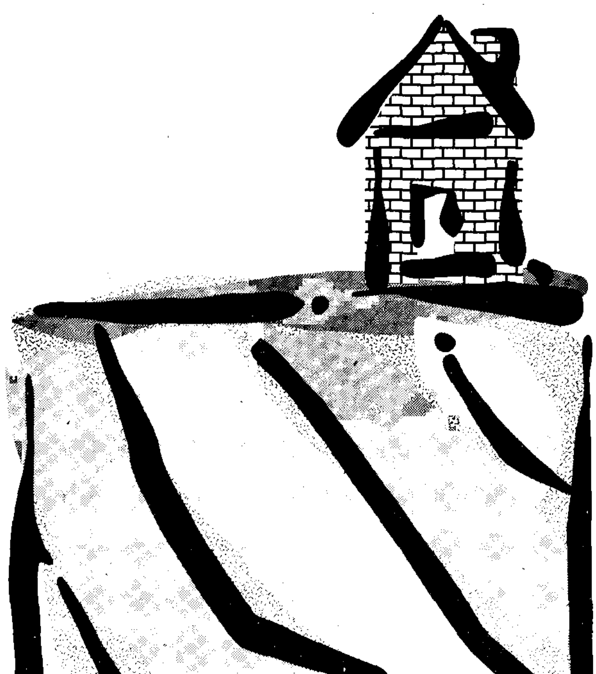
Special Publication 42

Heaving–Bedrock Hazards Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado

By David C. Noe and
Marilyn D. Dodson



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Executive Summary

Heaving bedrock is a distinctive geological hazard that is related to expansive soils. It is more complex than expansive soils in terms of its mechanisms and distribution of deformation, and is capable of causing exceptional damage to houses, roads, and utilities. Heaving bedrock is responsible for tens of millions of dollars worth of damage 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. A large area of undeveloped land in Douglas County is underlain by potentially heaving bedrock. Accordingly, special consideration is warranted for these areas during all phases of site planning and development.

Dipping Bedrock Overlay District

The general area of Douglas County where heaving bedrock hazards may occur is delineated in this Colorado Geological Survey (CGS) report. This area, called the Dipping Bedrock Overlay District (DBOD), is shown in a map on Plate 1. The DBOD is based upon the coincidence of steeply dipping (tilted or upturned) layers of sedimentary bedrock having dip angles of greater than 30 degrees from horizontal and zones of expansive bedrock that swell in volume when excess moisture is introduced. The DBOD Map is intended for use by Douglas County as a basis for problem-specific land use regulations.

Heaving Bedrock Hazard Potential

The heaving bedrock hazard potential has been ranked for 14 bedrock units within the DBOD, as shown in a map on Plate 2. This Heaving Bedrock Hazards Map is intended for use by the County, developers, builders, engineers, geologists, and others to help them assess individual parcels of ground for potential heaving bedrock hazards. The hard-copy report and map plates, and an optional digital file, is available to the public as CGS Special Publication 42. A digital database file is supplied to Douglas County as part of the report. The digital database is compatible with the Douglas County's Geographic Information System (GIS) and may be used as an overlay with other County GIS databases.

The actual distribution and magnitude of heaving bedrock damage within the DBOD is variable, and appears to be controlled by a number of geological and non-geological factors. Many of these factors were investigated by the CGS as a case study of a subdivision in northwestern Douglas County. This subdivision contains areas that are significantly affected by heaving bedrock and other areas that are unaffected. The case study shows that localized factors such as depth to bedrock (also known as overburden thickness), bedrock moisture content, and the cumulative age of a particular subdivision may play a part in the distribution of heave damage in addition to the effect of bedrock geology. Other factors (e.g., foundation design, construction quality control, lawn irrigation, and homeowner maintenance for individual houses) may also have a strong affect on heaving bedrock damage; however, it was not possible to fully evaluate these factors.

The CGS made no attempt to investigate or map any localized factors in Douglas County except as part of the case study. However, such factors are important, and should be taken into account by a developer's geotechnical engineering consultant when designing a project within the DBOD. It should be understood that the DBOD Map (Plate 1) and the Heaving Bedrock Hazards Map (Plate 2) are based solely on bedrock geology, and do not consider local factors that may be present and could reduce the hazard. Plate 2 should be considered as a worst-case hazard ranking for any particular location.

Land-Use Recommendations

Problem-specific regulations and minimum-standards requirements are needed in order to successfully address the heaving bedrock problem. In some cases, avoidance may be the most advisable land use alternative. There is a growing awareness of heaving bedrock by homeowners, builders, engineers, geologists, contractors, insurers, realtors, utility district managers, and national, state, and county agencies. Jefferson County enacted amendments specifically written for areas of potentially heaving bedrock to its land development and building regulations in April 1995. Douglas County is considering similar regulations and requirements for heave-prone areas.

The CGS recommends that the Douglas County's land-development regulations should be modified for lands within the DBOD to address the heaving bedrock problem. The scope and intent of such regulatory changes should reflect the County's overall direction and goals with regard to long-range planning. Douglas County has an advantage over Jefferson County to the north in that the area of dipping bedrock is sparsely developed at present. In Jefferson County, it was necessary to consider the large amount of development that had occurred within the dipping bedrock area, and the demand for more development in the area. All phases of planning and building permitting should be modified to ensure proper site evaluation, building and facilities design, and construction quality control if future growth is to be allowed within the Douglas County DBOD. Modified regulations are also needed if growth is to be discouraged within this area.

We recommend the April, 1995, revisions to the Jefferson County zoning and land development regulations as a starting point for any new Douglas County regulations. Jefferson County has chosen to allow continued development within their Designated Dipping Bedrock Area (DDBA). The Jefferson County regulations call for more detailed initial evaluations of lands within the DDBA. Specific types of mitigative technologies, such as overexcavation with fill replacement, are called for where the substrata are identified as being heave-prone. Minimum design standards are given for foundation, road, and utility designs. There are provisions for variances in cases where the substrata are shown to be non-heave-prone and conventional building techniques may be appropriate. There are also provisions for review by an independent Engineering Review Board in cases where new technologies are proposed, or where the geological conditions are marginal for potentially heaving bedrock.

1 Introduction

Purpose and Objectives

The purpose of this project is to create a final map of an area containing potentially heaving bedrock in Douglas County, called the Dipping Bedrock Overlay District (DBOD). A preliminary report and map of the DBOD (Noe and Dodson, 1995) was created during Phase 1A of this project. Douglas County has requested the DBOD Map for the purpose of administering future growth and development of lands that may be subject to heaving bedrock hazards. 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.

Specific objectives of Phase 1B are:

- To field-check and revise the DBOD boundaries that were initially delineated during Phase 1A using a compilation of available geologic literature.
- To investigate whether additional formations, particularly the Morrison Formation, should be included as part of the DBOD.
- To map and rank the internal stratigraphy (i.e., zonation) of the bedrock formations within the DBOD in terms of potential occurrence and severity of heaving bedrock, considering the geological and engineering properties and damage history of each bedrock zone.
- To create a final report incorporating the results of the Phase 1A and 1B investigations. This report is a result of the work done for both phases of the project.

Background: The Heaving Bedrock Problem

A high incidence of damage to roads, utilities, and lightly loaded residential and commercial structures has occurred where steeply dipping beds of expansive (swelling) claystone bedrock are encountered at shallow depth along Colorado's Front Range piedmont[1]. Uneven ground deformations can occur in such areas, resulting in the growth of elongate heave features. The geological hazard responsible for this type of deformation is "heaving bedrock". Individual heave features may attain sizes as large as two feet high, several tens of feet wide, and several hundreds of feet long (Fig. 1).

1. The term "piedmont" corresponds to the flat-to-moderate-relief area extending eastward from the base of the Front Range (Rampart range in Douglas County). This is an area where the younger sedimentary bedrock has been eroded away, exposing older bedrock formations in a series of hogback ridges, valleys, and benchlands. "Foothills" is an equivalent term.

Figure 1. Linear heave feature associated with heaving bedrock in Douglas County. This heave feature has literally formed a dam that blocks storm drainage, resulting in surface-water ponding. Heaving bedrock has caused extensive damage in this neighborhood.

Heaving bedrock damage is most pronounced in Jefferson, Douglas, and El Paso counties within 1 to 3 miles of the mountain front (Fig. 2), and is responsible for tens of millions of dollars in excess maintenance costs to homeowners, utility companies, and the counties and their taxpayers. The onset of damage typically occurs within ten years after construction. Homes, roads, and utility lines in 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 formations along the piedmont are capable of undergoing differential heave.

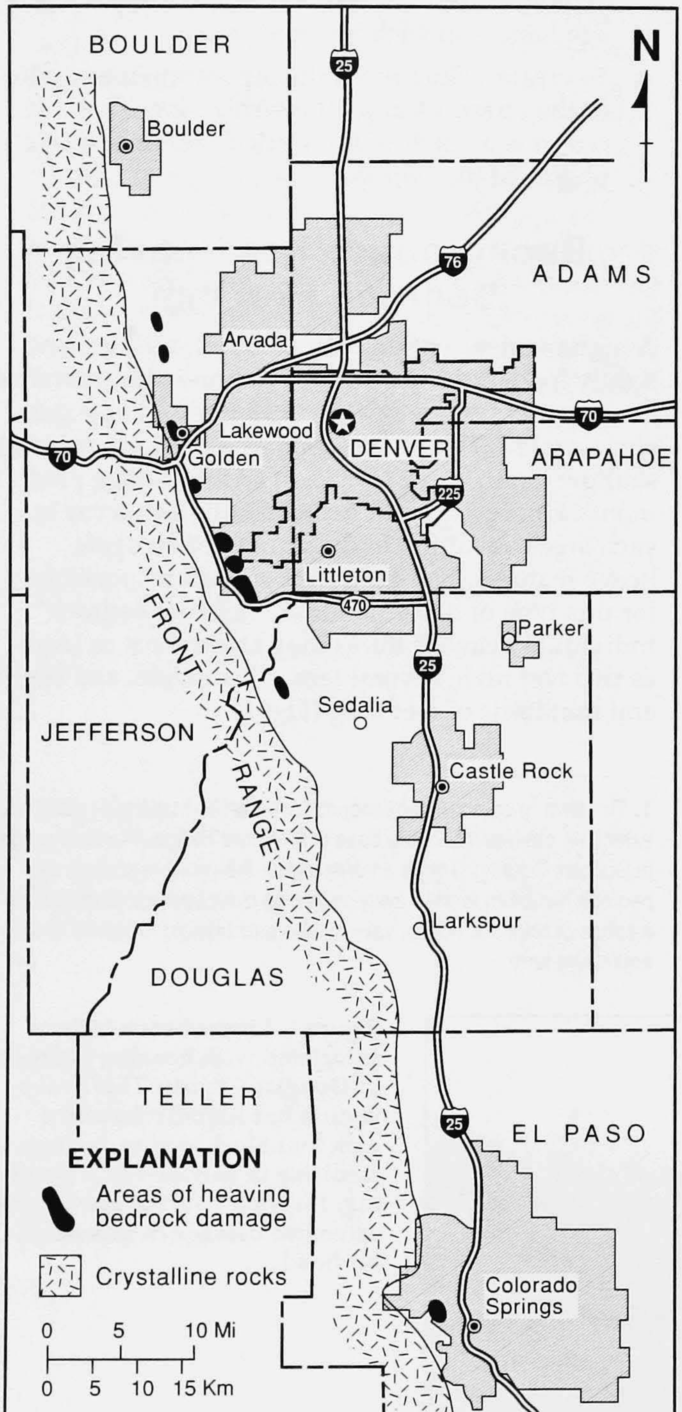


Figure 2. Index map of the Front Range piedmont in Jefferson, Douglas and El Paso Counties, Colorado, showing generalized areas where heaving bedrock damage has occurred.

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 that 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.

The mechanics of heaving bedrock deformation are not well understood. It is thought to involve volume expansion of clay particles in the bedrock due to swelling (hydration) and/or unloading (rebound). Shearing movement between expansive bedrock blocks also occurs, but this phenomenon has not been formally studied or explained. Ground deformation and damage caused by steeply dipping bedrock is often more localized and destructive than deformation and damage caused by flat-lying expansive soils and bedrock underlying the eastern plains. (Most of the highly populated areas of Douglas County, including Highlands Ranch, Castle Rock, and Parker, are underlain by flat-lying expansive bedrock.)

Although many existing piedmont-area developments in Douglas and Jefferson counties are affected by heaving bedrock, there are many developments within the area that 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 highly localized, linear pattern of heaving. The factors controlling the distribution and magnitude of damage are numerous and involve non-geological as well as geological factors.

Report Contents

This report delineates an area of Douglas County where heaving bedrock hazards are expected due to the presence of expansive, steeply dipping bedrock along the Front Range piedmont. Called the Dipping Dipping Bedrock Overlay District (DBOD), the bedrock in this area may be prone to differential heaving behavior under certain geological and human-influenced conditions. The DBOD is an area where special and specific considerations for land use planning, construction, and long-term maintenance are necessary.

The report contains a description of methodologies and pertinent findings used to define the DBOD boundaries and rank bedrock formations within the DBOD in terms of heaving bedrock potential. The results are described in the report text and are summarized in two maps:

- Plate I: The Dipping Bedrock Overlay District map (DBOD map), which outlines the areal extent of the DBOD, and
- Plate II: The Heaving Bedrock Hazards map, which shows the distribution and hazard ranking of fourteen bedrock units within the DBOD.

Finally, the report gives problem-specific recommendations for lands located within the overlay district.

The DBOD and Heaving Bedrock Hazards maps are available in two forms:

- As hard-copy maps (Plates 1 and 2, respectively) on a 1:24,000-scale USGS topographic map base, located in a map pocket at the end of the report. Each plate contains two map areas, with each area being informally named after its central geographic feature. Map A, the Roxborough Park area, covers the northern part of the DBOD from the county line at Chatfield Reservoir southward along the Front Range (Rampart Range) piedmont to a point on the drainage divide between Jarre Creek and Garber Creek. Map B, the Perry Park area, covers the southern part of the DBOD from the Jarre Creek/Garber Creek drainage divide southward along the piedmont to a point immediately north of the mouth of Stone Canyon at East Plum Creek.
- As digital, Geographic Information System (GIS) compatible data files. The digital map data consists of the outline of the DBOD, internal bedrock unit boundaries, and labeling of map features pertaining to the DBOD and Heaving Bedrock Hazards maps. Douglas County survey monumentation is used to ensure compatibility with the County's GIS databases. The digital data files are included as a product of the report to Douglas County. The digital data files are available to the gen-eral public as an optional part of CGS Special Publication 42, at additional cost.

Three appendices are included as part of this report. Appendix A contains engineering properties data compiled from existing, public-record geotechnical reports. Appendix B contains engineering properties data from laboratory analysis conducted as part of this project. Appendix C contains excerpts from the Jefferson County dipping bedrock regulations for zoning, land development, building, and road design. A technical discussion of the field and laboratory work done for this project is given in a Colorado School of Mines master's thesis written by the co-author of this report (Dodson, 1996).

2 Methodology and Data Sources

Five types of data are used to define and delineate the general area of Douglas County where heaving bedrock is anticipated and to rank individual geologic zones with regard to heaving bedrock hazards. They are: bedrock geology, geotechnical engineering, water well, house and road damage, and miscellaneous data. The following sections discuss the methodology of how these data were obtained and compared in order to fulfill the report objectives.

Bedrock Geology Data

Although specific references to "heaving bedrock" are absent in the geological literature, it is possible to identify potentially heave-prone formations by comparing their composition and structure (three-dimensional orientation of the bedding and location of faults) with that of known areas where heaving has taken place. A review of published geologic literature has been conducted to determine the compositional and structural characteristics of bedrock formations along the Front Range piedmont, and in other related areas in the northern Great Plains states. The major references are summarized in Table 1 and a full reference listing is given in the report reference section. Because the piedmont area of Douglas County has received scant attention by geological researchers, it is 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 geology characteristics.

The main purpose of the literature review is to identify, for each sedimentary formation in the study area: 1) the dominant rock type and variety of rock types (claystone, siltstone, sandstone, limestone, gypsum); 2) the presence of expansive clay minerals (montmorillonite, smectite, illite, mixed illite-smectite, and discrete bentonite beds); 3) the presence of accessory minerals (gypsum or calcite); and 4) swell potential results from engineering geology tests run on a potential volume change (PVC) apparatus. The results have been tabulated to show the relative occurrence of bentonite beds, moderate-to very high-swelling claystone, and low- to non-swelling bedrock for each formation.

The lateral continuity of bedding within each bedrock unit of interest is recorded. This characteristic is important because it may affect the validity of extrapolating known geologic information from one location to another location within the same bedrock unit. For this study, beds are classified as continuous if they extend for more than 2,000 feet along strike or discontinuous if they probably extend for less than 2,000 feet. Beds having both continuous and discontinuous characteristics are described as transitional. Areas underlain by steeply dipping sedimentary bedrock (tilted at angles of greater than 30 degrees from horizontal) and the location of major fault traces are delineated using existing geologic maps for Douglas County, augmented by field checking.

The results of the literature review are published as a preliminary report (Noe and Dodson, 1995). For this final report, the authors have conducted field geologic reconnaissance to verify boundaries, composition and strike/dip of certain bedrock units. It was necessary to map parts of the Perry Park area because of conflicting information and the lack of strike/dip data from previous studies. Glenn Scott and William Cobban from the U.S. Geological Survey provided information from their previous field work in the area (Scott, unpublished data) and assisted with the field reconnaissance.

Geotechnical Engineering Data

Engineering properties data from 21 public-record geotechnical investigations conducted in northwestern Douglas County have been compiled into a computer database (Appendix A). The sample and test data are grouped according to the geologic unit from which each sample was taken. These data include: 1) initial water content; 2) initial dry density; 3) material classifications using the USCS (Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Officials) classification systems; 4) material descriptions; 5) grain-size distribution; 6) Atterberg Limits (liquid limit and plasticity index); 7) percent swell, test-load surcharge, and swell pressure (from swell-consolidation tests); 8) penetration resistance (blow counts); and 9) unconfined com-

Table 1. List of pertinent geological literature for Colorado Front Range foothills and other related areas.

General Geology:	
Robb (1949)	Masters thesis (CSM) on Perry Park area
Malek-Aslani (1950)	Masters thesis (CSM) on Perry Park area
Van Horn (1957)	Map of bedrock geology of Golden quadrangle (1:24,000)
Scott (1962)	Map and geologic description of Littleton quadrangle (1:24,000)
Scott (1963a)	Map and surficial-geologic description of Kassler quadrangle (1:24,000)
Scott (1963b)	Map and bedrock-geologic description of Kassler quadrangle (1:24,000)
Sheridan and others (1967)	Map and geologic description of Ralston Buttes quadrangle(1:24,000)
Varnes and Scott (1967)	Map and geologic description of U.S. Air Force Academy (1:12,000)
Wells (1967)	Map of Eldorado Springs quadrangle (1:24,000)
Scott (1969)	Map and geologic description of Pueblo quadrangle (1:24,000)
Scott (1972a)	Map of Morrison quadrangle (1:24,000)
Van Horn (1972)	Map of Golden quadrangle (1:24,000)
Bryant and others (1973)	Map of Indian Hills quadrangle (1:24,000)
Scott and Wobus (1973)	Map of Colorado Springs area (1:62,500)
Van Horn (1976)	Description of bedrock geology of Golden quadrangle
Lindvall (1978)	Map of Fort Logan quadrangle (1:24,000)
Trimble and Machette (1979a)	Map of Greater Denver area (1:100,000)
Trimble and Machette (1979b)	Map of Colorado Springs–Castle Rock area (1:100,000)
Scott (unpublished)	Map of Perry Park area (1:24,000)
Stratigraphy, Biostratigraphy, Mineralogy:	
Cobban (1956)	Stratigraphy of Pierre Shale, southeastern Colorado
Reeside and Cobban (1960)	Stratigraphy of Mowry Shale, Upper Great Plains
Gill and Cobban (1961)	Stratigraphy of Pierre Shale, northern Great Plains
Scott and Cobban (1963)	Stratigraphy of Apache Creek Sandstone of Pierre Shale, Pueblo
Schultz (1964)	Mineralogy of Pierre Shale, Great Plains area
Scott and Cobban (1964)	Stratigraphy of Niobrara Formation, Pueblo
Gill and Cobban (1965)	Stratigraphy of Pierre Shale, North Dakota
Schultz (1965)	Mineralogy of Pierre Shale, South Dakota and Nebraska
Gill and Cobban (1966)	Stratigraphy of Pierre Shale, Wyoming
Mello (1969)	Stratigraphy of Pierre Shale and Fox Hills Sandstone, South Dakota
Izett and others (1971)	Stratigraphy of Pierre Shale, Kremmling
Cobban and Scott (1972)	Biostratigraphy of Graneros Shale and Greenhorn Limestone, near Pueblo
Elder and others (1994)	Stratigraphy of Greenhorn Limestone, Utah, Colorado, and Kansas
Scott and Cobban (1965)	Biostratigraphic map of Pierre Shale, Jarre Creek–Loveland (1:48,000)
Grimm and Guven (1978)	Bentonites and stratigraphy, Upper Great Plains
Scott and Cobban (1986)	Biostratigraphic map of Pierre Shale, Colorado Springs–Pueblo (1:100,000)
Engineering Geology:	
Gardner (1969)	Engineering Geology map of Eldorado Springs quadrangle (1:24,000)
Gardner and others (1971)	Engineering Geology map of Golden quadrangle (1:24,000)
Scott (1972)	Map of swelling clay in Morrison quadrangle (1:24,000)
Hart (1974)	Map of expansive soils and bedrock, Front Range (1:100,000)
Miller and Bryant (1976)	Engineering Geology map of Indian Hills quadrangle (1:24,000)
McGregor and McDonough (1980)	Engineering Geology map of Littleton quadrangle (1:24,000)
Simpson and Hart (1980)	Engineering Geology map of Morrison quadrangle (1:24,000)

pressive strength. Certain data have been compared to regional-scale engineering geology maps in neighboring Jefferson County to verify the presence of expansive claystones within the DBOD. Several individuals from building and geotechnical-engineering firms have supplied construction data that could not be located in CGS or Douglas County files (see Acknowledgements section).

