GEOHAZARDS '88

A Symposium Highlighting Research on the Causes, Effects, and Prediction of Geologic and Hydrologic Hazards

Program
Abstracts

GEOHAZARDS '88
USGS
Menlo Park
November
17 & 18
SYMPOSIUM

• U.S. GEOLOGICAL SURVEY CIRCULAR 1038 •

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CARROLL ANN HODGES, editor

Symposium convened by the U.S. Geological Survey
in Menlo Park, Calif., on November 17–18, 1988

U.S. GEOLOGICAL SURVEY CIRCULAR 1038

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GEOHAZARDS '88
A Symposium Highlighting Research on the Causes, Effects, and Prediction of Geologic and Hydrologic Hazards—Program Abstracts

"Civilization exists by geological consent—subject to change without notice."
—*Will Durant*

Carroll Ann Hodges, *editor*

INTRODUCTION

Durant's prophetic observation provided the dominant theme for "Geohazards '88"—a symposium highlighting research on the causes, effects, and prediction of geologic and hydrologic hazards. The U.S. Geological Survey has long been engaged in research on hazardous environments resulting from geologic and hydrologic factors, and few places in the United States host such a concentration of natural hazards as the west coast. It was appropriate, therefore, that this forum convene at the Survey's western region headquarters in Menlo Park, California.

The purpose of "Geohazards '88" was to provide an opportunity for USGS scientists and other investigators to engage in dialog with those local, State, and Federal officials who must react to the findings of earth science research with judicious policy decisions. Making such decisions is inevitably complicated and challenging. Yet the Nation demands and is entitled to enlightened policy regarding hazardous geologic and hydrologic conditions. California, in particular, continues to serve as de facto proving ground for building codes and land-use decisions because of the frequency with which they are tested by natural events throughout the State.

The symposium attendance comprised about 200 public officials from a broad spectrum of disciplines, including elected office-holders, city managers and planners, planning commissioners, senior engineers, city, county, and State geologists, emergency response personnel, diverse State and Federal agency representatives, and science writers from the press. Participants were thus a knowledgable and eclectic group of earth science users, translators, and decisionmakers from many levels.

The papers presented in "Geohazards '88" were grouped in four sessions: (1) earthquake research, (2) landslide hazards in California and the San Francisco Bay region, (3) water resource issues and research, and (4) volcanoes and volcanic hazards; a presentation on the application of map products preceded the session on landslides. The abstracts in this report (unbound handouts at the symposium) are placed in order of presentation on the program. Each of the talks represented by these abstracts dealt with research currently in progress toward one of the Survey's basic goals—that of understanding, mitigating, and predicting geologic hazards. The symposium also featured concurrent poster presentations that complemented each of the session themes. The following paragraphs attempt to extract a major point from each abstract with a single sentence or two in order to provide a broad overview of the symposium content; the abstracts are referenced by first author only. Poster presentations are listed by title and author at the end of the program (appendix A).

Earthquake Research

The National Earthquake Hazards Reduction Program derives funding authority from the Act of the same name (Public Law 95–124) of 1977. Initially funded for 3 years, it is now subject to congressional renewal each year. Foremost among the projects under this program is the Parkfield, California, earthquake experiment, a pioneering effort (in cooperation with university scientists and the State of California) in short-term earthquake prediction. It has resulted in the first official prediction of an earthquake, expected to occur along the Parkfield segment of the San Andreas fault before 1993. This prediction is based largely on the historical periodicity of magnitude 6 earthquakes in the Parkfield area. According to **Allan Lindh**, however, statistical probability gives the earthquake a 94 percent chance of occurring by the end of 1990, dictating a need for immediate vigilance on the part of both the scientific and emergency response communities. A method for deriving probabilities of earthquakes having a magnitude of 7 or greater on specific segments of the San Andreas, Hayward, and San Jacinto faults has been devised by a working group of experts organized by the USGS on recommendation of the National Earthquake Prediction Evaluation Council. **James Dieterich** described application of this method and the derived probabilities of earthquake occurrence that provide a useful framework for making hazard assessments in California. Techniques of identifying and mapping earthquake-related hazards throughout this State were addressed by **Joseph Ziony**, who noted that remarkable progress has been made in predicting the location and severity of such hazards, permitting California to become the Nation's leader in reducing potential losses through land-use planning, engineering design, and emergency preparedness.

Evidence of faulting as deduced from disturbed, near-surface strata (paleoseismology) is yielding significant understanding of earthquake processes and frequency, as discussed by **David Schwartz**. Ground-motion analysis is crucial to engineering design of structures, and an excellent empirical data base exists in California, according to **William Joyner**; however, critical data are lacking near the source of large-magnitude earthquakes, and new theoretical methods are being developed to complement the empirical measurements. As pointed out by **Thomas Hanks**, however, in the lead-off presentation, simply raising "earthquake consciousness," even in California, poses considerable challenge to local, State, and Federal officials charged with planning for and responding to those damaging earthquakes that fortunately occur infrequently.

Applications of Map Products for Natural Hazards Studies and Disaster Operations

In addition to research activities related to natural hazards analysis, the U.S. Geological Survey plays a fundamental role by producing the base materials on which hazards data are recorded. **John Swinnerton** presented several examples of new techniques in map production, notably the accelerating use of digital cartography. Of increasingly widespread application are computerized Geographic Information Systems, which enable separate data sets to be combined in different ways for different purposes. This approach to compiling geologic, hydrologic, and cultural information has proven ideal for a wide variety of research investigations and land-use projects.

Landslide Hazards in California and the San Francisco Bay Region

The USGS Regional Landslide Research Group is engaged in a nationwide effort to map and evaluate landslide hazards, to understand their causes, and to provide both warning of impending landslides and technical assistance when and where they occur. Research is funded under the Landslide Hazards Reduction Program. Each year, landslides within the United States cause 25 to 50 deaths and property damage estimated at $1 to $2 billion. Between 1973 and 1983, California alone sustained economic damage from landslides probably exceeding $1 billion; much of this loss occurred in the San Francisco Bay region, where landslides are triggered primarily by heavy rainfall, coastal erosion, construction activity, and earthquakes. **David Keefer** outlined the results of current research projects that address this pervasive national hazard. The need for such research was made patently clear during the Bay Area rainstorms of January 1982, which produced extensive damage and prompted the research group to begin an effort to develop a landslide warning system, as described by **Raymond Wilson**; the system is now in place and proved successful during a storm sequence in February 1986. Landslides can be of several different types, depending on the fluidity of the material, as explained by **Stephen Ellen**. The consequences of rapidly moving mud flows or debris flows are very different from those of other landslides that move relatively slowly for short distances; their distinction appears to relate to soil density, which affects the amount of water a soil can absorb during heavy rainfall.

The distribution of landslides caused by rainfall may be entirely different from that produced by seismic events; earthquakes generally do not reactivate preexisting landslides but create new ones, commonly including rock falls. Studies of earthquake-induced landslides, described by **Edwin Harp**, have led to derivation of a susceptibility map for San Mateo County (on the San Francisco Peninsula), depicting four degrees of vulnerability, and new methods of predicting probability of slope failure. Another significant and successful project has involved new methods of presenting hazards information in San Mateo County; a systematic approach, using digital cartographic techniques, has resulted in a variety of maps that enable local planning agencies to arrive at informed policies for land use; the project was initiated and continues to be guided by **Earl Brabb**. Recognizing the inevitable consequences of a burgeoning population in the Bay Area, increasing at the rate of about 250 persons each day, **William Brown** presented advice on how communities can cope with the geologic pitfalls in their midst.

Water Resource Issues and Research

The session on water resource issues and research included talks on hydrologic extremes, ground-water contamination, irrigation drainage problems, San Francisco Bay studies, and hydrologic hazards related to volcanism. **David Peterson** described his work on the effects of climate on river chemistry (characterized by dissolved solids concentrations) and consequent water use. Dissolved solids concentrations are predictably low in the high-rainfall region of the Pacific Northwest and relatively high in the arid to semi-arid Pacific Southwest; this climatic effect appears in river-basin soils as well, which become more saline in dry years and thus yield a stratigraphic record of climatic history. With the current California drought being much in the news, the perspective offered by **William Nichols** was welcome; analysis of drought history in northern Nevada, derived from a 383-year tree-ring chronology, suggested that the mean duration of a drought is about 2 years. The 1987–88 drought in California did not produce greatly serious consequences, according to **Byron Aldridge**, because a large quantity of reservoir storage was carried over from 1986; a third dry year could be serious indeed.

Ground-water contamination by hydrocarbons and other immiscible fluids leaking from underground storage tanks is a major problem, as described by **Hedeff Essaid,** who cited some alarming statistics—over 3,000 leaking tanks in the nine Bay Area counties. The volatile nature of the contaminants adds a potential hazard of explosion where vapors accumulate. **Steven Gorelick** has developed computer simulation models that help determine the best way to restore a given site, thus permitting water managers to consider the tradeoff between reliability and cost when searching for feasible remediation measures.

Studies of irrigation drainage in seven Western States, completed in 1987, determined that selenium is the constituent most commonly occurring at elevated concentrations in water, bottom sediment, and biota, according to **Marc Sylvester.** The selenium that attracted national attention at Kesterson Reservoir, California, has been traced to its source in alluvial fan deposits derived from the Coast Ranges on the west side of the San Joaquin Valley. As reported by **Kenneth Belitz,** distribution of selenium in soils reflects the patterns of recharge and discharge that existed before agricultural development, as well as geographic distribution of geologic source materials. **Ronald Oremland** has discovered that toxic selenium oxyanions are reduced to elemental selenium by anaerobic bacteria, offering a promising means of restoring agricultural wastewaters to nontoxic levels by anaerobic treatment. **Ralph Cheng** reported on hydrodynamic factors influencing circulation in San Francisco Bay and the intricate relations between them; among the most significant factors are astronomical tides, river inflow, bathymetry, stratification, and winds. Despite improved practices in handling and treatment of wastes discharged into San Francisco Bay, **Samuel Luoma** has found that the limited data available seem to show little change, or even increases, in the amount of toxicants introduced into the system in the last 10 years. **William Meyer** discussed remedial engineering required at Mount St. Helens, Washington, after the massive debris avalanche resulting from the volcano's eruption (in 1980) blocked outflow from three drainages, causing two lakes to form and Spirit Lake to rise; to prevent catastrophic flooding caused by inherent instability of these landslide dams, drainage tunnels and spillways were constructed.

