Special Publication 6

Guidelines and Criteria for Identification and Land-Use Controls of Geologic Hazard and Mineral Resource Areas

by
W. P. Rogers, L. R. Ladwig, A. L. Hornbaker, S. D. Schwochow,
S. S. Hart, D. C. Shelton, D. L. Scroggs, and J. M. Soule

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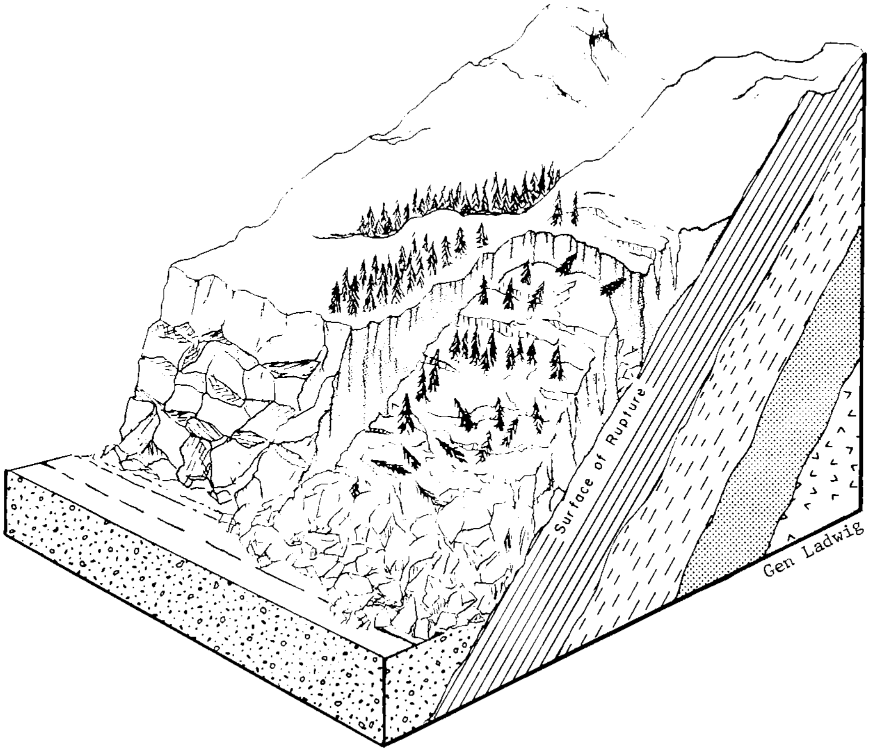

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PREFACE

These guidelines have been prepared by the Colorado Geological Survey in response to specific legislative charges of H.B. 1041. As we understand the intent of the law the guidelines serve a double purpose: 1) after consideration and adoption by the Colorado Land Use Commission they become a reference document for the L.U.C. in reviewing designations and guidelines developed and submitted by local government for administration of specific kinds of geologic hazard areas - for example, areas subject to recurrent mudflows; and 2) the guidelines are also provided to local government by the Colorado Geological Survey as a resource document in developing their guidelines and criteria for administration of designated geologic hazard areas. The law also provides for continued advice and counsel to be rendered to local government by state agencies as they proceed in designating and administering matters of state concern including geologic hazard areas. The appended Model Geologic Hazard Control Regulations are a companion document that outline suggested procedures for administration of geologic hazard areas. Because of the complexity of the problems covered and the specific needs and desires of the various units of local government, no single set of guidelines can provide cookbook solutions. Instead, we have elected to describe and explain the various geologic hazards according to the general outline. Development of actual guidelines for local adoption and use will undoubtedly require cooperative efforts and interchange between individual local governments and applicable state agencies.

The guidelines were prepared in conformance with the outline recommended by the State Technical Advisory Board. Every effort has been made to make the guidelines both technically sound and understandable to the intelligent layman who will in large part be the decision-makers and administrators of the law. To the extent possible within the available time, we have sought and incorporated comments from geologists, engineers, other professionals, and representatives of the user groups.

It should be plainly stated and thoroughly understood that if a geologic hazard exists and if development takes place, some risk is always involved. However, the guidelines and regulations set forth are intended to provide methods of recognizing and evaluating a specific hazard and either avoiding it by means of a nonconflicting land use or reducing the risk by allowing development only under certain specific conditions.

Preparation of the guidelines was a team effort by the entire staff of the Colorado Geological Survey in response to the urgent charges and expectations of H.B. 1041. Original drafts for individual sections were prepared by the following listed profesional staff members:

Stephen S. Hart: Expansive Soil and Rock
L. R. Ladwig: Identification Procedures; Qualifications of Investigators
J. W. Rold: Model Regulations
W. P. Rogers: Ground Subsidence; Seismic Effects
Stephen D. Schwochow: Mineral Resources
Doyle L. Scroggs: Landslides; Unstable or Potentially Unstable Slopes
David C. Shelton: Avalanches; Radioactivity
James M. Soule: Rockfalls; Mudflows and Debris Fans

Supervision, including organization, editing, and incorporation of suggestions from reviewers was as follows: 1) Mineral Resources by A. L. Hornbaker; 2) Geologic Hazards and general by W. P. Rogers and L. R. Ladwig. The entire undertaking was under the general supervision of J. W. Rold, Director, Colorado Geological Survey.

We wish to gratefully acknowledge the efforts and constructive suggestions by dozens of individuals, agencies, and organizations which contributed to preparation of the guidelines.

John W. Rold
John W. Rold
Director and State Geologist

William P. Rogers
William P. Rogers, Chief
Engineering & Environmental Section

A. L. Hornbaker
A. L. Hornbaker, Chief
Mineral Resources Section

L. R. Ladwig
L. R. Ladwig
Engineering Geologist

COMMISSION MEMBERS
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MRS. BEVERLY WARBURTON

STATE OF COLORADO
JOHN D. VANDERHOOF, Governor
OFFICE OF
COLORADO LAND USE COMMISSION
1550 Lincoln Street
Denver, Colorado 80203
(303) 892-2778

LEGISLATIVE ADVISORS
SEN. LORENA E. DARBY
SEN. JOSEPH B. SCHIEFFELIN

REP. FORREST G. BURNS
REP. LARRY E. O'BRIAN

GILBERT F. McNEISH
Staff Director

November 22, 1974

RESOLUTION ON APPLICATION BY THE LAND USE COMMISSION OF THE TEMPORARY EMERGENCY RULE UNDER THE COLORADO ADMINISTRATIVE PROCEDURE ACT (APA) TO GUIDELINES

WHEREAS, the Land Use Commission believes that the urgent need for land use control in Colorado necessitates the immediate promulgation of guidelines required under the Land Use Bill, H.B. 1041, and

WHEREAS, the local governments need state assistance in the form of guidelines to be promulgated by the LUC before they can begin the formation and adoption of guidelines for matters of state interest, and

WHEREAS, the LUC as an "agency" under the APA must follow the rule-making procedures set forth in that Act, and

WHEREAS, the guidelines are subject to the rule-making procedures under the Colorado APA, and

WHEREAS, the necessity of the situation warrants that the guidelines be adopted by the LUC as soon as possible, and

WHEREAS, the LUC finds that, because of the necessity of the situation, the time limitations of the ordinary rule-making procedure endanger the welfare of the public by slowing down the immediate implementation of H.B. 1041 throughout the State,

THEREFORE, be it resolved that the LUC hereby invokes the Temporary-Emergency Rule provision under the Colorado APA in order to adopt the required guidelines for matters of state interest, and declares this Commission meeting on November 22, 1974, to be the required notice to all persons under the Rule.

FURTHERMORE, the LUC specifically adopts the guidelines for identification and land use controls of geologic hazard and mineral resource areas as developed by the Colorado Geologic Survey, the appropriate state agency and submitted on this date, November 22, 1974, for use by local governments in identifying, designating and administering matters of state interest under H.B. 1041.

Adopted by the Colorado Land Use Commission at its regular meeting, November 22, 1974.

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I. Purpose of Guidelines

In 1974, the Colorado Legislature passed House Bill 1041:

> "Concerning land use, and providing for identification, designation, and administration of areas and activities of State interest, and assigning additional duties to the Colorado Land Use Commission and the Department of Local Affairs, and making appropriations therefore."

Within H.B. 1041, the Colorado Geological Survey is charged with specific responsibilities under item (1)(C) of Part 1, Section 106-7-101:

> "Appropriate state agencies shall assist local governments to identify, designate, and adopt guidelines for administration of matters of State interest."

Areas of State interest are covered in Part 1, Section 106-7-103, Definitions pertaining to natural hazards. Item 8 defines the term "Geologic Hazards" to which these guidelines relate.

These guidelines are in direct response to H.B. 1041. They have been prepared by the Colorado Geological Survey to meet the requirements and intent of this law. It is hoped that nontechnical people at all levels of local government can readily understand the explanation of each kind of geologic hazard and the general geologic environment in which each is most likely to occur. This does not imply that the non-geologist can become an instant expert on geologic hazards and their mitigation, but rather that they may aquire a working knowledge of the geologic environment to aid them in the multitude of daily decisions involved in land use planning and decisions. Obviously highly technical questions of fact or interpretation will require professional input from geologists, engineers, hydrologists and other appropriate professionals.

The individual geologic hazards enumerated in H.B. 1041 are discussed in Part III of these guidelines as follows: 1) Definitions, 2) Criteria of Recognition, 3) Consequences of Improper Utilization, 4) Mitigation Procedures, and 5) References (for those who wish to obtain a greater understanding of the individual geologic hazard). Also included is Part VIII - Glossary of Terms, in which all words in the text followed by an asterisk are defined.

The charge to local government concerning natural hazard areas is found in Part 2, Section 106-7-202, (2)(b)(III):

> "After promulgation of guidelines for land use in natural hazard areas by the Colorado Water Conservation Board, the

Colorado Soil Conservation Board through the soil conservation districts, the Colorado State Forest Service, and the Colorado Geological Survey, natural hazard areas shall be administered by local government in a manner which is consistent with the guidelines for land use in each of the natural hazard areas."

Assistance in the designation of mineral resource areas is a second area of State interest assigned to the Colorado Geological Survey (Part IV of these guidelines). After such areas have been designated, the law provides for their administration in Part 2, Section 106-7-202, (1)(a) as follows:

> "Mineral resource areas designated as areas of State interest shall be protected and administered in such a manner as to permit the extraction and exploration of minerals therefrom, unless extraction and exploration would cause significant danger to public health and safety."

The 1973 House Bill 1529 (Preservation of Commercial Mineral Deposits) and the Open Mining Land Reclamation Act of 1973 are specifically referred to regarding the mining of certain minerals and the reclamation of mined lands.

The purpose of these guidelines is to provide local governments with basic information about geologic hazards, identification procedures, and necessary qualifications of investigators. These factors will have to be carefully considered when the actual identification and mapping of specific geologic hazards take place. If this identification and mapping is to be done either by the staff of the local government or by private consultants, these guidelines can be used to aid in obtaining competent geologic input in implementing the goals of H.B. 1041. These guidelines should not, however, be considered the "last word" on any method or criteria presented.

For assistance in dealing with the geologic hazard and mineral resource aspects of H.B. 1041, local governments should address inquiries to: Colorado Geological Survey, 254, Columbine Building, 1845 Sherman Street, Denver, Colorado 80203, Phone: 303/892-2611.

II. Definition of a Geologic Hazard

> H.B. 1041 - "Geologic Hazard means a geologic phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property."

> Glossary of Geology (American Geological Institute) - "A naturally occurring or man-made geologic condition or phenomenon

that presents a risk or is a potential danger to life and property."

These definitions have one central theme--the potential adverse effects when man intrudes into or alters the natural geologic environment. The hazards described in these guidelines are all normal dynamic processes of our natural geological environment. Such processes or conditions become a real hazard to man only when his activities intrude upon or interact with them. Recognition of this fact is essential to rational land use decisions. Man's activities may either intensify or mitigate a hazard condition depending upon the choice of land use and other options discussed in these guidelines with respect to management of hazard areas.

Colorado's great diversity of rocks, geologic structures, soil types, topography, and climatic conditions combine to create vigorous and diverse environmental geologic processes and problems, particularly as to geologic hazards. For example, naturally occurring landslides that have long been inactive may be triggered into renewed activity and consequent destruction by the building of a highway or street, construction connected with a development project, changes in natural drainage ways, or even lawn irrigation.

It should be recognized that a thorough knowledge of the geologic environment is basic to the anticipation and solution of problems that may arise when man attempts to occupy or develop land where geologic hazards exist. The ultimate solution to development may be total avoidance of the area, a nonconflicting use, or engineered design and construction to correct the adverse condition.

Before a solution can be considered, the existence of a potential problem must be recognized. Therefore, equal emphasis should be placed (1) on obtaining the kind of geologic knowledge that will lead to early recognition of potential problems, and (2) ensuring that these geologic data are used in formulation of plans or regulations for safe and efficient utilization of our land.

III. Geologic Hazards Included in H.B. 1041

A. Avalanches

1. Definitions

a. Legal definition

H.B. 1041, Part 1, 106-7-103(2) "Avalanche" means a mass of snow or ice and other material which may become incorporated therein as such mass moves rapidly down a mountain slope.

b. Descriptive definition

Snow avalanches are the rapid downslope movement of snow, ice, and associated debris such as rocks and vegetation. "The forces generated by moderate or large avalanches can damage or destroy most manmade structures. The debris from even small avalanches is enough to block a highway or railroad" (Martinelli, 1974, p. 5). Avalanches occur in the mountainous areas of Colorado generally above 8,000 ft elevation, and most commonly occur from November through April. Avalanche occurrence is directly related to topography, climate, vegetation and aspect* of the area. Much of the information in this report was extracted from "Snow Avalanche Sites - Their Identification and Evaluation" by M. Martinelli, Jr. (1974). Readers with particular interest in avalanches will find that publication quite valuable.

An avalanche site or area is a location with one or more avalanche paths. Avalanche path refers to the specific area where a snow mass moves. A complete path is made up of starting zone(s) at the top where the unstable snow breaks away from the more stable part of the snowcover, runout zone(s) at the bottom where the moving snow and entrained debris stop, and track(s) that run between starting zone and the runout zone. Some paths may also have an airblast zone, where damage occurs from the turbulent winds that accompany fast-moving powder avalanches. The airblast zone is usually in the vicinity of, but not necessarily continuous with, the lower track or runout zone. In some cases it may even run part way up the slope across the valley from the avalanche path.

Avalanches start most frequently on slopes with average gradients* of 30° to 45°. Slopes steeper than 45° usually do not accumulate enough snow to produce very large avalanches in the Rocky Mountain climate. Avalanches may start on slopes of less than 30° if the snow is highly unstable as the result of a prolonged warming trend, heavy snowfall, or unusual wind condition.

These starting zone slope angles are, however, merely the range in which most dangerous avalanches occur; do not assume that slopes outside this range are safe from avalanches. The average gradient for the entire avalanche path will be more gentle than that of the starting zone. Average gradients of 20° to 35° are common for the tracks of Rocky Mountain avalanches while the slopes in the runout zones are often more gentle and sometimes completely flat, and may even extend up the opposite valley side.

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*Words with asterisk are defined in glossary; asterisk appears only the first time word is used.

Avalanches are not confined to specific terrain features: they may follow narrow gullies or ravines for all or part of their path; they may occur on broad, uniform slopes or even ridges and spurs. Longitudinal profiles of the paths may be concave, convex, or stepped. On stepped paths, small avalanches will often stop on a bench part way down the tract while larger ones run the full length of the path.

c. Severity of problem

The severity of avalanche hazard increases when the works of man extend into avalanche areas, therefore, the recognition of the potential areal extents of avalanches is necessary. This recognition is difficult to achieve when man has not had the opportunity to observe avalanche activity in any particular path over a long enough period of time so that a reasonable assessment of runout potential may be made.

The maximum measured impact pressure of an avalanche is 10 ton/ft^2 while 1 ton/ft^2 is more common. A typical range is from 0.5 to 5.0 ton/ft^2. Air blast from powder avalanches commonly exert a pressure of 100 lb/ft^2 of force (Martinelli, speech November 8, 1973). Pressures of only 20-50 lb/ft^2 are capable of knocking out most windows and doors. Roads, highways, and railroads are blocked for hours, or sometimes days, every year due to avalanches. Many skiers, other winter sportsmen, and travelers have been injured or killed by avalanche activity.

Lack of recognition of avalanche runout potential has resulted in residential building construction within runout zones in Colorado. When the infrequent, large avalanche event occurs, damage to these buildings will occur unless measures are taken to protect existing structures.

2. Criteria for Recognition

a. General

By far the most reliable way of locating avalanche areas is to study long-term, detailed records of past events - when they are available. Such records are available for many localities in Europe, but, unfortunately, compilation is just starting in Colorado.

Usually, data on the location, frequency, or severity of avalanche activity are completely lacking when new areas are considered for highways, winter sports, mining operations, or mountain home sites. Without adequate records of past events, the best alternative is to obtain what data are available, examine the area, map all recognizable paths, estimate the frequency and intensity of the avalanche action, and if possible, start a record of avalanche events.

Active or recently active avalanche paths are most easily identified on air photos or from low-flying airplanes or helicopters. The next best viewpoint is the slope or ridge across the valley from the suspected avalanche area. The entire path should be viewed from such vantage points so that there is less chance of misjudging the size of the path or of overlooking an indistinct or inconspicuous path. Such an overall view makes it possible to spot paths where the aspect of the starting zone and the track are different-- an important feature in determining what wind direction causes deposition in the starting zone. Surveys from the valley bottom or lower slopes (the usual road location) are often very misleading. Crooked paths or those with a short, steep pitch in the lower track or runout zone often appear much shorter and smaller than they really are or may not even be recognized as avalanche paths.

b. Field evidence of avalanches

1. Summer conditions

Avalanche paths in forested areas usually appear as strips straight down the mountain, characterized by a different type or age of the dominant vegetation. These vertical swaths through the trees can be very dramatic when the change is from natural timber to grasses and small herbs. They are less conspicuous but still obvious to most observers when the change is from conifers to aspen or brush. On the other hand, careful scrutiny and often a distant vantage point are needed to spot the change from mature timber to younger trees of the same species.

In some cases, avalanches run down slopes with only scattered trees or open parklike stands of trees. These paths are hard to see, and only long and complete records will reveal all of them. Suspected areas should be checked carefully for evidence of avalanche activity. Good indicators of avalanche activity are trees with scars or broken limbs on the uphill side, or trees that lean downhill. Leaning trees deserve a second look, however, to be sure they are caused by avalanches and not snow or soil creep or a landslide.

An accumulation of wood debris on lower slopes or in the valley may mark an avalanche runout zone, as might a patch of aspen or young trees at the bottom of a likely avalanche path. Patches of downed trees all aligned in the same direction are a good indication of avalanche activity. Do not discount such patches of downed trees because their tops point uphill. They may mark areas of airblast, or they may be the result of an avalanche that crossed the valley and ran part way up the opposite slope.

Summer identification of avalanche paths in nonforested areas is difficult and uncertain. Slope steepness, aspect, and surface roughness all offer clues but no proof. Other things being equal, avalanches will be more likely:

1) on lee slopes than on windward slopes, because of wind loading;

2) on grass slopes than on brush-covered slopes, because of lower surface roughness;

3) on shaded northern slopes than on sunny southern slopes, because the snow stays loose and unstable longer; and

4) on slopes between 30° and 45° than on steeper or gentler slopes because of their ability to accumulate sufficient snow on terrain steep enough to avalanche readily.

Large patches of bare soil surrounded on the sides and above by vegetation, if located on slopes steep enough to avalanche, should be considered possible avalanche starting zones. This lack of vegetation is often due to deep snow accumulation. Steep rock faces or cliffs that have numerous benches or pockets where snow can accumulate may also be the sources of avalanches in spite of the general statement that very steep slopes usually are not serious avalanche problems.

Many avalanche paths cross both nonforested and forested areas. In the Rocky Mountains, for example, many avalanches start above timberline, their track in the timber, and their runout zone in grassy or brushy areas below the timber. In such cases, the swath through the trees is the most obvious identification feature, but the starting and runout zones must be given full consideration when establishing size and estimating frequency and intensity of activity.

2. Winter conditions

Not all avalanche paths run every year. Many run only once every 5 to 15 years, and others even less frequently. Nor do all avalanches run the full length of their paths every time. Avalanches may stop in the starting zone, track, or runout zone, depending on the amount and condition of the snow in the path.

Field evidence -- usually confined to the starting zone -- that an avalanche has occurred includes:

1) A fracture line or fracture face where the unstable snow broke away as a slab avalanche from the remaining snow cover.

This is the most frequently observed and perhaps the most important, single, winter identification feature. The continuity of these fracture lines makes even small ones visible for great distances. New snowfall or drifting snow, however, soon obscures shallow fracture lines and makes even large ones much less distinct.

2) A change in snow depth and in the texture and features of the snow surface, without a distinct fracture face.

All of these features, which mark the start of a loose snow avalanche, are quickly erased by snowfall and drifting snow, and may be missed even by a careful observer.

Additional evidence of avalanches -- features that may be located in the starting zone, track, or runout zone, and whose size and location in the path are clues to the size of the avalanche -- includes:

3) Mounds of blocks of snow.

Major concentrations usually mark the lower end of the avalanche. Lesser amounts may be scattered higher on the path, at breaks in the slopes, or curved in the track. This is the second most important winter identification feature.

4) Snow dirtier and denser than the surrounding cover.

At times, even after avalanche debris has been covered by fresh snow and all surface indications of avalanche debris are lost, a ski tip or pole or a probe rod can detect the harder, denser avalanche snow beneath. In late spring or summer, these deeper and denser snow deposits often persist after the surrounding cover has melted, and they make excellent identification features. It may be difficult, however, to tell if the debris is from one or more avalanches on the same path.

5) A clean white swath through gray or dust-covered snow in steep terrain.

After snow surfaces have become dust covered or modified by weather during long snow-free periods, the removal of these surface layers by avalanches reveals the clean, unmodified snow beneath. The change in color and texture is noticeable, even if the avalanche left little other evidence.

6) Accumulations of broken trees, limbs, twigs, leaves, and needles.

Entire trees may be uprooted, broken off, or bent over and are usually oriented parallel to the downslope direction. Large amounts of timber in the debris indicate an avalanche that ran larger than usual or took a different route down the mountain.

7) Snow, mud, rock, or detached tree limbs plastered against uphill side of standing trees or rocks.

These signs often help mark the outer edges of the moving snow. They are most noticeable just after an avalanche has run and are quick to disappear.

8) Deep grooves in the snow and walls of snow; both usually oriented down the fall line.

These indicate avalanches in heavy, wet snow. Grooves and sides of walls are usually smooth and icy. These features are more common in spring avalanches than in winter ones.

9) "Flag trees" with fresh scars or broken limbs on uphill side of standing trees, and brush with healthy limbs confined to the downhill side. Confusion with wind-damaged trees can be avoided by a complete investigation of the site containing such "flag trees."

After an avalanche path has been located, it is important to know the size and frequency of avalanches on the path. Long term observation is the best way to establish avalanche frequency and size. These are, however, available for only a few locations in the United States. The next best thing is to systematically observe the destructive effects of avalanches on the terrain <u>during snow-free conditions</u>. Sometimes, evidence may be found of multiple avalanche events of various sizes and ages through a careful analysis of destruction in the avalanche track and through the distribution of debris in the runout zone. Additional sources of information may come from "old timers" in the area. Highway maintenance crews, powerline crews, ranchers, trappers, hunters, or fishermen should be quizzed. In more remote areas, ski touring, snow-mobiling, or winter mountaineering groups may be a better source of information. Newspaper and other written accounts occasionally help in establishing the data of major events, but are selective toward very large avalanches or those that took lives or did extensive damage.

All incomplete records will be selective in one way or another, and must be used with caution. Highway crews will be most concerned with slides across the road and will seldom pay much attention to those that do not reach the road. Sportsmen will be more apt to see the early avalanches that run during hunting season or those that leave large debris cones that persist in the valley well into fishing season. Such accounts are not definitive in establishing avalanche frequency.

3. Consequence of Improper Utilization

Avalanches are not a hazard until man's activities and land uses are affected adversely by the avalanches. Possible conflicting land uses are recreation, residential, transportation, and mining. Examples of this conflict would include property damage, injury, deaths and excessive maintenance costs.

a. Deaths

Deaths can be caused by avalanches whenever people are within the area affected by the avalanche. This area is the entire avalanche path including the airblast zone. Death can be caused by impact and/or suffocation. In Colorado there have been 43 recorded deaths from avalanches since 1950. This averages about two avalanche fatalities per year for the state (Martinelli, 1974, personal communication).

In the late 1800's and early 1900's the number of fatalities caused by avalanches in Colorado was far greater due to the extensive mining activity in avalanche-prone areas. It has been reported that 119 people died in 1899 alone while it was not uncommon to have dozens killed each year. Now in the 1970's, Colorado is again experiencing an increase of human activity in the high mountain area. H.B. 1041 provides government and citizens with the means to protect property and life from future high losses caused by snow avalanches.

b. Property damage

Property damage can occur throughout the entire avalanche path. Impact (air or snow) damage ranges from minor to major structural damage to any structure within the path. Vehicles and equipment can be moved great distances and damaged. When deposited, the debris associated with the avalanche might cause damage and be expensive to remove. Roads and bridges may be damaged.

c. Maintenanace

Roads, highways and railroads may become blocked by avalanche snow and debris. In addition to delaying highway and rail travel, it is costly to clear the transportation routes. In a few cases, where access roads to mountaintop radio and microwave communication sites are threatened by avalanches, emergency repairs and maintenance are delayed. In areas where efforts are underway to control avalanches, the maintenance of avalanche control structures and/or explosive control is costly.

In summary, man's activities in avalanche-prone areas can be costly in both money and lives. Improper utilization of avalanche areas include all uses that generate unacceptable costs in lives or property.

4. Mitigation Procedures

The location, time, and magnitude of avalanche events are difficult to predict. Because potentially destructive avalanches are relatively common in the Colorado mountains, anyone planning new facilities and land uses should avoid avalanche-prone sites, or otherwise provide for acceptable safety and economic feasibility of the proposed use.

a. Avoidance

The safest and probably the most economic mitigation procedure is to avoid building or any type of development involving winter use in avalanche-prone areas. This implies that all avalanche-prone areas can be identified and the avoidance is possible.

b. Nonconflicting use

Nonconflicting land uses of avalanche-prone areas include all uses that will not cause loss of life, property, or excessive maintenance. Agriculture and recreational activities that take place during non-avalanche months are desirable nonconflicting uses. Other uses that could be considered are those that involve no permanent unprotected structures in the avalanche path or those that could be moved or closed down during high avalanche-risk periods.

c. Engineered design and construction for correction of adverse conditions.

The two basic methods of avalanche control are: 1) explosive and 2) structural. Explosive techniques have been used for the deliberate release of avalanches for many years. The theory of this technique is to cause many smaller, controlled avalanches and thus avoid large unpredictable destructive avalanches. The principal methods of charge emplacement are: a) hand delivery, in which charges are placed on or in the snowpack for immediate firing, and b) projectile delivery, in which charges are fired into the snowpack by guns.

Explosive control has been very effective in areas with easy access to avalanche starting zones and ones that can tolerate many small slides without causing damage. Detailed information on current and past snowpack and avalanche conditions should be available,for this technique to be safe and effective. This method may be unacceptable in areas where easy access to the starting zones is not available, where projectiles must be fired over occupied buildings, where an occasional large avalanche would be especially destructive, or where manpower and facilities are not available to maintain an up-to-date evaluation of snow cover stability. In general, explosive control is probably unacceptable for areas of human occupancy.

Structures for the control of snow avalanches fall into four catagories (for details see Martinelli, 1972):

1) Supporting structures in the starting zone are built in the upper part of the avalanche path to prevent avalanches from starting, or to retard snow movement before it gains momentum. Some of the first supporting structures were massive earth and stone walls and terraces intended to interrupt the continuity of the steep slopes and to prevent avalanches. Modern supporting structures in the starting zone may be either rigid or flexible. The rigid ones are made of wood, steel, aluminum, prestressed concrete, or a combination of these materials. Flexible supporting structures called "snow nets" are constructed of steel cables or nylon straps and are held up by steel poles.

2) Deflecting and retarding structures in the runout zone are massive structures usually made of earth, rock, or concrete located in or near the avalanche track or runout zone. The purpose of the structures is to keep the moving snow of an avalanche away from critical locations of structures.

Structures to confine or deflect moving snow should deflect the avalanche as little as possible from the direction of natural flow. Walls built at sharper angles to the flowing snow will often be overrun by fast-moving masses of dry snow.

Retarding structures are usually earth mounds or large concrete structures called breakers or tripods. They should be built on benches or less steep parts of the path where avalanches slow or stop naturally. The additional roughness and cross currents set up by these structures usually stop all but large, dry snow avalanches. Mounds are inexpensive to install and relatively easy to maintain; however, they have been ineffective on slopes steeper than 20° (35%).

3) Direct protection structures are built immediately adjacent to the object to be protected, or in a few cases, incorporated in the design of the object itself. The aim is to render complete protection regardless of avalanche size, type, or frequency of occurrence. The avalanche gallery or avalanche shed is a good example. Avalanche sheds are merely roofs over a road or railroad that allows avalanches to cross the road without interrupting or threatening traffic. Avalanche sheds are more effective for railroads or narrow roads than for multilane superhighways currently being built.

In actual practice it is common for many different types of structures to be used on a single path. For example, to protect a village with its homes, schools, churches, and roads, from large avalanches, supporting structures, wind baffles, and snow fences may be used in or near the starting zone. These stabilize the upper part of the avalanche path. Mounds, walls, and concrete tripods may be used farther down the mountain to catch any avalanches that start below the supporting structures. Direct protection structures may also be needed to protect isolated objects such as powerlines or ski-lift towers, mines, or buildings, if any exist in or near the path between the supporting structures and the mounds. In addition, most European avalanche defense systems include reforestation up to the natural tree line.

Obviously, the most desirable and effective protection against avalanches is to locate buildings, roads, and other valuable objects in areas free from avalanches. With ample space and an informed mountain population this is not too difficult. However, as population grows and less desirable sites are considered for development, advanced planning and strictly enforced zoning and construction practices appear the best solutions. In some cases, even these are not adequate to completely eliminate risks for avalanche danger and certain risks must be assumed, especially in the case of roads, powerlines and railroads. These risks can, however, be reduced considerably if appropriate structural controls are employed.

Photo by Jerry Cleveland

Figure 1. A MIXED SURFACE AND POWDER AVALANCHE IN PROGRESS: THE TURBULENT MASS AT THE LEADING EDGE OF THE AVALANCHE CAN BE HIGHLY DESTRUCTIVE TO ANYTHING IN ITS PATH.