The geotechnical reports do not include data for all of the geologic formations capable of bedrock heave. Additional sampling and testing is conducted for this project to provide data from all bedrock units of interest (Appendix B). The procedures for conducting these tests are generally in accordance with ASTM standards. The tests performed were based on standard geotechnical testing procedures for the Denver area and included initial water content, initial dry density, grain-size distribution, Atterberg Limits (liquid limit, and plasticity index), and USCS material classification. Because few Denver swell-consolidation test results are available for Douglas County, the swell characteristics for each bedrock unit are interpreted using Atterberg Limits (method of Chen, 1988) and USCS classification results. (See Dodson, 1996, for further technical discussion.)

Water Well Data

Public-record water well data were collected from the Colorado Division of Water Resources. The data consist of descriptive well logs. Such well logs, although limited in their quality and overall usefulness, are the only source of subsurface geology data in undeveloped areas where no geotechnical studies have been conducted. The logs are especially useful for delineating the southern boundary of the DBOD, where heave-prone claystone bedrock is faulted out by the Rampart Range fault.

House and Road Damage Data

A reconnaissance field investigation has been conducted in parts of suburban Jefferson and Douglas Counties in order to compare areas of known heaving-bedrock damage with published geologic maps. The field work includes visual assessments to map damage to dwellings, flatwork, and roadways in several neighborhoods. The damage survey is limited to areas where the top of the bedrock is generally shallow (i.e., areas where maximum heaving damage is expected). The authors mapped a complete transect through the Pierre Shale, Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, and lowermost Denver Formation. No information is collected from the Ralston Creek Formation, Morrison Formation, Lytle and South Platte Formations, Graneros Shale, Greenhorn Limestone, Carlile Shale, Fort Hays Limestone, and Smoky Hill Shale because these geologic units have not been developed upon to any large degree. The Dawson Formation is not present within the transect area, although the Denver and Arapahoe Formations in Jefferson County may be laterally equivalent to certain parts of the Dawson Formation in Douglas County.

The results of the damage survey are summarized and tabulated according to the observed frequency of damage occurrence. (See Dodson, 1996, for further technical discussion). These designations do not indicate the severity of damage. This type of mapping is used for verifying which geological formations are prone to differential heave, although the overall accuracy is limited by the indirect nature of data collection and the inability to assess actual internal damage to houses. The eastern boundary of areas displaying distinctive, linear ground deformations caused by heaving bedrock has been tentatively located in Jefferson County by mapping of "roller coaster" deformation of roads.

Miscellaneous Data

Miscellaneous data include a large amount of unpublished information from private-sector site assessments and research, and from CGS research and land use reviews. There is an almost complete absence of heaving bedrock-related articles in the published literature. This is because the term "heaving bedrock" is relatively new, being introduced by the CGS in 1994 to alert people to important differences between heaving bedrock and expansive soils. In addition, a majority of the data concerning heaving bedrock damage that has been gathered by builders, warranty companies, and homeowners is not generally available to the public.

Since 1994, 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. This conference was sponsored by Douglas County, Jefferson County, the CGS, and numerous professional geological and engineering societies. Another source of valuable information comes from 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 as a result of these events are named in the Acknowledgement section.

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 include: land use reviews for county agencies to assess geologic hazards on parcels of land slated for development; swelling soils and heaving bedrock research, especially along the Front Range Urban Corridor; technical information transfer in the form of conferences and seminars that promote awareness of geologic hazards; and policy issues involving heaving bedrock. The CGS participated in the Jefferson County Expansive Soils Task Force and assisted in creating the Jefferson County Designated Dipping Bedrock Area (DDBA) Map and a variety of attendant regulations, which were adopted in April, 1995. Much of our knowledge of heaving bedrock has been derived from these activities.

Mapping and Delineation of Overlay and Hazard Areas

The data described previously in this section were analyzed and compared in order to assign a relative heaving bedrock hazard ranking for individual geologic formations or sub-units. A ranking of "high," "moderate," or "low" was assigned to each geologic unit, based on the criteria given in Table 2. Two types of hazard maps were created as a result, and are described below:

The *Dipping Bedrock Overlay District (DBOD)* map (Plate 1) shows the composite outcrop area of all sedimentary formations where heaving bedrock may be anticipated. This map is intended for use as a general, administrative tool. A formation is included as part of the BDOD if heaving damage has occurred within its outcrop belt or, if development has not yet occurred to a large degree, if it has geological and engineering characteristics that are similar to other formations in which heaving has occurred. The DBOD Map does not distinguish between different formations in terms of the potential severity of heaving bedrock, nor does it account

Table 2. Summary of characteristics used for heaving bedrock hazard ranking.

		Relative Heaving Bedrock Hazard Ranking and Attributes		
	Characteristics	**High**	**Moderate**	**Low**
Bedrock Geology	Occurrence of:			
	Bentonite beds	Absent to common	Absent to common	Absent to minor
	Moderate- to high-swelling bedrock	Common to major	Minor to common	Minor
	Low- to non-swelling bedrock	Minor to major	Common to major	Major
	Variation in composition	Moderate to high	Low to moderate	Low
Geotechnical Engineering Properties	Liquid limit	High: ranging to 50%+	Mod: ranging to 25–50%	Low: ranging to 25%
	Plasticity index	High: ranging to 30%+	Mod: ranging to 15–30%	Low: ranging to 15%
	Unified Soil Classification (fine fraction)	Mainly CH	CH, CL, ML	CL, ML
	Interpreted swell characteristics	Low to very high	Low to moderate	Low
	Variation in engineering properties	High	Moderate	Low
Observed Damage Frequency	Occurrence of damage to:			
	Roads	Infrequent to frequent	Infrequent to moderate	Infrequent
	Flatwork	Infrequent to frequent	Infrequent to moderate	Infrequent
	Residential structures	Infrequent to frequent	Infrequent to moderate	Infrequent

for localized geological factors (e.g., variations in moisture content and thickness of overburden soils) that may significantly reduce the heaving potential of the bedrock.

The *Heaving Bedrock Hazards* map (Plate 2) shows the areal extent of each of the component formations that make up the DBOD, ranked in terms of the potential occurrence and severity of heaving bedrock. This map is intended for use by geotechnical professionals as a technical tool. The ranking process considers the results of bedrock composition, geotechnical engineering properties, and observed damage compilations described previously in this section and in Table 2. These characteristics have been compiled and compared, and a relative ranking is formulated based on ranges of data values for each geologic unit. There are three categories of potential heaving bedrock severity: low, moderate, and high.

The DBOD and Heaving Bedrock Hazards maps are created using regional-scale geologic, engineering, and damage data. However, these maps do not consider certain localized geologic factors (e.g., bedrock moisture content or the thickness of overburden soils and/or fill) that may reduce or even negate the effects of heaving bedrock. Accordingly, these maps should be considered as a "worst-case" scenario. Localized geologic factors should be assessed on a parcel-by-parcel basis by a landowner or developer.

Case Study Methodology

A detailed case study of an existing subdivision in northwestern Douglas County has been undertaken to investigate how local geologic and non-geologic factors influence the occurrence and severity of heaving bedrock. This is the only area within the DBOD where the density of development data is sufficient to study such factors. The subdivision consists of several filings built at different times over a nine-year period (1986–1995). Some areas of the subdivision have severe heaving bedrock damage, while others show no appreciable damage. This is a critical location for investigating heaving bedrock because there is a wide variety of soil and bedrock geology and a wide variety of human impacts (e.g., different builders and design approaches, different dates of construction, and varying distribution and depths of grading cut and fill areas).

Road-deformation features (heave features) were mapped across the subdivision to create a damage map. The damage map has been compared to other maps created from published geological maps and public-record engineering tests from 165 drillholes. These maps included surface geology, bedrock geology, overburden soil thickness, bedrock swell potential, bedrock liquid limits, bedrock plasticity index, initial bedrock moisture content, depth to ground water, dates of construction, areas of cut and fill, and foundation types. Finally, interpretations are made as to which factors appeared to have the most influence on the damage patterns seen at this subdivision. The results of the case study are used to help formulate the land use recommendations given in this report.

3 Investigation Results

Expansive soils and expansive bedrock are potential geological hazards in arid and semi-arid regions of the world where they exist at shallow depths beneath the ground surface. These expansive materials are composed of clay particles that expand upon exposure to introduced water. In most cases, they cause uniform, mostly vertical deformations when wetted. Because of their many similarities, expansive bedrock is not usually distinguished from expansive soils (Fig. 3A) for engineering purposes. This appears to be a valid consideration for cases where the bedrock and soil layers are flat, or nearly so.

The CGS distinguishes heaving bedrock (Figs. 3B and 3C) as a separate geological hazard in cases where the internal composition and structure of the bedrock allows for more complex mechanisms of expansion and movement. Although expansive soil deposits may also be present at the surface, the highly uneven, linear deformation associated with heaving bedrock will be the dominant type of deformation under certain conditions.

Studies of heaving bedrock by the CGS and others show that damage will most likely occur where the near-surface bedrock is steeply dipping, composed of expansive claystone (at least in certain layers), and initially "dry" in its natural state. In general, the occurrence of heaving bedrock is a function of bedrock structure (bedding dip, folding, faulting, fracturing), sedimentology (stratigraphy, composition, and bedding continuity), loading and unloading history (overconsolidation, overburden thickness), and moisture characteristics (bedrock moisture content, depth to water table). These geological characteristics, and their relative usefulness for predicting heaving bedrock, are described below.

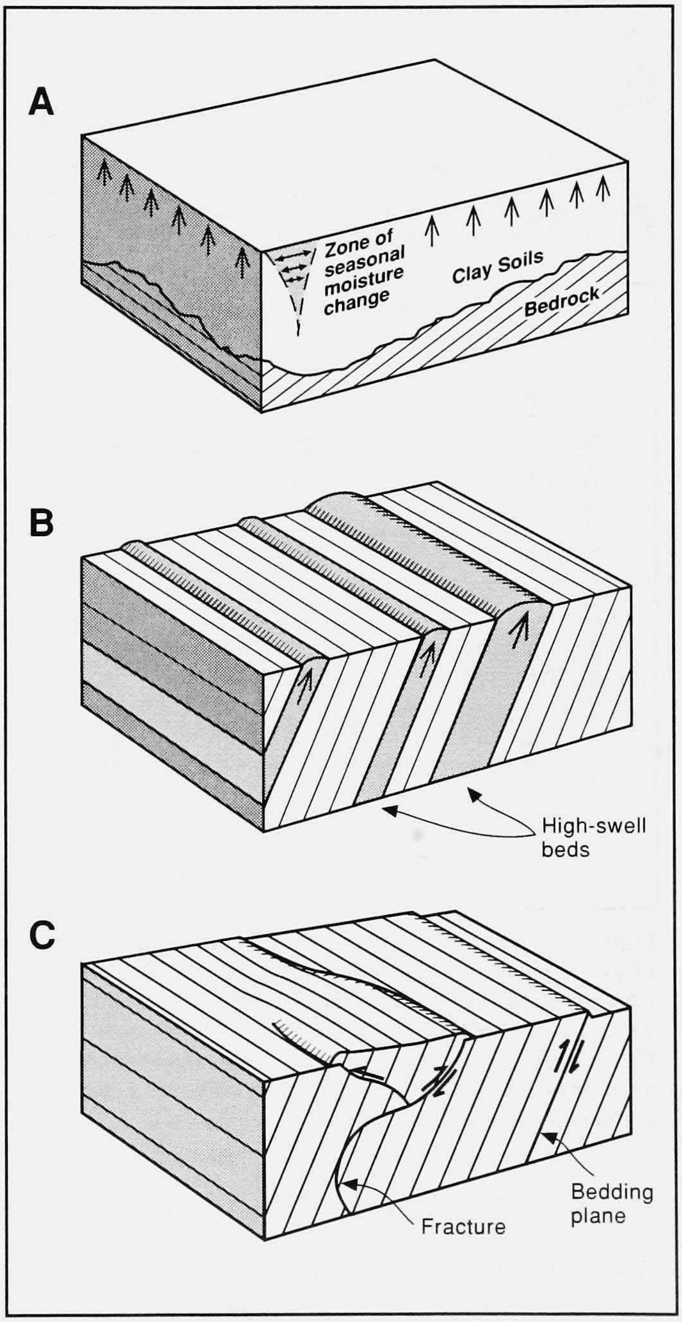


Figure 3. Block diagrams of expansive soils and heaving bedrock (modified from Noe and Dodson, 1995).

3A) General model for expansive soils and flat-lying expansive bedrock. Soil-volume changes and vertical, somewhat uniform ground heave (vertical arrows) occur within the near-surface zone of moisture change.

3B) Heaving bedrock related to hydration swelling of individual bedrock layers, each having a different swell potential. This type of differential heaving forms straight, longitudinal, and somewhat symmetrical heave features along the ground surface, running parallel to bedding strike.

3C) Heaving bedrock related to thrust-like, shear-slip movement along bedding planes or fracture surfaces. This type of heaving forms asymmetrical heave features along the ground surface. The bedding-plane features are straight-crested, with the crest oriented parallel with bedding strike, while the fracture-plane features have curvilinear crests that are oriented oblique to bedding strike.

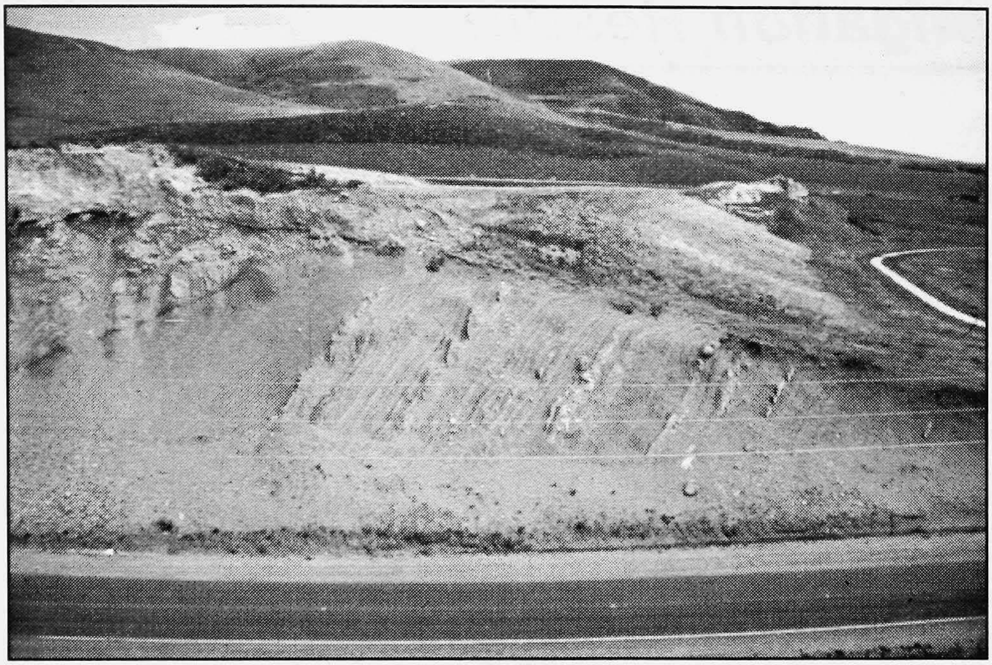


Figure 4. Outcrop of steeply dipping bedrock. The bedrock strata was originally horizontal when it was deposited millions of years ago, then was upturned at a later time when the Rocky Mountains were uplifted.

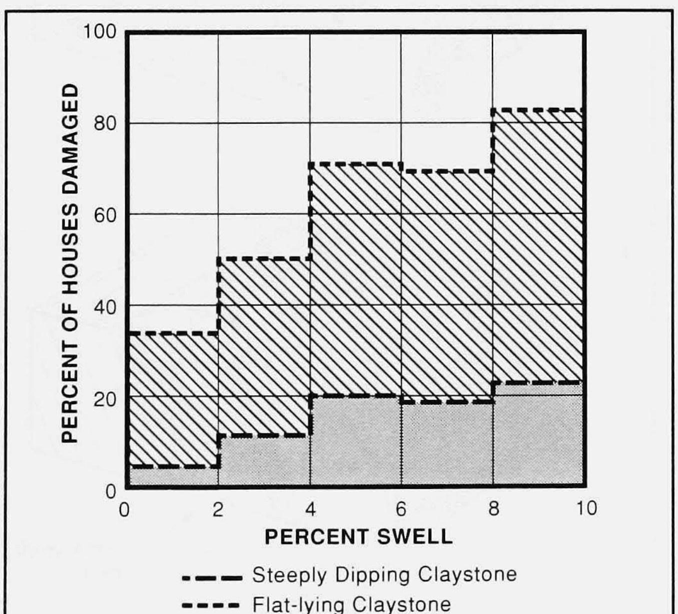


Figure 5. Chart showing damage to houses as a function of swell potential (percent swell) and bedding dip (steeply dipping vs. flat-lying) from a case study by Thompson (1992a). For any given value of swell potential, the percentage of damaged houses is markedly greater in areas of steeply dipping claystone than in areas of flat-lying claystone.

Bedrock Structure

Steeply Dipping Bedding

Heaving bedrock is most prevalent in an area underlain by steeply to moderately dipping, sedimentary bedrock formations (Fig. 4), within a few miles eastward from the Rocky Mountain front. Thompson (1992a) showed that damage to houses in areas of steeply dipping claystone greatly exceeded damage in areas of flat-lying claystone (Fig. 5). 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 from horizontal. Bedrock dip trends may be reasonably interpolated into areas where the bedrock is covered or unexplored, using regional-scale geologic data. As a result, this characteristic is generally useful for assessing where heaving bed-rock has occurred, and for predicting where future heaving could occur after development. Field verification is relatively easy where outcrops exist. Pits or trenches must be used to verify bedding dips where the bedrock is covered.

Heaving bedrock has also been recognized in low-dip to flat-lying bedrock in Boulder, Douglas, and El Paso counties, Colorado, and in South Dakota. The heave features in this case tend to be asymmetrical, with movement along shear-slip fracture planes. These features have been rarely observed in association with residential-type projects (However, intense heaving occurred in South Dakota in flat-lying Pierre Shale where extremely deep footings had been excavated for a major dam project.). Accordingly, parts of Douglas County underlain by flat-lying or low-dipping bedrock were not included in this study.

In Douglas County, bedding dips are mapped and well defined from Kassler southward to Jarre Canyon along the piedmont (Scott, 1963b), allowing for a ready delineation of the 30-degree dip line. The CGS mapped bedrock dips from Jarre Canyon southward, through the Perry Park area, to a point immediately south of East Plum Creek where the steeply dipping bedrock is not present due to faulting and/or thick overburden cover. South of East Plum Creek, the Rampart Range fault has faulted out all steeply dipping bedrock, and the near-surface sedimentary bedrock adjacent to the mountain front is essentially flat-lying.

Formations that were identified as containing steeply dipping bedrock in Douglas County include the Fountain Formation, Lyons Formation, Lykins Formation, Ralston Creek Formation, Morrison Formation, Lytle Formation, South Platte Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Pierre Shale, Fox Hills Sandstone, Laramie Formation, and the lowermost 500 feet of the Dawson Formation.

Large-Scale Folding

The sedimentary bedrock along the piedmont is upturned and steeply dipping at present because of large-scale folding that occurred during the uplift of the Rocky Mountains. When the once-flat layers of bedrock were folded, there was probably some separation of, and sliding between, the layers (similar to what happens when one folds a ream of flat paper while holding one end as fixed, and the individual sheets slide independently of each other). There may be some amount of residual stress along bedding planes in the case of previously folded, uplifted strata. This stress could be released in shallow bedrock if the bedrock is unloaded during grading, or if the bedding plane is lubricated by introducing water.

Slippage may be focused along a bedding plane if it contains smectite clays. Bentonite beds, which are highly smectitic, can become non-cohesive and lose their shear strength when wetted. Accordingly, nearly all of the bentonite beds observed by the CGS in the piedmont area show evidence of internal shearing. The exact contributions of rebound (from unloading) and wetting effects with respect to this type of heaving are not well understood, and the mechanics of the process are difficult to investigate.

Certain asymmetrical heave features in Douglas and Jefferson County may have been formed by the re-initiation of movement along a pre-existing bedding plane, triggered by the introduction of post-construction irrigation water. Unloading effects from site grading may also contribute to such movements (see subsequent section, "Loading and Unloading History"). Many bentonite beds in the area that are actively heaving show evidence of significant amounts of internal shear slippage that may be the result of past heaving. Because bedding-plane shear surfaces are not easily recognized, and because the folded strata is also steeply dipping, large-scale folding is not considered as a separate criterion for defining the DBOD.

