COLORADO GEOLOGICAL SURVEY

ROCK TALK

VOLUME ONE, NUMBER TWO APRIL, 1998

COLORADO'S GEOLOGIC HAZARDS—HOW TO LIVE WITH THEM

We tend to think that Colorado's mountains and plains have always looked just the way they look now—and that they always will. However, all landscapes are changing even as we admire them. Some of the events are too slow to notice—mountains inch upwards, streams cut down, frost wedging breaks up rocks. Other events may happen with lethal speed: rockfalls, landslides, debris flows. And still others fall somewhere in between: slumping ground, swelling or dissolving bedrock. These natural changes, recurring for many thousands of years, have produced the Colorado that we know.

These kinds of events didn't bother people much when populations were small and mobile. Now, however, Colorado has a large and growing population that lives here permanently. Even so, the landscape continues in its old ways, changing as it has always changed. We use a particular term to describe those events now: when people's lives and property are affected, we call these natural conditions "geologic hazards."

What geologic hazards cause the most damage in Colorado?

- unstable rock and soils: they may erode easily, shrink and swell, be corrosive, dissolve, or have low bearing strength
- unstable slopes: they may produce rockfalls, rock and debris avalanches, rockslides, mud and debris flows, landslides, earthflows, slumps, ground settlement
- snow avalanches
- explosive natural gases such as coalbed methane

The Colorado Geological Survey works to reduce the hazard, both personal and financial, that these natural changes pose to Colorado's citizens. One way it does this is by preparing publications and programs that educate citizens about Colorado's geologic hazards—such as SP 12, *Nature's Building Codes*.

Another way is by offering an impartial, expert "second opinion" on proposed new developments and other projects. At the request of city and county planning agencies, CGS reviews and provides objective advice on many plans that propose a new use of a parcel of land. Each proposal must describe the geology of the site and possible geologic hazards and include a plan for mitigating any hazards or serious constraints that are identified. CGS then reviews the accuracy and completeness of these descriptions and advises the local government on project feasibility.

Debris flow in Glenwood Springs

INSIDE THIS ISSUE

Call or write to get our FREE LAND-USE BOOKLET

Field Notes from the State Geologist

Land Use and Geology

In the first issue of RockTalk (v. 1, no. 1, Jan. 1998—call us if you didn't get a copy), we told you about Colorado's geologic mapping program. This, our second issue, looks at one of the many ways in which we use the basic information portrayed on a geologic map—understanding geologic hazards and supporting good land use decisions.

The Land Use Review program is one of the best ways that the geologists here at the CGS relate our understanding of geology to the people of Colorado. The success of the Land Use Review Program begins with a geologic map, but it's also based on our years of hands-on statewide staff experience and institutional files from thousands of earlier reviews.

If you've driven outside of the Denver Metro area in the last five years, you've seen the thousands of sites of new homes in formerly rural areas of Colorado. The "rural" counties of Douglas, Elbert and Park are in the "top ten" most rapidly growing counties in the U.S. As geologists, we understand that some pieces of real estate are perfectly benign—until you locate a structure on them. At that point, what was a geologic curiosity can become a geologic hazard. The Land Use Review Program is in place to help citizens and local governments be aware of the hazards before the building begins, thereby encouraging mitigation, or in extreme cases, avoidance.

continued on page 3

GEOLOGIC HAZARDS REVIEW

The Colorado Geological Survey reviews proposals for several kinds of developments. The review may be required by state or county statutes, or requested voluntarily.

Proposal for	Submitted to CGS by	Required by
New subdivisions	County planning departments	Senate Bill 35 (1972)
New subdivisions	Cities or towns	Voluntarily submitted
School sites	School districts	House Bill 1045 (1984)
Waste-water treatment plants	Engineering firms, water and sanitation districts, local governments, or health authorities	Colorado Department of Public Health and Environment*
Other proposed uses: airports, landfills, water-treatment plants, utility rights-of-way, highway rights-of-way, suitability of a given parcel of land for a particular kind of building, effects of large developments such as mines or ski areas	Counties or other governmental entities	House Bill 1041 (1974)

