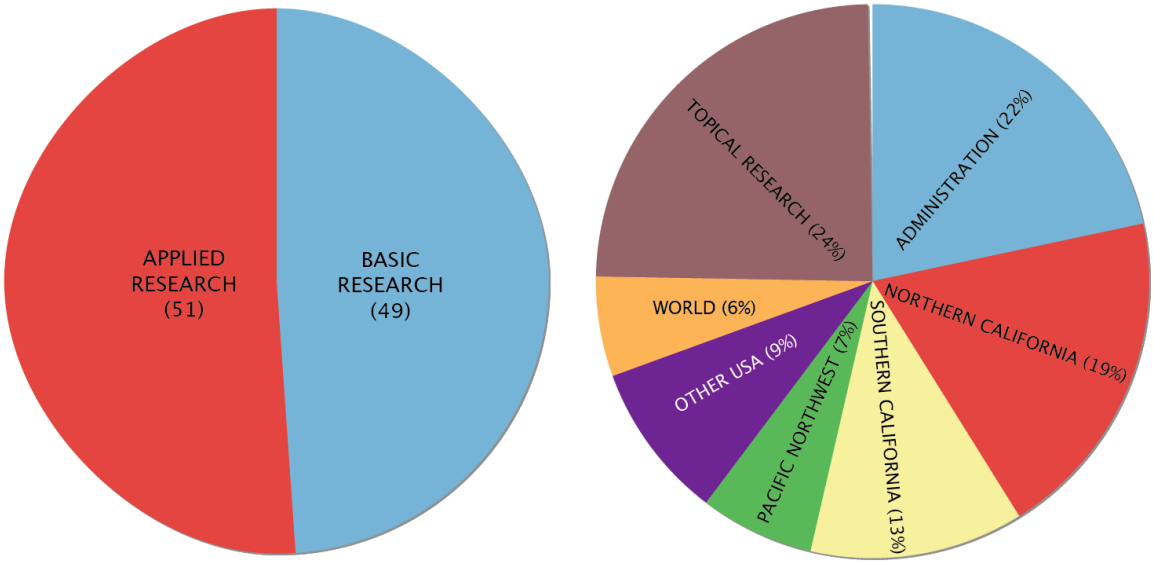
vacancies have served the group well for the past several decades and must continue to be the standard procedure for all future research hires. Mission-specific requirements may dictate an immediate need, but career potential for growth and development must be essential considerations as well. It is also clear that the ESC must continue to collaborate with our external partners in NEHRP, as we depend upon them to augment our skills and manpower. Such close partnership with academic, state government and private industry partners was essential for the successful execution of major projects such as the recently completed Unified California Earthquake Rupture Forecast (UCERF2). Maintaining the technical staff required to fulfill the major operational programs of the Center presents a different challenge, as a substantial period of training is often required to master the tasks. Staffing the seismic and geodetic networks, the laboratories and the field geology and geophysics programs needs to be carefully monitored by management to insure that the key skills required to maintain and evolve the technically complex systems will be available in the future.

The Roles, Responsibilities, and Balance among the Center Offices

Each of Center's three regional offices (Menlo Park, Pasadena and Seattle) operate seismic networks jointly with local research universities, conduct regional and topical research, and interface with the public on earthquake occurrence and hazard. Pasadena and Menlo Park also operate continuous GPS nets cooperatively with local groups. Menlo Park hosts about 80% of Center staff and carries out the widest range of monitoring, research and outreach activities. The much smaller Pasadena and Seattle offices, with 21 and 11 employees respectively, are thus challenged to execute their operational and monitoring duties and interface with the public while maintaining a vital research presence.

The Future Directions Group conducted a web poll of Center research scientists to broadly gauge the administrative, regional and topical distribution of effort and the balance between basic and applied research. Response was high (53 of 67 research grade scientists, or 79%, had replied by 8/5/09). Although these self-assessments are clearly subjective we believe the average scores provide a useful guide to how Center scientists divide their time. Results are summarized in two pie charts and discussed below.

Research is divided nearly 50-50 between 'basic' and 'applied', which we suggest is healthy and appropriate. Indeed, the majority of individual responders rated their work as at least roughly balanced (30-70 or better) between these two categories, indicating this dual role of Center research is widely practiced.



