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science for a changing world

Geology for a Changing World

A Science Strategy for the Geologic Division of the U.S. Geological Survey, 2000–2010

U.S. Geological Survey Circular 1172

U.S. Department of the Interior
U.S. Geological Survey

On the cover: Photograph of Mount Rainier, as seen from Tacoma, WA. Recent work by the Geologic Division of the U.S. Geological Survey has identified regions of hydrothermally altered rock at Mount Rainier that are particularly susceptible to collapse, potentially endangering developed population centers downstream from the volcano (see Highlight 1 on p. 3). Through the goals and actions outlined in this report, the Geologic Division can help reduce the risk and uncertainty in human interaction with the Earth. Photograph from the USGS Cascades Volcano Observatory.

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U.S. Geological Survey Circular 1172

The Geologic Division of the U.S. Geological Survey outlines seven science goals to address pressing issues facing the Nation in the next decade

U.S. Department of the Interior
Bruce Babbitt, Secretary

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Preface

In early 1997, the Geologic Division (GD) Policy Council established a team composed of scientists representing the breadth of research expertise in the GD, in other U.S. Geological Survey (USGS) divisions, and in the earth science academic community. The Science Strategy Team, or SST as we became known, was charged with creating "a succinct strategy for the activities of the GD in the first decade of the next century (2000–2010), within the broad outlines of the USGS Strategic Plan." Our objective was to develop a 10-year plan for the GD's scientific activities by anticipating broad national and global scientific issues and needs, identifying promising new research directions to address these needs, and evaluating the implications of these scientific directions on GD staffing.

In developing this science strategy, we reviewed the USGS Strategic Plan, other USGS division plans, draft 5-year plans for USGS programs, recent external reviews of USGS programs, and past recommendations of the GD Science Advisory Committee. We also examined science and strategic plans of other Federal agencies, of earth science agencies of other countries, and of national and international earth science organizations. Through a series of panel discussions, the SST heard from more than 250 people, including scientists and managers from within the GD and the USGS; leaders from within the U.S. Department of the Interior; representatives of other Federal agencies, the Office of Science and Technology Policy, and the U.S. Congress; State Geologists; industry leaders; faculty members; and professional societies. Meetings convened in Reston, VA, Denver, CO, and Menlo Park, CA, provided GD staff the opportunity for verbal input, and we received a tremendous number of written comments throughout the planning process.

Voluminous input from all these sources provided the foundation for defining seven overlapping science goals and six operational objectives. By undertaking the scientifically challenging and vital research activities outlined in this science strategy, the GD can effectively address the Nation's most pressing science issues of the next decade.

Our sincere thanks to all who participated in this strategic planning process. This science strategy has been reviewed extensively by our colleagues in the earth science community, both within and outside the USGS, and has benefited greatly from these reviews. The team would like to express its appreciation to Berwyn Jones of the Water Resources Division for facilitating our meetings and to Leslie McElroy of the GD for coordinating the production of this report.

As a result of our participation in this effort, we have a much greater awareness of and appreciation for the GD's diverse scientific programs and capabilities, as well as the enormous dedication of its staff. We look forward to the consideration and implementation of this science strategy.

Steven R. Bohlen
Associate Chief Geologist
for Science (Chair)

Robert B. Halley

Stephen H. Hickman

Samuel Y. Johnson

Jacob B. Lowenstern

Daniel R. Muhs

Geoffrey S. Plumlee

George A. Thompson
Stanford University and
President of the Geological
Society of America (1996–97)

David L. Trauger
Biological Resources Division

Mary Lou Zoback

**The Science Strategy Team
for the Geologic Division
of the U.S. Geological Survey**

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Acronyms

AVIRIS, Airborne Visible and Infrared Imaging Spectrometer
BRD, Biological Resources Division of the U.S. Geological Survey
DEM's, digital elevation models
DOE, U.S. Department of Energy
DOI, U.S. Department of the Interior
EPA, U.S. Environmental Protection Agency
GD, Geologic Division of the U.S. Geological Survey
GIS, geographic information system
GPS, Global Positioning System
GSN, Global Seismographic Network
InSAR, Interferometric Synthetic Aperture Radar
IRIS, Incorporated Research Institutions for Seismology (a consortium of more than 90 U.S. universities)
NASA, National Aeronautics and Space Administration
NMD, National Mapping Division of the U.S. Geological Survey
NOAA, National Oceanic and Atmospheric Administration
NPS, National Park Service
NSDI, National Spatial Data Infrastructure
PHIVOLCS, Philippine Institute of Volcanology and Seismology
SAC, Science Advisory Committee
SST, Science Strategy Team for the Geologic Division of the U.S. Geological Survey
USBR, U.S. Bureau of Reclamation
USGS, U.S. Geological Survey
WRD, Water Resources Division of the U.S. Geological Survey

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Executive Summary

This report presents a science strategy for the Geologic Division of the U.S. Geological Survey (USGS) for the years 2000–2010. The report describes seven science goals conceived to address pressing issues facing the Nation in the next decade. In general, these goals focus on understanding human interaction with the natural environment and build upon long-term USGS investments in basic research on the fundamental geologic processes controlling how the Earth works. These goals are consistent with the USGS's mandated role as a Federal science agency charged with providing long-term monitoring, research, and assessments. Although investigations will typically be at the regional to national scale, more localized studies and demonstration projects will also be conducted, either on Federal lands or in other areas of national interest, to develop principles and methods that can be applied much more broadly. The goals are intentionally ambitious for a Geologic Division of its current size; success will require extensive collaboration with other USGS divisions, other Federal agencies, State geological surveys, and academic colleagues.

The first three goals define future thrusts in traditional areas of national leadership for the Geologic Division—studies of the Nation's geologic hazards and natural resources:

1) **Conduct geologic hazard assessments for mitigation planning**

2) **Provide short-term prediction of geologic disasters and rapidly characterize their effects**

3) **Advance the understanding of the Nation's energy and mineral resources in a global geologic, economic, and environmental context**

There are strong links between the first two goals (see Highlight 1). Hazard assessments (Goal 1) integrate knowledge about the potential location, size, and frequency of a geologic hazard with knowledge of a region's or site's vulnerability to the effects of such an event. Goal 2 addresses the division's role in providing timely information on both the likely and the actual geologic effects of disasters in the short term before, during, and after a hazardous event.

By embracing a global perspective on natural resource supply and demand in Goal 3, the Geologic Division will enhance its ability to inventory the Nation's earth resources. Such assessments must be backed by fundamental studies of the character and distribution of natural resources, as well as the economic benefits and environmental consequences of their development.

Climate-related studies already represent a significant Geologic Division effort and are expected to be of increasing importance in the next decade. The next goal relates to climate change:

4) Anticipate the environmental impacts of climate variability

This fourth goal defines a leadership role for the USGS within the U.S. National Global Change Program in carrying out regional- to national-scale syntheses on the following two topics: first, reconstructions of past climates from terrestrial records and, second, assessments of the potential impacts of climate change or variability.

The final three goals address societal issues that the USGS anticipates will be of growing importance in the next decade due to increasing concerns over quality of life:

5) Establish the geologic framework for ecosystem structure and function

6) Interpret the links between human health and geologic processes

7) Determine the geologic controls on ground-water resources and hazardous waste isolation

These goals represent modest Geologic Division efforts at present and are envisioned as largely collaborative or support roles in the future when the USGS will form new partnerships with other agencies and groups. They represent exciting opportunities whereby the Geologic Division can take advantage of the new USGS role as the Nation's earth science and biological science agency.

Highlight 1— **Linking the Science Goals: Mineral Resource and Hazard Studies**

The scientific issues, products, and actions outlined in the seven science goals are intentionally broader than those currently addressed by any individual GD program. The science goals are also complementary, in that research information and results collected while working on one goal can directly affect research involving other goals. For example, long-term USGS research on volcanic systems has provided a fundamental understanding of the reactions that take place as volcanic gases condense into ground water in the shallow subsurface. The resulting acid-leached rocks are common hosts for gold deposits in volcanic settings. GD hazard-focused studies of active volcanic and geothermal systems have thus added immeasurably to the understanding of the origin and distribution of a broad suite of mineral resources. At the same time, techniques developed to map and locate the alteration assemblages associated with ore deposits can be used to understand volcanic hazards. Remote-sensing, field, and laboratory investigations traditionally conducted in the study of mineral deposits have been used at Mount Rainier to map and interpret the formation of hydrothermal alteration zones at a level of detail previously unrealized on active volcanoes. Such areas of hydrothermally altered and weakened rock have collapsed repeatedly within the last 10,000 years, producing some of the mudflows that inundated portions of what is now the Seattle-Tacoma metropolitan area (fig. 1). By applying mineral-mapping techniques, the GD can refine future hazard assessments while improving the understanding of the environment of formation for volcano-hosted mineral deposits.

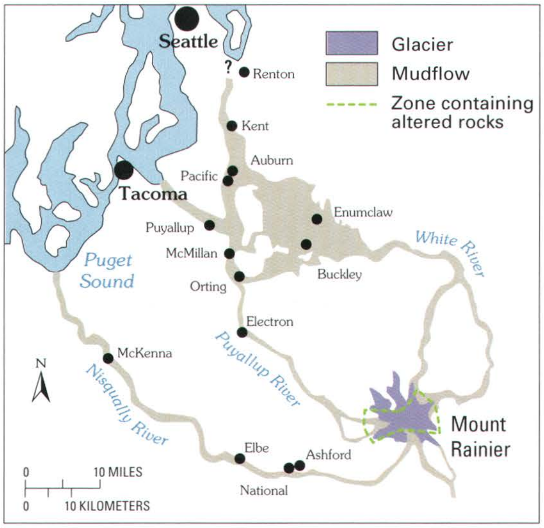


Figure 1. Photograph of Mount Rainier, as seen from Tacoma, WA, and map showing areas of hydrothermally altered rocks and regions covered by mudflows shed from the volcano within the past 5,600 years. Recent work by GD staff has identified regions of hydrothermal alteration that are particularly susceptible to collapse, potentially endangering developed population centers downstream from the volcano. Photograph from the USGS Cascades Volcano Observatory. Map from Sisson (1995).

Goals 4–7 have many obvious links and overlaps. Goals 4 and 5 both require a fundamental understanding of the geologic and geochemical processes that shape the Earth's surface and that exert control on the biosphere. Many of the same processes affecting human health (Goal 6) also affect ecosystem health (Goal 5). Because many of the pathways for material flux in the environment are related to water, an understanding of the geologic controls on water movement in the upper crust (Goal 7) will benefit human and ecosystem health, while it also will help to assure the quality and quantity of the Nation's ground water.

The Geologic Division's ability to respond to each of these societally driven goals requires a sustained investment in documenting the present and past state of the Earth and in using this information to predict future changes. For example, geologic mapping, which has long been a strength of the Geologic Division, is essential to achieving all seven science goals. Meeting these goals will necessitate a commitment to technological innovation and a broadening of expertise through interagency collaboration, training, and visiting scientist and postdoctoral programs.

Although this report does not contain a detailed implementation plan, it does describe six operational objectives. These objectives will improve the usefulness and accessibility of information created by Geologic Division activities and will promote the flexibility and vitality of the staff. The six objectives are listed below:

1) **Greatly enhance the public's ability to locate, access, and use Geologic Division maps and data**

2) **Maintain a first-rate earth-system science library**

3) **Effectively transfer the knowledge acquired through Geologic Division science activities**

4) **Promote vitality and flexibility of the scientific staff**

5) **Promote interdisciplinary research**

6) **Institute internal and external reviews**

Introduction

The U.S. Geological Survey (USGS) strives to provide the Nation with reliable earth science information that is used to minimize loss of life and property from natural disasters; to manage energy, mineral, water, and biological resources; to enhance and protect the quality of life; and to contribute to wise economic development and a sustainable future. This mission requires that the USGS anticipate and respond in a timely manner to a broad array of national earth science issues. The science strategy described in this report outlines how the Geologic Division (GD) of the USGS will face the challenges of the next decade and ensure maximum contribution and relevance to the national interest.

The GD, described in Highlight 2, will conduct an integrated mixture of monitoring, research, and assessment activities in support of seven major science goals. These seven science goals specifically address major societal issues involving geologic hazards and disasters, climate variability and change, energy and mineral resources, ecosystem and human health, and ground-water availability. For each science goal, a set of strategic actions and products is provided to aid in GD planning and to measure progress. Many of the actions and products require development of new methods, skills, and technologies in addition to continued support of division core capabilities (for example, geologic mapping, regional geologic synthesis, and basic process studies). Success will, therefore, depend greatly on the ability of the GD to continue to attract and support its most important resource, a flexible world-class staff.

The most significant change described for the GD in the seven science goals is a much larger emphasis on developing a broad understanding of the interactions between humans and the Earth. This emphasis necessitates an increased focus on understanding active geologic processes and events (from the commonplace to the catastrophic) and the use of models to predict their frequency and effects in the future. These predictive models will have the form of science-based deterministic scenarios and probabilistic assessments and will outline a range of possible consequences that should be incorporated into policymaking and land-management decisions. The science strategy also places particular emphasis on interdisciplinary research, acknowledging the importance of crossing traditional discipline boundaries in investigating complex Earth systems. This science strategy report proposes changes in GD operations to facilitate interdisciplinary work and significant fruitful collaboration with the USGS Water Resources Division (WRD), the National Mapping Division (NMD), and the Biological Resources Division (BRD). Achieving these science goals will also require extensive collaboration and partnerships with other Federal agencies, State geological surveys, industry, academia, and professional societies. At the project level, the GD's role may vary from leadership to participation to facilitation. The GD's responsibilities in developing and nurturing these partnerships are described below (see "Working with Others") and takes advantage of the unique USGS ability to provide a coherent, unbiased, long-term, national perspective on earth science problems and societal issues.

Highlight 2— **The Geologic Division Today**

The U.S. Geological Survey (USGS), a bureau within the U.S. Department of the Interior, manages four major Federal earth science activities: the National Mapping Program, Water Resources Investigations, Biological Research, and Geologic Hazards, Resources, and Processes. The Geologic Division (GD) of the USGS administers all programs under this last activity, including Earthquake Hazards, Volcano Hazards, National Cooperative Geologic Mapping, Coastal and Marine Geology, Global Change and Climate History, Mineral Resources, Energy Resources, and Integrated Natural Resource Science. The GD also has program responsibilities for the Global Seismographic Network, landslide hazards, and international activities.

In fiscal year 1998, the GD's appropriated budget for all programs is $235.2 million. In addition to Congressionally appropriated funds, the GD receives reimbursements from other Federal agencies for conducting research. For example, the National Aeronautics and Space Administration supports the GD's astrogeology program. In turn, the GD offers grants to State and local agencies, universities, and the private sector to undertake earth science investigations. GD scientists also conduct cooperative research with the private sector and international governments through formal agreements.

The GD staff strives to produce objective, reliable earth science information on geologic hazards, geologic resources, and geologic processes. Whether in the form of a technical report, map, data base, or software application, results of GD research are used by policymakers at Federal, State, and local levels to make informed land-use and resource decisions.