*Note: by action of the Water Quality Control Division in Feb. 1998, this review will soon become optional

Geologic-hazard review process

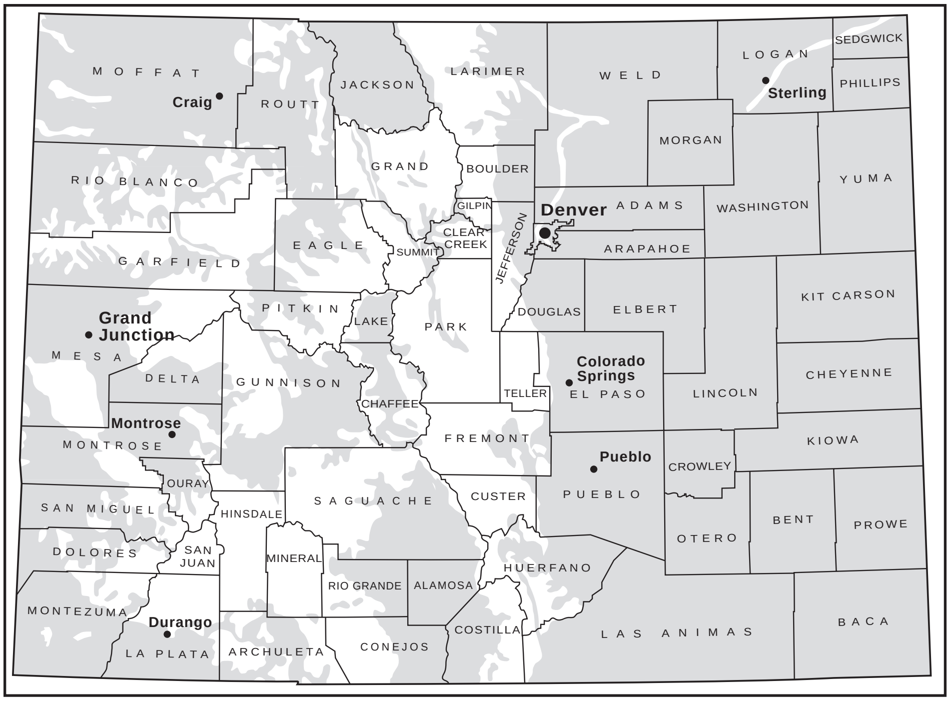
What do CGS geologists look for when they review a proposal? The focus is the mutual interaction of the geologic conditions at the site and the new human activities proposed for the site. Were geologic conditions described accurately? Was the work thorough? Were geologic principles used to interpret the evidence? If geological problems were found on the site, does the report describe those problems and how they might affect the proposed development? Does it describe reasonable ways to mitigate (or solve) those problems?

The CGS geologist who has reviewed a proposal advises the submitting agency that CGS considers the original plan to be acceptable, not acceptable, or in need of additional work. The agency that asked for a CGS review then makes its own decision about whether to approve the proposal or require modifications.

SWELLING SOILS

What geologic hazard costs Coloradans the most? It's not something dramatic, such as rockfalls or landslides. Rather, it is a process that works slowly, injures no one, but quietly damages buildings often beyond repair: swelling soils.

These soils are found in almost all parts of Colorado except the high mountains (see map on next page). Swelling soils contain clay minerals that swell when they get wet and shrink when they dry out. The stresses developed by swelling and shrinking can be strong enough to crack or even buckle house foundations, driveways, roads, and underground water or utility lines. Even when their up-and-down movements amount only to inches, swelling soils cause millions of dollars in damage in Colorado each year.



Distribution of swelling soils and bedrock (shaded areas) in Colorado

They have prompted bitter lawsuits against builders and have resulted in higher warranty insurance rates for Colorado.

A book by the Colorado Geological Survey, *A Guide to Swelling Soils for Colorado Homebuyers and Homeowners* (Special Publication 43), is written for people who live on swelling soils or who are considering buying a home built on swelling soils. The 76-page book describes the geology of swelling soils and how to safely build and maintain a home underlain by swelling soils. It is illustrated with 45 drawings and photographs and lists sources of information about geology, landscaping, soil improvement, building, and real estate.