On average Center scientists spend a little more than one-fifth (22%) of their time on administration (supervision, money management, training, contract oversight, etc), more than they spend, for example, on northern California hazards. This load is not equally shared among the scientific staff, pointing to the continued need to rotate administrative responsibilities periodically to maintain a vital cadre of researchers, and to seek ways to streamline money and travel management. We also note that administrative, operational, and public affairs responsibilities fall disproportionately high on research scientists in the Pasadena office, one of several reasons why new Center staffing should be focused there.

About half (54%) of Center researchers' effort is regionally focused and 90% of that is within the United States. Because much of the scientific staff is stationed at the Menlo Park office the largest regional effort (19%) is devoted to research in northern California. However, it is worth noting that Menlo Park scientists actually devote more time to regional research in other parts of the United States than to the Bay area. Nonetheless, although southern California carries half the U. S. National earthquake risk, the Center devotes only 13% of its total effort here (about 1/4th of US regional research). This imbalance is alleviated—in part--by strong USGS Earthquake Hazard Program support for the integrated

earthquake hazard assessment carried out by the Southern California Earthquake Center (SCEC). Similarly, because of the small size of the Seattle field office, research on the Pacific Northwest, only about 10% of the regionally focused studies, should be increased. Therefore we believe the Earthquake Science Center needs to implement proactive measures that will increase regional research by Menlo Park scientists both in southern California and the Pacific Northwest.

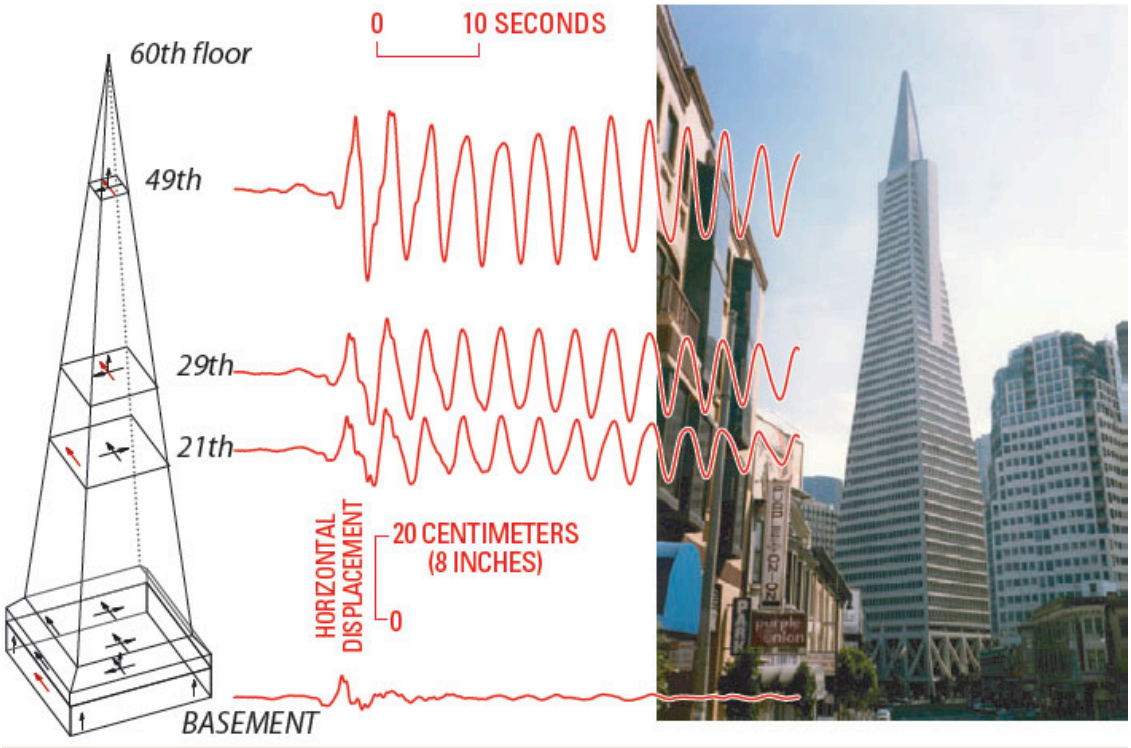
Inferred seismic sources of the Southern California Community Fault Model jointly developed by the USGS, the Southern California Earthquake Center, and the California Geological Survey, and used in the UCERF2 synthesis report.