Volcanoes and Volcanic Hazards

The ultimate goal of the USGS Volcano Hazards Program is to reduce loss of life, property, and resources that results from volcanic eruption and related phenomena. Predictions of future volcanic activity are dependent on analyses of a specific volcano's historic activity, detailed stratigraphic, geochronologic, and chemical studies, and geologic mapping of prehistoric and historic deposits. The reports presented here stem from research and hazards assessments at United States volcanoes, results of monitoring systems established on volcanoes of known potential threat, and fundamental research on volcanic processes. In addition to those in Menlo Park, program personnel are headquartered at Cascades Volcano Observatory in Vancouver, Washington, and at the Hawaiian Volcano Observatory on the rim of Kilauea caldera. **Robert Tilling** described the nature of volcanic hazards worldwide and the activities required for effective volcanic hazards mitigation: (1) identification and assessment of high-risk volcanoes, (2) systematic monitoring, (3) fundamental research on volcanic phenomena and monitoring techniques, and (4) active participation in emergency-response planning and public-education efforts. **Dan Miller** addressed potential hazards within California, noting that more than 500 volcanic vents have been identified within the State and at least 76 of these have erupted during the last 10,000 years; there is every expectation that eruptions will occur in the future. Before the Mount St. Helens eruption of 1980, Lassen Peak was the only volcano within the coterminous U.S. known with certainty to have erupted within this century; in addition to the summit eruptions of 1914–17, two other episodes of activity occurred at the volcanic center within the past 1,000 years. According to **Michael Clynne,** eruptions most likely to recur in the Lassen area are pyroclastic and debris flows that would primarily affect valleys peripheral to Lassen Peak.

During the early 1980's attention was directed to Long Valley, on the east side of the Sierra Nevada near the town of Mammoth Lakes, where there suddenly occurred a dramatic increase in seismic activity, bulging of the entire caldera floor, and outward displacement of points around the caldera. This deformation has continued at a rate currently the highest in California, according to **Malcolm Johnston**, and is being monitored continuously with a variety of techniques and a diverse array of equipment; about 50 cm of uplift on the resurgent dome has occurred since 1980. The exact location and depth of the magma chamber at Long Valley have been of considerable interest and concern during this decade of unrest, and **H.M. Iyer** described the latest technique for determining the subsurface configuration of a volcano. Seismic tomography has identified magma chambers as shallow as 4 to 5 miles beneath the surface at Long Valley, coincident with depths obtained using seismic shadow methods.

The session on volcano research closed with a panel discussion incorporating speakers from outside the USGS, who provided commentary on the effectiveness of scientists in communicating with the public in general and with officials responsible for policy decisions in particular. The panel, which included scientists, an emergency response officer, an elected county supervisor, and a representative of the press, was moderated by **David Hill**, USGS Chief Scientist for Long Valley investigations. Panelists were: Michael Guerin, Assistant Chief, Law Enforcement Division, California Office of Emergency Services; Andrea Mead Lawrence, Mono County Board of Supervisors; George Mader, City/County Planner, William Spangle and Associates; Stephen McNutt, seismologist, California Division of Mines and Geology; Dan Miller, volcanologist, U.S. Geological Survey; Brian Tucker, Acting State Geologist, California; and Linda Monroe, science writer, Los Angeles Times, San Diego Bureau.

Most panelists acknowledged the extreme difficulty faced by scientists in trying to inform without unduly alarming a community faced with an impending geologic hazard. The case in point was the sudden increase in seismicity and deformation that occurred in the early 1980's at Long Valley and its impact on the populace of Mono County and the town of Mammoth Lakes. A warning of possible eruption issued by the USGS had serious and unexpected political and sociological consequences, numerous aspects of which were addressed by the speakers. **Andrea Lawrence** commented on the highly emotional nature of public response to the hazard notice, and she emphasized the need for a single authoritative scientific spokesman to be in a community at times of hazard alert. **Stephen McNutt** stressed the inherent ambiguity in the role of government scientists who must announce to the public a possible hazard that can be neither quantitatively defined nor precisely predicted, but for which warning seems prudent; the importance of *pre*-crisis contact between the scientific and local communities cannot be overstated. **Brian Tucker** encouraged earth scientists to underscore the need for hazards mitigation by deferring to potential dollar loss wherever possible so that serious discussion of options available to a jurisdiction can proceed in a pragmatic manner. The great difficulty in persuading decisionmakers to include mitigation of geologic hazards in long-range community planning was discussed by **George Mader**, who spoke from experience as a consultant both on the San Francisco Peninsula and at Long Valley. The unenviable role of the State Office of Emergency Services was clarified by **Michael Guerin**, who remarked on the quandary of doing too much or too little in response to the usually inadequate and incomplete information available regarding a potential hazard at a given moment. **Linda Monroe** spoke to the issues of risk perception, difficulties of quantifying scientific information, and the perils of appearing to hide information from the public by excluding press access to scientific debate.

In addition to the above presentations, the Geohazards symposium included two principal addresses. A keynote talk by **Richard Eisner**, professional architect and Director of the Bay Area Regional Earthquake Preparedness Project, introduced the first morning's session, and **Julia Taft**, Director, Office of U.S. Foreign Disaster Assistance within the Agency for International Development, Washington, D.C., was the featured dinner speaker.

Mr. Eisner emphasized the importance of establishing close working relationships between the scientific community and emergency response agencies; only through continuous interactions and discussion can (1) emergency services personnel appreciate the inherently imprecise nature of earthquake prediction and (2) scientists begin to understand the demands and constraints governing those who must respond to sudden events in real time. The attainment of public confidence in both groups is dependent on credible and responsible press coverage, making it essential that the press corps be fully informed and accountable. Mr. Eisner cited the Parkfield prediction experiment and the earthquake advisories issued by the Office of Emergency Services as particularly successful examples of collaboration and cooperation. He concluded that "earth science information is enormously valuable in the development of public policy in earthquake safety" when the needs of all parties are considered and the "basic message is presented clearly and consistently."

Ms. Taft presented an international perspective on the magnitude of devastation caused by geologic calamities and the need to improve not only our research into their cause and prediction, but also our effort to mitigate and prevent their occurrence. Citing the multiplicity of hazards with which the Office of Foreign Disaster Assistance (OFDA) is faced annually, she noted that the effects are often exacerbated greatly by "political, social, and economic factors as capricious as the disaster-causing agents themselves." The goal of her agency is to reduce "death and human suffering caused by earthquakes, volcanoes, tsunamis, and landslides" by helping "disaster-prone countries to increase their technical competence and civil-preparedness organizational skills." For the 1990's, OFDA, in cooperation with the USGS and others, is embarking on two major initiatives: (1) a worldwide risk management program and (2) the International Decade for Natural Disaster Reduction, advocated by the National Academy of Sciences and endorsed by the United Nations. OFDA is supporting these programs with budgetary resources and technical assistance missions to a number of target host countries.

Additional highlights of the symposium dinner were scheduled remarks by former Congressman **Pete McCloskey** (local 12th District, California, 1967–83) and impromptu comments by newly elected 12th-District Congressman **Tom Campbell**. Mr. McCloskey exhorted the assembled earth scientists to remain steadfast when circumstances call for relating scientific observations that might be politically sensitive. Congressman Campbell acknowledged the importance of factoring accurate geologic and hydrologic data into the political process, particularly at a time when issues such as energy exploration in difficult environments, causes and effects of global change, and treatment of hazardous wastes are of increasing concern.

"Geohazards '88" encouraged and facilitated interchange between earth scientists and decisionmakers who seek to mitigate the hazards of living in a dynamic geological environment. As the Nation's principal earth science research agency, the USGS endeavors to transmit its research results clearly and accurately to those who depend on such information in the process of formulating public policy. This collection of abstracts is intended to enhance communication with the interested citizenry and to serve as a sourcebook outlining the range of Survey programs that address geologic/hydrologic hazards and how to cope with them.

A B S T R A C T S

[All authors are U.S. Geological Survey scientists unless otherwise noted]

EARTHQUAKE RESEARCH

DIMENSIONS OF THE EARTHQUAKE-HAZARDS-REDUCTION SPACE

Thomas C. Hanks

Give or take a few astronomical niceties, there are 3,155,760,000 seconds in a century, only several hundred of which will be attended by potentially damaging earthquake ground motion in any region of California, such as the San Francisco Bay area. Because nothing in the way of earthquakes is really happening 99.99999 percent of the time at any given place, stoking the earthquake consciousness, even in California, presents unusual challenges to local, State, and Federal officials who are nevertheless charged with the well-being of all of us, both before and after earthquakes. We applaud your steadfastness.

Other dimensions defining the space of meaningful earthquake-hazards reduction include scientific knowledge, engineering design and construction practices, quality control and regulatory concerns, and land-use policies, all of which have an implicit functional dependence on economic, social, and political matters. In this presentation, we will briefly—and incompletely—explore this *n*-dimensional space with examples from Mexico City, China, and Nevada.

MAPPING EARTHQUAKE HAZARDS IN CALIFORNIA

Joseph I. Ziony[1]

California is the Nation's leader in reducing future earthquake losses through land-use planning, engineering design, and emergency preparedness actions. This lead reflects the remarkable progress made in methods

[1]California Department of Conservation.

for predicting the likely location and severity of geologically controlled earthquake hazards.

Geologic studies of how faults have behaved during the past several hundred thousand years provide clues for predicting the location and size of future earthquakes and accompanying surface faulting.

Sediment characteristics and depth-to-water information, together with estimates of likely earthquake shaking, are used to map the liquefaction potential of alluvial basins. The potential for landslides triggered in upland areas by future earthquakes can be estimated using theoretical and empirical methods.

Predictive methods for mapping the shaking hazard are subject to considerable scientific controversy. Competing methods for mapping the potential severity of earthquake ground shaking include: (1) predicting seismic intensities from computer-based numerical models of a likely earthquake source; (2) predicting peak ground acceleration or velocity from equations linking expected ground motion with postulated earthquake magnitude, site geology, and fault slip rates; and (3) predicting relative ground response from comparative measurements of ground-motion recordings from small or distant earthquakes. An earthquake-prediction experiment in central California may provide a test of which method is most reliable.

HOLOCENE FAULTING—A GEOLOGIC GUIDE TO CHARACTERIZING SEISMIC SOURCES AND EVALUATING SEISMIC HAZARDS

David P. Schwartz

During the past 10 years the integration of geological, seismological, and geophysical information has led to a much better, though still far from complete, understanding of the relationships between faults and earthquakes in space and time. Geological studies, especially trenching and geomorphic analysis, mapping of coseismic surface faulting and secondary deformation from historical earthquakes, and investigations of fault zone structure in both unconsolidated sediments and bedrock have led to some of the most exciting and important contributions to the understanding of earthquake behavior. The ability to work backward in time and decipher past patterns of earthquake activity is critical for understanding the future behavior of faults. Such investigations are now referred to as paleoseismology, seismic geology, and earthquake geology. They have demonstrated that individual past large-magnitude earthquakes can be recognized in the geologic record and that the timing between events can be measured. Additionally, they have yielded information on fault slip rate, the amount of displacement during individual events, and the elapsed time since the most recent event. These data can be used in a number of different ways and have led to the development of new approaches to quantifying seismic hazard. Several areas appear to be especially important as paleoseismology and earthquake geology move into the 1990's. These are: fault segmentation, which provides a physical framework for evaluating both the size and potential location of future earthquakes on a fault zone; earthquake recurrence models, which provide information on the frequency of different size earthquakes on a fault; and long-term earthquake potential, an area in which significant advances have been made through the development of earthquake hazard models that use probabilistic methodology to incorporate the uncertainties in seismic source characterization and the evolving understanding of the earthquake process.