This book helps Coloradans reduce the damage caused by swelling soils. It also satisfies Colorado's disclosure law. This law requires anybody who sells new homes built on swelling soils to tell prospective buyers about the presence of swelling soils and to give them information about this condition. More than 37,000 copies of this book have been sold since its release in April 1997.

Besides being of interest to homebuyers and homeowners, Special Publication 43 is of interest to geologists, engineers, city and county planners, developers, contractors, home builders, home inspectors, real estate agents and brokers, insurers, and attorneys who work with parcels of land that do, or may, contain swelling soils.

See *How to Order CGS Publications* on page 7 to order Special Publication 43.

Cracks in brickwork caused by swelling soils

Field Notes from the State Geologist—continued from page 2

Colorado is a state with rich natural resources, significant geological hazards, and intense pressures of population growth and development. The citizens and local governments who are faced with deciding where and how best to add a new subdivision or how to safely site a new school depend on the careful and impartial review of information that the CGS provides. At CGS we're proud of our successful 25-year partnership with local governments in helping to keep Colorado a safe and beautiful place to live.

Geologic Mapping and Land Use Review are just two of the many programs at the CGS. Each issue of RockTalk will bring to you a look at a different aspect of the programs of the CGS. We hope you enjoy the publication.

Swelling soils may be Colorado's most costly and widespread geologic hazard, but rockfalls, debris flows, and avalanches are the most dangerous hazards. In a rockfall, individual or multiple rocks fall or bounce down a hillslope; in a debris flow masses of rock, soil, and water detach from the slope above and slide or flow downhill in steep channels placing both people and property at risk. Avalanches will be the topic of a future RockTalk.

Rockfalls

Rockfalls are common where there are steep slopes below exposures of broken or jointed rock, or below steep ledges that jut out beyond weaker underlying rock. Rockfalls become a problem when this rugged scenery that is most likely to produce rockfalls appeals to people hunting the perfect site for their mountain home. Along with residential developments come roads and commercial buildings that are vulnerable to the same hazard.

Many highways in the foothills and the mountains pass through prime territory for rockfalls. Every few years people are killed or seriously injured in rockfalls here in Colorado. In the 1980s a huge rock rolled off a steep slope and crashed into a bus traveling on Berthoud Pass, killing several passengers. In 1985 a rockfall onto Interstate 70 in Glenwood Canyon killed three people. In March 1997 a young boy was killed when a rock bounded through the middle of an automobile windshield and into the back seat.

What starts these rocks moving? It's a two-step weathering process. First, intact rocks become fractured. The fractured rock is further wedged into smaller pieces by the same thing that causes soils to swell: water. Water from rain, fog, or snowmelt on a warm day can fill cracks in the rock. When temperatures fall below freezing, the water freezes and expands. The pressures developed by water freezing to ice can continue to wedge apart the hardest of rocks. Repeated freezing and thawing and refreezing will slowly break a massive rock into smaller blocks.

Second, something eventually triggers these blocks to shift and fall. The trigger could be loss of support from softer rocks below that have eroded away. An intense rainstorm or rapid snowmelt may lubricate rock surfaces and reduce friction. Loss of vegetation (after a wildfire or during construction) may weaken a slope. A slope may be oversteepened by river erosion or by excavation of roadcuts. Vibrations from earthquakes, blasting, or even heavy traffic may eventually jostle rocks out of balance.

What are warning signs that a site might be in the path of a rockfall? Look high on the surrounding slopes. Are they steep? Are large areas of bare rock exposed? Does the rock look jointed or fractured? These features tend to promote rockfalls. Do large, angular rocks lie randomly oriented on lower slopes? If so, you are looking at the evidence of past rockfall events if the rocks are now surrounded by vegetation. Do you see fresh scars where rocks have rolled downhill and torn out vegetation? These are evidence of a more recent rockfall.

