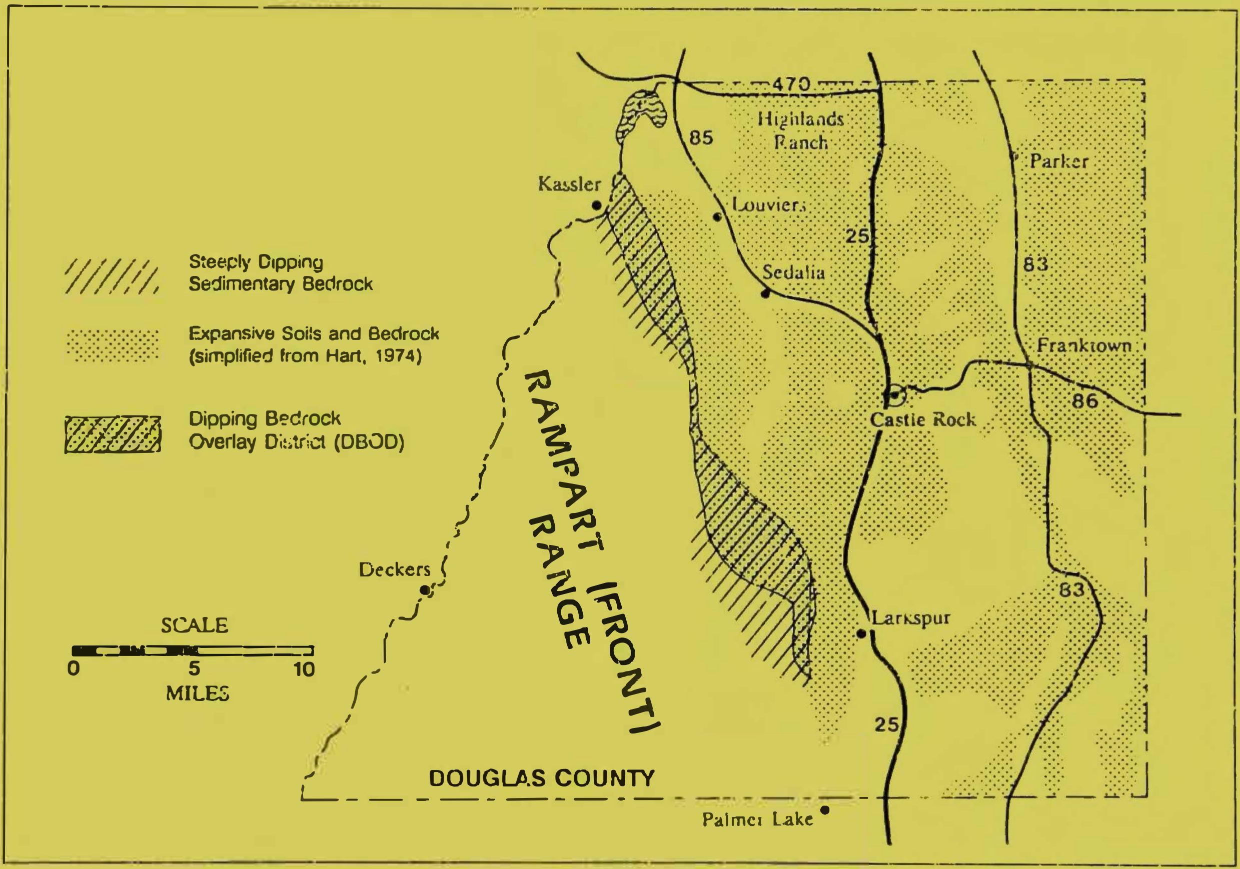
Open-File Report 95-05

The Dipping Bedrock Overlay District (DBOD):

An Area of Potential Heaving Bedrock Patterns Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado

By David C. Noe and Marilyn D. Dodson



Colorado Geological Survey
Division of Minerals and Geology
Department of Natural Resources
Denver, Colorado / 1995

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An Area of Potential Heaving Bedrock Patterns Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado

Phase 1-A of Piedmont High-Dip Shale Project

By David C. Noe and Marilyn D. Dodson

Prepared for:
The Board of County Commissioners
and
The Department of Planning and Community Development
Douglas County, Colorado

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PROJECT PERSONNEL AND ACKNOWLEDGEMENTS

Project personnel from the Colorado Geological Survey include David Noe (project manager and report author; data acquisition, preparation and interpretation), Marilyn Dodson (data acquisition, preparation and interpretation), Monica Pavlik (data acquisition and preparation) and Randal C. Phillips (GIS database and map compilation). Dr. W. Pat Rogers, Vicki Cowart, James Soule, James Cappa, and Ralf Topper provided in-house reviews of draft documents and maps.

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EXECUTIVE SUMMARY

Heaving bedrock, a distinctive geological hazard which is related to expansive soils, but is more complex in nature, is responsible for tens of millions of dollars worth of damage to homes, roadways, and utilities along the Front Range piedmont of Colorado. In Douglas County alone, several million dollars worth of damage has been incurred since suburban-type development began in the mid-1980s. Large undeveloped areas which are underlain by potentially heaving bedrock warrant special consideration during all phases of site planning and development, and, in some cases, avoidance may be the most advisable land use alternative.

There is currently a growing agreement among the region's major stake-holders (homeowners, builders, engineers, geologists, contractors, insurers, realtors, utility district operators, and national, state, and county agencies) that problem-specific regulations and minimum-standards requirements are needed in order to successfully address the heaving bedrock problem. Jefferson County recently enacted amendments specifically written for areas of potentially heaving bedrock to its land development and building regulations. Douglas County is also considering specific regulations and requirements for heave-prone areas.

The geographical area where heaving bedrock hazards are anticipated, and where problem-specific regulations and requirements are applicable, is effectively shown in the form of a geologically defined overlay map. The Colorado Geological Survey (CGS) has delineated an area of Douglas County, called the Dipping Bedrock Overlay District (DBOD), where heaving bedrock hazards are anticipated. The DBOD is based upon the overlapping presence of two regional-scale geological attributes: 1) steeply dipping sedimentary bedding, with dip angles of greater than 30 degrees from horizontal, and 2) zones of bedrock which expand when excess moisture is introduced (expansive bedrock). This report includes two 1:24,000-scale map plates and a digital data file, all of which show the DBOD. The digital database is compatible with the County's Geographic Information System (GIS) and may be used to overlay other GIS databases.

The CGS recommends that the existing land-development regulations should be significantly modified for lands within the Douglas County DBOD to address the heaving bedrock problem. The scope and intent of such regulatory changes should reflect the County's overall direction and goals. If future growth is to be allowed within the DBOD, all phases of development planning and permitting will need to be modified to ensure proper site evaluation, building and facilities design, and construction quality control. Modified regulations are also needed if future growth is to be discouraged within this area.

In Jefferson County, a similar overlay area is called the Designated Dipping Bedrock Area (DDBA). The DDBA boundaries were delineated in 1994 by the interdisciplinary Jefferson County Expansive Soils Task Force, assisted by the CGS. This report summarizes land use alternatives which were considered by Jefferson County as part of their regulation modification process for areas of heaving bedrock. The Jefferson County Expansive Soils Task Force looked at two "end-point" scenarios as a basis for new regulations and requirements, where growth is 1) discouraged, or 2) allowed but specifically regulated to ensure heaving bedrock mitigation. They recommended the second scenario, citing new mitigative technologies and the long history of allowed development within parts of the DDBA.

Several existing developments within the Douglas County DBOD are relatively unaffected, at least as of this date, by heaving bedrock. The factors controlling the distribution and magnitude of damage are complex and involve non-geological as well as geological factors. Even though a home or commercial building located within the map area may be structurally sound, extra care is warranted in evaluating it prior to purchase. When purchasing an existing house or commercial building within the DBOD, or any other area where expansive soils/bedrock are found, a buyer should have a registered structural engineer conduct a detailed evaluation of the building.

The CGS recommends that the Douglas County DBOD boundaries should be field-checked, and that the internal sedimentary formations should be tested and ranked for heaving potential, as part of the Phase 1-B study to be conducted by CGS in 1995. These investigations are necessary because available geological information is sparse for many critical localities within the Front Range piedmont area. Also, the CGS will complete a case study of the relationship between bedrock conditions, subdivision design, and performance in the Roxborough Village area, using data generated by our phase 1-A study.

PURPOSE

The purpose of the Phase 1-A project is to delineate and map the boundaries of an area containing potentially heaving bedrock in Douglas County, using all readily available sources of geological information. This area is called the Dipping Bedrock Overlay District (DBOD).

A map of the DBOD is requested by Douglas County for use as an overlay area, where problem-specific land-development regulations and minimum standard requirements may be implemented. Revisions to the existing regulations are needed to facilitate prudent planning and construction practices, and to protect County citizens from unnecessary exposure to heaving bedrock hazards. The northern part of the DBOD, in particular, is under pressure for future development due to its proximity to the mountain front and relative seclusion from the nearby Denver metropolitan area.

BACKGROUND: THE HEAVING BEDROCK PROBLEM

Historically, a high rate of damage to roads, utilities, and lightly loaded residential and commercial structures has occurred where steeply dipping beds of expansive (swelling) claystone bedrock are found in close proximity to the ground surface along Colorado's Front Range piedmont. In such areas, differential ground deformations can occur, resulting in the growth of elongate mounds or small ridges of "heaving bedrock". Individual ridges may attain sizes as large as two feet high, several tens of feet wide, and several hundreds of feet long. The cause of heaving bedrock is not well understood, but is thought to involve volume expansion from swelling of clay particles and/or unloading, as well as shearing movements among bedrock blocks. Surficial and subsurface ground deformations associated with expansive, steeply dipping bedrock are more complex in nature and difficult to predict, and the resulting damage is often more localized and destructive, than deformations and damage caused by flat-lying expansive soils and bedrock found to the east over much of the Denver metropolitan area.

Although many existing piedmont area developments are affected by heaving bedrock, there are also developments which appear to be relatively unaffected. It is possible for an individual structure showing severe damage to be flanked by undamaged structures, in part because of the linear nature of heaving. The factors controlling the distribution and magnitude of damage are complex, and involve non-geological as well as geological factors.

Heaving bedrock-caused damage is most pronounced in Jefferson, Douglas, and El Paso counties within 1–3 miles of the mountain front (Figure 1), and is responsible for tens of millions of dollars in excess maintenance costs to taxpayers and homeowners. The onset of damage typically occurs within ten years after construction. Some suburban areas have experienced recurring ground deformations and damage for nearly 20 years since being built. The Pierre Shale is the most prevalent, and heave-prone, sedimentary bedrock formation in this area. However, there is evidence that other adjacent formations are also capable of undergoing differential heave.

Most of our knowledge of differentially heaving bedrock comes from Jefferson County, where rapid, widespread suburban development (and subsequent damage) began in the mid-1970s. In contrast, Douglas County contains one subdivision filing which is significantly impacted by heaving bedrock, while several nearby filings appear to be unaffected to date. Only a fraction of the land in Douglas County that is underlain by potentially heaving bedrock has been developed.

REPORT CONTENTS

This report delineates and describes an area of Douglas County where heaving bedrock hazards are expected due to the presence of expansive, steeply dipping bedrock along the Front Range

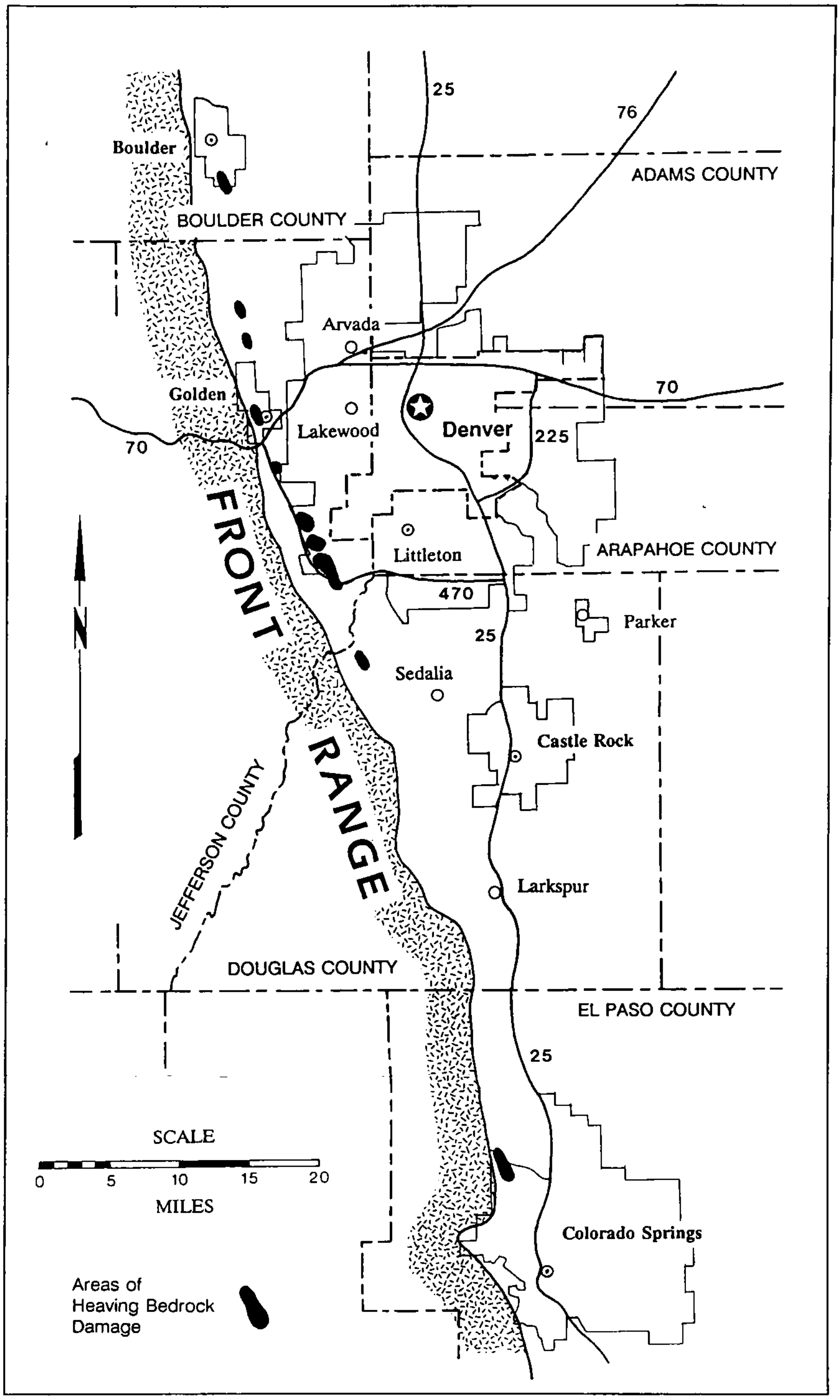

Figure 1. Base map of the Front Range piedmont in Jefferson, Douglas and El Paso Counties, Colorado, showing generalized areas (in black) where heaving bedrock damage has occurred.

piedmont. Designated the Dipping Bedrock Overlay District (DBOD), the bedrock in this area is prone to differential heaving behavior under certain geological and human-influenced conditions. The DBOD is an area which requires special and specific considerations in terms of land use planning, construction, and long-term maintenance.