To meet the earth science information needs of the Nation, the GD maintains a staff of nearly 1,250 research scientists and technical specialists. Areas of expertise are primarily geology, geophysics, and geochemistry but also include mineralogy, astrophysics, oceanography, biology, botany, soil science, hydrology, geography, and petroleum, mechanical, environmental, civil, and nuclear engineering.

The GD is headquartered at the USGS National Center in Reston, VA, and has facilities at three regional USGS centers: the Eastern Region Center is located in the National Center in Reston, VA; the Central Region Center is in Denver, CO; and the Western Region Center is in Menlo Park, CA (fig. 2). The Hawaiian, Alaska, and Cascades Volcano Observatories are managed through the GD, which also maintains field centers in Woods Hole, MA, St. Petersburg, FL, Reno, NV, Tucson, AZ, Flagstaff, AZ, Albuquerque, NM, and Spokane, WA. In addition, more than 30 GD scientists are stationed permanently at universities and research institutions.

Figure 2. Primary sites within the three USGS administrative regions, including regional centers, field centers, and volcano observatories, where GD scientists are stationed in the United States.

Implementing the strategic actions and completing the products described in the science goals will require a combination of rigorous short-term and long-term research. Short-term scientific responses to pressing national issues will require rapid, creative, flexible approaches and are predicated on the GD's ability to quickly deploy broad world-class expertise in earth sciences. Long-term investments in the deeper understanding of basic Earth processes will continue to provide the basis for solving some of the more complex and intractable problems facing the Nation, while leading to fundamental advances in science. The effectiveness of the GD in applying the results of long-term research to pressing short-term national needs has been repeatedly demonstrated in recent years, and specific examples are included throughout this report. Although not emphasized in the science goals, the national need for economic and environmental security and the global nature of many important hazard, resource, and environmental issues require that the GD engage in international science activities.

To achieve the science goals outlined in this report, the GD must also commit significant intellectual and fiscal resources to using and developing new technologies. Although it is impossible to predict the full range of technological advances that will affect the earth sciences over the next decade, it is certain that many basic tools and approaches to problem solving will change dramatically. As an example, space-based remote sensing should increasingly provide the opportunity for GD earth scientists to monitor and quantify geologic processes and changes associated with natural disasters and landscape evolution. Vastly enhanced computing capabilities will provide an important tool with which to model and understand these processes and changes and to evaluate the effects of possible human modifications to the surface and near-surface environment. For success, the GD must contribute to, reward, and thrive on such technological innovation.

Regardless of the scientific progress achieved by concentrating on the seven science goals, the success of the GD in serving the Nation will ultimately depend on the ability to communicate earth science information and its relevance to a broad range of users. To address that critical need, this report describes strategies to enhance the public's ability to locate, access, and use GD data.

Working with Others

The GD must maintain and develop partnerships with other USGS divisions and non-USGS organizations in order to achieve the science goals described in this science strategy report. Scientists and managers at all levels of the organization—from the Chief Geologist to the project scientist—should assume responsibility for incorporating partners in the planning and execution of GD science activities. As outlined below, exciting opportunities exist for collaboration with the full spectrum of the earth science community. GD staff must be mindful that the greatest synergy will occur when there is a broad understanding of each other's objectives and scientific priorities.

Other USGS divisions

The future of the agency will depend on the ability of the GD, the WRD, the NMD, and the BRD to work cooperatively to address some of the most pressing societal problems. Productive interdivisional partnerships will play a significant role in achieving all the science goals outlined in this report. All USGS divisions are striving to integrate their efforts, particularly at the planning stage.

WRD: Both the GD and the WRD have significant contributions to make in studies of ground water, hazards, resources, climate variability, and human health. Each division will benefit greatly from scientific collaboration, beginning with joint involvement in planning future efforts.

NMD: The GD has opportunities to increase work with the NMD on use of classified satellite data, to develop spatial data-base standards and techniques, to investigate applications of digital elevation models (DEM's) to geologic problems, and to explore cooperative agreements for data distribution and archiving.

BRD: GD scientists can work with BRD ecologists to understand how geologic processes are important in ecosystem studies and with BRD economists to develop total-cost perspectives on mineral and energy resources (see Goal 3).

Other U.S. Department of the Interior (DOI) agencies

As the only science agency in the DOI, the USGS has a special role in meeting the scientific needs of other DOI agencies—the National Park Service (NPS), the U.S. Fish and Wildlife Service, the Bureau of Land Management, the U.S. Bureau of Reclamation (USBR), the Bureau of Indian Affairs, and the Minerals Management Service—in managing Federal lands. The USGS provides objective scientific information and interpretation to these agencies and helps them determine the types of monitoring required for gauging the success of resource management policies.

As one example, excellent opportunities exist for collaborative efforts with the NPS. Many GD scientists are experts on the geology of national parks and monuments and have generated detailed geologic maps of these areas that are important to both park managers and park visitors. Also, GD investigations of surficial geologic processes and hazards at NPS sites can have tremendous significance in NPS planning. In all of these efforts, GD staff will work closely with NPS personnel to define and understand their science priorities and needs.

Other Federal agencies

In the past, the GD has collaborated with numerous Federal agencies outside the DOI, particularly the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration, the Department of Energy, the Department of Defense, the U.S. Forest Service, the Environmental Protection Agency (EPA; see Highlight 3), the Federal Emergency Management Agency, and the National Science Foundation. The multidisciplinary approach to problem solving, inherent in many of the goals outlined in this report and taking place in an era of limited fiscal resources, necessitates that this kind of collaboration be expanded.

For example, the GD has traditionally had a special relationship with NASA through the GD's astrogeology program. Exploration of the solar system is yielding exciting new results, and many of these findings are geologic. Hence, the GD should continue to play an important role in working with NASA toward understanding geologic processes on other planets. NASA's Earth Science Enterprise provides another outstanding opportunity for exciting science collaboration. Close collaboration will capitalize on NASA's technology and infrastructure and USGS expertise in field-based science and understanding of Earth processes.

Highlight 3— **Remote-Sensing Studies Save Taxpayers Millions of Dollars**

Interdisciplinary USGS studies are playing a key role in the EPA's efforts to clean up mine waste dumps at Leadville, CO, a historic mining district that is now an EPA Superfund site. USGS studies have integrated ground-based geologic and geochemical characterization of the mine dumps with advanced AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) remote-sensing techniques to identify mine dumps that are most likely to generate acid mine drainage and release heavy metals into the environment (fig. 3). AVIRIS is a remote-sensing technology originally developed by NASA to determine the mineralogical and atmospheric character of other planets. USGS applications of AVIRIS technology at Leadville enabled the EPA, its cooperators (including the USBR), and its contractors to rapidly determine which of the many mine waste dumps were in need of remediation and to prioritize the cleanup effort. According to the EPA (Sam Vance, 1997, written commun.), results of the USGS Leadville study ultimately saved taxpayers more than $2 million and trimmed more than 2 years off the estimated completion time of the environmental remediation process.

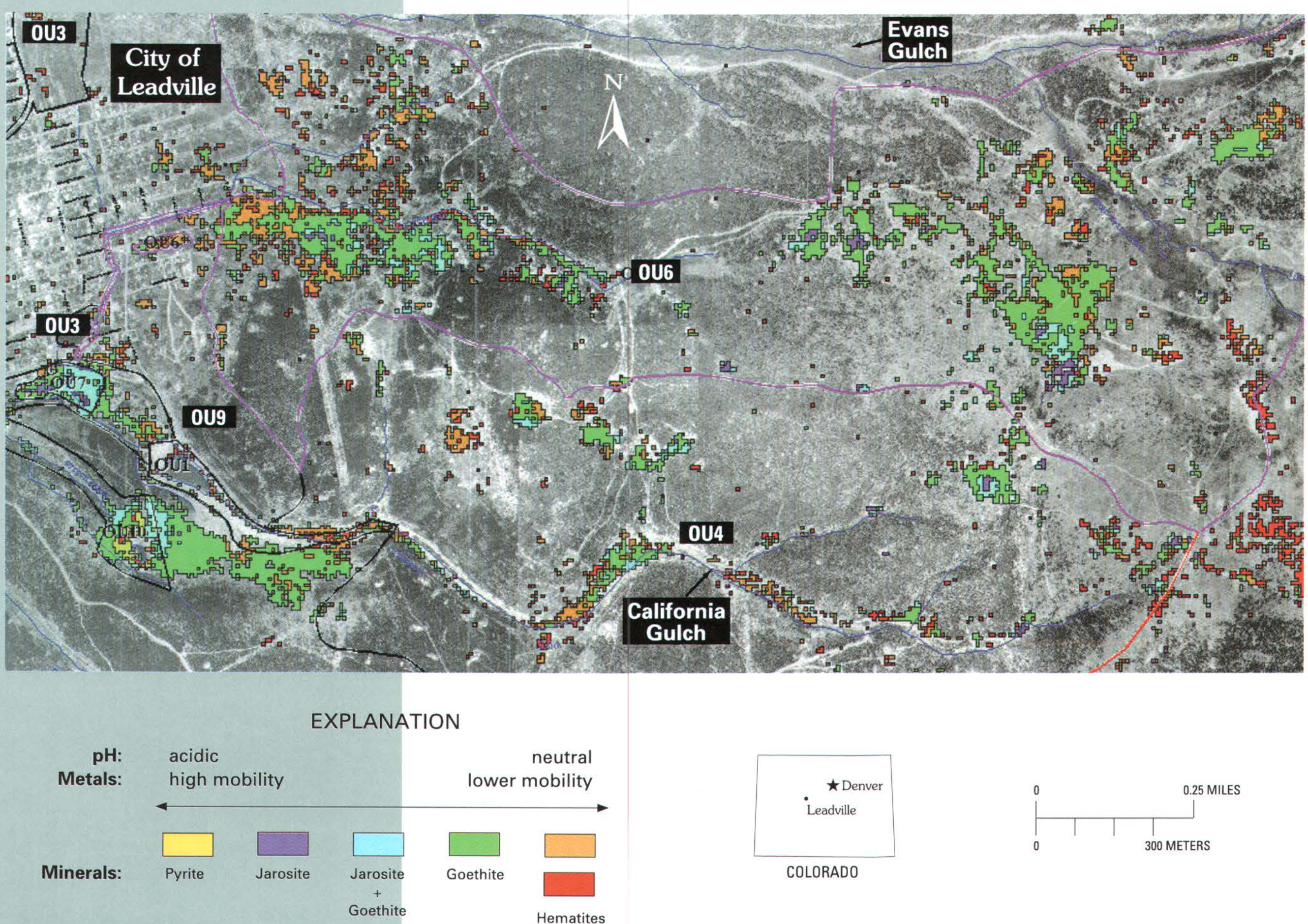


Figure 3. AVIRIS image of the Leadville, CO, mining district, showing distribution of minerals that could lead to acid mine drainage. Blue lines indicate hydrology; pink lines indicate operable unit (OU) 6 boundary. From Swayze and others (1998).

State geological surveys

Continued collaboration with State geological surveys will be critical to achieving the goals in this report. The GD will work more closely with State surveys to define methods for directing USGS regional- and national-scale studies toward the science and information priorities of individual States. The most important role of the State geological surveys will be in addressing geological issues in State and local land-use policy. The GD's role will be geologic mapping and other investigations on a regional or national scale, on Federal lands, or on specific topical studies in support of GD science goals.

Academia

The GD has a long tradition of successful collaboration with the academic community and will work to enhance this collaboration. Stronger ties can be established in several ways, including cooperatively funding graduate students, developing a strong postdoctoral hiring program, and providing support for temporary sabbatical appointments. To achieve its science goals, the GD needs access to cutting-edge research techniques and facilities that may not exist within the USGS. Partnerships between the GD and the academic community will avoid duplication of and ensure maximum utility of research facilities and laboratories.

Private sector

In order to serve the Nation better, the GD must maintain a dialog with members of the private sector, as they are end users of GD data and products. Understanding each other's needs and goals will ensure that collaboration is mutually beneficial. Opportunities for collaboration are particularly promising in the insurance, energy, minerals, and structural engineering industries. In addition, the GD can cooperate with data-base companies in facilitating access to USGS data and products.

Professional societies

The GD must continue to cooperate with a wide range of professional societies such as the Geological Society of America and the American Geophysical Union. As members of a broader earth science community, GD scientists should participate in professional meetings and publish, review, and edit scientific journal articles and books. Further, professional societies have made substantial investments in education and outreach, and the GD should explore opportunities for greater collaboration in these areas.

International agencies and institutions

Cooperative efforts with earth science agencies in other countries are essential given the present transition to a more global economy, the global nature of many earth science problems (such as climate variability), and the clear need for global monitoring (see Highlight 4). GD participation in international assessments of critical energy and mineral resources and of environmental problems will contribute to the development of national economic and security policy.

Highlight 4— **The Global Seismographic Network**

The USGS has operated seismographic stations throughout the world for more than 35 years and has recently upgraded the system to create a state-of-the-art Global Seismographic Network (GSN) in cooperation with the Incorporated Research Institutions for Seismology (IRIS), a consortium of more than 90 U.S. universities. The GSN is jointly funded by the USGS, the National Science Foundation, and the U.S. Air Force. When completed, the GSN will include 151 stations in more than 80 countries (fig. 4). By the end of 1996, 107 stations were operational. The USGS is responsible for operating 77 of these. This seismographic network, with rapid online access, advances understanding of the physical world. The GD uses GSN data for rapid earthquake reporting—accurate location and depth are available within an hour for significant earthquakes, generally magnitude 5.5 or greater, anywhere in the world—and for earthquake, tsunami, and volcano hazard research and warnings. In addition, 51 GSN stations are part of the International Monitoring System, which confirms the end of nuclear weapons testing. Every day, dozens of universities access global seismographic data for researching and teaching about the structure of the Earth's interior.

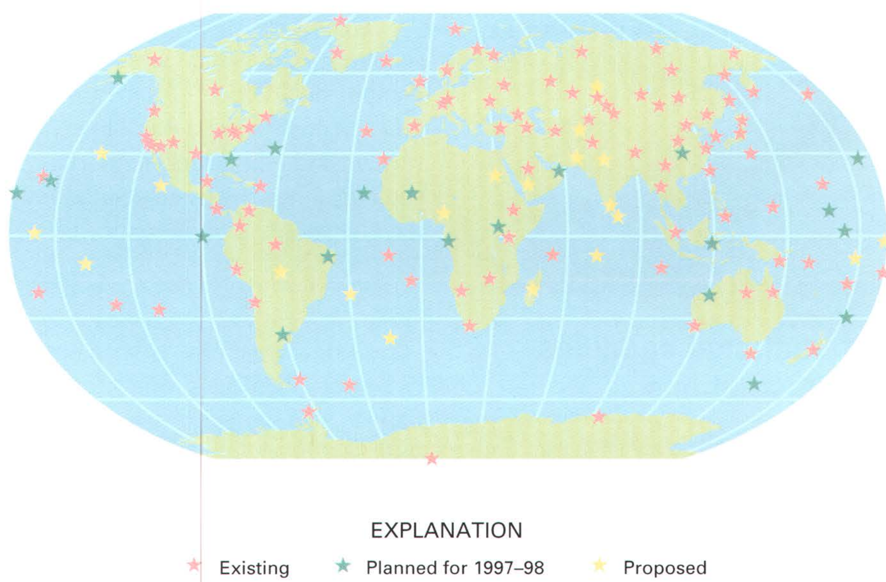


Figure 4. Locations of some of the stations in the Global Seismographic Network. From Lane and Eaton (1997).