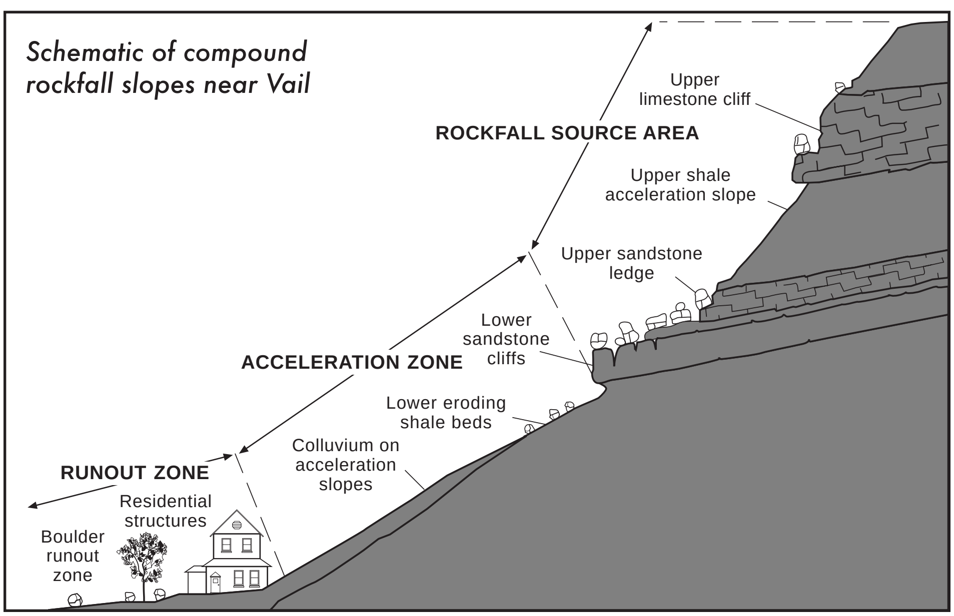
Is there any way to prevent rockfalls? Some loose rocks can be stabilized by buttresses, rock bolts, grouting or cables to prevent a rockfalls. In other cases people and property downslope can be protected with berms or walls. But these measures can be expensive and must be properly designed to be effective. The behavior of falling rock on a given slope can be analyzed by a computer program, the Colorado Rockfall Simulation Program (CRSP) that was developed for use on Colorado highways. It is widely used to help determine the runout zone and the type and height of barrier needed to stop the moving rocks. The computer program and manual (formerly MI 39) are being revised and will be available from CGS in several months.

The best way to avoid the hazard is simply not to build in an area that has been or might be hit by a rockfall. Even when past rockfalls are overgrown with mature vegetation and look very old, exactly when the next rockfall will happen cannot be predicted. Where human life or expensive construction is at risk, it's better to go someplace else.

Rockfall Case History

The CGS has assisted the Town of Vail in assessment of the rockfall hazard at Booth Creek since May 1983, when a severe rockfall event

Schematic of compound rockfall slopes near Vail



occurred there. Since then, the town and property owners in Vail Village filing 12 formed a Geologic Hazard Abatement District (GHAD). The district has mitigated much of the hazard by constructing a ditch and berm on the slope above the residential area. The ditch and berm configuration has been very effective for rocks that continually fall from the cliffs of the Minturn Formation (see below).

On March 26, 1997, another very serious, almost lethal, rockfall occurred that substantially damaged the Booth Falls Condominiums that exists west of the GHAD, outside the protection envelope provided by the ditch and berm. At 11:20 p.m., a ledge of Minturn Formation limestone at the highest exposed outcrop of the upper cliff failed. The ledge dimensions that detached and toppled are roughly 20 ft x 8 ft x 8 ft. As it fell, the ledge broke apart and loosened additional rock blocks from outcrops below. The rock mass broke apart as it tumbled down the cliff. As it fell down the slope, the rock fragments randomly fanned out such that the path of the rockfall formed a swath more than 500 ft across where they came to rest. The resident of the condominium that was hit was working a second shift that night, and she was relieved to view the remains of her bedroom from the outside (see photo).