The report describes methodologies, information sources, and pertinent findings used to define the DBOD boundaries. Geological results are summarized briefly and recommendations are given for land-use considerations for the DBOD. Recommendations are also given for a follow-up study which would allow field verification of the DBOD boundaries, mapping, and potential-hazards ranking of specific geological zones. The report contains a 1:50,000-scale, hard-copy map.

A technical summary written for Douglas County early in the project, titled "A Pierre Shale Primer", is included as Appendix A. The Pierre Shale Primer contains a more detailed description of key geological attributes of heave-prone areas; the morphology and potential causes of bedrock heave; engineering considerations for foundation, road, and utility design; and geological/geotechnical site-evaluation considerations. We believe that the observations and recommendations given in Appendix A remain valid, based on our latest research findings from the published geologic literature and other information sources.

METHODOLOGY AND SOURCES OF INFORMATION

The CGS compiled and reviewed all readily available sources of information concerning the heaving bedrock geological hazard along the Front Range, in order to define and delineate areas of Douglas County where heaving bedrock is anticipated. Four main sources of existing information were used: published geologic maps and reports; public-record development documents; oral descriptions and histories; and CGS experience and work files. Additionally, we conducted a field investigation of some areas of observable damage in Jefferson County. Each of these information sources, and their value toward the understanding of the heaving bedrock problem, are described below:

PUBLISHED GEOLOGIC MAPS AND REPORTS

Published technical literature, in the form of geologic maps and reports, provides the basic background information for defining areas of potential heaving bedrock hazards. The topic of heaving bedrock is extremely rare in the published literature, especially in the context of association with steeply dipping strata. However, useful information was obtained indirectly from many published geologic reports and maps by finding mention of key geological attributes—for example, bentonite beds—which are known to be present in areas where heaving bedrock damage has occurred. Because the piedmont area of Douglas County has received scant attention by geological researcher[1], it was necessary to look to nearby areas, and sometimes to nearby states, to find relevant descriptions of certain geological formations and their composition, bedding continuity, and engineering characteristics.

The published geologic literature reviewed for this project consists of over forty reports and maps, grouped into five broad categories as shown below (see bibliography for individual listings):

1) General geologic reports and maps (11 total) from the central Front Range area. These publications are used to establish the basic framework of composition, stratigraphy and areal extent of bedrock formations in Douglas County and adjoining piedmont areas to the north and south.
2) Engineering geologic reports and maps (five total) from Boulder and Jefferson counties, Colorado. These maps are the result of a project, co-sponsored by the U.S. Geological Survey (USGS) and the Denver Regional Council of Governments (DRCOG) and completed over 1969– 1980, which evaluated geological hazards and geotechnical characteristics of soil and rock units in rapidly growing areas of the central Front Range Urban Corridor.

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[1]Only four geological reports cover the sedimentary bedrock within Douglas County's piedmont area in any substantial detail: two masters theses in the Perry Park area (Robb, 1949, Malek-Asiani, 1950) and two USGS mapping reports in the Roxborough Park-Kassler area (Scott, 1963a; 1963b).

Although these reports do not cover the Douglas County area, they provide valuable data for regional-scale comparisons of engineering properties for different bedrock formations.

3) Specialty reports and maps (21 total) from Colorado which address the stratigraphy, composition and/or geological engineering attributes of the Pierre Shale and other Cretaceous age formations. Thirteen of the reports describe locations in the central Front Range area, while eight describe locations elsewhere in Colorado. These reports are used for making regional-scale comparisons of the different formations.
4) Specialty reports and maps (nine total) which address the stratigraphy, composition, and/or geological engineering attributes of the Pierre Shale in Nebraska, Wyoming, Montana, South Dakota, North Dakota, and Canada. These reports are used to make broadly regional comparisons of internal zones within the Pierre Shale. Also, some of the reports discuss types of scientific investigations that have not been done in Colorado because the Pierre Shale in the upper Midwest was the focus of concentrated study during the 1960s and 1970s.
5) A geologic textbook summarizing the stratigraphy, areal distribution and properties of bentonite deposits in the Western Interior region of the USA. The understanding of bentonites is an important key to addressing the heaving bedrock problem, and this text gives an overall synopsis that is not readily derived from individual geologic studies.

PUBLIC-RECORD DEVELOPMENT DOCUMENTS

We reviewed all available geotechnical engineering documents of public record for existing or proposed subdivisions located within the Douglas County piedmont area. The documents consist of preliminary soils investigations, roadway-design investigations, grading plans, and individual foundation and remedial-construction design documents. Certain data from those documents were checked against geological and engineering data from regional-scale, published maps in order to verify the presence of expansive claystones within the DBOD.

In addition, we began a detailed case study of the Roxborough Village subdivision using a larger set of public-record development data. This is a critical site for investigating heaving bedrock because of the wide variety of soil-and-bedrock geology, and because of human factors such as use of thick overburden fills, different builders and design approaches, and different construction-initiation dates ranging from 1986 to present. All of these factors may influence the presence/absence and relative severity of heaving. Most of the individual filing areas have not been affected by heaving to date, although certain areas are significantly affected. The case study is scheduled for completion in 1995, as part of the phase 1-B project report.

A number of individuals from building and geotechnical-engineering firms responded to our requests for construction data which could not be located in CGS or Douglas County files. Those individuals are listed in the acknowledgements section.

ORAL HISTORIES AND DESCRIPTIONS

Most of the local knowledge of heaving bedrock and its effects is unpublished. This is because private firms, and not public agencies, are involved in most of the data collection associated with construction, remediation, and litigation activities in the course of everyday business. A large part of the data dealing with heaving bedrock damage is kept by builders, warranty companies, and homeowners and is not generally available to the public.

Recently, however, many builders and engineers and involved private citizens have been increasingly willing to share their particular insights into the causes, effects, and remediation of heaving bedrock damage. Much of this information comes from the Pierre Shale Technology Transfer Conference of April 29, 1994, sponsored in part by the CGS and Douglas County, and the Jefferson County Expansive Soils Task Force, which convened in 1994 and created hazard-specific land development regulations for areas of expansive, steeply dipping bedrock. Individuals who have contributed to our overall understanding of the problem are named in the acknowledgement section.

CGS EXPERIENCE AND WORK FILES

The Colorado Geological Survey has been directly involved in issues relating to expansive soils and bedrock since the early 1970s. Our main areas of involvement are:

1) County Land Use Reviews. The CGS has provided counties with technical assistance on geological aspects of land-use issues since 1974 as part of the subdivision review process under the provisions of Senate Bill 35 (1972). Most recently, we have served as technical advisors for several development-planning projects in Jefferson and Douglas counties which involved detailed, site-specific geological evaluations of proposed subdivisions within steeply dipping bedrock areas. Each of these projects yielded new information about potentially heaving bedrock formations, as well as enhancements in mitigative technological approaches, which may be applicable regionally.
2) Swelling Soils and Heaving Bedrock Research. A major mapping project was completed by Stephen Hart (1974) showing the surficial distribution of swelling soils and bedrock in the Front Range Urban Corridor, including Douglas County. In 1990, the CGS began a detailed scientific study of three impacted sites associated with heaving bedrock in Jefferson County. At present, we are conducting field and laboratory research in the form of cooperative thesis projects with graduate students and faculty from Colorado School of Mines.
3) Technical Information Transfer. In the late 1980s, Dr. W. Pat Rogers was active in the first efforts to create a greater understanding and recognition of hazards associated with the heaving of expansive, steeply dipping bedrock. The CGS has led field trips and given technical presentations on this topic, beginning in 1993, for over 600 people including state legislators, county officials, planners, builders, architects, engineers, insurers, scientists, and students.
4) Policy Issues Involving Heaving Bedrock. In 1994, the CGS participated in the Jefferson County Expansive Soils Task Force and helped to create the Jefferson County Designated Dipping Bedrock Area (DDBA) map, which was adopted along with attendant regulations and requirements in April, 1995. The CGS is also involved with Jefferson County Public Schools in assessing remedial programs for school buildings damaged by heaving bedrock.

FIELD INVESTIGATIONS

A minor field investigation was done by the CGS in selected parts of suburban Jefferson County in order to compare areas of known heaving-bedrock damage with published geologic maps. Field work consisted of drive-by assessment and mapping of damage to dwellings, flatwork, and roadways in several neighborhoods. This type of mapping is generally useful for verifying which geological formations are prone to differential heave, although the overall accuracy is limited by the indirect, hands-off nature of data collection. The eastern boundary of areas displaying the distinctive, linear ground deformations was tentatively located by mapping of "roller coaster" deformation of roads.

SUMMARY OF FINDINGS: KEY GEOLOGICAL ATTRIBUTES AND THEIR USE IN DEFINING THE DBOD

Heaving bedrock and swelling soil[2] hazards are present in arid and semi-arid regions of the world

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[2]"Heaving bedrock" and "swelling soils" are both composed of clay particles which expand upon exposure to introduced water. Swelling soils are geologically "young" surficial deposits, and are usually eroded or weathered trom older claystone bedrock. The CGS distinguishes heaving bedrock as a separate geological hazard because the internal structure of the bedrock may allow for more complex mechanisms of heaving. Swelling soils which overlie heaving bedrock may be present at any given location, but heaving bedrock is seen as the dominant and most serious cause of damage to engineered facilities along the Front Range piedmont.

where expansive claystones and clays exist at or near the ground surface. In most cases, the bedrock and soil layers are flat, or nearly so. Highlands Ranch, in north-central Douglas County several miles east of our study area, and other suburbs which surround Denver to the north, east and south, are local examples of places where heaving and swelling of flat-lying bedrock and soils may occur. The piedmont area of Douglas, El Paso and Jefferson Counties is geologically atypical compared to other areas of the plains because of the steep dip of the underlying sedimentary bedrock, which accounts for the particularly destructive linear style of ground deformation.

Studies of differentially heaving bedrock show that damage is most likely to occur where the bedrock is *1)* steeply dipping, *2)* composed of expansive claystone, at least in certain layers, *3)* at or near to the ground surface, and *4)* naturally "dry" in terms of ground moisture. Some of these attributes may be present on a regional scale, and may be generally useful for predicting where bedrock heave will occur, while other attributes have a significant effect on localized areas. These geological attributes are described in the following paragraphs.

STEEPLY DIPPING BEDROCK

Linear, differential heaving occurs where the bedrock is steeply to moderately dipping within a few miles eastward from the Rocky Mountain front. In mapping road damage in Jefferson County, the CGS found that the easternmost extent of such heaving coincides approximately with bedrock dips of 30 degrees as shown on geologic maps. The CGS therefore concludes that differentially heaving bedrock occurs in areas where the underlying bedrock dip is 30 degrees or greater. Bedrock dip is a regional-scale geological attribute, and may be predicted with some degree of accuracy using existing geologic maps. Field verification is relatively easy where outcrops exist. Pits or trenches must be used to verify bedding dips where the bedrock is covered.

In Douglas County, bedding dips of greater than 30 degrees are mapped and well defined from Kassler southward to Jarre Canyon along the piedmont. Bedrock dips of greater than 30 degrees occur but are not well defined from Jarre Canyon southward, through the Perry Park area to a point near Plum Creek where the steeply dipping bedrock is not present due to faulting. South of Plum Creek, the near-surface sedimentary bedrock which abuts the Rampart Range is essentially flat-lying.

EXPANSIVE CLAYSTONE

The potential heaving bedrock hazard area is further defined by identifying which bedrock formations contain "expansive" claystone, composed of clay particles that expand (swell) forcibly upon wetting and shrink upon drying. Not all steeply dipping bedrock in Douglas County contains such claystone[3]. To determine which formations contain expansive claystone, it was necessary to review published, regional geologic literature for descriptions of the rock formations. Particular attention was given to bedrock described as having any of the following compositional, geochemical, or structural characteristics[4]:

1) **Claystone.** Claystone beds composed of types of clay called smectite (montmorillonite) and illite/smectite are widely linked to expansive behavior. Differential heaving is possible in steeply dipping bedrock where these types of claystones are interbedded next to bedrock layers having lower or negligible expansion potential (for example, sandstone or limestone).
2) **Bentonite.** A very particular type of claystone composed of pure smectite, bentonite was originally deposited as volcanic ash beds. Although individual beds seldom exceed one foot in thickness, bentonites may possess significant expansion potential which, in areas of steeply dipping bedrock, results in pronounced differential heaving after wetting.
3) **High Density of Fractures.** As a general rule, the CGS has found that the most expansive claystone intervals tend to be highly fractured. Thus, there should be a

[3]For example, the Fountain and Lyons Formations which underlie most of the Roxborough Park and Perry Park subdivisions behind the Dakota Hogback ridge are composed of non-expansive bedrock.

[4]See Appendix A, "A Pierre Shale Primer", for more detailed descriptions of these characteristics and how they influence differentially heaving bedrock.

high correlation between fracture density in claystones and the potential for heaving. Fractures are often conduits for ground water which allow more rapid and deeper wetting, or they may act as subsurface dams and allow ground water to build up; in both cases, heave is intensified. CGS and other research also shows that shearing-movement heaving of bedrock blocks, on the order of several inches, may occur along fracture or bedding planes in highly expansive claystone. This type of movement may be second only to movement associated with bentonites in the resultant severity of heave magnitude, distribution and damage.

4) **Gypsum and Fibrous Calcite Fracture Fillings.** Gypsum is a chemical by-product of the weathering of claystone; its presence as a fracture filling suggests that water has penetrated and affected the claystone in the past, and could do so again. Fibrous calcite, another weathering product, is almost exclusively linked to beds of bentonite. Published investigations from South Dakota show that the bentonites having the highest potential for expansion will almost always contain some secondary calcite, a relationship which appears to be substantiated by CGS observations in Colorado.