Science Goals

Goal 1—Conduct geologic hazard assessments for mitigation planning

Natural geologic hazards, such as earthquakes, landslides, volcanic eruptions, coastal erosion, and floods, result in considerable human suffering and billions of dollars in losses in the United States every year. Although the occurrence of these hazards generally cannot be prevented, the resulting losses to life and property can be significantly diminished through disaster mitigation based on scientific assessments of potential damage. These assessments indicate where and how often natural geologic disasters might occur, as well as provide information on their size and the effects these disasters could have on infrastructure.

The USGS is the acknowledged national leader in developing geologic-hazard assessment methods and products and will continue to strengthen and expand this role. The GD provides two essential types of hazard assessments. Deterministic assessments describe the effects that a particular disaster may have on a region. Probabilistic assessments describe the likelihood of a specific type of hazard and its geologic effects. For example, in a deterministic assessment, scientists could calculate the geologic effects of a magnitude 7.5 earthquake on a specific segment of the San Andreas fault, largely on the basis of observations of damage from past earthquakes. In contrast, a probabilistic assessment could portray the likelihood of earthquake-induced ground motion exceeding a particular threshold, due to an earthquake or any combination of earthquakes, in a given region over a set time period. This information is being used to help define national building codes, appropriate insurance rates, and local zoning regulations (see Highlight 5). GD hazard assessments will focus primarily at the national and regional scale, and will be supplemented by detailed local investigations in carefully selected high-risk areas. These local investigations are intended to lead to fundamental advances in hazard-assessment methodology and will be conducted in close collaboration with State and local agencies. The utility and credibility of geologic hazard assessments are based on the continuing long-term scientific research carried out by the GD, particularly studies of factors controlling the geographic distribution, magnitude, timing, and geological consequences of hazardous events. The cost-effectiveness of this integrated research and assessment effort has been demonstrated many times and will continue to provide similar benefits to the Nation.

Highlight 5— **Discovery of Significant Earthquake Hazard in the Pacific Northwest**

Following the 1964 magnitude 9.2 earthquake in Alaska (the largest historic earthquake to strike U.S. continental territory), a GD geologist recognized a regionally consistent pattern of coastal subsidence that he correctly attributed to slip on a shallowly dipping subduction zone fault. This interpretation was at odds with the initial seismological interpretation for the earthquake but proved to be correct and played a crucial role in the development of plate tectonic theory for convergent margins. A similar subduction zone fault is present along the Oregon and Washington coast, but large earthquakes on this fault are unknown in the historic record. In the mid-1980's, another GD geologist recognized that extensive remains of dead, saltwater-flooded forests along coastal Washington must have resulted from abrupt coastal subsidence; he also recognized that widespread deposits of sand high in coastal estuaries suggested tsunami inundation. With observations from the Alaskan earthquake as an analog and precise dating and regional correlation of the dead forests, the GD geologist deduced that great subduction-zone earthquakes (magnitude 8 to 9) have repeatedly struck the Pacific Northwest in the past thousand years, the most recent one occurring in 1700. As a result, public officials significantly revised the building codes for Oregon and Washington (fig. 5). Throughout most of this region, new buildings are now designed to resist earthquake forces 50 percent larger than they were under the old code, reducing the risk to life and property.

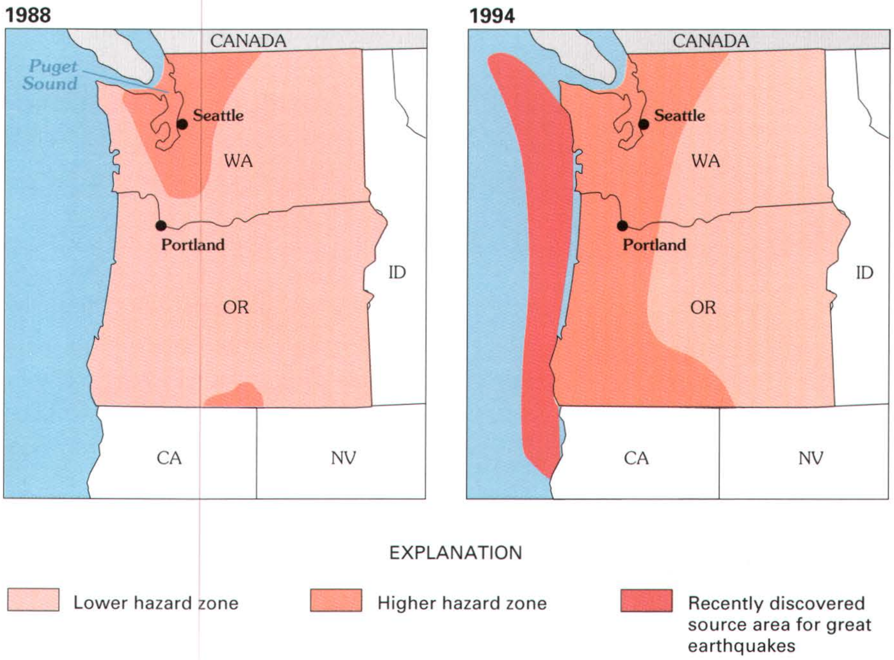


Figure 5. A dead forest in coastal Washington is evidence for a great earthquake that occurred about 1700 (photograph by B.F. Atwater, USGS). Seismic risk-assessment maps for the Uniform Building Code, which includes minimum standards for designing earthquake-resistant structures nationwide, were redrawn after the discovery of evidence of great earthquakes in the Pacific Northwest. Maps from Atwater and others (1995).

Goal 1 Products

Regional- and national-scale probabilistic hazard maps and interactive data bases.

These maps and data bases will be prepared for hazards such as earthquakes, volcanoes, landslides, coastal erosion, and floods (the last in collaboration with the WRD). For all probabilistic hazard maps, the likelihood of future hazardous events must be determined first. GD scientists make this determination on the basis of a chronology of past events and an understanding of physical causes for variability in event recurrence. Once the probability of such events is established, the resultant harmful effects can be quantified, as long as a variety of important source, site-response and other parameters can be estimated (see Highlight 6). Future generations of probabilistic seismic hazard maps should incorporate more complete scientific information on fault rupture characteristics, the materials through which seismic waves are transmitted, the response of surface deposits to shaking, the time elapsed since the last major seismic event, and possible stress transfer effects following large earthquakes.

Deterministic scenarios to aid in local and regional planning efforts.

Even when the probability of a given event is low, deterministic modeling allows land-use managers, urban and infrastructure planners, and emergency-preparedness groups to envision and plan for the range of potential consequences of natural catastrophes. For example, landslides and mudflows from Pacific Northwest volcanoes pose threats not only to local communities but also to transportation networks and power transmission lines that provide electricity to regional urban centers. Government agencies, private industry, and the public must be made aware of the full consequences of hazardous geologic events and ongoing geologic processes in order to plan appropriately.

Multihazard assessments for selected urban areas.

The GD will prepare these assessments in cooperation with State and local agencies. Individual hazardous events can have a range of spin-off effects that cause significant damage. For example, wildfires remove vegetation from entire hill slopes, creating the potential for subsequent landslides and floods. Earthquakes can cause liquefaction of soil, floods from collapsed dams, and fires (such as the one that devastated San Francisco in 1906). It is important to incorporate multiple, interrelated hazards in hazards assessments and models, particularly for major metropolitan regions.

Highlight 6— **Seismic Hazard Maps Help Save Lives and Property**

The latest revision of GD national probabilistic shaking-hazard maps (fig. 6), released in 1996, integrates information about the rate at which earthquakes occur in different areas and the distance that strong shaking extends from earthquake sources. Colors show the levels of horizontal shaking (as a percentage of the Earth's gravitational force) that have a 10 percent chance of being exceeded in a 50-year period. Maps such as this have been used by engineers to help update seismic risk maps and to establish building code provisions. More than 20,000 cities, counties, and local government agencies use these codes to help determine the construction requirements necessary to preserve public health and safety in earthquakes. A separate, more detailed seismic hazard map for California was developed cooperatively with the California Division of Mines and Geology (Frankel and others, 1997).

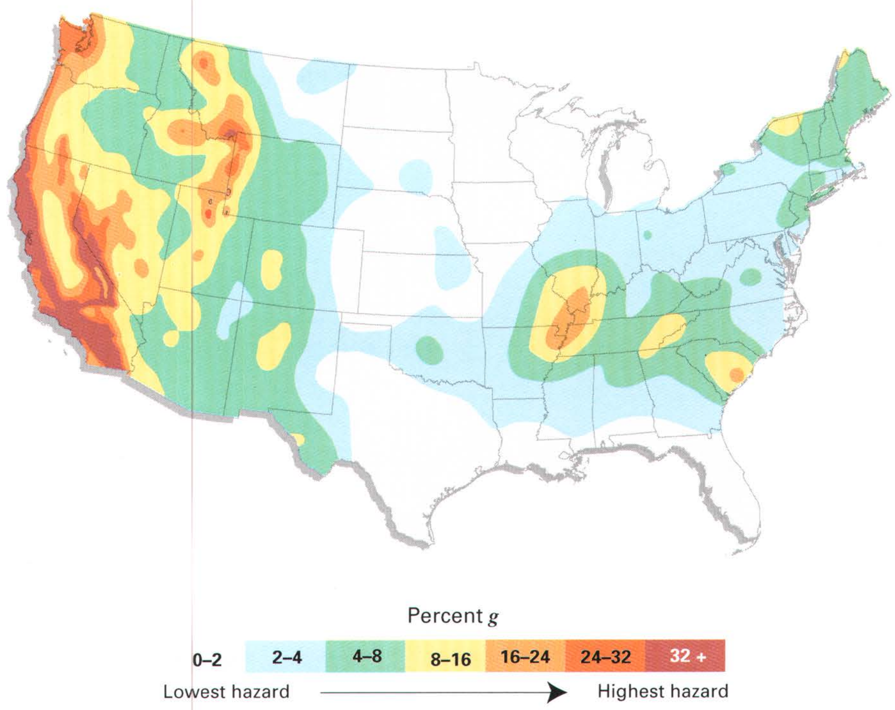


Figure 6. National probabilistic shaking-hazard map. Shaking is expressed as a percentage of *g*, where *g* is the acceleration of a falling object due to gravity. From Brown and others (1996).

Goal 1 Products, continued

Vulnerability maps and interactive data bases for geologic hazards.

These maps and data bases will incorporate information on the tendency of earth materials to fail or be remobilized by natural and manmade processes. For example, a vulnerability map showing areas underlain by artificial fill and other water-bearing sediments can help identify buildings and critical facilities at risk due to high levels of shaking or ground failure during earthquakes. Maps of playas and dunes will show sources of airborne sediment that are likely to be activated during dust and sand storms. Maps depicting the distribution of soils and poorly cemented sediments can be used to predict which areas are most susceptible to erosion during flash floods and coastal storms. In addition to providing data to be incorporated into the first three products, vulnerability maps and interactive data bases are useful in and of themselves for informing local planning agencies and the public about the types of human activities that may increase vulnerability to certain kinds of hazards.

Goal 1 Strategic Actions

Conduct detailed geological and geophysical field investigations.

These investigations will support probabilistic hazard mapping, deterministic scenarios, multihazard assessments, and vulnerability mapping in critical, high-risk (mostly urban) areas. This work, to be conducted in cooperation with USGS and non-USGS partners, will involve surficial and bedrock geologic mapping, surface-based geophysical imaging, shallow geotechnical studies, geomorphic analysis, and other investigations.

Document the recent geologic history of major hazardous events in the United States in unified data bases.

A chronology of past events is a critical ingredient in most probabilistic approaches to hazard assessment. These nationwide data bases will include the slip history of all faults with surface ruptures during the Holocene (the past 10,000 years) and selected faults with surface ruptures during the Quaternary (the past 1.8 million years). The data bases will also include the Quaternary eruption and debris-flow history for all active U.S. volcanoes and the history of major Holocene floods and landslides. Such work involves a mixture of geologic mapping, stratigraphy, Quaternary geochronology, and other investigations and will be undertaken in cooperation with non-USGS partners.

Goal 1 Strategic Actions, continued

Investigate factors controlling the geographic distribution, magnitude, and timing of hazardous geologic events.

As the physical processes that lead to natural disasters and control their magnitude are more fully comprehended, we can better quantify potential effects and predict and mitigate damage as the disaster occurs (see Goal 2). Also, some types of hazardous events occur independently of one another, whereas other types of events (such as earthquakes) may be linked through a variety of physical processes affecting when and where they will occur. Understanding the physical basis for event frequency and clustering is critical to any quantitative hazard assessment.

Determine the physical processes responsible for variations in local site response to natural hazards.

The consequences of a hazardous event depend not only on its intrinsic magnitude, but also on the characteristics of the affected areas, such as topography, rock and soil properties, and sedimentary basin geometry. The GD will develop easily measured proxies that can be substituted for parameters that are difficult to determine directly.

Develop and use consistent methods for local-, regional-, and national-scale hazard assessments for each type of hazard.

In addition, whenever possible, use similar hazard-assessment methods for different types of hazards. For example, techniques comparable to those now being used to calculate probabilities for earthquakes should be used to determine probabilities for floods and volcanic debris flows.

Goal 2—Provide short-term prediction of geologic disasters and rapidly characterize their effects

In addition to providing quantitative assessments of geologic hazards and long-term probabilistic forecasts for planning purposes (Goal 1), the GD also provides information critical to disaster response for Federal and local emergency management agencies in the short term before, during, and after a natural disaster strikes. The GD will focus on developing and implementing methods for predicting the onset of hazardous geologic events, evaluating the progress of natural disasters while they are occurring (that is, realtime warnings), and communicating timely information on the likely location and severity of damage and possible geological and biological consequences. These disasters include earthquakes, landslides, volcanic eruptions, floods, magnetic storms, tsunamis, hurricanes, and dust storms.

In contrast to probabilistic hazard forecasts, which are derived from information on the severity and frequency of past activity, short-term predictions generally are based on observations of physical parameters monitored in the hours to days preceding an impending disaster. Significant losses to life and property can be diminished by developing and implementing methods to predict disaster onset. For example, the international leadership provided by the GD in the short-term prediction of volcanic activity and its likely geologic effects has led to timely evacuation of people and safeguarding of valuable equipment (see Highlight 7). Although earthquake prediction remains an important societal goal, focused research on the physics of faulting is needed to determine if such prediction is possible and, if so, how it might be accomplished. Realtime information on the progress and likely geologic consequences of a disaster can be used to assist onsite emergency response and disaster mitigation and to avert further catastrophe. Finally, the GD will work with State and local colleagues to provide full documentation of the geological and biological effects of these disasters in their immediate aftermath and release that information in a timely fashion. This documentation will provide guidance for future land-use decisions and provide feedback to improve the natural hazard assessments in Goal 1. In addition, the GD can apply its disaster-response capabilities to monitoring the progress and ultimate geological and biological effects of certain manmade catastrophes, such as oil spills, dam collapses, and forest fires.

Goal 2 Products

Predisaster scenarios.