Fractures

The CGS has found that the most heave-prone claystone intervals tend to be highly fractured (Figs. 6A and 6B). Fractures are often conduits for ground water. They allow for relatively rapid and deep wetting of the bedrock. Conversely, some fracture surfaces and bentonite layers may act as subsurface barriers and allow ground water to build up along one side. Uneven ground heave, in the form of asymmetrical heave features (Figs. 3C and 6C), may result from this heterogenous distribution of ground water.

Research by CGS shows that shearing movements of up to 3 feet have already occurred along pre-existing fracture or bedding planes in highly expansive claystone. Movement along such surfaces may be re-initiated or significantly increased when the bedrock is exposed to abrupt increases of infiltrating water from rainstorms (Fig. 6C) or lawn irrigation. We have found evidence of fracture-plane shear to depths of 25 feet and bedding-plane shear (within a bentonite layer) to depths of 70 feet. This type of heaving movement may rival movements associated with wetting and expansion of bentonites in the resultant severity of heave magnitude, distribution and damage.

Gypsum and Calcite Fracture Fill

Gypsum is a chemical by-product of the leaching and weathering of claystone. Its presence as a fracture fill (see Fig. 6A) suggests that water has penetrated and chemically altered the claystone in the past, and could do so again. Fibrous calcite, another weathering product, is almost exclusively associated with beds of bentonite. Published investigations from South Dakota (summarized in Grimm and Guven, 1978) show that the bentonites having the highest potential for expansion will almost always contain some secondary calcite, a relationship that appears to be substantiated by CGS observations in Colorado (e.g., Fig. 7A).

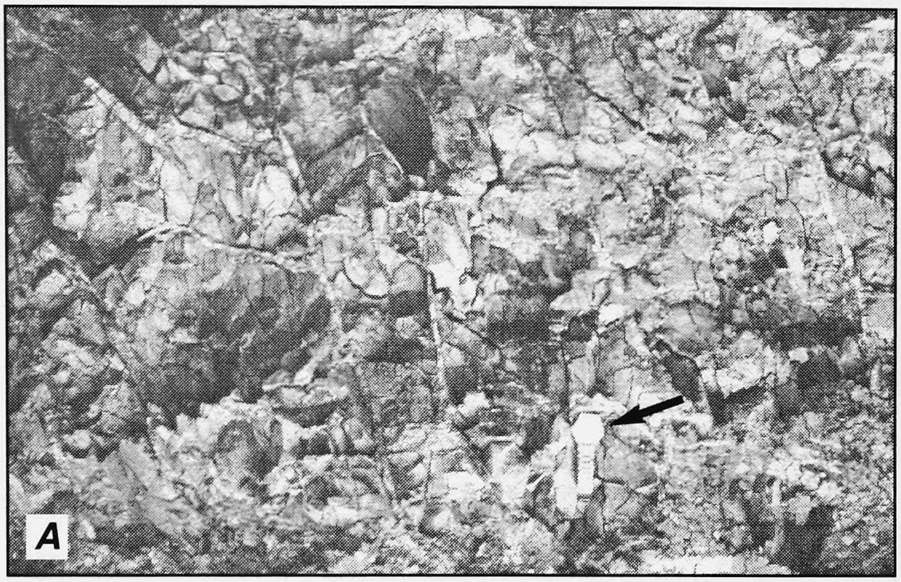
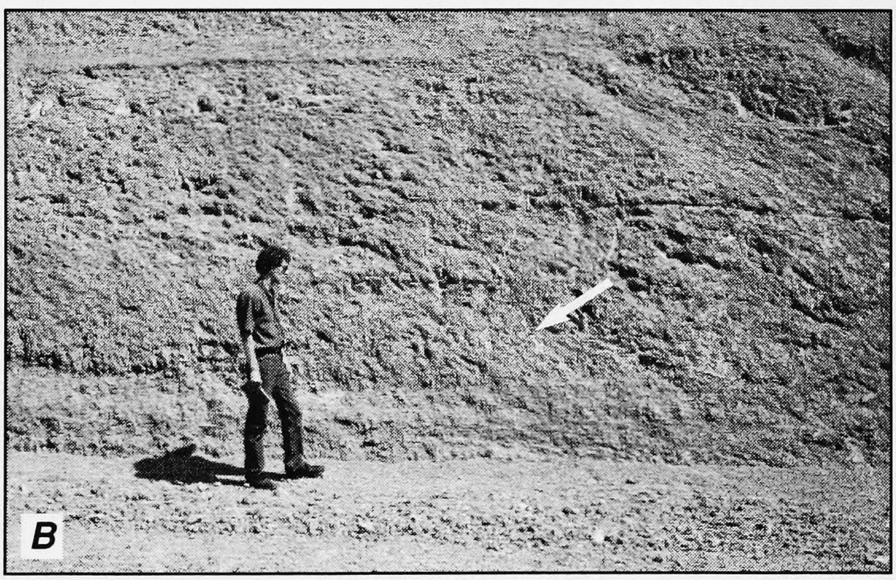
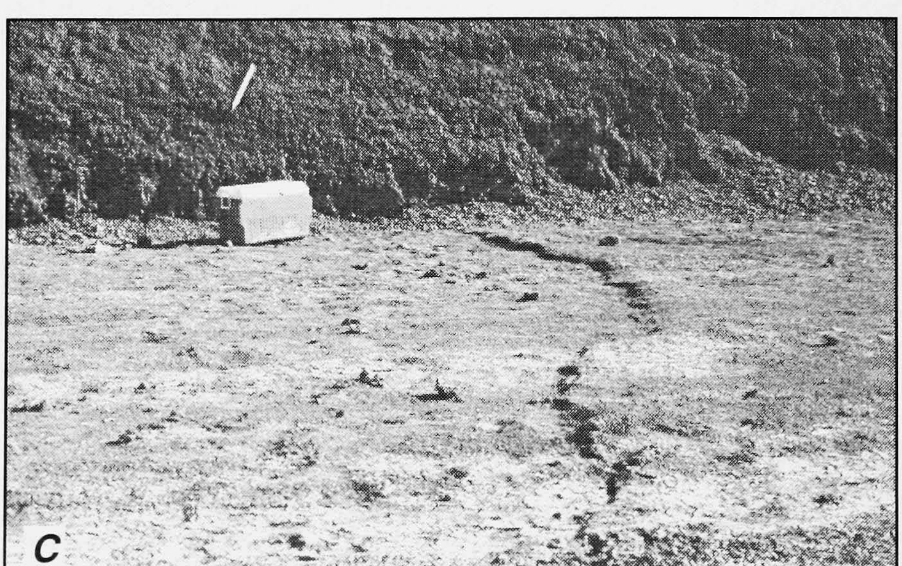


Figure 6. Fractured bedrock and characteristic heave features.

(6A) Highly fractured bedrock in an area where heaving bedrock damage has occurred. Most of these fractures are filled with veins of gypsum crystals. Note wristwatch for scale (arrow).



(6B) Fractured and sheared Pierre Shale exposed in a deep trench. The arrow points to a place where a steeply dipping bentonite bed has been offset nearly 4 inches by movement along a low-angle shear plane. The shear plane runs from behind the geologist's shoulders on the left side of the photo to the bottom right corner.



(6C) Asymmetrical heave feature in a graded cut area, caused by the heaving of the bedrock block on the right. Note the curving heave-front path. This feature formed along a pre-existing fracture plane. Over 12 inches of displacement had already occurred along the fracture plane before grading, and the re-initiation of movement resulted in another 3 inches of displacement within 24 hours after a rain storm.

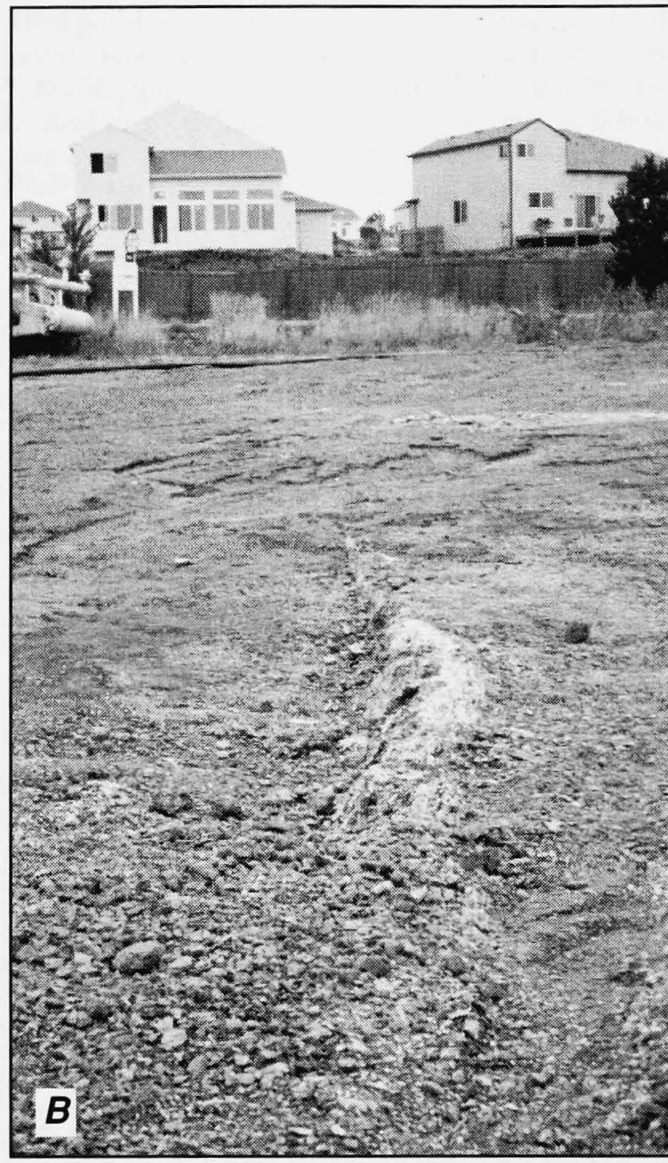


Figure 7. Bentonite beds and characteristic heave features.
(7A) Cross-sectional view of a near-vertical bentonite layer containing lenticular veins of fibrous calcite fracture-fill, flanked on either side by less-expansive claystone (note window scraper for scale). This one-foot thick bentonite layer forms the core of the large, linear heave feature shown in Figure 1.

(7B) Surface view of a near-vertical bentonite layer that heaved 3 inches vertically after a rainstorm at a construction area. Heaving bedrock damage has occurred in the neighborhood in the background, along the trend of this and other bentonite layers.

Regional Faults

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 does not appear to be related to deep movement of the fault. Rather, it is most likely due to wetting and expansion of the near-surface bedrock, resulting in shear movements between faulted and fractured bedrock blocks.

Bedrock Sedimentology

Stratigraphy

The science of stratigraphy is concerned with measuring and describing geologic units, usually in sediments and sedimentary bedrock, and assigning unique names (e.g., Pierre Shale, Laramie Formation). The significance of stratigraphy to this study is that a particular formation will have distinct characteristics that may be used to predict heaving bedrock hazards, such as composition and/or bedding continuity. Sedimentary formations can also be subdivided into smaller zones on the basis of composition and (sometimes) fossils. The stratigraphy of bedrock formations is well-established along the Front Range. It is used as the basis for delineating the distribution of potentially heaving bedrock for this study.

Expansive Claystone

The potential heaving bedrock hazard area is further defined by identifying which bedrock formations contain expansive clay minerals that expand (swell) forcibly upon wetting and shrink upon drying. Claystones that contain smectite (montmorillonite) and/or mixed illite/smectite clay minerals are widely linked to expansive behavior. In Colorado, these claystones consist of lake, shallow sea, and floodplain deposits. Bentonite, a particular type of claystone composed of smectite clay, was originally deposited as volcanic ash. Bentonite may exist as relatively pure, discrete layers (Fig. 7), or it may be intermixed to various degrees with other types of claystone (bentonitic claystone). Bentonites may possess significant expansion potential, although individual layers seldom exceed one foot in thickness. Uneven ground-surface heaving along a linear, strike-oriented trend is possible where steeply dipping, expansive claystone or bentonite beds are interbedded with other bedrock layers having lower or negligible swell potential (Figs. 3B and 7B).

Not all steeply dipping bedrock formations in Douglas County contain expansive claystone. For example, the upturned 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. These formations are not included in the DBOD.

Bedding Continuity

Because bedding zones within an upturned formation intersect the surface as an elongate swath in the strike direction, the continuity of the bedding zone will determine how extensive the occurrence of a particular heave-prone zone will be. For this study, a formation is considered to have continuous bedding if a majority of its bedding zones can be traced for more than 2,000 feet along strike. Such formations tend to be made up of marine deposits having widespread marker beds that can be traced for tens to hundreds of miles. A formation is denoted as "discontinuous" if its individual beds cannot be traced for 2,000 feet along strike. Formations containing discontinuous strata are largely continental (river and flood plain) deposits, having lenticular-shaped beds that pinch out or terminate laterally. A formation is denoted as "transitional" if it contains both continuous and discontinuous bedding zones. Such formations may be made of shoreline, lake, or a mixture of other types of deposits.

In the Front Range piedmont, bedding zones within the upturned formations occur at the ground surface as swathlike areas that run parallel to the mountain front. There is evidence, based on the distribution of damaged subdivisions, that bedding zones within certain formations may be highly continuous. Bedding continuity is used in this study to interpolate known information about certain bedrock units into areas of unknown (covered) geology.

Table 3 summarizes the bedrock stratigraphy, composition, and continuity for 12 sedimentary rock formations along the central Front Range piedmont that contain expansive claystone. This table shows the thickness of each formation, the relative proportion of three bedrock types (bentonite, other types of swell-prone claystone, and low- to non-swelling bedrock) within each formation, and the lateral continuity of strata along strike, parallel to the mountain front. The formations vary considerably in thickness and predominant composition.

The Pierre Shale is the formation of greatest concern in terms of heaving bedrock because it is exceptionally thick (nearly 5,200 feet total thickness), contains a proportionally significant amount of bentonite and swelling claystone, and underlies the largest area along the piedmont belt of steeply dipping bedrock.

Loading and Unloading History

Overconsolidation

The term overconsolidation refers to any soil or rock that has been previously subjected to a greater loading than at present. An overconsolidated, clay-bearing sediment may retain some amount of residual stress from previous loading and compression. The sudden unloading of an overconsolidated rock may trigger a process called rebound, whereby the clay particles decompress and expand at a microscopic level.

The upturned sedimentary bedrock exposed at the ground surface along the Front Range piedmont

Table 3. Geological characteristics of formations containing expansive bedrock along the central Front Range foothills, Colorado

Formation	Member of Informal Unit	Thickness[1] (feet)	Bedrock Type and Relative Proportion of Occurrence			Lateral Continuity Strata Along Strike[4]
			Bentonite[2] (High to Very High Swell)	Claystone (Moderate to Very High Swell)	Low- to Non-Swelling Bedrock[3]	
Dawson Formation	Middle and upper parts	1,450	Not present	Major	Common	Discontinuous
	Lower part		Not present	Common	Major	
Laramie Formation	Upper part	660	Not present	Major	Common	
	Lower part		Not present	Minor	Major	
Fox Hills Sandstone		185	Present?	Minor	Major	Transitional
Pierre Shale	Upper transition zone	1,150	Present?	Common	Major	Continuous
	Upper shale unit	2,275	Common	Major	Minor	
	Hygiene Sandstone	575	Not present	Minor	Major	
	Lower shale unit	1,200	Common	Major	Common	
Niobrara Formation	Smoky Hill Shale	535	Common	Common	Major	
	Fort Hays Limestone	35	Minor	Minor	Major	
Carlile Shale		55	Present?	Minor	Major	
Greenhorn Limestone		315	Common	Minor	Major	
Graneros Shale		225	Common	Major	Common	
South Platte Fm.[5]		320	Not present	Minor	Major	Transitional
Lytle Formation[5]			Not present	Minor	Major	
Morrison Formation		320–380	Common	Major	Major	Discontinuous
Ralston Creek Fm.		48	Not present	Minor	Major	

Notes: 1. Bedrock thickness from Kassler Quadrangle, Douglas County, Colorado (Scott, 1963b).
2. Bentonite is a particular type of claystone derived from layers of volcanic ash, found in thin (typically 1 foot thick or less), discrete beds.
3. Includes sandstone, siltstone, conglomerate, limestone, chalk, coal, and low- to non-swelling claystone.
4. See text for definitions and importance with regard to interpolating geologic information into unexplored areas.
5. These formations are collectively referred to as the Dakota Group; they form the Dakota hogback ridge in Douglas County.

is highly overconsolidated, having been buried several thousands of feet beneath other bedrock layers. When the Rocky Mountains were uplifted, the overlying bedrock was stripped away by erosion. As a result, the presently exposed bedrock is subject to only a fraction of its past overburden loading. Rebound has been proposed by Nichols (1990; 1992) and Nichols and others (1994) as the major cause of heaving bedrock in South Dakota and Colorado.

The CGS has found that it is difficult to separate the effects of rebound from those of water-induced swelling. The overall contribution of rebound is not well understood, and is difficult to investigate. Overconsolidation and rebound considerations may be critical where potentially heaving claystones are present, especially if a significant amount of cutting is proposed. Because of the overlapping occurrence of expansive and overconsolidated claystones, overconsolidation is not considered as a separate criterion for defining the DBOD.

Depth to Bedrock (Overburden Thickness)

The present-day depth to the top of bedrock (or, equivalently, the thickness of natural soil overburden on top of the bedrock) is a local-scale characteristic. Although some geologic maps show areas of surficial cover of soil deposits, there is usually considerable local variation in soil thickness. Site-specific drilling or geophysical investigations are necessary to quantify this characteristic at any particular location.

The potential for heaving bedrock may be significantly diminished in areas where thicker overburden deposits occur. Thompson (1992b) found that 10 feet or more of overburden beneath the base of a foundation wall, consisting of natural soils or engineered fill, is required to achieve satisfactory foundation performance in areas of heaving bedrock (Fig. 8). Depth to bedrock and overburden thickness is not generally predictable on a regional basis, and therefore was not used as a criterion for defining the DBOD.

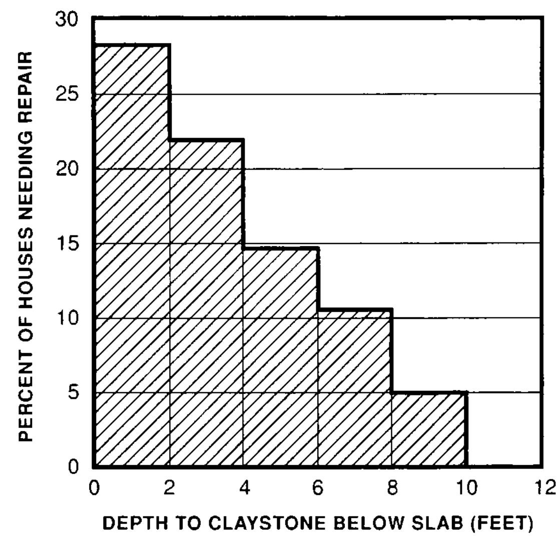


Figure 8. Chart showing damage to houses as a function of depth to claystone below foundation slab (overburden thickness) from a case study by Thompson (1992b). The percentage of damaged houses is decreases significantly where there is a thicker deposit of overburden material between the bedrock and the floor slab.

Moisture Characteristics

The initial, natural-state 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). Accordingly, moisture content values can vary considerably within relatively short lateral distances. It can also vary considerably at different depths beneath the ground surface.

If the initial moisture content is sufficiently high, it can generally reduce the potential for heaving bedrock. Land improvements such as irrigation ditches, roads, and lawns, usually result in local, long-term increases in subsurface moisture content (Fig. 9) and ground water levels. This increase in post-construction moisture may contribute significantly to the expansive swelling and heaving of clays and claystones having initially low moisture contents. 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.

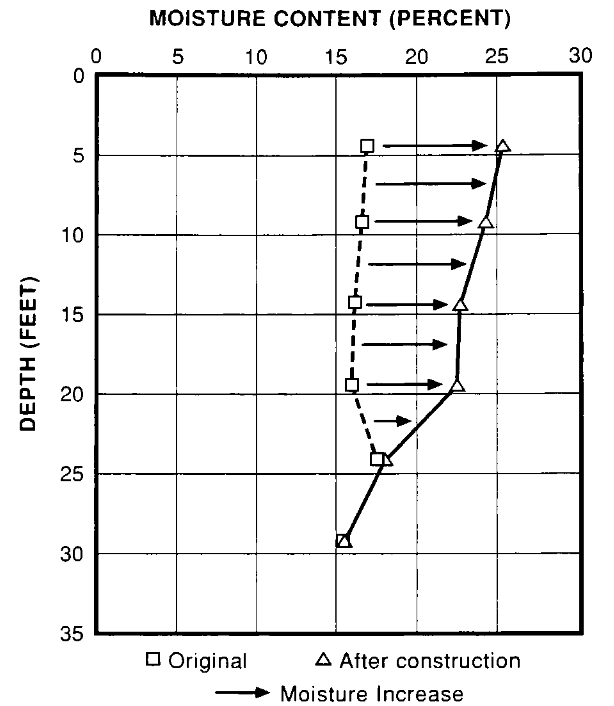


Figure 9. Example of post-construction increase of moisture content in steeply dipping claystone between depths of 0-25 feet (from Thompson, 1992a). This represents a much deeper wetting than the 7–10 feet of wetting commonly assumed for areas of flat-lying bedrock in the greater Denver area.