5) **Regional Faults in Claystone Formations.** Damage from heaving bedrock appears to be especially concentrated in one known case from Jefferson County where a large, regional fault crosses through a zone of expansive claystone. Such damage is most likely due to post-development wetting and expansion of—and shear-movement adjustments among—faulted and fractured blocks of bedrock rather than deeper-seated movement along the fault itself.

The above-described geological characteristics are recognized from a thick section of Cretaceous age sedimentary rock formations in Douglas County and flanking counties along the Front Range piedmont. Table 1 shows the regional distribution and occurrence of highly expansive claystones and bentonites within eight formations. They are, from youngest to oldest: the Dawson Arkose, Laramie Formation, Fox Hills Sandstone, Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale. The formations are considerably different from each other in terms of thickness, and most of them also contain zones of low- or non-expansive bedrock. With regard to total area underlain by expansive bedrock and, consequently, distribution and severity of damage to structures, roadways and utilities, the Pierre Shale is the formation of greatest concern. All eight formations lie completely within the piedmont area of steeply dipping bedding, with the partial exception of the Dawson Arkose[5]. The overlapping area which contains both steeply dipping and expansive bedrock (Figure 2) defines the DBOD.

The lateral geometry, or continuity, of bedding within the formations (Table 1) was used in a regional sense to help delineate the DBOD. Depending on the continuity of bedding zones, known geological characteristics may be extrapolated into areas where the geology is largely undescribed (such as the Perry Park area of Douglas County) with a certain degree of predictive accuracy. In formations where bedrock layers are relatively continuous, we expect individual zones to be internally consistent for many miles along the mountain front in terms of composition, engineering properties, and general potential for heaving bedrock damage. It is more difficult to predict those characteristics where the formations are discontinuous or lenticular in nature. Continuity may be especially useful at the site-investigation level in areas of steeply dipping bedrock for purposes of predicting heaving behavior across a property.

DEPTH TO BEDROCK AND OVERBURDEN THICKNESS

The depth to the top of bedrock and, equivalently, the thickness of natural soil overburden on top of the bedrock, is a subregional- to local-scale phenomenon. Although some geologic maps show areas of surficial cover of soil deposits, there is

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[5]The Dawson is the youngest of the Cretaceous formations and is widespread in outcrop throughout Douglas County. Although mostly a flat or gently dipping unit, it has steeper bedding dips near its western margin (See Figure 2) and has vertically dipping beds at Wildcat Mountain.

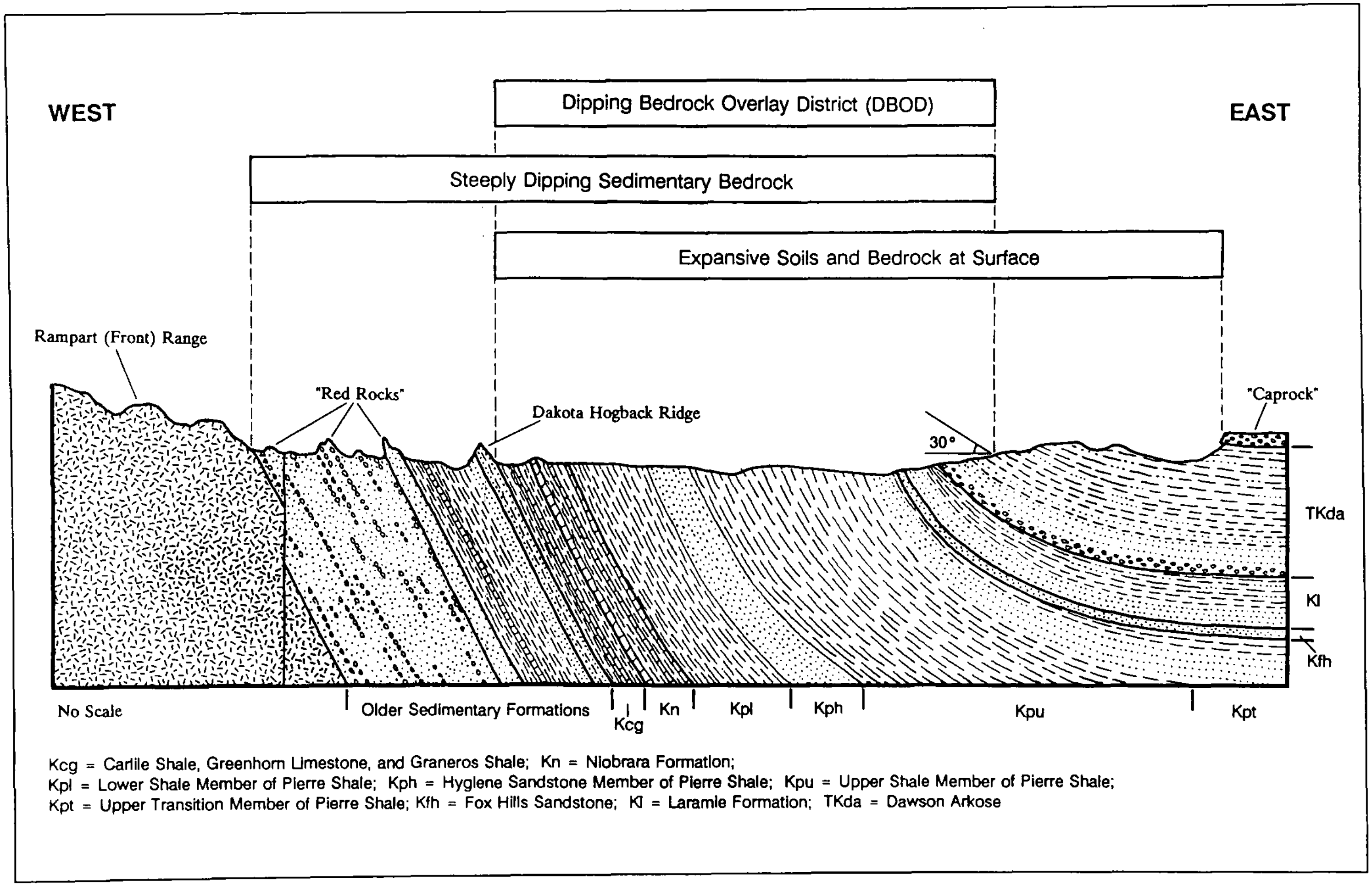

Figure 2. Schematic geological cross section showing steeply dipping sedimentary formations along the Front Range piedmont in northwestern and central Douglas County (modified from Scott, 1963a, 1963b). The DBOD extends up to 3 miles eastward from the Dakota Hogback ridge to a point within the Dawson Arkose where the bedrock dips into the ground at a 30-degree angle from horizontal.

Table 1. Occurrence of expansive bedrock types by formation along the central Front Range Piedmont, Colorado.

Formation	Member (or Informal Unit)	Thickness[1] (feet)	Occurrence of Bedrock Types[2] (and Swelling Potential)			Lateral Continuity of Bedrock Along Strike Direction[5]
			Bentonite[3] (High to Very High Swell)	Claystone (Moderate to V. High Swell)	Low- to Non-Swelling Bedrock[4]	
Dawson Arkose	(Middle and Upper Parts)	1,450	-	M	C	Discontinuous
	(Lower Part)		-	C	M	
Laramie Formation	(Upper Part)	660	-	M	C	
	(Lower Part)		-	m	M	
Fox Hills Sandstone		185	p?	m	M	Transitional
Pierre Shale	(Upper Transition Zone)	1,150	p?	C	M	Continuous
	(Upper Shale)	2,275	C	M	m	
	Hygiene Sandstone	575	-	m	M	
	(Lower Shale)	1,200	C	M	C	
Niobrara Formation	Smoky Hill Shale	535	C	C	M	
	Fort Hayes Limestone	35	m	m	M	
Carlile Shale		55	p?	m	M	
Greenhorn Limestone		315	C	m	M	
Graneros Shale		225	C	M	C	

1. Bedrock thickness from Scott (1963b) for Kassler Quadrangle, Douglas County.
2. Symbol explanation: M = major occurrence, C = common occurrence, m = minor occurence, p? = may be present, - = not present. Differential heave occurs at the contact of bedrock types having contrasting swell potentials or along fracture/fault planes in bedrock having generally high swell potential.
3. Bentonite is a special type of claystone which was originally deposited as thin beds of volcanic ash.
4. Includes siltstone, sandstone, conglomerate, chalk, limestone, coal and certain types of low- to non-swelling claystone.
5. Continuity of bedrock is useful for predicting engineering behavior for different zones of bedrock, especially at a subregional, or subdivision-sized scale.

usually considerable local variation in soil thickness which could influence the heaving behavior of the underlying bedrock. Thompson (1992) found that ten feet or more of overburden, beneath the base of a foundation wall, is required to achieve satisfactory foundation performance in areas of heaving bedrock. Depth to bedrock and overburden thickness are not generally predictable on a regional basis, and are not used as criteria for defining the DBOD.

NATURAL MOISTURE CONTENT

The natural moisture content of bedrock and soil at a particular location depends on many factors including composition, permeability, fracturing, topography and geomorphology, and the depth and configuration of the ground water system (hydrogeology). It may also vary considerably with depth at any particular location. Land improvements, such as irrigation ditches, roads, and lawns,usually result in local, long-term increases in subsurface moisture content and ground water levels. These, in turn, contribute to the expansive swelling and heaving of clays and claystones. Although important at the site-investigation level, moisture content is generally unpredictable on a regional basis and is not used as criteria for defining the DBOD.

MORRISON FORMATION OUTLIER AREA

In addition to the eight Cretaceous formations described above, the middle member of the Jurassic Morrison Formation also contains expansive claystones. The Morrison Formation crops out on the western side of the Dakota Hogback Ridge. It is steeply dipping and fractured where exposed in residential excavations. In one known location in Douglas County, the middle member appears to be relatively "dry" and is associated with a deep ground water table. The middle member is relatively thin, perhaps on the order of 100–200 feet thick, and underlies an area of recent development in the Roxborough Downs subdivision.

The heaving potential of the middle member of the Morrison Formation has not been investigated in detail by geologists or engineers. Because it is relatively thin and spatially unrelated to the other heaving bedrock formations, this unit is not included in the DBOD. Future studies should address whether the middle member should be considered as part of the hazard overlay area.

DIPPING BEDROCK OVERLAY DISTRICT (DBOD) MAP

The Dipping Bedrock Overlay District (DBOD) is an area along the Front Range piedmont in Douglas County where heaving bedrock hazards are expected due to the presence of steeply dipping, expansive claystone bedrock. The main product of this report is a map showing the DBOD boundaries. The map is included with the report.

The DBOD is a general overlay area created for regulatory use by Douglas County. The map does not show internal details, such as boundaries of the eight different bedrock formations which underlie the area, nor does it attempt to delineate areas of natural alluvial deposits which may cover the bedrock.

DESCRIPTION OF DBOD MAP AREA

The DBOD covers an elongate, 26.1 square mile area of Douglas County along the Front Range piedmont between Chatfield Reservoir and East Plum Creek, at the mouth of Stone Canyon (Figure 3). The district is approximately 23 miles long in a north-south direction and ranges from 1,000 feet wide to 3 miles wide in an east-west direction. Inclination of the sedimentary rock bedding within the DBOD usually ranges from 30 to 90 degrees, with beds dipping in an east or northeast direction. The Douglas County DBOD is contiguous with Jefferson County's DDBA[6] at the northwest corner of Douglas County, in the vicinity of Chatfield Reservoir (See Plate 1).

The western boundary of the DBOD corresponds with the base of the Graneros Shale, overlying the east dip slope of the Dakota Sandstone

[6]The Jefferson County DDBA was created by the Jefferson County Expansive Soils Task Force in 1994, assisted by the CGS. It is essentially contiguous with the Douglas County DBOD, contains the same bedrock formations, and was delineated using the same criteria as is used in this report. The DDBA regulations went into effect in April 1995.

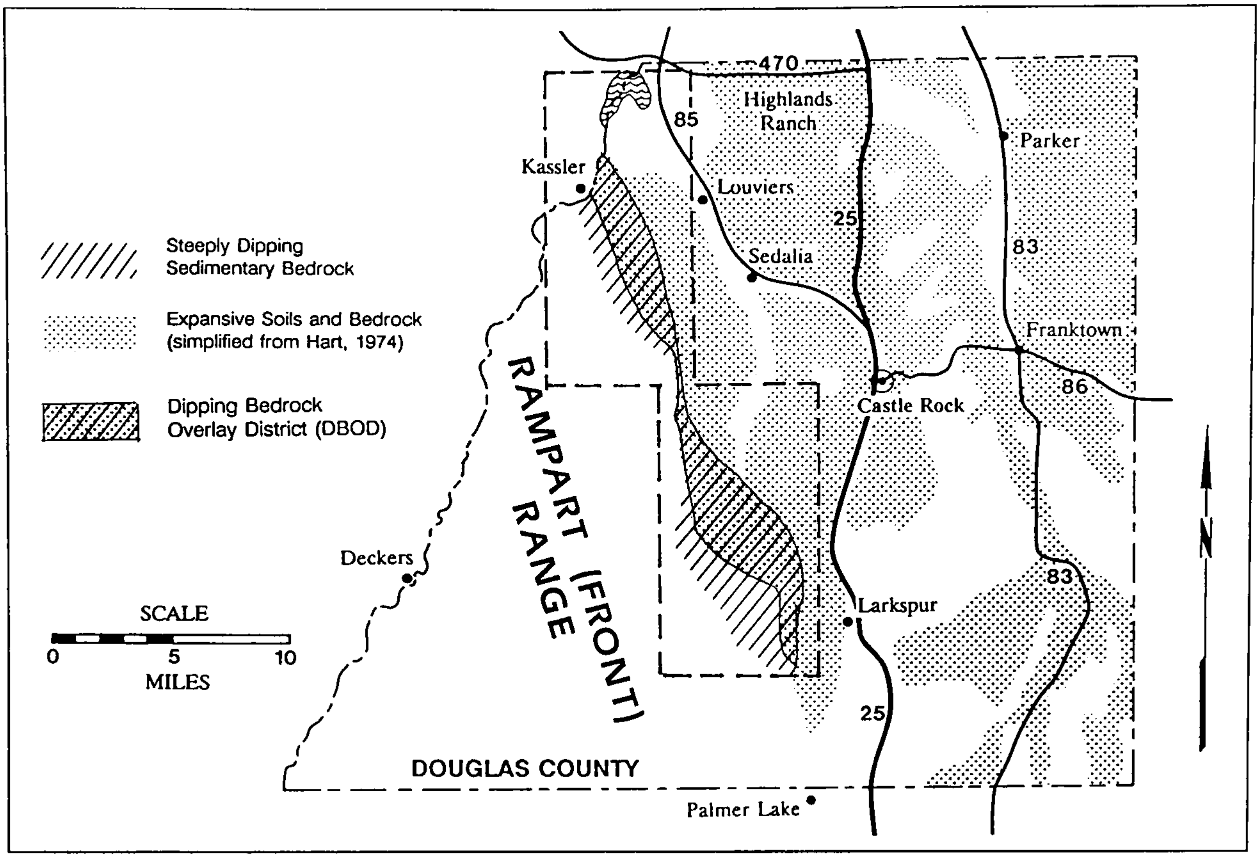

Figure 3. Map of Douglas County showing the DBOD area and the boundary of Plate 1.

along the Dakota Hogback Ridge. Where the Graneros Shale and Dakota Sandstone are not present due to faulting between Jarre Canyon and Perry Park, the western boundary corresponds with the mapped location of the Jarre Creek Fault. Similarly, a splay of the Rampart Range Fault forms the western boundary south of Perry Park.