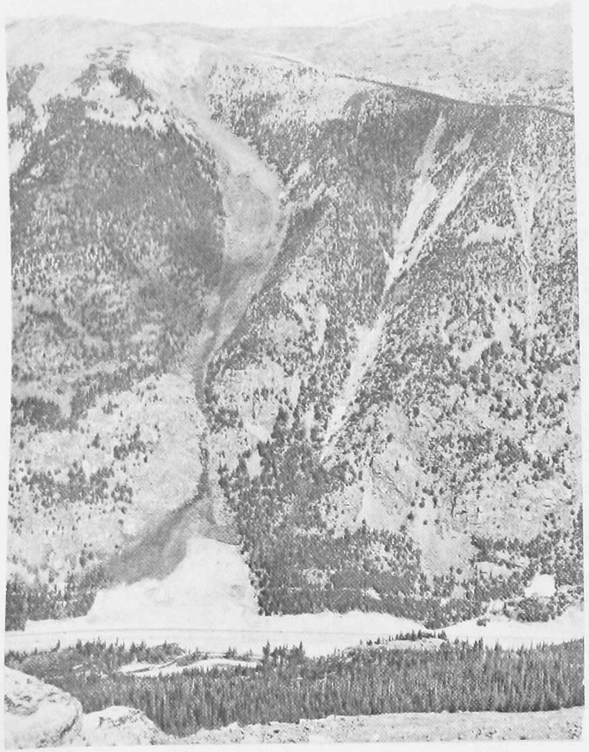

Photo by Art Mears

Figure 2. AN AVALANCHE PATH FROM STARTING ZONE TO RUNOUT ZONE. THE RUNOUT ZONE OF THIS AVALANCHE PATH HAS BEEN CROSSED BY AN INTERSTATE HIGHWAY. NOTE THE ELEVATION OF THE STARTING ZONE WHERE LARGE AVALANCHES BEGIN. COMMONLY, AVALANCHE-PRONE AREAS CAN BE IDENTIFIED MORE EASILY FROM A DISTANT VIEWPOINT THAN FROM CLOSE-UP ON-SITE INSPECTION.

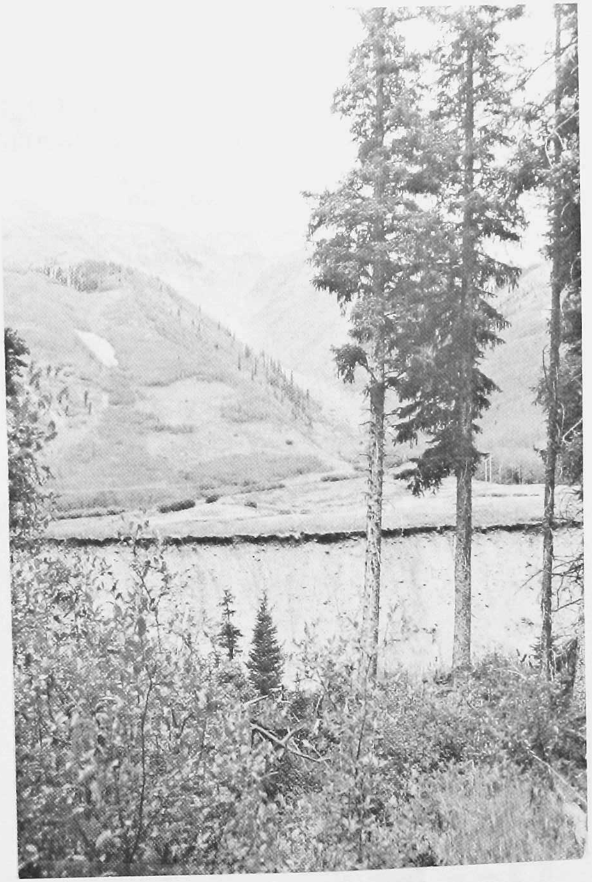

Photo by Art Mears

Figure 3. THIS PHOTO WAS TAKEN FROM THE RUNOUT ZONE OF A LARGE AVALANCHE PATH, LOOKING BACK TOWARD THE AVALANCHE TRACK. LIMBS ON TREES IN THE FOREGROUND, WHICH ARE 2500 FEET FROM THE GULLY MOUTH, WERE TRIMMED BY POWDER AVALANCHE IMPACT, INDICATING THE GREAT RANGE OF LARGE POWDER AVALANCHES.

Figure 4. SMALL SURFACE SNOWSLIDES: COMMONLY THESE OCCUR IN THE SPRING DUE TO WARMING AND SUBSEQUENT DECREASE IN THE STRENGTH OF THE SNOWPACK.

Photo by Art Mears

Figure 5. LARGE TREE TRUNKS ARE COMMONLY SNAPPED OFF BY AVALANCHE IMPACT.

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B. Landslides

1. Definitions

a. Legal definition (none given in House Bill 1041)

b. Descriptive definition

Many types of mass movement of natural material are included in the general geologic term "landslide." However, for purposes of these guidelines the term will be restricted to mean those mass movements where there is a distinct surface of rupture or zone of weakness which separates the slide material from more stable underlying material. Such slides involve en masse downward and outward movement of a relatively dry body of rock and/or surficial material in response to gravitational stresses. Other varieties of landslides that are treated separately in these guidelines include: 1) rockfall* which involves either direct fall or forward rotation of a rock mass followed by free-fall and/or rolling, bounding, or rapid sliding motions with only intermittent contact with the ground surface; and 2) mudflows* and closely related phenomena which involve movement by viscous flow of material with high water content and which may lack a distinct surface of separation between the moving mass and underlying more stable material.

Landslides as defined above include two major types: 1) Rotational slides (Fig. 6) which refer to all landslides having a concave upward, curved failure surface and involving a backward rotation of the original slide mass*; and 2) translational slides in which the surface of rupture along which displacement occurs is essentially planar (Fig. 7). Either type of landslides can involve various combinations of bedrock, broken bedrock, and unconsolidated surficial material (Figs. 6, 7, & 8), and the displaced material in either type of slide may be either greatly deformed or nearly intact.

Rate of movement of landslides varies from very slow to very rapid. They may be extremely small in extent or measurable in miles. Volumes of material involved may range from a few cubic feet to millions of cubic yards. Landslides result from some change in the physical condition of an unstable slope area (see section of guidelines on potentially unstable slopes). Such changes may be natural or man-induced. Some of the major mechanisms that initiate slides are: removal of the toe or lower end of a potentially unstable slope (commonly known as "daylighting"); removal of lateral support material adjacent to an unstable area; placement of additional material on the upper portion of an unstable area (commonly referred to as "loading"); weakening of clay or other fine-grained materials by wetting; weakening of natural cohesive forces by ground water circulating along potential failure surfaces; or decrease of stability by excessive pore water pressures within the slope-forming materials or along a potental failure surface. Other mechanisms include; redistribution of mass by erosion and deposition; chemical and physical weathering which may weaken slope materials; earthquake vibrations and release by erosion of stresses related to active faulting or past stresses "locked in" rock materials.

Many of the above described disturbances that are capable of inducing landsliding of unstable slopes can result from activities of man. The most common activities of man that can produce landsliding include: excavations such as road cuts, quarries, pits, utility trenches, site grading, landfill operations, stockpiling of earth, rock or mine waste; alteration of natural drainage which may lead to increased runoff and erosion or to local ponding and saturation of potentially unstable slopes; and vibrations from blasting or heavy vehicular traffic.

Actual landslide movement can occur in several ways. It may be rapid, and of short duration, after which natural equilibrium (stability) of landslide material is achieved. It may consist of intermittent periods of active movement, separated by relatively inactive periods. A third possibility involves slow, continuous movement, over a considerable period of time. Total displacement of slide material may involve movement that can be measured in a few feet, or it may involve displacement measurable in hundreds or thousands of yards, and in some cases even miles. Differential movement may also occur within an active slide mass. Isolated smaller slides may take place within the body of a large slide during its movement (multiple sliding), or they may occur after much of the larger slide has stabilized. Also, the reverse is true, where large parent slides include, or incorporate, smaller slides.

Figure 6 is a representation of a rotational landslide which depicts features common to this type of slide. All of these features may not be developed in any given slide or they may be too poorly developed to detect, and many of the minor features are quickly effaced by surface geologic processes. More permanent features that commonly aid in identifying the presence of old slides are the appearance of a main scarp and a corresponding bulge of landslide deposits on a hillside. These features or relict anomalous slope changes often remain for many years as evidence of past instability. It should be noted that all such breaks in the natural profile of a hillside are not necessarily remnants of landslide scarps or deposits, and that determination of slope stability requires study by an experienced engineering geologist.

Rotational slides can occur anywhere that the following conditions are present, and in the necessary combination to promote sliding: 1) slopes sufficiently steep to allow lateral downslope movement of materials in response to gravity; 2) gravitational stress sufficient to move such material; 3) presence of unstable material susceptible to sliding; 4) underlying zone of weakness as a potential surface of rupture; 5) introduction of a disturbing factor -- natural or man-made -- sufficient to initiate instability and movement.

Figure 7 is a three-dimensional representation of a translational landslide. This type of slide is characterized by a planar surface of rupture, and frequently by little deformation of slide material. Physical relationships prevalent in this type of slide are the presence of relatively competent materials above and beneath a planar zone of weakness along which sliding occurs. This condition is quite common in nature and may be the result of various combinations of materials and/or physical conditions. Translational slide material may range from fairly loose unconsolidated soil to extensive slabs of hard, resistant rock. Movement of translational slide material may be initiated by a variety of conditions, which are listed under general description of factors tending to produce landsliding.

The same criteria outlined above as prerequisites for rotational sliding to occur, apply to translational gliding, with the exception of item 3. In contrast to rotational slides, the entire slide mass in a translational slide need not necessarily be weak, unstable material itself -- there may be very thin zone of weakness such as a thin layer; bedding, joint or foliation plane; or the surface separating weak surficial material from underlying competent material.

c. Severity of problem

Landslides are widespread, naturally occurring geologic events through much of Colorado. Only when such phenomena conflict with the works of man do they constitute a serious problem or hazard. The severity of such a problem is directly related to the extent of man's activity in areas affected, and adverse effects can be mitigated by early recognition and avoidance or by corrective engineering. Actual losses can range from mere inconvenience or high maintenance costs where very slow or small-scale nondestructive slides occur, to severe losses where large-scale destructive slides are involved. Rapidly moving large slides have the capacity to completely destroy buildings, roads, bridges, and other costly man-made structures. Such slides also have the potential for inflicting loss of life when they occur in developed areas. Occurrence of landsliding is widespread throughout the mountainous and more hilly regions of the state, and countless slides take place annually. Costs in terms of road maintenance in slide areas, building damage, lost time on construction projects, inconvenience, and in some cases threat to life are large. Where man's activities invade areas of high landslide potential, this becomes one of Colorado's most severe geologic hazards.

2. Criteria of Recognition

The following criteria may be used in identifying both existing and potential landslide areas. Newly formed slides are easily recognized by the presence of one or more of the numerous features shown in Figures 6, 7, and 8. As a slide ages, weathering and natural "healing" processes steadily lessen the prominence of these features, thus rendering identification more difficult. Some indications of past sliding in an area are: erratic drainage patterns, trees growing in disarray at divergent angles; irregular, hummocky, poorly drained ground surface; anomalous slope changes described earlier; and disturbed or displaced cultural features such as roads, walkways, and buildings. Recognition of potentially unstable slopes are treated in a separate section of the guidelines.

3. Consequence of Improper Utilization

The consequence of improper utilization of areas subject to landslide for building and development may range from minor damage in extremely fortunate cases, to total destruction of structures and accompanying loss of life. Maintenance of structures in active slide areas is very costly, and in many cases will equal or exceed the price of the structure prior to expiration of its useful life.

4. Mitigation Procedures

Having properly identified a region as being prone to landslide failure, several approaches can be taken in attempting to utilize the area.

a. Avoidance

Some nonconflicting use could be designated for the area, whereby losses would be minimal in the event of failure. One such use is greenbelting, or open space including certain types of agricultural use.

b. Nonconflicting use

Where the proposed use is simply not compatible with an existing slide hazard, the hazard is best avoided by selective use of available development land and complete avoidance of high-risk areas.

Text Cont. p. 24

Rotational Slide Terminology

Figure 6 on the facing page is a three dimensional diagram of a rotational type landslide. The following is a listing of accepted terminology for the major features commonly present in such a slide:

main scarp: steep undisturbed ground surface above the highest part of the slide, resulting from downward movement of slide material.

minor scarp: steep surfaces in slide material resulting from differential movement within the body of the slide.

crown: in-place material just above the main scarp.

head: uppermost part of slide material along the contact between the main scarp and the slide material.

transverse cracks: tension cracks more or less perpendicular to the direction of slide movement, generally resulting from downward and outward movement of slide material over a hump in the rupture surface.

radial cracks: tension cracks resulting from lateral spreading of unconfined slide material.

tip: furthest forward extension of slide material.

toe: furthest forward margin of slide material.

foot: contact between original ground surface, and lowermost extension of surface of rupture.

surface of rupture: projection of main scarp surface beneath the slide mass.

right flank: right extent of slide as viewed from the crown, looking down onto the slide.

left flank: left extent of slide as viewed from the crown, looking down onto the slide.

prevailing slope: direction of predominant ground surface slope in undisturbed area.

original ground surface: undisturbed ground surface surrounding disturbed slide area.

longitudinal fault zone: faulting resulting from differential forward progress of downward moving slide material.

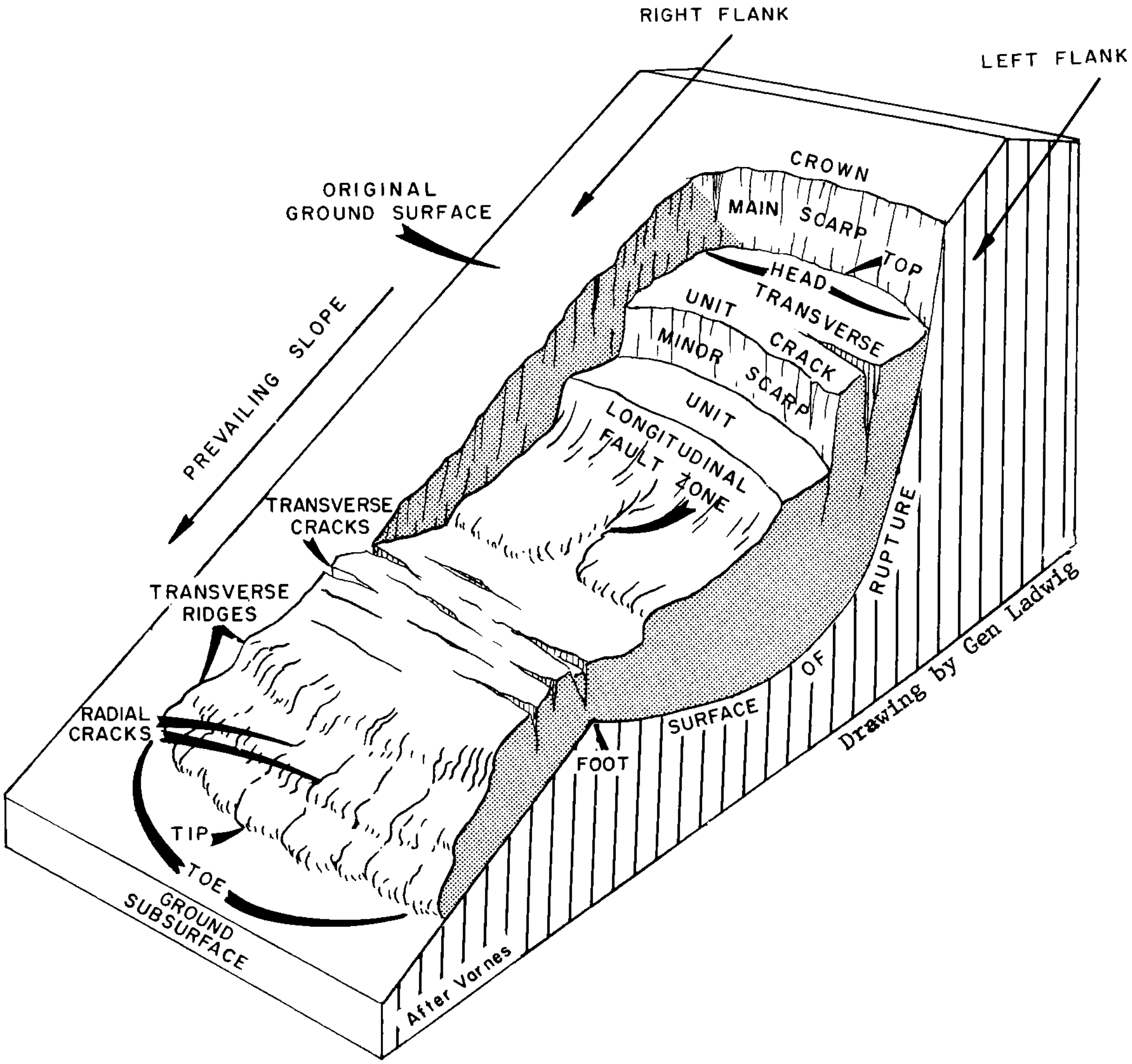

Figure 6. DIAGRAMMATIC DRAWING OF A ROTATIONAL LANDSLIDE

c. Engineered design and construction for correction of adverse conditions

Where economic pressures and limited available land militate for use of unstable or potentially unstable areas another alternative is to develop moderately unstable areas under specified and closely controlled conditions. This approach calls for careful evaluation of the physical extent, seriousness, and causes of geologic problems, and strict adherence to recommended design and construction procedures, as set forth by competent professional geologists and professional engineers evaluating the landslide area.

There are several common preventive methods employed to avoid sliding. One is to refrain from removing natural support material in the area immediately beneath or adjacent to the slide area. Another is the addition of artificial support material to this area. Such support can be in the form of rock- or earth-fill buttressing, retaining walls or cribbing, concrete slurry, rock bolting and reinforced pilings.

Another approach is to permanently improve and control surface and subsurface drainage in the vicinity of a potential slide area. This greatly decreases the lubricating and pore water pressure effects of water, and accompanying decrease in stability. This approach is often very effective, however, it may involve complex dewatering systems and costly long-term maintenance and monitoring problems.

Other alternatives include stabilizing the slide area by chemical treatment, bridging weak zones, removal of unstable material, and avoidance of loading on unstable areas.

In summary, it should be stated that landslides, and landslide-prone areas can be very complex in nature, and pose serious risks to any development placed in their vicinity. Landslides and potential slide areas should be evaluated only by competent professional engineering geologists and soil engineers. The information contained in the guidelines is only an introduction to the subject. More comprehensive treatment of landslides can be found in the references listed.

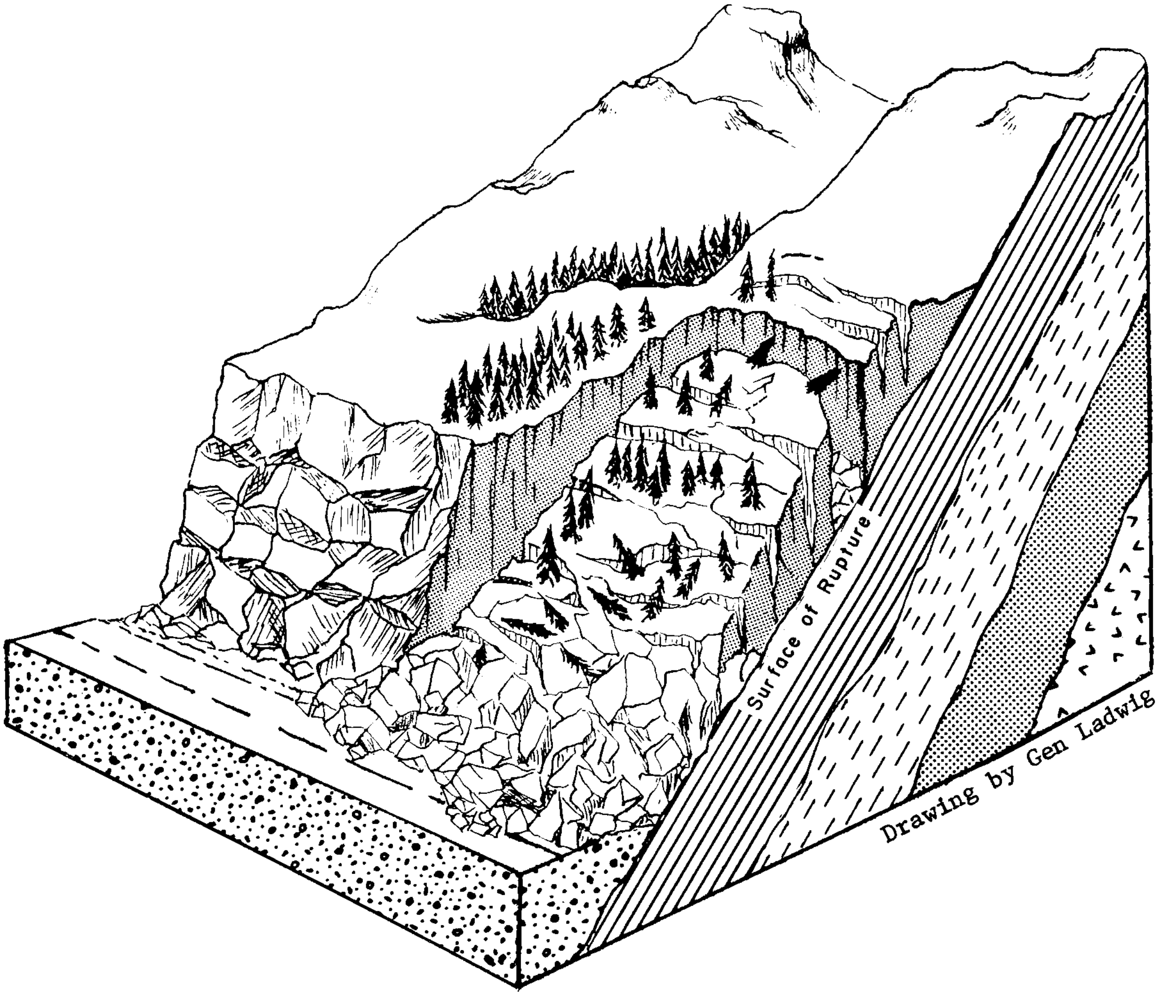

Figure 7. DIAGRAMMATIC DRAWING OF A TRANSLATIONAL LANDSLIDE

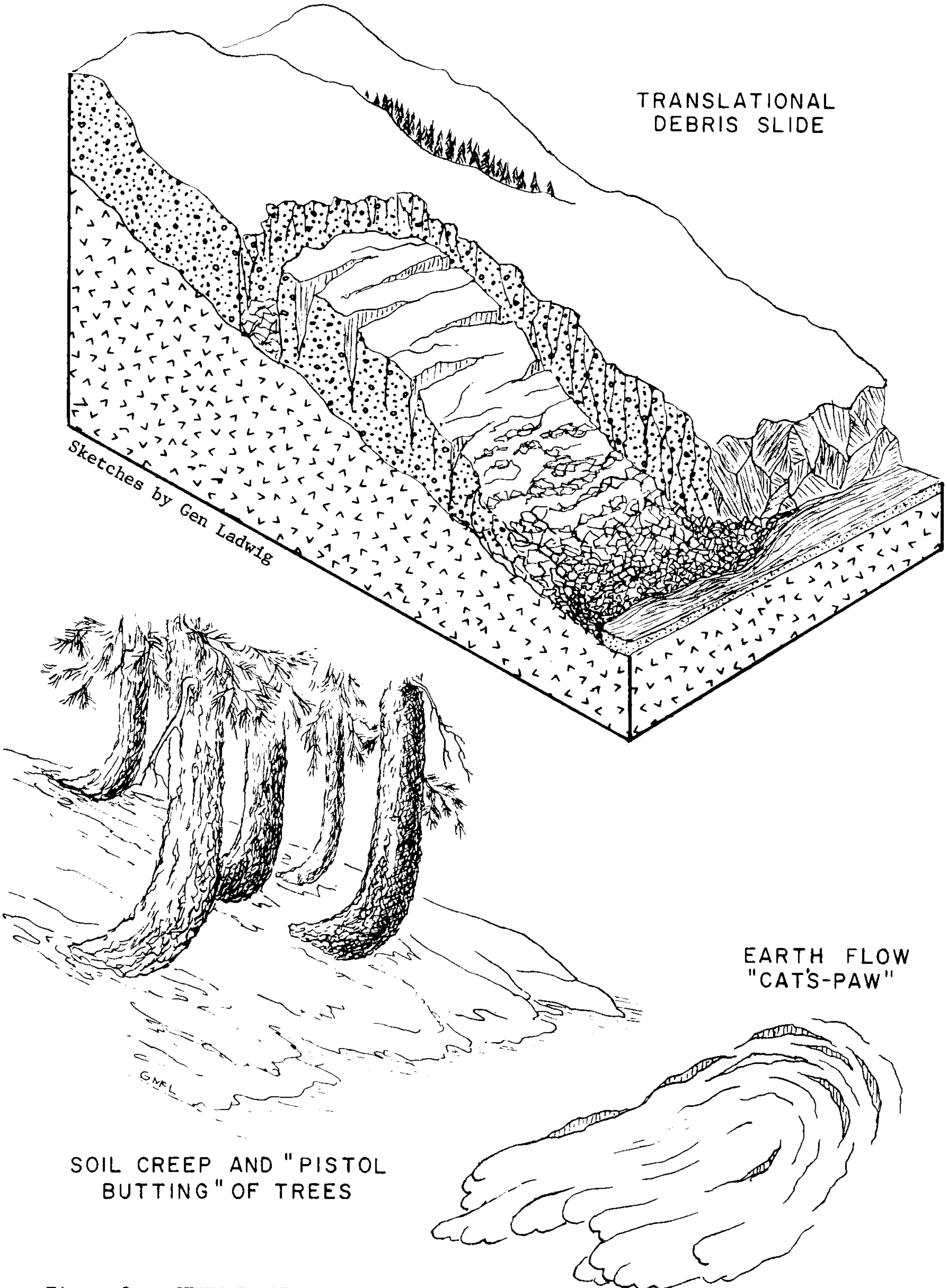

Figure 8. SKETCHES OF SOME LANDSLIDE FEATURES

Figure 9. A SMALL LANDSLIDE THAT WAS INITIATED BY A ROADCUT SHOWS SEVERE GROUND BREAKUP. RESIDENTIAL DEVELOPMENT WAS CONTEMPLATED IN THIS AREA.

Figure 10. A LANDSLIDE IN A RESIDENTIAL AREA THAT HAS DAMAGED SEVERAL BUILDINGS. NOTE THE CROWN, MAIN SCARP, AND OTHER FEATURES OF THE LANDSLIDE (SEE FIGURE 6).

Figure 11. THIS HIGHWAY, BUILT IN A HIGHLY UNSTABLE AREA, WAS SEVERELY DAMAGED BY A LANDSLIDE.

Figure 12. THIS LANDSLIDE-EARTHFLOW-MUDFLOW COMPLEX OCCURS IN AN AREA VERY SUSCEPTIBLE TO SLOPE FAILURE. NOTE THE HUMMOCKY GROUND SURFACE IN THE BACKGROUND: THIS IS COMMONLY INDICATIVE OF LANDSLIDE-PRONE AREAS.

5. References

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C. Rockfalls

1. Definitions

a. Legal definition

H.B. 1041, Part 1, 106-7-103(8) Rockfall is defined only as a kind of geologic hazard.

b. Descriptive definition

In a rockfall, relatively large fragments of rock become detached and by means of free-fall, rolling, bounding or rapid sliding, or a combination of these methods, moves rapidly down a very steep slope under the force of gravity. Rockfall can be a continuous process over a considerable period of time or a single or series of single, intermittent events. Simultaneous activation of a large mass of rock can result in a rockfall avalanche or very rapid downslope and spreading movement of a large quantity of rock material. Rockfall can be initiated by several means. Most commonly this includes exposure to multiple freeze-thaw cycles, precipitation wetting and weakening of material under blocks, seismic activity, or undercutting of cliffs by erosion or flow of weak rock material.

Rockfall is common where there are cliffs of massive broken, faulted*, or jointed* bedrock; or where steep bedrock ledges are undercut by natural processes or activities of man. A major cause of rockfall is the repeated freeze-thaw action of water. Because freezing water expands, it develops pressures capable of wedging apart contiguous blocks of massive rock. Water from rain or melting snow also plays an important role in producing rockfalls by erosion, air slaking, and weakening of soft rocks, and by percolation of rainwater through joints. These actions remove the support for the overlying blocks of rock and can eventually initiate downslope movement.

Some rock types (shales) that contain a high percentage of clay become weak and slippery when wet. The result is a reduction of static friction at the base of overlying metastable* blocks. This can cause slippage, which leads to forward rotation and results in subsequent rolling, bounding, or falling of rock fragments. Equilibrium of unstable blocks in rock exposures can be upset by shock from natural earthquakes, blasting, or movement of heavy vehicles.

Undercutting of rock slopes by stream erosion or construction excavations such as roadcuts, that remove support for overlying or overhanging rocks, can result in conditions conducive to rockfalls. Talus and talus slopes* are the usual natural result of numerous small rockfalls, and their constituent rocks have come to rest in metastable equilibrium*, especially those rocks on the surface of the talus slope. Thus, cuts into, and construction on, these slopes can interfere with the active natural rockfall process from the cliffs above, or cause increased movement or falling of the talus material below. Certain oversteepened roadcuts or other excavations are a common and dangerous areas for rockfalls.

c. Severity of problem

The combination of conditions that produce rockfalls is common in the hilly, mountainous, and tableland areas of Colorado. Rockfalls can result in almost unpredictable, nearly instantaneous losses of life and property, when man chooses to live or build structures in their paths without due consideration for the danger. Fortunately, many rockfall areas can be identified (see Criteria), and with proper recognition and engineering, much of the potential danger can be alleviated, if economic costs and benefits are justified and proper actions taken.

2. Criteria for Recognition

Many areas where rockfall may occur are relatively easy to recognize. Other areas where rockfall is a potential hazard are difficult to identify and evaluation of the degree of hazard present may be virtually impossible. Potential rockfall areas are those where relatively steep or barren cliffs rise above less steep talus or colluvial slopes. The talus slope and areas adjacent to it, occupied by larger angular randomly oriented rocks, constitute the long-term potential rockfall danger zone even though the talus may be partially overgrown with vegetation. Active rockfall areas are those showing evidence of recent falling and rock movement. Rock-displaced or damaged vegetation, fresh "tracks" of rocks rolling downslope, fresh scars on cliffs, anomalous or disoriented lichen growth on rock blocks, eyewitness accounts, and damage to fences or man-made works are some common criteria for identifying active rockfall areas. The most common difficulty with "inactive" rockfall areas is unexpected reactivation due to activities of man or exceptional natural conditions. Questionable rockfall areas should be monitored if there is the possibility that reactivation of a rockfall may take place and present a hazard to man.