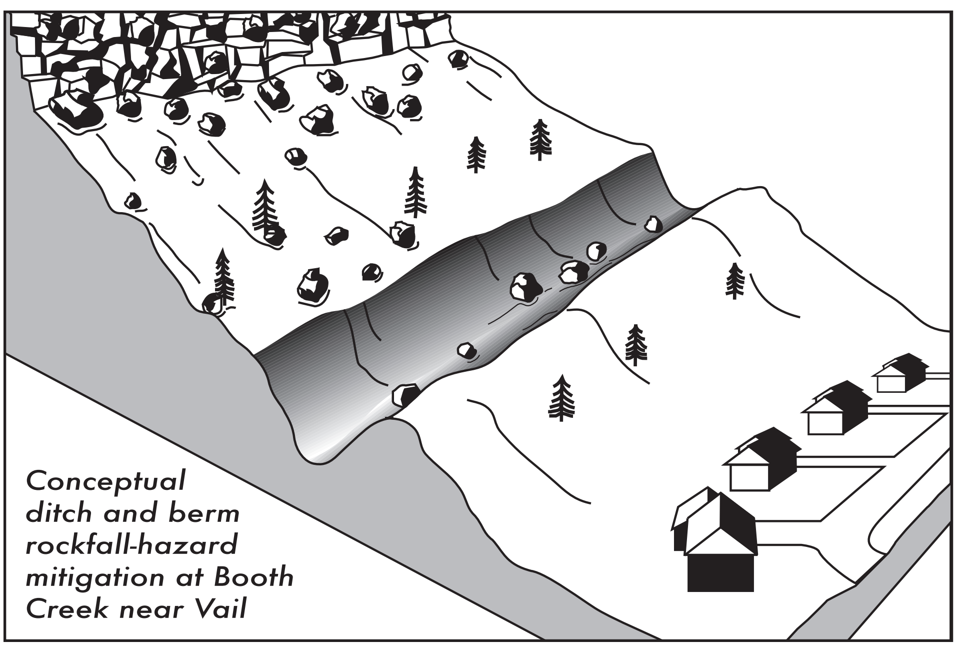
Resident surveys her bedroom after rock impact

Landslides

Landslides are the downward and outward movement of masses of soil and rock. Slopes of almost any angle can fail, even ones as gentle as 5 degrees. Landslides can move quickly or slowly; they may disturb only a few cubic feet of material or entire hillsides. The same agent, water, that helps to cause swelling soils and rockfalls is also a prime factor in causing landslides. But other factors are also important: steepening or changing the load on a slope; removing support from the base or sides of a slope.

Natural slopes are generally in equilibrium. The degree of steepness, amount of rainfall, soil thickness, angle of repose of rock debris, and vegetation combine to produce a slope that will tend to stay put until something changes. In many cases something does change that weakens the slope. The changes can be natural, such as a large rockfall sheet that overloads a slope, a run of several unusually wet months or years that saturates and weakens upper rock layers and soils, or stream erosion that undercuts the base of a slope.

Other changes can be induced by humans. The excavation of roadcuts, quarries, or trenches may remove supporting earth and rock from the base of a slope. Conversely, piling up mine tailings, landfills, or earth embankments for building



Conceptual ditch and berm rockfall-hazard mitigation at Booth Creek near Vail

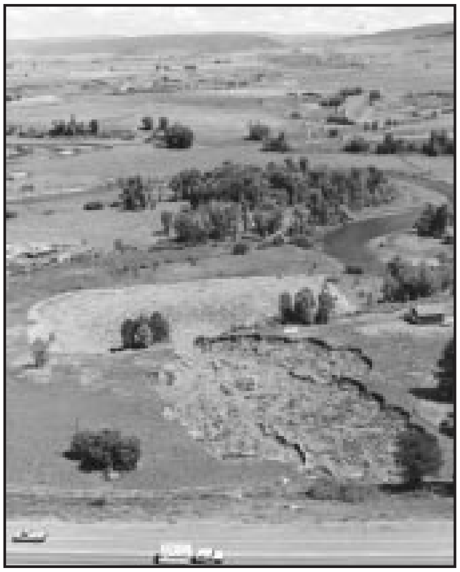
Upcoming Events Involving CGS

April 15–18
CMA National Western Mining Conference, Broadmoor Hotel, Colorado Springs, Nina Morrone, 894-0536