The eastern DBOD boundary corresponds approximately to the eastern edge of upwarped bedrock where rock layers dip at 30 degrees from horizontal. This boundary coincides with a horizon in the Dawson Arkose which is approximately 1,000 feet to the east of the mapped boundary between the Dawson and the Laramie Formation, based on regional geologic maps. In certain instances where all formation contacts are missing due to faulting by the Jarre Creek and Rampart Range Faults, the DBOD consists of a 1,000-foot wide strip extending eastward from the faults to the approximate 30-degree dip horizon in the Dawson Arkose.

The south end of the DBOD coincides with the southernmost mapped extent of expansive-claystone-bearing Cretaceous formations where they are faulted out by the Rampart Range Fault in the southeast quarter of section 7, T. 10 S., R. 67 W. This area is problematic, partly because the geology is complex due to faulting and partly because the data used to define this area was taken from a generalized geologic map. More work is needed to better define the southern terminus of the DBOD.

Key constructed facilities (roads, subdivisions, etc.) and natural landmarks found within the DBOD are shown in Table 2. Most of these facilities are unaffected by heaving bedrock, to date, because of local geological and human-influenced conditions or, in the case of a few subdivisions, because they are relatively new. Only sparse development has occurred, especially in the area shown in Plate 1.

Table 2. Constructed facilities and natural landmarks found within the DBOD.

AREA	LANDMARKS AND FACILITIES
Roxborough Park Area	Titan Road (in part) Platte Canyon Reservoir Rampart Road Roxborough Village Subdivision Roxborough Park Road (in part) Foothills Water Treatment Plant Aurora Rampart Reservoir South Downs Subdivision (proposed) Wildcat Mountain Mouth of Jarre Canyon
Perry Park Area	Dakan Road Perry Park Road, County Road 105 (in part) Tomah Road (in part) Sinclair Road (in part) Meribel Village Subdivision (in part) Valley Park Subdivision (in part)

Note: Being located within the DBOD does not imply that the given man-made facilities have incurred damage due to heaving bedrock movement. The actual extent and severity of heaving bedrock damage in Douglas County is not fully known.

RECOMMENDATIONS FOR LAND USE IN THE DBOD

The Dipping Bedrock Overlay District (DBOD) defines an overall area of Douglas County where heaving bedrock hazards and subsequent long-term damage are expected under certain geological conditions. Special considerations are warranted in all phases of property development including site exploration and evaluation, facilities design, construction quality control, and subsequent maintenance by homeowners associations, individual homeowners, utility districts, and the County. In some areas, avoidance with respect to certain types of commercial and residential development may be the most advisable land use alternative; such areas would be likely locations for parks, open space, or rural-agricultural usage.

The DBOD map is intended for use as a regulatory tool for developing and implementing area- and problem-specific land development and building regulations. Existing County regulations should be significantly modified for lands within the DBOD. The following paragraphs describe land use alternatives recently considered by Jefferson County for addressing the heaving bedrock problem, followed by considerations and recommendations for Douglas County.

CONSIDERATIONS AND RECOMMENDATIONS OF THE JEFFERSON COUNTY TASK FORCE

The major question being addressed by both Douglas and Jefferson Counties is, "Should construction of residential and commercial facilities and continued population growth be allowed within the area of potentially heaving bedrock?" In 1994, the Jefferson County Expansive Soils Task Force, composed of an interdisciplinary group having a great deal of experience with the heaving bedrock problem, looked at two basic scenarios for dealing with the heaving bedrock problem within that county's DDBA[7]. Residential and commercial development would be significantly limited under the first scenario. Low-impact uses such as agriculture, open space and other parkland, and possibly low-density residential development would be encouraged.

Under the second scenario, specifically regulated development and growth would be allowed while still encouraging avoidance and lower-impact land uses. Detailed geological-geotechnical investigations would be necessary at the rezoning stage of planning to delineate areas where favorable geological conditions occur, versus areas of potentially heaving bedrock where special, and more costly, mitigative designs must be employed. Minimum engineering and building requirements would be implemented to prohibit designs and practices resulting in poor past performance, where necessary. Effective, problem-

[7]The Jefferson County DBOD was recently renamed the Designated Dipping Bedrock Area (DDBA) to avoid any reference to "overlay" ot "hazard areas". This was done because of a perceived negative impact on residents of the numerous existing subdivisions there.

specific solutions would be encouraged. The CGS would map and rank individual formations or bedrock zones, in terms of heaving potential and historical damage, so that areas could be strategically identified for open space purchase and other low-impact use.

The Task Force chose the second scenario as a feasible approach to the heaving bedrock problem in Jefferson County. In part, this choice considers the long-lived and extensive nature of development in the South Jefferson County suburban area, as well as the sizeable part of the remaining undeveloped land that exists as infill property. The Task Force recognized that there are areas within the DDBA where the natural geological conditions are favorable for development, and that the engineering community is beginning to apply integrated mitigative designs in heave-prone areas (e.g., overexcavation of expansive, dipping bedrock layers to a prescribed depth; replacement with moisture-controlled, engineered fill; and subdivision-wide subsurface drainage systems).

In January, 1995, the Jefferson County Expansive Soils Task Force submitted their recommendation that continued, but specifically regulated, growth should be allowed in the piedmont area of Jefferson County. A map of the Jefferson County DDBA, and drafts of DDBA-specific regulations (in which minimum standards are given for site geological/geotechnical exploration, overlot grading operations, and design of roadways, cuts/fills, foundation systems, drainage systems, utilities, and remedial construction) were also submitted. The Task Force recommendations were adopted by the Jefferson County Planning Commission in February, 1995, and by the Jefferson County Board of County Commissioners in April, 1995.

CONSIDERATIONS AND RECOMMENDATIONS FOR DOUGLAS COUNTY

Douglas County's existing land development and building regulations should be significantly modified for lands within the DBOD in order to address the heaving bedrock hazard. We see the two basic scenarios considered by Jefferson County, involving limited growth or specifically regulated growth, as being applicable for consideration by Douglas County. It is our experience that the choice of regulatory approach must consider not only the geological/technical factors given in this report, but must also be consistent with the County's overall direction and goals. Some additional non-technical and technical factors which should be considered for regulating future development within the Douglas County DBOD include:

1) Long-range Master Plan goals for growth in specified areas,
2) Preservation of the rural nature of the Front Range piedmont belt,
3) Preservation of scenic or view corridors,
4) Desirability of lands in the DBOD for recreation and open space,
5) Ability of the County to identify and purchase lands for open space or other public use,
6) Natural and engineered mitigative factors (see preceding section),
7) General absence of aquifers to supply water for low-density, rural-type usage.

If continued growth and development is to be allowed, all phases of planning including zoning, platting and building permitting should be considered in order to promote a more integrated approach for mitigating heaving bedrock hazards. The timing of certain development activities should change, too, to allow for earlier and more complete site-evaluation, hazard-identification, and mitigative-design planning at the rezoning stage. Certain minimum-standards criteria for design of engineered earthworks, excavations, foundations, utilities, and roadways should be formulated based upon current best-mitigative engineering practices for heaving bedrock. Long-term maintenance by homeowners, homeowners associations, utility districts, and the County should be considered as part of the revised requirements. For example, the location of subsurface drain-system clean-outs should be platted, and a responsible party should be designated for maintaining the system. Watering and irrigation restrictions may need to be imposed by covenants or other means. Homeowner education regarding the distinct problem of heaving bedrock is also needed, and is a longer-term goal of the CGS.

The CGS recommends that Douglas County use the technical-requirement documents drafted by the Jefferson County Expansive Soils Task Force as a template for writing regulations which apply specifically to the Douglas County DBOD.

EXISTING DEVELOPMENTS

The Douglas County DBOD area is relatively undeveloped. Accordingly, heaving bedrock damage in Douglas County is limited in extent (although the damage is significant where it has occurred). Several existing developments within the Douglas County DBOD are relatively unaffected, to date, by heaving bedrock. The factors controlling the distribution and magnitude of damage are complex, and involve non-geological as well as geological factors. Even though a home or commercial building located within the map area may be structurally sound, extra care is warranted in evaluating it prior to purchase. When purchasing an existing home or commercial building within the DBOD, or any other area where expansive soils/bedrock are found, a buyer should have a registered structural engineer conduct a detailed evaluation of the home.

RECOMMENDATIONS FOR FOLLOW-UP STUDY

Regardless of Douglas County's intended approach to development and growth within the DBOD, the CGS recommends that actual geological data should be obtained in order to field-check and refine the area boundaries. It may also be necessary to provide a delineation and ranking of different bedrock zones within the DBOD with respect to potential heaving bedrock hazards; the results of such an investigation would be of direct use to developers, builders, geotechnical engineers, and County staff. The following is a broad listing of topics which should be considered for follow-up investigations as part of the CGS Phase 1-B study in 1995:

1) Investigate and further define the DBOD boundaries and map formation contacts, bedding dips, and the composition and continuity of bedrock zones at selected locations throughout the DBOD. This includes evaluation and mapping of internal bedrock zones in terms of heaving potential. An evaluation of the DBOD boundary at its southern terminus, between Perry Park and East Plum Creek at Stone Canyon, is also necessary because of the lack of detailed geological information there.
2) Map internal stratigraphy of the Pierre Shale in the Perry Park area using fossil occurrences. Fossil-zone stratigraphy is important for purposes of heave-potential prediction because the zones are relatively continuous, and many appear to be especially heave-prone. This is the final area of Pierre Shale along the entire Front Range where such mapping is not complete.
3) Investigate the potential for heaving bedrock in the middle member of the Morrison Formation on the west side of the Dakota Hogback Ridge, and recommend whether lands overlying this formation should be regulated similarly to lands within the DBOD.
4) Complete the Roxborough Village case study. Data for this group of subdivisions is being analyzed in 1995 by Marilyn Smith as part of her master's thesis project at Colorado School of Mines. The results will be supplied to Douglas County as part of CGS's Phase 1-B study.

CONCLUSIONS

1) The Dipping Bedrock Overlay District (DBOD) is a 26 square mile area in Douglas County where heaving bedrock hazards are expected along the Front Range piedmont. The sedimentary bedrock in this area is prone to heaving behavior under certain geological and human-influenced conditions.
2) The DBOD area is based upon the overlapping occurrence of two regional-scale geological attributes which are responsible for the distinctive, linear style of ground deformation and damage which is observed within the area: steeply dipping bedrock layers (dipping at angles of greater than 30 degrees from horizontal) and presence of zones of expansive

claystone (bedrock composed of clay particles that expand, or swell, forcibly upon wetting).

3) Two other geological attributes which greatly influence the heaving potential of bedrock, depth to bedrock/overburden thickness and natural moisture content, are highly localized and therefore are not used in delineating the DBOD.

4) Eight sedimentary bedrock formations of Cretaceous age are found within the DBOD, including the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and Laramie Formation, and part of the Dawson Arkose. With regard to total area underlain by expansive bedrock and, consequently, distribution and severity of damage to structures, roadways and utilities, the Pierre Shale is the formation of greatest concern.

5) The middle member of the Morrison Formation, a 100–200 foot thick band of Jurassic-age bedrock on the west side of the Dakota Hogback Ridge, is also thought to be capable of heaving bedrock behavior. This unit is not included in the DBOD at this time but deserves further study.

6) The DBOD defines an overall area of Douglas County where extra care is warranted in all phases of property development including site exploration and testing, facilities design, construction quality control, and subsequent maintenance by homeowners, homeowners associations, utility districts, and the County. In some instances, avoidance with respect to certain types of commercial and residential development may be the most advisable land use alternative; such areas would be likely locations for parks, open space, or rural/agricultural usage.

7) Existing land development regulations should be significantly modified for lands within the Douglas County DBOD to address the heaving bedrock hazard. The County should decide whether, and to what degree, continued growth and development should occur. This decision depends not only on the geological and technical factors presented in this report, but also on the County's overall direction and goals with respect to growth. We expect that all phases of development planning would be affected to some degree, including zoning, platting, and building permitting.

8) The CGS recommends that the Phase 1-B follow-up study should involve field-checking of the geology at certain locations in order to verify the DBOD boundaries, and mapping and evaluation of different zones of the component formations in terms of heaving potential. A case study of the relationship between bedrock conditions, subdivision design and performance is currently being done for the Roxborough Village group of subdivisions, and should be completed as part of the second-phase study. This study will be conducted in 1995.

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APPENDIX A
'A PIERRE SHALE PRIMER'

Key Observations and Site-Evaluation Considerations for Areas of Steeply Dipping Claystone Bedrock Douglas, Jefferson and El Paso Counties, Colorado

By David C. Noe

Prepared for Douglas County
Planning and Community Development
February, 1994

PART I
KEY OBSERVATIONS

The following are lists of general observations from areas that have experienced damage from differential heaving of underlying zones of steeply bedded claystone. Recognition of the factors that contribute to bedrock heave is a relevant first step in delineating special areas of County interest for this geological hazard and developing a cohesive planning and compliance policy for these areas.

A. Geological Formations Capable of Heaving

Differential bedrock heaving is known or suspected from the following geological formations along the Front Range in Douglas, Jefferson and El Paso counties. Starting from oldest to youngest and going eastward from the base of the Dakota Hogback, they are:

1) the Graneros or Benton Shale,
2) the Hartland Shale member of the Greenhorn Limestone,
3) the Blue Hill Shale member of the Carlile Shale,
4) the Smoky Hill Shale member of the Niobrara Formation,
5) the Pierre Shale, and
6) the Laramie formation.

Units 1–4 have not been extensively developed upon in the Douglas-Jefferson-El Paso County areas, but the Pierre and Laramie outcrop belts both contain developed areas that have been adversely affected by heaving bedrock, especially in Jefferson County.