Engineering Properties

A summary of selected engineering properties from 83 samples, taken from the twelve formations containing expansive bedrock along the Front Range piedmont in Douglas County, is shown in Table 4. Data from individual samples are compiled in Appendix A (data from geotechnical engineering reports) and Appendix B (data from CGS laboratory testing).

A wide range of Atterberg Limit values and Unified Soil Classification types are recognized for most of the formations. In addition, nearly all of the formations are known to have minor to major proportions of non-expansive strata that would register as zero (non-plastic), for which no Atterberg Limits tests were run. Quantitative swell-consolidation test data were found to be scarce in the study area. Because of this, a category called "interpreted swell characteristics" was derived based a composite of

Table 4 . Selected engineering properties of formations containing expansive bedrock along the Front Range foothills, Douglas County, Colorado.

Formation	Member of Informal Unit	Number of Samples Examined	Atterberg Limits		Unified Soil Classification	Interpreted Swell Characteristics[1]
			LL (%)	PI (%)		
Dawson Formation	Middle and upper parts	0	(n.d.)[2]	(n.d.)	(n.d.)	(n.d.)
	Lower part	13	30–75	12–52	SP, CL, CH, ML	Low–Very High
Laramie Formation	Upper part	5	35–85	15–70	CH, CL	Moderate–Very High
	Lower part	5	25–45	5–30	SP, CL, ML	Low–Moderate
Fox Hills Sandstone		0	(n.d.)	(n.d.)	SP, CL[3]	Low–Moderate[3]
Pierre Shale	Upper transition zone	2	35–90	15–50	CH, CL	Moderate–Very High
	Upper shale unit	12	34–90	12–54	CH, CL	Moderate–Very High
	Hygiene Sandstone	5	30–42	10–25	CL, ML, SM	Low–Moderate
	Lower shale unit	4	65–81	35–51	CH	High–Very High
Niobrara Formation	Smoky Hill Shale	7	45–55	20–32	CL, CH, MH, ML	Moderate-High
	Fort Hays Limestone	0	(n.d.)	(n.d.)	(n.d.)	Low[3]
Carlile Shale Greenhorn Limestone Graneros Shale		10 [(4)]	30–100	15–52	CL, CH, MH, ML	Low-Very High
South Platte Fm.[5]		0	(n.d.)	(n.d.)	(n.d.)	Low[3]
Lytle Formation[5]		0	(n.d.)	(n.d.)	(n.d.)	Low[3]
Morrison Formation		20	41–145	19–114	CL,CH,MH,ML,SP	Low–Very High
Ralston Creek Fm.		3	40–84	26–54	CL, CH	Moderate–Very High

Notes: 1. Based on Atterberg Limits (see Chen, 1988), USCS Classification, and Denver swell-consolidation test data.
2. (n.d.) signifies that no data was collected.
3. Based on literature review.
4. Data are undifferentiated between these three formations.
5. These formations are collectively referred to as the Dakota Group; they form the Dakota hogback ridge in Douglas County.

on several types of qualitative and quantitative data (e.g., Atterberg Limits, Denver swell-consolidation tests, and Unified Soil Classification). These interpreted swell characteristics are presented as being low, moderate, high, and very high.

Nearly all of the formations in the Douglas County piedmont area contain claystones that have high or very high swell characteristics. Heaving bed-rock hazards are likely in these formations because they also contain low-swelling strata. The data in Table 4 is interpreted to represent an approximate range of engineering property values that could be expected for claystone samples within a particular formation. However, there are not enough samples to show how much of a particular rock type having particular engineering properties is present within the formations. As a result, Table 4 should not be interpreted as being a statistically valid summary.

Damage Survey

The results of the damage survey from selected areas in Jefferson and Douglas counties are compiled in Table 5. The highest frequency of damage to roads, flatwork, and residential structures was observed in parts of the Laramie Formation and Pierre Shale. The most severe heaving bedrock damage was observed in areas underlain by the upper shale unit of the Pierre Shale. Heaving bedrock damage was also observed in the Dawson Formation (actually, in its lateral equivalents, the Denver and Arapahoe Formations) and the Fox Hills Sandstone, but the occurrence of observed damage was relatively infrequent. No damage surveys were run in the area underlain by the Niobrara through Ralston Creek Formations because that area is largely undeveloped in both counties.

It is important to note that there are developed areas where no damage is evident on all of the various formations in the study area. The scope of this study did not allow for a full investigation of why particular subdivisions appear to be damaged or undamaged. However, our experience with one subdivision (see the case study, next section) shows that heaving bedrock damage may be significantly diminished by local factors such as overburden thickness and/or bedrock moisture content.

Although we were not able to consider these local factors as part of the damage survey in Jefferson County, they should be considered carefully during site investigation for any particular property in this area.

For a more detailed discussion of this damage survey, see Dodson (1996).

Table 5. Summary of observed frequency of heaving bedrock damage in selected areas of Jefferson and Douglas Counties, Colorado.

Formation	Member of Informal Unit	Observed Damage Frequency		
		Roads	Flatwork	Residential Structures
Dawson Formation[1]	Middle and upper parts Lower part	(n.s.)[2] Infrequent	(n.s.) Infrequent	(n.s.) Infrequent
Laramie Formation	Upper part Lower part	Moderate Infrequent	Moderate Infrequent	Infrequent Infrequent
Fox Hills Sandstone		Infrequent	Infrequent	Infrequent
Pierre Shale	Upper transition zone Upper shale unit Hygiene Sandstone Lower shale unit	Moderate Frequent Infrequent Frequent	Infrequent Frequent Infrequent Moderate	Infrequent Frequent Infrequent Moderate
Niobrara Formation	Smoky Hill Shale Fort Hays Limestone	(n.s.) (n.s.)	(n.s.) (n.s.)	(n.s.) (n.s.)
Carlile Shale Greenhorn Limestone Graneros Shale		(n.s.) (n.s.) (n.s.)	(n.s.) (n.s.) (n.s.)	(n.s.) (n.s.) (n.s.)
South Platte Fm[3] Lytle Formation[3]		(n.s.) (n.s.)	(n.s.) (n.s.)	(n.s.) (n.s.)
Morrison Formation		(n.s.)	(n.s.)	(n.s.)
Ralston Creek Fm.		(n.s.)	(n.s.)	(n.s.)

Notes: 1. Data taken from Denver and Arapahoe formations in Jefferson County, which are laterally equivalent to the Dawson Formation.
2. (n.s.) signifies that no surveys for damage were conducted in these areas.
3. These formations are collectively referred to as the Dakota Group; they form the Dakota hogback ridge in Douglas County.

4 Dipping Bedrock Overlay District (DBOD) Map

For this report, the Dipping Bedrock Overlay District (DBOD) is defined as the area along the Front Range piedmont in Douglas County where heaving bedrock hazards are expected under certain conditions. The main product of the report is a map showing the DBOD boundaries. The map is available as a hard-copy map (Plate 1), and as a digital GIS file that is included in the report to Douglas County. The digital file is optional to CGS Special Publication 42.

The DBOD map is a general overlay map created for administrative and regulatory use by Douglas County. The map does not show internal details, such as boundaries of the different bedrock formations that underlie the DBOD[1], nor does it attempt to delineate areas where locally occurring geologic factors (e.g., thick overburden deposits, non-expansive formation zones, high initial moisture content) may diminish the potential for heaving bedrock.

Criteria for Delineation of the DBOD

The Douglas County DBOD consists of an area where the bedrock has two defining geologic characteristics: 1) a bedding dip of greater than 30 degrees from horizontal; and 2) expansive claystone present within all or parts of the formations. The DBOD is delineated as the area where these two characteristics overlap, as shown in a cross-section and a county map (Figs. 10 and 11). It encompasses the outcrop areas of several individual bedrock formations. All of the formations listed in Tables 3–5 lie completely within the DBOD with the exception of the Dawson Formation[2].

The DBOD does not include all areas of steeply dipping bedrock in Douglas County, nor does it include all areas underlain by expansive claystone bedrock. Steeply dipping bedrock is confined to a relatively narrow outcrop belt next to the Front Range (Rampart Range), but the western part is composed of non-expansive bedrock. Expansive claystone occurs over much of the central and eastern part of the county, but it is predominately flat-lying.

The DBOD does not include the Lykins Formation of Permian-Triassic age, which outcrops immediately to the west of the overlay area. A claystone sample from a recent drill-hole geotechnical investigation was found to have a moderate swell potential (4.5 percent, at a surcharge load of 1,000 psf). The thickness and distribution of expansive bedrock within this bedrock unit is not known, but is thought to be minor based on descriptions from the geologic literature. However, proper caution is advised for development projects located within the Lykins Formation outcrop.

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 (see Plate 1). It is approximately 23 miles long in a north-south direction and ranges from 1,000 feet wide to 2.5 miles wide in an east-west direction. Inclination (dip) 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 largely contiguous with Jefferson County's Designated Dipping Bedrock Area (DDBA)[3] at the northwest corner of Douglas County, in the vicinity of Chatfield Reservoir.The western boundary of the DBOD corresponds with the base of the Ralston Creek Formation, at its contact with the underlying Lykins Formation. The western boundary corresponds with the mapped location of the Jarre Creek Fault where the Ralston Creek/Lykins contact is not present due to faulting

1. A more detailed ranking of internal formations within the DBOD, with respect to potential for heaving bedrock hazards, is presented in a subsequent text section and in plate 2.

2. The Dawson Formation, also called the Dawson Arkose on older maps, is widespread in outcrop throughout Douglas County. Although mostly a flat-lying or gently dipping unit, it becomes steeply dipping near its western margin (see Figure 10). This western-most part of the Dawson Formation outcrop area is included within the DBOD.

3. The DDBA was created by the Jefferson County Expansive Soils Task Force in 1994 and was adopted into the Jefferson County Land Use Regulations in April, 1995. The DDBA is underlain by the same sedimentary formations along the Front Range foothills, and was delineated using criteria similar to that used in our preliminary DBOD report (Noe and Dodson, 1995). The only difference between the two counties' overlay areas is that the Douglas County DBOD has been amended in this report to additionally contain the Ralston Creek, Morrison, South Platte, and Lytle Formations.

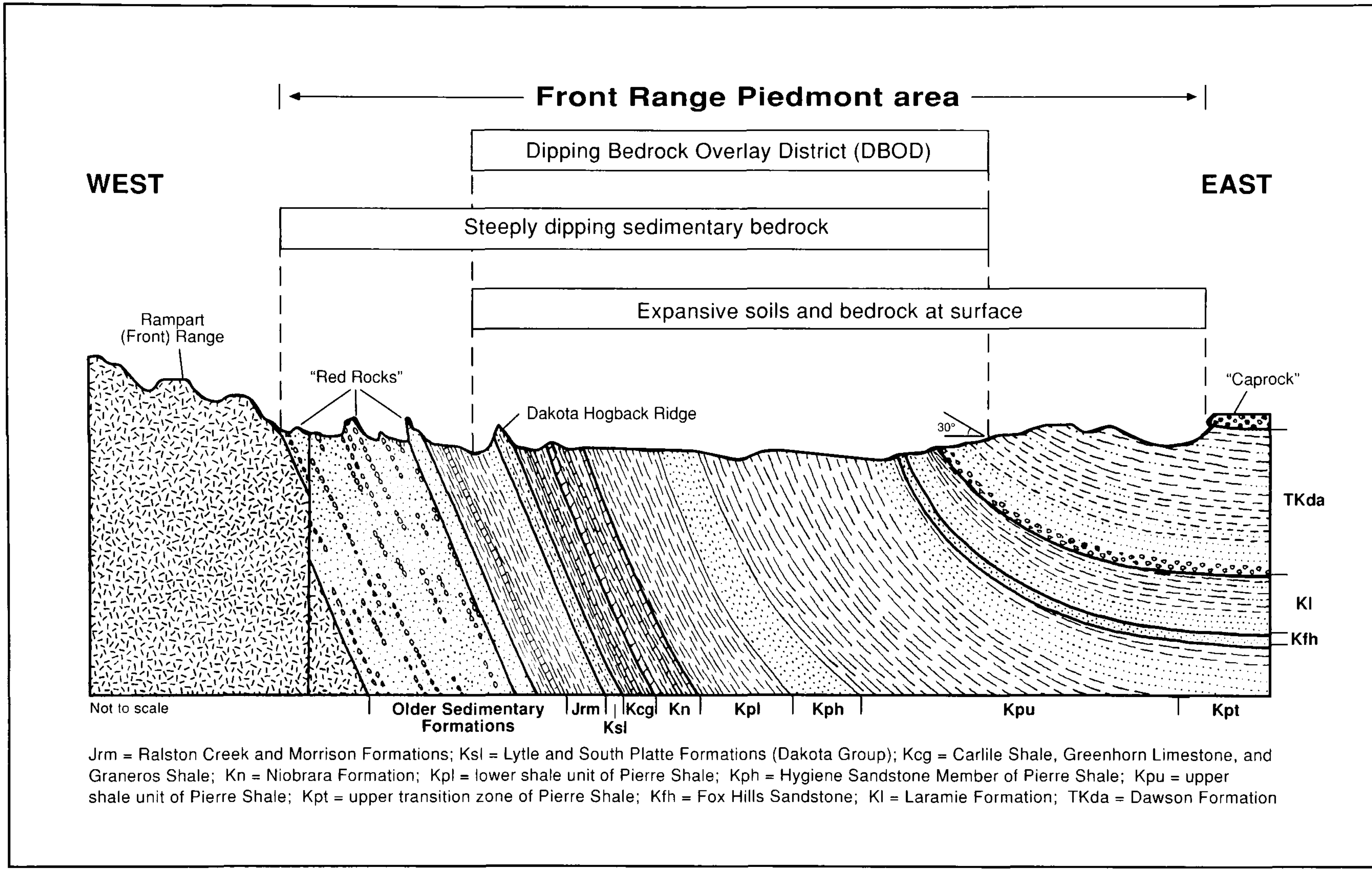


Figure 10. Schematic geological cross section showing the DBOD as related to steeply dipping sedimentary formations along the Front Range piedmont in northwestern and central Douglas County (modified from Scott, 1963a; 1963b). The DBOD extends up to 2.5 miles eastward from the base of the Ralston Creek Formation to a point within the outcrop of the Dawson Formation where the bedrock dips into the ground at a 30-degree angle from horizontal.

between Jarre Canyon and Perry Park. Similarly, it corresponds to the mapped location of a splay of the Rampart Range Fault where that contact is missing to the south of Perry Park.

The eastern boundary of the DBOD corresponds approximately to the eastern edge of upturned bedrock where rock layers dip at 30 degrees from horizontal. The boundary coincides with a horizon in the Dawson Formation that 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 Formation.

The south end of the DBOD coincides with the southernmost mapped extent of steeply dipping and expansive bedrock formations (in this case the Dawson Formation). The terminus is located in the northeast quarter of section 18, T. 10 S., R. 67 W., on the south side of East Plum Creek and immediately east of the mouth of Stone Canyon. To the south of this location, all dipping and expansive bedrock formations are known to be faulted out by the Rampart Range Fault.

Key constructed facilities (roads, subdivisions, etc.) and natural landmarks that are located within the DBOD are shown in Table 6. To date, most of these facilities are unaffected by heaving bedrock because of the existence of favorable local geological and human-influenced conditions or, in the case of a few newer subdivisions, because there has not been enough time for damage to fully develop. Only sparse development has occurred within the DBOD as a whole, especially in the southern part (i.e., the Perry Park area, shown in Map B of Plate 1).

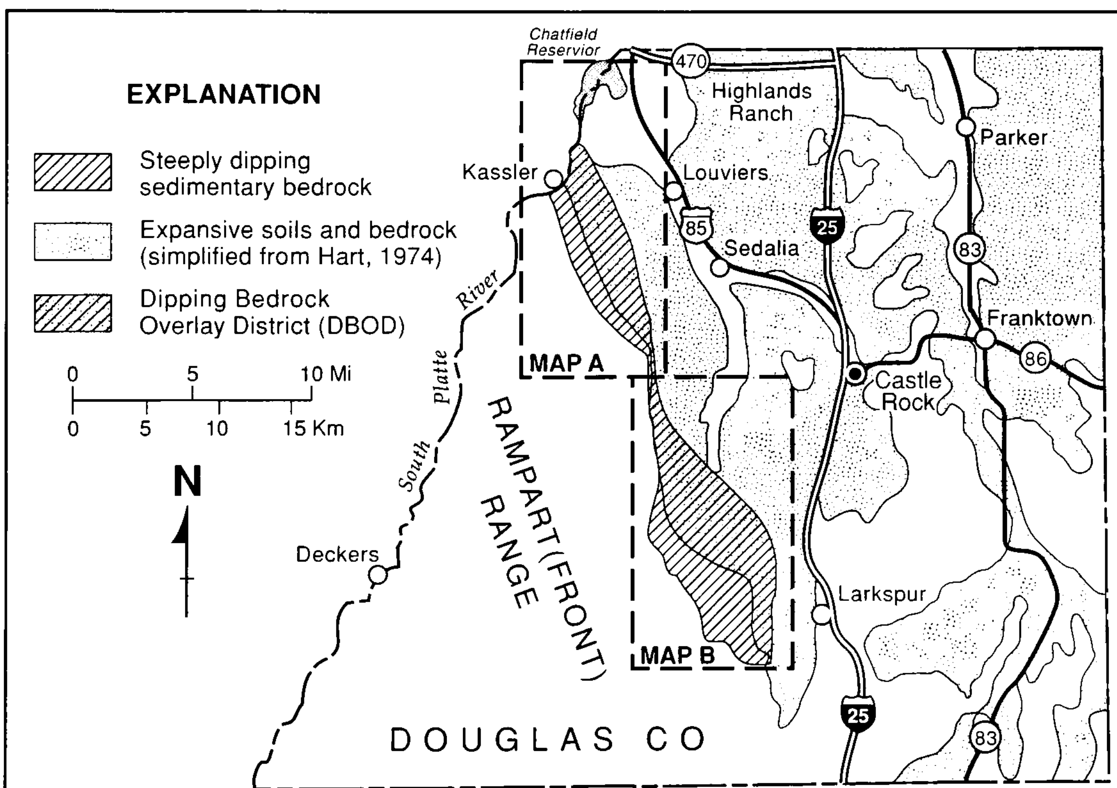


Figure 11. Map of Douglas County showing the DBOD and the boundaries of the hard-copy maps included in Plates 1 and 2 in this report.

Table 6. Constructed facilities and natural landmarks located within the Douglas County DBOD.

Map Area (from Plates 1 and 2)	Facilities and Landmarks
Map A 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 Roxborough State Park (Southdowns addition) Wildcat Mountain Mouth of Jarre Canyon
Map B Perry Park Area	Dakan Road Perry Park Rd., County Rd. 105 (in part) Tomah Road (in part) Sinclair Road (in part) Meribel Village Subdivision (in part) Valley Park Subdivision (in part)
Note: The existence of a constructed facility within the DBOD does *not* imply that the facility has incurred damage due to heaving bedrock movement. The actual extent and severity of heaving bedrock damage in this area is highly variable and depends on numerous geologic and non-geologic factors.	

5 Heaving Bedrock Hazards Map

The Heaving Bedrock Hazards map is a new product that was not included in the preliminary report. This map subdivides and ranks 14 bedrock units within the DBOD in terms of potential for heaving bedrock, based on the dominant bedrock characteristics, engineering properties, and damage occurrences (see Tables 3–5) for each geologic unit. These rankings are summarized in Table 7.

The Heaving Bedrock Hazards Map is available as a hard-copy map (Plate 2) and in a digital format (included in the report to Douglas County; optional to CGS Special Publication 42). It is intended to serve as a guide to county planners, consulting engineers and geologists, builders, and the general public, to inform them of bedrock conditions that may be anticipated for a certain parcel of land. The rankings should be considered to be "worst-case" because other localized factors that can reduce heaving bedrock hazards (e.g., overburden thickness and initial bedrock moisture content) were not investigated.

Each of the 14 bedrock units within the BDOD is designated with a ranking of low, moderate, or high. In general, the rankings indicate both the potential for bedrock heave to occur and the amount of heave expected. Identically ranked units may have similar or dissimilar geologic, engineering, and damage characteristics. There is a high potential for bedrock heave at the boundaries between geologic units because of the change in composition and properties.

The lateral continuity of bedding zones within the formations (see Table 3) is used as a form of quality control in delineating the Heaving Bedrock Hazards map. Bedding continuity may be used to interpolate known geological characteristics from specific locations into areas where the detailed

Table 7. Geologic units and heaving bedrock hazard rankings.