PROBABILITIES OF LARGE EARTHQUAKES OCCURRING IN CALIFORNIA ON THE SAN ANDREAS FAULT SYSTEM

James H. Dieterich

A working group consisting of 12 researchers drawn from the U.S. Geological Survey, academia and private industry was organized by the U.S. Geological Survey on the recommendation of the National Earthquake Prediction Evaluation Council. The working group evaluated the probability of a magnitude 7 or greater earthquake occurring in California on the San Andreas, Hayward, and San Jacinto faults. The faults were divided into their recognizable segments and a letter grade was assigned to qualitatively indicate the reliability of the probability estimate of each segment. For 5-year, 10-year, 20-year, and 30-year intervals, the probability for a large earthquake on each segment was calculated on the basis of time that has elapsed since the most recent large earthquake and the expected recurrence time. Expected recurrence time for most segments was estimated from displacement in the previous large earthquake and long-term fault slip rate. The probability density function employed in the computations incorporates uncertainties in recurrence time data. Along the southern San Andreas fault the principal uncertainties in derived probabilities are caused by doubts about the existence of an independent San Bernardino Mountains segment as well as by alternate interpretations of data for the Mojave segment. For the 30-year interval beginning January 1, 1988, the total probability of a magnitude 7.5–8 earthquake along the southern San Andreas fault is 0.7, assuming an independent San Bernardino segment, or 0.6, if the San Bernardino segment slips with either the Mojave segment to the north or the Coachella Valley segment to the south. In the San Francisco Bay area the 30-year aggregated total probability is 0.5 for a magnitude 7 earthquake on either the San Francisco Peninsula segment of the San Andreas fault or the Hayward fault. The 30-year probability for a magnitude 6.5–7 earthquake on the San Jacinto fault is 0.5. New data and improvements in the model on which the assessments are based will probably lead to revision and refinement of these probabilities. However, the aggregated probabilities for a region are less sensitive to uncertainties than individual segments and these results provide a useful framework for making hazard assessments in California. In addition the study provides a focus for identifying regions urgently requiring further study and illustrates some specific needs for improvement of analysis methods.

THE PARKFIELD, CALIFORNIA, EARTHQUAKE PREDICTION EXPERIMENT

Allan G. Lindh

The Parkfield segment of the San Andreas fault has experienced six magnitude-6 earthquakes at remarkably similar intervals during the last 130 years. Seismograms from the 1922, 1934, and 1966 events reveal these earthquakes to have been essentially identical to one another. The anticipation that this seismicity pattern will continue with another magnitude-6 Parkfield earthquake before 1993 has led to the first officially recognized long-term earthquake prediction issued in the United States.

The Parkfield prediction is an unprecedented opportunity for the U.S. Geological Survey, in cooperation with university scientists, the State of California, and the people and landowners of the Parkfield area, to conduct an extensive experiment in short-term earthquake prediction. The unique advantage of the Parkfield situation is that it has permitted us to concentrate large numbers of diverse geophysical instruments along a 30-km stretch of the San Andreas fault. Instrument networks that have been installed or expanded since 1985 include:

Several hundred seismometers, in several separate networks, designed to record activity ranging from microearthquakes through magnitude-5 foreshocks to mainshock strong motions;

A two-color laser geodimeter that measures changes of less than 1 mm in the lengths of 18 baselines 1 to 9 km long;

Ten creepmeters recording displacement across the surface trace of the San Andreas fault to a precision better than 0.1 mm;

Nine borehole strainmeters at depths of 200 to 300 m that measure deformation of the crust near the fault to a precision approaching 1 part in a billion;

Twelve ground-water-level sensors in specially drilled 100- to 200-m-deep wells that can detect water-level changes caused by deformation of the crust as small as 30 parts per billion;

Magnetometers that measure changes in the Earth's magnetic field to a precision of about 1 part in one hundred thousand.

Signals from Parkfield instruments are transmitted in real time to computers in Menlo Park via satellite, radio, microwave, and telephone telemetry. When noteworthy changes are detected in the automatic processing, programs alert scientists, who evaluate the changes against pre-approved criteria to determine an alert level grade between D (lowest) and A (highest). In the event of an A-level alert, which corresponds to an estimated 22 percent chance of the next magnitude 6 Parkfield earthquake within 24 hours, the State Office of Emergency Services in Sacramento will be notified and will in turn issue a public warning that a significant earthquake may be about to occur.

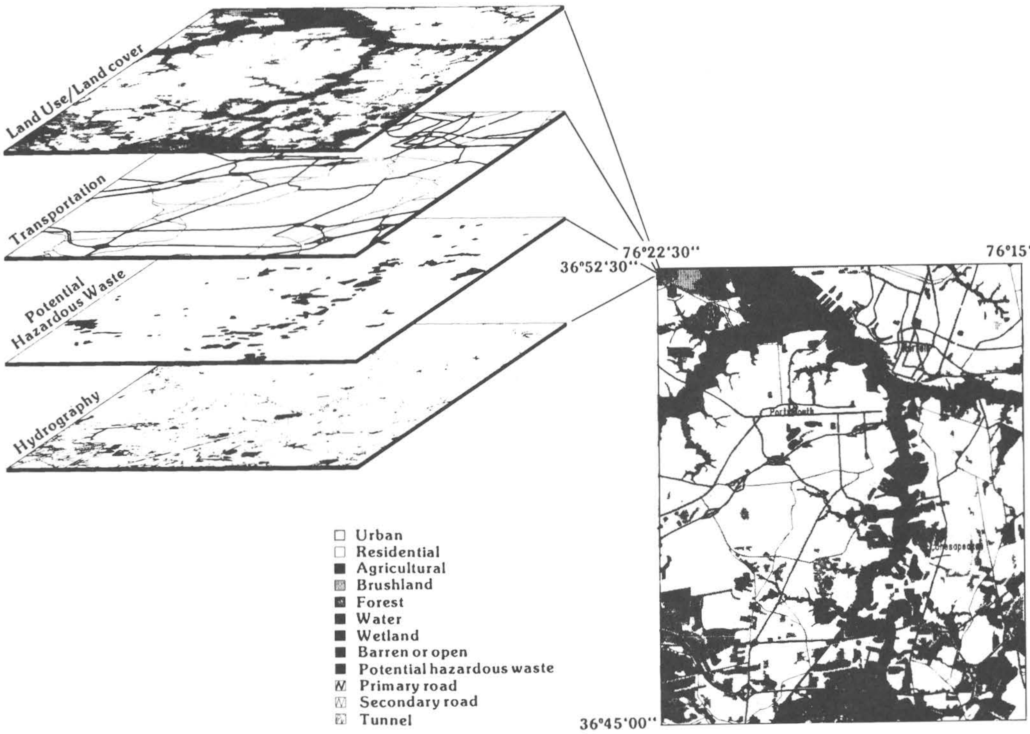
The official earthquake prediction states only that the next Parkfield earthquake is expected before 1993. But the standard probability model for Parkfield gives the earthquake a 67 percent chance of occurring in the next 12 months, and a 94 percent chance of occurring in the next 24 months. These dramatic probabilities call for vigilance by the earth scientists working to achieve the first successful short-term earthquake prediction in the United States.

ESTIMATING GROUND MOTION IN CALIFORNIA

William B. Joyner *and* David M. Boore

Estimates of ground motion in future earthquakes are required for the engineering design of structures. The primary method for obtaining such estimates is by analysis of ground-motion recordings made in past earthquakes. Equations have been developed that give the estimates in terms of magnitude, distance, and geologic conditions at the recording site. Current estimates are significantly more reliable than those of 10 years ago because of critical data recently recorded, particularly from the 1979 Imperial Valley, California, earthquake. There is still, however, a severe shortage of data from near the source of large magnitude earthquakes, just where the need for good estimates is most crucial. For that reason the top priority of strong-motion recording programs should be to obtain near-source recordings of large-magnitude earthquakes. Promising new theoretical methods are being developed for estimating ground motion. In the future these theoretical methods will complement the empirical methods.

APPLICATIONS OF MAP PRODUCTS FOR NATURAL-HAZARDS STUDIES AND DISASTER OPERATIONS



John R. Swinnerton

The earth sciences have developed many tools for observing nature's forces and processes and for documenting the changes in our environment that result from them. Maps have long been an integral element in hazards studies and disaster operations planning. In today's environment, the importance of maps takes on even greater significance when considering the growing population and its increased vulnerability to natural and technical disasters.

Within its geologic hazards activities, the U.S. Geological Survey plays an important role by producing detailed maps and measurements of the Earth's surface. Geologic and hydrologic hazards such as earthquakes, volcanic eruptions, floods, and landslides threaten public safety and can cause great economic losses.

As changes in the natural and man-made features of the land occur, the need for current and more detailed geographic information increases. Because of this need, new techniques such as map data in digital form are being applied to diverse and complex problems in the earth sciences. An important catalyst to the growth of digital cartographic data applications is the development of geographic information systems. These systems can sort rapidly through large amounts of digital data on multiple land and resource topics. Maps depicting the results of the analysis can be prepared quickly and more accurately than conventional methods by using automated procedures.

The ability to predict natural hazards is essential for land-use planning, engineering design, and emergency-preparedness decisions to reduce the loss of life, property, and natural resources. Maps help us to understand nature better. If used properly, these tools can help us live in concert with nature.

LANDSLIDE HAZARDS IN CALIFORNIA AND THE SAN FRANCISCO BAY REGION

NATIONAL LANDSLIDE RESEARCH PROGRAM AND ITS APPLICATION TO THE SAN FRANCISCO BAY AREA

David K. Keefer

Landslides cause loss of life and property damage throughout the United States. National economic losses caused by landslides are estimated to be from $1 to 2 billion and deaths from 25 to 50 each year. During the decade from 1973 to 1983, significant landslide damage occurred in at least 46 states, and 7 states—California, West Virginia, Utah, Kentucky, Tennessee, Ohio, and Washington—sustained estimated damages of more than $100 million each. Damage in California may have exceeded $1 billion. Much of this damage, as well as several landslide-caused deaths, has occurred in the San Francisco Bay region, where major causes of landslides include construction activity, coastal erosion, earthquakes, and heavy rainfall.

To respond to this nationwide problem, the U.S. Geological Survey (USGS) was designated in 1980 as the principal Federal agency for research on landslide processes, hazard mapping, and prediction. The USGS is also responsible for warning the public about landslide hazards and providing technical assistance in the wake of landslides. The Landslide Research Program of the USGS currently has funding of approximately $2.2 million per year and supports 20 researchers nationwide, including 6 in the Menlo Park, California, office. Current research applicable to the San Francisco Bay area, which is discussed as part of the Geohazards '88 symposium, includes: (1) computer-based techniques for mapping landslide hazards; (2) the first system in the United States for issuing public landslide warnings during severe storms, which has been operating in the Bay Area since 1986; (3) studies of how fast-moving, fluid debris flows are generated; (4) analyses of how and where landslides initiate during earthquakes; and (5) studies of techniques for mitigating landslide hazards and of prospects for future development considering landslide hazards and risk. Information on other elements of USGS research on landslides, such as data from our La Honda, California, experiment station and consultation on hazard mapping and warning systems, is available through the Landslide Research Program.