Connections with other USGS Science Centers and Programs, Federal and State Agencies, and Schools and Universities

Our external connections not only bring a wider range of expertise and experience to the Earthquake Science Center, they provide salary and research funding that enlarges the scope of the science that we can undertake. We have major partnerships with other Federal and State agencies that need our technical expertise in earthquake-hazards and other matters, including the Nuclear Regulatory Commission, the Department of Energy, the

Department of Veterans Affairs, US AID, the Office of Foreign Disaster Assistance, and the Centers for Disease Control. Our Center also serves several major public utilities in the western U.S. (e.g., Pacific Gas & Electric and Southern California Edison) as well as geotechnical consulting companies and public works projects.

Particularly rewarding are our public engagement activities with city and regional governments, citizens and businesses, especially those within large urban areas in the west. Notable outreach activities include the Great Southern California Shakeout of November 2008, the Great California Shakeout planned for October 2009, activities of the Cascadia Regional Earthquake Workgroup (CREW) in the Pacific Northwest U.S., the 1868 and 1906 Earthquake Centennial Alliance, the Earthquake Country Alliance, and our Center's important long-term contributions to the USGS Western Region Open House.



Performance of San Francisco's Transamerica pyramid, instrumented by the Center, during the 1989 M=6.9 Loma Prieta earthquake 100 km away. As the tower swayed back and forth, but the building was undamaged.

Within the USGS in Menlo Park, collaborations with Volcano Hazards, Earth Surface Processes, Western Coastal and Marine Science Centers, and the National Research Program of Water Resources are strong, exchanging insights and expertise in network seismology,

Quaternary geology, potential-field geophysics, tsunami science, landslide hazards, the marine geology and geophysics of our continental margins, and other topics relevant to the mission of our Research Centers and Programs. Research ties also extend to science centers in other USGS regions, such as the Hazards Science Center in Golden, Colorado.

A list of our Center publications shows the exceptional range of our research collaborations in U.S. academic institutions, especially the Southern California Earthquake Center (SCEC), the University of Southern California, the University of California at Berkeley, the University of Washington in Seattle, Caltech, Stanford University, and the University of Alaska. We also work together with colleagues at universities and government agencies outside the U.S., such as those in earthquake-prone countries, such as China, the Caribbean, Greece, Indonesia, Italy, Japan, New Zealand, Taiwan, and Turkey. These collaborations with institutions outside the U.S. are especially valuable to the USGS as they provide useful data and insights about earthquake occurrence and effects in seismic belts that are analogues to those in the U.S., thus augmenting the information that we can collect in the US in a limited amount of time. The Global Earthquake Model (GEM), currently a $30M effort to build a worldwide seismic risk model, is another example of an international project for which the Earthquake and the Hazards Science Centers are providing leadership and receiving funding.

Our Center is also heavily involved in public education on hazards-related topics from grade-school level to postgraduate instruction in the U.S. and abroad. This contact with the public makes us more effective in the mitigation of earthquake effects, and creates opportunities for newly-hired staff to work in a wider earthquake research arena and to be more effective in achieving the mission of our Program. Finally, our Center has also contributed to basic research in allied fields, such as earthquake engineering, volcano hazards, geothermal energy, scientific drilling, natural-gas hydrates, the physics of planetary ices, rock physics, and materials science.

Recommendations

Promising Growth Areas to Expand our Agenda and Funding Base

We recommend that these important national needs, for which the Center has expertise and contacts, should be explored to augment our research agenda and funding base:

- **Seismic risk to critical structures.** It is clear that nuclear power plants will again be built in the U.S., as there are currently 23 submitted applications for 34 nuclear power plant sites in the US. Although there are some applications in the moderately seismic areas of Utah, South Carolina, Idaho, and Missouri, most of the applications are in low seismicity areas in which hazard assessment is difficult and needs new thinking and tools. The Center should be involved in the science behind the seismic assessments of low seismicity areas, probably through the Nuclear Regulatory Commission and the Dept. of Energy. A more comprehensive approach to the earthquake hazard facing the nation's power generation system would potentially include hydroelectric facilities.