April 17
ASCE: 1998 Geotechnical Seminar— "Geodata: What Do the Numbers Mean?" sponsored by ASCE, CAGE, AEG, Denver, Stephen Dee, 841-6593

April 23
First Intergeo-Society Meeting, "Geology in the Next Millenium" Denver, Larry Cerrello, 674-6484

May 14–16
Northwest Colorado Coal Conference, Meeker and Craig, AGNC, Jim Evans, 970-625-1723

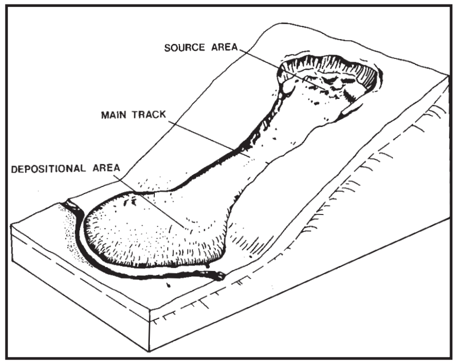


Earthflow near Meeker

sites or roads may overload a slope. In addition, any of these changes may alter the natural runoff of rain or snowmelt and streams.

Picture what often happens during the construction of a new subdivision. Natural vegetation is stripped off, earth is excavated from one spot and deposited in another, septic-system leach fields may be installed in the ground, landscape watering systems are used, certain areas become impermeable because of streets or parking lots, and then new loads—homes, warehouses, or other buildings—are added to the site. All of these changes—loads, runoff, and infiltration—can destabilize the ground. Landslides are one possible result.

The CGS geologist who evaluates a site for possible landslides asks three basic questions: (1) Is there evidence of recent (or continuing) landslides? (2) Is there evidence of past landslides? (3) Could landslides be triggered by construction or by normal use of buildings after construction?



Earthflow diagram, modified from Varnes, 1978

If the answer to any of these questions is "yes," then the cost of trying to forestall future landslides at that site must be weighed against benefit to be gained from the proposed new use of the land. Some ways of decreasing landslide risk have worked in given situations: benching slopes, placing ample subsurface drain tile, or installing buttresses or anchors. All of these measures are expensive, and they may not be effective in the long run. Again, the best advice is to build somewhere else.

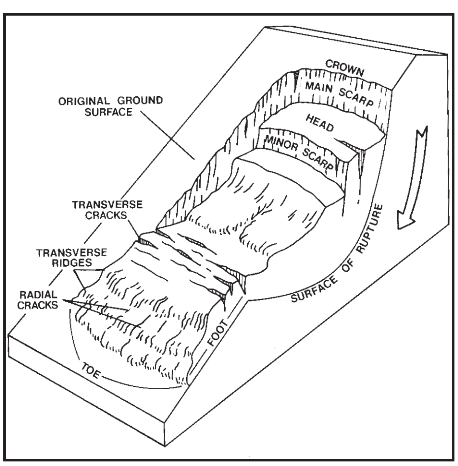
Landslide Case History

The spring of 1995 was very rainy for eastern Colorado. Besides producing numerous instances of flooding, in at least one case, in Colorado Springs, rains initiated landsliding. The site, a development built in the 1980s, was located on hilly terrain underlain by bedrock of the Pierre Shale in a mapped ancient landslide area. Rains saturated the native soil and lubricated shear planes in the shale , which started the hillside moving. Two homes were damaged so extensively that they were eventually condemned (see photo below). Since 1995 the City of Colorado Springs has requested CGS review for development within the city limits.