In collaboration with USGS divisions and other agencies, the GD will define and quantify likely event scenarios (by using vulnerability maps and deterministic hazard assessments developed in Goal 1), establish alert levels, and provide appropriate warnings for volcanic eruptions, earthquakes, landslides, floods, tsunamis, hurricanes, magnetic storms, and other geologic disasters. For example, rainfall intensity data, land cover and soil-property data, and DEM's will be used to create landslide scenarios and to determine alert and warning levels.

Goal 2 Products, continued

Mid-disaster estimates.

During natural disasters, the GD will rapidly estimate the extent and magnitude of destruction and potential collateral hazards. For example, during and shortly after large earthquakes, the GD will define the areas where the most severe ground shaking occurred in order to guide post-earthquake emergency response. During volcanic activity, the GD will define potential risk zones for post-eruption mudflows and landslides. During geomagnetic storms (which can cause severe disruption of power transmission and communication networks), the GD will provide realtime information on the intensity and distribution of magnetic disturbances to appropriate government and industry representatives.

Postdisaster documentation.

The GD will prepare maps and other documentation of the geological, hydrological, and biological effects of natural disasters in a timely fashion to aid in recovery efforts and to provide ground truth needed for improvement of hazard assessments conducted under Goal 1. For example, the GD will produce forecasts of earthquake aftershocks or post-eruption volcanic scenarios and maps of the extents of storm surge and erosion due to hurricanes and tsunamis.

Goal 2 Strategic Actions

Significantly expand and upgrade monitoring capabilities.

This monitoring capability includes networks of broadband seismic sensors to record earthquake ground motion and volcanic signals, continuous Global Positioning System (GPS) stations, and prototype acoustic flow meter arrays to detect volcanic mudflows. The GD will ensure the continuity of monitoring and transmission capabilities during disasters.

Create Rapid Response Teams.

The GD will work with other USGS divisions and State and local governments to create Rapid Response Teams to assess the geological, hydrological, and biological effects of natural disasters. The GD will also develop plans to ensure rapid response by GD scientists to selected natural disasters and will define alert levels and rehearse necessary procedures.

Highlight 7— **USGS Response Helps Avert Catastrophe at Mount Pinatubo**

On April 2, 1991, villagers of Patal Pinto, on the Island of Luzon, Philippines, observed minor ash and steam coming from the upper slopes of Mount Pinatubo, a dormant volcano that had last erupted 500 years before. On April 23, USGS personnel joined ongoing monitoring by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), installed a radio-telemetered seismic network (fig. 7) and tiltmeters, and began measuring volcanic gases. The expanded monitoring efforts were guided, in part, by new technologies developed by the USGS in response to the eruptions of Mount St. Helens, Mount Redoubt, and other volcanoes during the 1980's. Geologic reconnaissance and monitoring soon convinced the USGS–PHIVOLCS team that a large eruption was imminent. Eruption forecasts caused local officials to evacuate about 100,000 residents from the Pinatubo area, including 18,000 U.S. military personnel and their dependents from nearby Clark Air Base. Several days after the forecast, about 5 cubic kilometers (1.2 cubic miles) of magma exploded from Pinatubo, devastating hundreds of square kilometers of the Philippine countryside. It was the second largest volcanic eruption of the 20th century, after the 1912 eruption of Mount Katmai in Alaska.

Losses of at least $US200 million–$275 million were averted by timely movement of military aircraft and other equipment out of the region. Scores of aircraft were warned of the location of ash clouds and steered clear; those few aircraft that failed to heed the warnings suffered about $US100 million in damage. Between 5,000 and 20,000 lives were saved by the timely forecasts. The entire cost of the USGS–PHIVOLCS mission is estimated at $US1.5 million, and development of those agencies' capability to monitor volcanoes and produce short-term forecasts has cost approximately $US15 million over a 10-year period. The Pinatubo event clearly illustrates how long-term investment in scientific understanding can result in enormous benefits.

"All of us who were at Subic Bay during Mount Pinatubo's 1991 eruption owe the outstanding USGS staff a tremendous thank you for timely warnings and very accurate predictions."

— ***Capt. David Krieger***
U.S. Navy
Commanding Officer,
Subic Bay Naval Station

Figure 7. Volcanologists from PHIVOLCS and the USGS attempting to restore seismic signal from Patal Pinto, June 14, 1991. Photograph courtesy of Val Gempis, U.S. Air Force.

Develop and implement strategies to use innovative remote-sensing technologies.

These strategies include exploiting classified data for monitoring and analysis of the geologic precursors and effects of natural disasters and developing indicators to quickly define damage zones and regions at risk. For example, by using Interferometric Synthetic Aperture Radar (InSAR) for realtime strain and erosion monitoring and GPS network data, GD scientists can evaluate precursory phenomena to earthquakes and volcanic eruptions and document the aftereffects of earthquakes, volcanic eruptions, and floods.

Focus research on the fundamental physical processes that result in or occur during natural disasters.

This research will enhance predictive abilities and emergency response. Specific topics and processes that need to be investigated include coastal erosion, earthquake generation and recurrence, magma ascent and volcanic eruption, landslides, and sediment transport during floods and hurricanes.

Goal 3—Advance the understanding of the Nation's energy and mineral resources in a global geologic, economic, and environmental context

The United States is among the world's leading producers and consumers of energy and mineral resources, and the Nation's economic security depends on maintaining adequate supplies from various domestic and global sources. The Nation constantly faces decisions involving the supply and utilization of raw materials, substitution of one resource for another, competing uses for Federal lands, and the environmental consequences of resource development. The ability to make these decisions, whether in the public or private sector, requires current and accurate information on the origin and global distribution of energy and mineral resources, the economic factors influencing their development, and the environmental consequences of exploitation. The GD collects and provides this information through an integrated long-term program of research, assessments, and data gathering. The GD's Congressionally mandated role in comprehensive assessment of energy and mineral resources is unique within the Federal Government and the private sector and has recently been enhanced by the incorporation of the Minerals Information Team from the former U.S. Bureau of Mines.

Future scientific challenges for the GD involve (1) anticipating new and changing resource demands, such as the shift from coal and oil to natural gas, and technology-driven substitutions, such as the potential shift from lead to other metals in batteries; (2) developing new principles and concepts to increase scientific understanding of critical, high-value resources that are expected to have increased future demand; (3) formulating and (or) improving science-based assessment methods (including total-cost assessments); and (4) conducting global assessments of resources having substantial economic importance, such as oil and strategically important mineral commodities. The reliability and value of these assessments and related products are based on rigorous supporting geological, geochemical, and geophysical research and on the broad, objective, scientific perspective and expertise of the GD staff.

Goal 3 Products

National, issue-specific, and total-cost assessments of the Nation's petroleum, coal, and selected metallic and industrial mineral resources.

These assessments will be conducted at the National, regional, and local scale, commonly in collaboration with a variety of partners (see "Working with Others"). Much of this effort will focus on Federal lands, offshore waters and other areas of critical national interest at the request of Federal and local land-management agencies. Rapid-response assessments will be conducted to support short-term policy decisions. Assessments will be tailored to meet customer needs and can involve qualitative or quantitative evaluation, compilation of existing data or collection of new information, and process-oriented investigations of resource origin, distribution, and environmental effects. Total-cost assessments, which evaluate the quantity and availability of resources, as well as the environ-

Goal 3 Products, continued

mental and economic effects and benefits of their development, stem from an increased societal need to understand the potential effects of human activities and add a new dimension to this traditional GD effort.

Geological, geophysical, and geochemical maps, surveys, and syntheses of carefully selected geographic areas in support of resource assessments.

Examples of these areas include potentially important and (or) newly discovered mineral districts on Federal lands and in offshore regions that have been leased or are being considered for mining of aggregates or for hydrocarbon exploration and development.

Quantitative global assessments of oil and gas resources and selected high-value mineral resources.

These global assessments require considerable interaction and cooperation with foreign institutions and the private sector and are essential elements in the design of national economic and security policies.

Integrated life-cycle models of selected mineral and energy commodities.

These models describe global geologic occurrences, genetic processes, present and future uses, recycling potential, possible substitutions, disposal strategies, and associated environmental effects.

Goal 3 Strategic Actions

Evaluate national and global trends in energy and mineral resource use.

The GD will evaluate trends jointly with other technical groups and agencies, such as the State Department and the U.S. Department of Energy (DOE), as a means of prioritizing future resource investigations.

Focus geoscience field investigations on carefully selected geographic areas in support of national resource assessments.

The GD field investigations will include geologic mapping, geophysical and geochemical surveys, sedimentary basin analysis, mineral-deposit genesis, and environmental effects. The GD will develop and (or) use new principles, methods, and technologies to enhance the efficiency, resolution, and application of these field investigations.

Focus interdisciplinary research on the key geologic processes that control the origin and distribution of energy sources and mineral deposit types with present or anticipated high demand.

This GD research will reduce uncertainties in national and global resource assessments. For example, prediction and assessment of petroleum resources in producing fields will be improved through investigations of reservoir heterogeneity and other controls on field growth. Investigations of gas hydrates and other carefully selected unconventional energy resources, such as geothermal energy, will be conducted to help determine their future viability and importance to the Nation. For example, continuous-type natural gas resources are helping to meet growing national demand (see Highlight 8). Investigations of the tectonic, structural, hydrologic, and climatic controls of selected mineral deposit types will provide the scientific foundation needed for more comprehensive assessments and evaluations.

Develop quantitative total-cost assessment methods.

These methods will integrate current advances in mathematics and logic theory, economic factors in resource development, potential environmental effects of resource development, and environmental mitigation and remediation costs. The GD will develop comparable methods for assessing all energy resources so that the Nation's energy mix can be continuously tracked and evaluated.

Highlight 8— ***Identifying Critical Energy Resources***

In the early 1980's, natural gas in the United States was produced mainly from localized conventional stratigraphic and structural traps in oil fields, and there was little recognition of the potential for disseminated natural gas resources in more regional continuous accumulations (formerly termed "unconventional"). Since that time, the GD (with $15 million in funding from the DOE), has intensively investigated the origin and distribution of continuous gas resources in tight (low-permeability) reservoirs (fig. 8), basin-centered gas accumulations, and coal-bed methane. The GD work identified the magnitude of continuous gas resources in the United States and documented their origin and distribution, providing the basis for a new phase of natural gas exploration. Today, one-third of U.S. gas resources identified are from continuous-type accumulations (U.S. Geological Survey, National Oil and Gas Resource Assessment Team, 1995, p. 2), and they will have growing importance in providing the U.S. domestic supply in the years 2000–2010. This resource has particular policy significance because much of it occurs on Federal lands in the Western United States and because national demand for gas—an energy fuel that is cleaner than coal or oil—is expected to grow. With funding from non-USGS partners, GD geologists have identified continuous gas resources throughout the world, including the former Soviet Union, Eastern Europe, China, and the Middle East.

Figure 8. Steeply dipping Cretaceous strata (rocks 136 million to 65 million years old) at the south end of the Green River basin near the Utah-Wyoming border. Cretaceous strata in the deeper part of the Green River basin contain major energy gas resources in tight (low-permeability) sandstone reservoirs. Photograph by B.E. Law, USGS. From McCabe and others (1993).

Goal 4—Anticipate the environmental impacts of climate variability

Climates are constantly changing, and understanding and assessing the impacts of climate change are some of the most significant and controversial issues facing scientists and society today. For example, the 20th century instrumental record suggests that global warming is occurring, but the driving force for this change is not understood. Is this apparent warming part of normal climate variability, does it reflect increasing levels of atmospheric greenhouse gases due to human activities, or are both factors involved? Further complicating this question are paleoclimatic data suggesting that climate may undergo abrupt global-scale shifts over a matter of a decade or two, rather than smooth, gradual transitions over longer periods. Regardless of the cause of climate change, the environmental and economic consequences of continued warming are enormous. Densely populated coastal zones may be inundated and (or) face large-scale erosion as sea level rises (see Highlight 9); some agricultural regions may face significant droughts; and other areas may face increased frequency of floods or hurricanes.

Defining the range and rates of natural climate variability is the key both to assessing the historic human influence on climate and to predicting the effects of climate changes. The instrumental record of climate is restricted largely to the last hundred years and is grossly inadequate to understand the dynamics of the modern climate. The only way to extend this meager climate record is through continued detailed paleoclimatological analysis of the historic and geologic past. The USGS is working to help define the magnitude, extent, and impact of past climate change as well as the frequency of climate variability. Specifically, there are two areas in which the GD will assume a leadership role in the U.S. Global Change Program: (1) continental- and regional-scale reconstruction of key past climates, using a combination of terrestrial and marine paleoclimate records, and (2) modeling or forecasting the effects of climate changes on landscapes of the United States, including effects on both geomorphic processes (see Highlight 10) and vegetation distribution (see Highlight 11). The GD will make this information available so that it can be considered in formulating local and national land-use decisions, as well as in national and global economic policies responding to ongoing climate change.

Goal 4 Products

National- and regional-scale reconstructions of past climates (precipitation and temperature) and past environments (landforms and vegetation).

The GD will provide reconstructions for both Holocene (the past 10,000 years) and pre-Holocene time periods to compare with results from atmospheric general-circulation models.

Quantitative regional assessments of vulnerability to climate change and likely environmental impact scenarios.

Examples of scenarios the GD will prepare include the effect of precipitation changes on fluvial erosion and landslide hazard, the impact of sea-level changes on coastal erosion and inundation, the impact of drought-induced remobilization of dune sand on crop land and atmospheric dust levels, the impact of precipitation changes on ground- and surface-water supplies, and the shift in distribution of plant species due to climate change.

High-resolution time series of past climatic conditions.

The GD will prepare series particularly for (but not limited to) the Holocene, using key climate proxy data, with emphasis on the terrestrial record. Such efforts will be conducted in order to document the natural range of climate variability and to identify the frequency of extreme climatic conditions, such as droughts or extended periods of very high precipitation.

National and regional maps showing possible early warning indicators of climate change.

Examples of indicators that the GD might map include areal and volumetric changes in glaciers, shifts in vegetation distribution, extent and depth of permafrost, extent and magnitude of atmospheric dust flux and dust storms, and distribution and degree of activity of dune sand.

Highlight 9—
Areas of Florida That Could Be Inundated by Sea-Level Rise

Cooperative mapping by the Florida Bureau of Geology and the GD, through the Quaternary Geologic Atlas of the United States effort, identified those parts of coastal Florida dating to the last interglacial period; these areas are underlain by rocks known as the Anastasia Formation, the Miami Oolite, the Key Largo Limestone, and the upper part of the Fort Thompson Formation. This interglacial period is the last time that global climate was significantly warmer than present, and sea level was 7–8 meters (about 23–26 feet) higher than it is today. Figure 9 depicts where the coastline of Florida was during this past warm climate and where it could be in the future should global warming reach the same levels as in the past. Wildlife habitats such as the Everglades and critical facilities such as the Kennedy Space Center on Cape Canaveral would be under water, and the lives and properties of more than 7 million Florida residents would be affected.