- **The science of seismic hazard assessment.** The USGS is a leader in probabilistic seismic hazard assessment, as evidenced in the recent release of the USGS-SCEC-CGS Uniform California Rupture Forecast (UCERF2). Tools like Ned Field's OpenSHA, Fred Pollitz's earthquake simulator and Tom Parson's California finite element model could become very important in the next few years. We believe there would be support available for these efforts, through Cooperative R&D Agreements with risk modeling and insurance companies; and in fact the industry looks to the USGS to develop the best tools and make them standards. OpenSHA has a very high profile outside the USGS and so the Center will benefit by supporting its growth. The simulators (also those under development by Steve Ward and Jim Dieterich through the external program) could be part of the next generation of seismic hazards tools. Folding geodetic strain data into seismic hazard assessment is another exciting possible growth area that would be welcomed by industry. Coulomb and CoulombExpress could play a modest role here as well.

- **Fault zone rheology, fluids, fracturing, and friction.** Seismogenic faults are hydrothermal systems with fluid transport enabled by deformation-induced permeability. One source of time-dependence in earthquake occurrence likely derives from poroelastic diffusion processes in rocks outside fault zones, changes in fracture porosity and permeability within the zones, fracture healing within fault materials, fluid migration, mineralogical changes in fault zones, and changes in the physical states of sliding surfaces, including contact melting. An important long-term goal of this Science Center is to plan research in the laboratory and in scientific drilling that isolate and quantify these governing processes, and research in model design that tell us what we need to know in order to model such time-dependent behavior numerically in 3D.

- **Southern California Multi-Hazards Demonstration project**. Lucy Jones' initiative embodies the new interdisciplinary goals of the USGS for how science can best be brought to bear for the public good. She has accomplished a great deal in her first two years, and has built strong relations with the California congressional delegation. She has generously supported salary for a number of Center scientists, which is otherwise hard to win from government agencies. We should continue to remain deeply involved in the Multi-Hazards project, and help her expand its funding base.

- **Earthquake early warning.** If providing electronic warnings of earthquakes in progress seconds to tens of seconds before or after the shaking begins proves feasible and potentially useful, we inevitably will have statutory responsibility (through the Stafford Act) to issue such warnings. Exploratory joint work by U.C. Berkeley, Caltech, and the Menlo Park and Pasadena offices of the Center is funded and underway, but a working system would require a very substantial funding increase. This might be something that the Keck Foundation would be interested in launching. The scientific benefits are the required hardening of the data stream, and the increased visibility of our program.

- **Geothermal and alternative energy research**. Seismically active fault zones are geothermal systems. The Center is already involved in a number of geothermal projects, ranging from the national assessment that Colin Williams and Marshall Reed have been updating, to long-term involvement at Coso volcanic field funded by the Naval Air Weapons Station (where both Steve Hickman and Bruce Julian both have projects), to

cutting-edge enhanced recovery programs at DOE (Steve Hickman is a leader in this community and DOE will be supporting several Post-Doc at the Center under his supervision). The rock mechanics labs also have made important contributions here in the past. The potential growth in this area is obvious, and the question is if and how the Survey and the Center should participate. In addition, geological sequestration of CO_2, geothermal energy production, and enhanced recovery in oil fields can induce seismicity that can create serious problems for these industrial activities. Laboratory measurements of the key physical properties of natural-gas hydrates, considered an important clean-burning energy source of the future by DOE, was pioneered in the Center by Steve Kirby and Laura Stern and their collaborators, and are widely used in seismic exploration, well-log assessment, and pilot natural gas production from hydrates.

- **Seismic vulnerability of the Sacramento River–San Joaquin River delta levee system.** The delta lies at the intersection of seismic, flooding, water supply and contamination hazards, and so is a key vulnerability to California. The State is nearly bankrupt, so despite the importance of this topic, how do we fund it? The EPA has a new administrator, Lisa P. Jackson, who has pledged to use and abide by science. Could we seek EPA funding? Some in the Center probably have EPA contacts, and certainly our colleagues in the USGS Water Resources program do. We would suggest working with Joe Fletcher, John Tinsley, Tom Holzer, and Erol Kalkan about this, and we should engage Jeff Mount at U.C. Davis, who has been vocal and articulate about the levee threat.

- **EarthScope data analysis.** We believe that more of this massive data archive should be analyzed at the USGS. About a dozen Center scientists in all three offices are already working on the San Andreas Observatory at Depth, USArray, or Plate Boundary Observatory elements of EarthScope. We should try to take maximum advantage of this infrastructure and free data stream because of its enormous potential.

Staffing Recommendations to the Center Director

Center-wide recommendations

Associate Directors. We recommend that Tom Brocher fill the positions of Associate Director for Science and Associate Director for Operations. We feel that these people, even if serving in these capacities part-time, would free up valuable time for Tom to focus on strategic issues.