LANDSLIDES IN SAN MATEO COUNTY, CALIFORNIA

Earl E. Brabb

Landslides in San Mateo County range from enormous parts of hillsides that gradually shift downhill to garage-size slabs of soil that break loose during intense rainfall, liquefy, and flow rapidly downslope. Such diverse types of ground movement frequently cause millions of dollars in property damage in the county and occasionally kill people. Much of the damage and many of the fatalities can be eliminated if the problem is recognized, preferably before development takes place.

The standard technique for predicting where landslides are most likely to occur in the future is to study those locations where they have occurred in the past. This information is usually obtained from aerial photographs. Landslides interpreted from aerial photographs are plotted on a *landslide inventory map* to show where the problem has been most severe.

The landslide inventory map can then be compared with geologic and topographic maps to determine which areas are most susceptible to failure in the future. For example, a geologic map may indicate which bedrock units are tightly cemented and resistant to bedrock landslides and, conversely, which units are poorly cemented and likely to fail. A topographic map used in combination with the geologic maps shows where in a given geologic unit slopes are gentle and not usually associated with landsliding and, conversely, where the slopes are steep and generally susceptible. By comparing the distribution of landslides on the inventory map with geologic units and slope, a *landslide susceptibility map* can be prepared showing which areas are more susceptible to future landsliding. The analysis is easier if all of the maps are in digital form so that the operations can be performed by computer.

The technique of combining information from different maps to produce a new map by computer is called Geographic Information Systems (GIS) analysis. This powerful new tool has made conventional map-making techniques obsolete and has opened the door for making many different kinds of geologic hazard maps that were not possible before.

The landslide susceptibility map has been used by San Mateo County to restrict the density of housing permitted in landslide-prone areas. In areas where landsliding has occurred in the past or in areas considered to have a high potential for future landsliding, only 1 dwelling unit per 40 acres is allowed. In these areas, a detailed geologic study is needed to determine whether any dwelling can be constructed safely. If the landowners and their geologic consultant believe a higher housing density is justified, they can petition the County Planning Commission.

County-wide landslide inventory and susceptibility maps do not determine whether particular sites are safe for development; detailed geologic studies are needed to determine the stability and safety of a site. The maps do indicate those areas that have had landslide problems in the past and are likely to have problems in the future.

LANDSLIDE PREDICTION: A LANDSLIDE WARNING SYSTEM FOR THE SAN FRANCISCO BAY REGION

Raymond C. Wilson

Following the widespread destruction and loss of life from landslides triggered by the catastrophic rainstorm of January 3–5, 1982, in the San Francisco Bay region, the U.S. Geological Survey (USGS) began a concentrated research effort to develop a system to issue public warnings of landslide hazards during or before severe rainstorms. Rapidly moving debris flows (colloquially known as "mudslides") are among the most numerous and dangerous of several different types of landslides produced by severe rainstorms in California. Debris flows begin when the soil mantle on a steep hillside becomes saturated with water, fails by sliding or slumping, then transforms into a flowing mass of loose soil and rocks. Debris flows pick up fallen trees and other debris as they rush downslope, and finally come to rest at the bottom of the slope or mouth of a stream. Debris flows can begin suddenly, move rapidly (up to 40 miles per hour), and flow down streams or other channels for distances of up to several miles. They can smash homes and other structures, wash out roads and bridges, sweep away cars, knock down trees, and finally, bury everything under several feet of mud, rock, and other debris where they come to rest. Because debris flows often happen suddenly, usually during the course of the rainstorm, public warnings must be provided in "real time," during the storm, or better still, in advance of an approaching storm.

The landslide warning system in the San Francisco Bay region is oriented primarily toward debris flows, and is operated by the USGS in cooperation with the National Weather Service (NWS). This system consists of several elements: (1) the NWS weather-forecasting system based on satellite imagery, allowing storms to be tracked from such distant origins as the Gulf of Alaska or the equatorial Pacific into northern California; (2) a network of automatic rain gaging stations, connected by radiotelemetry to computer systems in the NWS, USGS, and other public agencies, allowing accurate, real-time monitoring of rainfall throughout the San Francisco Bay region; (3) a set of numerical relationships that predict the likelihood of debris flows in different areas, based on observed or forecast rainfall intensity and duration; and (4) the VHF-radio broadcast service operated by the NWS providing continuously updated weather bulletins to other public agencies, news media, and private citizens. The landslide warning system is still under development, but has already established its feasibility by successfully providing official public warning of hazards from debris flows during the February 12–21, 1986, storm sequence.

HOW SLIDES TRANSFORM INTO FLOWS: WHAT HAPPENS TO HILLSIDES IN THE SAN FRANCISCO BAY REGION DURING AND AFTER HEAVY RAINS

Stephen D. Ellen

During heavy rainfall, the water that soaks into the ground can trigger very different kinds of landslides. Some landslides move slowly for only a few inches or feet, during periods of days, weeks, or months, whereas others move suddenly and rapidly for hundreds of yards during periods of only several seconds or minutes. The rapidly moving landslides, which are called mudslides, mud flows, or debris flows, typically result when the slide mass becomes fluid and flows downslope. Debris flows obviously have very different consequences from those landslides that move slowly for short distances, so it is useful to understand how and why some landslides become fluid.

Our research in the San Francisco Bay area has led us to suspect that the density of soil is important to the change from solid to fluid. Soil that is densely packed cannot hold enough water to flow, so it must loosen up during sliding to become juicy enough for flow. Soil that is loosely packed, in contrast, can hold enough water in its pore spaces to permit flow immediately when the soil mass shifts even slightly by sliding. Also, the debris flows that result from loose soils can be considerably more fluid than those that originate from dense soils, so loose soils appear capable of faster and farther flows. We are devising ways to test soils for the critical degrees of looseness, and we are applying these tests to sites of known landslide hazard. Such research is aimed at developing test procedures that consulting geologists and engineers can use to determine the behavior and impact area of potential landslides, and is part of our work on a landslide warning system for the San Francisco Bay region.

Predicting the likely sources and paths of debris flows is also an important element in our landslide warning system, because people need to know where, as well as when, landslide hazards exist. We are developing a method for mapping debris-flow hazard that uses computers to measure the landscape in order to identify the most likely sites of landslides capable of turning fluid, as well as the likely paths and extents of debris flows from these sites. Hazard maps created by such methods, when combined with our developing understanding of landslide timing and behavior, will help change debris flows and other landslides from unpredictable, frightening, and costly hazards into predictable and largely avoidable events that we can live with.

LANDSLIDES CAUSED BY EARTHQUAKES: WHAT HAPPENS TO HILLSIDES DURING EARTHQUAKES

Edwin L. Harp

Landslides cause many of the fatalities and much of the property damage during earthquakes. Post-earthquake studies worldwide show that when mountainsides collapse during an earthquake, tens of thousands of people and large tracts of towns and cities can be destroyed. Even a moderate earthquake can cause landslides over hundreds of square miles and cause landslides many tens of miles from the epicenter.

Using data from historical earthquakes worldwide, scientists systematically have analyzed the types, geological environments, and areal distribution of earthquake-triggered landslides. These studies indicate that certain slopes and materials are especially susceptible to particular types of failures. Materials most prone to failure are: (1) weakly cemented, weathered, sheared, intensely fractured or closely jointed rocks; (2) less fractured rocks with prominent discontinuities; (3) cohesionless sand deposits; (4) saturated volcanic soils; (5) deposits of wind-blown glacial silt; (6) cemented soils; (7) clay-free sediments from river deltas; (8) river deposits with little or no clay; (9) uncompacted or poorly compacted artificial fill with little or no clay. The studies also show that earthquake-triggered landslides may occur in areas entirely different from landslides caused by rainfall. Furthermore, earthquakes generally do not reactivate pre-existing or old landslides but create new ones in different locations. Of the types of landslides occurring during earthquakes, rock falls are the most common.

Geologists and engineers at the U.S. Geological Survey have devised a method for predicting the potential for earthquake-induced landslides in San Mateo County, Calif. A map depicting potential slope instability during an earthquake was prepared using slope steepness, average properties of the slope material, and estimated ground motions from earthquakes of the type likely to occur in the county. The map depicts four degrees of landslide susceptibility, ranging from very low to high, and has an explanation of its uses and limitations for decisionmaking about land use in the county.

USGS scientists have also used seismic slope-stability information in a probabilistic format to predict the distribution of slope failures that might occur during a given earthquake. In map form these data show the areas affected by a postulated earthquake and the probability that susceptible slopes will fail during that earthquake.

Maps such as these, the first of their type ever produced, present new and significant insights into the problem of earthquake-induced landslides and present opportunities to prepare for them.

COPING WITH LANDSLIDE HAZARDS IN CALIFORNIA AND THE SAN FRANCISCO BAY REGION

William M. Brown III

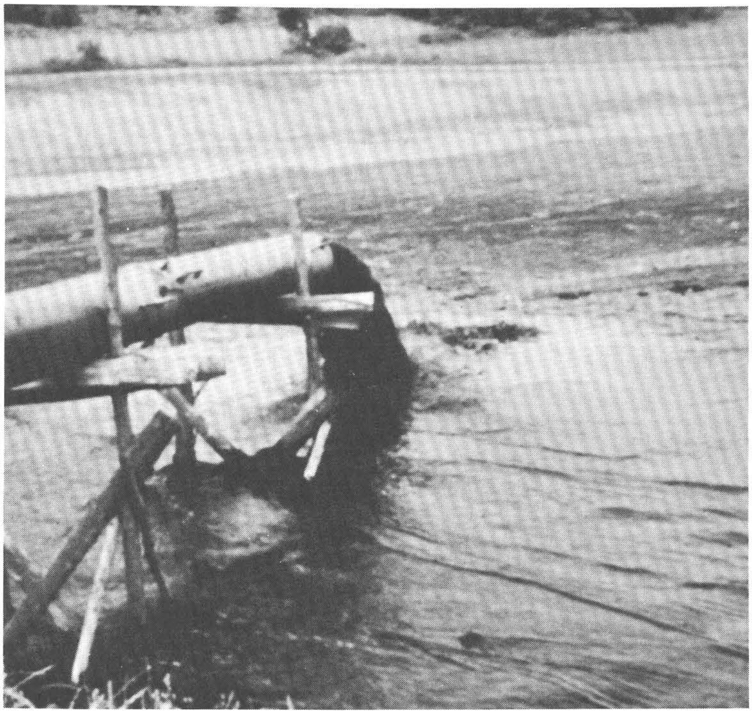
Landslides pose hazards of undermining or overriding structures; disrupting roads, pipelines, canals, powerlines, and other lifelines; damaging reservoirs; blocking streams and rivers; and other potentially catastrophic actions. For California, landslide hazards are present in most of the hilly and mountainous areas of the Coast Ranges and Sierra Nevada. Particularly in the Coast Ranges, many broad hillside areas are almost completely mantled with active landslides, ancient landslide deposits, or combinations thereof. The widespread presence of these features guarantees that landsliding will occur under the proper circumstances. The history and potential of landslide activity, as evidenced by occurrences in recent rainstorms and earthquakes, and because of certain land-use practices, assures that the risks posed to people and structures by landslide movement commonly are very high in certain areas.