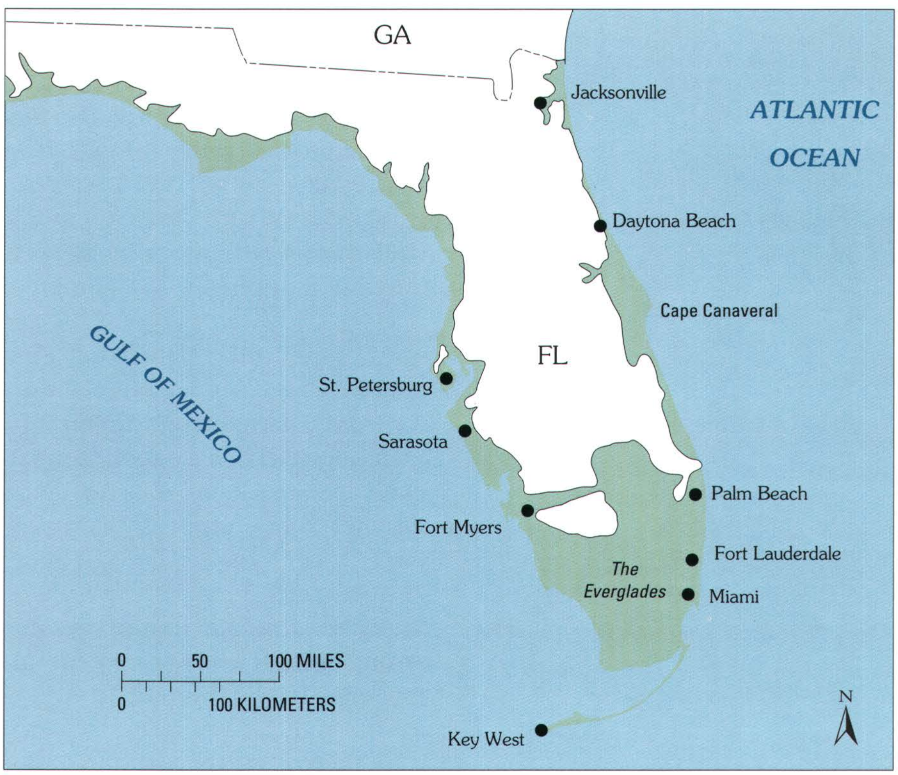


Figure 9. Shoreline of Florida during the last geologic period of significantly warmer climate. Areas shown in green might be under water if global warming should reach the same levels as in the past. From Scott and others (1986a,b) and Copeland and others (1988).

Goal 4 Strategic Actions

Reconstruct key past climates under a range of conditions and compare these to atmospheric general-circulation model results.

These reconstructions will emphasize warm climates of the past but will also include some studies of cold climates and the transitions between past climate states. Highly interdisciplinary paleoclimate studies of both terrestrial and marine records and frequent interaction with the climate-modeling community will be required.

Identify areas highly sensitive to climate variability and determine critical thresholds of temperature and precipitation changes that can induce vegetation and geomorphic changes.

Changes in highly sensitive areas such as arid zones and Arctic regions can result in extensive fluvial erosion, landsliding, dune reactivation, and enhanced coastal erosion. The GD will establish quantitative measures of vulnerability to climate change and incorporate these into predictive models of landscape and ecosystem evolution resulting from probable future climate changes.

Refine data on the magnitude and frequency of climate and paleoecological changes during the Holocene to higher resolution.

High-resolution records are required for sedimentation, landforms, pollen, and stable isotopes in fossil materials, and obtaining them will necessitate developing and exploiting cutting-edge Holocene dating techniques. This effort will also include developing and testing new climate proxies available from the geologic record.

Collaborate with other agencies to initiate and expand long-term baseline mapping of key climate-change indicators.

The GD will collaborate with other Federal agencies, particularly NASA and the National Oceanic and Atmospheric Administration (NOAA), and foreign institutions to map key climate-change indicators, such as glaciers, vegetation, permafrost, and dune sand. Such efforts will likely include extensive use of remote-sensing and geographic information system (GIS) techniques.

Study the fundamental processes and key biogeochemical cycles governing climate change and climate-related hazards, with emphasis on the terrestrial domain.

One process affecting the carbon cycle and influencing climate change may be the release of methane by destabilization of natural carbon storage reservoirs. This destabilization can result from melting of permafrost or depressurization of sea-floor hydrates due to a drop in sea level.

Highlight 10— ***Great Plains Sand Dunes Show Recent Mobilization***

Sand dunes are extensive on the Great Plains, and the Nebraska Sand Hills region is the largest sand sea, active or stabilized, in the Western Hemisphere. Although winds on the Great Plains are presently stronger than in most of the world's deserts, these Great Plains sand dunes are now inactive, stabilized by sparse prairie vegetation cover. Recently, GD geologists and coworkers determined that most dunes on the Great Plains have been active in the past 3,000 years. Many were found to be active during the 1800's, and some were active during the Dust Bowl drought of the 1930's. Thus, it can no longer be assumed that these dunes pose little threat of reactivation in the future since they have been active under climatic conditions that are only slightly different from the present.

If the dunes are reactivated in the future, either from human-caused global warming or natural climatic variation, there would be significant changes in the region (fig. 10). These potential changes include loss of grazing and crop land, sand movement onto interstate highways and railroads, and loss of wetlands and other wildlife habitats. By understanding how climate variability can affect the landscape, GD geologists can provide essential information to Federal, State, and local planners and land managers, as well as to residents of climatically sensitive regions.

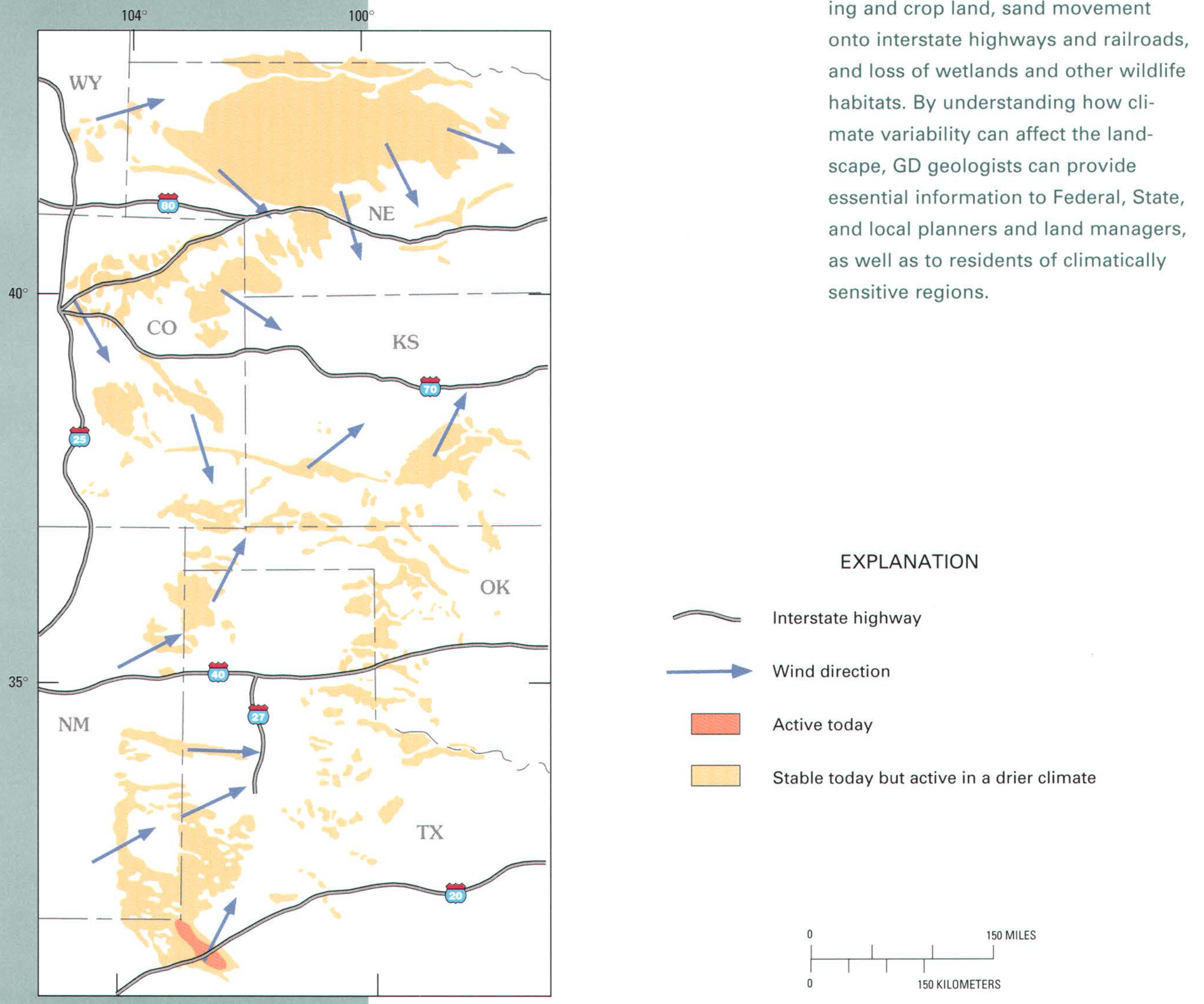


Figure 10. Distribution of dune sands on the Great Plains. Arrows show direction of modern winds. Only one small area of dunes is active today, but most of the region could become active in the future under a drier climate. Map from Muhs and Maat (1993) and Muhs and Holliday (1995).

Goal 5—Establish the geologic framework for ecosystem structure and function

Human population growth and economic development are strong forces that drive land-use decisions and have the potential to alter the distribution, structure, function, and health of ecosystems. As this development proceeds, however, the importance of healthy and diverse ecosystems to the quality of human life is becoming widely recognized and more highly valued by the public (see table 1). In the face of human modifications to ecosystems, resource managers must develop and implement ecosystem management strategies that conserve biological diversity, restore degraded habitats, facilitate sustainable plant and animal harvests, control invasive species, and maintain water quality. The USGS, as the Nation's earth science and biological science agency, will assist ecosystem managers by providing the essential scientific information needed to make wise land-use decisions.

The scientific basis for ecosystem management, particularly the role of geology in sustaining or restoring ecosystems, is emerging as a major, multidisciplinary scientific challenge for the GD. It is now widely recognized that the living resources of ecosystems have a spatial organization imposed upon them by the geologic framework of the region and that geologic processes (for example, sediment transport, soil formation, ground-water flow) significantly influence ecosystem evolution and vitality on time scales of days to decades. Moreover, the geologic record contains valuable clues to the structure, history, and behavior of ecosystems.

GD geologists will work with biologists, ecologists, hydrologists, and chemists to characterize the geologic framework and hydrologic cycle of ecosystems and to identify the geological and geochemical processes critical to ecosystem structure, function, and restoration. The temporal focus will be on time scales of agricultural, industrial, and urban development to provide the scientific understanding necessary for management of ecosystem health, sustainability, and restoration. GD geoscience studies of ecosystems will be concentrated in rapidly urbanizing areas, coastal zones, public lands, and other regions of national importance or interest such as the Florida Everglades (see Highlight 12), the Mojave Desert, the North Slope of Alaska, the Rocky Mountain Front Range Urban Zone, and the Chesapeake Bay region.

Goal 5 Products

Maps of surficial and shallow-subsurface lithologic, mechanical, and geochemical properties of ecological significance for selected ecosystems.

For example, the GD will prepare maps of cryptogamic soils (lichen and blue-green algal encrusted soils), found in some desert regions; these maps can aid land managers in devising proper land-use policies by highlighting areas vulnerable to overgrazing. When disturbed, cryptogamic soils become susceptible to erosion, resulting in loss of vital soil and invasion of non-native plants.

Highlight 11—
The Effects of Climate Change on Ecosystems

GD scientists with experience in relating past climates to vegetation cover have produced maps showing potential changes in the distribution of Douglas fir (*Pseudotsuga menziesii*). Figure 11 shows the distribution of this tree in the present climate and in a modeled future climate having carbon dioxide levels twice those of pre-industrial times (a 2 x CO_2 climate). Under such future climate conditions, temperatures in the Western United States may be as much as 3°–5°C warmer than present. The left panel illustrates where this tree is found today. On the right panel, green represents sites where the species is found today and where it could continue to live under the simulated 2 x CO_2 climate. Red indicates sites where it occurs today but would not survive under the simulated 2 x CO_2 climate. Blue represents sites where it does not exist today but could be found under the simulated future conditions. Although the changes illustrated by this figure are specific to the particular climate simulations used here, they are probably representative of the changes that may occur.

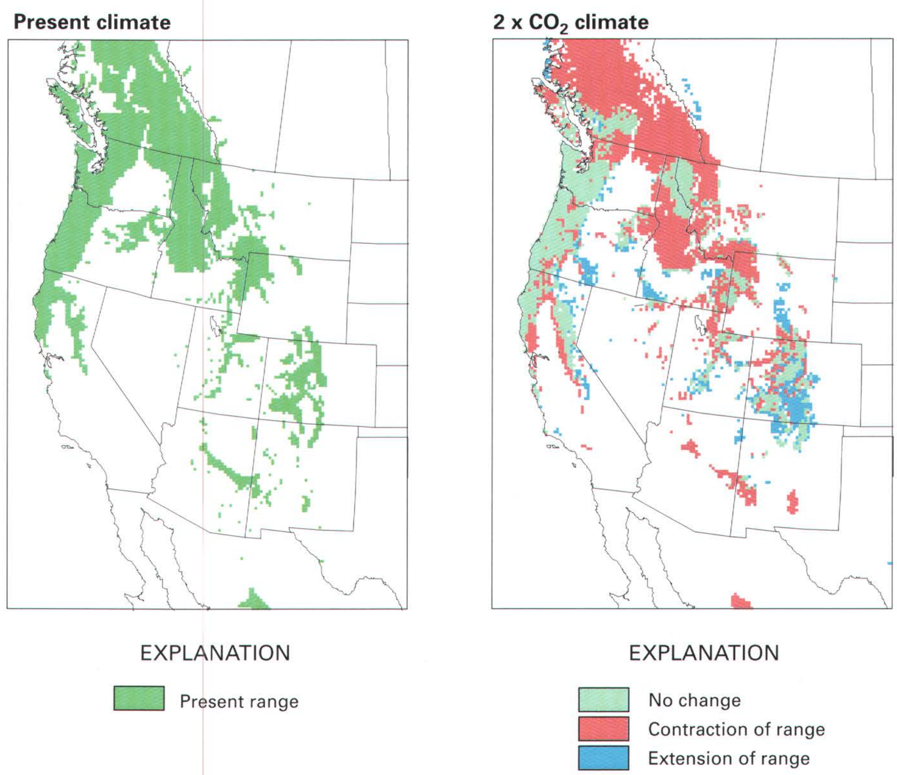


Figure 11. Present distribution of the Douglas fir in western North America and predicted changes in its distribution in a 2 x CO_2 climate. A 2 x CO_2 climate has twice as much carbon dioxide as pre-industrial times. Map from Thompson and others (in press).

Goal 5 Products, continued

Models of geologic and geochemical processes that affect ecosystem functions.

The GD will develop models that can be used to anticipate changes in those portions of the ecosystem linked to geologic phenomena. For example, the dynamics of coastal barrier islands and lagoons and nutrient cycling in wetlands can be modeled to provide forecasts of vegetative change due to both natural variability and human disruption.