B. Geological Attributes of Areas Incurring Heaving Bedrock Damage

Areas experiencing heaving bedrock damage share several geological attributes. These attributes are listed and described for known locations where damage has occurred:

1) bedrock is steeply bedded due to proximity to Front Range uplift,
2) large portion of bedrock is composed of expansive claystone,
3) bedrock is not as heavily loaded as it was in the distant past (overconsolidation),
4) bentonite is present as discrete beds or as a dispersed component of other beds,
5) bedrock is highly weathered and has abundant, mineral-filled fractures,
6) "dry" bedrock (low natural moisture content) is more susceptible to heaving,
7) increased post-development water is a trigger for the heaving process,
8) ground water occurrence and flow is highly irregular and compartmentalized,
9) movement of bedrock blocks along shear surfaces is recognized,
10) large, regional faults may cross the affected area in certain locations, and
11) heave damage is greatest where bedrock is close to surface.

Steeply Dipping, Overconsolidated, Expansive Bedrock

The general effect of steeply dipping bedding is that rock layers which have distinctly different swelling characteristics are found in close proximity to each other along or near the ground surface, in the form of thin bands or zones (Figure 1). These zones respond differently to the increase of soil-moisture that usually occurs after development, with the "fatter" (more expansive) claystones undergoing more swelling and vertical uplift than adjacent beds. The resulting effect is differential, often destructive, heave. Once the ground is disturbed and heaving begins, the process is extremely difficult if not impossible to stop; this means that post-development mitigation efforts are largely destined not to succeed.

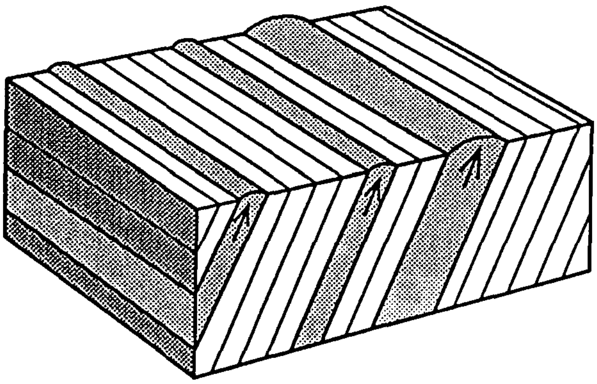


Figure 1. Block diagram showing steeply dipping bedding and surficial heave "ridges" caused by the differential expansion of certain high-swell beds. The heaves form linear trends along bedding strike.

A second effect of upturned bedding is the development of higher-than-normal lateral swell pressures. Millions of years ago, after being deposited as saturated, flat-lying layers of clay, water was squeezed out and the clay was compressed (consolidated) by the pressure of burial beneath thousands of feet of younger sediments. Now exposed at or near to the ground surface, these layers (now claystone bedrock) are mostly free of their burial confining pressures and will try to attain their original thickness, density and saturation by pulling water into their crystalline structure and expanding. This is especially true in the direction of original squeezing: perpendicular to the bedding surface. Thus, in areas where rock layers are now highly tilted, the preferential direction of swelling is sideways (lateral).

Bentonite

Bentonite is a special type of claystone that exhibits extremely high swelling potentials and is documented to be present beneath some of the more destructive heaving bedrock ridges. Discrete beds of nearly pure bentonite or disseminated particles of bentonite in other claystones were originally deposited as volcanic ash-falls and cover extensive areas of the upper-midwestern U.S. Their continuity along the Front Range is presumably high, meaning that certain beds of bentonite or bentonitic zones from known bedrock-heave areas could be correlated with areas of future development to assess potential risks.

Fracturing and Weathering

Fracturing and weathering are closely related in these shales, and both are important visual indicators of the condition of the bedrock. The coincidence of weathering and fracturing to great depths in the Pierre Shale (70–75 feet in our studies) tells us that water is able to circulate to these depths (through what many people assume to be "impermeable" bedrock) and chemically alter the shale. Weathering has leached out certain compounds from the shale and has reacted with the clays in ways that are not well understood. As a result, the claystones are weakened, both at the particle level and as a fractured rock mass, by weathering processes; this means that the "competent bedrock" targeted by engineers for emplacing foundation piers may not exist within economic drilling depths.

Effects of Water

Water, specifically the increase in underground moisture following development, is probably the most important factor controlling the initiation of bedrock heaving. Moisture changes in upturned claystone areas may occur to greater depths than are usually anticipated for the Denver area (Figure 2) because of fracturing and weathering. Thin beds of sandstone are also seen as avenues of water transport into the surrounding shales; however sandstone beds need not be present in order for water to penetrate into the fracture systems in the shale.

The simple cut-off of evaporation is enough to trigger heaving as seen in the case of roadways (e.g., Waterton Road, Douglas County) crossing otherwise undeveloped land. Other consequences of development that introduce excess water into the ground (e.g., lawn irrigation and leaking water pipes) greatly magnify the heaving process. Ground-water flow through upturned, fractured shales appears to be extremely complicated; flow and moisture characteristics may change markedly over several tens of feet.

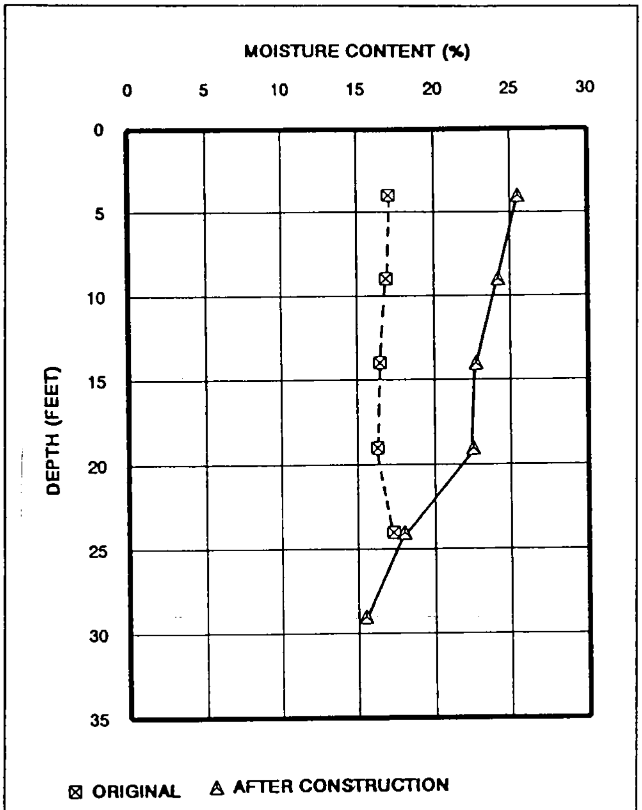


Figure 2. Example of post-construction moisture content increase to a depth of 25 feet on steeply dipping claystone (from Thompson, 1992a). The common standard of practice for the greater Denver area assumes that such changes will only occur to depths of about 7 feet.

Movement of Bedrock Blocks

Thrusting movement of bedrock blocks along shear surfaces (Figure 3), on the order of several inches to feet, are recognized in Douglas County, Colorado Springs and South Dakota. These thrust "faults" occur along certain weathered bedding or fracture planes and may be the product of the gross expansion of the near-surface body of bedrock. Lateral pressures exerted by this type of movement have not been estimated but may be locally high along the shear plane. This type of feature is not widely recognized by the engineering community nor is it used in the design calculations for drilled piers and basement foundation walls. Sudden reactivation of these "faults" by adding excess moisture to the bedrock (3 inches of heave on one such "fault" within a 24-hour period was observed after a large rain storm) could actually shear standard-design piers at any depth and effectively nullify the intended anchoring effects of deep pier emplacement.

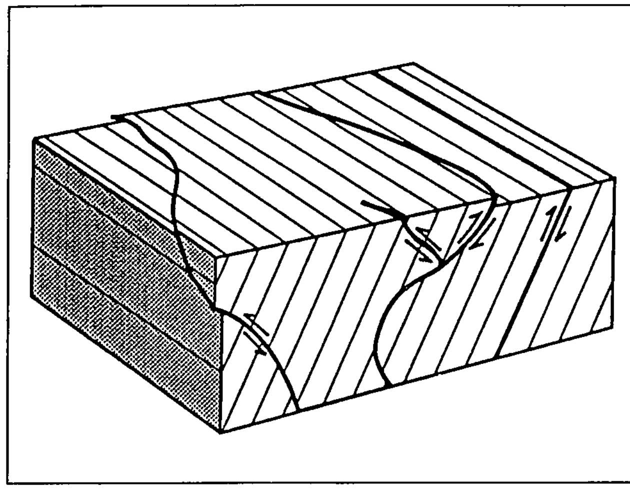


Figure 3. Block diagram showing three curvilinear shear-slippage surfaces (thrust "faults") and another shear-slippage surface along a bedding plane.

Larger, regional faults such as the Golden and Jarre Creek faults may be an additional focus for differential ground movements. Bedrock in the vicinity of these faults is probably more highly fractured than is normal, resulting in more water infiltration and more potential planes of shear slippage. Ground movement in these areas is seen as a near-surface adjustment phenomenon (to increased water infiltration after development) rather than an actual reactivation of the fault.

Depth to Bedrock (Overburden Thickness)

Heaving damage is shown to be strongly influenced by how close the bedrock is to the surface. The potentially heaving bedrock formations may be covered with different types of unconsolidated materials ("soils"). Areas having thin soil cover have sustained some of the most notable damage, and the damage in these areas most closely displays the same linear patterns as the underlying bedrock. Cuts made directly into the top of the shale bedrock may perform extremely poorly because fresh exposure of the fracture surfaces may allow easy transmission of water into the bedrock (rendering most peripheral drain systems ineffective), and because the sudden unloading of unconsolidated shale may cause some degree of rebound uplift of the immediate shale mass.

C. Natural Conditions That Inhibit or Neutralize Heaving

There are certain areas within the outcrop belt of formations 1–6 where structures, roadways and utilities have performed well. In many cases, the following geological conditions may be considered as natural mitigating factors against destructive bedrock heave:

a) sufficient thickness of non-expansive soil above expansive bedrock, and
b) expansive bedrock having high internal moisture content.

Many neighborhoods having satisfactory performance are built where a large thickness of natural or imported soil overlies the expansive bedrock. In what is probably the only published, statistical study of geological damage attributes in this area, Thompson (1992b) concluded that low- or non-expansive soil on the order of 10 feet deeper than the lowest constructed slab-on-grade is needed in order to fully counteract the effects of differential heave. This translates to approximately 17 feet of fill needed for a full-basement excavations. Although there is a degree of concurrence among geotechnical engineers in the greater Denver area, others believe this "10 feet plus" figure is too conservative, especially in the case where structural instead of slab basement flooring is used.

As for claystones having elevated moisture contents, there is no consensus that I know of for how "wet" a claystone formation must be to exist in an already expanded (therefore "safe") condition. A related question is at what depth from the surface or lowest excavated grade must the ground-water table must be for pre-development expansion to have occurred. There are several houses at the northeastern corner of the Executive Homes at Roxborough Village subdivision, Douglas County, whose performance may be enhanced by their proximity to a boggy, high water table area. Homesites in down-hill proximity to long-lived irrigation ditches may in some places be rather wet and expanded.

D. Human Factors That Influence Heaving

There are numerous other factors concerning design and on-site workmanship that may tremendously improve or significantly degrade the performance of facilities built in areas having steeply bedded, expansive bedrock. An example of improved risk is seen in the use of structural, rather than slab-on-grade floors. Poor workmanship and use of lower-grade materials for certain facility components may have a large and adverse effect on that facility, but it must be remembered that we are looking first and foremost at a significant geological problem and that even top-quality workmanship and materials may not matter in some instances where the ground is predisposed to heaving.

Re-compaction of fill material, especially if the material is remolded expansive claystone, is a factor that may affect performance of peripheral foundation fills and road beds.

Activities or incidents that introduce an excess of water into the ground (e.g., lawn irrigation or breaks in water pipes) can greatly accelerate heaving and increase the rate and magnitude of damage. In the case of one subdivision, it is known that a marked change in ground moisture occurred after nearly ten years of satisfactory performance, resulting in a tremendous amount of damage. Introduction of additional water from off-site sources (such as construction of an adjacent, up-hill development) may have similar negative effects.

E. Related Geological Hazards

Two geological hazards are sometimes closely related to the expansive claystone bedrock. They are:

a) expansive (shrink-swell) soils, and
b) slope instability.

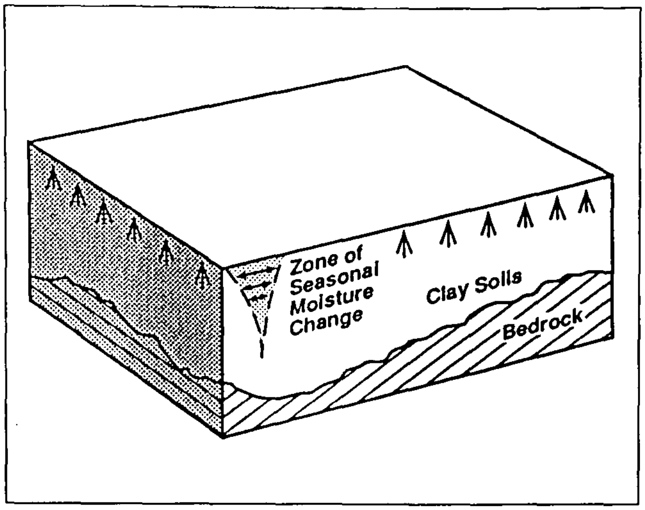


Figure 4. Block diagram showing a widely used, general model for swelling (expansive) soils. Volume changes, seen as heave, occur within the uppermost zone where moisture changes occur.

Expansive clay soils are distributed widely around the three counties and their distribution is somewhat independent of the underlying bedrock type or bedding dip. These deposits are derived from parent claystones by processes that include residual (in-place) weathering, gravity transport (slope creep), or stream erosion and re-deposition. Some of these clay deposits can be highly destructive to facilities that are not properly designed, constructed or maintained. The linear-heave component normally seen in heaving bedrock is absent or greatly diminished for expansive soils. The state-of-practice of the geotechnical consulting industry for site exploration and evaluation assumes a sort of standard "swelling soils model" (Figure 4), which is also usually valid for horizontal or low-dip claystone but does not address the linear tendencies and other complexities of high-dip claystone.