National searches for scientists. We recommend that all scientist hires be vetted through an open national search, and that the immediate Center needs to be filled are considered along with the talents, research promise, and breadth of the candidates. Many of our most accomplished scientists have had graduate research backgrounds that had little to do with the research for which they are best known. Resourcefulness, adaptability, and an ability to make progress in new fields are essential attributes .

Mission-critical operational, technical, and administrative personnel. We need to ensure that the steady retirement of our superb technical staff does not handicap our ability to meet our role in gathering fundamental observations without any breakdowns in the data stream.

Pasadena Office: *Research and technical staff are needed immediately*

About half of the nation's seismic hazard is concentrated in southern California, and the likelihood of a M~8 San Andreas event is considerably higher in southern than northern California. This essential office has suffered the greatest losses of its scientific staff over the past 5-6 years, including Erdal Safak, David Wald, Ned Field, Lisa Wald, and Lucy Jones (who, while located in Pasadena, is no longer a Center scientist). Recent term hires and Mendenhall post-Docs have strengthened the office, but do not substitute for permanent staff who can dedicate themselves to the Center's long-term mission.

We recommend that the Pasadena office be expanded by two research scientists in either Geodesy (GPS, InSAR or LiDAR) or Seismology. We also recommend that the office add two technicians, also in Geodesy and Seismology.

Seattle Office: *A research scientist in GPS geodesy would strengthen this office*

This office has recently attained critical mass through University of Washington appointments of John Vidale, Paul Bodin, and Heidi Houston, combined with USGS appointments of Joan Gomberg, and Art Frankel. In combination with Brian Atwater, Craig Weaver, Tom Pratt, and Ralph Haugerud (Earth Surface Processes), strong and diverse programs in seismology and earthquake geology have been established. Because Cascadia is a natural laboratory for the study of transient and episodic slip in subduction zones, we believe that a GPS geodesist would greatly complement the existing group, and could also interact with geodesists at the Pacific Geoscience Center in Victoria, B.C., and at Central Washington University. If necessary, this might be pursued as a shared position between the Center and the University of Washington. Such a person might also develop projects studying deformation in eastern Washington, where the Hanford reactor is located and new research needs are emerging.

Menlo Park: *A research hire to support our Fundamental Observations or Synthesis mission*

Of all the offices, Menlo Park is most affected by recent and foreseeable retirements. Over half of our research and technical staff are currently eligible for retirement. In just the past five years 11 Ph.D. scientists (Bill Bakun, Mike Blanpied, Jim Dieterich, Dave Keefer, Allan Lindh, Paul Reasenberg, Woody Savage, Bob Simpson, Bill Stuart, Ray Wilson, and Mary Lou Zoback) have retired or left the Center for employment elsewhere, and this trend will accelerate in the next 5-10 years. Over the same time period, we have hired just 4 research scientists, Brad Aagard, Jeanne Hardebeck, Erol Kalkan and Jessica Murray-Moraleda. They bring new technical strengths to the Center and are already carrying important programmatic responsibilities. But the reality of a shrinking research staff is the loss of capability to pursue new opportunities and research directions. To take full advantage of the major investments in the seismic and geodetic networks, the unique facilities for rock mechanics and borehole geophysics, and opportunities for collaboration with the other Science Centers located in Menlo Park, we believe that strategic hiring of research scientists in Menlo Park must also occur.

We recommend that the Center hire at least one research scientist with broad interests and capabilities to support our '*Fundamental Observations*' and '*Synthesis*' missions. These complementary missions frequently meet in major undertakings such as the reports of The Working Group on California Earthquake Probabilities (WGCEP) or the California Integrated Seismic Network evaluation of earthquake early warning technology. In their 2007 report, *Uniform California Earthquake Rupture Forecast, Version 2*, WGCEP identified multiple areas where a deeper understanding of fault systems and earthquake dynamics will be required to improve the resolution and accuracy of these premier Earthquake Hazards Program products. The same can be said of our ability to forecast strong ground motion and the response of buildings and lifelines. These are precisely the kinds of work that the public wants and expects us to be doing. We believe that the best way to meet these expectations and insure the Center's long-term health and vitality is to continue to renew the permanent research staff with the most capable scientists available. We should hire candidates with breadth, leadership potential, and capabilities in both basic and applied research.