The risk of landslide disasters can be reduced by avoiding, partly eliminating, or reducing landslide hazards. Avoiding hazards can be done by selecting suitable sites for construction; this activity is one of intelligent foresight or, more commonly, is controlled by land-use zoning or building codes. Thorough geotechnical examination of potential building sites, including surrounding terrain whose movement might affect the sites, might allow a design that avoids the hazard. If a landslide deposit or other landslide threat cannot be avoided, it may be mostly eliminated if the unstable material can be removed and replaced with recompacted, properly drained material prior to construction. If the deposit cannot be economically removed and replaced, the risk of failure it presents can be markedly reduced by engineered methods, including partial excavation, drainage, retaining walls, pilings, and other techniques, usually in combination. Many examples of successfully avoiding, eliminating, and reducing landslide hazards in California, such as practices engendered by the grading code of the City of Los Angeles, the zoning laws of San Mateo County, or pre-construction landslide repair in many areas, show the immediate and long-term benefits of carefully considered site selection and preparation.

California's population is increasing at a net rate of about 1,000 people per day, of which about one-fourth is absorbed in the 10 counties surrounding San Francisco Bay. Because flatland building space in the region is at a premium, and hillside building sites are in demand, and the demand continues to rise, the risk of landslide disasters increases concurrently. In this situation, there is a continuing need for governments, developers, and others to reassess landslide hazards in making land-use plans, before issuing building permits, and before and during actual construction. For hazardous sites already developed, governments particularly must consider options like remedial engineering, abatement, purchase, advisories, warning, or combinations thereof. (Because governments generally must approve building, they often are held liable when a building site fails.) Governments need to have plans in place for how to react to new discoveries of hazardous areas, and how to react to warnings of impending landslide activity. For example, modern legislation affecting land-use zoning, real-estate disclosure procedures, and the like places liability on both the public and private sectors for inattention or improper attention to known hazards.

The U.S. Geological Survey (USGS), in cooperation with other agencies of the State and Federal Government, continues to develop and refine landslide-hazard maps and an experimental landslide warning system. Although the USGS does not do site-specific consulting on landslide-hazard mitigation, it makes its research results available to geotechnical consultants, engineers, planners, legislators, and others who are directly involved with and responsible for local landslide problems. For the immediate future the USGS, through its Landslide Hazards Program, seeks to encourage the prompt and productive use of its maps and warning system by all who might benefit from them toward living more safely on unstable terrain.

WATER RESOURCE ISSUES AND RESEARCH



SOME EFFECTS OF CLIMATE ON RIVER CHEMISTRY, WESTERN NORTH AMERICA

David Peterson, Daniel Cayan,[1] *and* Randy Brown[2]

Many factors influence river-water chemistry, including geology, climate, and man, the latter as a result of water- and land-use practices. Such factors are not necessarily independent. In dry years, for instance, surface-water chemistry can change by the natural processes associated with lower river flow regimes. But water use also typically changes in dry years. Ground-water consumption by agriculture generally increases in dry years, and ground-water chemistry is commonly different from river and stream chemistry. Characterizing space-time variations in river-water chemistry, simplified here as dissolved solids concentrations, is helpful in sorting out these causes of variability. The large-scale spatial variations in stream chemistry along the west coast of North America, due partly to large-scale spatial variations in climatic factors operating over time scales of centuries, millenia and longer, are obvious. Mass emissions of dissolved solids per unit river basin area are consistently high, and dissolved solids concentrations remain low in the high-rainfall region of the Pacific Northwest. These ambient relations are reversed in the arid and semi-arid regions of the Pacific Southwest. This dynamic climatic mechanism, as expressed by differences in specific mass emissions, also operates over the shorter time scales of instrumental records, as suggested by twenty years of mean-monthly specific conductance observations from the Snake River, Idaho. That is, in dry years dissolved solids concentrations in rivers and streams and, presumably, in river-basin soils increase. A series, then, of wet or dry years can shift the nature of the system to the extent that subtle but new variations in

[1]Scripps Institution of Oceanography.
[2]California State Department of Water Resources.

stream chemistry with flow are observed. For instance, over a series of dry years, specific mass emissions decline relative to the long-term average, and, presumably, soil salinity increases. This results in a shift in the annual cycle of mass emissions of dissolved solids to a higher level per unit flow for an average hydrologic year. Apparently the reverse phenomenon can follow a series of wet years. Understanding climatic-associated effects in more semi-arid regions, such as the San Joaquin River basin, California, is of interest to water users because in dry years dissolved solids concentrations can exceed 500 milligrams per liter, a threshold concentration considered critical for water use.

DROUGHT DURATION AND FREQUENCY IN THE NORTH-CENTRAL GREAT BASIN, 1601–1982

William D. Nichols

Fifty years of drought history in the north-central Great Basin, based on the July Palmer Drought Severity Index (PDSI), suggest a mean drought duration of about 2 years and a mean drought frequency of 3 to 4 years. Of the 18 drought years from 1932 to 1981, six occurred during two 3-year droughts and 5 occurred during a 5-year drought event, accounting for 11 of the 18 years. The drought recurrence interval is complicated by a 12-year period from 1941 to 1953 during which no drought occurred. The question arises as to whether 50 years of record is sufficient to define satisfactory duration and frequency statistics.

A reconstructed drought history for the same area based on July PDSI derived from a 383-year tree-ring chronology provides a longer time series to examine drought duration and frequency. The calculated July PDSI suggests there have been 100 drought years between 1601 and 1982. Of these, 32 were single-year droughts and 32 occurred as 2-year droughts. The mean interval between droughts is about 5 years, but there were non-drought periods of 16, 18, and 24 years.

DROUGHT IN THE WEST

Byron N. Aldridge

The U.S. Geological Survey (USGS) operates more than 7,000 stream-gaging stations in the United States. Most are financed jointly by the Survey and Federal, State or local government agencies. The data collection program includes documentation of significant hydrologic events such as floods and droughts. At present there is much interest in droughts, because the Western States had below average streamflow in 1987 and 1988.

Drought conditions in the Pacific Northwest were much worse in 1987 than in 1988, but little national interest developed until the Midwestern States and California began to experience droughts in the spring of 1988. A report published by the Oregon Office of the Water Resources Division summarized the 1987 drought. Annual rainfall in the West during 1987 was variable, ranging from slightly above average to much below average; streamflow was below average almost everywhere except in Arizona. Climatic elements leading to the drought were a light snowpack and a hot dry summer. What snow there was melted early. In Washington and Idaho, streamflow fell below average in late April or early May and by early June had reached all time lows for that time of year. At many stations, the flow for almost every day from June through November was the lowest recorded for that date in the last 40 or more years; however, streamflow in California was not as low as in the severe drought years of 1976–77.

Another light snowpack developed in 1988. Late spring rains in the Pacific Northwest eased drought conditions there, but these rains did not reach California; streamflow and storage in certain individual reservoirs, especially those used for municipal supply, became critically low. The normal spring rains in the Midwest did not occur, and that area went into a drought at the time crops should have been sprouting.

Some Congressmen and Department of Interior officials wanted up-to-date briefings on the drought. The USGS developed a computerized briefing program for the Secretary of Interior. The program contained current streamflow data in hydrograph form for several selected locations and maps showing the spread of the drought from April to July and the subsequent slight retreat of the drought during August and September in parts of the country.

Drought conditions as of November 12, 1988, were uncertain. The drought had eased in the Pacific Northwest because of the fall rains. Northern California had received some rain, but little had fallen in central or southern California. There was almost no snow in the central Sierra Nevada. Many streams that normally would have been flowing by this time were dry. The State and Bureau of Reclamation reservoir systems had about the same amount of water in storage as they did at the start of the 1977 drought. Reservoirs supplying water for San Francisco, Oakland, and San Jose were critically low but had not reached the extreme conditions of 1977. The water level in Lake Tahoe had dropped below the normal outlet and was within half a foot of the extreme low of 1977. Water suppliers in the Humboldt River basin of Nevada had finished the irrigation season with water in their reservoirs; however, the semi-fluid substance remaining in two reservoirs was estimated, with unknown sincerity, to be 25 percent fish.

GROUND-WATER CONTAMINATION BY IMMISCIBLE ORGANIC FLUIDS

Hedeff I. Essaid

Many ground-water contaminants commonly found in the subsurface occur as organic fluids that do not mix with water. These compounds are highly toxic and, despite their low solubility, pose a widespread hazard to ground-water resources. Approximately 20 percent of the total water requirements of the United States are supplied by ground water and, in many areas, ground water is the only economical source of high-quality water. Immiscible fluids include natural and refined hydrocarbons, as well as synthetic organic compounds such as trichloroethylene (TCE), coal tar, and creosote wastes. Leaking underground storage tanks, leaking pipelines, accidental spills, and improper waste disposal are the principal mechanisms by which these contaminants enter the ground. In 1984, the Congressional Research Service of the Library of Congress reported that 85 percent of the 1.4 million underground gasoline storage tanks in the United States were made of steel, had no corrosion protection, and were over 20 years old. At that time, it was estimated that 75,000 to 100,000 of these underground tanks might be leaking their contents into ground-water supplies. In the state of California it is estimated that there are 23,000 leaking fuel storage tanks as well as 4,500 tanks leaking solvents and other toxic chemicals. Current statistics of the San Francisco Bay Regional Water Quality Control Board indicate that there are 3,006 leaking underground fuel tanks in the nine Bay Area counties, with 990 in Santa Clara County alone. Ground-water contamination has been confirmed at 910 of these sites.

Knowledge concerning the nature of the transport of immiscible contaminants in the subsurface is limited. These fluids enter the ground as a distinct non-aqueous phase which infiltrates through the soil and flows downward to the water table. Because of the highly volatile nature of the compounds, an envelope of vaporized contaminant develops in the soil surrounding the liquid core. Build-up of these vapors in confined spaces (such as basements and sewage pipes) can lead to the potential hazard of explosion. A small fraction of the immiscible fluid will dissolve in the water phase and will be transported as a solute within the flowing water. Even at small concentrations, these compounds pose a substantial threat to the quality of drinking water supplies. Some immiscible fluids, such as gasoline, are less dense than water, and once they reach the saturated zone tend to float and migrate laterally along the water table. The fluids that are denser than water, such as TCE, sink when they reach the water table and then migrate laterally above lower-permeability horizons encountered along the flow path. Because of the complex nature of multiphase flow through heterogeneous systems and the accompanying chemical and biological interactions, the development of methodologies for predicting the movement and fate of such contaminants is still in its infancy. Current research on immiscible fluids at the U.S. Geological Survey involves study of the physics of multiphase flow, and of the geochemical and biological processes influencing the transport and fate of such contaminants. These multi-disciplinary research efforts involve field studies, laboratory experiments, and numerical simulation.