Geologic Symbol	Formation	Member or Informal Unit	Thickness[1] (feet)	Heaving Bedrock Hazard Ranking[2]
Tkda	Dawson Formation	Lower part	500 [3]	Moderate
Klu	Laramie Formation	Upper part	460 [3]	High
Kll		Lower part	200 [3]	Moderate
Kfh	Fox Hills Sandstone		185	Moderate
Kpt	Pierre Shale	Upper transition zone	1,150	Moderate
Kpu		Upper shale unit	2,275	High
Kph		Hygiene Sandstone Mbr.	575	Moderate
Kpl		Lower shale unit	1,200	High
Kns	Niobrara Formation	Smoky Hill Shale	535	Moderate
Knf		Fort Hays Limestone	35	Low
Kcg	Carlile Shale		55	
	Greenhorn Limestone		315	Moderate
	Graneros Shale		225	
Ksl	South Platte Fm.[4] Lytle Formation[4]		320	Low
Jm	Morrison Formation		320–380	High
Jrc	Ralston Creek Fm.		48	Moderate
		Fault gouge[5]	650 [3]	High

Notes: 1. Bedrock thickness from Kassler Quadrangle, Douglas County (Scott, 1963b).
2. See text for descriptions of ranking criteria for each geologic unit.
3. Approximate thickness of informal bedrock unit.
4. These formations are collectively referred to as the Dakota Group.
5. Located in southeast 1/4, section 5, T. 8 S, R. 68 W.

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, individual bedding zones are expected to be internally consistent for many miles along the mountain front in terms of composition, engineering properties, and general potential for heaving bedrock damage. For example, the upper shale unit of the Pierre Shale is consistent in being highly heave-prone for tens of miles along its outcrop. It is more difficult to interpolate those characteristics where the formations are discontinuous or lenticular in nature. Bedding continuity may be especially useful at the site-investigation level in areas of steeply dipping bedrock for purposes of interpolating and predicting heaving behavior across a property.

The characteristics that are common to each rank and the specific characteristics of each geologic zone within common ranks are discussed in the following section. The names and symbolic geologic-unit abbreviations used for the formations and their sub-units are taken from Scott (1963b) and Scott and Cobban (1965)[1]. Unified Soil Classification System (USCS) symbols are included in parentheses following a described sediment type.

Low-Ranked Bedrock Units

Low-ranked units primarily consist of sandstones, non-swelling siltstones, limestones, or claystones with low swelling characteristics. Bentonite beds are absent or rare. Some units may contain minor interbeds of finer-grained material with low swelling potential. Damage is rarely observed. Atterberg Limit maximum values and ranges are low. These areas have a low potential for bedrock heave, and if bedrock heave did occur, a low amount of differential movement (less than 6 inches vertical uplift) would be expected. However, trenching may be needed to define the boundaries of these units where they are in contact with potentially higher-swelling units.

Bedrock units that received a low ranking are, from west (oldest strata) to east (youngest) in Plate 2: the combined Lytle and South Platte Formations; and the Fort Hays Limestone Member of the Niobrara Formation.

Lytle and South Platte Formations (Ksl)

These formations are sometimes considered as a single bedrock unit called the Dakota Group. The unit consists of mostly sandstone with some siltstone and occasionally kaolinite-bearing claystone. Bentonite has not been observed. The bedding is transitional, but it may be highly discontinuous within the Lytle Formation. No damage has been observed across the outcrop of this unit due to a lack of development. A low potential for heaving bedrock is assigned because of the relative scarcity of swell-prone claystone.

Fort Hays Limestone Member of the Niobrara Formation (Knf)

This is a thin limestone unit with very thin interbeds of claystone. Each claystone bed is thin enough that it would probably not affect structures built over this unit. Bedding within the unit is highly continuous. Damage was not observed in the outcrop area due to a lack of development. Bedrock heave could occur at contacts of the unit, depending on the composition of the underlying Carlile Shale and overlying Smoky Hill Shale.

Moderate-Ranked Bedrock Units

Moderate-ranked units contain both low- and high-swelling material. Bentonite is sometimes present. Bedding is continuous in some units, discontinuous in others. Damage is infrequently observed, although the magnitude of individual heave features may be low to moderate (as much as 6 to 12 inches of vertical uplift). Atterberg Limit values are variable, although the range between readings from different beds is usually moderate. The distribution of heave-prone areas and the severity of heaving may vary considerably. Trenching is critical in order to quantify variability and identify zones where heaving bedrock may be a problem. Overexcavation with fill replacement may be necessary as a mitigative measure over certain areas.

Moderate-ranked bedrock units include, from west (oldest) to east (youngest) in Plate 2: the Ralston Creek Formation; the combined Carlile Shale, Greenhorn Limestone, and Graneros Shale; the Smoky Hill Member of the Niobrara Formation; the Hygiene Sandstone Member of the Pierre Shale; the upper transition zone of the Pierre Shale; the Fox Hills Sandstone; the lower part of the Laramie Formation; and the lower part of the Dawson Formation[2].

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1. The capital letter of the geologic-unit symbol stands for the geologic age (J = Jurrasic, K = Cretaceous, T = Tertiary), followed by a one or two-letter abbreviation for the unit in small letters.

2. The middle and upper parts of the Dawson Formation lie outside of the DBOD and do not contain steeply dipping bedding. Therefore, only the lower part of the Dawson Formation was ranked for heaving bedrock hazards.

Ralston Creek Formation (Jrc)

This formation is primarily composed of low-swelling claystone, but some distinct zones of medium- to high-swelling claystone exist. There are also interbedded zones of non-swelling siltstone, gypsum, sandstone, and limestone. No bentonite beds are recognized. The bedding is transitional and may consist of continuous as well as discontinuous strata. Some high values of liquid limits and plasticity index recorded. Liquid limits for 3 samples ranged from 40 to 84 percent and plasticity indices ranged from 26 to 54 percent. The gypsum-rich zones may be prone to recrystallization/swell or dissolution/collapse upon wetting. Due to the variable composition as well as discontinuous bedding properties, moderate differential bedrock heave could occur within this formation.

Graneros Shale, Greenhorn Limestone, and Carlile Shale (Kcg)

These formations are sometimes considered as a single bedrock unit called the Benton Formation. The unit contains interbedded zones of high- and low-swelling bedrock, with numerous discrete beds of bentonite throughout (Fig. 12). Although some of the claystone-bearing zones are relatively pure, others are known to be calcareous, silty, or sandy. Bedding is highly continuous. Damage was not

Figure 12. Graneros Shale outcrop in south-central Douglas County

(12A) Outcrop during dry weather. The dark areas are composed of silty claystone, and the white stripes are bentonite beds.

(12B) The same outcrop after a spring snowstorm. The bentonite beds have absorbed the moisture from the melted snow, turned darker in color, heaved out of the ground, and are beginning to desiccate in the sun. The desiccated chips will later blow away, and the scene will quickly revert into one resembling that shown in (A).

observed across the outcrop area due to a lack of development. Liquid limits from 10 different samples have a very high range (30 to 100 percent), as do the plasticity indices (15 to 52 percent). The majority of the bedrock is composed of low-swelling clay (CL). The highest values and ranges of Atterberg Limits are those associated with the Graneros Shale. The Greenhorn Limestone and the Carlile Shale appear to have less variation in composition and engineering properties than the Graneros Shale, and are interpreted as being less heave-prone. Because these formations are relatively thin and somewhat similar, they are combined on the map and assigned a moderate ranking.

Smoky Hill Shale Member of the Niobrara Formation (Kns)

The Smoky Hill Shale consists primarily of low- to moderate-swelling claystone, but there are some bedding zones that contain high-swelling claystone. Bentonite beds are common in many of the higher swelling zones (Fig. 13). The low-swelling claystone can be silty, sandy, or calcareous and chalky. Bedding zones are continuous within the unit. No damage was observed due to lack of development. Liquid limit values for seven samples ranged from 45 to 55 percent and plasticity indices values ranged from 20 to 32 percent. Most of the material is low-swelling clay (CL) with some high swelling clay (CH). Due to the variability of the swelling characteristics of different zones within this unit, there is a moderate potential for heaving bedrock.

Hygiene Sandstone Member of the Pierre Shale (Kph)

The Hygiene Sandstone is composed of low-swell siltstone and sandstone in Jefferson County, and damage is infrequent in areas that have been developed across this unit. However, in El Paso County, the same biostratigraphic zone is occupied by claystone and siltstone (Scott and Cobban, 1986). We interpret this to mean that the Hygiene interval becomes progressively finer and clay-rich (i.e., it "shales out") toward the south across Douglas County. No bentonite beds have been recognized within the interval at any location. In northwestern Douglas County, an excavation in the Hygiene Sandstone Member contained silty clays and clayey, fine sandstones, and occasional zones of higher-swelling claystone have been tested nearby (see Case Study; next section). The bedding is relatively continuous. Most of the material is classified as low-swelling clay (CL) with some low-swelling silt (ML). The liquid limit for five samples ranges from 30 to 42 percent and plasticity index ranges from 10 to 25 percent. This unit is ranked as having a moderate potential for bedrock heave due to the minor variation in composition and engineering properties and isolated cases of heaving deformations. The potential for bedrock heave may increase southward across Douglas County, especially in the Perry Park area, as the unit "shales out."

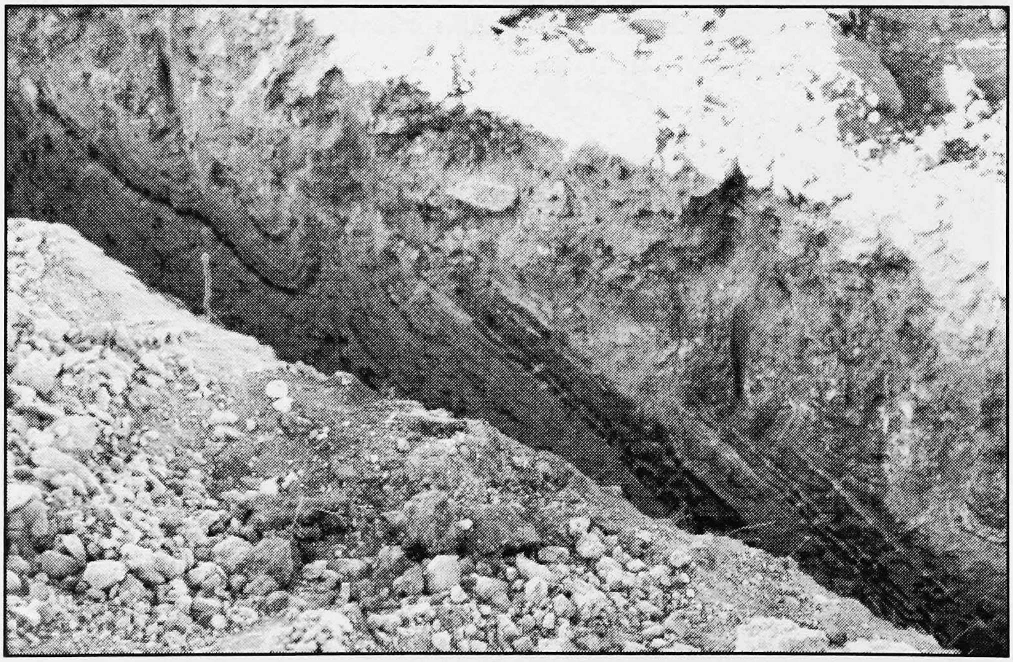


Figure 13. Smoky Hill Shale exposed in a trench in Jefferson County. Bentonite beds are seen in the trench as dark bands that are contorted on the left and steeply dipping on the right.

Upper Transition Zone of the Pierre Shale (Kpt)

This unit is transitional between the high-swelling claystones of the upper shale unit of the Pierre Shale and the non-swelling sandstones of the Fox Hills Formation. Accordingly, it contains low-swelling sandy zones as well as moderate- to high-swelling claystone zones. Bedding within the unit is continuous. Damage is infrequent in developed areas, but the magnitude of heaving in some Jefferson County roads is low to moderate (up to 12 inches of vertical uplift). Two samples were tested, one in the lower portion, and one in the upper portion. The sample from lower in the unit has a liquid limit of 90 and plasticity index of 50, while the upper sample has a liquid limit of 35 and plasticity index of 15. The majority of the material is low-swelling clay (CL) interbedded with thick zones of sandstone (up to hundreds of feet thick), with some thinner interbeds of high-swelling clay (CH). Because of the variable swell characteristics within this unit, there is a moderate potential for heaving bedrock. Successful development in the upper transition zone of the Pierre Shale will depend on careful exploration to delineate and assess zones of bedrock that may be heave-prone.

Fox Hills Sandstone (Kfh)

The Fox Hills Sandstone consists of clean to silty sandstone with minor zones of low-swelling claystone. Bentonite has not been recognized. The bedding continuity is transitional. Damage is infrequent where there is development across the outcrop area. The claystones were not sampled and tested for this study. However, Van Horn (1976) states that a majority of claystone samples tested from the Fox Hill Formation contain more montmorillonite than illite, which indicates that there may be swelling materials within this unit. Because of these properties, the Fox Hills has a moderate potential for differential bedrock heave.

Lower Part of the Laramie Formation (Kll)

The lower one third of the Laramie Formation (approximately 200 feet in thickness) consists predominately of sandstone with minor zones of siltstone, claystone, and coal. Bedding is lenticular and discontinuous. Damage occurs infrequently in areas that are developed over this unit. Liquid limit values for five samples ranged from 25 to 45 percent and the plasticity index ranged from 5 to 30 percent. Most of the fine-grained material is low-swelling clay (CL) with some low-swelling silt (ML). This zone is moderately susceptible to differential bedrock heave because of the variability of composition and discontinuous bedding.

Lower Part of the Dawson Formation (TKda)

The lower part of the Dawson Formation contains cross-bedded sandstone with occasional lenses or beds of moderate- to very high-swelling claystone. No bentonite has been reported. Bedding is highly lenticular and discontinuous. Damage occurs infrequently across developed areas on the Arapahoe and lower Denver Formations in Jefferson County (which are age-equivalent to the Dawson Formation in Douglas County, but are somewhat different in composition). However, those heave features have low to high magnitude (less than 6 to greater than 12 inches vertical uplift). There has been no significant development on the Dawson Formation within the study area in Douglas County. Samples of the claystone material have liquid limit values ranging from 30 to 75 percent and plasticity index values ranging from 12 to 52 percent. Grain-size distributions show that the sandstone consists of a poorly sorted sand (SP). Because of the possibility of encountering a moderate to high swelling claystones within the sandstones of the Dawson Formation, there is a moderate potential for differential bedrock heave. Heaving, if it does occur, could be significant.

High-ranked Bedrock Units

High-ranked units are primarily composed of very high-swelling claystone. Bentonite is common in some units and rare to absent in others. Damage has frequently been observed in these areas, and the magnitude of heaving may be low (less than 6 inches vertical uplift) to severe (greater than 12 inches vertical uplift). Liquid and plastic limit values generally range from low to very high, and high contrasts between adjacent strata are possible. Serious heaving bedrock problems will most likely be encountered within these areas unless localized geologic factors (e.g., thick overburden, high initial bedrock moisture content) are present to mitigate the hazard. Overexcavation may be necessary in most cases unless otherwise indicated by trenching and other site-specific investigations.

High-ranked bedrock units include, from west (oldest) to east (youngest) in Plate 2: the Morrison Formation; the lower shale unit of the Pierre Shale; the upper shale unit of the Pierre Shale; and the upper part of the Laramie Formation.

Morrison Formation (Jm)

This unit is composed of interbedded claystone, siltstone, sandstone, and limestone. The middle part of the formation is primarily composed of high-swelling, smectite-bearing claystone with occasional, thin interbeds of very high-swelling bentonite and non-swelling sandstone and limestone (Fig. 14). The upper and lower parts of the formation contain more sandstone beds, and the claystones consist of kaolinite and illite. Because of these geologic characteristics, the middle part of the formation is the most heave-prone. Bedding continuity is transitional in the middle part, and discontinuous and lenticular in the upper and lower parts. Damage was not observed because the outcrop area is largely undeveloped, and because the developed areas have only recently been constructed. Liquid limit values from 20 samples ranged from 41 to 145 percent and plasticity index values ranged from 19 to 114 percent. Most of the material in the middle part is a high swelling clay (CH), with some low swelling clay (CL) and poorly sorted silty sand (SP-SM). Because of the large variation in bedrock compositions, swell potentials, and bedding continuity, the Morrison Formation has a high potential for bedrock heave.

Lower Shale Unit of the Pierre Shale (Kpl)

The lowest 1,200 feet of the Pierre Shale contains mostly moderate- to very high-swelling claystone and siltstone, with occasional, thin interbeds of silty sandstone. Bentonite beds up to 1 foot thick are common, but secondary veins of calcite within the bentonite are uncommon. The unit is highly fractured, but veins of gypsum are uncommon within the fractures. Bedding is continuous. Damage is moderate to frequent in developed areas along the outcrop. Liquid limit values from four claystone samples range from 65 to 81 percent and plasticity index values range from 35 to 51 percent. Most of the material is a high-swelling clay (CH). This unit does not have as many compositional variations as the Morrison Formation, but it does display a large variation in swell characteristics and many of the claystone zones have a consistently high swell potential.

Upper Shale Unit of the Pierre Shale (Kpu)

This unit is similar in composition to the lower shale unit of the Pierre Shale, and it is the thickest of all bedrock units within the DBOD (2,275 feet thick). It contains mostly medium- to very high-swelling claystone and siltstone, with occasional, thin interbeds of silty sandstone. Bentonite beds up to 1 foot thick are common (Fig. 7), most of which contain secondary veins of calcite. The unit is highly fractured, and veins of gypsum are common within the fractures (Fig. 6A). Bedding is continuous.Damage has been frequently observed in developed areas. Historically, many developed areas along this outcrop belt have experienced severe heaving bedrock

Figure 14. Middle part of Morrison Formation exposed in a basement excavation in northwestern Douglas County. The bedrock consists of steeply dipping layers of dark-red claystone, light-gray claystone, and medium-brown sandstone. The claystone beds tend to be moderate- to high-swelling, while the sandstone beds are typically non-swelling.

movement. Low- and moderate-sized heave features are common, and occasional large features may grow to sizes of 18 inches or more. Liquid limit values for 12 samples range from 34 to 90 percent and plasticity index values range from 12 to 54 percent. The majority of the material within this unit is moderate- to high-swelling clay (CH). Because of the common presence of high-swelling claystone and bentonite and the widespread occurrence of heaving bedrock damage, this unit is perhaps the most critical in terms of heaving bedrock hazards.

Upper Part of the Laramie Formation (Klu)

The upper part of the Laramie Formation is approximately 460 feet thick. It contains mostly moderate- to high-swelling claystone interbedded with some low-swelling claystone, siltstone, sandstone, and coal (Fig. 15). No bentonite has been observed. Bedding is discontinuous and somewhat lenticular. Damage in this zone is moderate in frequency of occurrence and magnitude (up to 12 inches vertical uplift). Engineering properties for adjacent strata within the unit can have large ranges in values. Liquid limit values from five claystone samples range from 35 to 85 percent and the plasticity index values range from 15 to 70 percent. The majority of material is high-swelling clay (CH), with some low-swelling clay (CL). Al-though these beds are not consistently of high-swell-ing composition, there are extremely variations be-tween the claystone beds and adjacent non-swelling beds.

Fault Gouge

A small area in the southeast 1/4 of sec. 5, T. 8 S., R 68 W. is mapped as "fault gouge" by Scott (1963b). The area of gouge is bounded by splays of the Jarre Creek fault to the west, north, and east. It is separated from the undifferentiated Graneros Shale, Greenhorn Limestone, Carlile Shale, and Smoky Hill Shale to the south by a Cambrian-age sandstone dike within a fault splay. The fault gouge is assigned a high potential for bedrock heave because it contains shattered rock of various origins and because it has been subjected to previous differential movements.

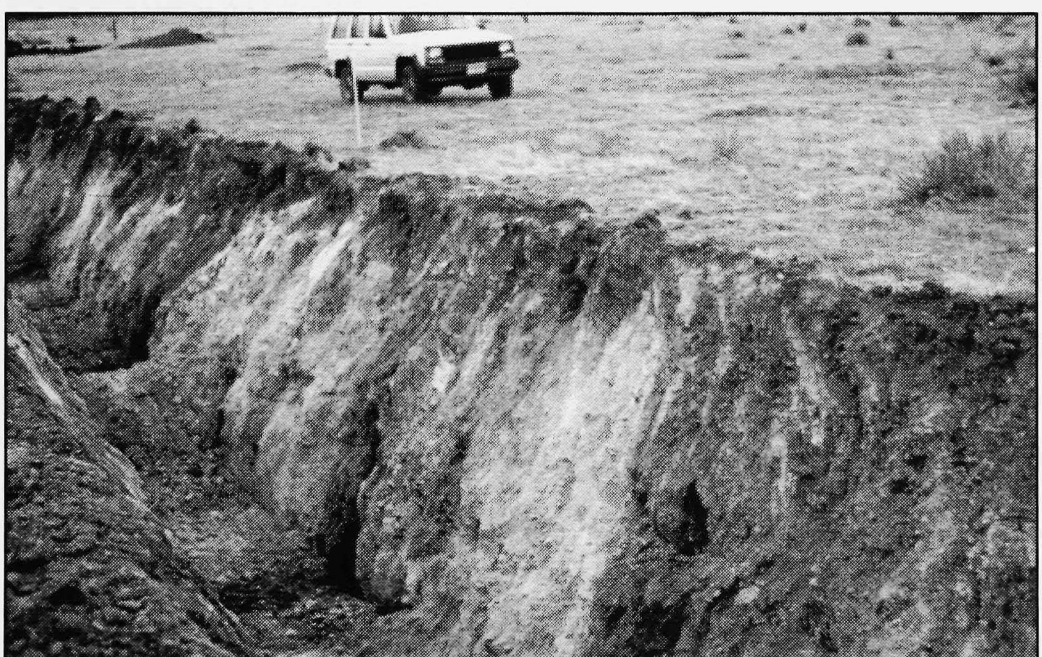


Figure 15. Upper unit of Laramie Formation exposed in a trench in Jefferson County. The bedrock consists of steeply dipping layers of black coal, medium-gray shale, and white sandstone. The claystone beds tend to be moderate- to high-swelling, while the sandstone beds are typically non-swelling.