3. Consequences of Improper Utilization

Improper utilization of rockfall areas is any use for which occasional, unpredictable, rolling, bounding, or falling of rocks could constitute a threat to life or property. Unless completely protected (see mitigation), buildings, some roads, pipelines, railroads, and most other works of man are in potential jeopardy in rockfall areas. A 3-ton block of sandstone, for example, rolling downhill into a typical unprotected house, probably would destroy it, whereas this same block crossing a concrete roadway probably would do relatively little damage. A major rock avalanche could, however, destroy a roadway or a whole subdivision. In the case of costly engineered structures, expenses for mitigation of rockfall danger would likely be warranted, especially if alternative locations are prohibitively expensive. Housing, on the other hand, might easily be planned elsewhere with less expense if other potential sites are available.

Areas of potential rockfall are subject to constraints similar to those of active rockfall areas. However, if activation can be prevented, such areas could be used safely, but the cost of protection from the potential hazard can in many cases exceed the economic gain from the change in land use.

4. Mitigation Procedures

The simplest and most effective way to mitigate rockfall hazard is to avoid rockfall-prone areas entirely. There is no way to completely eliminate possible damage by rockfall, and practically any human use of active rockfall areas is incompatible with the risk. However, if a rockfall area is to be used, there are several ways that the hazard can be decreased. They fall into the following general classes: 1) stabilization of rocks; 2) slowing or diverting the moving rocks; 3) and physical barriers against rock impact around vulnerable structures. Rocks can be stabilized by bolting, gunite application (cementing), outright removal of unstable rocks (scaling), cribbing, or installation of retaining walls. Movement of rocks can be slowed or diverted by rock fences, screening, channeling and dams, or by concrete barriers or covered galleries. All these measures are expensive, and seldom completely eliminate the hazard. All require periodic maintenance. Stabilization is usually only a short-term solution. Complete removal of all potentially unstable rocks is usually not possible. Dams and fences fill with rock and deteriorate structurally, and concrete barriers and galleries are relatively short-lived considering their cost.

An important factor to keep in mind is that although the place of potential rockfalls is to some degree predictable, the time of failure is not. Hence, complete avoidance of areas of potential rockfall is the most sensible mitigation measure where human lives or high property values are at stake.

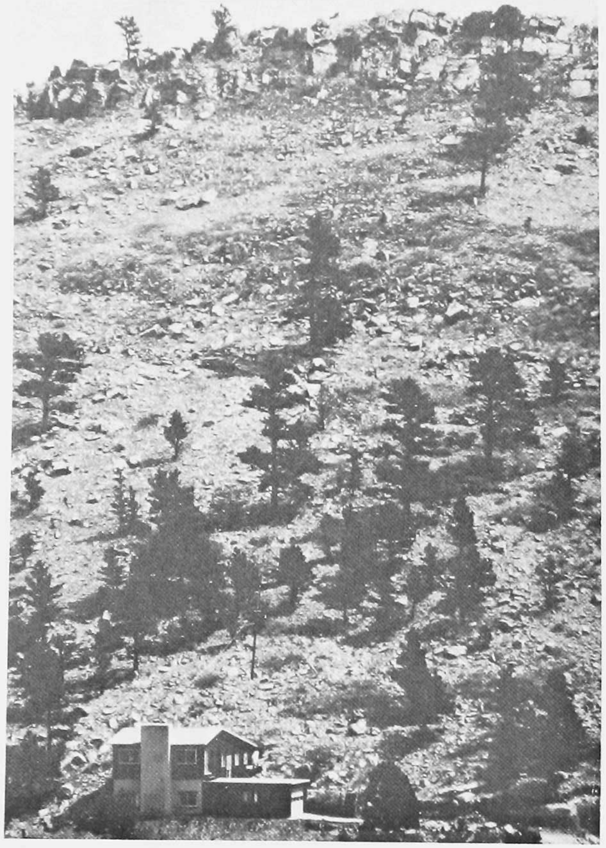

Figure 13. ROCKFALLS ARE COMMON IN AREAS LIKE THIS. NOTE THE NUMEROUS RANDOMLY ORIENTED LARGE BLOCKS OF ROCK ALL OF WHICH WERE DERIVED FROM THE CLIFFS ABOVE. ROCKFALLS ARE UNPREDICTABLE IN TIME AND EXACT LOCATION, AND IN AREAS LIKE THIS PERMANENT HUMAN HABITATION IS ALMOST ALWAYS UNSAFE.

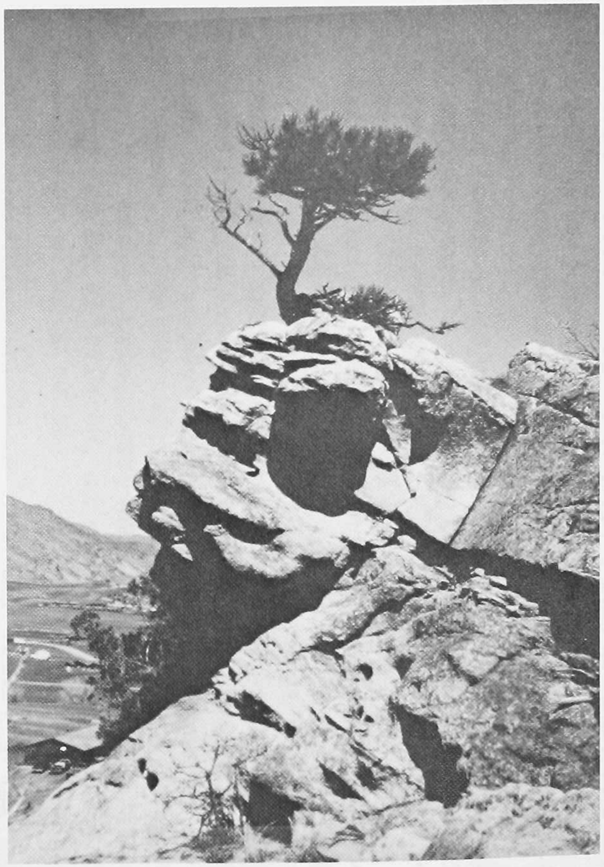

Figure 14. CLOSE-UP APPEARANCE OF A TYPICAL CLIFF THAT PRODUCE ROCKFALLS. JOINTS AND OTHER ZONES OF WEAKNESS ALLOW MASSIVE PIECES OF ROCK TO BECOME DISLODGED FROM THE CLIFF, THEN FALL, ROLL, OR BOUND DOWNHILL UNTIL THEY COME TO REST.

Figure 15. A BLOCK OF ROCK ROLLED DOWNHILL AND DAMAGED THIS HOUSE. WHAT MIGHT HAVE HAPPENED IF THE ROCK HAD BEEN LARGER OR IF IT HAD ROLLED DOWN A STEEPER SLOPE?

5. References

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D. Mudflows and Debris Fans

1. Definitions

a. Legal definition

H.B. 1041, Part 1, 106-7-103(12) defines a mudflow as follows:

> "Mudflow" means the downward movement of mud in a mountain watershed because of peculiar characteristics of extremely high sediment yield and occasional high runoff.

H.B. 1041, Part 1, 106-7-103(4) defines a debris-fan floodplain as follows:

> "Debris-fan floodplain" means a floodplain which is located at the mouth of a mountain valley tributary stream as such stream enters the valley floor.

b. Descriptive definition

A mudflow is a geologic phenomenon whereby a wet, viscous* fluid mass of fine- to coarse-grained material flows rapidly and turbulently* downslope, usually in a drainageway. This results typically from torrential rainfall or very rapid snowmelt runoff that initiates rapid erosion and transport of poorly consolidated surficial materials that have accumulated in the upper reaches of the drainage area. Included in this complex process are such strict terms as earthflow*, mudflow*, and debris flow* (A.G.I., Varnes, 1958). Very high viscosity usually results in slow earthflow movement or a combination of slow movement and internal fracturing of landslides.

Fluvial (water) transport of materials is characterized by flow of very low viscosity water and fine-grained sediments in suspension*.

Mud is composed predominantly of silt-*and clay*-sized particles, whereas the term "debris" is commonly applied to material that consists mostly of boulder-* and cobble*-sized stones mixed with displaced soil and vegetation.

Mudflows are typically recurrent events in certain drainage basins. The combination of climatic and geologic conditions that produces mudflows is a characteristic of mudflow-prone drainages. The moving mixture of water, soil, rock and vegetation most commonly has the consistency of freshly mixed concrete. As it moves down a drainageway, a mudflow may incorporate nearly anything in its path -- trees, rocks, and debris left by previous flows, that in turn increase the erosive power and destruction energy of the moving mass. In the lower reaches of the drainageway, the stream channel may be deeply eroded, overrun and flooded by the flow, or filled, and the location and configuration altered.

A debris fan is a triangular-shaped landform that forms by deposition of material at the intersection of a tributary valley with a larger valley. The material consist of stream-flood sediments and/or mudflow material and is deposited where the stream changes gradient* as it enters the larger valley.

Like the mudflows to which they are related and sometimes associated, flooding and deposition of material on debris fans are recurrent events. The cause of flooding is a cloudburst, extended rain or rapid snowmelt followed by rapid runoff into the drainageway. As the water and associated debris move downstream, they pick up and carry large amounts of material -- rocks, vegetation, soil, and at times man-made works. Farther downstream, where the drainage course is less confined by valley walls and where the stream gradient is lower, the water spreads out into multiple channels. It is this area, typically near or at the mountain front, that is called a debris-fan floodplain. At this point stream and debris velocities are lower, and there is insufficient energy to move the debris. The debris load is deposited as a mixed mass forming the debris fan, and the water progressively changes from multiple-channel flow to sheet flow.

Most mudflows in Colorado originate in drainage basins that head in high barren mountainous areas. Such areas are more susceptible to erosion by rapid runoff than are gentler, vegetated slopes. Associated debris fans and their flood plains occur mostly along mountain fronts and steep valley sides.

c. Severity of problem

Mudflows become a serious threat to man-made works and human life when man inadvertently chooses to live in active mudflow areas. Mudflows can occur with no more advance warning than a rising storm cloud or rapid increase in springtime temperature. Most Colorado mudflows occur in the spring and summer, the months of greatest snowmelt runoff and rainfall.

Many scenic mountain valley areas in Colorado are under intense development pressure. The uncertain periodicity of mud and debris flows and floods, combined with the short memories of people can result in very dangerous circumstances if these mudflow prone areas are developed.

Because debris fans and mudflows are genetically related, probelms associated with them are similar. The location of debris fans at mountain fronts makes them more accessible to people and development pressure.

2. Criteria for Recognition

Nearly all mudflow areas in Colorado are located in the lower parts of tributary streams of major streams as they enter the major valley. They are most easily recognized by occurrence of recent mudflow deposits and by the distinctive undulating topography of the fan areas. The maximum extent of these deposits and the associated fan represents the probable maximum extent of mudflows and danger. This is true even though some parts of the fan may be covered by vegetation, indicating temporary inactivity. Mudflow material is a heterogeneous mixture of mud, angular pebble- to boulder-sized or larger rocks, soil, vegetation, and coarse debris of trees. The top of a mudflow or debris fan is usually rough to undulatory when larger sized material predominates and relatively smooth if most of the material in the flow is fine grained. The color and composition of the flow material is commonly similar to the predominant bedrock near the upper reaches of the drainage basin from which it was derived. At the edge of the flow area, there is a pronounced transition from disturbed vegetation and undulatory ground surface to normal vegetation and slope conditions. The most recent mudflows are nearly devoid of vegetation. The gross appearance of the mudflow area is most commonly a mud and debris-laden stream bed terminating down valley as a fan in the depositional area. In the case of certain drainages that carry a large volume of water as well as occasional mudflows, the stream may cut its channel deeply into the fan rather than shifting channels constantly. In such cases the typical debris-fan topography is absent or not easily recognized and the mud and debris may be deposited in or near the stream occupying the major valley.

Preliminary recognition of debris fans is aided by their location near mountain fronts, their irregular surface, the multiplicity of small stream channels on their surface, their triangular (fan) shape, poorly sorted deposits typical of debris flows. Other criteria for recognition include bruised and/or partially buried standing trees. Careful inquiries may provide documentation of historic occurrences.

3. Consequences of Improper Utilization

The consequences of improper utilization of mudflow and debris-fan areas range from occasional inconvenience to human inhabitants to loss of life and total destruction of all works of man in the area affected. Few mudflow-prone areas are suitable sites for construction of permanent structures. The unpredictable nature and often rapid movement of mudflows makes even the location of semipermanent structures, such as mobile homes, extremely hazardous. Even in cases where either frequency or magnitude of mud or debris flows is such that some development is acceptable, the nature of old mudflow deposits is uncertain, and normal human activities such as excavations and lawn irrigation could upset and possibly reactivate movement of the deposits. In addition many fan areas have very high seasonal water tables that can adversely affect on-site sewage disposal and other planning considerations.

In general, the more hazardous mudflow and debris flow areas should be avoided. In less severe cases, careful mitigation measures and compatible kinds of development are recommended.

4. Mitigation Procedures

Mud and debris flows can be channelized, diverted, or in some cases dammed, although the cost may be very high relative to the amount of real protection afforded. The principal difficulties associated with engineering structures to control mudflows are related to the great volume and mass of material contained in the flow. Because most of the flow consists predominantly of heavy solid matter, structures must be physically very strong and consequently expensive. Debris basins will fill and become ineffective unless cleaned out after each flow. Channelization may be effective in some cases, but this usually diverts the mudflow into the nearest stream or adjacent property to become a problem at a different location. In many cases, the unpredictability of which channels will act as distributaries for future flows makes siting of protective structures conjectural. In less severe cases, combinations of channelization, diversion dikes, and special foundations may be acceptable. In such cases careful geologic evaluations and engineering designs will be essential.

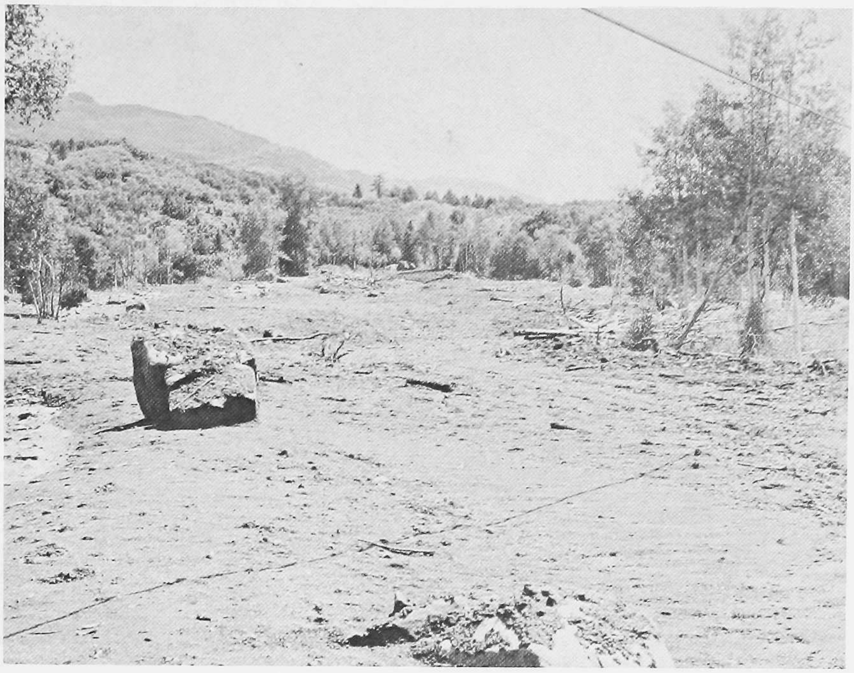

Figure 16. A MUDFLOW TRAVERSED THIS AREA AND LEFT IT COVERED WITH DEBRIS. NOTE THAT THE DEBRIS CONSISTS OF TREES AND LARGE BOULDERS, IN ADDITION TO THE ROCKS AND MUD THAT MAKE UP MOST OF THE MUDFLOW.

Figure 17. THESE TREES IN THE PATH OF A MUDFLOW SHOW THE EXTENT OF ITS ACTION. THE MAN'S HAND SHOWS THE HIGHEST LEVEL THE MUDFLOW ATTAINED DURING FLOWAGE. ALSO NOTE AVALANCHE TRACKS ON THE DISTANT SLOPE.

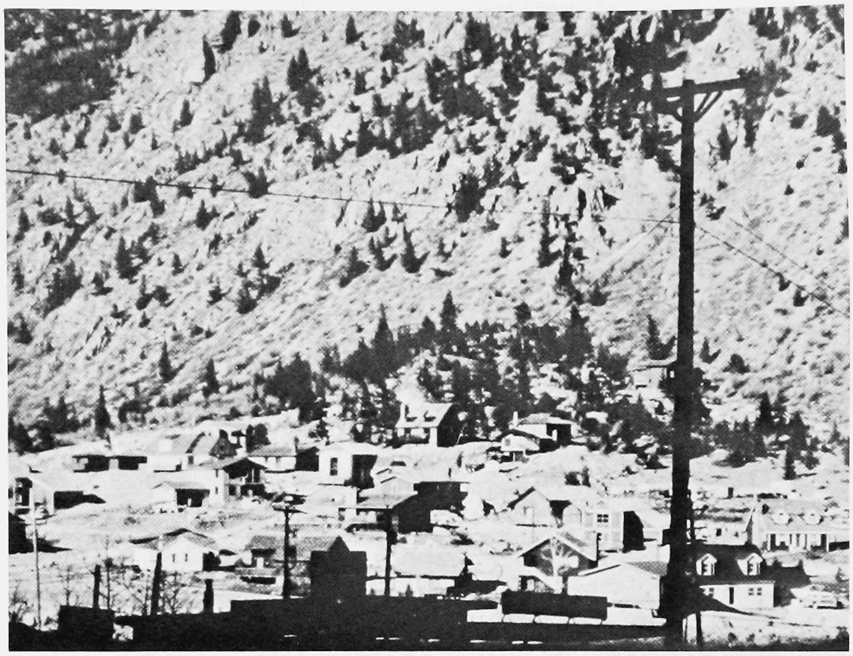

Figure 18. DEVELOPMENT ON A DEBRIS FAN (MOST OF THE DEBRIS FROM THE LATEST EPISODE OF DEPOSITION HAS BEEN REMOVED BY MAN). THE PROCESS OF DEBRIS DEPOSITION IS A RECURRENT EVENT AT MANY LOCATIONS.

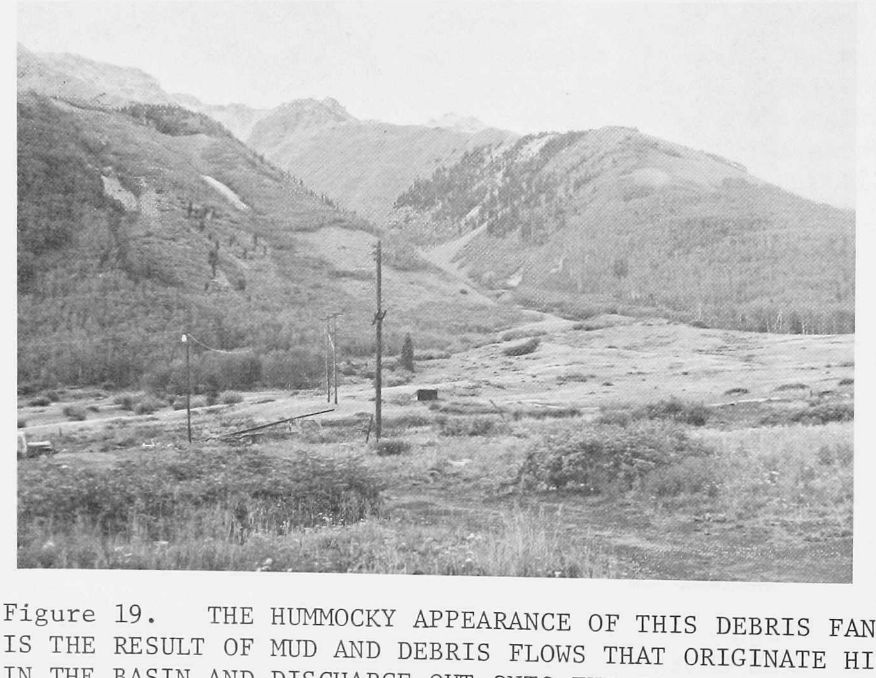

Figure 19. THE HUMMOCKY APPEARANCE OF THIS DEBRIS FAN IS THE RESULT OF MUD AND DEBRIS FLOWS THAT ORIGINATE HIGH IN THE BASIN AND DISCHARGE OUT ONTO THE FAN. NOTE THE TRIMLINE OF TREES ALONG THE GULLY, CAUSED BY A POWDER AVALANCHE.

Figure 20. THIS DEBRIS FAN IS ALSO THE COMMON RUNOUT ZONE FOR THE COALESCING AVALANCHE TRACKS SEEN AT THE APEX OF THE FAN. THIS DEBRIS FAN IS SUBJECT TO BOTH AVALANCHE AND MUD DEBRIS FLOW HAZARDS. THIS KIND OF FAN OCCURS ADJACENT TO MANY OF COLORADO'S MOUNTAIN VALLEYS, AND THESE FANS COMMONLY ARE TEMPTING SITES FOR DEVELOPMENT.

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E. Unstable or Potentially Unstable Slopes

1. Definitions

a. Legal definition

H.B. 1041, Part 1, 106-7-103(19), "Unstable or potentially unstable slope" means an area susceptible to a landslide, a mudflow, a rockfall, or accelerated creep of slope-forming materials.

b. Descriptive definition

A potentially unstable slope differs from active areas of landslide, mudflow, and rockfall in that, rather than being an ongoing process, it is an imminent one. Such slopes may be composed of natural rock, soil, artificial fill, or combinations of these materials. They are in a state of metastable* equilibrium and actual slope failure can be initiated by a change of conditions; either natural or man induced.

Unstable slopes are common under both natural and modified conditions. Natural factors contributing to instability include weathering, erosion, hydrologic changes, earthquakes, and slow natural deterioration of strength in slope-forming materials. Artificial factors include redistribution of mass by cut and fill operations, alteration of surface drainage, blasting, or heavy vehicular traffic.

Accelerated creep has not been discussed in earlier sections of these guidelines and since such a process is evidence of near-failure conditions it is especially significant in recognition of potentially unstable slopes. Creep is a normal, slow geologic process acting on nearly all slopes not composed of strong bedrock. It consists of a slow downslope movement of soils and/or weak bedrock in response to gravity. It generally does not constitute a threat to the works of man. However, when a slope approaches the failure condition, the process intensifies and can be termed accelerated creep. At this stage it becomes an engineering problem in that it exerts increased pressures on the upslope side of structures, and more importantly, it is premonitary to active sliding if further detrimental changes occur. Observations of field evidence of accelerated creep constitutes one of the best evidences of a potentially unstable slope. These include soil ripples, catsteps, and incipient tension features in the soil surface.

c. Severity of problem

Potentially unstable slopes are much more widespread than those where there is direct evidence of current or recent slope failures. They are more difficult to recognize than areas of more active mass wasting, and their recognition requires evaluation by an experienced engineering geologist. The combination of widespread occurrence and difficulty of recognition makes this hazard a very serious one to man's activities in certain types of terrain and geologic environments that are common in Colorado.

2. Criteria for Recognition

In addition to a geologic similarity of environment to nearby areas of active sliding, the criteria for recognition of unstable slopes include past occurrences of landslides, mudflows, rockfalls, and evidence of current surficial creep; displacement of roads, walkways, power lines, and buildings; tension cracks in soils; disturbance of trees and natural vegetation; and bending, tilting, or "pistol butting" of tree bases in response to movement.

3. Consequence of Improper Utilization

The consequences of improper utilization of an unstable slope range from minor damage to total destruction. The amount of financial losses incurred depends upon the value of the structures affected.

Rate of movement is a significant factor that enters into all considerations of unstable slopes. Where movement is slow, structures such as roads, walkways and power lines can be repaired or realigned and the expense may be tolerated. In cases of slow creep or sloughing of road cuts, the cost of occasional maintenance may well be less than the cost of initial corrective action.

In the cases where man's activities can initiate more rapid movement or where structures cannot tolerate movement, total destruction or complete economic loss is possible.

4. Mitigation Procedures

Unstable slopes present many potential development problems, and their identification and evaluation should be a fundamental part of any geologic study of a proposed land-use. Unstable slopes may be dealt with in a variety of ways depending upon proposed land use and the severity of the slope instability. Mitigation procedures applicable to unstable slopes are discussed in considerable detail under landslides.

a. In certain extremely hazardous, localized areas of instability, complete avoidance is probably the most advisable course of action.

b. A nonconflicting use that is compatible with the natural geologic constraints of an area is one of the most constructive methods of approaching utilization of unstable or potentially unstable slopes.

c. A controlled approach of engineered design and construction can be used in areas where instability is moderate and is amenable to remedial engineering. Continued maintenance is normally necessary for long term stability of any development placed in such an area.

Figure 21. ACCELERATED DOWNHILL CREEP OF SURFICIAL MATERIALS MAY RESULT IN SOIL RIPPLES SUCH AS THESE. THIS TYPE OF SLOPE MOVEMENT CAN BE DESTRUCTIVE TO MANY KINDS OF CONSTRUCTION IF IT IS NOT RECOGNIZED OR IF STRUCTURES ARE IMPROPERLY DESIGNED.

Figure 22. INCIPIENT SLOPE FAILURE: THIS ENTIRE AREA IS SUBJECT TO LANDSLIDES AND EARTH FLOWS LIKE THAT IN THE CENTER OF THE PICTURE. THIS CAN RESULT FROM NATURAL OR ARTIFICIAL INCREASE IN GROUND MOISTURE, LOADING BY BUILDINGS, OR STEEPENING OF NATURAL SLOPES BY EXCAVATION.

5. References

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F. Seismic Effects

1. Definitions

a. Legal definition

H.B. 1041, Part 1, 106-7-103(16), "Seismic effects" means direct and indirect effects caused by an earthquake or an underground nuclear detonation."

b. Descriptive definition

Seismic effects consist of direct and indirect effects from naturally occurring earthquakes and from those effects created directly by man or triggered by man's activities. The effects from naturally occurring earthquakes that are a hazard are well known. These include: 1) ground displacement due directly to surface faulting or other abrupt earthquake-related land level changes; 2) damage from earthquake-generated ground shaking; 3) ground failure--such as landsliding, differential soil settlement, soil liquefaction, lurching, dam failures, and ground cracking - all of which result from interaction of earthquake shaking and near-surface soil, rock and ground water; and 4) seiching* or other abnormal water wave action. Potentially hazardous seismic effects due to activities of man include those resulting from: 1) nuclear detonations; 2) injection of fluids under high pressure into the earth, which may trigger earthquakes; and 3) impoundment of large bodies of water, which has been known to increase the seismicity of an area.

The potential for damage from naturally occurring earthquakes and from nuclear detonations is in general proportional to the actual energy released (magnitude*), to the distance from the source of energy release, and to local rock and soil characteristics of a given site. The latter item (site characteristics) significantly affects the intensity* of ground shaking at a particular place.

Earthquakes may or may not be triggered by fluid injection under high pressure, or impoundment of large reservoirs. These activities of man only trigger the release of strain energy* already stored in rocks in the vicinity. Presence of such strain energy stored in rocks underlying parts of Colorado has been demonstrated at Rangely and at Rocky Mountain Arsenal where man-induced earthquakes have been triggered by fluid injection.

c. Severity of problem

Although the historical seismicity of Colorado is fairly low (Simon, 1969), the record is far too short to provide an accurate assessment of the earthquake hazard of the state. The earthquake record for Colorado includes approximately 100 years of informal "felt reports" with adequate instrumental coverage for only the past 12 years. Several lines of geologic evidence suggests that the seismicity of several parts of Colorado may be considerably higher than indicated by the scanty historical record (Scott, 1970; Matthews, 1973). Thus, a number of geologists and geophysicists believe that the present seismic risk classification (entire state in Zone 1, see figure 23.) is too low or at least not sufficiently detailed. Figure 24 is a compilation of the historical record of earthquakes in Colorado, and Figure 25 shows instrumental record that covers approximately the last 12 years. These data were furnished through the courtesy of Dr. Maurice Major and Mrs. Ruth B. Simon of the Department of Geophysics, of the Colorado School of Mines.

Two underground "plowshare" nuclear experiments (Rulison and Rio Blanco) have been conducted in Colorado under sponsorship of the Atomic Energy Commission. Additional nuclear experiments will probably be proposed, and if such experiments are successful in aiding economic recovery of energy resources, hundreds and perhaps thousands of additional nuclear detonations may be considered. High pressure fluid injection operations at three locations in Colorado appear to have triggered release of natural strain energy in the form of local earthquakes. The future will undoubtedly see much additional fluid injection related to liquid waste disposal, secondary recovery of hydrocarbons, and temporary underground storage of hydrocarbon fuels. No examples of increased seismicity related to impoundment of large surface reservoirs are known in Colorado, although such effects have been documented elsewhere. However, because of the geologic complexity and known seismicity, this factor should be evaluated in the siting of future major reservoirs in Colorado.

2. Criteria for Recognition

Colorado's seismic records are too short to serve as the only basis for evaluating future seismicity. Geologic features such as surface fault scarps that have been described by various workers as being a few hundred to a few thousand years old indicate that major earthquakes have occurred in the recent past and may occur in the foreseeable future. Because it is critical for both state and local government to have a realistic evaluation of potential earthquake hazards, the Colorado Geological Survey is proposing a 2-year study to evaluate existing seismic and geological data, to stimulate additional earthquake hazard studies, and to arrive at a better informed assessment of such hazards than is now possible. In the course of the study, the Colorado Geological Survey will seek cooperation and make full use of existing expertise and programs of academic institutions, federal agencies, and industry.

3. Consequence of Improper Utilization

A realistic assessment of the earthquake hazard is necessary in order to evaluate the risk involved for the various works of man. Under-assessment of the hazard could result in an enormous potential for losses of life and property. Conversely, over-assessment could result in unnecessary over-design and resulting excessive construction costs.

4. Mitigation Procedures

a. If active faults[1] are identified complete avoidance of man-made structures is generally recommended for areas astride the known active faults. Because faults are generally rather long, and extend to great depth, complete avoidance by facilities such as transportation corridors, and water and sewer lines, may be impossible or impractical. In such cases, special engineered designs and construction are essential.

b. Nonconflicting uses such as parkland or agriculture are recommended for areas described in "a" above and might be considered for other areas known to be highly susceptible to seismic-related ground failure.

c. Engineered design and earthquake-resistant construction are the commonly accepted solution to increased safety in development of seismic areas. Studies should be conducted to determine areas especially susceptible in indirect effects such as landsliding, liquefaction, and differential settlement. Nonconflicting uses described above may be recommended for areas determined to be potentially hazardous.

General studies of ground response* should be conducted in areas of high seismicity to determine expectable local intensity of shaking and probable predominant frequencies -- both of which are necessary input for design of earthquake-resistant construction, which is intended to resist or at least to fail-safely under the greatest expectable earthquake that the structure will experience. In order to optimize engineering design and safeguards, the design earthquake* must be carefully determined, adequate building codes and design review procedures adopted, and inspection and certification required to ensure compliance with design details.