Slope instability situations are most dependent on slope angle, stress distribution, internal moisture and internal composition, and may involve both bedrock and soil deposits. Claystone bedrock and clay soils are infamous for having low internal resistance to slippage and commonly form the bulk of landslide and creep deposits along the Front Range piedmont. Development on clayey slopes usually increases the slope instability hazard because of added moisture and redistributed stresses from cuts and fills. In Colorado, clay slopes of less than 10 degrees are known to have failed after development.

PART II
FOUNDATION, ROAD AND UTILITY DESIGN CONSIDERATIONS

A. General Concepts

As summarized in the previous section, the most important attribute of steeply dipping claystone that sets it apart from the more widespread and widely recognized swelling soils (and flat-lying claystone) is the fabric or structure of the upturned bedrock. This fabric, which manifests itself as linear ground heave, has important consequences for foundation and infrastructure designs and methods of site exploration and characterization. Parts II and III discuss pertinent design and site-characterization issues.

The following design considerations are the result of field observations by the author as well as discussions with building, engineering and geological professionals having experience in the high-dip claystone area. If the previous 20 years of building history in the area have anything to teach us, it is that foundation and infrastructure systems constructed into or near to the claystone bedrock are at severe risk of heaving. Because of the sensitivity of the bedrock to construction and post-construction activities, there is an emerging feeling that foundations and other facilities should be isolated from the bedrock fabric as much as possible. The pros and cons of different designs are discussed below.

B. Drawbacks of Drilled-Pier Foundations

The drilling of foundation piers directly into steeply dipping, expansive claystones has not been successful in many developed areas where heaving-bedrock damage has occurred. The incidence of piers undergoing shearing or tensile failure at shallow depths or entire piers heaving up from the bedrock is thought to be relatively high in these areas, although post-mortems into the exact causes of pier failure are difficult to perform and are not done in normal mitigative practice. Damage to piers in some cases may be caused by swelling of certain beds or by shear movement along bedding planes or near-surface thrust fault planes.

Many engineers will argue that "deep" (>20-foot) piers are of sufficient design to prevent heaving of individual piers in areas of upturned claystone. However, the pier-depth calculations are based upon a standard accepted model of swelling soils that does not take into account shear movements of bedrock blocks or swelling of a particular upturned bed. In the event of block shear movement or swelling of a bed, there may not be enough reinforcement in a standard pier to resist the shear, in which case the pier will fail. Even if only one or a few piers heave, a structure could be severely damaged.

Thompson (1992a) compared damage to foundation slabs built on flat-lying versus steeply dipping claystone bedrock and found, for any given value of pre-construction swell percentage, that the damage rate incurred by houses on steeply dipping claystone was 30–50 percent higher than for houses built on flat-lying claystone with the same percent swell (Figure 5). At 4 percent swell, 50 percent of the houses in the subdivision built

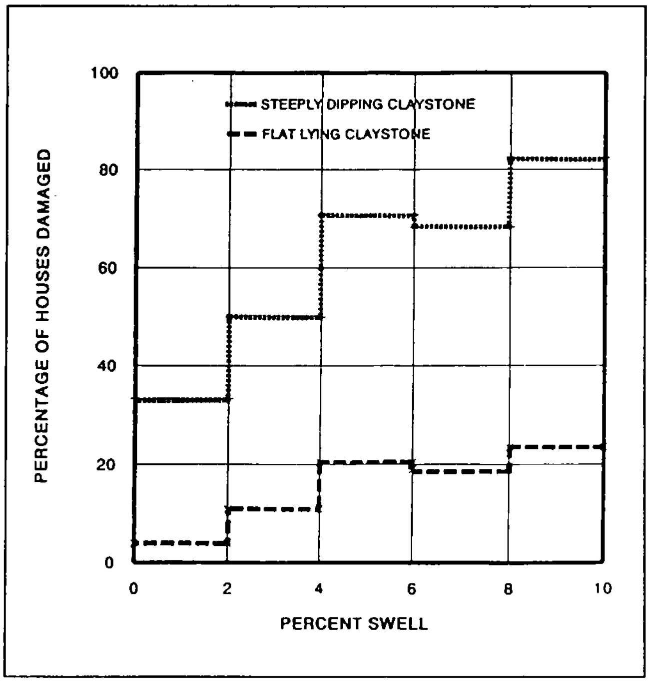


Figure 5. Percentage of homes damaged on steeply dipping versus flat-lying claystone (from Thompson, 1992a). Homes on upturned claystone are much more damage-prone for similar percent swell values.

over steeply dipping shale experienced slab damage; these houses tended to experience structural (foundation) damage as well. Since most of the houses in this study have drilled-pier foundations, the questionable performance of this foundation type in areas of upturned claystone is demonstrated.

For areas of steeply dipping claystone, drilled pier foundations (even deep piers) are a gamble because the foundation are so closely coupled to bedrock that is unstable and can shift or swell. Drilled pier foundations should not be regarded as the design of choice without first considering other mitigative options.

C. Foundations on Natural Alluvium or Imported Fill

It is well known by geotechnical professionals around the Denver metropolitan area that houses, roads and utilities constructed on thick accumulations of natural, low-swell alluvial deposits overlying expansive claystone have a much lower incidence of damage than those engineered facilities constructed where steeply dipping claystone formations are found at shallow depths. Likewise, subdivisions built atop lifts of non-expansive fill over expansive claystone have performed reasonably well (e.g., Parcel 1 at Roxborough Village, filing 1).

The reason for the success of building on natural or imported fill is that the granular fill material is able to distribute heave displacements from underlying expansive beds in an outwardly shifting, grain-by-grain manner, thus decreasing the magnitude and locus of any underground linear heave.

Thompson (1992b) also compiled detailed damage records for 9,040 houses from 51 subdivisions in the Denver metropolitan area and performed statistical analyses of geological conditions. He observed that 1056 houses built upon near-surface Pierre Shale incurred a damage rate of 38.44 percent (as opposed to 8.95 percent average for all houses in the study). Where alluvium overlies the Pierre Shale, 643 houses had a damage rate of 9.49 percent. Thompson found a strong correlation between the percentage of houses needing repair and depth to claystone below the foundation slab (Figure 6); slab repairs increased dramatically where the claystone was encountered at depths of less than 10 feet.

Discussions with area engineers reveal some agreement that ten feet of non-expansive fill is an acceptable conservative figure for slab-on-grade flooring as well as outdoor flatwork and roadways. If structural basement flooring is used, the acceptable thickness of overburden may be somewhat less than 10 feet.

In areas having a sufficient thickness of low- or non-swelling alluvium or fill, the current foundation of choice is some type of spread footing with slab-on-grade floors. Where a marginal thickness of overburden is encountered, there is a newer trend toward using a "hybrid" foundation combining pad footings with structural floors. In certain cases, additional fill can be imported from off-site or elsewhere on the parcel where an "excess" of granular soil deposits exists as a way to augment the buffering effect of the overburden.

Although certain costs may be incurred by the developer where fill-augmentation is needed, comparative savings may be realized in that spread-footing foundations are generally less expensive to build than drilled-pier systems. Fill augmentation is not necessarily problem-free (damage from settlement is possible if the fill is improperly compacted), but such problems can be minimized by engineering quality control measures. Compared to the long-lasting, often recurring problems associated with near-surface, steeply dipping claystones, the augmentation process is certainly the lesser of two evils.

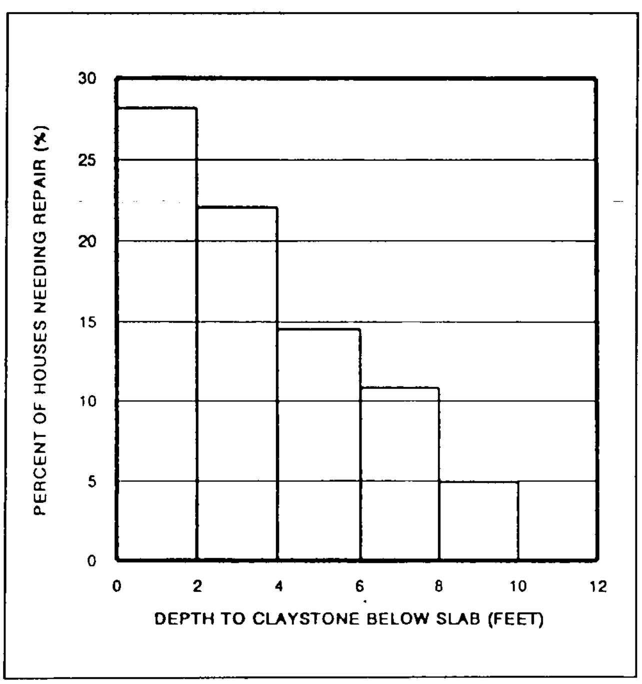


Figure 6. Graph showing decreasing damage to houses as the depth to claystone bedrock (and related thickness of natural or overburden soil) increases (from Thompson, 1992b).

D. Overexcavation and Soil Mixing

Overexcavation involves downcutting and removal of bedrock and replacement with either non-expansive soil materials, remolded bedrock (which becomes essentially a soil), or a mixture of the two. The ultimate goal is much the same as fill augmentation as described earlier: to create a buffer of soil having no particular fabric between the foundation, road, etc. and the top of the in-place bedrock. The excavations range in size from individual lot-sized holes, dug with conventional construction equipment, to subdivision-scale operations (such as Canyon Point near Golden) where entire areas are removed, mixed and replaced using heavy machinery.

Individual-lot overexcavation appears to be the method of choice for building on steeply dipping Pierre Shale in the Colorado Springs area; however, Denver-area engineers appear to be wary of this approach. The main concern is that the lot-sized overexcavations effectively form a "bathtub" and retain water due to the impermeable nature of the claystone (We know, though, from Part IB. that this "bathtub" can leak due to the severe fracturing of the bedrock, and thus could accelerate heaving. This is a concern especially if drilled-pier foundations are used in tandem with the overexcavation.).

The employment of overexcavation at any scale requires several considerations including excavation-area size, type of equipment, drainage design, type and composition of fill soils to be backfilled in the excavation, type of foundation (pad-type vs. pier; note that pier foundations defeat the purpose of the overexcavation) and flooring systems, fill-compaction detail and, most importantly, project economics.

E. Considerations for Roads and Utilities

Roads and buried utility lines are protected against heaving displacements when isolated from the bedrock by a sufficiently thick layer of non-expansive alluvium or fill. However, in areas where claystone bedrock is encountered near the ground surface, severe and recurring deformation of roadways and breakage of water and sewer mains has occurred. It is extremely important to keep the infrastructure of roads and utilities from heaving in the first place, since introduction of excess water into the bedrock, whether due to negative pockets of drainage in roads or broken water and sewage pipes, can markedly increase the rapidity, magnitude and areal extent of heaving.

There is at present an unsolved controversy between the building and water/sanitation districts sectors regarding the use of area underdrains in new subdivisions. These systems carry excess water from foundation perimeter drains into central collector systems, usually consisting of perforated pvc pipe within a course gravel at the bottom of a trench (in most cases, beneath the sewer lines in the sewer trench). Even though most excess water should flow through the gravel and perforated pipe in an adequately graded area underdrain, there is ample geological evidence that at least some water will drain into exposed fractures where the trench cuts into bedrock. This minor amount of water, leaking along the length of the underdrain, may be all it takes to initiate heaving. In areas where unsaturated and steeply dipping bedrock occurs at or near to the base of area-underdrain excavations, I would suggest that certain mitigative measures be considered to address the bedrock fabric and leakage, such as trench overexcavation and better sealing of the trench base (using a liner of remolded and compacted clay or some type of geo-fabric).

Lime-solution treatments are often used effectively for road bases in areas of swelling soils. This operation may not be as effective, however, in areas underlain by steeply bedded claystone because the heaving emanates from greater depths than in flat-lying claystones or clay soils). It is doubtful that the lime treatments have the effective "reach" to address the entire thickness of bedrock that may be involved in post-construction heaving.

PART III
SITE-EVALUATION CONSIDERATIONS

A. General Concepts

Due to the serious and recurring nature of damage from differential bedrock heave, we feel that there needs to be a philosophical shift in the planning and permitting process where such problems are possible (as defined by the overlay zone), namely:

1. *Increased levels of site exploration, evaluation and review are needed in the earlier phases of the permitting process.* This is especially true for the zoning/rezoning stage, after which the property becomes essentially "buildable" over all parts that were not excluded. The definition of "buildable" is extremely problematic and may in part depend on a developer's willingness and/or economical ability to take on some kind of site modification.
2. *Burden of proof should be placed upon the developers and their technical consultants to delineate those locations, using both site-specific and off-site information, where differential bedrock heaving hazards either a) do not exist, b) exist, but in degrees that are mitigable using specified design considerations, or c) exist and cannot be (economically) brought into compliance with County prerequisite conditions and therefore would be considered as non-buildable.* Any or all of the three conditions could occur over a single subdivision. This concept assumes that all known geological information about the area is weighed against data collected directly from the site itself. Off-site information includes damage history of nearby or geologically similar neighborhoods, and includes considerations for the effects that neighboring subdivisions (both existing and future) will have on each other. Insufficient data-collection and analysis would lead to deferral, not approval, of permit requests.

These two concepts would provide the County with a means of protecting its citizens and its transportation and utilities infrastructure by enhancing problem-area recognition and delineation, encouraging better methods of hazard mitigation, and allowing increased selectivity of areas to be developed.

B. Methodologies and Levels of Investigation

The methodologies and current levels of investigation detail used in geotechnical site evaluations are, in my opinion, inadequate for recognizing and delineating areas of potential differential bedrock heaving damage. Standard site-evaluation programs assume that local areas of geological variation can be delineated and characterized on the basis of a prescribed grid spacing (which varies with the stage of permitting) for test boreholes. Such programs ignore three key attributes of steeply bedded claystones:

a) variable properties across bedding (dip), on order of inches to feet,

b) extremely continuous properties along bedding (strike), on order of tens of feet to miles, and

c) anomalous bentonite beds or fault planes.

With regard to conventional test-borehole exploration programs, there are certain tests or observations that are of use in evaluating a subdivision for potential heaving-bedrock problems, *but only if the relationship between the samples and the rest of the strata is known.* This means that local, grid-based drilling programs cannot possibly identify the amount of subsurface variation beneath a property on any scale (even on a lot-by-lot basis). The assumption that a sample is "characteristic" of the bedrock may be erroneous because of the variability of bedding properties, and more importantly, because anomalous beds and other features that have the greatest potential for heaving are only rarely encountered in test-hole drive samples.

At the same time, the idea that characteristics of certain beds or zones may be essentially similar and thus transferrable along strike for hundreds to many thousands of feet has not been recognized and accepted by the geotechnical community. We feel, therefore, that *a major predictive element that takes advantage of bedding continuity along strike is being not being utilized* as a part of site investigation.