6 Subdivision Case Study

In the previous section, the various bedrock units in the DBOD were ranked in terms of their expected heaving bedrock hazards. These rankings provide a general, "worst-case" approximation of potential heaving. However, there are numerous other geological factors that may reduce the amount of heaving that will actually occur at a site. This case study demonstrates the importance of all of these different factors and their influence on the localized distribution of heaving bedrock.

The case-study subdivision is located completely within the DBOD in northwestern Douglas County (Fig. 16A). There are six residential parcels (Parcels A–F) and one school site (Parcel G). The subdivision overlies six bedrock units: the combined Graneros Shale/Greenhorn Limestone/Carlile Shale; the Fort Hays Limestone and Smoky Hill Shale of the Niobrara Formation; and the lower shale unit, Hygiene Sandstone Member, and upper shale unit of the Pierre Shale (Fig. 16B). Although five of these bedrock units are rated as having moderate or high heaving bedrock hazards (see Table 7), actual damage within the subdivision is limited to a few discrete areas as of August, 1997. Figure 16B also shows the location of recent two bog deposits composed of saturated silt, clay, and organic soils.

Heave features associated with heaving bedrock were recognized within two of the parcels. The most significant area of heaving damage encompassed nearly all of Parcel A. Small to large heave features were noted, with some having apparent vertical uplifts of 1 foot or more. In nearly all cases, the heave features in Parcel A are aligned with their longitudinal axes parallel to the regional bedrock strike (approximately north 25–30 degrees west). Two small areas of heaving were mapped in Parcel B. Heave features in Parcel B were small, having less than six inches vertical uplift, and are interpreted to be incipient (possibly in early stages of formation) because the neighborhood is less than three years old. No discernable road-deformation features were found in Parcels C, D, E, F, and G. Parcels C and F were undergoing construction at the time of the study.

The following section summarizes heaving damage (or lack of) with respect to the different bedrock units, and offers interpretations of the controlling factors. The severity of heaving appears to be controlled by a complex interplay of many factors in addition to bedrock composition and swelling characteristics. Such factors may include initial bedrock moisture content, depth to ground-water table, thickness of overburden soils (or depth to bedrock), modification by cutting or filling, type of foundations constructed, and/or amount of time since construction.

Damage Summary by Bedrock Unit

Graneros Shale, Greenhorn Limestone, and Carlile Shale (Kcg)

The combined Graneros Shale, Greenhorn Limestone, and Carlile Shale underlies the southwestern corner of Parcel D. No road heaving or other damage is evident. The area is relatively mature (5–7 years old) and initial cuts were made into 0–20 feet of soil. The main inhibiting factor against heave appears to be the bedrock itself. Although the entire geologic interval is rated as a moderate heaving bedrock hazard, the parcel overlies the easternmost part of the outcrop belt that is underlain by the uppermost Greenhorn Limestone (composed primarily of low-swelling limestone, claystone, and chalk) and the Carlile Shale (composed primarily of low- to moderate-swelling siltstone).

Fort Hays Limestone (Knf)

The Fort Hayes Limestone underlies a narrow strip across the southwestern part of Parcel D. No road heaving or other damage is evident. The Fort Hays Limestone is rated as having a low heaving bedrock potential. It is composed almost entirely of non-heaving limestone, which explains the absence of observed damage.

Smoky Hill Shale (Kns)

The Smoky Hill Shale underlies parts of developed parcels D and E and a corner of Parcel C, which is currently being developed. No road heaving is evident, although some sporadic ground movement was noted in the southwest part of Parcel E. The Smoky Hill Shale is rated as having a moderate heaving bedrock potential. In Parcels C and D, however, it is capped by a very thick cap of non-expansive overburden soil, the Slocum Alluvium. The

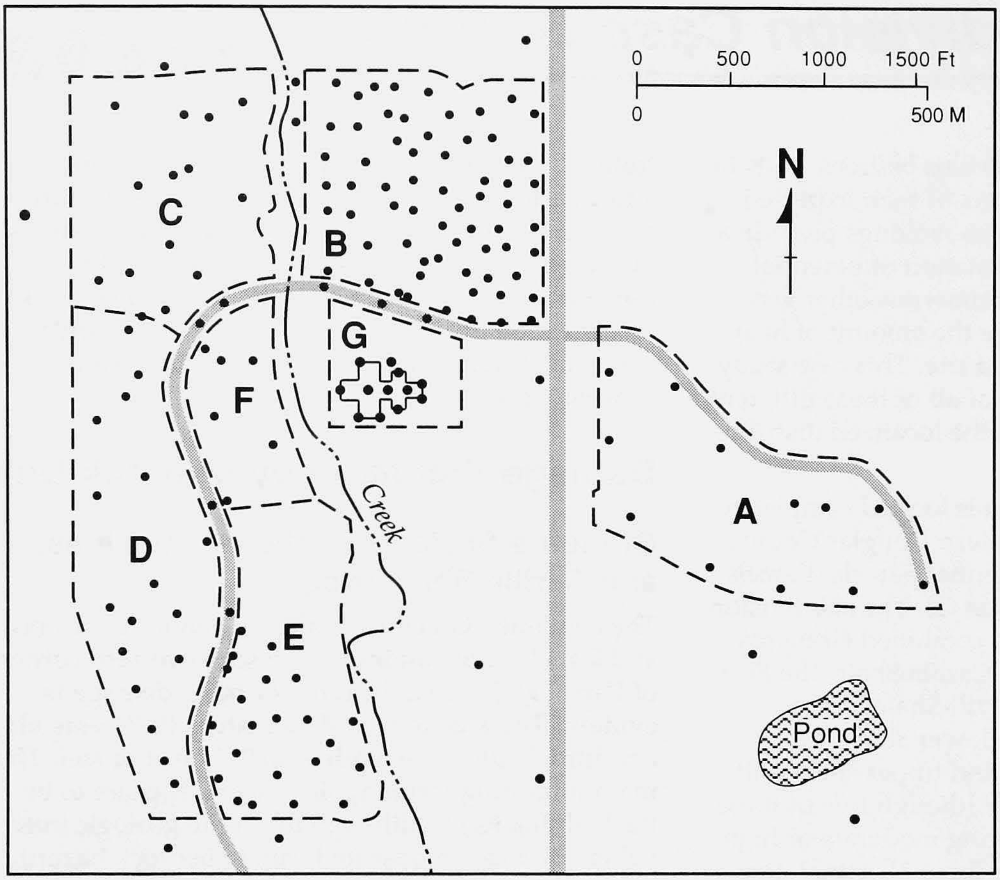
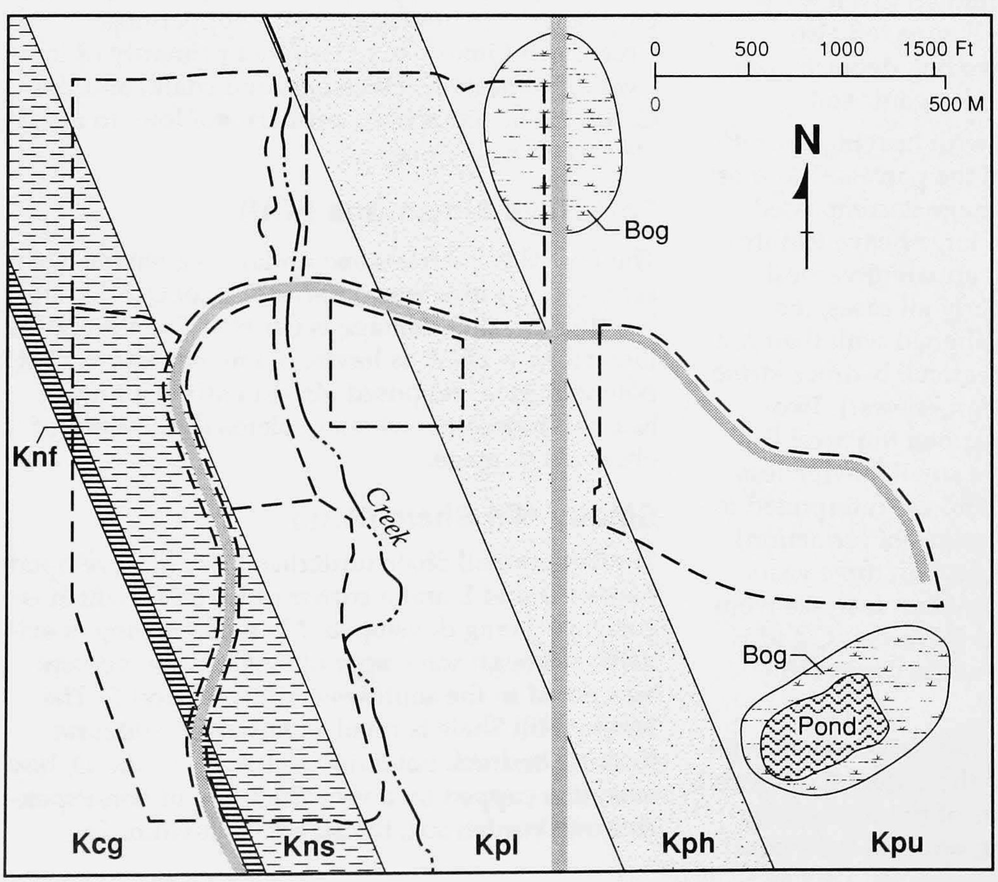


Figure 16. Maps of the case study area.

(16A) Base map showing subdivision residential parcels A–F and school site G (modified from Douglas County Planning and Community Development subdivision map). Geotechnical engineering test holes that were drilled in this area shown as dots.



(16B) Bedrock geologic map (modified from Scott, 1963a; 1963b). Bedrock units include the undifferentiated Graneros Shale, Greenhorn Limestone, and Carlile Shale (Kcg); Fort Hays Limestone (Knf) and Smoky Hill Shale (Kns) of the Niobrara Formation; and lower shale unit (Kpl), Hygiene Sandstone Member (Kph), and upper shale unit (Kpu) of the Pierre Shale. Also shown are two bog deposits of recent geologic age.

original thickness of the alluvium was 20–30 feet and, although grading cuts were made, there appears to be enough alluvium left over to provide for a sufficient buffer between the bedrock and the houses and roads. The western part of Parcel E is a cut area, and minor areas of shallow bedrock occur along the south and west edges. Houses in those parcels were only recently constructed and, as a result, the parcels are too new to assess long-term heaving effects.

Lower Shale Unit of the Pierre Shale (Kpl)

The lower shale unit of the Pierre Shale underlies the western part of developed Parcels B and G, the northeastern part of developed Parcel E, and Parcels C and F, which are currently being developed. No road heaving or other damage is evident in any of these parcels. This bedrock unit is rated as having a high heaving bedrock potential. There are numerous factors that appear to have diminished the local heaving potential within this unit, including thick overburden cover (Parcels C, E, F, and G), use of conventional fills[1] (Parcels B, C, E, F, and G), and relatively high initial moisture contents (15–30 percent). The high moisture contents may reflect a long-term ground water flow into the bedrock from Little Willow Creek, which flows down a valley located preferentially within the shale. It is notable that two areas of shallow bedrock in Parcels C and F are being constructed using overexcavation with engineered fill replacement (Fig. 17). This mitigation design was chosen because the bedrock was found to contain numerous bentonite layers.

Hygiene Sandstone Member of the Pierre Shale (Kph)

The Hygiene Sandstone Member underlies the central part of Parcel B and the eastern part of Parcel G, both of which are developed. It is rated as having a moderate heaving bedrock potential. Two areas of linear ground heave were noted in Parcel B, where the bedrock is generally shallow and was additionally cut during grading. One area, in the northwest corner of Parcel B, has three low (less than 6 inches vertical uplift), broad, and parallel heave features. These features can be correlated along bedding strike to two test holes showing anomalously high bedrock swell potentials (6 percent and 9 percent swells at 500 psf surcharge). They are probably at an incipient stage of growth because that part of Parcel B is only 1–2 years old. It is not known whether these heave features will continue to grow.

The second area of heaving within the Hygiene Sandstone subcrop is located in the south-central part of Parcel B. It consists of a single, asymmetrical, heave feature with approximately 6 inches of vertical displacement. The feature cuts across a street at

1. "Conventional fills" refers to engineered fills designed for the purpose of bringing the original ground level up to higher finish elevation. Such fills, although not designed for heaving bedrock mitigation, generally increase the overburden thickness between foundations or roadways and the underlying bedrock and therefore act to diminish the potential for heaving.

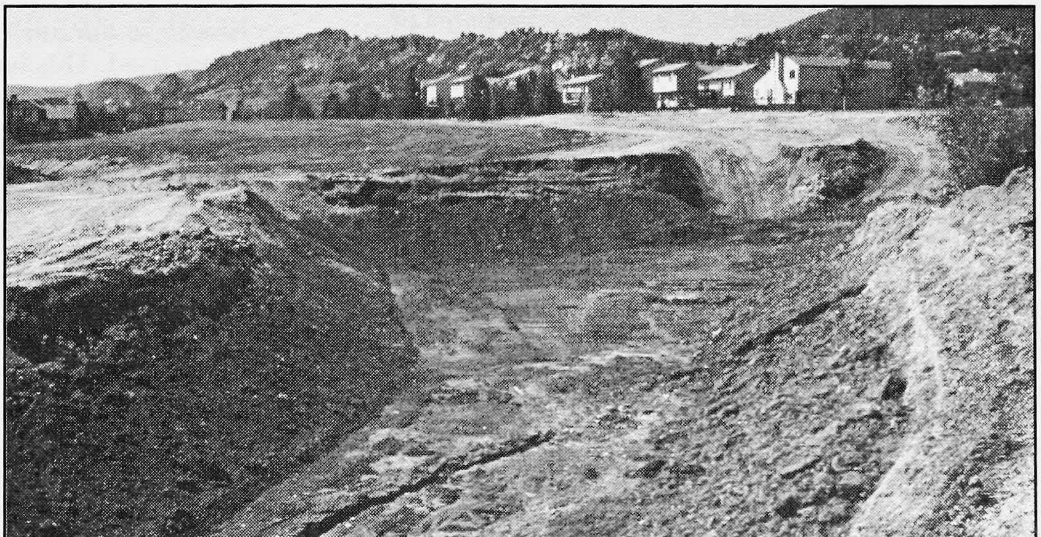


Figure 17. Overexcavation operation in progress at a subdivision in northwestern Douglas County. The overexcavation area consists of a 16–20 foot deep cut that has been partially refilled with claystone as a sealant. The upper part of the cut was later filled with non-expansive material, and houses were built on the fill.beds are typically non-swelling.

an oblique angle to bedding strike. This is probably a shear-slip heave feature associated with a fracture zone. There is evidence of a highly variable ground water surface in the Hygiene Sandstone near the two areas of damage (ranging from 19 to 39 feet deep, before development, over a short distance). The high water table readings are anomalous. They lie between the bog area to the northeast of Parcel B and a creek to the west (Fig. 16B), and may mark a zone of long-term lateral seepage from the bog to the creek.

No heaving was noted at the school site, Parcel G. This site is underlain by relatively thick overburden deposits of alluvial soil.

Upper Shale Unit of the Pierre Shale (Kpu)

The upper shale unit of the Pierre Shale underlies the northeastern part of newly developed Parcel B and all of Parcel A, which was developed in 1986-1988. This bedrock unit is rated as having a high heaving bedrock potential. Two areas of heaving bedrock road damage were noted. One area consists of a 300 foot by 1,000 foot, strike-oriented belt of parallel heave features in Parcel B, some showing as much as 6 inches of vertical uplift. These features began forming shortly after build-out and are actively growing and deforming the roads, based on recent observations by the authors. This area of heaving is constrained on the west by the low-swell Hygiene Sandstone Member, and on the east by as much as 30 feet of alluvial and bog deposits and artificial fill. Upper Pierre Shale claystones beneath the bog deposit have a high moisture content (18–23 percent) compared to claystones beneath the heaving area (13–15 percent). Clearly, this first area of heaving is influenced by bedrock composition, moisture content, and thickness of overburden.

The second area of heaving within the outcrop of the upper shale unit of the Pierre Shale covers nearly all of Parcel A. Heave features in this area range from small to large (up to 1 foot of vertical displacement), and there are several large features that can be traced for 1,000 feet or more through the area. Many of the heave features have been growing and deforming for 10 years since build-out. This area is characterized by shallow claystone bedrock that was additionally cut, numerous discrete bentonite beds, deep original water table (greater than 45 feet in one test hole), and highly variable (12–34 percent) but mostly dry initial moisture contents. The only parts of Parcel A where road heaving is absent are at the east and southwest ends of the parcel, where conventional fills were constructed. A more-detailed report on the effect of heaving on roads in this area is given by Gill and others (1996).

Discussion of Influencing Factors

The results of the subdivision case study demonstrate that there are several different types of factors that can influence the occurrence and severity of heaving bedrock. These factors may be related to the composition of the bedrock itself, or they may be unrelated to bedrock composition. They may be natural or human-caused.

This case study shows that the most severe heaving bedrock occurs where the bedrock is steeply dipping; expansive (or has distinct expansive and less-expansive zones); shallow (less than 20 feet below the ground surface); and relatively dry (or has distinct wet and dry zones). Severe heaving occurs where the original soil profile was relatively dry (i.e., where there is a relatively deep predevelopment water table). Several human-caused factors appear to contribute to heaving include the removal of overburden (emplacement of cuts) and the installation of roads and irrigation systems.

Conversely, the study shows that even moderate- or high-swelling formations do not produce heaving bedrock damage under certain conditions. Several factors appear to inhibit heaving bedrock. These factors include low swell potential (or low variation in swell potential between adjacent bedrock layers), relatively high initial bedrock moisture content, and thick soil overburden cover. Heaving bedrock also appears to be diminished in areas where engineered fills were used. This has influenced the current response of the engineering community to consider overexcavation as a means of replacing heave-prone bedrock with engineered fill.

Several builders and engineers have asserted that lack of construction quality control and improper building or foundation designs are major contributing factors with regard to severity of damage. It was impossible for CGS to assess these factors in this subdivision because we did not have access to data to do so. We know that one parcel in the case-study area has incurred significant heaving bedrock damage to houses and roads; this situation is being monitored by a private geotechnical engineering firm. All of the houses have drilled pier foundations in areas of the subdivision where heaving bedrock road damage is observed. Our regional experience is that *drilled pier foundations, which are the foundation design of choice for expansive soils, have been ineffective in several areas of heaving bedrock along the Front Range piedmont.* However, it should be realized that the uneven ground deformations associated with heaving bedrock could cause damage to any foundation system constructed in proximity to the bedrock, regardless of design. Our case study results generally agree with those of Thompson (1992a, 1992b), who found that the thickness of a soil or fill buffer between the base of the foundation and the top of bedrock is a major factor that influences foundation performance.

Of all the factors that influence heaving bedrock at this subdivision, only bedrock dip and bedrock-unit boundaries could be readily predicted using published geologic maps and geologic reconnaissance. The other factors, which are highly variable in their distribution across the subdivision, could only be assessed using data from site-specific subsurface drilling and trenching investigations. This case study shows that localized conditions are crucial and may either enhance or diminish heaving bedrock hazards. Localized conditions should be carefully investigated and assessed for any particular development project.

7 Recommendations for Land Use within the DBOD

The Dipping Bedrock Overlay District (DBOD) defines an area of Douglas County where heaving bedrock hazards and subsequent long-term damage may occur, depending on 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 within the DBOD, 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. In other areas, special mitigation methods such as overexcavation with fill replacement may be necessary in order to reduce heaving bedrock hazards. In some areas, special mitigation may not be necessary because of favorable geologic conditions such as thick overburden or high initial bedrock moisture content, but these conditions must be well documented during development planning. Still, other areas may be "gray areas" that are difficult to assess. In such cases, a conservative approach to design and mitigation is advised.

The DBOD Map is intended for use as an administrative and regulatory tool by Douglas County 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 adopted by Jefferson County for addressing the heaving bedrock problem, followed by considerations and recommendations for Douglas County.