Adequate earthquake-resistant construction is especially important in critical and high-occupancy structures such as institutional buildings, high-rise apartments, etc. Essential key public facilities such as bridges, water supply lines, fire, police, government, and hospital facilities must be designed to remain functional under the maximum expectable earthquake shaking. Certain other

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[1] A fault along which there is recurrent movement, that is usually indicated by small periodic displacements or seismic activity (A.G.I. Glossary of Geology).

engineering structures such as those housing fissionable material or other highly toxic substances should receive especially careful and conservative seismic risk analyses and designs. Dams and reservoirs whose failure would affect heavily urbanized areas should also receive careful seismic risk analyses and conservative designs.

It should also be noted that much earthquake-related damage is from indirect ground failures, thus if other geologic hazards are carefully identified and avoided, possible future seismic damage can be greatly decreased.

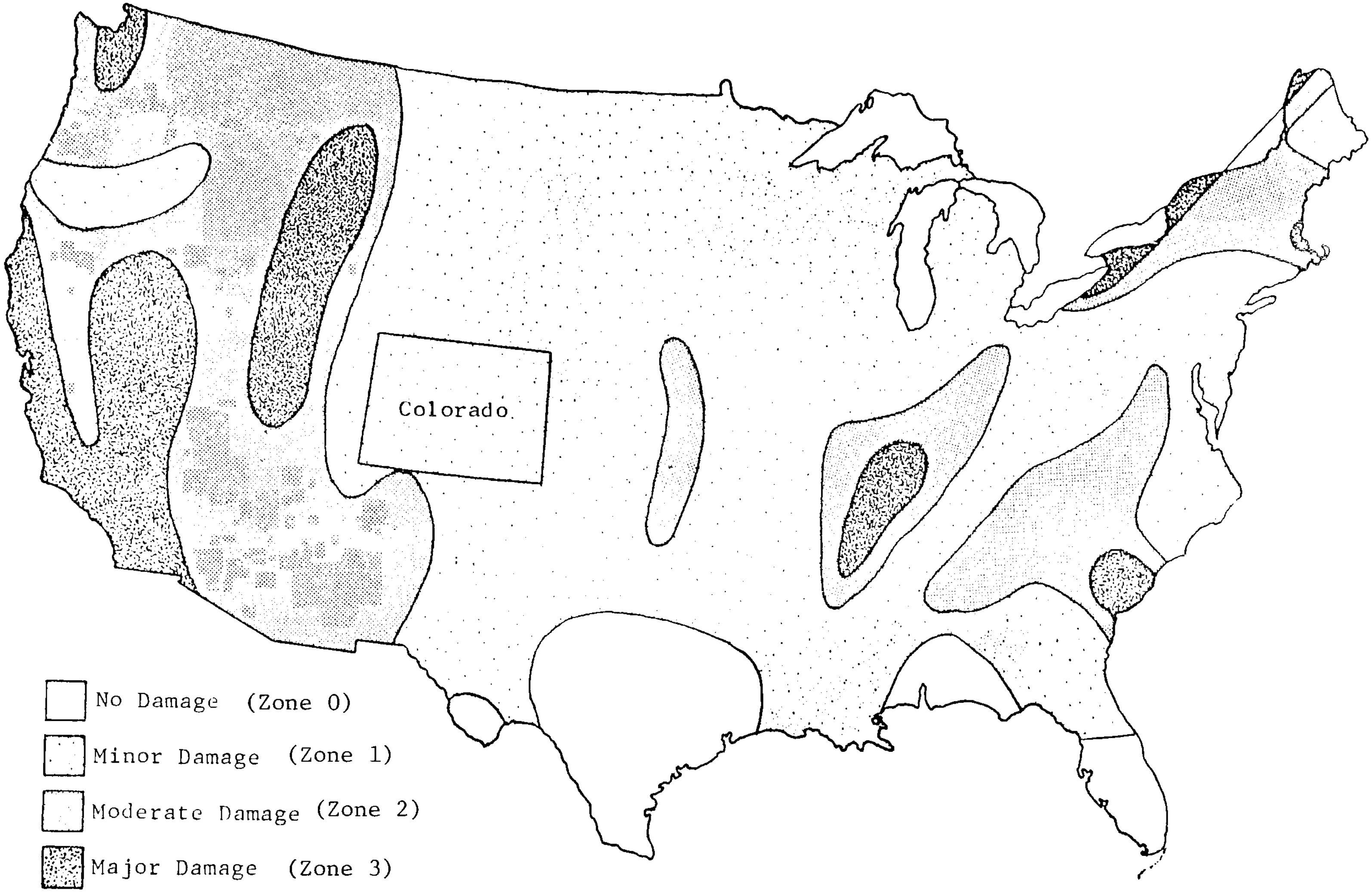
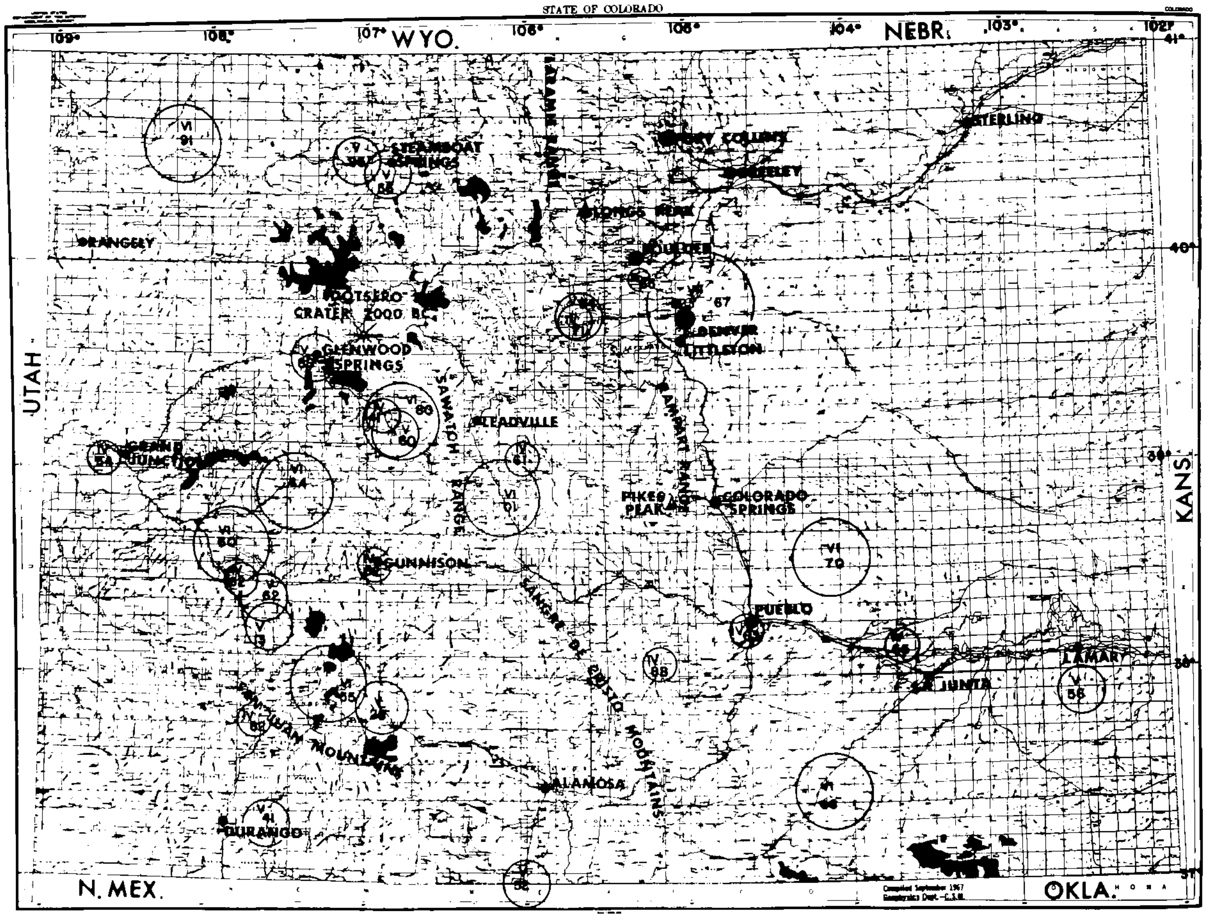
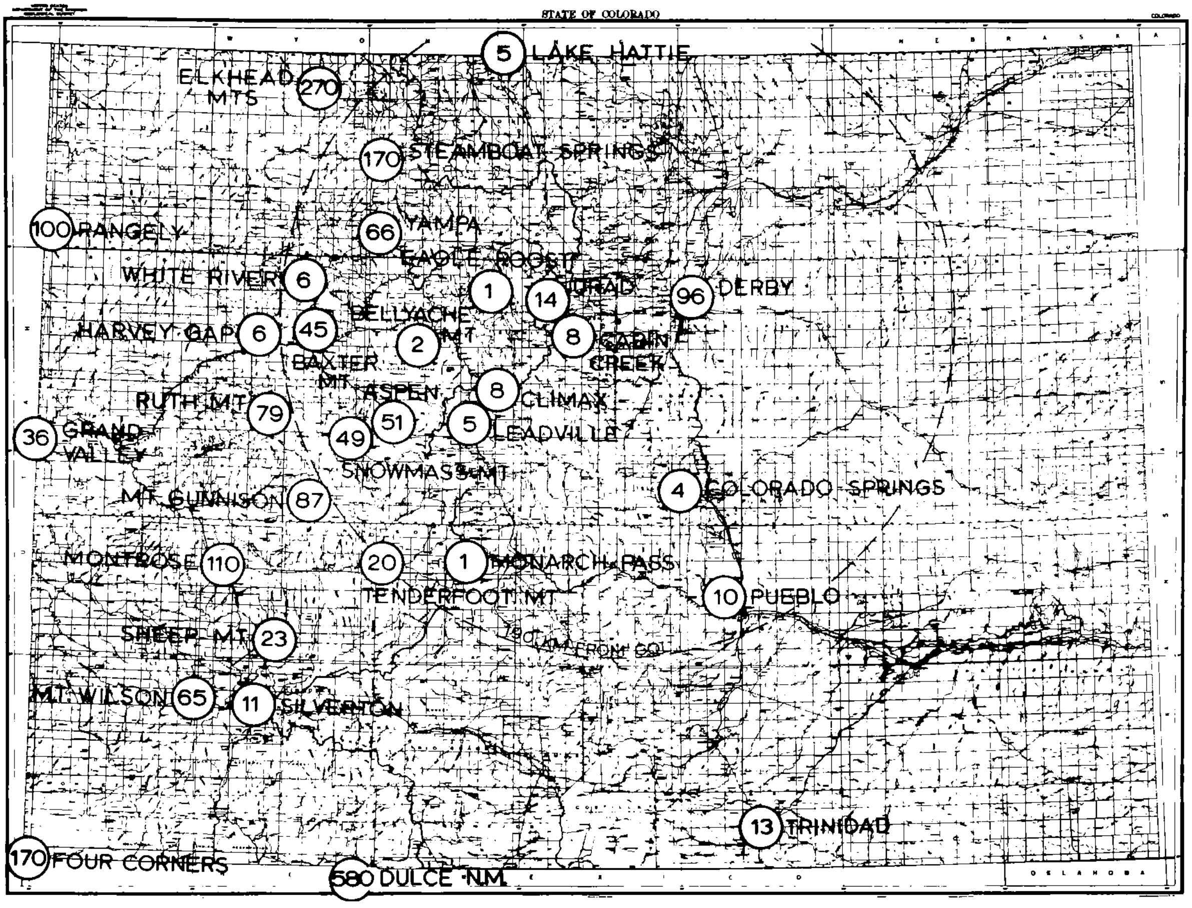


Figure 23. SEISMIC RISK MAP OF THE UNITED STATES (FROM ALGERMISSEN, 1969)



Source: Hadsell, 1968

Figure 24. HISTORICAL SEISMICITY OF COLORADO: THE KNOWN SIGNIFICANT EARTHQUAKES OF COLORADO FROM 1870 TO 1967 ARE SHOWN ABOVE. ROMAN NUMERALS AND THE RADII OF THE OPEN CIRCLES DENOTE MAXIMUM OBSERVED INTENSITY. TWO DIGIT ARABIC NUMBERS DENOTE THE YEAR OF THE EARTHQUAKE. IRREGULAR, SOLID BLACK AREAS REPRESENT POST-OLIGOCENE EXTRUSIVE VOLCANIC ROCKS.



Source: Unpublished data from Major and Simon, 1974

Figure 25. INSTRUMENTAL RECORDS OF EARTHQUAKES IN COLORADO: THE ABOVE MAP INDICATES THE PRESENT BEST ESTIMATE OF THE NUMBER OF EARTHQUAKES GREATER THAN MAGNITUDE 2.5 WHICH OCCURRED IN COLORADO BETWEEN JANUARY 1, 1966 AND AUGUST 31, 1973. MAGNITUDE 2.5 REPRESENTS THE SMALLEST SIZE EARTHQUAKE WHICH NORMALLY CAN BE FELT BY PEOPLE CLOSE TO THE LOCATION OF THE EVENT. EACH CIRCLE INDICATES A REGION WITHIN WHICH EVENTS HAVE BEEN DETECTED BY THE CECIL H. GREEN GEOPHYSICAL OBSERVATORY (GOL) IN BERGEN PARK, COLO. WITH LOCATION CONFIRMED BY DATA FROM THE UINTA BASIN OBSERVATORY (UBO) IN VERNAL, UTAH. FROM THIS DATA EVENTS MAY BE LOCATED WITH AN UNCERTAINTY OF ABOUT 10 MILES. IN THIS TIME PERIOD 14 OF THESE REGIONS HAVE HAD ONE OR MORE EVENTS OF MAGNITUDE 4.0 OR GREATER. THEY ARE BAXTER MOUNTAIN, DERBY, DULCE, FOUR CORNERS, GRAND VALLEY, LEADVILLE, MONTROSE, MOUNT GUNNISON, PUEBLO, RANGELY, RUTH MOUNTAIN, SILVERTON, STEAMBOAT SPRINGS, AND TRINIDAD. IN ADDITION DULCE AND DERBY (NORTHEAST DENVER) HAVE HAD EVENTS IN THE RANGE OF 5.2 TO 5.5 ON THE RICHTER MAGNITUDE SCALE.

5. References

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G. Radioactivity

1. Definitions

a. Legal definition

H.B. 1041: "Radioactivity means a condition related to various types of radiation emitted by natural radioactive minerals that occur in natural deposits or rock, soil, and water."

b. Descriptive definition

Radioactivity is the spontaneous emission of energy from the atoms of certain unstable isotopes* in the process of forming new isotopes. Such new isotopes may be stable, or undergo further decay until a stable isotope is finally created. The emissions of energy include alpha particles*, beta particles*, and gamma rays*, and are accompanied by the generation of heat. Each radioisotope has a characteristic combination of emissions for which the energies are unique. The type and quantities of energy emissions are dependent upon the concentration and type(s) of radioactive isotopes present. The transfer of energy from the radioactive emissions to the human body can constitute a hazard to human health.

Most naturally occurring rocks contain trace concentrations of radioactive isotopes. Within Colorado, however, several rock formations have relatively high concentrations as a result of their past geologic history. Soil,water and gases associated with these rock formations* can have correspondingly high concentrations of radioactive materials due to leaching of soluble radioactive substances and release of radioactive gas.

c. Severity of problem

Rocks containing known high levels of uranium*, thorium*, radium*, and associated radioactive isotopes are found in many areas of Colorado (see Criteria for Recognition). It is well established that radioactivity is a hazard to humans (National Academy of Science, Nov. 1972). Some exposure to radiation is unavoidable; however, elevated exposures for which no commensurate benefit can be shown should be avoided. The Colorado Department of Health and federal agencies publish guidelines and standards that can be used when evaluating a potential radioactive hazard. Natural rocks, soils, and water in Colorado may contain sufficient quantities of radioactive material that under certain conditions, can produce levels of radiation or concentrations of radioactive material higher than the current standards for exposure of the general public from radioactive sources under the control of licensed users. This elevated natural radiation background can cause health problems for those exposed either to low concentrations over extended periods or to high concentrations over short periods. The exposure can be external or internal. Alpha radiation must be inhaled or ingested to be hazardous. Beta and gamma radiation can be hazardous, either externally or internally.

2. Criteria for Recognition

Geologically, the criteria for recognition of radioactive hazards are based on the geologic setting and mineral assemblages present in crustal rocks, soil, and water. In areas where mining operations for radioactive minerals have taken place or are presently taking place, there are a variety of potential hazards in the mine dumps, tailings* piles, soils, wastewater, and the mines themselves. Any such areas may have radiation hazards that exceed the current accepted standards. Wherever these natural or man-made occurrences of radioactive material are subjected to the normal geologic processes of erosion*, transportation (including wind), mass wasting, and solution, they should be identified as potential radioactive hazards. It should be understood that mining and milling of any ore containing non-ore grade quantities of radioactive materials may also have associated hazards resulting from increased leach rates, wind transport, and gaseous release. In addition to known areas of mining and milling of radioactive material (as the primary product or as a contaminant), if geologic conditions suggest a radiation hazard, a survey should be conducted to identify and locate any possible source(s) of radiation. This type of survey should be conducted using scientifically accepted standard procedures for identification and evaluation.

For known localities of thorium and uranium, refer to "Mineral and Water Resources of Colorado", 1968, p. 132-144. Uranium and thorium minerals are found in sedimentary, metamorphic, and igneous rocks. The sandstones of the Morrison Formation have been the sources of about 85% of the uranium mined in the State. Rocks of Tertiary age also contain large quantities of uranium at several localities in Colorado; the largest deposits being in the Browns Park Formation in Moffat County. Radium is found in association with uranium minerals. Most thorium has come from the igneous veins in the Powderhorn area, Gunnison County, and the Wet Mountains area of Custer and Fremont Counties. Other deposits are known from the sedimentary rocks of Moffat County and the metamorphics of the Ralston Creek area of Jefferson County.

Local occurrences of water containing high levels of radiation have been described from the Dakota Sandstone aquifer in Pueblo County and other areas of southeastern Colorado. Surface waters are generally not a problem due to the high dilution factor from runoff.

3. Consequence of Improper Utilization

Exposure to radiation can cause a health problem. Any increase in the exposure to radiation increases the probability of causing a health problem. Excessive exposures to radioactivity can cause illness and death as well as congenital birth defect in future generations.

4. Mitigation Procedures

The only way to mitigate the effects of radiation is to avoid receiving all unnecessary exposure. This can be done by the recognition and avoidance of potentially dangerous conditions, such as land areas with elevated exposure rates or drinking water known to contain excessive amounts of radioactive material. In some cases, it may be possible to remove potential hazards by relocating mine wastes and mill tailings piles, and treating of affected water. In the case of removal, disposal of the hazardous radioactive materials should be carefully conducted in keeping with sound radiation control practice and in full recognition of geologic conditions of the site.

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H. Ground Subsidence

1. Definitions

a. Legal definition

H.B. 1041, 106-7-103(10): "Ground subsidence" means a process characterized by downward displacement of surface material caused by natural phenomena such as removal of underground fluids, natural consolidation, or dissolution of underground minerals, or by man-made phenomena such as underground mining.

b. Descriptive definition

There are several distinct types of natural processes and man's activities that may produce ground subsidence. These are discussed and explained below under separate headings. In general, the type and severity of surface subsidence is governed by the amount of material removed or compressed, the interval (depth) between the ground surface and the location of removal or compression, and the geologic conditions of a particular site. Some examples of the types of ground subsidence, and how they are affected or produced by geologic conditions are explained below.

1) Withdrawal of pore fluids, usually ground water, is a common cause of ground subsidence. Massive lowering of the ground-water table by "mining" of ground water* in a poorly consolidated aquifer results in subsidence of the ground surface. We know of no documented cases of serious subsidence from ground-water withdrawal in Colorado; however, several areas of extremely thick and extensive alluvial aquifers may have this potential if intensive future ground water development occurs. This is especially true of such large intermontane basins as the San Luis Valley, Wet Mountain Valley, North and Middle Park, and parts of the Upper Arkansas Valley. A second kind of ground subsidence results from dessication (drying up) of very wet clay deposits following lowering of the water table.

2) Hydrocompaction produces ground surface collapse from excessive wetting of certain low-density weak soils. This can occur in two general types of soil that are common in Colorado: a) wind deposited silts (loess), and b) predominantly fine-grained colluvial soils. In either case, collapse occurs from excessive wetting of previously dry, collapsible soils*. Wetting of these materials weakens the already weak or unstable soil structure, which undergoes internal collapse and densification (reduction of air voids). Densification of the weak soil column produces ground surface collapse and subsidence in the vicinity of excessive wetting. Removal of fine material by piping* is probably an additional factor

in some cases of subsidence by wetting. Such excessive wetting can occur from irrigation, broken water lines, surface ponding, or drainage diversions.

Wind-blown silt (loess) deposits cover broad areas of Colorado from the Front Range to the eastern border of the state. Predominantly fine-grained colluvial soils* are generally associated with mountainous areas where they occur as moderately sloping surfaces (colluvial wedge*) between steep valley sides and deposits of the valley floor.

3) Dissolution of soluble rock or soil materials also results in ground subsidence. This occurs in areas underlain by highly soluble rock formations -- especially gypsum ($CaSo_4 \cdot 2H_2O$), or halite ($NaCl$); and to lesser extent in limestone ($CaCO_3$) materials. Removal of earth materials by water solution leads to surface collapse. Hydrologic factors that may cause the solution and removal of material may be natural or man-induced. Natural solution is the result of the normal hydrologic processes of downward percolation of surface water and/or lateral movement of ground water within the water table (either the main ground water table* or a perched water table*). Man-induced hydrologic changes or activities can have much the same effect on soluble earth materials. Such activities include temporary or permanent stream channel changes, irrigation ditches, land irrigation, leaking or broken pipes, temporary or permanent ponding of surface waters, the mining of soluble minerals by means of forced circulation of water within the earth. Large areas of western Colorado are underlain by soluble rock materials that are subject to possible ground subsidence.

4) Removal of support by underground mining is a common cause of ground subsidence in many areas of Colorado. Extensive removal of minerals, mineral fuels, rock aggregate, and other materials results in large underground void spaces. Subsequent natural processes including fracturing, chemical changes, caving, flowage, and other related adjustments often produce surface subsidence, fissures, and tilting of the land surface above and/or adjacent to the surface projection of underground workings. Man-induced changes in the hydrology of the underground workings and/or overlying rock and soil materials can affect subsidence. In addition to actual undermined areas, special hazards are posed by certain appurtenant structures such as air shafts and various other mine workings. Additional problems in identifying and delimiting areas of potential subsidence include the presence of faults and other geologic complications, and the fact that "final mine maps" may not show the actual extent of mining. Also, discrepancies in survey ties between the mine maps and surface reference points may be sizeable. Many undermined areas have incomplete or nonexistent records.

Potential subsidence hazards from underground mine workings and shafts exist in many parts of Colorado. These include areas of past and present coal mining, "hard rock" mining areas, and undoubtedly others.

c. Severity of the problem

Geologic conditions conducive to all of the basic types of subsidence described above exist in extensive areas of Colorado. Known serious problems of mining related subsidence, hydrocompaction, and dissolution subsidence are known to occur in the state. With increased demand for mineral fuels, other mining activities and pressures for intensive urban and recreational development throughout much of the state, these problems will intensify unless recognized and wisely dealt with. These guidelines and accompanying model regulations are intended to help local governments to identify problem areas and prevent needless economic losses in the future development of the state.

2. Criteria for Recognition

The criteria for recognition of actual or potential ground subsidence conditions include a careful evaluation of all pertinent historic, geologic, and hydrologic factors of the area, and/or actual periodic measurements. Onset of actual or observed subsidence is in many cases related to changes in land use; accordingly land use changes in areas identified as having potential for subsidence should be carefully scrutinized.

a. Historic evidence includes common knowledge of long-term area residents concerning characteristics of land under present and past usages. This kind of information is important but must be carefully evaluated for accuracy and objectivity. Additional sources of information include official records of state, local, and federal agencies (especially with respect to past mining activity). Unofficial sources of information include unofficial mine maps, newspaper accounts, and published books of a historical nature.

b. Engineering geologic factors should include a complete survey of existing geologic and engineering data that are available by way of a background study. These data will identify areas in a general way known to be underlain by geologic formations containing evaporite minerals, limestone, and potentially minable mineral deposits. More detailed information such as local geologic and engineering studies for highways or dam sites may reveal specific pertinent data and how similar geologic problems were (or were not) solved in areas of actual construction.

c. Knowledge of hydrologic factors is critical for evaluating most types of ground subsidence. Because of this, it is necessary to define hydrologic conditions to identify potential subsidence areas. The hydrologic analysis should include evaluation of all available geologic data as described above, but in a hydrologic context. Additional hydrogeologic data including published information, well logs, and field information from the site of the investigation should be compiled and evaluated. Finally the impacts of possible land uses should be evaluated as they apply to lands susceptible to ground subsidence.

3. Consequences of Improper Utilization

The consequences of improper utilization of land subject to ground subsidence will generally consist of excessive economic losses. This includes high repair and maintenance costs for buildings, irrigation works, highways, utilities and other structures. This results in direct economic losses to citizens, and indirect losses through increased taxes and decreased property values.

4. Mitigation Procedures

a. In certain extremely hazardous, localized areas of ground subsidence, complete avoidance is probably the most advisable course of action. Even these lands are usually amenable to reclamation and limited types of sequential uses.

b. Nonconflicting uses are the safest, surest, and most economically acceptable utilization of many lands subject to ground subsidence. In general, agriculture, park land or other open space, and highly selective industrial uses are the most feasible.

c. Engineered design and construction is a third alternative. This should be reserved for areas of moderate hazard and in which careful engineering and geologic studies have shown the feasibility of corrective engineering to mitigate unfavorable site conditions.

Photo by R. B. Colton

Figure 26. UNDERGROUND MINING OF COAL WAS CARRIED OUT IN THIS AREA. THE GROUND SURFACE HAS SINCE PARTIALLY SUBSIDED, RESULTING IN LIMITED POTENTIAL LAND USE AND PROBABLE HAZARDS TO RESIDENTIAL DEVELOPMENT.

Figure 27. THIS HOLE IN A TRAILER PARK RESULTED FROM SURFACE COLLAPSE OVER AN AREA OF AN UNDERGROUND COAL MINE. AFTER THE INITIAL COLLAPSE, THE HOLE ENLARGED SLOWLY DURING A 24-HOUR PERIOD. NOTE UNDERGROUND UTILITIES THAT ARE SUBJECT TO DAMAGE.

Figure 28. A SURFACE DEPRESSION RESULTING FROM HYDROCOMPACTION. INITIALLY A SHALLOW EXCAVATION WAS DUG FOR A FARM POND. AFTER THE POND WAS FILLED, THE AREA BEGAN TO SUBSIDE, AND SUBSIDENCE CONTINUED FOR ABOUT TWO WEEKS UNTIL THE POND WAS DRAINED. NOTE THE COMMONPLACE AND APPARENTLY HARMLESS APPEARANCE OF THE COLLUVIAL MATERIAL IN THE FOREGROUND AND AT A DISTANCE BEHIND THE MAN.

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I. Expansive Soil and Rock

1. Definitions

a. Legal definition

H.B. 1041, 106-7-103(6): "Expansive soil and rock" means soil and rock which contains clay and which expands to a significant degree upon wetting and shrinks upon drying.

b. Descriptive definition

Sedimentary rocks* and surficial soils* are composed of gravel, sand, silt, and clay particles*. In order to visualize the relative grain sizes of these particles, an example using familiar objects can be given. Although the average diameter of a gravel particle is approximately 3/4 in., suppose an average gravel particle were the size of a basketball. An average sand particle would then be the size of a baseball and a silt particle the size of a pea. The average clay particle, however, would be almost invisible, with a pencil dot representing a large clay particle. These clay particles may consist of a variety of minerals--quartz, feldspar, gypsum, and clay minerals*. Common clay minerals in Colorado are montmorillonite, illite, and kaolinite. To return to the previous analogy, gravel, sand, silt, and some clay particles are often round, three-dimensional objects. Clay minerals, however, are generally flat, nearly two-dimensional plates just as the above-mentioned pencil dot is flat and two-dimensional.

The clay minerals in rocks and soils are responsible for their expansion, or "swell", as it is generally called. This swelling is caused by the chemical attraction of water to certain clay minerals. Layers of water molecules can be incorporated between the flat, submicroscopic clay plates. As more water is made available to the clay, more layers of water are added between the plates, and adjacent clay plates are pushed farther apart as shown in the simplified diagrammatic sketch below.

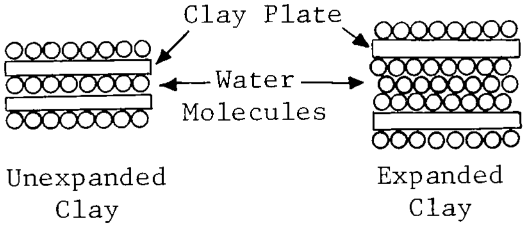

Figure 29. DIAGRAMMATIC SKETCH OF A MONTMORILLONITE CLAY PARTICLE AS IT INCORPORATES WATER WITHIN THE CLAY STRUCTURE.

This pushing apart, or swelling, occurs throughout the mass of soil that is being wetted, and causes increased volume and high swell pressures within the mass. The opposite effect, called shrinkage, may occur if a previously wet swelling clay is dried. Although no large positive pressures are exerted, shrinkage will cause a volume decrease of the soil mass. These processes of swelling and shrinkage may occur any number of times for a single soil mass. Either swell or shrinkage may cause damage to streets and buildings, but swell accounts for nearly all such damage in Colorado.

The clay mineral responsible generally for swelling is montmorillonite*, often called "bentonite*". A sample of pure montmorillonite may swell up to 15 times its original volume. However, most natural soils contain considerably less than 100 percent montmorillonite, and few swell to more than 1 1/2 times their original volume (a 50 percent volume increase)(Jones and Holtz, 1973). A small load may decrease the actual swell to less than 1 1/4 times the original volume (a 25 percent volume increase). However, a 25 percent increase can be extremely destructive because volume increases of 3 percent or more are generally considered by engineers to be potentially damaging and require specially designed foundations.

c. Severity of problem

Swelling soils are a nationwide problem, as shown by Jones and Holtz (1973):

> Each year, shrinking or swelling inflict at least \$2.3 billion in damages to houses, buildings, roads, and pipelines - more than twice the damage from floods, hurricanes, tornadoes, and earthquakes!...Over 250,000 new homes are built on expansive soils each year. 60 percent will experience only minor damage during their useful lives, but 10 percent will experience significant damage - some beyond repair...One person in 10 is affected by floods; but one in five by expansive soils.

Swelling is generally caused by expansion due to wetting of certain clay minerals in dry soils. Therefore, arid or semi-arid areas such as Colorado with seasonal changes of soil moisture experience a much higher frequency of swelling problems than eastern states which have higher rainfall and more constant soil moisture.

Rocks containing swelling clay are generally softer and less resistant to weathering and erosion* than other rocks and therefore, more often occur along the sides of mountain valleys and on the plains than in the mountains. Because the population of Colorado is also concentrated in mountain valleys and on the plains, most of the homes, schools, public and commercial buildings, and roads in the state are located in areas of potentially swelling clay. Swelling clays are, therefore, one of the most significant, widespread, costly, and least publicized geologic hazards in Colorado.