Anomalous bentonite beds are very seldom recognized during drilling, and potential fault planes are indiscernible from other fracture planes in drive samples. *Clearly, conventional drilling, sampling and testing techniques do not allow for recognition of these features where heave is most likely.*

C. A Suggested Site-Exploration Program

For subdivision permit applications within the mapped "overlay zone" of steeply bedded claystone formations, I envision that "more data sooner" criteria for adequately evaluating site risks could be met by combining an initial, moderately dense drilling reconnaissance with a subsequent (and optional in some cases), selective trench and test pit digging program as outlined below. This multi-step approach could be used for currently zoned properties that await platting, or could even be used for rezoning cases located within the overlay zone where heaving bedrock hazards are suspected.

Step 1, Test-Borehole Reconnaissance

This would entail a somewhat denser than usual drilling and testing program for purposes of outlining areas where a sufficient thickness of overburden soil is present and, conversely, where areas of near-surface claystone is present. Also specifically assessed are the water table and general soil moisture. This would entail:

a) drilling of test-boreholes on 500-foot centers (closer holes on smaller properties), and

b) minimum hole depth of 25 feet (to assess "basement + 10-foot" soil envelope)

Testing would entail standard tests and measurements as is done currently. It would be extremely helpful to CGS and County reviewers if the engineers displayed the results of certain tests (such as swell/consolidation potential, moisture content, Atterberg limits, dry density, percent silt and clay sized particles) on the drilling log profiles, adjacent to the interval from which the sample was taken. Sampling should include at least on sample from overburden soil (if present) and one from the bedrock (if present). Standing water table depths should be measured at the completion of drilling and also several days (at least four to seven days) later.

Step 2, Preliminary Geotechnical Report
Results from the test-borehole reconnaissance, plus any applicable off-site information, would be incorporated into a preliminary geotechnical report by the developer's geotechnical engineer. In addition to "normal" report considerations, the property should be specifically evaluated in terms of the heaving bedrock hazard. The report should delineate areas of the proposed subdivision that are generally "not prone to heaving", "marginally prone to heaving" and "prone to heaving", keeping in mind that all three types of ground could be present within a particular property. CGS would similarly delineate potential areas of concern as part of the review process.

Areas on the property meeting one or more of the following listed criteria would be considered as "not prone to heaving" and would be considered as generally buildable barring presence of other geological hazards or non-geologic issues. The justification for these criteria can be found in parts I and II.

a) bedrock interval is non-expansive,
b) overburden soil is non-expansive or has a low swell potential, and is >10 feet deep below lowest anticipated slab depth for slab-on-grade floors (soil thickness needed beneath structural floors yet to be determined),
c) water level and soil moisture are sufficiently "high" (levels yet to be determined),

Areas designated as "marginally prone to heaving" are those that approach but do not meet the criteria listed above. In certain cases, relatively straight-forward mitigative measures such as redistribution of on-site soils or importation of fill from off-site may be used to reduce the heaving ground hazard. Other marginal situations may require their own unique solutions (the case of thick but expansive overburden soils comes to mind as a hybrid problem).

Areas of shallow, expansive, "dry" bedrock on the property should be delineated by the developer's engineer as "prone to heaving" as a product of the step 1 investigation. If the developer and his/her geotechnical engineers cannot advance an economically acceptable mitigation plan for such areas (e.g., involving large-scale overexcavation or soil/bedrock mixing), or if the developer and his/her geotechnical engineers disagree with the CGS over interpretations of the heaving ground hazard, or if certain boundaries between favorable and unfavorable areas cannot readily discerned, a second level of investigation would be necessary for areas thought to be "prone to heaving". No acceptance would be given to the applicant's permit request until those areas are explored, the potential hazard is described, and an agreement is reached between the developer and the County on appropriate subsequent actions (which could include either mitigative action to reduce the hazard or exclusion of certain lots or areas from the plat).

Step 3, Trench and Test Pit Description
In shallow-bedrock areas that are suspected to be "prone to heaving", an intermediate-level exploration and testing program is needed to further assess and locate potential contiguous (strike-oriented) zones where destructive heave is probable. Depending on the size of the parcel and of the areas of concern, CGS would work with the County and the developer's geotechnical engineer to identify appropriate trench and test pit locations and dimensions. (Note: CGS would not be involved as a consultant in any way, but would lend technical expertise to the developer and County as mandated by State law and would review the amended geotechnical engineering report for the County. Jefferson County has recently determined that such activities go beyond the normal base level of CGS's involvement in the review process; therefore, additional project time incurred by CGS would be charged to the developer through the County as an extension of review activities.)

Trenches are seen as a primary source of information about the structure and composition of the near-surface bedrock, while test pits would be used for supplemental information. A main trench would ideally be dug by a standard backhoe to a depth of as much as 14 feet, and would be generally aligned in a west-to-east direction (along bedding dip) to expose as much of the bedding as possible. Test pits, also dug with a backhoe, could be dug in smaller outlying areas where more information is needed.

Applicable safety standards (OSHA, etc.) would apply if workers are to enter the trench. Clay or claystone walls tend to be vertical and should hold for the duration of logging, whereas alluvial soils may cave, necessitating trenching in the area of thinnest alluvial cover. Appropriate precautions, in the form of support or sloping, should be taken for caving soils.

The following information should be logged by an experienced geologist from the trench and/or test pits:

a) nature of the bedrock/soil contact,
b) soil thickness (depth to bedrock),
c) soil composition variations,
d) bedrock composition variations,
e) presence of bentonite beds and "fat" claystone zones,
f) bedding dip,
g) presence and density of fracturing,
h) presence of past shearing along bedding planes,
i) presence of reactivated shear planes (thrust faults) across bedding planes.

(Note: In many cases it is desirable to use a shovel blade to remove the backhoe "scrape" to expose the sidewalls for viewing.)

The trench should be logged, photographed and described by a consultant who meets the Colorado legal definition of a Professional Geologist (see attached CRS 34-1-201 as Part VI) and with required experience in engineering geology. If possible, CGS could provide a geologist to examine the trench, make suggestions for sampling and determine adequacy of the trench for bedrock characterization.

Several samples should also be taken from the trench walls where deemed necessary. The sample locations should be surveyed so as to be located on the subdivision plat (for purposes of extending certain beds, etc. along strike) and the sample depth should be noted. Tests such as Atterburg Limits, moisture content and grain size would allow for a quickly and inexpensive means of assessing the relative composition of the samples and could readily be compared to the results of other samples taken during the step 1 drilling program.

If necessary, additional test holes could be drilled immediately next to the trench to test specific zones (as an example, for swell/consolidation test samples, which are more easily and appropriately recovered as a drive sample).

Step 4, Development of an Integrated Building Plan

Results from the exploration and testing program, in the form of an amended geotechnical report by the developer's geotechnical engineer, would be used to evaluate the potential for bedrock heaving and geological hazards on the studied parcel. Anomalous bedrock features conducive to heave, as located from trenches and test pits, could be extended along the strike direction and evaluated elsewhere on the property with proper account given to changing overburden characteristics. The overwhelming benefit of this type of study would be the improved recognition of potential problem areas.

With the gathered knowledge, the question of whether the situation is mitigable could then be addressed. If the County were to define certain prerequisite criteria for some of the controlling characteristics of the soils and bedrock that influence heaving (such things as swell potentials, Atterberg limits, thickness of overburden, ground-moisture characteristics), these criteria could be used in a pass-fail manner.

The final use of, and decisions based on site exploration studies would vary, depending upon the stage of the application. For areas already zoned and platted, the exploration program would give enough first-hand information to the developer's engineer to come up with the best possible design strategy, and would give the County, through consultation with CGS, enough information to reach an acceptable agreement (such as an amended plat if necessary). For areas undergoing re-zoning and initial plat request, the criteria could be used in a more creative manner (deletion of certain plots or reconfiguration of the sketch plan before preceding to the preliminary plat stage).

For areas deemed mitigable, there will be a greater understanding of the nature of the hazards to be addressed, and this knowledge will give us the means to assure that future County homeowners will not be burdened with the high level of damage and financial misfortune that has been prevalent in many previously built subdivisions.

PART IV
OTHER CONSIDERATIONS

A. Limitations of Certain Standard Tests

Certain standard tests and exploration methods have drawbacks that should be recognized when assessing geotechnical investigations. Here are a few common (and sometimes subtle) examples:

Thickness of overburden soil and depth to top-of-bedrock (which are the same thing) is most often determined using a standard penetration test, also called blow counts, usually in five-foot depth intervals. Top-of-bedrock is commonly assigned to the test depth where the earth materials become more resistant and dense. Two problems are apparent. First, strict use of the 5-foot spacing, without using other clues (change in drilling rate, presence of diagnostic bedrock debris in cuttings) may lead to top-of-bedrock depths that are up to five feet too deep. Second, it is entirely possible for some claystone bedrock to be extremely weathered and soft. In such a case, the penetration test would also assign too deep a top-of-bedrock horizon. Both mistakes are significant, since any inclined bedrock, even extremely weathered, can impart a strong pattern of linear heave on the surface. Logging and interpretation by an experienced Professional Geologist can resolve questions about extent of weathered zones and thickness of low- or non-swelling overburden materials.

Another test used in the Denver area, the swell/consolidation test, is fairly standardized except for the amount of weight ("surcharge") that is initially placed upon the sample before wetting. Apparently, this has a significant effect on the exact value of swelling or consolidation. Therefore, any arbitrary limit on swell potential for County acceptance, would be meaningless. I would be in favor of either standardizing the surcharge used for such tests to something like 1000 lbs or loading each sample with an estimate of the actual overburden surcharge based on anticipated cut/fill configuration (or both).

Trenching, as described in the previous section, allows for a more accurate delineation of the top-of-bedrock. Additionally, it allows "worst-case" (most sensitive to construction changes in soil moisture) zones of bentonite or "fat" claystones to be identified for testing.

B. Developer vs. Homeowner Risk

Under present conditions, homeowners in areas of heaving bedrock incur the long-term cost of maintaining their homes despite recurring damage. Likewise, the County and public utility districts incur costly and recurring maintenance to their streets and buried utility lines. Except for lawsuits (after which the damage is repaired—temporarily at best), developers have not had a stake in the long-term fate of their project subdivisions.

Many developers and geotechnical engineering companies are not fully aware that the area in question is a sensitive, high-risk area for building. Developers must be made aware that this is indeed a high-risk area (much the same as floodways or rockfall hazard zones), and that if they intend to build in this area they should be prepared to incur a higher degree of risk themselves. Developers should realize that parts of their properties may be found to be too risky for County acceptance for building purposes (assuming the area-wide standard of design based on swelling soils). Where building is allowed, the developer should be made a longer-term partner in the success of the project.

Some County officials believe that the County should not incur the maintenance cost of roads in the "overlay area", and that the roads should be maintained by the local homeowner's association. While the Counties' wish to refuse to take on the liability of road ownership and upkeep is understandable, there is a risk that HOA ownership will hasten that which we most wish to avoid: the financial devastation of the individual homeowner. An alternative scenario would be to have County-owned roads, with the developer posting a significant bond for the performance and upkeep of the roads, over a period of years. This follows the "you must incur more risk if you want to build in this risky area" philosophy.

C. Homeowner Education

The idea that this is a higher-risk area is similarly down-played when new or used homes are marketed. For new homes, claims such as "Those problems are in neighborhoods built by out-of-state companies. We're local and understand the problem.", and "We walk away from buying any (larger subdivision) property where we tested more than 6 percent swell" only serve to candy-coat the problem and confuse the prospective home-buyer.

Likewise, with homes being sold by an individual homeowner, claims that a problem has been fixed may be made. In this case, the present homeowner may or may not understand that those same problems may recur at a future date. There are numerous cases of homes built on the Pierre Shale that have undergone several cycles of major repair work over a period of years. In some cases, a damage settlement has resulted in the owner doing cosmetic repairs to the house, then selling the house and keeping the remainder of the settlement.

It is apparent from these and other instances that the risks involved with home ownership on developed areas of heaving bedrock are poorly understood by, and poorly communicated to, the general public as well as the real estate industry. There appears to be a need for a specifically tailored document for homeowners (that includes a description of the heaving bedrock problem and its risks, as well as essential homeowner maintenance for existing homes). This is a project that could be undertaken by CGS. Field seminars, such as those led by CGS last fall, or shorter in-house seminars given for builders (such as those to be offered by the Colorado Association of Home Builders) and real estate professionals may also contribute to the accountability of those groups.

D. Construction Quality Control

The CGS supports the recent and ongoing efforts of Douglas and Jefferson Counties to review and improve standards for construction quality control. A major issue in this area is the quality control of drilled piers, more specifically the attainment of design standards by contractors during drilling and construction and the effectiveness of engineering inspection of piers. Questionable construction practices, in addition to inadequate inspection and quality control, may add greatly to the amount of damage that occurs in areas that are prone to heaving. This is yet another example of how drilled-pier foundations may not be the appropriate first-choice foundation system for areas of steeply dipping claystone.

PART V
REFERENCES

Thompson, R.W., 1992a, Performance of foundations on steeply dipping claystone: Dallas, American Society of Civil Engineers Geotechnical Division and others, Proceedings of the 7th International Conference on Expansive Soils, p. 438–442.

Thompson, R.W., 1992b, Swell testing as a predictor of structural performance: Dallas, American Society of Civil Engineers Geotechnical Division and others, Proceedings of the 7th International Conference on Expansive Soils, p. 84–88.

PART VI
DEFINITION OF GEOLOGIST
(COLORADO CODE OF REGULATIONS, 34-1-201)

GEOLOGY

34-1-201. Definitions. As used in this part 2, unless the context otherwise requires:

(1) "Geologist" means a person engaged in the practice of geology.