Geochemical baselines of metals and other contaminants.

The GD will document predevelopment background variability in minor- and trace-element chemistry and subsequent change during human occupation. Baselines are most easily developed in areas of rapid change, but in mature urban areas, geologic records may be derived from sediments in lakes, reservoirs, and estuaries. Paleobiological records, such as those derived from tree rings or annually banded corals, may also be available in some settings. Activities associated with these products have strong links with Goal 6 and complement efforts in other USGS divisions and other Federal agencies such as the EPA and NOAA.

Rates of faunal and floral change during recent geologic history determined from paleontological and geochemical studies.

The GD studies will support landscape, ecological, and climate modeling. Landscape models used to predict faunal and floral change are constructed, in part, from empirically determined rates of landscape processes such as plant succession. In the Everglades, for example, analyses of pollen from well-dated peat cores provide the best estimates of the rate of replacement of sawgrass by mangroves. Time scales for these products will generally be more recent than those for Goal 4, but strong links must be made in order to separate natural transitions from human-induced alterations.

Assessments of fundamental geologic fluxes that affect ecosystem dynamics.

The GD will study geological fluxes, including the roles of sedimentation and erosion, soil and dust generation, and other surficial processes, in maintaining or degrading sensitive ecosystems (for example, tundra, western and desert soils, and coral reefs).

Table 1— **Values of Natural Resources**

Ecologists and economists have collaborated to begin placing dollar values on a vast array of benefits and services provided to humans by ecosystems. Estimates range from $3 trillion to $30 trillion per year. Typical ecosystem services include fish provided by the sea, feed for cattle provided by grasslands, and tropical hardwoods provided by forests. This table exemplifies one attempt to place a price on nature and provides a basis for understanding the tradeoff that must be made when a wetland, for example, is destroyed.

Table 1. Values of natural resources.

[Reprinted with permission from Roush, W., 1997, Putting a price on nature's bounty: Science, v. 276, p. 1029. Copyright 1997, American Association for the Advancement of Science. Data from Costanza, R., and others, 1997, The value of the world's ecosystem services and natural capital: Nature, v. 387, p. 256]

Ecosystem[1]	**Area** (million ha)[2]	**Value** ($/ha/yr)	**Global value** ($trillion/yr)
Open ocean	33,200	252	8.4
Coastal	3,102	4,052	12.6
Tropical forest	1,900	2,007	3.8
Other forests	2,955	302	.9
Grasslands	3,898	232	.9
Wetlands	330	14,785	4.9
Lakes and rivers	200	8,498	1.7
Cropland	1,400	92	.1
Total worth of the biosphere			$33.3

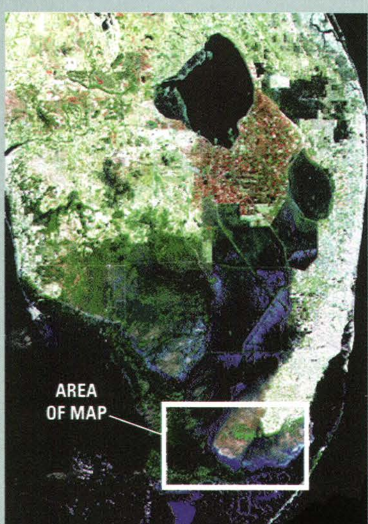
[1] Desert, tundra, urban, and ice/rock ecosystems are omitted.

[2] Area in hectares (ha). 1 ha=100 square meters =2.471 acres.

Highlight 12—
Protecting the Everglades Ecosystem

Everglades National Park, the magnificent "River of Grass" in South Florida, is threatened by enormous water demands for rapid urban development and water diversions for intensive agriculture and flood control. The flow of freshwater through the Everglades into Florida Bay at the southern coastal tip of Florida is critical to the well-being of this fragile ecosystem. The USGS is participating in a multibillion dollar restoration program, in partnership with other Federal agencies, to mitigate the impact of current water management policies in South Florida. A major concern is the degree of saltwater intrusion into the aquifer underlying the Everglades, causing changes in plant communities that adversely affect fish and wildlife habitats.

USGS scientists use a helicopter-borne electromagnetic device to conduct rapid and economical surveys of aquifer quality where ground access is difficult; these surveys determine ground-water salinity by mapping changes in electrical resistivity of shallow subsurface rocks. The surveys have demonstrated an abrupt increase in resistivity 5–10 km (3–6 miles) inland from Florida Bay, corresponding to the infiltration of seawater beneath the Everglades (fig. 12). In addition to mapping saltwater intrusion, these surveys monitor changes in subsurface conditions and help constrain regional flow models. The imprint of human activity is dramatically apparent at several locations within the park, particularly along old roads and canals. This information is contributing to strategies that the NPS is using to protect living resources in the endangered Everglades ecosystem.



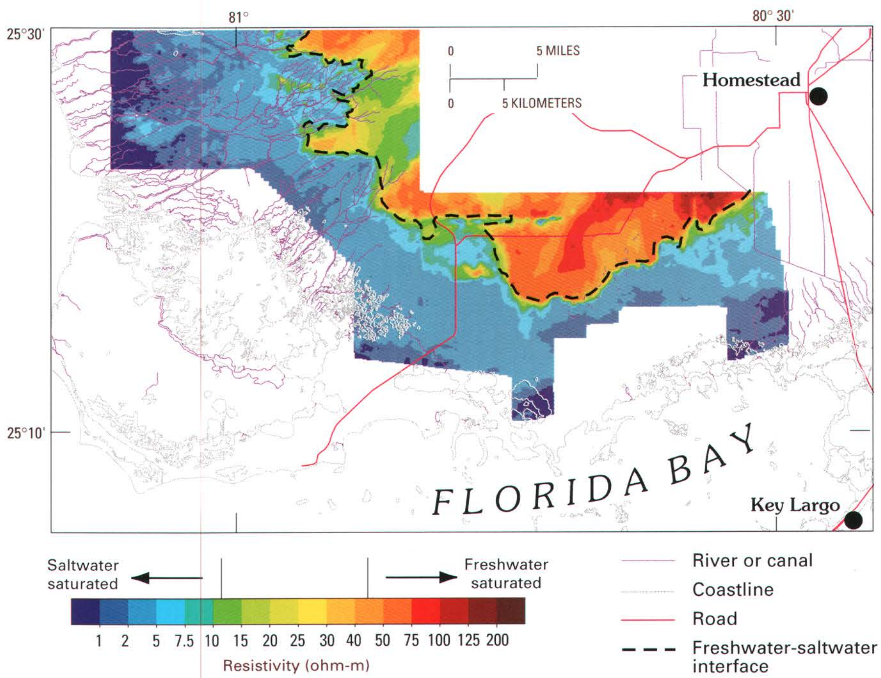


Figure 12. Satellite image showing mapped area and map showing saltwater intrusion beneath the Everglades. Ground-water salinity can be determined by mapping changes in electrical resistivity of subsurface rocks. Increases in resistivity (measured in ohm-meters) correspond to the incursion of seawater beneath the Everglades. From Fitterman (1996).

Goal 5 Strategic Actions

Develop partnerships with scientists outside the GD.

For example, GD scientists will collaborate with ecologists, hydrologists, and microbiologists in interdisciplinary teams to study the controls of ecosystem dynamics and the potential for ecosystem restoration.

Focus geologic mapping of both bedrock and surficial deposits in ecosystem gradients.

Ecosystem gradients are regions where human needs for development and use of natural resources are competing directly with the need for preservation. These areas will occur primarily along the margins of rapidly urbanizing areas, in coastal zones, and on public, multiuse lands.

Determine rates of floral, faunal, and other environmental changes.

By using stratigraphy, paleontology, sedimentology, soil science, geochemistry, and high-resolution geochronology, GD scientists can determine rates of change to provide information on ecosystem development and history.

Conduct fundamental research to understand the roles of surface geology and geomorphology and surficial geologic processes.

GD studies of bedrock, slope stability, soil formation, and sediment transport and deposition will aid in understanding the structure and function of natural ecosystems.

Investigate biogeochemical cycles in ecosystems focusing on the sediment-soil interface and on elemental pathways.

GD scientists will study the carbon, nitrogen, sulfur, and phosphorus cycles using trace-element and isotopic tracers and will investigate the role of microbes in soil formation.

Goal 6—Interpret the links between human health and geologic processes

It is widely recognized that some aspects of human health can be affected by geologic materials and processes. Once released, toxic substances can be circulated and concentrated by geologic processes through a range of sensitive environments and are commonly incorporated into food chains, increasing the risks to human health. GD studies in cooperation with health experts have already contributed to the understanding of these effects and demonstrate the need for expanded research efforts in this area. For example, GD scientists were among the first to recognize that not all mineralogical forms of asbestos lead to increased incidences of cancer in humans, and GD scientists are currently helping to understand the origin of acidic volcanic fog in Hawaii (see Highlight 13). Earth science research can also identify how geologic processes transport and store substances that are toxic to humans (see Highlight 14), including both naturally occurring materials and those produced by human activities. By understanding these processes, improved strategies for pollution prevention, mitigation, and remediation can be developed.

Research linking geologic processes to human health and environmental pollution will continue to grow in scope and societal impact. Interpreting the links between geology and human health will provide major research opportunities and challenges for GD scientists and their cooperators. Research will continue in traditional earth science areas, such as examining geologic and geochemical processes that control contaminant source, transport, and fate in the environment and establishing natural baseline concentrations of potential toxins in soils, sediments, rocks, and plants. Significant scientific advancements will also result from increased collaboration between GD scientists and specialists from the medical and biological communities, such as other Federal agencies (EPA, the National Institutes of Health, and the Agency for Toxic Substances and Disease Registry), State health agencies, medical societies, and other USGS divisions. Earth scientists can provide crucial geological and geochemical insights into epidemiological studies examining the elevated regional occurrences of some diseases. For example, outbreaks of valley fever in the Los Angeles area resulting from earthquake-generated dust clouds underscore the need for input from earth scientists in understanding the potential controls of soil and rock type on some pathogenic illnesses.

Goal 6 Products

Lay-oriented and publicly accessible summaries of the geology, geochemistry, and health effects of selected potentially toxic elements, mineral phases, and organic compounds.

In cooperation with appropriate health experts and agencies, GD scientists will prepare these summaries of potentially toxic substances, which can include data on their distribution in the environment as a function of geology, climate, and ecosystem; their natural concentration ranges in rocks, soils, sediments, ground and surface waters, and plants;

their geoavailability (the ease with which they are liberated into the environment from earth materials); important geochemical and sedimentological processes that control their environmental mobility and degradation; and their potential health effects on humans, animals, aquatic species, and plants.

Nationally consistent, regional-scale environmental geology and geochemistry data bases and maps.

GD scientists will produce environmental geology maps depicting the distribution of rock types likely to produce, through natural weathering or anthropogenic enhancement of weathering, elevated levels of potentially toxic elements such as selenium, arsenic, and uranium. The GD will also prepare geochemical maps delineating, as a function of geologic terrane and climate, the measured or inferred natural baseline concentrations (and, where possible, the environmental availability) of selected toxic elements in rocks, soils, sediments, and plants. These maps will be based upon data included in a variety of data bases such as the USGS national geochemical data base and the coastal contaminated sediment data base for Atlantic and Gulf coasts, prepared in cooperation with the EPA.

Integrated geological, geochemical, and biological assessments of regions where contaminated sediments may accumulate.

These regions include selected lacustrine, estuarine, and coastal areas (for example, Massachusetts Bay). In making these assessments, GD scientists will collect and interpret data and develop models that can predict, for a variety of environments and contaminants, the physical transport and deposition of contaminated sediments, the potential release of contaminants from sediments to the water column, and the incorporation of contaminants from sediments and the water column into the food chain.

National and (or) regional, geology-based health assessments.

Similar to past GD assessments of radon, these assessments should evaluate the potential for a variety of health effects tied to geologic factors, such as the health effects of naturally elevated concentrations of heavy metals in certain rock terranes. The assessments can also evaluate the potential for various rock and soil types to foster pathogen colonies, as well as the potential for various earth processes such as landslides and earthquakes to release the pathogens into the environment.

Highlight 13— **Vog Hazard in Hawaii**

Kilauea Volcano on the Island of Hawaii is currently the largest stationary source of sulfur dioxide gas in the Nation. Sulfur dioxide and other pollutants emitted from Kilauea react with oxygen and atmospheric moisture to produce volcanic smog (known as vog) and acid rain, affecting the lives of many of the 138,000 residents and 1.2 million annual visitors to the Island of Hawaii (fig. 13). Vog poses a health hazard by aggravating preexisting respiratory ailments, and acid rain damages crops and leaches lead from rainwater catchments into household water supplies. The USGS's Hawaiian Volcano Observatory is closely monitoring emissions from Kilauea and working with local officials and health professionals to better understand volcanic air pollution and to increase public awareness of this hazard.

Figure 13. Vog (volcanic smog) viewed from the summit of Kilauea Volcano on the Island of Hawaii. Sulfur dioxide and other pollutants emitted by Kilauea react with oxygen and moisture in the air to produce vog. From Takahashi and others (1995).

Goal 6 Strategic Actions

Increase cooperative research efforts with specialists in human health, toxicity, epidemiology, and other life sciences.

GD scientists will collaborate with these specialists to examine the integrated role of geochemical and biological processes in controlling contaminant transport, fate, uptake, and health effects.

Continue research on the geologic occurrence, geoavailability, environmental mobility and degradation, and health effects of potential toxins.

GD scientists will conduct process-oriented studies on these factors for potentially toxic elements, minerals, and naturally occurring organic compounds.

Determine the transport mechanisms and ultimate fate of sediment-associated contaminants.

The GD will study sediment-associated contaminants that are transported through rivers to estuaries and coastlines and will establish sediment distribution and transport directions for selected offshore coastal waters of the United States

Understand the role of geology and geologic processes in the development and release of potential pathogens.

GD scientists will evaluate the role of factors such as parent rock composition, mineralogy, and soil type in fostering pathogen development and will examine the potential for various geologic processes, such as earthquakes and landslides, to release pathogenic material into the environment.

Highlight 14— ***Cleaning Up Boston Harbor***

Long-term research and environmental monitoring by the GD in Boston Harbor and Massachusetts Bay have made vital contributions to the $4 billion Boston Harbor clean-up program. Detailed geologic maps constructed from sidescan-sonar surveys of the bay floor were critical to selecting the new location for discharge of treated sewage wastes in Massachusetts Bay. These maps also guided the required monitoring program by identifying regions where fine-grained sediments and sewage-related contaminants are likely to accumulate. Computer models of ocean circulation produced convincing predictions that the upgraded sewage treatment system and proposed discharge site will improve conditions in Boston Harbor without impairing the environmental quality of Massachusetts Bay (fig. 14). Results of the GD research, carried out in cooperation with the Massachusetts Water Resources Authority, also showed that water-quality standards can be met with a smaller secondary treatment facility than originally planned, thereby saving millions of dollars in construction costs.