2. Criteria for Recognition

Although several visual methods for identification of potentially swelling clays exist, only a competent, professional soil engineer and engineering geologist should be relied upon to identify this potential hazard. Some warning signs for swell might include: a) soft, puffy, "popcorn" appearance of the surface soil when dry; b) surface soil that is very sticky when wet; c) open cracks (desiccation polygons) in dry surface soils; d) lack of vegetation due to heavy clay soils; e) soils that are very plastic and weak when wet but are "rock-hard" when dry.

Engineering soil tests include index tests and design tests. Rapid, simple index tests are used to determine whether more complex design tests are necessary. Some index properties that may aid in the identification of probable areas of swelling clay include Atterberg limits*, plasticity index*, grain size determination, activity ratio*, dry unit weight*, and moisture content (Asphalt Institute, 1964). The potential-volume-change test developed for the Federal Housing Administration (Lambe, 1960) has been widely used in the past but is now seldom used by Colorado soil engineers. The primary design tests for swelling soils are the consolidation-swell* test for buildings, and the California Bearing Ratio* swell test for roads (Asphalt Institute, 1964).

3. Consequences of Improper Utilization

Damage from swelling clays can affect, to some extent, virtually every type of structure in Colorado. Some structures, such as downtown Denver's skyscapers, generally have well engineered foundations that are too heavily loaded for swelling damage to occur. At the opposite extreme are public schools and single-family homes, which are generally constructed on a minimal budget and which may have under-designed lightly loaded foundations that are particularly subject to damage from soil movements. Homeowners and public agencies who assume they cannot afford more costly foundations and floor systems often incur the largest percentage of damage and costly repairs from swelling soil.

In 1970, the State of Colorado spent nearly $1/2 million to repair cracked walls, floors, ceilings, and windows caused by swelling-clay damage at a state institution near Denver. In 1972, a state college library in southern Colorado required $170,000 to repair swelling-clay damage. Recently, a 6-yr-old, $2 million building on the same campus was closed pending repairs to structural components pulled apart by swelling clay. A college building in western Colorado and a National Guard armory near Denver are among the other state buildings severely damaged in recent years by swelling clay. These examples of damage to public buildings do not include the hundreds of thousands of dollars spent annually for swelling-clay-related repairs by local school districts. One school district near Denver is attempting to circumvent these expensive repairs by spending an additional $42,000 per school on structural floors. No figures are available for the total damage to homes in Colorado from swelling clays. However, several examples are known where the cost of repairs exceeded 20 percent of the value of the house. Cracked and heaved sidewalks, patios, driveways, and garage and basement floor slabs are very common indicators of swelling clay throughout Colorado.

Highways in some areas of Colorado have required frequent and very expensive reconstruction or maintenance due to damage from swelling clay. As much as one foot of uplift from swelling clay forced the repair of two concrete lanes of interstate highway in eastern Colorado only six months after completion of paving. In the same area, additional right-of-way had to be purchased, and the highway design had to be revised to eliminate cuts and fills in order to prevent similar problems with the two remaining lanes.

4. Mitigation Procedures

a., b., Complete avoidance or nonconflicting use:

In Colorado, swelling clays are so common in urban areas that complete avoidance is generally not feasible. However, the widespread distribution of swelling soils should be recognized by all, and precautions must be taken to require engineered foundations and floor systems designs and to provide detailed maintenance instructions to owners in affected areas that are to be developed.

c. Engineered design for correction of adverse conditions:

Swelling clay damage may be minimized by combinations of four methods -- engineered foundation design, well planned site drainage, landscaping to enhance drainage, and careful interior construction details.

1) Foundation design. In areas of relatively low swell potential, spread footings* are commonly used. For slightly higher swell pressures, extended bearing walls* or pads* may be used. In areas containing moderate to highly swelling clay, drilled* pier

and grade beam foundations are used. The weight of the building is transmitted through bearing walls to horizontal grade beams. These beams rest on cylindrical, reinforced-concrete piers that concentrate the weight on a very small area below the zone* of seasonal moisture change. The foundation is thereby founded upon soil that because its moisture content remains constant throughout the year, should not experience a volume change.

With each of these special foundation designs, floating slabs* are commonly used for all on-grade floors. These interior concrete floor slabs are completely isolated by joints or void spaces from all structural components. Complete isolation from bearing walls, columns, non-bearing interior partitions, stairs, and utilities allows the slab to move freely without damaging the structural integrity of the building. In the Denver area, swelling soil below the level of the proposed floor slab is sometimes excavated to a depth of several feet and replaced by various kinds of engineered backfill.

Pre-construction chemical soil stabilization utilizing lime or organic compounds may reduce the potential of swelling soil damage more economically than the utilization of structural floors and special foundations. The chemical stabilization technique has a short history and limited use in Colorado. Where it has been used, it appears to have been successful for the period of time since application.

2) Drainage. The Federal Housing Administration recommends slopes of no less than 6 in. of vertical fall in 10 ft (12 in. in 10 ft is safer) around all buildings for drainage (Federal Housing Administrations, 1966). These slopes must drain water into drainage swales, streets, or storm sewers. Water must not be allowed to stand near foundations in areas of swelling clay due to the potential for wetting foundation soils. All downspouts and splash blocks should be placed so that roof runoff will be carried at least 4 ft from the building. In areas of heavy lawn irrigation, peripheral drains* have proven effective in preventing the formation of perched water tables* and the resulting downward seepage of surface water (Sealy, 1972). The clay-tile or perforated plastic peripheral drains completely surround the building just below the level of the floating floor slab. The drain is placed on heavy plastic film that is glued to the foundation wall and covered with washed gravel and felt paper. The drain is normally connected to a storm sewer (where legal) or at a gravel-filled utility trench so that water can be carried away from the structure.

3) Landscaping. Proper foundation design and construction will not solve all swelling-clay problems. The owner of a structure is responsible for maintaining proper drainage by careful landscaping. Backfill around foundations is often not properly

compacted. Therefore, additional soil may be required on the slope around the structure in order to compensate for settlement of the backfill. This prevents "ponding" and percolation of water around the foundation. Although not aesthetically pleasing to many persons, asphalt, concrete, or gravel-covered plastic sheeting should be placed around the entire foundation. These 4-ft or wider strips prevent surface moisture penetration and excessive desiccation cracking near the building. Grass, shrubs, and sprinkler systems should be kept a minimum of 4 to 5 ft from the foundation. Trees should be planted no nearer than 15 ft from a building. The most critical aspect of landscaping in swelling clay areas is *not to flatten a properly designed slope*.

4) Interior finishing. One of the most costly mistakes a homeowner or careless contractor can make is to defeat the design purpose of a floating floor slab. A floating garage or basement floor slab is designed to move freely. Therefore, any furring, paneling, dry wall, or interior partitions added to a basement or garage must maintain this freedom of vertical movement. Any added walls or wall coverings should be suspended from the existing walls or ceiling, and should not be attached to the floor slab. A minimum void space of 3 in. should then be provided just above the floor slab. This void space may be covered with flexible molding, or inflexible molding attached to the floor rather than the wall. Although these recommendations provide for 3 in. of upward swell of the soil beneath the floor slab, more void space may be necessary in areas of highly swelling clay.

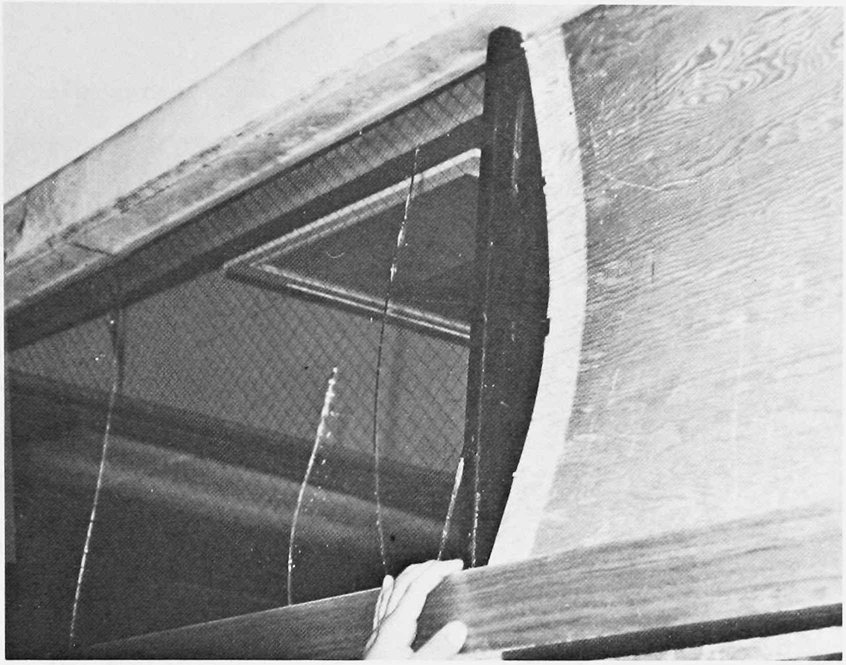

Figure 30. THE EFFECT OF EXPANSIVE SOIL ON THE INTERIOR STRUCTURE OF A BUILDING ARE DIRECTLY EVIDENT. THE PLYWOOD THAT REPLACES BROKEN GLASS LIKE THAT ON THE LEFT HAS ITSELF BEEN DEFORMED IN A FIVE-MONTH PERIOD.

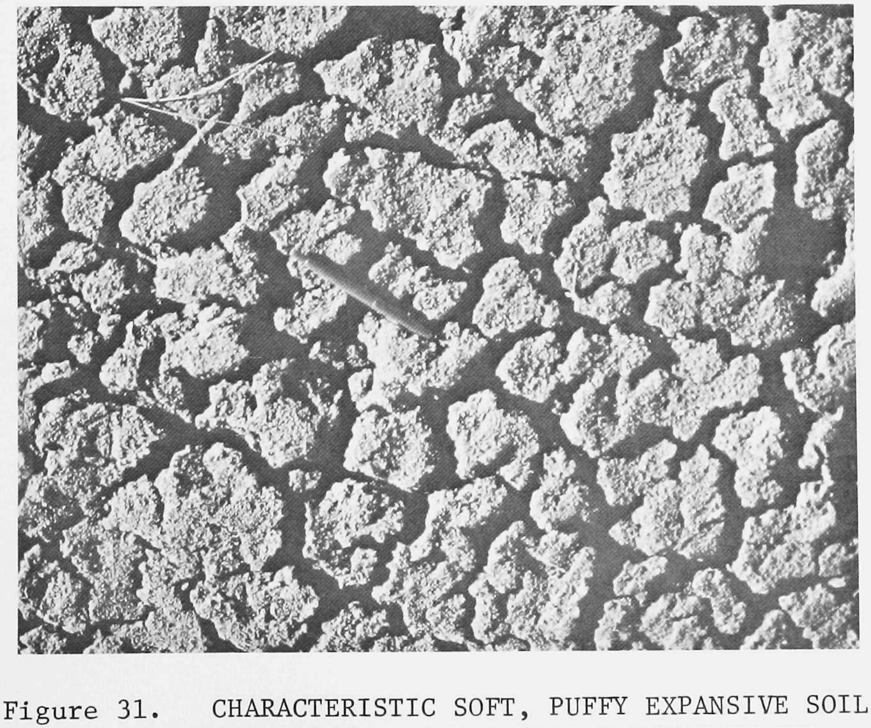

Figure 31. CHARACTERISTIC SOFT, PUFFY EXPANSIVE SOIL WITH DESICCATION CRACKS. THESE CRACKS INDICATE THE RELATIVE AMOUNT OF EXPANSION/CONTRACTION THAT OCCUR IN EXPANSIVE SOILS. NOTE PEN FOR SCALE.

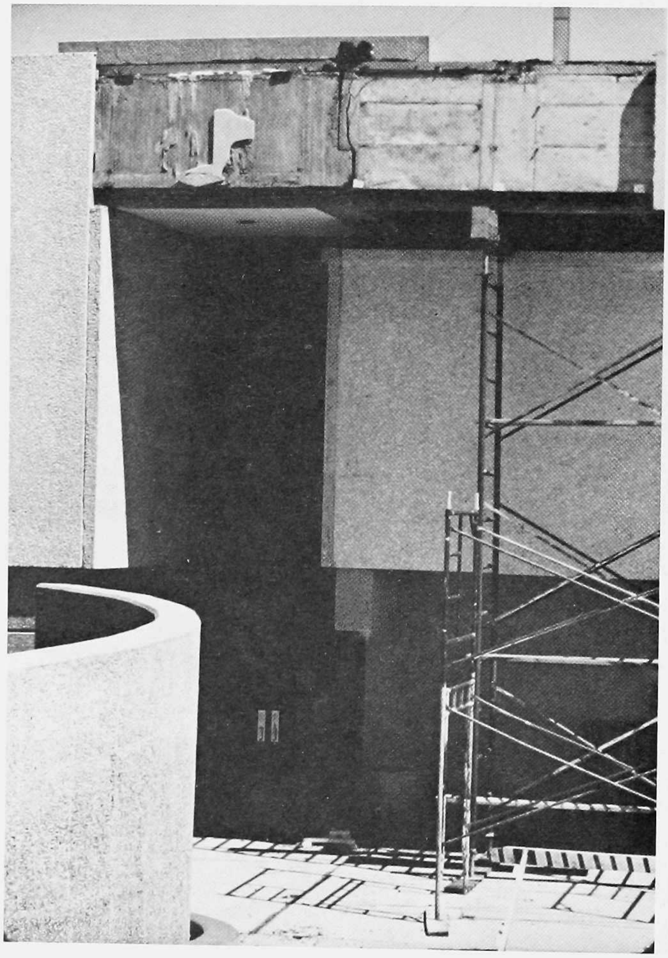

Figure 32. EXPANSION OF CLAY RESULTING FROM WETTING CAUSED THIS SERIOUS MAJOR STRUCTURAL FAILURE AT THIRD-FLOOR ROOF LEVEL. THE BUILDING WAS LOCATED IN AN AREA OF KNOWN SWELLING SOILS.

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IV. Mineral Resources Included In H.B. 1041 - Part I

Legal definition

In the 1974 Colorado House Bill 1041, a mineral is defined in 106-7-104-10 as:

> "...an inanimate constituent of the earth, in either solid, liquid or gaseous state which, when extracted from the earth, is usable in its natural form or is capable of conversion into usable form as a metal, metallic compound, a chemical, an energy source, a raw material for manufacuring, or construction material. This definition does not include surface or ground water subject to appropriation for domestic, agricultural, or industrial purposes, nor does it include geothermal resources."

In 106-7-104(11), a mineral resource area is defined as:

> "...an area in which minerals are located in sufficient concentration in veins, deposits, bodies, beds, seams, fields, pools, or otherwise, as to be capable of economic recovery. The term includes but is not limited to any area in which there has been significant mining activity in the past, there is significant mining activity in the present, mining development is planned or in progress, or mineral rights are held by mineral patent or valid mining claim with the intention of mining."

Descriptive definition

The mineral resource area (MRA) refers to a specific area from which extraction is possible under present economic conditions and with existing technology. The economic conditions at any particular time are established by interactions among market demand, access, distance to market, size and quality of the deposit, zoning, and governmental regulations. However, by including areas of past mining and areas where development is planned, a condition of "future commerciality" is implied. To best handle this problem and to conform with federal mineral-land classifications, these guidelines will be based on the terminology and definitions set forth by the U. S. Bureau of Mines.

The "mineral resource area" or MRA, as defined above, is effectively synonymous with a "mineral reserve," which is defined by the USBM as follows:

> "...the quantity of mineral which is calculated to lie within given boundaries. It is described as total (gross), workable, or probable working, depending on the application

of certain arbitrary limits in respect of deposit thickness, depth, quality, geological conditions, and contemporary economic factors. Proved, probable, and possible reserves are other terms used in general mining practice."

The MRA therefore includes 1) proved reserves, 2) probable reserves, and 3) possible reserves. The USBM definitions for those reserves and ores appear in the glossary.

Proved reserves

Proved reserves are known ore deposits that have been sampled, tested, and evaluated and whose volume and quality have been established. Proved reserves are those being mined at the present time in most districts. Proved reserves probably have been outlined in areas of immediate interest to some extractors. The renewed interest and exploration in areas of past mining could enable the conversion to proved reserves of some probable reserves that were noneconomic during the period of past mining.

Probable reserves

Probable reserves are those lying near the developed or proved reserves and that could reasonably be considered proved. Although theoretical and workable* tonnages can be calculated and grades assigned, the deposits are not immediately available for mining. The proximity to proved reserves and current excavations, impending availability, and grade-tonnage assignments definitely imply that the deposits are or soon will be economically workable.

Probable reserves may thus exist now in areas of past mining as unmined low-grade ore noneconomic at the time of the first mining. Such reserves may also include waste materials or tailings now minable for primary or by-product minerals and metals.

The probable reserves that exist in areas of present mining have more than likely been accounted for in the extractor's operations, total acreage, leases, and long-term production schedule.

In areas where development is being planned, a general idea of the extent or probable reserves has been noted as a part of the general exploration, sampling, and testing programs.

Possible reserves

The consideration for and identification of areas of possible reserves should be based primarily on two aspects, as stated in the definition:

1) Favorable lithological, mineralogical and structural relationships and geophysical anomalies--Careful analysis of prominent geologic trends, supplemented with past experience and standard geologic principles, helps the geologist to broadly define areas in which detailed exploration will outline workable mineral deposits.

2) Extent of ore bodies already developed--This aspect is intimately associated with 1) above in that the same geologic conditions responsible for an ore deposit in one locality may sometimes validly be projected into a promising nearby area. In some cases these geologic conditions may, however be highly localized , and any projection beyond the area would be unproductive.

In areas of past mining activities, possible ores may be present as undiscovered, unanticipated deposits or as anticipated deposits that were unevaluated or noneconomic at the time of mining. With renewed interest in some of the old mining districts, possible reserves may be discovered and reclassified to probable reserves. In areas of present mining, possible ores are reasonably thought to exist, but their grade and tonnage cannot be practicably determined.

Qualifications

Several important ideas must be taken into account in the identification and designation of either the proved, probable, or possible MRA's. In 106-7-202(1)(a), it is stated:

> "Mineral resource areas designated as areas of state interest shall be protected and administered in such a manner as to permit the extraction and exploration of minerals therefrom, unless extraction and exploration would cause significant danger to public health and safety. If the local government having jurisdiction, after weighing sufficient technical or other evidence, finds that the economic value of the minerals present therein is less than the value of another existing or requested use, such other use should be given preference; however, other uses which would not interfere with the extraction and exploration of minerals may be permitted in such areas of state interest."

In order to delineate future mineral reserves, extensive exploration must be done in a skilled and conscientious manner. Exploration should be encouraged not only in and near old mining districts but also in those relatively unexplored national forests designated as "wilderness areas," under the conditions of the Wilderness Act of 1964 (Public Law 88-577). This law states that no new mining patents will be issued for claims within wilderness areas after December 31, 1983. After that date, prospecting will be permitted for the purpose of gathering scientific information, but stringent restraints should preclude most activity. Mining can be initiated after the deadline if the respective patent was issued before the deadline.

Another facet of exploration is that mineral deposits can be converted or reclassified. The reclassification of one type of MRA to another, e.g. a probable MRA converted to a proved MRA, depends upon the availability of the land for further mineral exploration and upon the prevailing economic and political circumstances.

Factors such as access to the deposit, plant and mill sites, water availability, storage, waste disposal areas, and others pertaining to surface-area requirements are also matters of concern in determining the viability of a working mineral deposit. Sufficient area for these activities must be included in the MRA designation.

Although HB 1041 implies the present commerciality of mineral deposits, definitions must be realistic in terms of future and marginal commerciality. Some proved and probable reserves may have been accurately outlined, but solely because of legal or political circumstances, the ore cannot be mined at the present time. Some probable and even possible reserves may have been outlined but are only marginally economic because of fluctuating market conditions, limited technology, or lower grade. Such areas must be given serious consideration in light of our increasing demand for minerals, the critical shortages of certain minerals, and the long-term benefits to the counties and the state.

One concept inherent to most geologic exploration programs and to the designation of any MRA is that the full extent of a mineral deposit may never be known until it is completely mined out due to the state of the art and industry, market prices and demand, and the extremely variable nature of mineral deposits.

Due to the very nature of geology and to the great variability and complexity of geological processes, minerals may occur in many different forms and places, some of which are listed above in the legal citation. Most minerals originate through igneous*, metamorphic*, or sedimentary* actions or through some combination of these processes--a kind of geologic "recycling" of rock materials. Colorado is fortunate to possess a wide variety of minerals and earth materials, many of which have been extensively mined in the past.

The state's mineral resources can be grouped into 3 categories--metallics, nonmetallics, and mineral fuels. Metallics include the precious- and base-metal* ores, ferrous-metal ores, and metals of somewhat lesser importance derived primarily as by-products of processing. A wide range of construction aggregates, building stones, clay, and industrial minerals along with several evaporites* and gases comprise the nonmetallics group. The mineral fuels consist of coal, oil, natural gas, oil shale, uranium, and various asphaltic materials. Tables 1, 2, and 3 show the metals and commodities that are or have been produced commercially in the state and the 1973 and cumulative production figures.

Severity of the problem

The severity of the mineral resource problem stems from our nation's enormous demand for and consumption of natural resources in recent decades. Consumption has accelerated so rapidly that some areas now face critical shortages of important commodities. But just as important as the need for more mineral products is the need to care for our land, water, and air. In the past, all groups, whether industry, governmental, or environmental, have failed to recognize several basic aspects of the problem. First, all minerals are the result of geologic processes, and economic concentrations of minerals are limited. Folding, faulting, uplift, and volcanism play a dual role in forming the spectacularly scenic areas of our mountains as well as providing the channelways through which mineral deposits, especially the metallic ores, are emplaced. Some of our valuable mineral areas thus coincide with our scenic and recreationally desirable areas because both are the result of the same geological processes. Second, our minerals can be mined only where they occur naturally. Third, minerals play important roles in most aspects of our life style--construction, manufacturing, agriculture, transportation, communications, food processing, medicine, and recreation. Fourth, waste materials from mining operations often can be utilizied as possible sources of minor by-product minerals and as fill or landscaping material in the reclamation of mined lands. Fifth, mined lands can and must be reclaimed, revegetated, and returned to a condition that will benefit all citizens.

The conflicts that have arisen over priorities have resulted in lobbying battles, weak or no legislation, and scores of court cases. All but a few citizens eventually suffer from such actions, and in the end, valuable mineral deposits either are lost or are vigorously extracted at the expense of the land. Although Colorado has taken positive steps to lessen the problems of mining, reclamation, and overall land use, the most efficient solution remains to be found.

Table 1. METALLIC, NONMETALLIC AND MINERAL FUEL RESOURCES OF COLORADO

METALLICS

Precious- and base-metals:

- Gold
- Silver
- Copper
- Lead
- Zinc

Ferrous metals:

- Iron
- Manganese
- Molybdenum
- Tungsten
- Vanadium

Miscellaneous:

- Beryllium
- Colbalt
- Nickel
- Niobium
- Tantalum
- Thorium*
- Titanium
- Uranium*
- Zirconium
- Rare earths*

Smelter by-products:

- Antimony
- Arsenic
- Bismuth
- Cadmium
- Selenium
- Tellurium
- Tin

MINERAL FUELS AND ASSOCIATED RESOURCES

- Coal
- Oil
- Natural Gas
- Oil shale
- Rock asphalt
- Asphaltic bitumens
- Uranium
- Peat

NONMETALLICS

Construction material (including aggregate and building stones):

- Gravel*
- Sand
- Limestone*
- Dolomite*
- Sandstone
- Alabaster
- Travertine
- Quartzite*
- Gneiss
- Marble
- Granite
- Volcanic rock

Lighweight aggregate:

- Perlite*
- Pumice*
- Scoria*
- Welded tuff*
- Vermiculite*
- Shale
- Blast-furnace slag
- Fly ash, cinders

Clay:

- Fire clay
- Brick and tile clay
- Pottery clay
- Refactory* clay
- Bentonite*

Industrial minerals:

- Abrasives
- Barite
- Feldspar
- Fluorite*
- Frac sand*
- Gemstones
- Graphite
- Gypsum/Anhydrite
- Kaolin*
- Limestone
- Mica
- Pegmatite minerals*
- Peat
- Perlite
- Pyrite
- Quartz
- Silica sand
- Sulfur
- Vermiculite
- Volcanic ash

Evaporites:

- Salt (halite)
- Potash minerals
- Gypsum

Gases:

- Helium
- Carbon dioxide

Table 2. VALUE OF PRODUCTION OF METALS, NONMETALLICS AND MINERAL FUELS IN COLORADO*

Metallics	1973 Production $	Cumulative Production $
Molybdenum	$ 96,654,249	$1,633,494,370
Zinc	15,890,102	535,718,983
Silver	8,764,824	643,491,318
Lead	7,596,107	407,419,390
Uranium	7,508,996	995,966,142
Tungsten	6,931,270	91,437,648
Gold	6,177,731	937,226,540
Vanadium	4,874,688	250,117,479
Copper	3,312,705	142,999,979
Iron	1,058,574	17,584,862
Tin	490,131	2,799,139
Cadmium	396,186	NA
Total Metallic Mineral Production	$159,655,563	
Nonmetallics		
Sand & Gravel	$ 48,137,660	$ 429,000,295
Cement	10,778,594	285,897,049
Limestone	7,446,203	81,146,908[1]
Fluorspar	4,061,117	54,887,368
Clay	2,644,909	32,590,533
Stone	1,567,130	60,377,483
Dolomite	846,787	81,146,908[1]
Volcanic Scoria	707,698	3,026,593[2]
Gypsum	292,361	4,766,435[3]
Peat	148,773	1,751,309
Perlite	65,262	3,150,613[4]
Oil Shale	8,750	754,083
Feldspar	196	NA
Misc. Nonmetallics	4,107,999	--
Total Nonmetallic Mineral Production	$ 80,813,439	
Mineral Fuels		
Crude Oil	$274,424,740	$3,007,318,843
Gas	61,111,485	419,806,827
Coal	50,731,909	2,453,275,989
Total Mineral Fuel Production	$386,268,134	$5,880,401,659
TOTAL STATE MINERAL PRODUCTION	$626,747,136	

Table 2. (cont.)

Mineral refined or processed but not necessarily produced in the State included lanthanum, neodymium, yttrium, uranium, molybdenum, base metals, perlite and clay and the State's mineral economy was increased in the amount of $49,599,956 by this processing. This gives the State a gross mineral value produced and/or processed of $676,347,092.

Additional gas production is shown in the tables below but no dollar value has been computed for this production.

Hydrocarbon gas (million cubic feet)	138,665,484	2,725,418,892
Carbon dioxide (million cubic feet)	5,126,250	636,153,405
Helium (million cubic feet)		53,000

[1] Total limestone and dolomite

[2] Scoria, ash, pumice

[3] Gypsum, alabaster

[4] Perlite, vermiculite

*Figures shown, because of the early date of compilation, cannot be accepted as final; they are intended as an indication of the production and cannot be used for tax or other evaluation purposes.

Source of Information: Colorado Division of Mines.

Table 3. VALUE OF MINERAL PRODUCTION IN COLORADO COUNTIES IN 1973[†]

County	1973 Production $	County	1973 Production $
Adams	27,886,150	Lake	101,813,125
Alamosa	84,855	La Plata	13,783,700
Arapahoe	27,861,345	Larimer	9,716,110
Archuleta	384,335	Las Animas	5,225,093
Baca	2,215,655	Lincoln	99,515
Bent	380,662	Logan	11,835,414
Boulder	4,203,568	Mesa	3,344,866
Chaffee	1,236,348	Mineral	5,218,630
Cheyenne	3,872,527	Moffat	21,658,064
Clear Creek	10,037,193	Montezuma	2,094,956
Conejos	142,269	Montrose	3,209,593
Costilla	609,754	Morgan	5,388,842
Crowley	--	Otero	213,869
Custer	61,887	Ouray	5,145,141
Delta	376,838	Park	129,750
Denver	1,200,388	Phillips	--
Dolores	3,777,696	Pitkin	8,419,939
Douglas	3,612,681	Prowers	206,021
Eagle	5,722,887	Pueblo	2,938,059
Elbert	1,304,095	Rio Blanco	167,822,960
El Paso	8,898,866	Rio Grande	31,447
Fremont	10,502,097	Routt	21,982,065
Garfield	2,149,848	Saguache	9,723
Gilpin	6,318	San Juan	9,532,611
Grand	104,048	San Miguel	17,044,292
Gunnison	8,538,580	Sedgwick	--
Hinsdale	--	Summit	2,010,115
Huerfano	170,413	Teller	156,910
Jackson	9,356,188	Washington	19,588,286
Jefferson	17,310,410	Weld	29,295,164
Kiowa	6,549,381	Yuma	--
Kit Carson	110,856		

Source of Information: Summary of mineral industry activities in Colorado 1973: Colorado Division of Mines.

[†] Includes metals, nonmetals, fuels

Consequences of improper use

As implied above, the misuse of mineral resources most obviously results in shortages and losses of certain commodities and in scarred landscape. Urban and suburban development clash vehemently with the mining of such material as sand and gravel because most large cities are located on major rivers or streams, and where there is a major stream, there are usually commercial aggregates. In rapidly developing areas, agricultural and other sectors also become involved in the land-use conflicts.

Due to dwindling supplies and urban pressures, extractors are forced to explore, mine, and process farther from the principal markets. The increased costs for these operations, especially the longer transport distances, are paid for by the consumer. Longer haulage routes also involve problems in road maintenance and truck traffic through residential districts.

A long-recognized problem in the mountains is that of exposed mine tailings* from old operations. These tailings can represent sources of both sediment and chemical pollution of surface waters as well as areas of low slope stability--a potential hazard to downslope inhabitants in new mountain communities. Those tailings containing appreciable amounts of radioactive material are especially hazardous because winds and water can transport the particles over many miles.

Air, ground-water, and surface-water pollution may result from various types of mining operations if governmental regulations and proper reclamation guidelines are not followed.

Improper mining and reclamation may also cause changes in the local water table level, changes in flood frequency along certain streams, and caving, sinking, collapse, or other types of mined-land subsidence. Inadequate technology and improper processing could create more wastes than normal, both in actual volume and in loss of usable material.

Mitigating procedures

The earnest efforts of government, industry, science, and the citizenry will help to alleviate some of the problems of mineral resource management and land use. First is the need for effective federal, state, county, and municipal regulations. Colorado is in a fortunate position to expand such existing laws as SB 35, HB 1529, and HB 1041 in a way that zoning and land-use planning will retain certain vital mineral deposits either by mineral conservation or extraction districts or by nonconflicting uses. Theoretically, nonconflicting and interim land uses will permit resource mining at some time in the future; however, current public opinions and rulings would indicate that future mining in such areas is not likely to proceed.