How to improve Center communication, Coordination, and Socialization

Communication outside the USGS. The web presence of Center scientists is a key means by which we fulfill our dissemination mission, and our compact to inform the public. The web is often how the public learns what we are doing and becomes excited by our discoveries. We thus think the Center should put greater emphasis in getting our data mapped into Google Earth and NASA World Wind (an open source alternative), YouTube, and other widely used public sites. The new earthquake.usgs.gov site is now properly structured and hosted to permit content from our former quake.gov site to be migrated and enhanced, but this must happen right away before quake.gov goes offline in December. The USGS Professional Pages websites have also just been opened to the public (https://profile.usgs.gov/professional/About.php). These will give all participating Center scientists and their posted publications greater visibility, and it will give the public and potential collaborators better access to our research. Interlinking the Professional Pages with Center activities, such as Contact information, Recent Earthquakes, NetQuakes, etc., will be important. We suggest that Luke Blair and Scott Haefner draft a plan for these

efforts. We recommend that Professional Pages participation be voluntary but assisted and evangelized.

Communication within offices. Everyone we spoke with valued the Center seminar series as an important and open dialogue about key scientific findings. But we also received a very clear and unanimous message from our young scientists, post-Docs, interns, and volunteers that in Menlo Park there is no gathering place for casual scientific conversations. There are no regular coffee hours, and few Center social events such as BBQs (although we acknowledge that some groups, notably the Northern California Seismic Network, project do a great job of maintaining coherency and *esprit de corps* through regular social events). The Pasadena office has Friday morning 'bagels for science' gatherings, and frequent 'dog day' BBQ lunches, and often gather for bag lunches in their dining room. Even though about one-quarter of the current seminars feature USGS speakers, and most people work with their office doors open, the young scientists also felt they knew too little about the work being done by Center scientists. We recommend that a *central lounge* be provided as a way toward meeting the important goal of encouraging young scientists to talk more among themselves and with senior scientists about their work.

Communication between offices. A very clear message was sent by the Pasadena and Seattle staff that they feel like second-class citizens of the Center. We were reminded that their much smaller staffs are burdened with equal if not larger demands by the press and public than Menlo Park, and that they need to be able to contribute as equal partners with very strong scientists at Caltech, the Southern California Earthquake Center, and the University of Washington. They view these partnerships as valuable but time-consuming. The Pasadena staff spends a majority of their time maintaining the seismic and geodetic data stream for use by other scientists, and liaising with their partner academic and government institutions. They view this expenditure as insufficiently appreciated, and they feel it leaves too little time for research. "We are drowning in data" was a common refrain in both Pasadena and Seattle. Many felt that this creates an environment where the field offices are regarded as operational and Menlo Park as research-focused. Both Pasadena and Seattle offices describe themselves as critically understaffed; should a large earthquake strike either region, this shortage of people would be exacerbated. Beyond staffing increases, perhaps the most important way to change this unacceptable dynamic is to encourage a

much greater exchange among the three offices. People in Menlo Park doing work in southern California or using southern California data, for example, should spend on average a week per year working in Pasadena. Similarly, Pasadena and Seattle scientists should be welcomed and encouraged to spend more time in Menlo Park, probably also for extended stays rather than brief visits. Exchange visits between Seattle and Pasadena staff should also be encouraged. These interactions build collegial relations, and they improve the quality of research. Even day-long visits to give informal seminars and to have relaxed non-email conversations with field office scientists help break the existing patterns and start new ones. We recommend that the Center Director allocate an *inter-office exchange travel fund* to promote such travel.

Communication with other USGS programs and Centers. We feel it is equally important that scientific and collegial exchanges be promoted among the Earthquake Hazards Center staff and those in the Geologic Hazards Center and National Earthquake Information Center in Golden and Memphis, and with the Alaska Science Center in Anchorage. Understanding global earthquakes is a shared mandate of the Earthquake Science and Geological Hazards Centers, and learning from seismic and volcanic processes in Alaska is highly pertinent to the assessment of hazards in the lower 48 states. Earthquake Science Center scientists have been heavily involved, for example, of studies of the 2002 M=7.8 Denali earthquake and the behavior of the Denali fault, as well as on the 1811-1812 M~7.0-7.5 New Madrid quakes.

References and Links

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http://www.nehrp.gov/pdf/strategic_plan_2008.pdf

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http://www.usgs.gov/science_strategy/

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