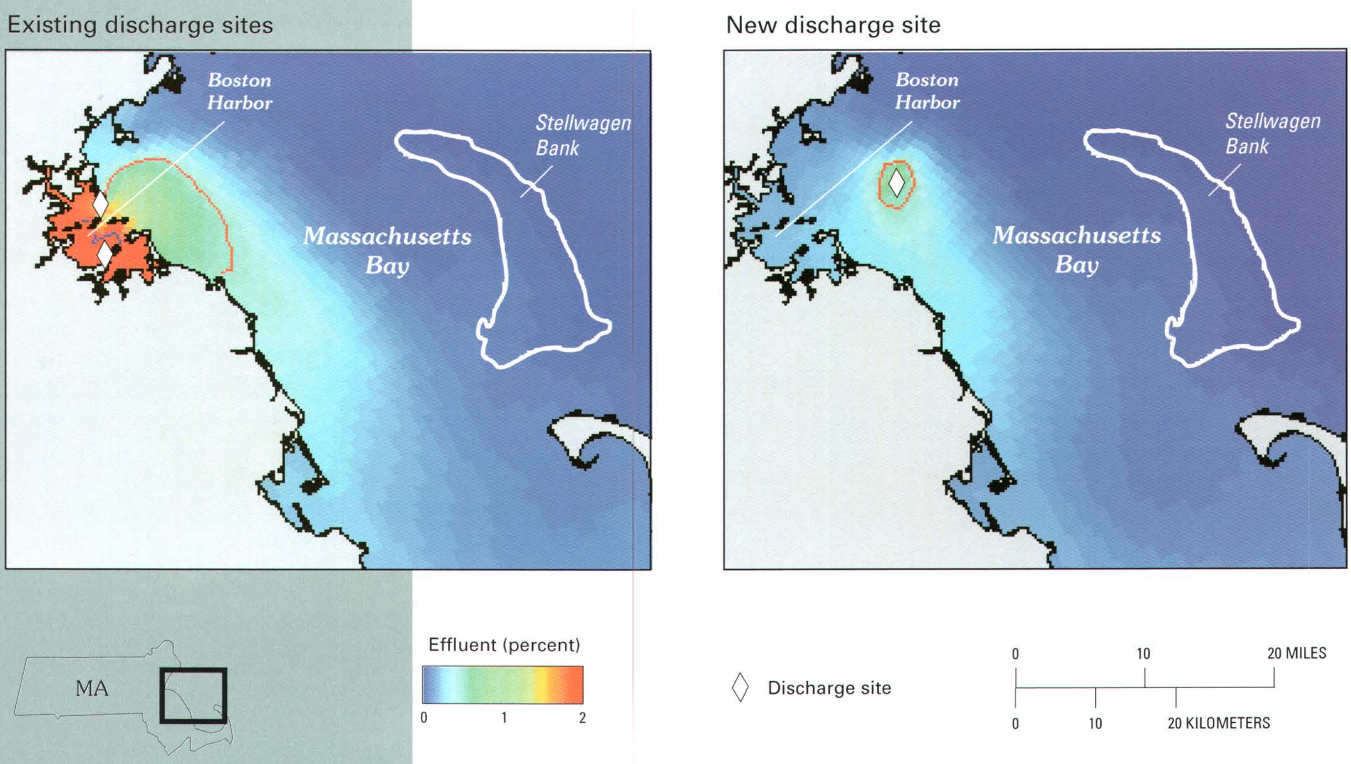


Figure 14. Existing and new discharge sites and effluent distribution in Boston Harbor and Massachusetts Bay. Red line indicates area beyond which nutrient levels in the effluent are comparable to background variability. From Signell and others (1996).

Goal 7—Determine the geologic controls on ground-water resources and hazardous waste isolation

The adequacy of ground-water resources to meet ever-increasing demands for municipal, agricultural, and industrial uses is emerging as one of the Nation's primary resource issues. Rising demand for high-quality ground water results from a number of factors, including the proliferation of large urban centers and irrigation projects in arid and semiarid areas (see Highlight 15), the contamination of existing surface- and ground-water reservoirs, and the desire to maintain adequate supplies of surface water for critical ecosystems. Major sources of ground-water contamination include agricultural runoff, municipal wastes, and saltwater intrusion, as well as the disposal of potentially toxic wastes from industrial processes, energy generation, and mineral extraction. Although factors controlling the quantity, quality, and availability of ground water are the primary responsibility of the WRD, the scientific problems involved are so broad and so closely linked to the more traditional geological disciplines that their solution requires active participation across all USGS divisions.

Assessing the quality and availability of ground water and its vulnerability to contamination requires adequately characterizing the geologic, geophysical, and geochemical factors controlling subsurface fluid flow and contaminant dispersal. Although it is relatively easy to determine the average hydrologic properties of a rock mass or sediment, one of the greatest challenges to effective waste isolation lies in accurately characterizing hydrologic heterogeneity and preferential flow paths (for example, the one fracture, fault, or stream-channel deposit that may carry most of the contaminants). Also, predicting the long-term hydrologic behavior of aquifers and aquitards and the attenuation or degradation of toxic wastes requires an improved understanding of the physical, chemical, and biological processes controlling the evolution of hydrologic properties and fluid chemistry through time.

The GD will contribute geological, geophysical, and geochemical expertise to ground-water issues that are in the broad national interest; that is, issues that are regional to national in scale, pertain to Federal lands, or are expected to lead to fundamental advances in understanding the scientific basis for ground-water resource assessments and the mitigation and remediation of ground-water contamination. GD work will be conducted in close collaboration with the WRD's Toxic Substances Hydrology Program and their new Ground-Water Resources Program.

Goal 7 Products

Basin-scale, nationally consistent maps showing the three-dimensional distribution of hydrogeologic properties.

The GD will generate these maps, using its expertise in surficial and bedrock geologic mapping, sedimentology, geophysical imaging, and other techniques, in support of ground-water resource development initiatives. Such maps will help define aquifer permeability structure and storage capacity, particularly in rapidly expanding urban and agricultural areas. These products will be developed in collaboration with the WRD and State and local agencies conducting hydrologic testing, computer modeling, and other activities.

Three-dimensional hydrogeologic maps and conceptual models of fluid flow and ground-water contamination associated with hazardous waste-disposal sites and other sources.

These sources of potential contamination include high- and low-level nuclear waste, industrial chemical leaks, and saltwater intrusion. Creation of these maps and models will involve the same techniques and cooperators as the first product listed but will also incorporate GD expertise in neotectonic studies, borehole geophysics, rock mechanics, and geochemical investigations of fluid-rock interactions. These products will help define the heterogeneous permeability structure of critical aquifers and aquitards and the rates and pathways of contaminant transport.

Goal 7 Strategic Actions

Conduct geological mapping, geophysical imaging, geochemical testing, and borehole measurements in support of ground-water resource and contamination studies in critical areas.

Key parameters (or their proxies) to be determined include overall geologic structure; mineralogy and physical properties of rocks and sediments; nature, geometry, and hydrologic properties of fractures and faults; and the mechanisms and rates of chemical water-rock interactions.

Investigate the fundamental geologic factors controlling subsurface fluid flow in sedimentary basins and other deposits.

The GD will determine how depositional environment, diagenetic processes, and deformation affect permeability structure and storage capacity in highly porous, sediment-dominated hydrologic systems.

Highlight 15— ***Finding Water for Thirsty Southwestern Cities***

The explosive growth in urban areas of the arid Southwest has placed exceptional demands on limited ground-water resources. Interdisciplinary GD studies in several Southwestern U.S. cities, conducted in cooperation with the WRD, State and local governments, and universities, have used geologic mapping, geophysical imaging, and geochemical studies to better understand geological limitations on the quantity and quality of municipal ground-water supplies. For example, near Albuquerque, NM, detailed geologic mapping, coupled with high-resolution airborne geophysical surveys, has been used to identify the location and geometry of buried, intrabasin faults that offset the principal gravel aquifer units within the Middle Rio Grande Basin (fig. 15). In addition, GD geochemical studies of drill core samples and ground waters have helped track the origin and pathways of naturally elevated arsenic concentrations in some of the municipal water-supply wells. Knowing that aquifers supplying the city with potable water are more limited than originally thought, local governments can plan more realistically for urban growth. Similar USGS projects in Flagstaff, AZ, and Las Vegas, NV, have helped identify important basins or geologic structures that may host ground water or affect its flow.

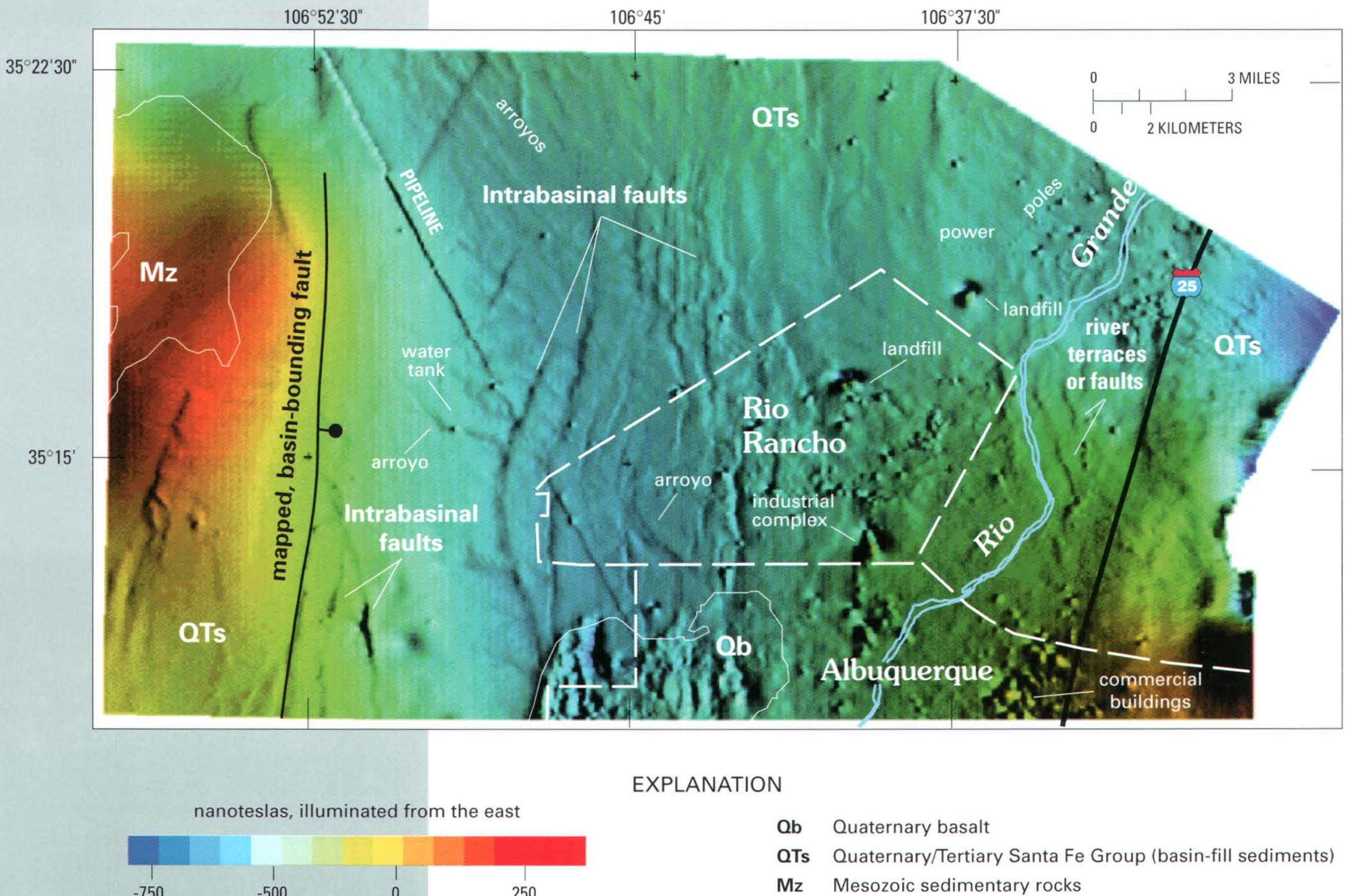


Figure 15. Buried intrabasinal faults that limit the extent of the aquifer units in the Middle Rio Grande Basin near Albuquerque, NM. Magnetic data collected by high-resolution airborne geophysical surveys were used to identify the location and geometry of the faults. 1 nanotesla=1 gamma, a measurement of magnetic field strength. From Grauch and Millegan (1998).

Goal 7 Strategic Actions, continued

Conduct multidisciplinary research on the origin, development, and hydrologic properties of fracture and fault systems.

GD studies in a variety of geologic and tectonic environments will facilitate development of large-scale fluid flow models, especially where detailed in situ fracture data are lacking.

Conduct investigations to understand the links between geochemical, biological, and hydrogeologic processes.

These processes include mineral precipitation and dissolution reactions, permeability and fluid-pressure changes induced by earthquakes and volcanic eruptions, and biochemical interactions between microbes and mineral surfaces. Experimental, field, and theoretical studies will allow the GD to produce models showing the evolution of fluid permeability and water chemistry through time.

Operational Objectives

This science strategy report defines critical areas where GD scientific activities can have the most positive impact on society. It is the responsibility of all GD staff to reach the seven science goals through completion of the products and strategic actions listed for each. To help in this effort, the GD Policy Council must outline operational measures that can be used to stimulate and evaluate progress. These operational measures include communicating GD information to users, facilitating interdisciplinary and interdivisional work, conducting periodic internal and external reviews of GD programs, and fostering a work environment that encourages and rewards GD staff for contributions toward achieving the science goals.

Objective 1—Greatly enhance the public's ability to locate, access, and use Geologic Division maps and data

The GD best serves the Nation by producing high-quality scientific information relevant to pressing national issues and making this information easily accessible and usable. The GD must devise and regularly update new strategies to ensure timely presentation of scientific information and effective use of this information by decisionmakers. To reach this objective, there is a strong need for coordination at the division level.

With the proliferation of GIS and integrated digital data bases, users of GD products now expect both paper products and digital products. These products must be accessible through a searchable index such as the GD's National Geologic Map Data Base, which allows users to easily locate USGS geological, geochemical, and geophysical maps and spatial data. The GD will ensure that its products, both new and old, are published in digital format, have consistent data standards, and are available through the Federal Government's National Spatial Data Infrastructure (NSDI).

Objective 1 Strategic Actions

Ensure that programmatic data-base-management objectives are consistent with GD and USGS objectives and that diverse data systems can be integrated seamlessly.

Achieving integration may require hiring information technology experts as coordinators, working with external consultants, or assuring data-format consistency through the publication-approval process.

Objective 1 Strategic Actions, continued

Expand the GD's National Geologic Map Data Base.

This data base is a searchable index of all geological, geophysical, geochemical, geochronological, and paleontological spatial data and maps of U.S. areas. This distributed, integrated data base will be developed at the division level, will include all relevant USGS data, and will link to existing State and university data bases. Industrial partners and contractors will be encouraged to contribute. The digital products of the National Geologic Map Data Base will be searchable through the NSDI Clearinghouse, and the digital map data of the data base will be made available by using the principles of the NSDI framework. Out-of-print maps will be digitized (rasterized) and made available through an on-demand printing system.

Move rapidly toward consistent data structures and standards for all GD and USGS products and maps.