Second, there is a need for more detailed studies that will inventory all mining operations in the state; tabulate past, current, and projected production, reserves, demand, and water requirements; outline potential new uses; and map statewide the occurrences of the important mineral commodities.

Third, cooperative projects among industrial, technical, and governmental persons could develop better, more efficient methods of mining, processing, and transporting of minerals and products as well as new techniques for the total utilization and recycling of wastes, economic upgrading of ores, and reclamation of mined areas.

Fourth is the need for a public awareness program that will stress 1) the vital importance of minerals and mineral products in our society, 2) the social and economic benefits of multiple or sequential land use, 3) the historical, educational, and cultural value of some of Colorado's mineral lands and 4) the strategic importance of certain commodities such as gold, silver, molybdenum, tin, aluminum, uranium, coal, and oil shale. These and other materials may have tremendous importance in the event of regional, national, and international emergencies.

MINERAL RESOURCES INCLUDED IN H.B. 1041 - PART 2

Purpose

The purpose of this section is to present a classification of mineral deposits that will be useful in identifying MRA's, to outline the important factors in the exploration, testing, and evaluation of mineral deposits, and to present criteria that determine the viability of some mineral deposits.

Classification of Mineral Deposits

Mineral deposits can be classified in various ways--by mineralogy, occurrence, mode of emplacement, or configuration. This report will use a classification based on both mode of emplacement and configuration. The first group consists of bedded and tabular deposits, which include primarily sedimentary rocks that occur mostly in the eastern plains and western plateau regions of the state. The second group consists of vein-lode and disseminated mineral deposits, which are primarily metallic ores* and related nonmetallics associated with the emplacement and crystallization of molten rock masses and with the metamorphism of rock bodies under various pressures and temperatures. These deposits occur mainly in a southwesterly trending belt through the mountains of central and western Colorado.

Bedded and Tabular Deposits

Bedded and tabular deposits include basically 4 classes of rocks and minerals: 1) aggregates and dimension stone, 2) mineral fuels, 3) clays, and 4) evaporites. Other miscellaneous bedded materials used for various industrial purposes include placer deposits (sources of gold, gemstone, abrasives, and heavy minerals), volcanic ash and glass, quartz, and silica sand.

Colorado aggregates were formed by sedimentary, igneous, and metamorphic processes and occur in the valley-fill and terrace deposits along most prominent streams in high isolated remnants of old stream channels, and in alluvial fans in mountain valleys and along mountain fronts. Quarried rock used as aggregate occurs in the igneous and metamorphic terrains of the mountain ranges, in certain upturned sedimentary beds of the hogback belts bordering the mountains, and on small isolated remnants of volcanic rocks in the plains area. Rhyolite (volcanic) and quartzite (metamorphic) are two other rock types that show potential for use as aggregate, especially in the central Front Range area. Lightweight aggregates are produced by the heating and expansion of shale or volcanic ash and glass. Such man-made materials as blast-furnace slag, ash, and cinders are also processed.

Granite, limestone, marble, and sandstone are the principal rock types quarried for dimension stone (monumental and building stone). Most of the dimension stone quarries of Colorado lie in the granitic and sedimentary terrains of the Front Range counties and in Fremont and Chaffee Counties. The more notable quarries include the famous marble quarries in Gunnison County and the Boulder-Larimer County sandstone quarries. Rhyolite, basalt, alabaster, and travertine have also been quarried at several localities.

The principal mineral fuels under consideration are coal and oil shale, both of which are abundant in Colorado and are expected to play important roles in the state's and the nation's energy economy. In addition to the many active coal fields, coal-bearing sedimentary rocks underlie extensive areas in the western quarter of the State. The extensive Piceance Creek basin contains some of the richest and thickest oil shales in the world. Uranium, which can be considered in some respects as a mineral fuel, occurs in numerous localities within the Mineral Belt and is also found associated with vanadium in the Uravan district of southwestern Colorado.

The high-quality clays that occur in several sedimentary formations in the State were deposited in lakes, bays, and shallow inland seas. In some areas, volcanic ash was deposited and later altered to bentonite, an expansive variety of clay. Minable clays are found in a narrow belt along the Front Range, in areas south of the Arkansas River in south-central and southeastern Colorado, and in the Gunnison River valley in western Colorado.

The bedded evaporite deposits include halite or common salt (sodium chloride), several potassium minerals, and gypsum (calcium sulfate). These minerals were formed by precipitation when natural saline waters evaporated in lagoons, bays, and lakes. Although their areal extent is not entirely known, they do exist at depth in the Paradox basin of southwestern Colorado. The Eagle Valley Evaporite, which consists mainly of gypsum, anhydrite, limestone, dolomite, and halite, has been mapped in west-central Colorado. Two of the important criteria for determining the commerciality of these evaporites are 1) the method of mining (room-and-pillar or solution), and 2) depth of the beds below the ground surface.

Listed on the following pages are the important geologic and industrial features, and physical and chemical properties that should be investigated for the evaluation of the bedded mineral deposits discussed above.

Table 4. GEOLOGIC, INDUSTRIAL, PHYSICAL, AND CHEMICAL PROPERTIES IMPORTANT FOR EVALUATION OF BEDDED AND TABULAR MINERAL DEPOSITS

Aggregate/Dimension stone (modified after Currier, 1960)

Aggregates

Sand
Gravel
Limestone
Dolomite
Quartzite
Gneiss
Granite
Basalt
Rhyolite

Dimension Stone

Sandstone
Limestone
Alabaster
Travertine
Granite
Rhyolite
Basalt
Marble

Geologic features:

- Distribution of formation
- Stratigraphic position
- Thickness of formation and of workable part
- Lithologic classification and description
- Petrographic description and classification
- Mode of origin and occurrence
- Contact relations to other formations
- Texture and fabric
- Major structural elements: attitudes, folds
- Fractures and fracture systems
  - Joints: attitude, distribution, spacing
  - Faults: attitude, displacement, width of shattered or gouge zones
- Rock cleavage: natural parting planes
- Veins and dikes: nature, distribution, attitude
- Inclusions and segregations
- Overburden: nature, thickness
- Weathering: depth, nature
- Degree of alteration

Industrial features:

- Classification, similarities with other commercial aggregate or stone in class
- Use of aggregate/stone
- Topography
- Accessibility
- Working facility, structural elements
- Workability, production, milling, cleaning, finishing
- Color
- Durability: strength, abrasion, soundness, resistance to atmosphere
- Reserves

SUMMARY OF THE STANDARDS FOR THE CLASSIFICATION OF PUBLIC COAL LANDS (Bass and others, 1970)

1. Land shall be classified as coal land if it contains coal having:

   (a) A heat value of not less than 4,000 Btu (as-received basis) for an unwashed or washed, unweathered mine sample.

   (b) A thickness of 14 inches for coals having a heat value of 12,000 Btu or more (as-received basis), increasing 1 inch for each decrease of 750 Btu between 12,000 and 9,000 Btu, and 1 inch for each decrease of 250 Btu between 9,000 and 4,000 Btu. Any coal bed whose thickness is more than 6 feet is treated as a 6-foot bed. In calculating the thickness of a coal bed that contains partings of shale, bone, or impure coal, the thickness of the thinner bench of coal directly above or below the parting is reduced by the thickness of the parting; thus, the total thickness of the coal bed (including partings) is reduced by twice the total thickness of the partings.

   (c) A depth of not more than 6,000 feet for a bed of coal 6 or more feet thick having an as-received heat value of 15,000 Btu. The depth decreases 333 feet for each decrease of 1,000 Btu between 15,000 and 9,000 Btu and decreases 400 feet for each decrease of 1,000 Btu between 9,000 and 4,000 Btu. For a bed of minimum thickness, the depth may not be more than 1,000 feet. For beds of any thickness between the minimum and 6 feet, the depth is graduated between 1,000 feet and the maximum depth for a 6-foot bed. Moreover, the depth limit shall be computed for each individual bed except that, where two or more beds occur in such relations that they may be mined from the same opening, the depth limit may be determined on the group as a unit and is fixed at the center of weight of the group; no coal below the depth limit thus determined is to be considered.

2. Classification shall be made by quarter-quarter section, surveyed tract, or surveyed lot.

Mineral Fuels continued

Other factors affecting quality:

1. moisture content
2. sulfur content
3. ash content
4. washability
5. grindability

RECOVERY PARAMETERS FOR OIL SHALE (Murray, 1974; Allred, 1964)

1. Oil yield (gal/ton), approximate cutoff for Colorado shale is 25 gpt.
2. Thickness of producing interval (s)
3. Thickness of overburden
4. Mining method, dependent on 2) and 3) above
5. Type and efficiency of retort process
    - a) minimum richness of oil-shale feed
    - b) porosity
    - c) permeability
    - d) spontaneous ignition temperature
    - e) distillation time-temperature relations
    - f) air-injection pressures
6. Possible adverse structural conditions
7. Possible high water-flow rates from aquifers above and below rich shale interval.

Clays (Yingst, 1961; U.S. Geological Survey, 1968)

Brick and tile clay
Pottery clay
Refractory clay
Bentonite

Physical properties

moisture content
pH
particle size
viscosity
cracking
abrasion
disintegration
shrink-swell capacity
brightness
settling velocity
color
oil absorption

Chemical properties

silica/alumina ratio
volatile content
impurities
ion-exchange capacity

Firing properties (refractory clays)

Pyrometric Cone Equivalent (PCE), ASTM standard
Shrinkage
Strength
Freeze-thaw resistance
Bloating

Electrical properties

conductivity
dielectric content
power loss

Vein-Lode* and Disseminated Deposits*

Most of Colorado's famous base- and precious-metal deposits were vein or lode deposits that were emplaced at moderate or shallow depths by ascending hot, mineral-laden solutions associated with intruding masses of molten rock or magma. Others were formed at moderate and shallow depths by circulating ground-water solutions that leached metallic ions from rock masses in which the metals were sparsely distributed. Other metals and related nonmetallics occur in pegmatites--thin, dike-like igneous bodies that were expelled from larger igneous masses into fractures in the surrounding country rocks.

The disseminated ore deposits were emplaced 1) at or near the contacts of intruding igneous magmas, or 2) as a result of contact or regional metamorphism of the surrounding rock masses. They are distinguished in form from the vein deposits by their apparent independence of fissures in the country rock and by the fact that the ore itself is distributed or "disseminated" as small particles or veinlets through large bodies of country rock.

Associated with the precious metals (gold and silver) in these deposits are several base metals--copper, lead, and zinc. Ferrous metals include iron, molybdenum, and tungsten. A number of other metals are mined directly or recovered as by-products from the smelting operation. Many of these metals may occur in vein-lode deposits as 1) metallic sulfides, 2) salts, such as sulfates, carbonates, and chlorides, 3) oxides, and 4) native elements. Associated with the ore minerals are a variety of nonmetallic minerals, collectively known as "gangue", which are usually discarded as waste but may have secondary commercial value as sources of industrial minerals and compounds.

Most of the mineral wealth of Colorado has come from the Colorado mineral belt, which extends southwestward from the mountain front in Boulder County through the San Juan Mountains. Several prominent mining districts, namely the Cripple Creek, Silver Cliff-Rosita, and Summitville-Platoro volcanic centers, and the Uravan district, lie outside the mineral belt. Although new discoveries will certainly be made outside the belt (as evidenced by numerous reported occurrences of important minerals), the future major metallic resources almost certainly lie within the belt, just as the bulk of past production has come from the belt. The locations of known and potentially productive mineral deposits within the mineral belt are shown on the maps of Henderson (1926), Lovering and Goddard (1950), and Eckel (1961).

Exploration, Field Geology, and Sampling

The geologist uses a variety of both simple and rather exotic tools in his search for and evaluation of mineral deposits. Inventorying existing data, interpreting aerial photographs and topographic maps, and drilling are discussed in a later chapter of this report. Additional methods are outlined below.

Geophysics

1. Gravity
    a. torsion balance
    b. pendulum
    c. gravimeter
2. Magnetic
    a. magnetic field balance
    b. flux-gate magnetometer
    c. nuclear magnetometer
3. Electrical
    a. self-potential
    b. galvanic
    c. induction
4. Seismic
    a. reflection
    b. refraction
5. Others
    a. radioactive
    b. thermal
    c. elasticity

Remote Sensing

1. High-altitude imagery (aircraft and balloon)
    a. black and white
    b. color
    c. black-and-white infrared
    d. color infrared
    e. thermal
    f. radar
    g. imaging microwave
    h. electro-optical (television)
2. Space imagery
    a. Skylab
    b. ERTS
    c. Apollo
    d. Gemini

Important geophysical exploration tools are used below, on, and above the ground surface to develop a picture of the subsurface structure and stratigraphy--a vital aspect of most mineral resource investigations. The main classes of geophysical methods include gravity, magnetics, electrical, and seismic. 1) In gravity prospecting, small lateral changes in the earth's gravitational field that are caused by underground structures and density differences among rock masses can be detected and recorded. After correcting for latitude, elevation, and topography, one may plot and contour the data to form isogal maps. The configuration and gradient of the contours help to a) locate structural highs and lows, and b) determine the presence or absence of relatively heavy and light rock masses. 2) Magnetic surveying instruments measure surface modifications in the earth's magnetic field. These variations are caused by induced and remanent magnetisms present in certain rock bodies, especially igneous, in the subsurface. Geologic ground control and careful interpretation of magnetic-contour maps may ascertain the size, shape, and position of the anomalous rock masses. Magnetic surveying is well suited for airborne use especially in sparsely populated, inaccessible, or rugged terrains. 3) Electrical prospecting methods depend on both natural and artificially introduced electric fields. Various tools measure the distribution and magnitude of electric potential caused by variations in conductivity among rock strata. 4) In seismic surveying, energy pulses introduced into the ground reflect from or travel along certain horizons. At nearby points on the ground surface, instruments graphically record the resulting ground motions. Interpretation of such data help to identify structures and rock strata with differing wave velocities.

A variety of borehole tools are used to establish relatively smaller scale rock properties such as porosity, permeability, conductivity, and water saturation. Several radioactive tools are used in the search for uranium, thorium, and the rare earths. Airborne gamma-ray spectrometers and scintillometers detect areas of high energy in outcrops of formations known to contain radioactive minerals. On the ground, the Geiger-Müller counter and scintillometer may be used to more accurately locate anomalies both in sedimentary rocks and in igneous veins. The more exotic remote sensing techniques such as infrared and electronic satellite imagery aid in constructing regional geologic frameworks and in identifying features too gross to be seen by conventional methods.

The most familiar application of geophysical tools is the use of seismic surveys and borehole logs in petroleum exploration. However, other techniques have been successfully applied in mining. Magnetic surveys have aided in locating gold placers and ferrous ores in several western states. Electrical methods were used in tracing tungsten-bearing ores in Colorado. Seismic and resistivity tools are useful in locating certain coals, cement raw materials, and aggregates.

Although some definite geophysical indicators have been confirmed (e.g., gravity minima over salt domes, magnetic highs over basement-rock uplifts), these tools do not locate specific mineral deposits, but, through their detection of anomalies and physical changes at the earth's surface, only give indications which must be interpreted in geologic terms and investigated by more direct means.

No exploration program could succeed without a close field examination of the area's rocks and their temporal and spatial relationships. In his search for mineral deposits, the prospector relies on 6 basic indicators or guides to mineralization (Brown, 1965): physiographic, structural, stratigraphic and lithologic, mineralogical, geobotanical, and ground water. Although these guides are somewhat more applicable to metallic ores, variations can be adapted for other types of mineral deposits.

Physiographic: Within a given climatic region, certain lithologies tend to have characteristic topographic expressions--positive, such as ridge- or ledge-formers, or negative, such as valley- or slope-formers. Recognition and areal tracing of known ore-bearing units both on topographic maps and in the field help to delineate structure and direct attention to the critical rock layers.

Structural: Because so many mineral deposits are intimately associated with fractures and faults, these structural features are of utmost importance in exploration. In addition to their density or spacing, continuity, and orientation, the relative and absolute movements along faults may help locate additional ore, especially if a fault has offset an earlier mineral deposit. Knowing the magnitude and direction of movement will enable the geologist to tell whether the offset portion of ore 1) was lowered and now exists at depth, 2) was elevated and eroded away, 3) was shifted laterally, or 4) has undergone some combination of these movements.

Just as individual faults and systems of parallel faults and fractures are likely the channelways for mineralization, so also are intersecting faults or systems. Three-dimensional models of these systems, constructed from surface and subsurface data, may help to establish the configuration, depth, and orientation of possible buried ore bodies.

Various types of folding in the rock layers can affect the migration of mineral-laden waters and, hence, the deposition of their minerals. Because faulting usually accompanies folding, structural analysis in regard to ore emplacement can become very complicated.

Stratigraphic and lithologic: In a stratigraphic study, the geologist establishes the temporal sequence of a group of different rock beds in one locality and attempts to recognize the same sequence and the variations therein from place to place. Recognition of a particular bed within a sequence over a large area aids in the identification of possible ore deposits because certain stratigraphic or lithologic layers are particularly receptive to certain types of mineralization. Permeability and chemical reactivity of the rock layer most affect its ability to receive mineralizing solutions. An excellent example of this phenomenon is the zinc and lead mineralization of the Leadville limestone in the famous Leadville district. Other examples of the affinity of certain ores for particular rock types are given by Brown (1965). Contacts between rock layers may also be favorable locations for mineralization especially if faults or fractures intersect the contacts.

Mineralogical: The closest examination of rocks will reveal which strategic ore-indicating minerals are present, to what degree they have been altered, and, through associations, the type and location of the important mineralization. Certain ore deposits have associated with them characteristic mineral assemblages that, upon surface weathering, may stain the outcrops various colors. Because one color may be indicative of several different metals, the geologist must combine his knowledge of the geologic terrain with the physical and chemical aspects of the total mineral assemblage to predict the type and location of mineralization. In areas of contact metamorphism, definite mineral zones occur, and the "higher-grade" assemblages are located nearer the center of activity.

Several types of alteration are recognized as general ore indicators: 1) dolomitization near ore deposition in limestone; 2) red, yellow, and brown iron oxides formed by the alteration of pyrite associated with most sulfide deposits; 3) sericitization of feldspars in hydrothermally altered rocks associated with some metallic deposits; 4) chloritization of iron- and magnesium-bearing minerals; 5) manganese, iron, lead, and other carbonates associated with sulfide ore bodies; 6) quartz, in silicified zones; and 7) 7) argillic zones lying beyond more intensely altered zones.

Geobotanical: A number of plants have natural affinities for certain metals and, so, live in those mineralized areas. Conversely, other plants are poisoned by other metals. Therefore, either the conspicuous presence or absence of these plants may be useful indicators or nearby ore deposits. An example of this phenomenon is the loco weed, Astragalus, which has an affinity for selenium, an element commonly associated with uranium on the Colorado Plateau.

Ground water: Ground waters may become unpotable as they pass through zones where ores have been oxidized. Stains on water plants and stream gravels also are indicators of oxidized zones.

An important phase of any field exploration program is the careful, systematic, and representative sampling of an area's rocks, soil, water, and vegetation. Sampling is the process of taking a small portion of an article such that the consistency of the portion will be representative of the whole. The type and amount of sampling depend upon the type of deposit and the degree of development--whether the property is only a prospect, an exploration, or a partly or fully developed mine. The more reliable sampling methods include 1) channel and chip sampling of the ore body and related rocks at exposed surfaces either on the outcrops or in underground workings; and 2) drill core sampling at regular intervals to delimit lateral and vertical variations. Random "grab" sampling of the broken ore is objectionable because the tonnage represented by the sample cannot be accurately determined.

Rock samples are generally assayed to determine the content and value of the precious metal contained therein. Soil, water, and vegetation samples are analyzed for their concentrations of metallic ions, and the results are plotted on maps and contoured to outline anomalous or favorable areas. Other laboratory techniques include mechanical tests, atomic analyses (absorption, X-ray mineralogy), and optical analyses.

Evaluations

The results of exploration, field geology, sampling, and testing lead to the quantification of the two aspects of a mineral deposit that determine its real viability--grade* and tonnage. The content and value of the desired metal or mineral must be high enough, or the amount of worthless material low enough, within the calculated tonnage to prove minability of the deposit under present or impending economic conditions. The tonnage can be calculated if the dimensions of the deposit and the amount of desired minerals per unit volume are known. If percentages of ore vary at graduated intervals, the dimensions of each interval must be approximated and the tonnages calculated accordingly. When grades and tonnages have been estimated, the results are integrated with the economic and technical aspects of the mining, processing, marketing, and reclamation phases of the operation to determine the total feasibility.

Because the mining, processing, and general geology in areas of metallic ore emplacement usually are more complicated than that in areas of bedded deposits, no definite guidelines, other than the exploration criteria and geographic aspects discussed above, can be tabulated for the vein-lode and disseminated deposits. Mining companies have spent years in establishing such criteria, and for reasons of uncertainty and confidentiality, such information is not available. Therefore, areas of past, present, and planned development, and other geologically favorable areas, as yet unexplored, must suffice in identifying and designating the MRA's.

Sources of Information

The U. S. Geological Survey publications describing the geology and ore deposits of the various Colorado mining districts are listed in a pamphlet entitled "Geologic and water-supply reports and maps of Colorado." The Colorado School of Mines Quarterly and Mineral Industries Bulletins, the 10 volumes of the Proceedings of the Forums on Geology of Industrial Minerals, and the journals of various professional societies and industries provide a wealth of useful information. Williamson and Burgin (1960b) give an excellent listing of many sources of geologic and mineral-resource literature and their governmental, public, and university depositories. Table 5 is a summary of sources of mineral-resources information.

Table 5. SOURCES OF INFORMATION FOR MINERAL RESOURCE AREAS

KIND OF INFORMATION	Federal Govt.	State Govt.	Univ. & Colleges	Industry	Profess. Societies	Geol. Journals	Geol. Consultants
Geologic maps, reports, papers	USGS	CGS	X		X	X	Y
Mineral distribution, occurrences	USGS USBM AEC BLM USFS	CGS CDM OGC	X	Y	X	X	Y
Geophysical maps, reports, papers	USGS		X		X	X	Y
Well logs		CWCB CGS CDWR	Y	Y			Y
Mine/well location, distribution	USBM USGS	CDM OGC CWCB CDWR	X	Y			
Mine/well production statistics	USGS USBM AEC	CDM OGC		Y			
Specifications, standards, testing	USBM NBS	CDH		Y		X	
Case histories, historical background	USGS USBM			X	X	X	
New technology, equipment, processes	USBM NBS			Y			

USGS - U. S. Geological Survey
USBM - U. S. Bureau of Mines
NBS - National Bur. of Standards
AEC - Atomic Energy Commission
BLM - Bur. of Land Management
USFS - U. S. Forest Service

CGS - Colo. Geological Survey
CDM - Colo. Division of Mines
CDH - Colo. Division of Highways
CWCB - Colo. Water Conservation Board
CDWR - Colo. Div. Water Resources
OGC - Colo. Oil & Gas Conservation Comm.

X - generally available, especially in public and university libraries
Y - restricted distribution

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V. Identification Procedures

A. Inventory of Existing Data

Geologic hazards studies should be supplemented by a thorough review of available geologic literature. Sources of useful geologic information to which the public has ready access are the libraries of the Colorado School of Mines in Golden, the University of Colorado in Boulder, Colorado State University in Fort Collins, other universities and colleges throughout the state, the U. S. Geological Survey at the Denver Federal Center in Lakewood and the Federal Building in Denver, and the Denver Public Library and other libraries throughout the state.

Topographic maps and aerial photographs are basic tools for any kind of field geologic studies. These tools are discussed in separate sections of these guidelines.

Small-scale, regional geologic maps show the general distribution of rock units that underlie areas, and may give an indication of expectable hazards. The Geological Map of Colorado and the 1:250,000-scale geologic maps of the Geological Survey are examples of small-scale maps. The principal use of this kind of map for hazard studies is to signal areas where additional study may be needed.

Intermediate scale geologic studies are useful for anticipation of the kinds of hazards likely to be encountered in particular areas. These studies may give insight into how and why hazardous geologic processes operate, and in a general way what geologic factors are involved. An example is the Geologic Aspects, Soils and Related Foundation Problems, Denver Metropolitan Area, Colorado, prepared for the Colorado Geological Survey and the Front Range Urban Corridor studies by the U. S. Geological Survey. These maps are not sufficiently detailed for specific identification and designation of geologic hazards.

Geologic quadrangle maps exist for less than 10 percent of Colorado, as they are expensive and time-consuming to produce. These maps will aid the geologist in locating potentially hazardous areas, but additional work and analysis is necessary to adequately identify and designate areas of geologic hazards.

Interpretive environmental geologic mapping is a new subdiscipline of geology. Consequently, very few of these maps exist. Where they exist, they can, however, yield information directly to the layman about the geologic constraints on land use. They are derived in part from conventional bedrock and surficial geologic maps.

Table 6. SOURCES OF GEOLOGIC HAZARD-RELATED INFORMATION

KIND OF INFORMATION	Private Geological Consultants	Federal Government	State Government	Colleges & Universities	Geologic Literature	Private Industry
Regional topical geologic studies	X	USGS	CGS	T, FP	X	X
Small-scale regional geologic mapping		USGS	CGS	FP	X	X
Large-scale quadrangle detailed geologic mapping	X	USGS		T, FP	X	
Interpretive environmental geologic mapping	X	USGS USFS USBLM	CGS	FP	X	X
Flood-related geologic information	X	USSCS USGS USACE USBR	CWCB CGS SCD CSCB	FP	X	
Soils and surficial geologic information	X	USSCS USGS	CSCS SCD CSCB	T, FP	X	

CGS - Colorado Geological Survey
CSCS - Colorado Soil Conservation Service
SCD - Soil Conservation Districts
CSCB - Colorado Soil Conservation Board
CWCB - Colorado Water Conservation Board
USGS - United States Geological Survey
USFS - United States Forest Service
USBLM - United States Bureau of Land Management
USACE - United States Army Corps of Engineers
USSCS - United States Soil Conservation Service
USBR - United States Bureau of Reclamation
T - Thesis or Student paper, faculty paper
FP - Formal Publication
X - Generally available

Soil and surficial geologic maps are valuable preliminary information for planning of engineered works. General soils and surficial geologic studies will alert the project engineer or geologist to possible foundation problems and provide a basis for estimating general development and foundation costs.

B. Base Maps - Scale and Quality

A base map is necessary before most investigations involving either environmental geology or land-use planning can be undertaken. A base map shows the distribution of certain specific characteristics of the land and of man-made features. The essence of any mapping program is plotting the distribution of some characteristic(s), geologic or other. For this, some base or reference map is always useful, and for identification of hazards it is an absolute necessity. In any mapping project, certain factors should be kept in mind; the purpose of the mapping, the size of the area to be mapped, the degree of accuracy desired, and the time and cost required to achieve these ends. Each of these factors are interrelated.

The size of the area to be mapped, the scale and accuracy required, and the complexity of characteristics to be mapped determine the cost and speed of coverage of a mapping program. A broad ongoing mapping program at a given scale is the most economical and cost is largely proportional to the area covered. Smaller programs of intermittent coverage are less efficient and cost more per unit area because of increased mobilization costs. In specialized mapping such as hazard identification, the cost of projects will vary widely depending on geologic complexity, terrain, accessibility, and other factors. Topographic mapping, which is in a large part done by photogrammetry, involves more easily predictable costs.

Large geographic areas, such as counties, are usually mapped at a smaller scale with less stringent requirements of accuracy. A scale of 1 inch on the map equal to 4,000 ft on the ground (1:48,000) is a convenient working scale for mapping of a large area such as a county.

Areas of intermediate size are generally mapped at a larger scale and a higher degree of accuracy is required. A scale of 1:24,000 or larger is typical for this type of mapping. This will give a more detailed coverage of an area while still minimizing costs and mapping time. We consider 1:24,000 scale (1 inch = 2,000 ft) to be a desirable and recommended general scale for most hazard identification studies.

Small or specific areas of concern such as building sites, and areas of localized severe geologic hazards should be studied and mapped in considerable detail. In such cases, whatever scale is needed to accurately locate the features of interest should be used. This does not usually require a map scale larger than 1 inch equal to 50 ft.

The best base map for most purposes is a topographic map - one that by use of contours, or lines connecting all points of equal elevation, shows slope, relief, and landform characteristics. Additionally, roads, buildings, and other cultural features are usually shown. These serve as a useful frame of reference as well as increasing the readability of the map. The most common and highest quality topographic maps of Colorado are those made and sold by the United States Geological Survey. Approximately 85 percent of the State has been mapped, much of it with very high quality 7 1/2' (1:24,000) maps. The only areas where coverage is absent is in parts of sparsely-populated eastern and northwest sectors of the state. U.S.G.S. maps come in several scales: 1:24,000 quadrangles; 1:62,500 quadrangles; 1:100,000 regional maps; 1:250,000 (2° x 1°) sheets. The Front Range Urban Corridor from Ft. Collins to Colorado Springs is the only area of the state in which 1:100,000 maps have been made. There is also a 1:500,000 topographic-political map of the entire state. The Colorado Division of Planning and the U.S.G.S. is commencing a cooperative program to produce county maps at a convenient scale of 1:50,000.

Due to a combination of factors, there may be cases that require a special base map. In such cases, aerial photographs can be used to economically compile a topographic map of any scale and to the required detail and accuracy. Photo coverage exists for nearly all of Colorado and is available from public agencies, with individual areas also covered by photos available through private photogrammetric consultants.

Factors discussed above are very important considerations in any mapping plans undertaken or commissioned by a local planning group. In order to optimize success, and benefits to local government, the mapping plans and specifications should be very carefully outlined and followed. Where expertise is lacking, assistance in making decisions on a geologic hazard mapping and identification program may be acquired from the Colorado Geological Survey.

C. Photogeology

The use of aerial photography is an invaluable tool for geologic studies. Cultural features such as roadways, power lines, fence lines and buildings can be identified. Natural features such as variations in vegetative distribution, stream drainage patterns, and steep slopes are readily apparent. Such geologic features as landslides, rockfall areas, faults, formations, and dip and strike of rock outcrops can be identified. Subtle and important geologic details can often be observed on the aerial photographs which are difficult to determine on the ground.

Aerial photographs vary as to the area covered on each photo (scale), this is directly related to the height of the camera above the earth's surface and the type of lens used. Most available air photos are black-and-white, but the use of color is increasing. Either type will depict most features but color yields certain environmental and geologic detail not seen on black-and-white photographs.

Information can be obtained from individual photos but to obtain a three dimensional view it is necessary to have stereo coverage. Other useful types of coverage are rectified photos, orthophotos and oblique photos, but their availability is limited.

Some of the unique advantages of using aerial photos to study an area include the following:

1) The area can be viewed in an overall perspective, and regional relationships noted.

2) Air photos are easily aquired and are readily available for most areas of Colorado. Sources include the U. S. Geological Survey, U. S. Forest Service, U. S. Soil Conservation Service, N.A.S.A., and consultants in the field of photogrammetry.

3) Considering time saved and potential benefits to the user, they are relatively inexpensive.

4) Many complex and subtle geologic relationships that are not always apparent in the field may be seen.