MODELS AS AN AID FOR GROUND-WATER QUALITY MANAGEMENT

Steven M. Gorelick[1]

Ground-water contamination problems in the United States are widespread. There are over 30,000 hazardous waste sites that have been inventoried by the Environmental Protection Agency and most threaten ground-water resources. It is estimated that a typical contaminated ground-water remediation activity costs about $25 million to complete. It is clear that tools to reduce this cost will be essential if the national problem is tackled.

Computer simulation models have been developed to predict the movement and redistribution of subsurface contaminants. In more recent work, these simulation models have been combined with optimization models which help determine the best way to restore a contaminated site. The simulation-management models determine the optimal well selection and their pumping rates to capture the subsurface contaminated water. New model developments have enabled inspection of prediction uncertainty so that reliable remediation schemes can be targeted. In general one wishes to know the cost of a scheme that will have a high probability that the contaminated water will be removed. On the other hand, the cost associated with overdesigning such a reliable aquifer restoration system may be prohibitive. The combined simulation and optimization model under uncertainty enables water managers to inspect this tradeoff between reliability and cost and to explore alternatives.

PRELIMINARY RESULTS OF THE DEPARTMENT OF THE INTERIOR'S IRRIGATION DRAINAGE STUDIES

Marc A. Sylvester, Jonathan P. Deason,[2] Herman R. Feltz, *and* Richard A. Engberg

Responding to increasing concern about the quality of irrigation drainage and its potential effects on human

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[2]Department of the Interior.

health, fish, and wildlife, the Department of Interior began irrigation drainage studies in 1986 in nine areas in seven Western States. These studies were done to determine whether irrigation drainage has caused or has the potential to cause harmful effects on human health, fish, and wildlife, or might reduce the suitability of water for beneficial uses. Results of the seven studies completed in 1987 are presented and are compared to baselines, standards, criteria, and other guidelines helpful for assessing the potential of observed constituent concentrations in water, bottom sediment, and biota to result in physiological harm to fish, wildlife, or humans. Selenium is the constituent most commonly found at elevated concentrations in water, bottom sediment, and biota in the study areas. Yearly variation in precipitation and streamflow, geologic sources of trace elements, arid to semi-arid climate, internal drainage basins, irrigation drainage, and pesticide usage were the factors that affected concentrations of constituents in water, bottom sediment, and biota in the study areas.

HYDROGEOLOGY OF ALLUVIAL FANS ON THE WEST SIDE OF THE SAN JOAQUIN VALLEY, CALIFORNIA

Kenneth Belitz

Alluvial fan deposits on the west side of the San Joaquin Valley, California, are the source of selenium present in agricultural-drainage water. The fans are derived from the Coast Ranges to the west and are significantly coarser at the fan heads than at the fan margins. The oxidized alluvium has prograded from the west and interfingers with reduced fluvial deposits of Sierra Nevada origin in the valley trough.

The distribution of selenium in soils reflects the patterns of recharge and discharge that existed prior to agricultural development as well as the distribution of geologic source materials. Soils beneath areas traversed by ephemeral streams have lower concentrations of selenium than those beneath interfan areas. Evaporation from shallow ground water along the valley trough and at the toes of the alluvial fans has resulted in zones of increased selenium concentration.

Most of the area is underlain by a regionally extensive lacustrine clay, which divides the system into a lower confined aquifer and an upper semiconfined aquifer. Percolation of irrigation water past crop roots and historic pumping from the lower aquifer have caused increased rates of flow and development of large downward gradients in the semiconfined alluvial deposits, but have also caused rising water levels. These changes in the flow system have increased (1) leaching of soils by irrigation water, particularly in interfan areas, (2) downward displacement of solutes, (3) evaporation of shallow ground water, and (4) the need for drainage in areas of fine-textured deposits. The areas requiring drainage tend to be characterized by the highest concentrations of selenium in the shallow ground water.

MICROBIAL GEOCHEMISTRY OF SELENIUM: A SOLUTION TO AN ENVIRONMENTAL PROBLEM

Ronald S. Oremland

Selenium oxyanions are toxic constituents of agricultural wastewaters in the San Joaquin Valley as well as other arid, irrigated regions of the Western United States. Selenium is chemically similar to sulfur and also participates in many analogous biochemical reactions. However, research conducted in my laboratory has indicated that these two elements do not have the same biogeochemical behavior. Porewater profiles of selenate and sulfate in a San Joaquin Valley core indicate that the former is removed by a near-surface process while the latter is consumed farther down the core by bacterial sulfate reduction. Experiments with sediment slurries confirmed that this near-surface process was a reduction to elemental selenium carried out by anaerobic bacteria. These bacteria use electron donors like hydrogen or acetate to reduce the selenate electron acceptor. Thus selenate is used as an oxidant to support bacterial growth in the absence of oxygen. Because sulfate does not interfere with this reduction, elemental selenium can be precipitated in high sulfate wastewaters like those of the San Joaquin Valley. This process occurs naturally in a variety of environments tested: San Francisco Bay mud, San Joaquin Valley agricultural wastewater pond sediments, and ground waters of the Central Valley. The dissimilatory reduction of selenate removes micromolar to millimolar quantities of the compound from solution. Therefore, this process holds the promise of restoring agricultural wastewaters to non-toxic levels by an anaerobic treatment.

CIRCULATION IN SAN FRANCISCO BAY

Ralph T. Cheng

Knowledge of circulation in a bay or a coastal embayment is fundamental in order to understand the evolution of the respective ecosystem. Our research efforts on tidal hydrodynamics of San Francisco Bay are an element of an interdisciplinary research program designed to address questions related to the ecosystem of the bay.

Many hydrodynamic processes take place concurrently in a tidal embayment acting at time scales differing by orders of magnitude. Thus, it is important to distinguish the characteristics of turbulence, mean flows, and long-term residual flows. Each of these processes, independently and interactively, affects to a varying degree the dynamics of an estuarine ecosystem. Similarly, spatial variations of certain control variables, such as the bay's bathymetry or the local wind distributions, determine the spatial variability of circulation in the bay. The important driving forces and important factors affecting tidal circulation in San Francisco Bay include astronomical tides, river inflows, bathymetry, stratification, and winds. Using the field data collected in the bay by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration along with the results derived from mathematical models, distinctive characteristics of tidal and residual currents and their implications on short-term (1–3 days) and long-term (weeks or longer) transport processes can be demonstrated.

FATE AND EFFECTS OF TOXICS IN SAN FRANCISCO BAY

Samuel N. Luoma

San Francisco Bay has undergone substantial physical, chemical, and biological change since the mid-1800's. These changes undoubtedly have had many causes, one of which might be discharges of toxic wastes by the growing human population surrounding the bay. It is clear that the investment in improved treatment in the last 15 years has reduced discharges of pathogenic microorganisms and oxygen-consuming wastes to San Francisco Bay. It is not certain that such improvements have kept pace with the increasing use of potentially toxic chemicals. Estimates of the fate and effects of toxic materials in the bay are plagued by uncertainties, however. The physical and chemical setting of the bay is complex; a large number and complex variety of potential toxic inputs exists; and scientific understanding in fields such as geochemistry, ecology, and ecotoxicology has some important limitations.

Understanding of toxicants in the bay has improved in the recent decades. It is becoming increasingly clear that the distribution of toxicants is patchy, in both time and space. "Hotspots" of contamination have been documented, as have areas of little detectable contamination. Contamination occurs in some localities for a year or more then recedes. Ecological disruption has been documented in the most severely contaminated "hotspots"; and physiological stress in individual organisms has been shown in other localities. In general, frequent disturbance appears to play a major role in shaping the animal community that inhabits the bay. Unfortunately, determining with certainty how important toxic inputs are as a source of such disturbance awaits advances in hydrologic science and further systematic study of the bay itself.

LANDSLIDE DAMMED LAKES AT MOUNT ST. HELENS, WASHINGTON

William Meyer, Martha A. Sabol,[1] and Robert Schuster

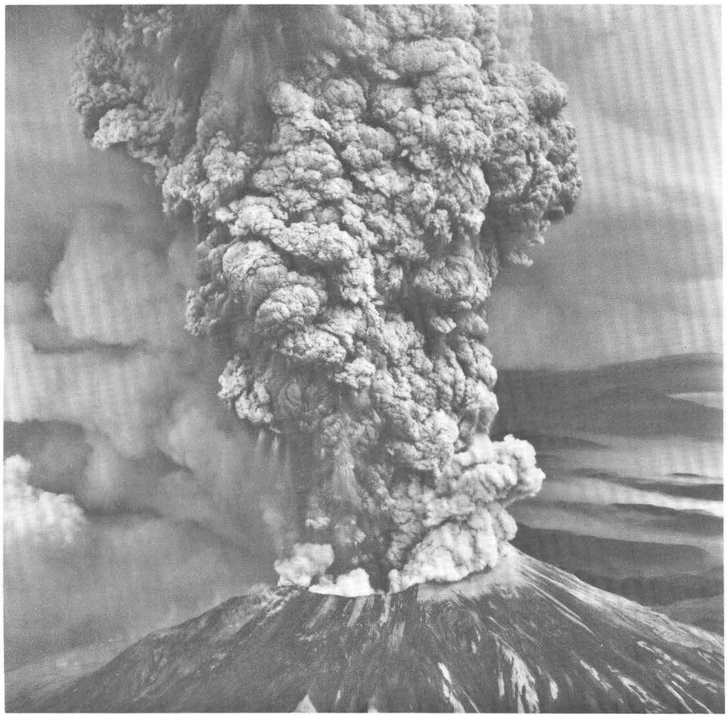
The collapse of the north face of Mount St. Helens on May 18, 1980, and the debris avalanche that resulted blocked outflow from Spirit Lake and Coldwater and South Fork Castle Creeks. Spirit Lake began to increase in size and lakes began to form in the canyons of Coldwater and South Fork Castle Creeks. Pyroclastic deposits on the crest of the Spirit Lake blockage are susceptible to piping; thus the lake level had to be stabilized below these deposits to prevent lake breakout and catastrophic flooding. Without human intervention, Coldwater and Castle Lakes would have overtopped their respective blockages in late 1981 or early 1982. Overtopping most probably would have resulted in a quick release of lake waters as a result of rapid erosion of the blockages. Catastrophic flooding would have occurred from the breakout of Coldwater Lake while serious flooding probably would have resulted from the breakout of Castle Lake. As a result, the level of both lakes was stabilized with spillways in 1981.

The three blockages are stable against liquefaction and gravitationally induced slope failure. The Spirit Lake and Coldwater Lake blockages are stable against piping at their existing lake elevations, while the Castle Lake blockage is considered to be only marginally stable against piping.

The existence of ground water in the blockages was observed in piezometers installed between 1981 and 1983. Ground-water mounds with water levels above lake level exist under the crest of the blockages. The water-level elevations are important when analyzing for blockage stability.