By using uniform data models and standards, the USGS eases the process by which the public obtains and integrates earth science information. The GD will lead the effort to define and update the geoscience map standards that will be used by State-, industry- and university-based mapping programs. Once the standards are established, procedures can be developed to link data products.

Explore cooperative agreements for data archiving and distribution.

These agreements can be made with the NMD, other Federal agencies, or the private sector. Maintaining multilayered, integrated data bases is labor intensive and expensive. Yet it is an integral part of the USGS mission, requiring the GD to keep abreast of advancing technologies. By relying on partnerships for data archiving and distribution, the GD can focus on improving and updating the scientific content of its data bases and on interpreting and effectively using GD science.

Extend the function of digital maps.

The GD will link data bases, GIS technologies, and interpretive computer models in integrated, digital, earth science information systems that can be used to support scientifically informed decisions by scientists, policymakers, regulators, the public, and others. A prototype information system is described in Highlight 16.

Highlight 16—
Digital Information Systems Assist in Decisionmaking

A prototype digital earth science information system developed by GD scientists illustrates the important role that GD data, data models, and interpretations can play in policymaking decisions. This system will be used to identify and prioritize cleanup of thousands of abandoned mine sites on Federal lands. The prototype information system (fig. 16), developed for Federal cooperators in Montana, integrated information from geological, geochemical, geophysical, and mining data bases and other information. Environmental geology and geophysics models of mining districts and the surrounding rock terranes were then weighted with the data base information to rank areas of the State on the basis of their potential for mining-related environmental problems. This system proved instrumental to an interagency Federal working group in prioritizing Montana watersheds for further field investigations, site identification, and possible site remediation.

Figure 16. The Montana GeoExplorer, a prototype digital earth science information system, was used to help policymakers prioritize abandoned mines on Federal lands for environmental characterization and possible remediation. Watersheds in areas of the map colored red, magenta, and yellow were estimated to have the greatest potential occurrence of acid drainage released from mines and unmined, mineralized rocks. The methods used to develop such digital systems are being refined by using information gathered by USGS field studies of specific watersheds such as the Boulder Creek watershed (outlined in white on the map).

Objective 2—Maintain a first-rate earth-system science library

The USGS library is the premier earth science library in the Nation and contains numerous unique holdings and continuous records of important journals and published series. Besides its critical value for GD investigations, the library is a vital agency resource and is invaluable to the national geoscience community and general public. Approximately 50 percent of library users come from outside the USGS. The role of the USGS as the DOI science agency heightens the necessity to maintain the library as a national resource.

Objective 2 Strategic Actions

Create a publicly available system for computerized searches.

This system will permit access to the holdings of the USGS and other library systems and information data bases. The system will also allow USGS employees at all field and regional centers to make electronic requests for materials.

Increase holdings necessary for investigations of environmental science and biological resource issues.

While expanding holdings in these areas, the GD will maintain those critical to geologic, cartographic, and water-resource studies.

Consider instituting a cost-recovery system for non-USGS customers.

Such a system will require other institutions to reimburse the GD for time-consuming reference work and reproduction costs. In this way, the important role of the USGS library as a national geoscience resource will be acknowledged and the GD will assure that library funding is sufficient to meet the demands of both USGS and non-USGS users.

Objective 3—Effectively transfer the knowledge acquired through Geologic Division science activities

To ensure that GD scientific information and data are incorporated into public-policy decisionmaking, the GD must make the Nation aware of its research and help the public understand its significance. This objective demands proactive technology and information transfer from GD personnel at all levels of the organization. Information transfer efforts should focus on those most in need of GD expertise, and the data must be provided in a usable and comprehensible manner. For example, an innovative presentation of geologic and seismic data that may be more useful to planners than standard geologic maps or data is described in Highlight 17.

Objective 3 Strategic Actions

Establish temporary duty assignments for GD staff with State and other Federal agencies.

Such assignments will enhance exchange of scientific information and understanding. The GD will encourage other agencies to send their staff to GD facilities.

Devise an effective strategy for working with media representatives.

The GD will recognize that science writers, newspaper and television reporters, and documentary filmmakers can reach extensive audiences, creating awareness of GD science activities and emphasizing the value of GD data in solving critical problems in the earth and environmental sciences.

Cultivate relationships with Congress and the Executive Branch.

The GD will forge new relationships and expand existing ones by placing GD scientists in targeted temporary-duty assignments and by conducting proactive project-level briefings. These efforts will help policymakers become better informed on earth science issues.

Identify capable spokespersons to work effectively with the media.

The GD will provide training in media relations to scientists who have the ability and interest in becoming GD spokespersons. A list of these spokespersons will be made available to managers and outreach and public affairs officials within the USGS.

Coordinate outreach and education efforts with earth science professional societies.

These organizations are very effective at promoting research and public awareness of the critical role geology plays in many of the Nation's pressing problems. The GD will collaborate with these groups to enhance the impact of its outreach.

Highlight 17—
Experimental Three-Dimensional Geologic Maps

Figure 17 is derived from a three-dimensional (3-D) geologic and geophysical data base consisting of digitally defined 3-D map elements (for example, faults, depositional strata, and topography) for the southern San Francisco Bay area. It also includes scattered data such as earthquake hypocenters and continuous physical and chemical property fields. These elements are linked by quantitative relationships that specify the spatial interactions among the various data. In this portrayal of the relationships among geology, active faults, and seismicity in the San Francisco Bay area, Cenozoic deposits are shown in yellow, Franciscan Complex rocks are shown in green, and Cretaceous granitic basement rocks are shown in pink. Major strike-slip faults are indicated by vertical red curtains, and earthquake hypocenters for 1969–94 are represented by spheres color coded by magnitude.

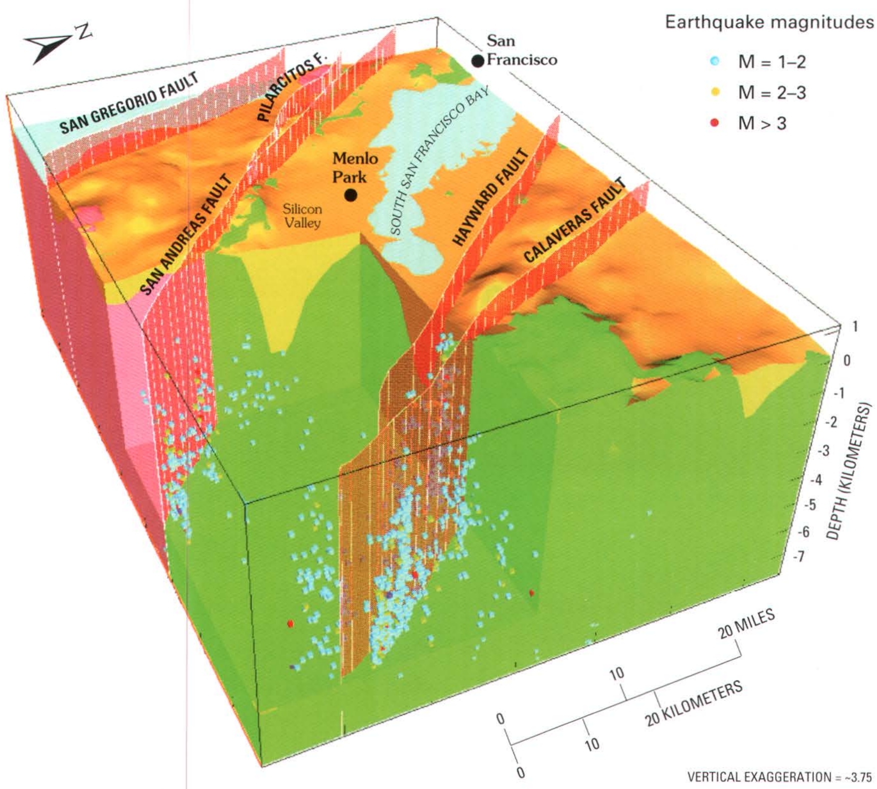


Figure 17. Experimental three-dimensional depiction of geologic and seismic data for the southern San Francisco Bay area. From Robert C. Jachens, USGS (unpublished data, 1998).

Objective 4—Promote vitality and flexibility of the scientific staff

A highly flexible, adaptive, and multidisciplinary GD work force will be required to respond to new earth science issues, to continue development of quality scientific products, and to ensure their timely dissemination. It is critical for the GD to maintain, expand, or develop through partnerships, certain core capabilities that will allow achievement of this objective. Many of these capabilities are currently available within the GD, such as geologic mapping of surficial and subsurface deposits, geochronology with emphasis on the recent geologic history, geophysical surveying, sedimentary basin analysis, remote sensing, and GIS incorporating three-dimensional visualization methods. However, there is a need for development in several fields not traditionally found in the GD, such as microbiology, biochemistry, economics, and soil science. The GD will determine the best method for acquiring these new core capabilities: by developing them within the GD, by forming partnerships with others outside the GD, or by obtaining services from contractors.

Objective 4 Strategic Actions

Strive for a diverse and balanced workforce to ensure programmatic and fiscal flexibility.

The GD will use an appropriate mix of permanent, short-term, and temporary staff. Permanent scientific position vacancies will be filled through well-advertised national searches.

Create a formal postdoctoral program.

Such a program will bring scientists with recent training into the GD on 2- to 4-year rotations. Much of the work conducted by postdoctoral staff will focus on interdisciplinary, cross-programmatic projects. Twenty positions will be created during fiscal year 1999, and these positions could eventually constitute 15 to 20 percent of the GD research staff.

Maintain scientific leadership and develop the skills required to cross discipline boundaries.

The GD will make training available for permanent research staff members so that they can pursue interdisciplinary opportunities as outlined in the science goals.

Objective 4 Strategic Actions, continued

Maintain an appropriate balance of research and support staff.

This balance will help improve the efficiency of GD science and operational activities.

Create a scientist exchange program.

The GD will provide the mechanism and the funding to allow scientists from industry, academia, and other Federal, State, and local government agencies to spend time working on GD projects and training GD employees. Reciprocal opportunities for GD staff will also be arranged.

Objective 5—Promote interdisciplinary research

Achieving the seven science goals requires a significantly increased level of cross-discipline integration and will have major impacts on existing programs. To facilitate progress, mechanisms should be established to promote interprogram and interdivisional research.

Objective 5 Strategic Actions

Prepare an integrated GD science plan.

This plan will present a common prospectus based on the seven science goals. The prospectus will integrate the priorities outlined in each program's 5-year plan.

Enhance the flow of expertise between programs.

The GD will develop strategies to foster interactions at program boundaries. Staffing will shift from a program basis to a division basis so that each program may take advantage of the full range of expertise within the GD.

Encourage rotation of managers and scientists outside the GD.

By working outside their area of expertise, staff members will acquire a broader agency perspective and can enhance scientific interaction across the USGS.

Objective 6—Institute internal and external reviews

The GD will formalize the process of internal and external reviews to measure progress toward achieving the seven science goals. In addition, these reviews will allow the GD to locate and take advantage of new scientific opportunities and to respond to new societal priorities.

Objective 6 Strategic Actions

Reactivate the GD Science Advisory Committee (SAC).

The SAC will conduct regular internal reviews of GD scientific activities to evaluate progress and to help establish research priorities. The SAC will include scientists from other USGS divisions in the review process.

Solicit input on GD activities from a variety of organizations and disciplines.

The GD will establish a mechanism to obtain input from other USGS divisions, other Federal agencies, States, academia, and industry. Research, assessments, and monitoring conducted by the GD will effectively merge the priorities of customers and partners with GD programmatic priorities.

Next Steps

The USGS provides the Nation with reliable and timely earth science information that is used to minimize loss of life and property from natural disasters; to manage energy, mineral, water, and biological resources; to enhance and protect the quality of life; and to contribute to wise economic development and a sustainable future. This science strategy report describes how the GD will carry out its share of this mission for the years 2000–2010. Acquisition of scientific knowledge through research, assessment, and insightful monitoring and the effective communication of that knowledge to planners and decisionmakers will allow the GD and its partners to assist the Nation in meeting a complex, challenging, and promising future.

This science strategy will be implemented by the Chief Geologist, the Associate Chief Geologist for Science, the Associate Chief Geologist for Operations, the three Regional Geologists, and the nine Program Coordinators of the GD. To learn more about GD activities, refer to the list of contacts at the end of this report or visit the GD's World Wide Web site at **http://geology.usgs.gov/**

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For More Information

P. Patrick Leahy
Chief Geologist
U.S. Geological Survey
911 National Center
Reston, VA 20192
703-648-6600
pleahy@usgs.gov

Steven Bohlen
Associate Chief Geologist for Science
U.S. Geological Survey
910 National Center
Reston, VA 20192
703-648-6640
sbohlen@usgs.gov

Linda Gundersen
Associate Chief Geologist for Operations
U.S. Geological Survey
911 National Center
Reston, VA 20192
703-648-6100
lgundersen@usgs.gov

David Russ
Eastern Regional Geologist (Acting)
U.S. Geological Survey
953 National Center
Reston, VA 20192
703-648-6660
eregeol@usgs.gov

Thomas Fouch
Central Regional Geologist
U.S. Geological Survey
Mail Stop 911, Box 25046
Denver Federal Center
Denver, CO 80225
303-236-5438
cregeol@usgs.gov

L.J. Patrick Muffler
Western Regional Geologist
U.S. Geological Survey
Mail Stop 919
345 Middlefield Rd.
Menlo Park, CA 94025
650-329-5100
wregeol@usgs.gov

S. Jeffress Williams
Coastal and Marine Geology Program Coordinator
U.S. Geological Survey
915B National Center
Reston, VA 20192
703-648-6511
jwilliams@usgs.gov

John Filson
Earthquake Hazards Program Coordinator (Acting)
U.S. Geological Survey
905 National Center
Reston, VA 20192
703-648-6785
jfilson@usgs.gov

David Houseknecht
Energy Resources Program Coordinator
U.S. Geological Survey
915A National Center
Reston, VA 20192
703-648-6470
dhouse@usgs.gov

Elliott Spiker
Global Change and Climate History Program Coordinator
U.S. Geological Survey
906 National Center
Reston, VA 20192
703-648-5330
espiker@usgs.gov

Sarah Gerould
Integrated Natural Resource Science Program Coordinator
U.S. Geological Survey
918 National Center
Reston, VA 20192
703-648-6895
sgerould@usgs.gov

Vacant
Mineral Resources Program Coordinator
U.S. Geological Survey
913 National Center
Reston, VA 20192
703-648-6620
minerals@usgs.gov

John Pallister
National Cooperative Geologic Mapping Program Coordinator
U.S. Geological Survey
908 National Center
Reston, VA 20192
703-648-6960
jpallist@usgs.gov

Marianne Guffanti
Volcano Hazards Program Coordinator
U.S. Geological Survey
905 National Center
Reston, VA 20192
703-648-6708
guffanti@usgs.gov

Paul Hearn
International Activities Coordinator
U.S. Geological Survey
917 National Center
Reston, VA 20192
703-648-6287
phearn@usgs.gov

National Earthquake Information Center
303-273-8500

National Geomagnetic Information Center
303-273-8494

National Landslides Information Center
1-800-654-4966

Alaska Volcano Observatory
907-786-7474

Cascades Volcano Observatory
360-696-7693

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808-967-7328

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