5) They may be used in the field, and annotated while field observing and studying an area.

6) Aerial photographs may be used for preliminary office studies during times of the year when field work is not possible. They are also useful in planning field work in difficult terrain.

D. Geophysics

Geophysics is a branch of physics dealing with the earth and its constituent materials and their physical properties. Geophysicists measure certain physical parameters at locations that may be above the earth, on the earth's surface or in a borehole or other opening within the earth. The parameters measured include gravitational, magnetic, electrical, elastic, radioactive, and detection and evaluation of electromagnetic energy (remote sensing). From interpretations of such measurements, geophysicists can make valid inferences as to earth structure, composition, and processes.

One of the common applications of geophysics is in determining relatively shallow subsurface geologic conditions for evaluation of site feasibility, hydrologic conditions, and specific indications of certain geologic hazards. Such investigations and evaluations have maximum value when integrated with available geologic data and confirming drill-hole borings. Seismographs are used in monitoring earthquake activity of faults, and in detecting active subsidence, or incipient landslide movements. Continuous geomagnetic observations, and various types of strainmeter and tiltmeter observations may give premonitory indications of impending earthquakes. Remote sensing is a rapidly developing new field of geophysics that may yield much useful data for geologic hazard evaluation. Radioactivity surveys are essential in providing both qualitative and quantitative data for evaluation of possible radioactivity hazards. Gravity surveys have proven useful in detection of concealed faults, and in locating localized bodies of evaporite or clay that may constitute subsidence hazards.

The above is only a brief sketch of possible applications of geophysics as a tool in geologic hazard evaluations. Although there are no specific texts dealing with this special application of geophysics, much helpful information can be gained through standard texts and the professional literature of Engineering Geology and Applied Geophysics.

E. Geologic Field Work

All available published and unpublished data should be examined preparatory to field work in a given area. This review should include study of the technical literature of the area including geologic and topographic maps, aerial photographs,and subsurface data. This information is referred to as control or background data. Usually, the more extensive and accurate the control, the more economical and reliable the geologic study will be.

After the control data has been reviewed, an important step in a geologic study of a given area is sufficient field work to check reliability of control data. This will determine the reliability, accuracy and pertinence of work already done, and the extent to which additional work is needed.

In many cases, available geologic maps and reports do not include details that are directly significant to engineering geologic and environmental geologic evaluations. However, final maps and reports that are responsive to specifics such as geologic hazards can be prepared by combining and evaluating information from all available sources with additional necessary photogeologic and field studies.

F. Drilling

There are times in nearly all geologic and soils surveys when the use of a rock or auger drill is necessary or advantageous to obtain additional subsurface information.

The type of drilling and the equipment necessary are directly related to the information needed and the expected geologic deposits that must be penetrated to obtain this information. There are basically three types of drill equipment in general use today: 1) rotary drills using tri-cone-type bits, roller bits, and core bits; 2) rotary drills using an auger-type bit and drive samplers; and 3) cable tools.

For shallow exploration in soft soils or poorly cemented rock, the auger-type equipment is adequate. The kinds of information that can be obtained in this manner are soil types, depth to soil changes, depth to water table, quality and thickness of sand and gravel deposits. Samples for swelling-soil tests, holes for percolation tests, and information for other soils engineering tests may also be obtained by drilling. It is very important that shallow drilling programs be planned by an interdisciplinary effort of engineering geologists and soil engineers.

Deep exploration or drilling into hard rock generally requires the use of rotary-type equipment. The older cable-tool method is now generally restricted to water well drilling. A rotary drill can yield information about types of unconsolidated surface material, depth to water table, depth to bedrock, types and thickness of bedrock, water resource information, and other engineering-geologic properties of rocks.

The open borehole itself can be used for a variety of testing procedures such as static water level, electric logs, percolation rates, and instrumentation for strain measurements.

The use of the drill as an investigative tool usually becomes more important as the scale of a project is reduced. Its most advantageous use is for individual structures or specific projects.

G. Laboratory Investigation and Instrumentation

Laboratory tests have been used by engineers and engineering geologists to aid in the identification of certain geologic hazards and other conditions. Some commonly used laboratory tests are listed in Table 7. The purpose of the table is to familiarize the

Table 7. SELECTION TABLE FOR LABORATORY INVESTIGATIONS AND INSTRUMENTATION

Type of Test / Geologic hazard	Avalanches[2]	Landslides	Rockfalls	Mudflows & Debris Fans	Unstable or Potentially Unstable Slopes	Seismic Effects	Radioactivity	Ground Subsidence					American Society for Testing and Materials (ASTM) Test Designation Numbers
								Removal of underground fluids	Natural Consolidation	Dissolution of underground minerals	Underground mining	Expansive soil & rock	
Geophysics[1]		X			X	X	X	X	X	X	X		
Field Instrumentation	X	X	X	X	X	X	X	X	X	X	X		
Grain size distribution		X		X	X	X		X	X			X	D421-58; D422-63; D2217-66
Natural moisture content		X		X	X	X		X	X			X	D2216-71
Permeability*		X			X	X		X	X	X			D2434-68
Triaxial shear*		X		X	X	X		X	X		X		D2664-67; D2850-70
Unconfined compressive strength*						X		X	X		X		D2166-66; D2938-71a
Consolidation-swell*						X		X	X			X	D2435-70
Atterberg limits*		X		X	X	X						X	D423-66; D424-59
Shrinkage limit*												X	D427-61
Dry unit weight*		X				X		X	X			X	D1556-64; D2166-66 D2167-66; D2937-71
California Bearing Ratio*									X			X	D1883-67
Stabilometer (R-value)*									X			X	D2844-69
Penetrometer	X	X		X	X	X		X	X				D1558-71

[1] See separate section of guidelines for "Geophysics"

[2] Laboratory and field tests for shear strength are sometimes run on snow and ice.

non-geologist with some of the tests used, and with which particular geologic hazard the tests might be utilized. Laboratory tests other than those listed in the table may also be used in geologic hazard investigations. The asterisks found after the name of the test indicate terms that are defined in the glossary. The identifying numbers for the American Society of Testing and Materials (1973) soil and rock tests are listed in the last column.

None of the tests listed below provides positive identification of a specific geologic hazard. Only when appropriately used in conjunction with photogeology, field geology, geophysics, and drilling can these tests provide useful information. Also, many of the tests listed below may not be used, and should not be required for the identification of a specific geologic hazard. The engineer or geologist who is performing a particular geologic hazards study should be free to select which, if any, of the tests is necessary to evaluate the specific conditions he has encountered.

Some instrumentation methods are commonly used either in the field or in the laboratory. For example, seismicity studies for earthquakes may utilize large laboratory seismographs, but small field-portable seismographs are normally used in ground subsidence studies. One important method of study in areas susceptible to rockfall or rockslide is the instrumentation of rock outcrops with "extensometers" (a type of strain measuring device). In the lab, extensometers may be used on a smaller scale to study exfoliation (spalling of granitic rocks due to strain relief). Field instrumentation methods ranging in complexity from resurveying of bench marks to continuously recording slope-angle indicators are used in landslide, slope stability, and subsidence studies. Some of these instruments can only be used in soils, others in hard rock, and some in either soil or rock. Because of the variety of techniques and equipment available, the selection of the proper instrumentation method for a geologic hazard should be the responsibility of a qualified engineering geologist.

H. Comprehensibility and Credibility

Scientific reports written by professionals are often directed to a select audience, and are, therefore, versed in very technical language. Each particular field, and even specialties within a field, has its own specilized vocabulary. Such writing is generally unintelligible to persons not trained in the particular specialty.

For this reason, persons writing technical reports of a geologic nature for use by non-geologists should make a special effort to write in a style and vocabulary that is easily understood by those who will receive the report. Persons such as planners, developers, and local government officials should be to read and understand these reports. Because such persons are an integral part of the review process, writing in this manner will assure that they can make a more accurate, fair, and useful judgment of the proposed land use as related to geology.

The author of such reports should clearly establish guidelines of his own prior to actually beginning to prepare a report. He should determine exactly what information the report is to provide, and strictly devote his writing and illustrations to presenting this information in the clearest possible manner. An outline should be set forth as a guide in preparing the report. The text should be well organized, easily understood, complete as to content and explanations, and clearly presented. Attention should be given to such details as location or index maps; pagination; agreement of maps, text, and illustrations, and inclusion of all material needed to make the report complete.

The final report should be proofread carefully. This should include final checks as to accuracy and validity of content; spelling and grammatical correctness; and comprehensibility and clarity for the intended users. To evaluate comprehensibility, the author (or preferably a co-worker) should read the report as an unbiased and uninformed recipient of the report would read it for the first time. Any obscure or ambiguous parts should be rewritten.

As discussed in other sections of these guidelines, an integral part of any geologic report is a survey of previous technical writings relating to the subject or area. Accordingly, nearly every geologic report should include references. Essential references fall in to two general categories: (1) those that were actually used in preparation of the report, and (2) those that would provide additional material of interest to the user. In the first case, it is only accepted professional courtesy to acknowledge work by others that one has drawn upon; and in the second case, it is important to provide additional sources for the serious reader.

To establish credibility the author should not only sign the report but also include his professional qualifications and affiliation (individual consultant, consulting firm, etc.). For the convenience of users he should include, by means of letterhead or otherwise, his address and telephone number.

In summary, it should be emphasized that a written report is not just a discussion of a particular subject -- it is also assumed to represent the best professional efforts and abilities of the individual or firm that prepared that report.

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VI. Qualifications of Investigators

For identification of geologic areas of state interest as required by House Bill 1041, certain minimal standards of professional training and competence should be required of any geologist doing such work. Agencies reviewing or otherwise aiding in such work should monitor and require acceptable levels of competency and professional work from all individuals submitting reports.

A. Professional Geologist

House Bill 1574 enacted in 1973 makes the following stipulation concerning geologic reports:

> 53-3-2. Reports containing geologic information. Any report required by law or by rule and regulation, and prepared as a result of or based on a geologic study or on geologic data, or which contains information relating to geology, as defined in section 51-3-1(3), and which is to be presented to or is prepared for any state agency, political subdivision of the state, or recognized state or local board or commission, shall be prepared or approved by a professional geologist, as defined in section 51-3-1(4).

The same act defines professional geologist as follows:

> 51-3-1. (4)(a) "Professional geologist" is a person who is (b) A graduate of an institution of higher education which is accredited by a regional or national accrediting agency, with a minimum of thirty semester (forty-five quarter) hours of under-graduate or graduate work in a field of geology and whose postbaccalaureate training has been in a field of geology with a specific record of an additional five years of geological experience to include no more than two years of graduate work.

As in other disciplines, most professionals in geology are specialized. In addition to the minimum education or experience required by the Act, professional geologists should therefore have a specific background in the specialty to which they are addressing themselves, e.g. engineering and environmental geology, mineral deposits, or hydrology.

The stipulation that work on a specific geologic project be done by professional geologists with a specialty and experience in that area is of utmost importance. This will result in the greatest assurance that such work will be of acceptable quality and have the highest probability of long-term utility and benefit to the people of the State of Colorado.

B. Engineering Geologist

Engineering geology is a commonly accepted specialty within the profession of geology and is defined as "the application of geologic knowledge and principles in the investigation and evaluation of naturally occurring rock and soil for use in the design of civil works." (Uniform Building Code, Chapter 70, 1973). An engineering geologist <u>must</u> be well qualified, through both education and experience, in field geology and identification of geologic hazards. If these qualifications are met, the engineering geologist should be capable of producing maps and reports acceptable to both local government and the state in H.B. 1041 hazard investigations.

C. Professional Engineer

Professional engineers are persons who meet certain qualifications and have passed an examination as set forth by the State Board of Registration for Professional Engineers and Land Surveyors. As defined in the 1965 Permanent Cumulative Supplement to the Colorado Revised Statutes 1963, Chapter 51, article 1, Section 51-1-2, subsection (4) an engineer is defined as:

> "...a person who, by reason of intensive preparation in the use of mathematics, chemistry, physics, and engineering sciences, including the principles and methods of engineering analysis and design, is qualified to perform engineering work as defined in this areticle."

Subsection (5) of the same section defines "Professional Engineer" as: "...an engineer duly registered and licensed."

As within the geologic profession, there are specialties within the ranks of the professional engineers such as civil, soils, structural, and electrical. All professional engineers are obviously not qualified to work within the area of soils, slope stability, hydrology, rock mechanics, or geology. Such work should require experience and competency in those specialties.

D. General Summary

It is important that the geologic portion of a hazard investigation be carried out by, or under responsible charge of a qualified professional geologist, especially an engineering geologist, and that his signature be on the report. It is equally important that if part of the investigation is concerned with soil mechanics, foundation design requirements or other engineering or design aspects, then that portion of the investigation should be performed by a qualified professional engineer and that report should be signed by the engineer who performed the work.

Obviously some tasks should only be performed by qualified geologists and some should only be performed by qualified engineers. Others could be adequately handled by either profession. Persons who would like more detailed information on the qualifications of engineering geologists and civil engineers to perform certain work are referred to an excellent article, "Guidelines for Practice in California-- Engineering Geologists versus Civil Engineers" in the Eleventh Annual Symposium on Engineering Geology and Soils Engineering edited by Wilferd W. Peak, April 1973, available from Idaho State University Department of Geology and Engineering.

VII. Suggestions to Local Government for Implementation of Geologic Hazards Provision of HB-1041

(1) Identification

All units of local government should begin immediately to inventory possible areas of geologic hazard within their jurisdiction, based on experience and currently available data. Assistance in this will be provided on a time-available and priority basis by the Colorado Geological Survey. More formal and specific evaluation will require identification by professionals as described in section VI. of these guidelines with actual designation being the function of local government. A comprehensive plan and time schedule for completing the identification program should be devised by each unit of local government for land within its jurisdiction.

Actual professional geologic studies required to identify geologic hazards can be accomplished in one of several ways: (1) through studies conducted by professional staff geologists employed by local government; (2) by Colorado Geological Survey professional staff; or (3) by professional consultants performing the required studies either under direct contract with local government or under contract with the Colorado Geological Survey. In either of the latter cases, the moneys may consist of various combinations of state, federal, and local matching funds. To ensure timely completion of geologic hazard identification, many units of local government will rely on contract studies initiated locally rather than wait for state-initiated studies that will be on a priority-need basis. The Colorado Geological Survey can provide advice in program design and other technical aspects of contracts that may be initiated locally. Whichever method is selected, it is essential that the professional geologic work performed meet the standards specified in these guidelines.

(2) Designation of Geologic Hazard Areas

When identification of geologic hazards for all or any part of a city or county has been completed, local government should act upon this information by proceeding to the designation procedures of H.B. 1041.

(3) Administration of Geologic Hazard Areas

Local governments should adopt regulations for administration of designated and/or identified geologic hazard areas that are adapted to local needs and conditions and consistent with the guidelines and model regulations prepared and promulgated by the Colorado Geological Survey.

Local governments, land owners, state agencies and potential developers should understand completely that the designation as a "geologic hazard area" does not necessarily mean that no development can take place within that area. Designation only means that the probability exists that geologic conditions in the area might have a serious adverse impact on future development. Therefore, development should not take place until a careful, detailed evaluation of adverse geologic conditions within the area has been made and it can be shown either that the conditions will not result in a significant hazard to that particular proposed development, or that engineering and design of the development or special protective measures are such that the impact of the adverse conditions can be mitigated to the extent that they do not constitute a serious hazard.

VIII. Glossary of Terms

Activity ratio - the ratio of the plasticity index to the percentage of clay (particles less than 0.002 mm in diam) in a soil sample.

Alpha particle - a positively charged particle consisting of 2 protons and 2 neutrons that is emitted from an atomic nucleus during radioactive decay.

Alluvium - clay silt, sand, gravel, or similar unconsolidated detrital material deposited by a stream or other body of running water.

Aspect - the compass direction which the land surface faces, e.g., a north-facing slope has a north aspect.

Atterberg limits - certain properties of clay soils that are dependent upon water content. The three most common limits are: the liquid limit, the plastic limit, and the shrinkage limit. These represent the water content as a percent of dry soil weight at transitions from liquid to plastic behavior from plastic to solid, and the water content below which further loss of water by evaporation does not result in a reduction in volume of the soil. These soil parameters are determined by standard laboratory tests.

Base metal - usually the more common, less valuable metals, such as copper, lead, and zinc, which are chemically more active than the precious metals such as gold, silver, and platinum.

Bearing wall - a wall that transmits part of the weight of a roof or upper floor to the foundation; may be extended below frost line for use as the foundation.

Bentonite - a common name for layers of white or yellow clay containing a mineral called "montmorillonite" which is formed from the weathering of volcanic ash; it may be highly swelling if exposed to water while dry.

Beta Particle - a negatively charged particle consisting of one electron that is emitted from an atomic nucleus during radioactive decay.

Block - a large angular rock fragment, showing little or no effects of movement by water or wind and having a diameter greater than 10 in. (256 mm).

Boulder - a large rock fragment somewhat rounded by abrasion in movement having a diameter greater than 10 in. (256 mm).

California bearing ratio (CBR) test - the ratio of the pressure required to penetrate a soil mass with a 2-in. diam, circular piston at the rate of 0.05 in./min. to the pressure required for corresponding penetration of a standard material.

Clay mineral - a group of generally platy silicate minerals that form by chemical weathering of primary rock-forming minerals such as feldspar and mica.

Clay particle - the finest particle size among these normally measured in the range of particles from gravel to sand, silt and clay; any particle less than 0.002 mm in diam.

Cobble - a somewhat rounded rock fragment larger than gravel (2.5 in. or 64 mm diam) and smaller than a boulder (10 in. or 256 mm diam).

Collapsible soil - certain relatively dry soils that have a high void ratio and will support a heavy load at natural moisture content but, when water is added, undergo a collapse of internal structure and a reduction in volume that results in subsidence of the ground surface and densification of the wetted soil column.

Colluvial soils - any loose, poorly-sorted mass of soil or rock material deposited by rapid, water-deficient, gravity-dominated processes such as normal surficial creep, landslides, and rockfalls; the soil or rock may range in size from clay to boulders.

Colluvial wedge - the deposit of colluvial soil found at the base of a slope; similar to a talus slope, but consists of fine-grained soil rather than blocks of rock; and generally has much flatter slope than talus.

Consolidation - any process that forms material into a compact mass (general usage). Technically consolidation consists of the slow reduction in volume and increase in density of a soil mass due to the squeezing of water from the soil mass in response to increased loading. The increased load may be man-made, e.g., a house built on saturated clay, or natural, e.g., the weight of sand being deposited on underlying clay by a stream.

Consolidation swell - a test in which a thin cylindrical soil sample, confined by a brass ring, but with free access to water, is loaded axially to determine percentage consolidation or swell under load.

Creep - the slow, gradual, more-or-less continuous deformation sustained by ice, soil, and rock materials under gravitational body stresses.

Debris avalanche - the generally sudden and very rapid sliding and flow of masses of unsorted mixtures of soil and rock material on steep slopes. The flow may progress for long distances out on flat areas below a mountain front or other steep slope from which they originate.

Debris flow - a mass movement involving rapid flowage of debris of wet soil, rock, and displaced vegetation; specifically, a high-density flow containing abundant coarse-grained materials and resulting almost invariably from an unusually heavy rain or from a dry rock fall of unusually large volume.

Design earthquake - the earthquake for which protective measures should be taken in the design of all construction. The highest magnitude and intensity earthquake that can be expected to affect a given site.

Disseminated deposit - a type of ore deposits in which the ore minerals occur as small particles or veinlets scattered through the country rock. Though not very high in grade, such deposits are sometimes of great size and often form important sources of copper, molybdenum, and gold.

Dolomite - a carbonate of calcium and magnesium, $CaMg(CO_3)_2$, used primarily as a refractory in the steel industry.

Drilled pier and grade beam - a type of foundation in which the weight of the building is transmitted to the soil through walls resting on horizontal, reinforced-concrete beams (grade beams), which are in turn resting on vertical reinforced-concrete posts (drilled piers or "caissons") placed in drilled holes; more usually designed for highly swelling clays than spread footing, bearing wall, or pad foundations because loads can be concentrated on the small bottom end of the drilled piers.

Dry unit weight - the ratio of the oven-dried weight of a soil sample to its original wet volume; also called "dry density."

Earthflow - type of slope movement and process characterized by downslope translation of soil and weathered rock over a discrete basal shear surface within well defined lateral boundaries in which the internal motions of the flowing mass approaches those of viscous fluids. Earthflows grade into mudflows through a continuous range in morphology associated with increasing fluidity.

Earthquake resistant construction - construction that can tolerate the motions (vertical and horizontal) induced by an earthquake without serious ill effects.

Equilibrium - in geology, a balance between physiographic form and process, or between disturbing force and resistance.

Erosion - the wearing away of rock or soil and the movement of the resulting particles by wind, water, ice, or gravity.

Evaporite mineral - a sedimentary mineral that is deposited from an aqueous (water) solution as a result of extensive or total evaporation of the water, e.g., Bonneville Salt Flats, also including gypsum and potash.

Fault - a surface or zone of rock fracture along which movement or displacement of the rocks on either side is parallel to the zone or surface.

Floating slab - a type of interior concrete floor slab commonly used for basements and garages in which the slab is poured separately from bearing walls and is isolated with joints or void spaced from all bearing walls, columns, stairs, utility lines, and interior partitions; the slab is isolated to allow movement of the slab without damaging the structural components of the building.

Flowage - an irreversible and permanent deformation of rocks without fracture; deformation may be plastic, viscoelastic, or viscous, depending on the stress conditions of the rock at the time of failure.

Fluorite - a natural calcium fluoride, CaF_2, occurring in veins commonly associated with metallic ores. Also known as fluorspar, it is used as a flux in the steel industry and in the production of glass and enamel. Also an important source of fluorine gas for the production of hydrofluoric acid.

Formation - (geologic) - the ordinary unit of geologic mapping recognizable by field criteria consisting of a large, persistent and mappable strata of predominately one kind of rock.

Frac sand - graded sand that is mixed with various fluids and additives and injected into a rock formation under high pressure to hold fractures open and increase permeability for oil and gas production.

Gamma ray - very short wavelength electromagnetic radiation emitted from an atomic nucleus and usually accompanying the emission of alpha and beta particles.

Grade - the classification of an ore according to the proportion of desired to worthless material in it or according to market value.

Gradient - the slope of a stream measured in the direction of flow, generally measured in feet (vertical drop) per mile (horizontal distance); the angle formed between a slope and a horizontal line generally measured in degrees or percent.

Gravel - rounded rock fragments larger than sand (1/12 in. or 2 mm dia), including cobble- and boulder-sized material.

Ground response - refers to the alteration in amplitude and frequency of seismic waves as they interact with shallow soil, rocks and ground water of a specific site. Different ground response due to varying geologic site conditions accounts for wide local variations of intensity that are frequently noted for a given earthquake.

Ground water - that part of the subsurface water that is in the zone of saturation.

Ground water table - the upper surface of the water-saturated zone in the ground; also, the shallowest point at which water will flow into a well.

Gypsum - hydrated calcium sulfate, $CaSO_4 \cdot 2H_2O$, the most common sulfate mineral found in Colorado soils; corrosive to ordinary concrete.

Hydrocompaction - a property of some dry, unconsolidated deposits to undergo, after wetting, spontaneous compaction, settling and cracking. Commonly this occurs in areas that are normally dry, but are subjected to abnormal wetting from sewage disposal systems, stream diversions, irrigation systems, or water-carrier breakage.

Igneous - refers to processes of intrusion into country rock of molten rock masses or extrusion of molten rock out onto the ground surface; rocks formed from the cooling of molten rock.

Intensity (earthquake) - a measure of the effects of an earthquake at a particular place on humans and/or structures. The intensity at a point is dependent not only upon the earthquake magnitude* but also on distance from the earthquake and the local geology at the point.

Isotope - any of two or more atoms of a chemical element with the same atomic number and nearly identical chemical behavior, but with differing atomic mass (weight).

Joint - a crack (parting or fracture) formed in rock by movements normal to the cracks and without shear movements (displacement) of the rock on either side of the crack.

Kaolin - a light clay rock produced by the decomposition of rocks of high feldspar content and used in the manufacture of porcelain; contains high percentages of the clay mineral kaolinite.

Lightweight aggregate - all minerals used as aggregate that are suitable for use in producing a concrete that weighs from 70 to 100 lb/ft^3.

Limestone - a sedimentary rock containing more than 50% calcium or magnesium carbonate and that effervesces (bubbles) when in contact with dilute hydrochloric acid.

Lode - several veins spaced closely enough so that all of them, together with the intervening rock, can be mined as a unit.

Loess - a wind-deposited unstratified, unconsolidated, blanket-like surficial deposit consisting primarily of silt, and generally yellowish-brown in color. It is generally found as a mantle, as thick as 25 or 30 ft, covering gentle hillslopes and uplands. Undisturbed loess may stand unsupported in very steep or vertical faces.

Magnitude (earthquake) - a measure of the strength of an earthquake or the strain energy released by it as determined by standardized seismographic observations and calculations.

Metamorphic - refers to processes that change the form and composition of rocks and minerals under conditions of heat and pressure; rocks formed by changes due to heat and pressure, although heat and pressure are not high enough to melt rock.

Metastable; metastable equilibrium - a delicate, easily changed condition where movement can be initiated by slight upset of the natural state.

Mining of ground water - withdrawal by man of water from ground water storage areas (aquifers) for an extended period of time at a rate greater than the replacement (recharge) rate for the aquifer. Although renewable over a long time period (thousands of years), over the shorter term (several generations) ground water may be depleted in the same way mineral resources may be depleted.

Mitigate - to make less severe.

Montmorillonite - a clay mineral composed of loosely bonded silica layers that may be expanded by the absorption of water molecules; the most highly swelling of the clay minerals; often locally called "bentonite."

Mudflow - a general term for a mass-movement landform and a process characterized by a flowing mass of predominantly fine-grained earth material possessing a high degree of fluidity during movement. With increasing fluidity, mudflows grade into loaded and clear streams; with a decrease in fluidity, they grade into earthflows.

Ore - a natural mineral aggregate of which one at least is a metal that can be extracted at a profit; applied more loosely to all metalliferous rock, though it contains the metal in a free state, and occasionally to the compounds of nonmetallic substances.

Pad - a type of foundation on which the weight of the building is transmitted to the soil through bearing walls resting on columns or grade beams which are in turn resting on flat, rectangular, reinforced-concrete pads which rest on the ground; generally used in large buildings rather than single-family residences.

Pegmatite - a coarse-grained igneous rock found usually as dikes associated with a large mass of intrusive rock. Some contain rare minerals rich in such elements as lithium, boron, fluorine, niobium, tantalum, uranium, and rare earths.

Perched water table - a water-saturated zone that is separated from the underlying water table by a zone of tight (impermeable) rock through which water cannot flow.

Percolation - a flow of water, usually downward, by force of gravity or under pressure through small openings (pores) within a porous material such as soil or certain sedimentary rocks.

Peripheral drain - also called a "footing drain;" open-jointed clay tile or perforated plastic pipe laid in a trench beside the foundation of a structure and covered with coarse gravel backfill; aids in preventing swell or settlement by collecting water near the foundation and draining the water away through "French drains" (gravel fill) or by "daylighted drains" (tile or pipe discharging onto a slope below the level of the peripheral drain).

Perlite - a volcanic glass that upon heating expands to form a light fluffy material similar to pumice and useful for lightweight aggregate, insulation, or for catalyst support.

Permeability test - a test that measures the rate of flow of water through a cross-sectional area of a cylindrical soil or rock specimen under known hydraulic head.

Piping - erosion by percolating water in a layer of subsoil, resulting in caving and in the formation of narrow tunnels, or "pipes," through which soluble or transportable granular soil material is removed.

Plasticity index - the difference in water content between the liquid limit and the plastic limit (see "Atterberg limits").

Possible ore - a class of ore whose existence is a reasonable possibility, as based primarily upon the strength and continuity of geologic-mineralogic relationships and upon the extent of ore bodies already developed, and a measure of whose continuity is therefore available as a criterion of what may be expected as mining excavations progress into further reaches. Because of the comparative absence of mine workings which would reveal assay values, possible ore cannot be assigned a grade with any practicable certainty nor can the quantity be expressed as a definite absolute amount.

Probable ore - a class of ore whose occurrence is for all essential purposes assured but not absolutely certain. A definite grade can be assigned to the tons thus classified, but mining excavations have not progressed to the stage where the probable tons are available to current mining, although the tonnage could become ready for withdrawal in a relatively short time. The grade assigned to many probable ore blocks may be the grade determined for contiguous developed blocks. Some probable ore thus distinguished may be the essential couterpart of some measured ore as classified under the governmental plan.

Probable reserve - areas of coal or mineral lying beyond the developed reserves but still close enough to be considered proved within ordinary probability. Where the acreage of probable reserves is known from maps or surveys, the tonnage of coal may be calculated as: 1) theoretical tonnage = 101.37 x spec. gravity of coal; and 2) workable tonnage - deduct 10 to 20 percent or more according to geological report and the area's known consistency.

Proved ore - ore where there is practically no risk of failure of continuity.

Proved reserve - ore deposit which has been reliably established as to its volume, tonnage, and quality by approved sampling, valuing, and testing methods supervised by a suitably qualified person. The proved reserve is the overridingly important asset of the mine, and by its nature is a wasting one from the start of exploitation save insofar as it is increased by further development.

Pumice - a light, cellular, glassy, volcanic rock used as lightweight aggregate, abrasive, and in stucco plaster.

Quartzite - 1) orthoquartzite - a sandstone in which the grains are cemented by precipitated silica; used mainly as a building stone; 2) metaquartzite - a tough, durable metamorphic rock derived from sandstone and used as construction aggregate.

Radium - a radioactive, white, metallic element that resembles barium chemically. Radium occurs as compounds in minute quantities in uranium minerals such as pitchblende or carnotite, and it emits alpha particles and gamma rays as it decays to form radon.

Rare earths - a group of 16 metallic elements, all but one of which have atomic numbers between 57 and 71. They include yttrium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dyprosium, holmium, erbium, thulium, ytterbium, and lutetium. They have a wide range of uses that include alloying agents, refractories, ceramic coatings, fluorescent and mercury-vapor lamps, nuclear shields, and control rods, glass decolorizers, electronic parts, catalysts, and chemical processing.

Refractory - a nonmetallic material, usually a clay or high-alumina mineral, with a high melting point, suitable for furnace construction. Also used to resist abrasion, chemical attack, and rapid temperature changes.

Rockfall - the relatively free falling or precipitous movement of a newly detached segment of bedrock of any size from a cliff or other very steep slope; it is one of the fastest moving types of slope movement and is a frequent occurrence in mountain areas especially during spring when there is repeated freezing and thawing.

Sand - a rock or mineral particles larger in diameter than silt (0.0025 in. or 0.0625 mm in geologic literature, or 0.003 in. or 0.074 mm in engineering literature) and smaller in diamter than gravel (1/12 in. or 2 mm).

Scoria - irregular, rough, clinker-like volcanic rock or debris used as lightweight aggregate, building stone, and roofing aggregate.