Jefferson County Dipping Bedrock Regulations

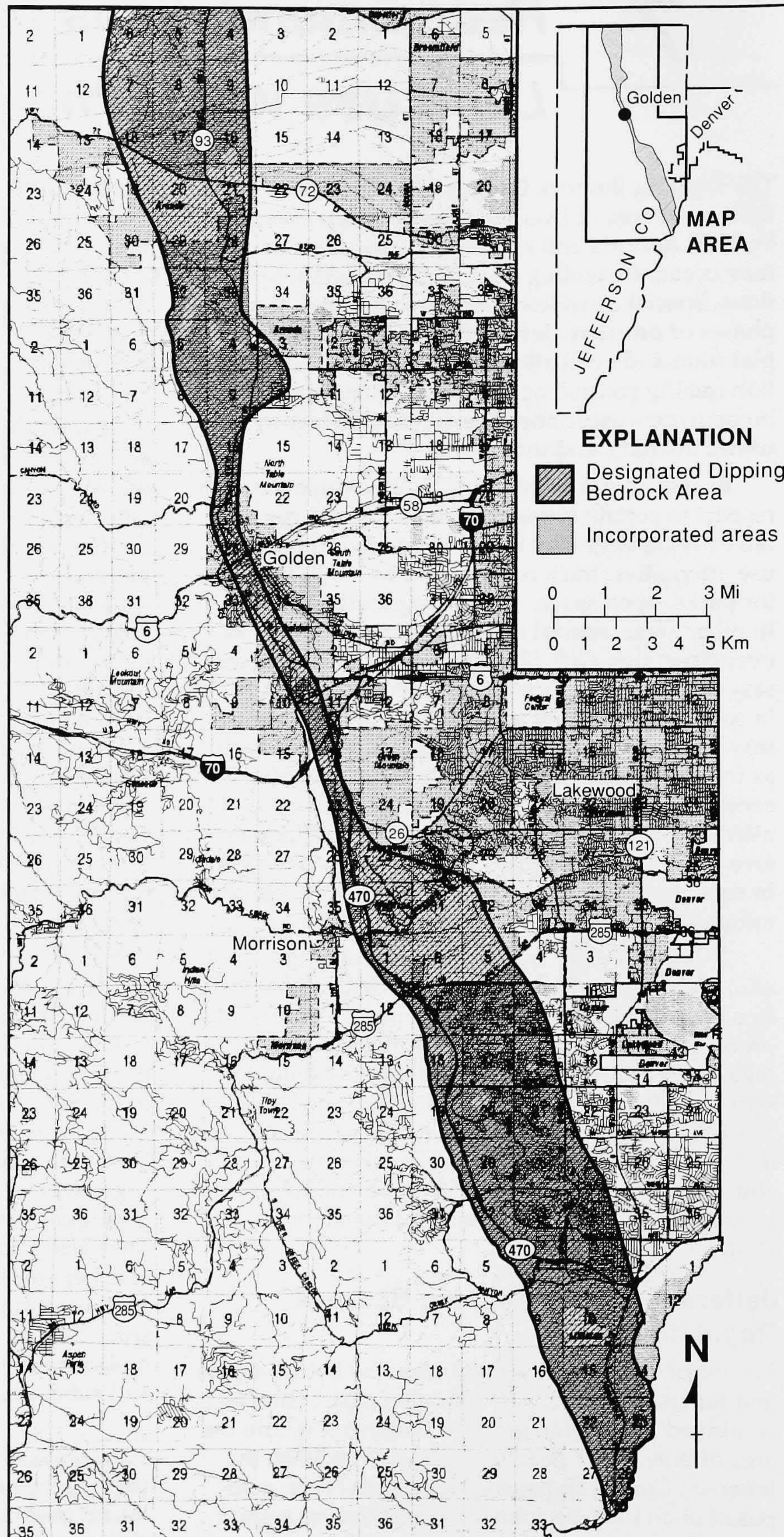
The major question being addressed by both Douglas and Jefferson Counties is, "Should construction and continued population growth be allowed within the area of potentially heaving bedrock?" In 1994, the Jefferson County Expansive Soils Task Force, composed of an interdisciplinary group having a great deal of knowledge and experience with the heaving bedrock problem, looked at two basic scenarios for dealing with the heaving bedrock problem within that county's DDBA[1]. Under the first scenario, residential and commercial development would be significantly limited. Low-impact uses such as agriculture, open space and other park-land, 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 formulated and implemented where necessary to prohibit the continued use of designs and practices that had resulted in poor performance in the past. Effective, problem-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 parcels could be strategically identified for open space purchase and other low-impact uses.

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 geological conditions are favorable for development. They also recognized 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).

1. The Jefferson County DBOD was renamed the Designated Dipping Bedrock Area (DDBA) to avoid any reference to "overlay" or "hazard" areas because of a perceived negative impact on residents of the numerous existing subdivisions there.

Figure 18. Map showing location of the Jefferson County Designated Dipping Bedrock Area (modified from Jefferson County GIS Department, 1995).



In April 1995, the Jefferson County Board of County Commissioners adopted new land-development regulations that allow for continued, but specifically regulated growth should be allowed in the Designated Dipping Bedrock Area. A map of the Jefferson County DDBA (Fig. 18) was produced as an administrative tool to delineate where the new regulations are applicable. Minimum standards were given for site geological/geotechnical exploration, overlot grading operations, and design of roadways, cuts/fills, foundation systems, drainage systems, utilties, and remedial construction. Appendix C contains excerpts from the Jefferson County dipping bedrock regulations.

Effectiveness of the Jefferson County Regulations

The Jefferson County DDBA regulations appear to be effective in terms of the administrative process and actual hazard mitigation. The number of new projects being proposed in the area has slowed. We interpret this as meaning that developers are seriously considering the regulations, and only those who are committed to abiding by the regulations are proceeding with their applications.

The CGS has reviewed several development proposals that fall under the DDBA regulations. A majority of these reports are excellent, and contain an adequate consideration of the heaving bedrock hazard from both a geological and a geotechnical engineering standpoint. Problems have arisen in cases where the author of a report is an engineer who has little professional geological expertise. In such cases, we have found that the regulations have enough "teeth" to require that the appropriate geological expertise is ultimately incorporated into the proposal.

As for actual effectiveness of mitigation, we have noted satisfactory performance of houses and roads at four circa-1994 developments in Douglas and Jefferson Counties where overexcavation was used to mitigate heaving bedrock. In contrast, severe heaving bedrock damage to houses and roads has occurred in another circa-1994 development in Jefferson County where overexcavation was not used.

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/geotechnical 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 that 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) land parcels already zoned for development that are not yet developed; 3) desirability of lands in the DBOD for agriculture, recreation, and open space; 4) natural mitigative factors and new engineering mitigative techniques; 5) general absence of aquifers to supply potable water for low-density, rural-type housing; and 6) presence of other resources such as sand, gravel, and aggregate.

All phases of planning including zoning, platting and building permitting should be considered, if continued growth and development is to be allowed, in order to promote a more integrated approach for mitigating heaving bedrock hazards. The timing of certain development activities should change to allow for earlier and more complete site-evaluation, hazard-identification, and mitigative-design planning at the rezoning or conceptual plan stage. Certain minimum-standards criteria for design of engineered earthworks, excavations, foundations, utilities, and roadways should be formulated based upon the most recently developed mitigative practices for heaving bedrock. In particular, the CGS recommends the following:

- Site exploration should entail trenching in addition to borehole drilling. Trenches should be dug at least 3 feet into the bedrock in order to allow viewing of shear-slip planes and the true orientation of bedding planes.
- The 10-foot-minimum, base-of-foundation to top-of-bedrock depth of overexcavation adopted by Jefferson County should be considered by Douglas County.
- The County should form an Engineering Advisory Board similar to Jefferson County's, or at least retain one or two reputable geotechnical engineering firms to provide additional technical guidance in the event of controversial development submittals.
- The County should strive to restrict the use of high-water turfs and plantings in this area through plat restrictions or other means, except in the case where high plasticity, high moisture-content fills are used.

It is important that any geological or geotechnical report that assesses heaving bedrock hazards should be co-authored by a geotechnical engineer and a professional engineering geologist (or by a single person having both professional qualifications). Our experience since the Jefferson County dipping bedrock regulation went into effect is that a geotechnical engineer who is not also a professional geologist typically does not have the full extent of training or experience necessary to assess and graphically log trenches and interpolate geological information across a site. We have also found that many engineers are resistant to the idea of considering heaving bedrock differently from swelling soils for the purpose of site and structure design. The most comprehensive reports we have received are those in which the engineering geologist has used the trench and drill-hole information to establish a site's geologic framework and delineate units that may be heave-prone, and the geotechnical engineer has used the geologist's findings along with engineering test results to present a mitigative development plan.

According to C.R.S. 34-1-201-(3), a 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 30 semester (45 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."

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 Colorado Geological Survey.

The CGS recommends that Douglas County should use Jefferson County's technical-requirement documents as a template for writing regulations that apply specifically to the Douglas County DBOD. Excerpts from the Jefferson County documents are included in Appendix C of this report.

DBOD Designation and Existing Developments

The Douglas County DBOD area is relatively undeveloped. The distribution of heaving bedrock damage is limited in extent, to date, although the damage may be significant where it has occurred. Several existing developments within the Douglas County DBOD are relatively unaffected by heaving bedrock. The factors controlling the distribution and magnitude of damage are complex and involve geological and non-geological factors, as was shown in the subdivision case study.

Even though a home or commercial building located within the map area may appear to 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.

Structural and geotechnical engineers and contractors performing remedial repair work or building homes on infill lots in this area should be familiar with heaving bedrock in order to avoid an incorrect diagnosis of problems. We have seen several cases in Jefferson County where differential heave of a house was improperly interpreted as differential settlement. The effectiveness of the repair may depend to a large degree on understanding the cause of the problems, and many engineers and contractors in the area may be unfamiliar with heaving bedrock.

8 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 may be 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 characteristics: 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 characteristics that greatly influence the heaving potential of bedrock, overburden thickness (alternately known as depth to bedrock) and initial bedrock moisture content, are highly localized and were not used in delineating the DBOD.
4) Twelve sedimentary bedrock formations of Jurassic and Cretaceous age are found within the DBOD, including the Ralston Creek Formation, Morrison Formation, Lytle Formation, South Platte Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, Laramie Formation, and lower part of the Dawson Formation. 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 DBOD defines an 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. Development alternatives may include avoidance,use of special mitigative engineering designs such as overexcavation with fill replacement, or (where warranted) use of conventional engineering designs.
6) 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 geotechnical factors presented in this report, but also on the County's 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.

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APPENDIX A: GEOTECHNICAL REPORT DATA

Appendix A contains a table of engineering properties data that were compiled from existing, public-record geotechnical reports for subdivisions and other engineered projects. All of these projects are located within the Kassler quadrangle, in the northwest part of Douglas County. The data are sorted by geologic unit (see Table A1), name of reporting company (see Table A2), test hole number, and sample depth. The geologic unit is assigned by the authors based on the test hole location with respect to the geological formations mapped by Scott (1963b); all other data were taken directly from the geotechnical reports.

The geotechnical report data are shown in Table A.3. Each sample is represented by a single row, with the exception of seven samples recovered from the lower shale unit of the Pierre Shale by Empire Laboratories, Inc. (1994a; 1994b). For those seven samples, five rows of data are used to show the results of Denver swell tests that were run using five different surcharge loads. Data from 165 individual samples are shown.

Engineering properties included in this table are: natural water content, natural dry density, soil classification (Unified and AASHTO systems), material description, grain-size distribution, Atterberg limits (liquid limit and plasticity index), Denver swell (percent swell, test surcharge, and swell pressure), standard penetration, and unconfined compressive strength. For sample locations and a detailed technical discussion of these data, see Dodson (1996).

Table A1. Geologic unit abbreviations.

Geologic Unit (and Age[1])	Abbreviation[2]
Ralston Creek Formation (J)	Jrc
Morrison Formation (J)	Jm
Carlile Shale, Greenhorn Limestone, and Graneros Shale (K)	Kcg
Smoky Hill Shale of the Niobrara Formation (K)	Kns
Lower shale unit of the Pierre Shale (K)	Kpl
Hygiene Sandstone Member of the Pierre Shale (K)	Kph
Upper shale unit of the Pierre Shale (K)	Kpu

Notes: 1. Standard geologic symbols used to denote Jurassic (J) and Cretaceous (K) age.
2. Abbreviations used in Table A.3.

Table A2. Reporting company abbreviations.

Company[1]	Abbreviation[2]
A.G. Wassenaar, Inc.	AGW
Chen and Associates, Inc.	Chen
CTL/Thompson, Inc.	CTL/T
Empire Laboratories, Inc.	ELI
Fox and Associates of Colorado, Inc.	Fox
Geotek, Inc.	G-tek
Ground Engineering Consultants, Inc.	GEC
Lincoln-Devore, Inc.	L-D
Soils and Materials Consultants, Inc.	SMC
Terracon Consultants Western, Inc.	TCW

Notes: 1. Full name used for citation in Selected References section.
2. Abbreviations used in Table A.3.

Table A3. Summary of public -record, geotechnical report data.

Geo-technical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification Unified	Classification AASHTO	Material Description	Grain Size Distribution (%) Gvl	Sand	Fines	Denver Swell: Atterberg Limits LL(%)	PI(%)	Swell (%)	Sur-charge (psf	Pres-sure (psf)	Pene-tration (blows/in.)	Uncon Comp Strength (psf)	Geo-logic Unit
Chen, 1973a	2	3	20.6	98.9			Weathered claystone, very stiff, moist, variegated, very calcareous			88	77	45.5				33/12		Jm
Chen, 1973a	2	8	17.9	106.1			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation						1.5	1,000	4,000	22/6		Jm
Chen, 1973a	6	8	12.2	112.7			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation									20/6	1,764	Jm
Chen, 1973a	8	8	22.6	100.6			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation						5.0	1,000	22,000	20/6		Jm
Chen, 1973a	9	13	23.3	101.9			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation						3.0	1,000	9,500	37/12		Jm
Chen, 1973a	11	18	19.9	108.7			Weathered claystone, very stiff, moist, variegated, very calcareous						2.0	1,000	5,000	27/12		Jm
Chen, 1973a	15	8	25.3	97.2			Weathered claystone, very stiff, moist, variegated, very calcareous"			95.4	76.5	50.6	2.0	1,000	3,500	22/12		Jm
Chen, 1973a	17	8	20.6	100.7			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation						3.8	1,000	8,500	21/6		Jm
Chen, 1973a	18	8	31.5	89.8			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation						3.5	1,000	9,000	50/12		Jm
Chen, 1973a	19	8	11.3	122.4			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation									21/6	25,600	Jm
Chen, 1973a	22	8	13.6	111.1			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation			87.5	45.9	25.4	3.5	1,000	4,000	23/6		Jm
Chen, 1973b	1	9	18.0	112.3			Disturbed claystone bedrock, claystone fragments in clay matrix, stiff, moist, mottled red, yellow, green			60	44.9	28.7				14/12		Jm
Chen, 1973b	1	14	27.9	91.7			Disturbed claystone bedrock, claystone fragments in clay matrix, stiff, moist, mottled red, yellow, green									6/12		Jm
Chen, 1973b	1	19	20.7	108.7			Claystone bedrock, moist, hard, blocky, greenish gray, Morrison Formation									28/9		Jm
Chen, 1973b	Pit 1	6	19.6	105.5			Disturbed claystone bedrock, claystone fragments in clay matrix, stiff, moist, mottled red, yellow, green										3,960	Jm
Chen, 1973b	Trench 1	3	15.7	110.9			Disturbed claystone bedrock, claystone fragments in clay matrix			27			0.5	1,000	N/A			Jm
SMC, 1993	2	7			CH	A-7-6 (54)	Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	7	93	78	50					20/6		Jm
SMC, 1993	2	9			CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/2		Jm
SMC, 1993	3	3	20.6	99	CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/6		Jm
SMC, 1993	3	7			CH		Claystone, medium to high plasticity, some iron staining in fractures medium hard to very hard, medium moist to very moist, gray									20/1		Jm
SMC, 1993	4	3			CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/1		Jm
SMC, 1993	4	7			CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/1		Jm

Table A3. (Continued.)

Geo-technical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification Unified	Classification AASHTO	Material Description	Grain Size Distribution (%) Gvl	Sand	Fines	Atterberg Limits LL(%)	PI(%)	Denver Swell Swell (%)	Sur-charge (psf	Pres-sure (psf)	Pene-tration (blows/in.)	Uncon Comp Strength (psf)	Geo-logic Unit
SMC, 1993	6	19	33.1	86	CH	A-7-6 (111)	Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray		100	135	88					20/6		Jm
SMC, 1993	7	3			CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/2		Jm
SMC, 1993	8	3	11.3	107	CH		Weathered claystone, high plasticity, very stiff, med. moist to moist, white gray									14/12		Jm
SMC, 1993	8	7			SP-SM		Sandstone, fine-grained, silty, weakly cemented, hard, slightly moist, yellow-brown									20/3		Jm
SMC, 1993	9	3	15.9	112	CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/6		Jm
SMC, 1993	9	7			CH	A-7-6 (36)	Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	5	95	58	34					20/6		Jm
SMC, 1993	9	19	26.6	96	CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/6		Jm
SMC, 1993	10	3	16.6	107	CL		Claystone, firm, medium moist, gray									20/9		Jm
SMC, 1993	10	7	25.8	93	CL		Claystone, firm, medium moist, gray									20/9		Jm
SMC, 1993	10	19			CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/4		Jm
SMC, 1993	13	2	16.1	95	CL		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	0	14	86	41	22	-0.1	500	N/A	20/4		Jm
SMC, 1993	17	3	18.4	104	CL		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	0	2	98	41	19	-0.1	500	N/A	20/3		Jm
SMC, 1993	18	3	21.8	84	CL-CH		Claystone, medium to high plasticity, firm to medium hard, medium moist to moist, gray						4.0	500	2,800	20/9		Jm
SMC, 1993	22	2			SP-SM		Sandstone, silty, moderately to well cemented, fine grained, very hard, slightly moist, yellow-brown									20/1		Jm
SMC, 1993	27	2	19.8	91	CL		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	1	4	95	53	31	4.0	500	3,000	20/4		Jm
SMC, 1993	27	6	18.2	109	CL-CH w/SM		Claystone, with thin sandstone lenses, hard, medium moist to moist, gray and brown						5.0	500	6,500	20/5		Jm
SMC, 1993	28	7	25.4	97	CL		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	0	5	95	65	35	3.0	500	6,000	20/7		Jm
SMC, 1993	28	19			CL		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/3		Jm
SMC, 1993	29	6	26.0	96	CH		Weathered claystone, high plasticity, very stiff, medium moist to very moist, white gray	0	2	98	73	44	5.0	500	6,500	18/12		Jm
Chen, 1973b	2	14	15.1	117.3			Disturbed claystone bedrock, claystone fragments in clay matrix, stiff, moist, mottled red, yellow, green									28/9		Jrc
Chen, 1973b	2	19	13.4	120.7			Claystone bedrock, moist, hard, blocky, greenish gray, Morrison Formation			92						50/5		Jrc
Chen, 1973a	3	8	20.7	101.9			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation									39/12	11,844	Jrc

Table A3 (Continued.)

Geotechnical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification Unified	Classification AASHTO	Material Description	Grain Size Distribution (%) Gvl	Sand	Fines	Atterberg Limits LL(%)	PI(%)	Denver Swell Swell (%)	Surcharge (psf	Pressure (psf)	Penetration (blows/in.)	Uncon Comp Strength (psf)	Geologic Unit
Chen, 1973a	7	8	19.7	80.2			Claystone bedrock, very stiff, moist, variegated, very calcareous, blocky, Morrison Formation						3.0	1,000	6,500	31/12		Jrc
SMC, 1993	1	7			CH	A-7-6 (37)	Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	0	14	86	65	38				20/6		Jrc
SMC, 1993	1	19			CH		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray									20/2		Jrc
SMC, 1993	2	3			CL		Claystone, firm, medium moist to moist, gray									20/9		Jrc
SMC, 1993	11	14	14.3	118	CL		Claystone, medium to high plasticity, some iron staining in fractures, medium hard to very hard, medium moist to very moist, gray	0	23	77	40	26	3.3	500	7,500	20/5		Jrc
SMC, 1993	34	14	33.5	88	CL-CH		Claystone, medium to high plasticity, firm to medium hard, medium moist to moist, gray	0	0	100	84	54	3.5	500	5,000	20/6		Jrc
SMC, 1993	34	24			CL-CH		Claystone, medium to high plasticity, firm to medium hard, medium moist to moist, gray									20/5		Jrc
Chen, 1972b	1	3	6.7	115.9			Claystone, medium hard to hard, moist, brown						1.0	1,000	N/A	18/12		Kcg
L-D, 1985	4	4	11.4		CL		Claystone/shale, weathered Niobrara Formation, low plasticity, silty, sandy, very stiff, moist						0.7	1,470	N/A	30/12		Kcg
L-D, 1985	4	9	11.7		CL		Claystone/shale, Niobrara Formation, low plasticity, silty, sandy, very hard, damp to moist	0	28.4	71.6	32.3	15.5				50/5		Kcg
L-D, 1985	4	13	6.5		CL		Claystone/shale, Niobrara Formation, low plasticity, silty, sandy, very hard, damp to moist									50/3		Kcg
Chen, 1972a	2	13	27.0	114.2			Siltstone, hard to very hard, moist, lt. brown, dk. gray, stratified and inclined bedding						0.1	1,000	N/A	14/6		Kns
Chen, 1972b	4	18	18.9	108.8			Claystone, medium hard to hard, moist						1.0	1,000	N/A	24/6		Kns
Chen, 1972b	5	8	15.7	112.2			Claystone, medium hard to hard, moist						5.0	1,000	N/A	25/6		Kns
Fox, 1984c	10	18			SC-GC	A-2-6 (0)	Claystone, fractured, clay in fractures, firm, medium moist, white	34.5	34.3	31.2	30	17				30/12		Kns
Fox, 1984c	10	29			CL		Claystone with limestone pieces, hard, moist, light gray									33/6		Kns
Fox, 1984c	11	9			CL		Claystone, medium hard to hard, some very sandy lenses, near vertical beds, moist, gray to brown									42/12		Kns
Fox, 1984c	12	18			CL-CH	A-7-6 (20)	Claystone, slightly sandy, med. hard to hard, some very sandy lenses, near vertical beds, moist, gray to brown	0	9.6	90.4	50	30				37/6		Kns
Fox, 1984c	12	21	16.8	98	CL		Claystone, slightly sandy, med. hard to hard, some very sandy lenses, near vertical beds, moist, gray to brown						4.3	500	N/A	36/3		Kns
Fox, 1988	6	2	24.1	90	ML		Siltstone, very hard, medium moist, buff						-0.5	500	N/A	50/7		Kns
Fox, 1988	7	7	28.9	94	CL		Claystone, silty, weathered, very stiff, very moist, yellow-brown						0.0	500	N/A	19/12		Kns
Fox, 1988	18	6	19.5	105	CL		Claystone, silty, weathered, very stiff, very moist, yellow-brown						-0.3	500	N/A	20/12		Kns
Fox, 1988	18	14	16.5	116	CL-CH		Claystone, medium hard to hard, moist, light gray to brown						2.5	500	8,000	50/7		Kns
GEC, 1990	12	24	20.1	104.5			Claystone, med-high plasticity, medium hard to hard, moist, brown to dark gray	0	0	100	53	32	3.5	1,000	5,000	37/12		Kns
TCW, 1995	4	5	20.4	101			Claystone, hard, stratified, light brown, light olive to black with depth, moist			75	44	19	0.5	500	1,000	50/6		Kns

Table A3. (Continued.)