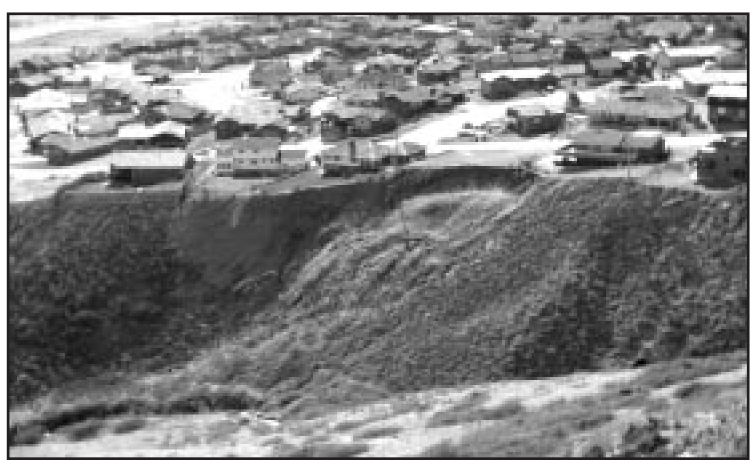
House condemned because of landslide damage

GEOGRAPHIC INFORMATION SYSTEMS

What is the most commonly used tool in the earth sciences? Next to books, journals and existing publications, the answer is probably maps. Maps provide a common language by which scientists can depict the structure and appearance of the earth and the features on or under the



Rotational landslide, modified from Varnes, 1978



Rotational landslide near Golden

surface. Recent innovations in computer technology have made it possible to store, display and analyze large amounts of information in ways previously unimaginable. The computers and software that make this possible are called geographic information systems (GIS).

The power of GIS technology lies in the ability to quickly overlay, compare and display map data. Digital maps are broken up into layers of similar types such as vegetation, water, topography, geology—to name a few. Each of these layers is attached to a data file that allows the user to ask questions about the map in addition to viewing. Look closely at any map and you will see that it is really composed of several layers displayed in such a way as to convey information about a certain area of the earth. Regardless of what type of map you use there is one thing that it has in common with other maps—it tells where things are on the earth.

CGS is involved in an on-going program to convert new and existing maps to a digital form that makes them useful in the GIS environment. All new geologic map products are available in both paper and digital form. Many CGS publications originally available only in paper form have now been digitized and are available in GIS format.

In addition to these digital map conversion projects CGS is pursuing GIS database development projects in cooperation with several Colorado counties. A package of digital geologic hazard maps with supporting geographic information has been prepared for Gunnison County. In Fremont County a set of databases including mine and geologic hazard databases were developed for the Canon City-Florence area. Digital conversion of geologic maps and other information useful in land use planning has recently been completed for the Fort Collins, Loveland and Greeley areas.

Each of these areas is of interest to land-use planners due to increased development pressure or the nature of the hazards present in the area. CGS will continue to explore ways of delivering data sets in GIS format that will enhance the usefulness of geologic maps and their derivatives to the land use planning process.

HOW CGS WORKS WITH COUNTIES IN LAND-USE PLANNING

Let's say that you have a great site on which to build: down on the plains just east of the mountains, enough slope to drain well but flat enough to make building easy, bedrock sandstones and shale that look pretty ordinary, thin soils that should pose no problem, a dazzling view. But a few weeks or months after your building is completed and occupied, it doesn't look so wonderful: zigzag pull-apart zones in the brickwork walls, canted stairs, uneven floors, cracks in the driveways and parking lot, even ruptured water lines are found. Moreover, the grounds seem to have re-landscaped themselves: low, linear ridges have grown under the new turfgrass.

This situation has played itself out many times in Jefferson and Douglas counties, and it has caused millions of dollars of damage to houses, commercial buildings, roads, and utility lines. Early attempts to solve the problem by using conventional engineering techniques were largely unsuccessful. What was going on? The Colorado Geological Survey led investigations to answer just that question and to help local planning agencies deal with the problem. CGS and the counties cooperatively studied the cause and areal extent of this problem at several research sites.

The first step was to determine the cause of the problem. CGS geologists found that there is a bedrock equivalent of swelling soils. They term this phenomenon "heaving bedrock." Just as certain kinds of clays in soils can swell when they

How to Order CGS Publications

Bulletin 48
Colorado Landslide Hazard Mitigation Plan
over the counter—$15.00
mailed—$20.00.

Environmental Geology 7
Potentially Swelling Soil and Rock in the Front Range Urban Corridor, Colorado
over the counter—$15.00
mailed—$20.00.