[1]Environmental Protection Agency.

VOLCANOES AND VOLCANIC HAZARDS



VOLCANIC HAZARDS AND THEIR MITIGATION: INTRODUCTION AND OVERVIEW

Robert I. Tilling

Worldwide, more than 1,300 volcanoes have erupted one or more times during the past 10,000 years, and about half of these have erupted during recorded history. A volcano is classified as active if it has erupted historically, dormant if it is presently quiet but expected to erupt again, and extinct if it is not expected to erupt again. However, this pigeon-hole classification is unsatisfactory because some of the worst volcanic disasters have been caused by eruptions of "extinct" volcanoes! Since A.D. 1000, more than 300,000 people have been killed directly or indirectly by volcanic eruptions, and about 350 million people currently live on or near potentially dangerous volcanoes.

Most volcanoes are found along or near the boundaries of the Earth's shifting tectonic plates, especially along the circum-Pacific "Ring of Fire"; some (as in Hawaii) are found over "hot spot" far from plate margins. The United States has nearly 60 active volcanoes in Alaska, Hawaii, and the Cascade Range of the Pacific Northwest. Only Japan and Indonesia have more. The Hawaiian volcanoes generally erupt nonexplosively, posing greater hazards to property than to life. In contrast, eruptions of Alaskan and Cascade volcanoes are usually explosive and potentially more hazardous. Because of their remoteness, the Alaskan volcanoes, except those in the Cook Inlet region, pose relatively little danger. Comparatively, the Cascade volcanoes perhaps constitute the greatest potential volcanic risks in the U.S.—both at present and in the near future—because of their explosiveness and proximity to populated or cultivated areas in Washington, Oregon, and California. Over a longer term, however, the geologically youthful, but currently inactive, larger volcanic systems, such as the Yellowstone caldera (Wyoming) and Long Valley caldera (California), pose far greater threats. Large eruptions from such systems can be thousands of times more powerful than the cataclysmic eruption of Mount St. Helens in May 1980, which caused the worst volcanic catastrophe in U.S. history. Fortunately, the volcanic systems capable of wreaking the most havoc are the least likely to erupt in any given time frame.

In 1974, the U.S. Geological Survey (USGS) was designated by Congress to be responsible for volcanic-hazards investigations and to provide "timely warning" of volcanic and related hazards. Effective volcanic-hazards mitigation requires (1) identification and hazards assessments of high-risk volcanoes, (2) systematic monitoring of potentially hazardous volcanoes, (3) fundamental research on volcanic phenomena and monitoring techniques, and (4) active participation of volcanologists in emergency-response planning and public-education efforts. To date, seismic and ground-deformation monitoring of volcanoes still provide the most reliable precursory data, but several other monitoring techniques show promise.

The USGS carries out its Volcano Hazards Program in close cooperation with State and local agencies, and with volcanologists from academia. Although the USGS primarily focuses on U.S. volcanoes, in the 1980's it began to assume an increasing role in providing technical assistance to developing nations in response to major volcanic disasters and crises (for example, El Chichón [Mexico], 1982; Galunggung [Indonesia], 1982–83; Rabaul [Papua New Guinea], 1983; and Nevado del Ruíz [Colombia], 1985). An important component of USGS cooperative studies abroad is the Volcano Early Warning Disaster Assistance Program (VDAP), supported in part by the Office of Foreign Disaster Assistance (OFDA) of the U.S. State Department, which at present largely focuses on volcanic crises and hands-on training needs of volcanologists in Latin America.

Technology already exists to mitigate substantially volcanic and related hazards on a global basis. The challenge lies in marshaling the political will and/or resources—currently lacking—to study and adequately monitor the world's high-risk volcanoes.

POTENTIAL HAZARDS FROM FUTURE ERUPTIONS IN CALIFORNIA

C. Dan Miller

More than 500 volcanic vents have been identified in California. At least 76 of these vents have erupted, some repeatedly, during the last 10,000 years. Past volcanic activity has ranged in scale and type from small rhyolitic and basaltic eruptions through large catastrophic rhyolitic eruptions. Sooner or later volcanoes in California will erupt again, and they could have serious impacts on the health and safety of the State's citizens as well as on its economy.

The potentially more hazardous eruptions in the State are those that involve explosive eruption of large volumes of silicic magma. Such eruptions could occur at vents in the vicinity of Mount Shasta, Medicine Lake volcano, Lassen Peak, and in the Mono Lake-Long Valley area. Large eruptions could eject pumice high into the atmosphere and produce destructive blasts, debris avalanches, or pyroclastic flows that could reach distances of tens of kilometers from a vent. Eruptions of Mount Shasta and Lassen Peak could produce lahars and floods that could reach distances of hundreds of kilometers. Smaller eruptions would produce similar but less severe and less extensive phenomena.

The hazard is greatest close to a volcanic vent; slopes on or near a volcano and valleys leading away from it will be affected most often and most severely by eruptions. In general, risk from volcanic phenomena decreases with increasing distance from a vent, and for most flowage processes, with increasing height above valley floors or fan surfaces. Tephra from explosive eruptions can affect extensive areas downwind from a vent. In California, prevailing winds will cause the area east of a volcano to be affected most often and most severely. Risk to life and property from ashfall decreases rapidly with increasing distance from a vent, but even thin deposits of ash could disrupt communication, transportation, and utility systems at great distances, and over wide regions.

Volcanic eruptions are certain to occur in California in the future. Though eruptions can be neither prevented nor stopped, risk to life and property can be reduced by avoiding threatened areas and by taking protective measures to reduce the effects when and where vulnerable areas cannot be avoided. Monitoring of volcanic precursors generally can identify the location of impending volcanic activity, even though it often does not pinpoint the nature or timing of an eruption, or even its certainty. Hazard-zonation maps can then be used by public officials to guide decisions regarding land use and access and other hazard-response activities.

RECENT VOLCANISM AND HAZARDS IN THE LASSEN AREA, CALIFORNIA

Michael A. Clynne

Three episodes of volcanism have occurred at Lassen volcanic center in the past 1,100 years. These are the complex eruption at Chaos Crags, the eruptions at Cinder Cone, and the summit eruptions of Lassen Peak in 1914–1917. Each eruptive episode was different. Similar volcanism will reoccur in the future.

The eruption of Chaos Crags illustrates a cycle of activity typical of silicic volcanism. Careful study of the deposits of the Chaos Crags indicates that they formed during a complex eruption 1,100–1,000 years ago. Initial activity included formation of a tephra cone, emplacement of two pyroclastic flows, and growth of a dome that plugged the vent. After a quiet interval of 70 years, the dome was destroyed by a violent eruption that emplaced a pyroclastic flow and an air-fall tephra lobe. The violent eruption was followed by the growth of five domes, three of which had hot, dome collapse avalanche events. The Chaos Jumbles formed by a series of three cold rockfall-avalanches that illustrate an additional noneruptive hazard in the Lassen area.

The eruption of Cinder Cone is typical of mafic volcanism in the Lassen area. The Cinder Cone eruptive deposits consist of 4 basaltic andesite lava flows, a complex vent cone, and a widespread ash blanket. Two lava flows erupted before the ash blanket and two followed the ash blanket. All of these erupted over a short time interval 425 radiocarbon years ago.

The eruption of Lassen Peak in 1914–1917 included a diverse series of events that illustrate the destructive potential of snow-covered volcanoes. Mild vent-opening and crater-forming explosions persisted for a full year before the violent explosions of May 19 and 22, 1915. Lava first appeared in mid-May 1915, as a small dome filling the crater. On the evening of May 19, explosive disruption of the still-hot lava dome onto the snow-covered upper slopes of Lassen Peak generated an avalanche, debris flow, and flood that affected downslope valleys for at least 30 mi. On May 22, a subplinian eruption deposited an air-fall tephra lobe. Partial collapse of the eruption column generated a pyroclastic flow that devastated the northern flank of the volcano. Melting of snow incorporated by the pyroclastic flow generated a fast-moving debris flow. Fall of hot tephra onto the snow-covered upper slopes of the volcano generated additional debris flows.

Because these eruptions are fairly young, and their deposits are well preserved, their histories are better understood than those of older eruptions at the Lassen volcanic center. Yet even the deposits of the 1915 eruption of Lassen Peak are being rapidly obscured by vegetation and other natural processes. Erosion, especially glacial erosion, selectively removes unconsolidated volcanic deposits produced by the most explosive and hazardous events. Consequently, the preserved geologic record of older volcanism at Lassen is biased toward resistant deposits such as lava flows and domes produced by less hazardous activity.

Eruptions similar to these described are the types of volcanism most likely to recur. The principal volcanic hazards in the Lassen area are pyroclastic flows and debris flows that would primarily affect valleys peripheral to Lassen Peak. Avalanches resulting from volcanic activity or nonvolcanic sources also pose a hazard to downstream valleys. Air-fall tephra poses a widespread though less serious hazard. Emplacement of lava flows and domes are an additional, more localized hazard. Fortunately, the Lassen volcanic center is in a national park, and the surrounding area is sparsely populated. However, people now live in areas affected by the Chaos Crags and 1915 eruptions, and the population in the vicinity continues to increase. Continued development in such areas could have serious consequences in the event of future eruptions.

RESEARCH AND MONITORING IN THE LONG VALLEY CALDERA, CALIFORNIA

Malcolm Johnston

The Long Valley caldera forms part of an active volcanic region in the upper Owens Valley that could, as it has in the past, impact this and the surrounding area should an explosive eruption occur. Scientific research in this region has been primarily focused on (1) understanding the structure and evolution of the region through geologic time, and (2) monitoring the present seismic and deformational activity to identify physical processes such as dike injection, magma pressure changes, fault rupture, and so forth, that have preceded eruptive activity of other volcanoes. Techniques from many disciplines (for example, geologic, seismic, magnetic, gravity, telluric, direct drilling, and so forth) have been used to define the detailed structure of the region, eruption types, and occurrence times. Indications of increasing hazard occurred in the early 1980's with a dramatic increase in seismic activity, bulging of the entire caldera, and outward displacement of points around the caldera. While the seismic activity has decreased during the past few years, bulging and straining is continuing at a uniformly high rate of about one part per million per year. This deformation rate is currently the highest in California. The region is presently monitored continuously with arrays of seismometers, strainmeters, tiltmeters, magnetometers, water wells, and so forth. These data are transmitted by radio or satellite telemetry to computers in Menlo Park for rapid (real-time) detection of seismic and deformation events. Horizontal displacement is regularly monitored with a two-color laser geodimeter within the caldera and over the entire region with standard geodimeter techniques. Vertical displacement (uplift) is also regularly monitored with level lines along existing roads, a long-baseline tiltmeter, and by measurements of apparent tilting of Crowley Lake. About 20 inches of uplift, centered on the resurgent dome, has occurred since 1980. Alert criteria have been defined in computer algorithms for detection of both seismic and deformation related events. When these criteria are satisfied, computers automatically call telephone beepers to allow verification of the situation and, if necessary, public notification.