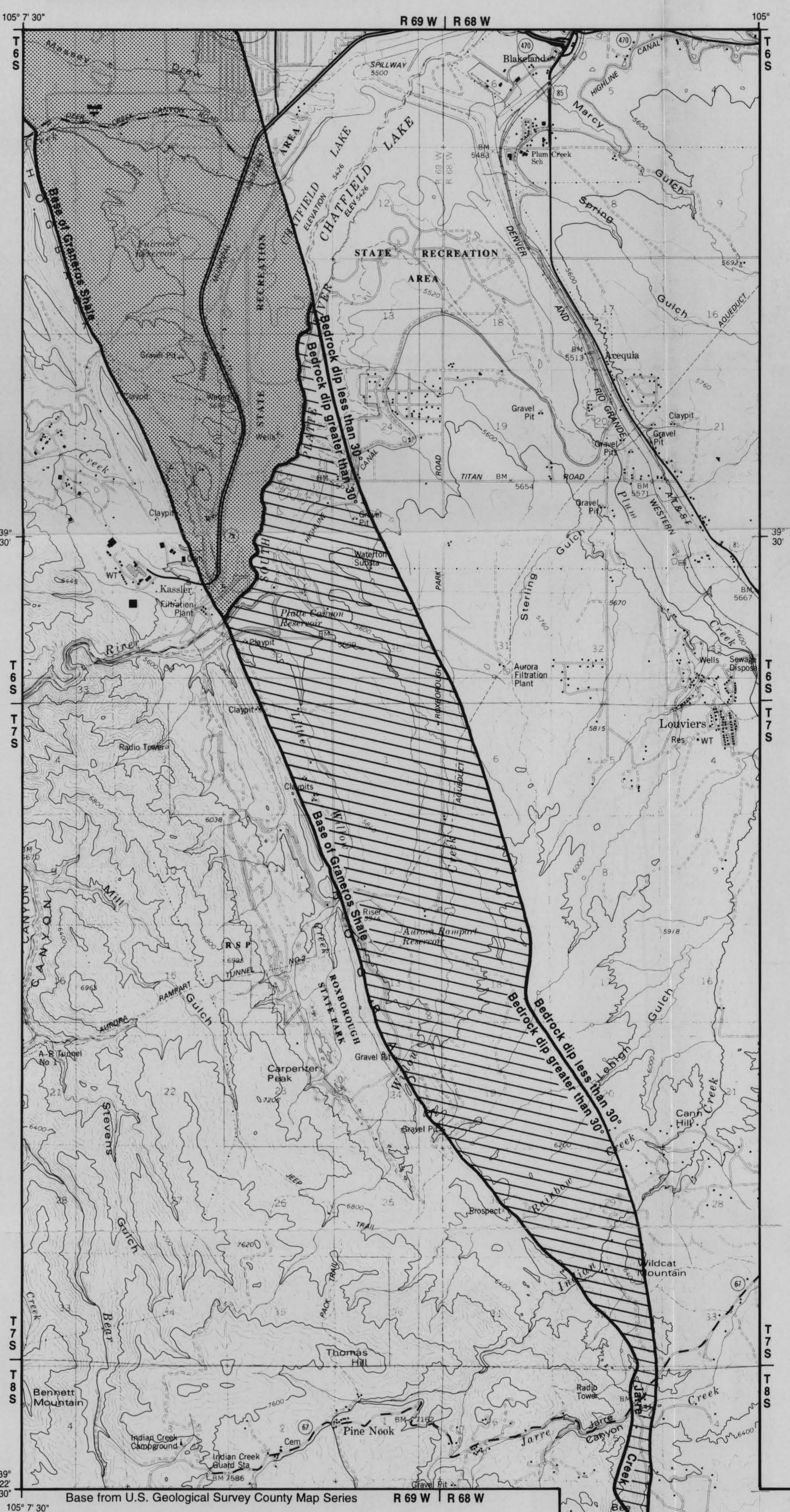
(2) "Geology" means the science which treats of the earth in general; the earth's processes and its history; investigation of the earth's crust and the rocks and other materials which compose it; and the applied science of utilizing knowledge of the earth's history, processes, constituent rocks, minerals, liquids, gasses, and other materials for the use of mankind.

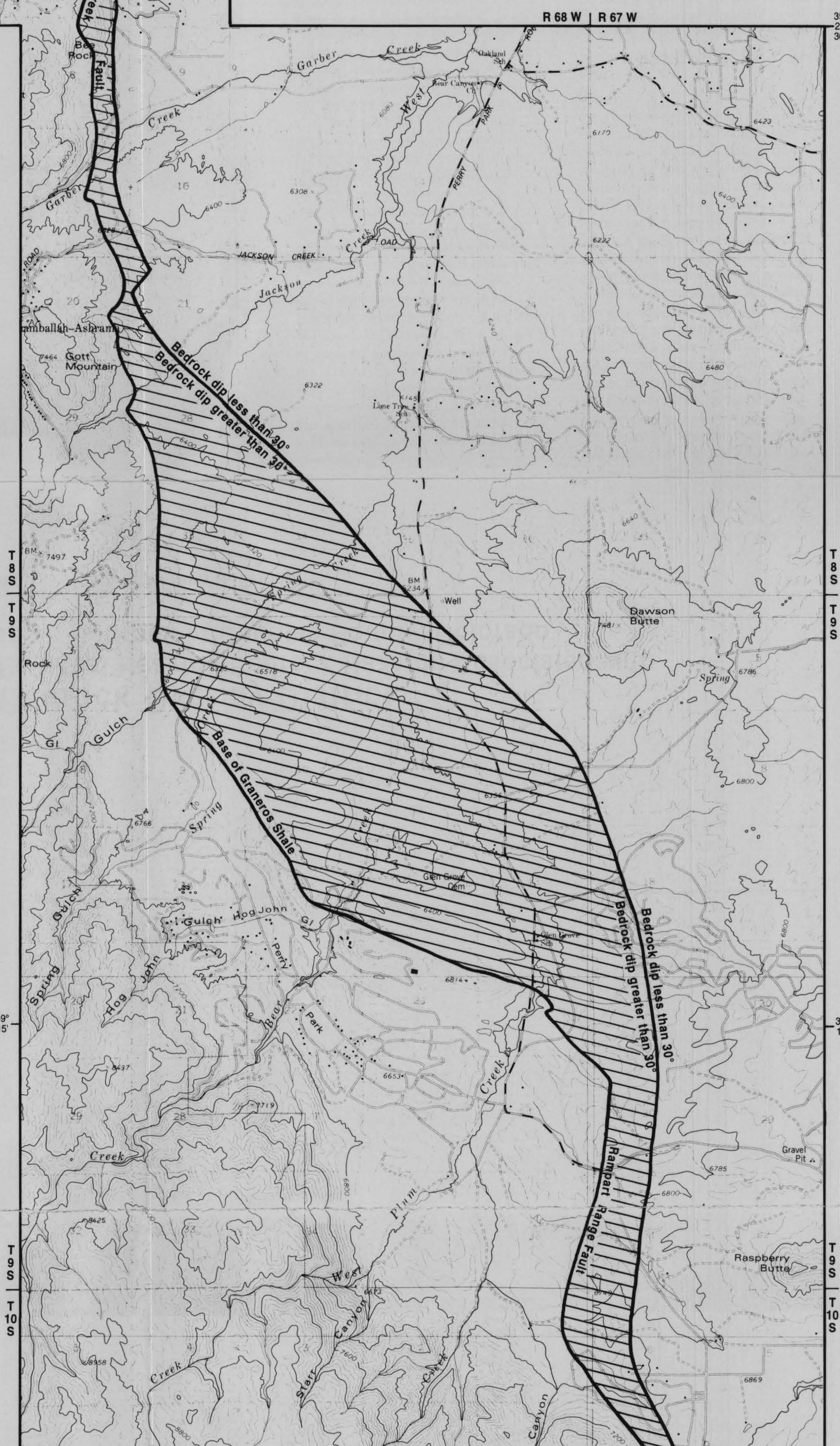
(3) "Professional geologist" is a person who is a graduate of an institution of higher education which is accredited by a regional or national accrediting agency, with a minimum of thirty semester (forty-five quarter) hours of undergraduate or graduate work in a field of geology and whose postbaccalaureate training has been in the 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.

Source: L. 73, p. 610, § 1; C.R.S. 1963, § 51-3-1.

COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES

OPEN-FILE REPORT 95-5
1995
PLATE 1





DISCUSSION

Introduction

The Dipping Bedrock Overlay District (DBOD) defines an overall area of Douglas County where heaving bedrock hazards are possible under certain geological and human-influenced conditions. Special considerations are warranted in all phases of property development including site exploration and evaluation, facilities design, construction quality control, and subsequent maintenance by individual homeowners, homeowner's associations, utility districts, and the County. In some areas, avoidance with respect to certain types of commercial and residential development may be the most advisable land use alternative; such areas may be favorable for parks, open space, or rural and agricultural use.

Heaving Bedrock Geological Hazard

A high rate of damage to roads, utilities, and lightly loaded residential and commercial structures has occurred along Colorado's Front Range piedmont where steeply dipping beds of expansive (swelling) claystone bedrock are found in close proximity to the ground surface. In such areas, differential ground deformations may occur in the form of elongate mounds or ridges of "heaving bedrock" that may grow to dimensions of two feet high, several tens of feet wide, and several hundreds of feet long. The ridges form where adjacent, dipping layers of bedrock, each possessing a different potential for expansion, are exposed to excess moisture after construction. Heaving bedrock is complex in nature and difficult to predict using conventional site-exploration methods. Damage from heaving bedrock is typically first seen within ten years after development of raw land, and ground deformations may continue for years or decades. The resulting damage is often more localized and destructive than damage caused by the flat-lying expansive soils and bedrock found to the east over much of the plains. Regionally, this geological hazard is responsible for tens of millions of dollars in excess maintenance costs to taxpayers and homeowners.

Considerations for Proposed and Existing Subdivisions

The DBOD also contains numerous areas where geological conditions are favorable for development, and where satisfactory performance of houses and other facilities has occurred. Detailed geological and geotechnical investigations should be conducted for proposed developments to delineate areas where favorable conditions occur, such as thick alluvial soils or layers of non-expansive bedrock. Special mitigative designs must be employed where near-surface zones of potentially heaving bedrock are encountered. Potential home buyers should be aware that the distribution of areas of damage within the DBOD may be erratic. A house that exhibits structural damage may be located next to others that have no damage. When purchasing an existing house within the map area, or any other area underlain by expansive soils and bedrock, the buyer should have a qualified soils, foundation, or structural engineer, or house and foundation inspector conduct a detailed evaluation to ensure that the house is structurally sound.

Geology and Boundaries

The DBOD is underlain by eight sedimentary formations of Cretaceous age: the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and Laramie Formation, and part of the Dawson Arkose. The western boundary corresponds to the base of the Graneros Shale on the eastern dip slope of the Dakota Hogback Ridge. Where this contact is missing due to faulting, the western boundary corresponds to the mapped location of the Jarre Creek and Rampart Range Faults. The eastern boundary corresponds roughly to the eastern extent of bedrock which dips at greater than 30 degrees from horizontal. Bedrock layers underlying the DBOD dip to the east or northeast at 30 to 90 degrees from horizontal. This map does not show internal contacts between different bedrock formations, nor does it attempt to delineate areas of natural alluvial deposits which may cover and significantly reduce the heaving potential of the bedrock.

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Scott, G.R., 1962, Geology of the Littleton quadrangle, Jefferson, Douglas and Arapahoe Counties, Colorado: U.S. Geological Survey, Bulletin 1121-L, 53 p.

Scott, G.R., 1963, Bedrock Geology of the Kassler Quadrangle, Colorado: U.S. Geological Survey, Professional Paper 421-B, p. 71-125.

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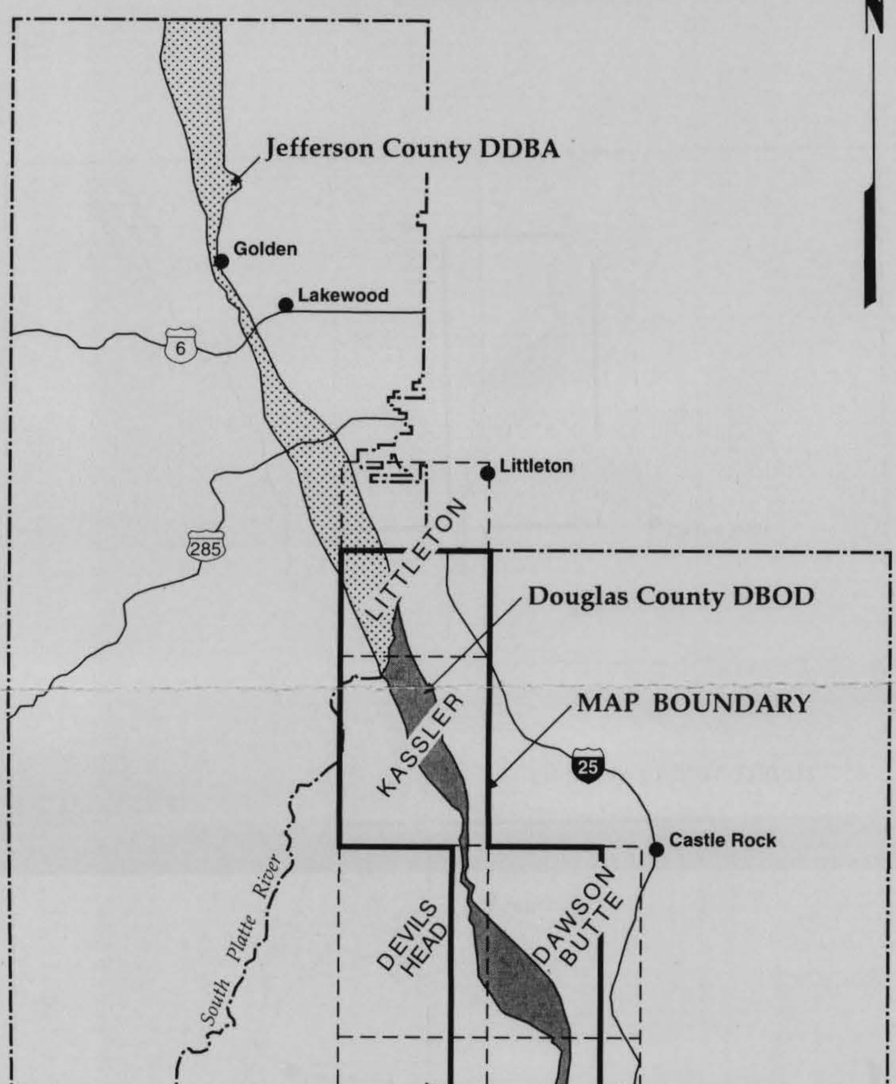
EXPLANATION

Douglas County Dipping Bedrock Overlay District (proposed)

Jefferson County Designated Dipping Bedrock Area (adopted April, 1995)

COUNTY INDEX

MAP AND 7.5-MINUTE QUADRANGLE INDEX



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CONTOUR INTERVAL FEET

Dipping Bedrock Overlay District:

Preliminary Map of an Area of Potential Heaving Bedrock Hazards Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado

By David C. Noe and Marilyn D. Dodson