Special Publication 12
Nature's Building Codes—Geology and Construction in Colorado
over the counter —$4.00
mailed—$7.00.

Special Publication 33
Landslide Loss Reduction: A Guide for State and Local Government
over the counter—$3.00
mailed—$6.00.

Special Publication 43
A Guide to Swelling Soils for Colorado Homebuyers and Homeowners
over the counter —$7.00
mailed—$10.50.

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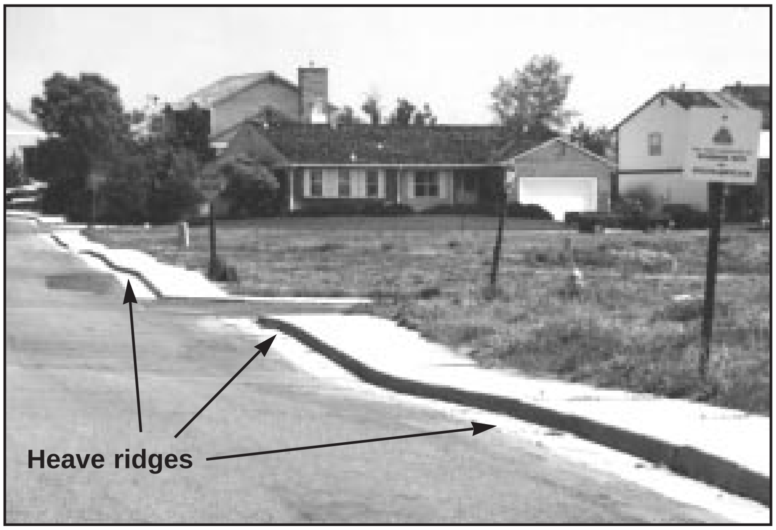
get wet, so the same clays in clay-rich rocks (claystones, shale) can swell also. Because rock layers just east of the mountain front are tipped up at an angle, the edge of any one rock unit tends to crop out in a more or less linear fashion, parallel to the mountain front. Claystone layers follow this pattern too. Changes in drainage after construction and watering of new grass around a building allow more water than usual to soak into the claystones. The claystones respond by doing what comes naturally: they swell. As long as extra water is provided, the claystones will stay expanded. Rocks on either side of the claystones that contain little clay do not swell. The linear ridges, then, mark the tipped-up edges of claystones that swell more than the surrounding rocks do.



Road damage from heaving bedrock in Morrison

Once this cause was understood, CGS and county planning agencies designed a program for managing these areas. Simply excluding construction on such land was never an option; Jefferson and Douglas counties have attracted new residents steadily for nearly two decades and the counties will continue to grow. Land must be developed to provide homes and jobs for county residents, even if some of it is underlain by heaving bedrock.

What CGS did do was educate county officials about the presence, areal extent, and cause of heaving bedrock. CGS led four field trips for county planning officials to visit areas where construction is damaged by heaving ground. CGS geologists chaired two subcommittees of the Jefferson County Expansive Soils Task Force in 1994. The task force outlined an "overlay district" that identified areas of potentially heaving bedrock. It also wrote amendments to local land-development regulations that explicitly named heaving bedrock as a problem and described ways to safely build on such ground. A map of the overlay district was created for Jefferson County by the Colorado Geological Survey. It is in a GIS digital format that is fully compatible with the Survey's other GIS mapping and planning functions (available from Jefferson County GIS). CGS is completing a similar report on heaving-bedrock hazards in Douglas County. This report and accompanying maps, Special Publication 42, will be published in May 1998.

Once the hazard is identified, CGS also helps with the next step: ensuring safe use of the land. CGS works with counties to ensure that a proper subdivision plan is submitted and that ways to safely construct on heaving bedrock are described in the plan. CGS geologists then look closely at these aspects of the plan if they are asked to review the subdivision plan.

CGS MISSION STATEMENT

The CGS mission is to serve and inform the people of Colorado by providing sound geologic information and evaluation and to educate the public about the important role of earth sciences in everyday life in Colorado.

ROCKTALK

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