Sedimentary - materials formed by the deposition of particles (gravel, sand, silt, or clay) or precipitation of chemicals (calcium carbonate "lime," sodium chloride "salt" etc.) by water, wind or ice, e.g., sandstone, shale, limestone.

Seiche - a periodic free oscillation of a body of water whose period is determined by the resonant characteristics of the containing basin as controlled by its shape and physical dimensions. Seiching can be initiated by meteorological changes or by earthquakes. Periods vary from a few minutes to several hours and their height from several centimeters to several meters, the oscillations of the water surface continues pendulum fashion for a time after cessation of the originating force.

Seismic - pertaining to earthquakes or earth vibrations, including those that are man-made, e.g., explosions, underground nuclear blasts.

Seismicity - the phenomenon of earthquakes, their distribution and characteristics.

Seismic zonation - classification of a region at different levels of risk based on seismic history and geological studies. Seismic zonation maps are necessarily imperfect and are periodically revised to reflect new data and evaluations. Such maps are frequently incorporated in building codes.

Shrinkage limit - the moisture content below which no volume change will occur.

Silt - rock or mineral particles larger in diameter than clay (0.002 mm) smaller in diameter than sand (0.0025 in. or 0.065 mm in geologic literature, or 0.003 in. or 0.074 mm in engineering literature).

Slide mass - that material which moves as a result of failure of earth, snow or rock under shear stress along one or several surfaces that are either visible or may be reasonably inferred.

Soil - in engineering work a soil is any earthen material, excluding hard bedrock, composed of 1) loosely bound mineral and orgainic particles, 2) water, and 3) gases. In agriculture, a soil is the loose surface material capable of supporting plant growth, and having properties resulting from the integrated effect of climate and living matter on the decomposition of bedrock surficial deposits.

Spread footing - a type of foundation in which the weight of the building is transmitted to the soil through bearing walls supported on concrete strips which are wider than the bearing wall; may be "continuous" or "discontinuous," with discontinuous being similar to pads.

Stabilometer (R-value) test - a test in which a remolded, compacted, cylindrical soil specimen enclosed in an air-filled compression chamber is tested for resistance to a one-dimensional (axial) load.

Stereoscope - an inexpensive optical instrument used to obtain the mental impression of a three-dimensional image while viewing two overlapping aerial photographs.

Strain energy (earthquake) - that energy stored in rocks along a fault zone due to deformation caused by stress. The sudden release of this strain causes an earthquake. This is analagous to the energy stored in a spring as it is deformed and then released.

Stress - the internal force per unit area acting on any surface within a solid, generally expressed in pounds per square inch or newtons per square meter; also, the external pressure which creates the internal force.

Surficial deposits - unconsolidated residual, alluvial, eolian, gravity, or glacial deposits lying on bedrock or occurring on or near the Earth's surface, such deposits may be unstratified and represent the most recent of geologic deposits.

Suspension - a mode of sediment transport in which the upward currents in eddies of turbulent flow are capable of supporting the weight of undissolved sediment particles.

Tailings - waste material from mines and mills, including gangue and other refuse material, and portions of washed ore that are too poor to be treated further.

Talus - the sloping deposit of rock fragments formed at the base of a steep slope or cliff by falling, rolling, or sliding of rock from the slope.

Talus slope - the steep upper surface of a talus deposit.

Tectonics - a branch of geology dealing with the broad architecture of the upper part of the Earth's crust.

Thorium - a radioactive metallic element sometimes found in nature in granite and pegmatite, generally in association with rare-earth minerals.

Triaxial shear test - a test in which a cylindrical specimen of soil or rock encased in a waterproof jacket is subjected to a three-dimensional confining pressure (generally by immersion in a water- or oil-fill pressure chamber) and then compressed in one dimension (axial load) until the specimen fails by fracture or flowage.

Turbulent flow - a fluid flow in which the velocity at a given point varies erratically in magnitude and direction.

Unconfined compression test - a test in which an unjacketed, unconfined cylindrical specimen of soil or rock is compressed in one dimension (axial load) until the specimen fails by fracture or flowage.

Uranium - a silvery, heavy, radioactive metallic element found in the minerals pitchblende and uraninite.

Vein - a zone or belt of mineralized rock lying within boudaries clearly separating it from neighboring rock. It includes all deposits of mineral matter found through a mineralized zone or belt coming from the same source, impressed with the same forms, and appearing to have been created by the same processes.

Vermiculite - a hydrated magnesium-aluminum silicate that is formed by the alteration of basic igneous rocks. When heated, it expands and is suitable for use as insulation, lightweight aggregate, fire-retardent plaster, and refractories.

Viscous - thick fluid-like behavior of a material. A very low viscosity material would flow like water, intermediate like oil, and high like grease or honey.

Weathering - the destructive processes - physical disintegration and chemical decomposition that change rock into loose rock fragments and soil; caused by water, wind, ice, and chemical and biological agents, e.g., salt solutions, plant roots, burrowing animals.

Welded tuff - volcanic ash that has been indurated by heat and hot gases.

Workable - a coal seam or ore body of such thickness, grade, and depth as to make it a good prospect for development. In remote and isolated locations, other factors would influence its workability, such as access, water supply, transport facilities, and other factors.

Zone of seasonal moisture change - the upper portion of an engineering soil in which the moisture content varies with the season, i.e., high moisture content during the wet spring, lower moisture content during the dry summer.

IX. APPENDIX: MODEL GEOLOGIC HAZARD AREA CONTROL REGULATIONS

PREFACE

The following Model Regulations for identification, designation and control of land use in Geologic Hazard Areas were prepared by the Colorado Geological Survey in accordance with statutory charges contained in HB-1041. Whereas, at least to our knowledge, comparable laws or regulations dealing with geologic hazard areas have never been written, this has been a pioneer effort. However, since laws, regulations, and administrative procedures for flood plain hazard areas have been developed and tested during the past, we have drawn heavily upon the language of tested flood plain regulations in drafting these Model Regulations. We have also utilized certain of the administrative and review procedures now being successfully used in SB-35.

To meet the very critical need of controlling the quality of designs and construction in geologic hazard areas where development is allowed, we have recommended adoption of Chapter 70 of the Uniform Building Code. As with SB-35, Chapter 70 places responsibility for sound design and construction upon the proponent of the activity and his professional consultants. However, it is much more detailed and specific in requirements for safe construction than is required for "routine" SB-35 developments.

Preliminary drafts of this Regulation have been circulated to many interested parties in local government, the legislature, state agencies, consultants, industry, and the Attorney General's staff. Their many and varied comments and suggestions were appreciated, and all were given serious consideration. Many could not be implemented. For example, we could not be briefer as some suggested and be more detailed as other suggested.

The preceding Guidelines should explain many of the features in these model regulations and explain many of the reasons and needs for land use controls in Geologic Hazard Areas. The Guidelines and the Model Regulations should aid local government in its legislative charge to identify, designate and administer land use in geologic hazard areas. As indicated in the Model Regulations and the Guidelines, the Colorado Geological Survey will furnish advice and counsel to local government in the various aspects of implementing those portions of HB-1041 pertaining to Geologic Hazards and Mineral Resource Areas.

MODEL GEOLOGIC HAZARD AREA CONTROL REGULATIONS

Prepared by:
Colorado Geological Survey

WHEREAS, authority for the governing body of a municipality or a county to adopt, amend, repeal, enforce and otherwise administer under the police power reasonable Geologic Hazard Area Land Use Control Regulations and orders pertaining to land use within the areas of its jurisdiction is contained in Section 1, Chapter 106, Article 7, C.R.S. 1963 as amended, and

WHEREAS, the uncontrolled use of lands within geologic hazard areas within the jurisdiction's boundaries adversely affects the public health, safety and welfare of the citizens of the county (municipality), and

WHEREAS, the governing body of a municipality or county is empowered by Section 1, Chapter 106, Article 7, C.R.S. 1963 as amended, to designate and administer areas of state interest in a manner that will minimize significant hazards to public health and safety or to property due to a geologic hazard, and

WHEREAS, geologic hazards are declared to be matters of state interest and are defined by Chapter 106, Article 7, C.R.S. 1963 as amended, to include but not be limited to avalanches, landslides, rockfalls, mud flows, unstable or potentially unstable slopes, seismic effects, radioactivity and ground subsidence;

WHEREAS, a public hearing on the Geologic Hazard Area Control Regulations proposed by the county (municipality) has been held at which any person having an interest therein had an opportunity to be heard as required in Section 1, Chapter 106, Article 7, C.R.S. 1963 as amended;

WHEREAS, the Board of County Commissioners (City Council) has with due consideration determined said Geologic Hazard Area Control Regulations to be necessary to execute the legal duties imposed upon the county (municipality) by Section 1, Chapter 106, Article 7, C.R.S. 1963 as amended;

NOW, THEREFORE, the Board of County Commissioners (City Council) does enact the following Geologic Hazard Area Control Regulation:

SECTION 1.0 PURPOSES

To promote the public health, safety and general welfare, to minimize the effect of significant hazards to public health and safety or to property due to a geologic hazard by the proper administration of all land use changes within such geologic hazard areas, and to promote wise use of geologic hazard areas. This Geologic Hazard Area Control Regulation has been established with the following purposes intended:

1.1 To reduce the impact of geologic hazards to life and property by:

  1.11 Prohibiting certain land uses which are dangerous to life or property in areas of geologic hazard;

  1.12 Restricting the uses which would be hazardous to the public health or property in geologic hazard areas;

  1.13 Restricting the uses which are particularly vulnerable to geologic hazards so as to alleviate hardship and reduce the demands for public expenditures for relief and protection.

  1.14 Requiring permitted land uses in geologic hazard areas, including public facilities which serve such uses, to be protected from geologic hazards by providing for geologic hazard investigation and the avoidance of or mitigation of such hazard impacts at the time of initial construction.

  1.15 Adopting Chapter 70 of the Uniform Building Code (1973 Edition) for the regulation of excavation and grading of lands, with respect to the management of lands in Geologic Hazard Areas, with the further requirement that soil engineering reports and engineering geology reports specified in Section 7015 (a) of said Chapter 70 shall be mandatory for all grading, filling and construction on lands within geologic hazard areas.

1.2 To protect geologic hazard area occupants or users from the impacts of geologic hazards which may be caused by their own, or other, land use and which is or may be undertaken without full realization of the danger by:

  1.21 Regulating the area in which, or the manner in which, structures designed for human occupancy may be constructed so as to prevent danger to human life or property within such structures;

  1.22 Designating, delineating and describing areas that could be adversely affected by geologic hazards so as to protect individuals from purchasing or improperly utilizing lands for purposes which are not suitable.

1.3 To protect the public from the burden of excessive financial expenditures from the impacts of geologic hazards and relief by:

1.31 Regulating land uses within geologic hazard areas so as to produce a pattern of development or a soundly engineered manner of construction which will minimize the intensity and/or probability of damage to property and loss of life or injury to the inhabitants or the users of geologic hazard areas.

1.32 Regulating the cutting, filling, or drainage changes and other man-made changes which could initiate or intensify adverse conditions within geologic hazard areas.

1.33 Encouraging such uses as agriculture, grazing, greenbelt, open space and recreation within geologic hazard areas.

SECTION 2.0 GENERAL PROVISIONS

2.1 Jurisdiction: This Regulation is applicable to all lands within Designated Geologic Hazard Areas within the county (municipality).

2.2 Boundaries: The boundaries of the Designated Geologic Hazard Areas shall be as they appear on the official recorded Designated Geologic Hazard Area Maps as adopted by the County Commissioners (City Council) and kept on file with the County (municipality) Planning Director. A copy of the official maps shall also be kept on file in the office of the Colorado Geological Survey, Denver, Colorado. The boundary lines on the map shall be determined by the use of the scale appearing on the map. Where there is a conflict between the boundary lines illustrated on the map and actual field conditions, or where detailed investigations show that hazardous conditions are not significant throughout the entire designated area, the dispute shall be settled according to Section 5.5 "Mapping Disputes" of this Regulation.

2.3 Interpretation: In their interpretation and application, the provisions of this Regulation shall be held to be minimum requirements and shall be liberally construed in favor of the governing body, and shall not be deemed a limitation or repeal of any other powers of the county (municipality). Interpretations of this Regulation shall be consistent with GUIDELINES AND CRITERIA FOR GEOLOGIC HAZARD AREAS prepared by the Colorado Geological Survey[1]

2.4 Warning and Disclaimer of Liability: The degree of protection from geologic hazards intended to be provided by this Regulation is considered reasonable for regulatory purposes, and is based on accepted geologic and scientific methods of study. This Regulation is intended to minimize the dangers, costs and impacts from geologic hazards. Therefore, unforeseen or unknown geologic conditions or natural or man-made changes in conditions such as climate, ground water, drainage, or structural strengths of the rocks and other geologic materials may contribute to future damages to structures and land uses even though properly permitted within Designated Geologic Hazard Areas. This Regulation does not imply that areas outside Designated Geologic Hazard Area boundaries or land uses permitted within such areas will always be totally free from the impact of geologic hazards. This section shall not create a liability on the part of or be a cause of action against the county (municipality) or any officer or employee thereof, or the Colorado Geological Survey or any employee thereof for any personal or property damage that may result from reliance on this Regulation or from damages occurring in areas which for any reason have not been officially designated as Geologic Hazard Areas.

2.5 Adoption of Official Maps: The location and boundaries of the Designated Geologic Hazard Areas established by this Regulation are shown upon the official Designated Geologic Hazard Area Maps of the county (municipality) which are hereby incorporated into this Regulation. The said maps and all amendments thereto shall be as much a part of this Regulation as if fully set forth and described herein. Each change in the official maps shall be subject to the Amendment procedure as required in Section 5.5 "Map Disputes" and Section 7 "Amendments."

SECTION 3.0 NON CONFORMING USES

3.1 The existing lawful use of land, structures, or premises which is not in conformity with the provisions of this Regulation may be continued subject to the following conditions:

3.11 No such land use shall be changed, expanded or enlarged, except in conformity with the provisions

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[1] Guidelines and Criteria for Identification and Land Use Controls of Geologic Hazard and Mineral Resource Areas. S.P. NO. 6

of this Regulation.

3.12 No structural alteration, addition or repair to any nonconforming structure over the life of the structure shall exceed fifty (50) percent of its assessed value at the time of its becoming a nonconforming use unless permanently changed to a conforming use.

3.13 If such use is discontinued for twelve (12) consecutive months, after adoption of these Regulations, any future use of the land, structures and premises shall conform to this Regulation.

3.14 Uses or adjuncts thereof which are nuisances, or which significantly increase the severity of geologic hazards and create an increasingly severe impact on current or proposed land use in or adjacent to a Designated Geologic Hazard Area, shall not be permitted to continue as nonconforming uses.

3.15 Any alteration, addition, or repair to any nonconforming structure or significant change in land use permitted pursuant to Section 3.12 of this Regulation shall be designed to minimize, mitigate or avoid the significant adverse impact of geologic hazards.

SECTION 4.0 DESIGNATED GEOLOGIC HAZARD AREAS

4.1 Application: Provisions of this Regulation apply to all Geologic Hazard Areas for which appropriate identification and evaluation have been made, which have been reviewed by the Colorado Geological Survey and which have been designated by the Board of County Commissioners (City Council).

4.2 Description of Designated Geologic Hazard Areas: The Designated Geologic Hazard Areas shall include the area delineated on the official maps which have been reviewed by the Colorado Geological Survey, adopted by the Board of County Commissioners (City Council) and kept on file and available in the office of the County (municipal) Planning Director and the office of the Colorado Geological Survey.

4.3 Description of Permitted Uses: The following open uses shall be permitted within Designated Geologic Hazard Areas to the extent that they are not prohibited in a particular area by any county or municipal zoning ordinance or regulation.

4.31 Agricultural uses such as general farming, grazing, truck farming, forestry, sod farming and wild crop harvesting;

4.32 Industrial-commercial uses such as loading areas, parking areas not requiring extensive grading or impervious paving, and storage yards for equipment or machinery easily moved or not subject to geologic hazard damage.

4.33 Public and private recreational uses not requiring permanent structures designed for human habitation such as parks, natural swimming areas, golf courses, driving ranges, picnic grounds, wildlife and nature preserves, game farms, shooting preserves, target ranges, trap and skeet ranges and hunting, fishing, skiing and hiking areas if such uses do not cause concentrations of people in areas during periods of high hazard probability.

SECTION 5.0 ADMINISTRATION

5.1 Designated Geologic Hazard Area Administrator: The County (municipal) Planning Director (Land Use Administrator) shall administer the provisions of this Regulation. When necessary, he shall call upon the Colorado Geological Survey to provide technical and scientific assistance in administering the provisions of this Regulation.

5.2 Application for Development Permit: Any person, company or corporation desiring to undertake development or to make land use changes in a Designated Geologic Hazard Area shall file an application for a permit with the County (municipal) Planning Director. The application shall be filed on a form prescribed by the Colorado Land Use Commission. Reasonable fees for this permit will be ____________________. These shall be set sufficient to cover the cost of processing the application including the cost of holding the necessary hearings. Such fee shall be paid at the time of filing such application.

5.22 Application for Development Permit: An application for development permit shall include:

(a) An index map showing the general location of the permit area and its relationship to surrounding topographic and cultural features. A standard U.S.G.S. quadrangle map would usually be adequate.

(b) A topographic map or maps showing location, nature and density of the proposed development or land use change. Such maps shall be on a scale sufficiently detailed to meet the objectives of this Regulation but, in no case, shall be less detailed than 1 inch = 500 feet.

(c) A map or maps portraying the geologic conditions of the area with particular attention given to the Designated Hazard conditions and those geologic, hydrologic, soil and topographic factors affecting geologic hazard conditions. If appropriate or needed, subsurface geologic cross sections shall also be utilized to portray such conditions at depth. Such maps shall also show the topography with a contour interval of 10 feet or smaller. Such maps shall be on a scale sufficiently detailed to meet the objectives of this Regulation but, in no case, less detailed than 1 inch = 500 feet. If possible, the geologic maps shall be at the same scale and format as the development plan maps.

(d) All maps shall show a true north arrow and shall show section corners and the appropriate land grid.

(e) A geologic report explaining the above maps and cross sections with particular emphasis on evaluating and predicting the impact of such geologic or hazardous conditions on the proposed land use changes and developments. It shall also include recommended mitigating procedures to be employed in meeting the purposes of this Regulation.

(f) All geologic maps and reports prepared under this Regulation shall be prepared by or under the responsible direction of and signed by a professional geologist (as defined by Chapter 51, Article 3, C.R.S. 1963 as amended) who also has adequate experience in the specialty of "engineering geology."

(g) All engineering work prepared under the requirements of this Regulation shall be prepared by or under the responsible charge of a registered professional engineer as defined in Chapter 51, Article 1, C.R.S. 1963 as amended.

Such engineer shall also be experienced and competent in the engineering specialty required to meet the objectives of this Regulation.

(h) The applicant, in narrative, pictorial or graphic form shall explain the nature, density and intensity of the proposed development or land use change, and shall explain mitigation procedures which will be needed and are planned to carry out the objectives of this Regulation.

(i) The geological reports required by Chapter 106-2-34 C.R.S. 1963 as amended (Senate Bill 35) need not be duplicated to meet the requirements of this Regulation.

5.23 Exemptions: This Regulation shall not apply to any development which meets any one of the following conditions as to the effective date of this Regulation (____________________):

(a) The development or activity is covered by a current building permit issued by the appropriate local government; or

(b) The development or activity has been approved by the electorate; or

(c) The development or activity is to be on land:

(I) which has been conditionally or finally approved by the appropriate local government for planned unit development or for a use substantially the same as planned unit development; or

(II) which has been zoned by the appropriate local government for the use contemplated by such development or activity; or

(III) with respect to which a development plan has been conditionally or finally approved by the appropriate governmental authority.

5.3 Permit review:

5.31 Not later than 30 days after receipt of a completed application for a permit, notice of a public hearing on said application shall be published. Such publication shall be at least once in a newspaper of general circulation in the County (municipality), not less than 30 or more than 60 days before the date set for hearing. Such notice shall also be given to the Colorado Land Use Commission. The County Commissioners (City Council) shall preside over such public hearing. The County (municipal) Planning Commission and Planning staff shall participate in such hearing which could be held in conjunction with a regularly scheduled Planning Commission hearing.

5.32 Upon receipt of a complete application for development, the county (municipality) shall forward a complete copy of such application together with maps and plans to the Colorado Geological Survey for review and recommendations. It shall also include any additional available information pertinent to the application. It shall notify the Colorado Geological Survey of the date of the proposed hearings on said application, and shall request the Colorado Geological Survey to make its reviews and recommendations on said application to the County Commissioners (City Council) by a date ten (10) days prior to the public hearing.

5.33. If a person proposes to undertake any development in a known area of significant geologic hazard which has not been previously Designated, and for which guidelines or regulations have not been adopted, the county (municipality) may hold one hearing for the determination of Designation and guidelines and the granting or denying of the permit.

5.4 Permit Approval or Denial:

5.41 Deliberations on the application shall include but not be limited to:

(a) Objectives and definitions of Chapter 106, Article 7, C.R.S. 1963 as amended;

(b) Guidelines and criteria promulgated and distributed by the Colorado Geological Survey;

(c) The geologic and other technical information presented by the applicant;

(d) Recommendations of the Planning Commission;

(e) Recommendations of the Planning staff;

(f) The recommendations of the Colorado Geological Survey;

(g) Any other available pertinent geological or technical information;

(h) The severity of hazardous conditions and the future effect of those conditions on the proposed development;

(i) The intensity and character of the proposed development and its future effect on those hazardous conditions;

(j) Relationship between (h) and (i) above and the related potential impact upon future users of the subject and adjacent or affected lands.

5.42 A complete record of such proceedings shall be made and preserved.

5.43 The county may approve a permit to allow a development in a Designated Geologic Hazard Area if the proposed development complies with the objectives of Chapter 106, Article 7, C.R.S. 1963 as amended, and with the Guidelines and Regulations governing such Geologic Hazard Areas. If the proposed development does not comply with the objectives of Chapter 106, Article 7, C.R.S. 1963 as amended, the Guidelines and these Regulations, the permit shall be denied.

5.44 Within forty-five (45) days after conclusion of hearings on the Development Application Permit, the county (municipality) shall render a decision as to approval or denial. It shall state in writing reasons for its decision and its findings and conclusions, and shall provide timely transmittal of its findings to the applicant, the Colorado Land Use Commission and the Colorado Geological Survey.

5.45 After the effective date of this Regulation, any person desiring to engage in a development in a Designated Geologic Hazard Area who does not obtain a permit pursuant to this Regulation may be enjoined by the Colorado Land Use Commission or the appropriate local government from engaging in such development.

5.46 The denial of a permit by a local governmental agency shall be subject to judicial review in the district court for the judicial district in which the proposed development was to occur.

5.5 Mapping Disputes: The following procedure shall be used by the County Commissioners (City Council) in deciding contested cases in which the boundary of a Designated Geologic Hazard Area is disputed or in cases where because of local, detailed circumstances, the designated hazard condition does not present a significant hazard to public health, safety or to property at the specific location for the particular proposed land use.

5.51 In all cases, a person contesting the location of the Designated Geologic Hazard Area boundary or the severity of conditions at a specific location within the Designated Geologic Hazard Area shall be given a reasonable opportunity to present his case to the Board (council) and shall submit technical and geologic evidence to support such contest. The Board shall not allow deviations from the boundary line as mapped or non-permitted land uses within the boundary areas unless technical and geological evidence clearly and conclusively establishes that the map location of the line is incorrect, or that the Designated Hazard conditions do not present a significant hazard to public health, safety or to property at the specific location within the hazard area boundary for the particular proposed land use.

SECTION 6.0 ENFORCEMENT AND PENALTIES

6.1 Every structure, building, excavation, drainage change, fill or development constructed, placed, or maintained within any Designated Geologic Hazard Area in violation of this Regulation is a public nuisance, and the creation thereof may be enjoined and maintenance thereof may be abated by action at suit of the City, Town, or County in which it is located or by the County Commissioners (City Council) or any citizen thereof. Any person who places, constructs, or maintains any structure, building, fill, excavation, drainage change or development within any Geologic Hazard Area in violation of this Regulation may be fined not more than Three Hundred Dollars ($300) or imprisoned for a period of time not to exceed ninety (90) days for each offense. Each day during which such violation exists is a separate offense.

SECTION 7.0 AMENDMENTS

7.1 The Board of County Commissioners (City Council) may from time to time alter, supplement or change the Designated Geological Hazard Area boundaries and the provisions contained in this Regulation in the manner provided by law.

7.2 Amendments to this Regulation may be made on petition of any interested party to the County Commissioners (City Council). Amendments shall undergo the same procedures for adoption as followed for original designation.

SECTION 8.0 SEVERABILITY

8.1 If any section, clause, provision or portion of this Regulation is adjudged unconstitutional or invalid by a court of competent jurisdiction, the remainder of this Regulation shall not be affected thereby.

SECTION 9.0 DEFINITIONS

Definitions of terms utilized in this Regulation shall follow definitions and usages specified in Chapter 106-7-102 and 103 C.R.S. 1963 as amended, and the Criteria and Guidelines promulgated by the Colorado Geological Survey.

SELECTED PUBLICATIONS OF THE COLORADO GEOLOGICAL SURVEY

ENGINEERING & ENVIRONMENTAL

ENVIRONMENTAL GEOLOGY 1 -- Geologic Aspects, Soils and Related Foundation Problems, Denver Metropolitan Area, Colorado, J. L. Hamilton and W. G. Owens, 1972, 20 p., $2.00.

ENVIRONMENTAL GEOLOGY 7 -- Potentially Swelling Soil & Rock in the Front Range Urban Corridor, Colorado, S. S. Hart, 1974, to be reprinted.

ENVIRONMENTAL GEOLOGY 9 -- Ground Subsidence & Land-Use Considerations Over Coal Mines in the Boulder-Weld Coal Field, Colorado, Amuedo & Ivey, Geologic Consultants, 1975, 6 plates, scale 1:24,000, $10.00.

ENVIRONMENTAL GEOLOGY 10 -- Geologic Hazards, Geomorphic Features, and Land-Use Implications in the Area of the 1976 Big Thompson Flood, Larimer County, Colorado, J. M. Soule, W. P. Rogers, and D. C. Shelton, 1976, 4 plates, scale 1:12,000, $4.00.

ENVIRONMENTAL GEOLOGY 11 -- Promises and Problems of a "New" Uranium Mining Method: In-Situ Solution Mining, R. M. Kirkham, 1979, 21 p., $3.00.

ENVIRONMENTAL GEOLOGY 12 -- Energy Resources of the Denver and Cheyenne Basins, Colorado, Development Potential and Environmental Problems, 1979, in preparation.

SPECIAL PUBLICATION 1 -- Proceedings of the Governor's First Conference on Environmental Geology, Assoc. of Engineering Geologists & American Institute of Professional Geologists, 1970, 78 p., $1.00.

SPECIAL PUBLICATION 6 -- Guidelines and Criteria for Identification and Land-Use Controls of Geologic Hazard and Mineral Resource Areas, W. P. Rogers and others, 1974, 146 p., $6.00.

SPECIAL PUBLICATION 8 -- Proceedings, Governor's Third Conference on Environmental Geology--Geologic Factors in Land-Use Planning, D. C. Shelton, ed., 1977, 111 p., $4.00.

SPECIAL PUBLICATION 12 -- Nature's Building Codes--Geology and Construction in Colorado, D. C. Shelton and Dick Prouty, 1979, 72 p., $2.00.

GEOTHERMAL ENERGY AND GROUNDWATER

INFORMATION SERIES 9 -- Geothermal Resource Development in Colorado, Processes, Promises and Problems, by B. A. Coe, 1978, 48 p., $3.00.

INFORMATION SERIES 12 -- Hydrogeologic Data Pertinent to Uranium Mining in the Cheyenne Basin, Colorado, by R.M Kirkham, W. J. O'Leary, and J. W. Werner, 1979, in preparation.

INFORMATION SERIES 13 -- Chemical Analyses of Selected Water Wells Near Proposed Coal Strip Mines, Denver Basin, Colorado, by R. M. Kirkham, and W. J. O'Leary, 1980, in preparation.

RESOURCE SERIES 6 -- Colorado's Hydrothermal Resource Base -- An Assessment, by R. H. Pearl, 1979, $3.00.

URANIUM

MAP SERIES 11 -- Uranium-Vanadium Mining Activity Map of Colorado with Directory, J. Collier, A. L. Hornbaker, and W. Chenoweth, 1978, scale 1:500,000, incl. Uravan Mineral Area 1:100,000, over-the-counter, $4.00; mailed, $5.00.

GENERAL

GEOLOGIC MAP OF COLORADO -- U.S. Geological Survey, 1935, 1 sheet, multi-colored, scale 1:500,000; reprinted by Colorado Geological Survey, 1975, $2.00 ($3.50 rolled and mailed).

MAP SERIES 13 -- State Lands Status Map, Lands and Minerals Administered by Agencies of the Colorado Department of Natural Resources, 1979, scale 1:500,000, $3.00.

BULLETIN 37 -- Bibliography and Index of Colorado Geology 1875-1975, compiled by American Geological Institute, 1976, $7.50 (soft cover); $10.00 (hard cover) (mail orders add $1.00 for each copy, postage and mailer).

COAL

RESOURCE SERIES 1 -- Geology of Rocky Mountain Coal--a Symposium, 1976, edited by D. Keith Murray, 1977, 175 p., $4.00.

RESOURCE SERIES 3 -- Colorado Coal Directory and Source Book, by L. C. Dawson and D. K. Murray, 1978, 225 p., $6.00.

RESOURCE SERIES 4 -- Proceedings of the Second Symposium on the Geology of Rocky Mountain Coal - 1977, edited by Helen E. Hodgson, 1978, 219 p., $5.00.

RESOURCE SERIES 5 -- Coal Resources of the Denver & Cheyenne Basins, Colorado, by R. M. Kirkham & L. R. Ladwig, 1979, 70 p., 5 plates, over-the-counter $7.00; mailed $8.00.

RESOURCE SERIES 7 -- Evaluation of Coking Coals in Colorado, by S. M. Goolsby, N. B. S. Reade, and D. K. Murray, 1979, 80 p., 3 plates, in preparation.

BULLETIN 34-A -- Bibliography, Coal Resources in Colorado, by R. D. Holt, 1972, 32 p., $1.00.

BULLETIN 41 -- Bibliography and Index of Publications Related to Coal in Colorado, 1972-1977, by H. B. Fender, D. C. Jones, and D. K. Murray, 1978, 54 p., $2.00.

OPEN-FILE REPORT 78-8 -- Location Map of Drill Holes Used for Coal Evaluation in the Denver and Cheyenne Basins, Colorado, by R. M. Kirkham, 1978, $3.00.

OPEN-FILE REPORT 78-9 -- Coal Mines and Coal Analyses of the Denver and Cheyenne Basins, Colorado, by R. M. Kirkham, 1978, over-the-counter, $5.00; mailed, $6.00.

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