THE SEARCH FOR MAGMA CHAMBERS USING SEISMIC METHODS

H.M. Iyer

Determining how magma chambers form, change, and move in the crust in volcanic areas should provide clues to understanding the eruptive behavior of volcanoes, and thereby in turn help to predict volcanic eruptions, determine their associated hazards, and estimate the amount of magmatic and hydrothermal heat exploitable in the form of geothermal energy.

During the past decade, seismic techniques are increasingly being used to study the subsurface anatomy of volcanic systems. One method is to locate in three dimensions the small earthquakes generated by magma conduits beneath volcanoes. This technique has been successfully applied by U.S. Geological Survey (USGS) scientists to map in great detail the magma chambers beneath the Hawaiian volcanoes. Another technique is based on the fact that molten rock does not allow the transmission of certain kinds of seismic waves. The magma body casts a "seismic shadow" on the opposite side of an earthquake. USGS scientists in collaboration with others have used this technique to locate magma chambers at depths as shallow as 4 miles beneath the Long Valley caldera, California. The most modern technique to determine the subsurface configuration of volcanoes is called seismic tomography and was developed about 10 years ago. This technique, adapted from the medical sciences, is based on the CAT-scanning technique which is used to "image" tumors and other abnormal growths in the human body. The medical scientists use X-ray to image their objects, whereas seismologists use seismic waves from natural earthquakes and artificial explosions. The USGS has played a pioneering role in applying seismic tomography to image magma chambers in several volcanoes in the Western United States. Using advanced computer processing of data and sophisticated analytical techniques we have studied large volcanic systems like Yellowstone, several of the Cascade volcanoes including Mount Lassen and Newberry volcano, and many volcanic centers (including The Geysers and Long Valley) of great interest to the geothermal energy industry. Our studies reveal that there are substantial differences in the size and form of the magma chambers of these volcanoes. For example, Yellowstone has a deep rooted magma chamber almost 50 miles wide and 100 miles deep. On the other hand, Long Valley, The Geysers, Mono Craters, and several other volcanic centers have considerably smaller magma chambers only 1–5 miles wide, 10–15 miles thick, and 4–5 miles beneath the surface. The Cascade volcanoes, including Mount St. Helens, seem to have only tiny magma chambers, less than a mile wide and one or two miles thick. Luckily for humankind, in historic times the most devastating eruptions have only come from moderate-sized magma chambers (for example, Santorin, Tambora, Krakatau). But there is no reason to dismiss the possibility of even more devastating eruptions from large chambers like those found in Yellowstone and Long Valley, and prudence dictates that they be continuously monitored.

APPENDIXES A AND B

Appendix A—GEOHAZARDS '88 Program

[All speakers are U.S. Geological Survey scientists unless otherwise noted]

Thursday, November 17

8:00–8:30 a.m Registration
8:30–8:35 a.m. Welcome and introductory remarks
George Gryc, *Director's Representative, U.S. Geological Survey*
8:35–9:00 a.m. Keynote address
Richard K. Eisner, *Director, Bay Area Regional Earthquake Preparedness Project, Governor's Office of Emergency Services (California)*
9:00–12:00 noon EARTHQUAKE RESEARCH
Moderators: **Robert D. Brown**
Carl E. Mortensen

Introduction and scientific overview
Thomas C. Hanks
Mapping earthquake hazards in California
Joseph I. Ziony, *Assistant Director for Mining and Geology, California Department of Conservation*
Holocene faulting—the geologic evidence
David P. Schwartz
Probabilities for large California earthquakes
James A. Dieterich
Parkfield earthquake experiment
Allan G. Lindh
Estimating ground motion in California
William B. Joyner

9:00–12 noon Concurrent poster session on Water Resource Issues
12 noon–1:00 p.m. Box lunches on campus
1:00–1:30 p.m. APPLICATIONS OF MAP PRODUCTS FOR NATURAL HAZARDS STUDIES AND DISASTER OPERATIONS
John R. Swinnerton
1:30–5:00 p.m. LANDSLIDE HAZARDS IN CALIFORNIA AND THE SAN FRANCISCO BAY REGION
Moderators: **William M. Brown III**
David K. Keefer

Introduction: Landslide hazards program of the U.S. Geological Survey—Activities in California and the San Francisco Bay Region
David K. Keefer
Landslides in San Mateo County, California: How landslide maps are made, and examples of modern geologic hazards maps: digital cartography and geographic information systems applied to geologic hazards
Earl E. Brabb
Landslide Prediction: A landslide warning system for the San Francisco Bay Region
Raymond C. Wilson
How slides transform into flows: What happens to hillsides in the San Francisco Bay Region during and after heavy rains
Stephen D. Ellen
Landslides caused by earthquakes: What happens to hillsides during earthquakes
Edwin L. Harp
Coping with landslide hazards in California and the San Francisco Bay Region: An overview of the way society reacts to landslides, and prospects for the future
William M. Brown III
Summary and Discussion: Panel of speakers will field questions from the audience

1:00–5:00 p.m. Concurrent poster session on Volcano Research

Thursday, November 17—*Continued*

6:30 p.m. COCKTAILS AND DINNER AT STANFORD UNIVERSITY FACULTY CLUB

8:15 p.m. Welcome and introductions
Carroll Ann Hodges, *Chairman, "Geohazards '88," U.S. Geological Survey*

8:30 p.m. Perspective from the Hill, by a former denizen thereof
Paul N. (Pete) McCloskey, *Attorney, Palo Alto, CA (Representative from the 12th Congressional District, California, 1967–1983)*

8:40 p.m. Remarks
Tom Campbell, *Congressman-Elect (12th Congressional District)*

8:45 p.m. Bon Mots—Official and otherwise
George Gryc, *Director's Representative, U.S. Geological Survey*

9:00 p.m. Conference address—Reducing geologic hazards: A scientific challenge for humanity
Julia V. Taft, *Director, Office of U.S. Foreign Disaster Assistance, Agency for International Development, Washington, D.C.*

Friday, November 18

8:15–12 noon WATER RESOURCE ISSUES AND RESEARCH
Moderator: **Benjamin L. Jones**

Welcome and overview
T. John Conomos

Hydrological Extremes

Western North American climate implications
David Peterson
Long-term climate cycles in the West
William D. Nichols
Update on current drought conditions
Byron Aldridge

Ground-Water Contamination

Contamination by hydrocarbons and other immiscible fluids
Hedeff Essaid
Models as an aid for ground-water-quality management
Steven Gorelick, *Stanford University*

Irrigation Drainage Problems

Irrigation drainage problems in the West
Marc A. Sylvester
Hydrogeology of a selenium source area
Kenneth Belitz
Microbial geochemistry of selenium: solution to an environmental problem
Ronald S. Oremland

San Francisco Bay Studies

San Francisco Bay circulation
Ralph T. Cheng
Fate and effects of toxics
Samuel N. Luoma

Volcanism and Hydrologic Hazards

Landslide-dammed lakes at Mount St. Helens
William Meyer

8:30–12 noon Concurrent poster session on Earthquake Research

Friday, November 18—*Continued*

12 noon–1:00 Box lunches on campus

1:00–4:00 p.m. VOLCANOES AND VOLCANIC HAZARDS

Moderator: **Roy A. Bailey**

Overview of volcano research programs: Hawaii, Alaska, and continental United States
Robert I. Tilling

Volcanic hazards in California
C. Dan Miller

Volcanism and hazards at Mount Lassen
Michael A. Clynne

Research and monitoring at Long Valley caldera
Malcolm Johnston

The search for magma chambers using seismic methods
H.M. Iyer

4:00–5:00 p.m. Panel discussion

Moderator: **David P. Hill**
Michael Guerin, *Assistant Chief, Law Enforcement Division, California Office of Emergency Services*
Andrea Mead Lawrence, *Mono County Board of Supervisors*
George G. Mader, *City/County Planner, William Spangle and Assoc., Inc.*
Stephen R. McNutt, *Seismologist, California Division of Mines and Geology*
C. Dan Miller, *Volcanologist, U.S. Geological Survey*
Brian E. Tucker, *Acting State Geologist, California Division of Mines and Geology*
Linda Monroe, *science writer, Los Angeles Times, San Diego Bureau*

1:00–5:00 p.m. Concurrent poster session on Landslide Research

5:00 p.m. Concluding remarks

George Gryc, *Director's Representative, U.S. Geological Survey*

5:15 p.m. Symposium adjourned

Poster Presentations

EARTHQUAKE RESEARCH

The Parkfield Prediction Experiment
Steve Walter and **Jean Olsen**

Probabilities of Large Earthquakes in California
Allan Lindh

A Look at Today's Earthquakes
Stan Silverman

LANDSLIDE RESEARCH

Catastrophic Landslides During the Storm of January 3–5, 1982, the San Francisco Bay Region; Landslide Warning System

Geologic Hazards Products for San Mateo County (multi–panel display showing types and evolution of geologic hazards maps)

Debris Flow Dynamics
U.S. Geological Survey

The Abbottsford, New Zealand Landslide Disaster, 1979
University of Otago

LANDSLIDE RESEARCH—*Continued*

Dateline: San Francisco, 1982—Edited compilation of television and other videotape coverage of the January 1982 flood and landslide disaster in the San Francisco Bay region, California
Flood Loss Reduction Associates, Palo Alto, California

Landslides on the Sea Floor
Homa J. Lee, Monty A. Hampton, and **Michael E. Field**

WATER RESOURCE ISSUES

Trace Metals in Lake Tahoe Creeks
Cecily Chang

Sediment Sources at Lake Tahoe
K.M. Nolan and **B.R. Hill**

Long–Term Trends in Chemistry of Mississippi River and Great Lakes
John Hem

Irrigation Drainage Problems in the West
Marc Sylvester

Chemistry and the Movement of Metals in Ground Water
Douglas Kent, James Davis, and **Brigid Rea**

A Practical Methodology for Evaluating Aquifer Restoration Alternatives
Brian Wagner

GIS Used for Aquifer Protection Management
Patricia Cascos

Land–Subsidence Monitoring in the Sacramento Valley Using Global Positioning System Survey
J.C. Blodgett, M.E. Ikehara, and **G.E. Williams**

Land Subsidence in the Sacramento/San Joaquin Delta
Stuart Rojstaczer, Christine Massey, and **Lisa Shepherd**

Hydrogeologic Research in Long Valley
Chris Farra and **Michael Sorey**

VOLCANO RESEARCH

Potential Hazards from Future Eruptions in California
C. Dan Miller

The Search for Magma Chambers Using Seismic Methods
H.M. Iyer, J.R. Evans, and **P.B. Dawson**

Tiltmeter Measurements in the Long Valley Caldera, California
Carl Mortensen

Volcano Monitoring at the Hawaiian Volcano Observatory
Christina Heliker, Jane Takahashi, Robert Koyanagi, Thomas Wright, and **Arnold Okamura**

The 1985 Nevado del Ruíz Disaster (video)
Pan–American Health Organization

The 1902 Eruption of Mont Pelée, Martinique (video)
Maurice Kraft

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SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

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Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

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