Geo-technical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification Unified	Classification AASHTO	Material Description	Grain Size Distribution (%) Gvl	Sand	Fines	Atterberg Limits LL(%)	PI(%)	Denver Swell: Swell (%)	Sur-charge (psf)	Pres-sure (psf)	Pene-tration (blows/in.)	Uncon Comp Strength (psf)	Geo-logic Unit
CTL/T, 1990	3	14	10.0	112			Sandstone, clayey, silty, hard, dry, olive to gray to brown, upturned bedding						-0.5	1,000	N/A	50/9		Kph
CTL/T, 1990	5	29	13.0	110			Sandstone, clayey, silty, hard, dry, olive to gray to brown, upturned bedding									50/6	3,900	Kph
CTL/T, 1990	9	14	11.7	113			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						0.3	1,000	2,000	50/8		Kph
CTL/T, 1990	9	29	14.6	114			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						0.3	1,000	1,500	50/5		Kph
CTL/T, 1990	10	35	12.2	90			Sandstone, clayey, silty, hard, dry, olive to gray to brown, upturned bedding									50/5	16,000	Kph
Fox, 1984b	2	19	14.9	97	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						0.3	500	750	32/6		Kph
Fox, 1984b	3	19	13.0	106	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						0.3	500	1,000	41/9		Kph
Fox, 1984b	12	23	16.8	105	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						1.0	500	1,300	41/9		Kph
Fox, 1984b	12	27	16.4	101	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						0.5	500	700	36/6		Kph
Fox, 1984b	12	34	16.3	110	CL		Claystone, sandy, medium hard to hard, some very sandy lenses high angle of structural dip, moist, gray to brown						2.0	500	4,000	50/8		Kph
Fox, 1984b	13	24	16.2	104	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						-0.5	500	N/A	33/6		Kph
Fox, 1984b	15	7	10.8	115	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						2.0	500	6,500	24/6		Kph
Fox, 1984b	15	19	12.6	111	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						1.0	500	2,000	52/6		Kph
Fox, 1984c	1	4			CL	A-6 (17)	Claystone, medium hard to hard, some very sandy lenses, near vertical beds, moist, gray to brown	0	22.7	77.3	39	24				22/12		Kph
Fox, 1984c	1	8	15.3	113	CL		Claystone, medium hard to hard, some very sandy lenses, near vertical beds, moist, gray to brown						1.3	500	N/A	29/9		Kph
Fox, 1984c	1	14	15.0	115	CL		Claystone, medium hard to hard, some very sandy lenses, near vertical beds, moist, gray to brown						1.0	500	N/A	34/9		Kph
G-tek, 1986	2	4	12.0	120			Claystone, weathered, silty to very silty, occasionally sandy, medium hard to very hard, medium moist to moist, gray, brown, yellow						6.8	300	9,000	56/6		Kph
G-tek, 1986	2	7	12.6	119			Claystone, weathered, silty to very silty, occasionally sandy, medium hard to very hard, medium moist to moist, gray, brown, yellow						2.3	300	3,500	50/6		Kph
G-tek, 1986	B5L17	6	13.4	107.1			Siltstone/sandstone						0.1	500	600			Kph
G-tek, 1986	B5L17	6	9.6	97.9			Siltstone/sandstone						0.1	500	700			Kph
G-tek, 1986	C	2	11.9	120			Claystone, weathered, silty to very silty, occasionally sandy, medium hard to very hard, medium moist to moist, gray, brown, yellow				37	18				30/6		Kph
G-tek, 1986	C	4	11.2	123			Claystone, weathered, silty to very silty, occasionally sandy, medium hard to very hard, medium moist to moist, gray, brown, yellow						5.5	300	6,000	59/6		Kph
G-tek, 1986	C	12	11.3	124			Claystone, weathered, silty to very silty, occasionally sandy, medium hard to very hard, medium moist to moist, gray, brown, yellow						2.3	300	2,500	100/6		Kph

Table A3. (Continued.).

Geo-technical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification		Material Description	Grain Size Distribution (%)			Atterberg Limits		Denver Swell				Uncon Comp Strength (psf)	Geo-logic Unit
					Unified	AASHTO		Gvl	Sand	Fines	LL(%)	PI(%)	Swell (%)	Sur-charge (psf	Pres-sure (psf)	Pene-tration (blows/in.)		
AGW, 1986	B1L2	4					Claystone, sandy, hard to very hard, silty, scattered sandstone lenses, slightly moist to moist, light brown	0	18	82	30	10				28/6		Kph
AGW, 1987	B1L2	9	11.8	116.7			Sandstone-claystone, hard to very hard, medium moist, dark olive, gold-brown, gray						2.0	1,000	7,000	26/16		Kph
AGW, 1987	B1L15	4	15.8	116.5			Sandstone-claystone, medium hard, medium moist, olive, brown, gray, gold						0.3	1,000	1,600	23/6		Kph
AGW, 1986	B2L1	4	14.6	118.4			Claystone, firm to medium hard, slightly sandy to sandy, slightly moist to moist, brown, olive, gold-brown						2.0	1,000	10,000	22/6		Kph
AGW, 1986	B2L1	14	14.0	122.8			Claystone, firm to medium hard, slightly sandy to sandy, slightly moist to moist, brown, olive, gold-brown						1.0	1,000	6,000	25/6		Kph
AGW, 1989	B2L4	9	10.5	104.2			Sandstone, firm to medium hard, silty, clean to clayey, with claystone lenses, moist, brown to rust brown						0.0	1,000	0	24/12		Kph
AGW, 1987	B2L4	14	13.0	128.1			Sandstone-claystone, hard to very hard, medium moist, olive-gold, gray, tan						1.0	1,000	2,500	30/6		Kph
AGW, 1989	B2L7	4	15.4	116.8			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust brown to dark gray						1.0	1,000	4,000	23/12		Kph
AGW, 1986	B2L7	9	14.9	118.9			Claystone-Sandstone, firm to medium hard, silty, scattered sandstone lenses, slightly moist to moist, brown, olive, gold-brown						1.5	1,000	8,000	25/6		Kph
AGW, 1989	B2L7	14	17.5	113.5			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust brown to dark gray						1.0	1,000	4,000	23/6		Kph
AGW, 1989	B2L10	9	16.4	115.5			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive brown to gold brown						0.3	1,000	2,000	30/6		Kph
AGW, 1989	B3L1	9	12.2	112.8			Cllaystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive brown to gold brown						0.5	1,000	3,500	40/6		Kph
AGW, 1989	B3L4	14	14.9	115.5			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive brown to gold brown						0.5	1,000	4,000	41/6		Kph
AGW, 1986	B3L22	1	16.4	113.6			Claystone-Sandstone, firm to medium hard, silty, scattered sandstone lenses, slightly moist to moist, brown, olive, gold-brown						1.5	1,000	10,000	25/9		Kph
AGW, 1989	B4L5	14	12.2		CL		Claystone, lean, sandy, light olive	0	29	71						50/4		Kph
AGW, 1989	B4L8	14	14.1	115.9			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive grown to gold brown, 0.016% soluble sulfates						0.0	1,000	N/A	41/6		Kph
AGW, 1989	B4L12	9	13.6	117.6			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive grown to gold brown						1.3	1,000	4,600	43/6		Kph
AGW, 1989	B4L16	14	11.4		CL		Claystone, lean, very sandy, tan	0	38	62	34	12				34/6		Kph
AGW, 1989	B4L19	9	15.6	113.5			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive grown to gold brown						0.3	1,000	1,800	29/6		Kph
AGW, 1989	B4L23	9	16.9	115.3			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust to dark gray						0.3	1,000	2,200	26/9		Kph
AGW, 1989	B4L26	4	13.1	115.6			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive grown to gold brown						1.0	1000	4000	35/6		Kph
AGW, 1989	B4L30	14	15.4	114.3			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust to dark gray						0.3	1000	2000	20/6		Kph

Table A3. (Continued)

Geo-technical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification		Material Description	Grain Size Distribution (%)			Denver Swell						Uncon Comp Strength (psf)	Geo-logic Unit
											Atterberg Limits							
					Unified	AASHTO		Gvl	Sand	Fines	LL(%)	PI(%)	Swell (%)	Sur-charge (psf	Pres-sure (psf)	Pene-tration (blows/in.)		
AGW, 1989	B4L33	24	13.1	119.4			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive grown to gold brown						0.3	1000	2000	50/6		Kph
Chen, 1972a	8	13	21.1	105.8			Claystone, hard to very hard, moist, light brown, dk. gray, stratified and inclined bedding						3.0	1000	N/A	20/9		Kpl
Chen, 1972b	6	13	20.8	109.8			Claystone, medium hard to hard, moist									39/6	20,350	Kpl
CTL/T, 1990	1	34	12.2	121			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						1.5	1000	4500	50/4		Kpl
CTL/T, 1990	2	34	14.9	117			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						3.0	1000	3000	50/9		Kpl
CTL/T, 1990	6	29	13.1	120			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						2.5	1000	11000	50/9		Kpl
CTL/T, 1990	6	38	13.9	117			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding									50/5		Kpl
CTL/T, 1990	7	40	20.1	106			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding									50/10	12,100	Kpl
CTL/T, 1990	8	39	17.6	110			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						4.0	1000	12000	50/6		Kpl
CTL/T, 1990	11	24	14.2	122			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						3.0	1000	10000	50/7		Kpl
CTL/T, 1990	11	29	14.6	117			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						1.0	1000	2000	50/6		Kpl
CTL/T, 1990	12	19	17.1	110			Claystone, sandy, silty, hard, dry, olive to gray to brown, upturned bedding						4.3	1000	10000	50/9		Kpl
ELI, 1994a	3	24	19.0	107			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						2.5	250	2000	53/12		Kpl
ELI, 1994a	3	24	17.0	110			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						1.0	500	2300	53/12		Kpl
ELI, 1994a	3	24	19.0	108			Claystone, mottled, vertical bedded, hard, moist,						1.0	1000	2700	53/12		Kpl
ELI, 1994a	3	24	19.0	107			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						2.5	250	2000	53/12		Kpl
ELI, 1994a	3	24	17.0	110			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						1.0	500	2300	53/12		Kpl
ELI, 1994a	3	24	19.0	108			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						1.0	1000	2700	53/12		Kpl
ELI, 1994a	3	24	19.0	108			Claystone, mottled, vert. bedded, hard, moist, grey to yellow brown						1.0	1500	3000	53/12		Kpl
ELI, 1994a	3	24	23.0	102			Claystone, mottled, vert. bedded, hard, moist, grey to yellow brown						1.0	2000	3600	53/12		Kpl
ELI, 1994b	3	19	20.0	108			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						3.0	250	3500	50/11		Kpl
ELI, 1994b	3	19	20.0	105			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.0	500	2000			Kpl
ELI, 1994b	3	19	20.0	106			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.0	700	2100			Kpl

Table A3. (Continued.)

Geo-technical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification Unified	Classification AASHTO	Material Description	Grain Size Distribution (%) Gvl	Sand	Fines	Atterberg Limits LL(%)	PI(%)	Denver Swell: Swell (%)	Sur-charge (psf	Pres-sure (psf)	Pene-tration (blows/in.)	Uncon Comp Strength (psf)	Geo-logic Unit
ELI, 1994b	3	19	20.0	108			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.5	1000	3000			Kpl
ELI, 1994b	3	19	21.0	107			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.3	1250	3500			Kpl
ELI, 1994b	4	24	23.0	102			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						2.0	250	2200	50/10		Kpl
ELI, 1994b	4	24	23.0	101			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.8	500	1800			Kpl
ELI, 1994b	4	24	24.0	101			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.5	750	2000			Kpl
ELI, 1994b	4	24	23.0	104			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						1.8	1000	3500			Kpl
ELI, 1994b	4	24	21.0	102			Claystone, mottled, near vertical bedded, some salts, med. hard to hard, moist, gray-yellow-brown						0.3	1250	2500			Kpl
ELI, 1994a	6	19	18.0	107			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						2.5	250	2600	50/11		Kpl
ELI, 1994a	6	19	21.0	103			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						2.5	500	4600	50/11		Kpl
ELI, 1994a	6	19	20.0	103			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						1.0	1000	2700	50/11		Kpl
ELI, 1994a	6	19	20.0	106			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						1.5	1500	4200	50/11		Kpl
ELI, 1994a	6	19	18.0	107			Claystone, mottled, vertical bedded, hard, moist, grey to yellow brown						1.0	2000	3500	50/11		Kpl
Fox, 1984a	11	14	19.8	105			Claystone, high plasticity, fractured, high angle of structural dip, medium hard to hard, medium moist, olive-brown						9.0	500	15000	32/12		Kpu
Fox, 1984a	12	7	33.6	90			Claystone, high plasticity, fractured, often calcareous, sulfate crystals common, weathered to firm, medium moist to wet, olive brown to yellow brown						0.5	500	900	27/12		Kpu
Fox, 1984b	1	39	27.5	98	ML		Siltstone, hard, moist, light brown						-0.8	500	N/A	36/9		Kpl
Fox, 1984b	5	29	21.9	102	CL-CH		Claystone, medium hard to hard, moist, high angle of structural dip, gray-brown						1.0	500	3500	21/6		Kpl
Fox, 1984b	6	19	18.8	107	CL-CH		Claystone, medium hard to hard, moist, high angle of structural dip, gray-brown						3.0	500	8000	20/6		Kpl
Fox, 1984b	14	14	17.4	103	CL		Claystone, sandy, medium hard to hard, some very sandy lenses, high angle of structural dip, moist, gray to brown						1.0	500	2500	36/9		Kpu
Fox, 1984c	6	9			CL-CH		Claystone, weathered to firm, moist to very moist, gray to brown									20/12		Kpl
G-tek, 1986	A	22	16.7	109			Claystone, severely weathered, silty, very stiff, medium moist to moist, brown				62	38	5.5	600	7500	11/6, 32/6		Kpl
G-tek, 1986	B	32	21.3	106			Claystone, weathered, firm to medium hard, moist, gray, brown, occasionally calcareous						3.0	600	6000	13/6, 26/6		Kpl
TCW, 1995	3	10	22.1	102			Claystone, weathered to firm, calcareous, olive gray, moist, (gypsum crystals @20ft)				63	38	1.9	500	2000	29/12		Kpl

Table A3. (Continued.)

Geotechnical Report	Test Hole No.	Sample Depth (ft)	Water Content (%)	Dry Density (pcf)	Classification Unified	Classification AASHTO	Material Description	Grain Size Distribution (%) Gvl	Sand	Fines	Atterberg Limits LL(%)	PI(%)	Denver Swell Swell (%)	Surcharge (psf	Pressure (psf)	Penetration (blows/in.)	Uncon Comp Strength (psf)	Geologic Unit
AGW, 1989	B1L10	29	17.9	109.5			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust brown to dark gray						0.8	1000	2200	23/12		Kpl
Fox, 1986	1	9	18.8	107			Claystone, firm to medium dense						2.5	500	6200	33/12		Kpu
Fox, 1986	6	14	18.2	129.1			Claystone, firm to medium dense						3.2	500	7500	42/12		Kpu
Fox, 1986	7	3	16.1	110.1			Claystone, firm to medium dense									24/12		Kpu
Fox, 1986	7	7	17.5	119.4			Claystone, firm to medium dense				63	42	4.3	500	5000	35/12		Kpu
Fox, 1986	9	9	12.7	112.7			Claystone, firm to medium dense						3.8	500	7000	26/9		Kpu
Fox, 1986	10	34	19.3	109.2			Claystone, firm to medium dense						1.1	500	6500	45/12		Kpu
Fox, 1986	11	2			CH	A-7-6 (47)	Claystone, weathered		2.7	97.3	62	44				15/12		Kpu
GEC, 1990	2	29	23.3				Claystone, medium-high plasticity, medium hard to hard, moist, brown to dark gray		1	99	62	37				50/6		Kpu
GEC, 1990	8	19	22.2	102.8			Claystone, medium-high plasticity, medium hard to hard, moist, brown to dark gray		3	97	64	44	4.0	1000	11000	37/12		Kpu
AGW, 1987	B1L8	4	13.8	110.5	CL		Weathered claystone, sandy, calcareous, medium moist, brown, gray, olive						5.5	1000	9000	20/12		Kpu
AGW, 1987	B1L10	14	14.7	122			Claystone, firm to medium hard, medium moist, dark olive, gold-brown, gray						1.5	1000	9000	23/6		Kpu
AGW, 1987	B2L7	9	13.0	128.1			Claystone, firm to medium hard, medium moist, dark olive, gold-brown, gray						1.0	1000	3500	26/9		Kpu
AGW, 1987	B2L10	9	14.9	109.8			Claystone, firm to medium hard, medium moist, dark olive, gold-brown, gray						3.5	1000	18000	18/6, 14/3		Kpu
AGW, 1987	B2L10	19	16.8	112.7			Claystone, hard, medium moist, olive, gold, rust, gray						3.3	1000	25000	30/6		Kpu
AGW, 1986	B2L12	9	20.9	106.2			Claystone, firm to medium hard, silty, slightly sandy to sandy, slightly moist to moist, brown, olive, gold-brown						3.3	1000	10000	23/12		Kpu
AGW, 1986	B2L12	19	21.0	110.9			Claystone, firm to medium hard, silty, slightly sandy to sandy, slightly moist to moist, brown, olive, gold-brown						2.5	1000	10000	24/6		Kpu
AGW, 1989	B2L19	24	18.1	112.3			Claystone, hard to very hard, silty, sandy, with sandstone lenses, moist, olive brown to gold brown						2.0	1000	7000	25/6		Kpu
AGW, 1989	B2L28	24	20.0	106.5			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust brown to dark gray						1.5	1000	6000	26/9		Kpu
AGW, 1989	B2L36	29	19.0	107.4			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust brown to dark gray						2.0	1000	5500	20/6		Kpu
AGW, 1989	B2L39	29	19.1	106.7			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses, calcareous, moist, olive brown to rust brown to dark gray						0.8	1000	5000	20/6		Kpu
AGW, 1989	B3L11	29	23.0	99.4			Claystone, firm to medium hard, silty, sandy with sandstone lenses, sulfate lenses (1.2% soluble sulfates), calcareous, moist, olive brown to rust brown to dark gray						3.8	1000	5500	20/6		Kpu

APPENDIX B. CGS LABORATORY TEST RESULTS

Appendix B contains a table of engineering properties data from laboratory analysis conducted by Marilyn Dodson as part of this project. A total of 77 samples were collected from three areas (Figs. B1-B3) in order to complete a transect across all of the bedrock formations that make up the Dipping Bedrock Overlay District in Douglas County.

Engineering properties included in this table are: natural water content, natural dry density, grain-size distribution, Atterberg limits (liquid limit and plasticity index), soil classification (Unified Soil Classification System), and material description. A list of these tests and the ASTM standard procedures used for testing is shown in Table B1. The test results are shown in Table B2. The data are sorted by location and sample number. The geologic unit is assigned by the authors based on the sample location and field verification. For a detailed technical discussion of the testing procedures and the test results for these data, see Dodson (1996).

Table B1. CGS laboratory tests and ASTM standard procedures.

Laboratory Test[1]	ASTM Procedure[2]
Natural water content	ASTM D 2216-92
Natural dry density	ASTM D 2937-94
Grain size	ASTM D 0422-63
Grain size	ASTM D 0421-85
Atterberg limits	ASTM D 4318-93
Atterberg limits	ASTM D 0421-85
Atterberg limits	ASTM D 2217-85
USCS classification	ASTM D 2487-93

Notes: 1. Test results are presented in Table B2.
2. See Dodson (1996) for a detailed discussion of testing procedures.

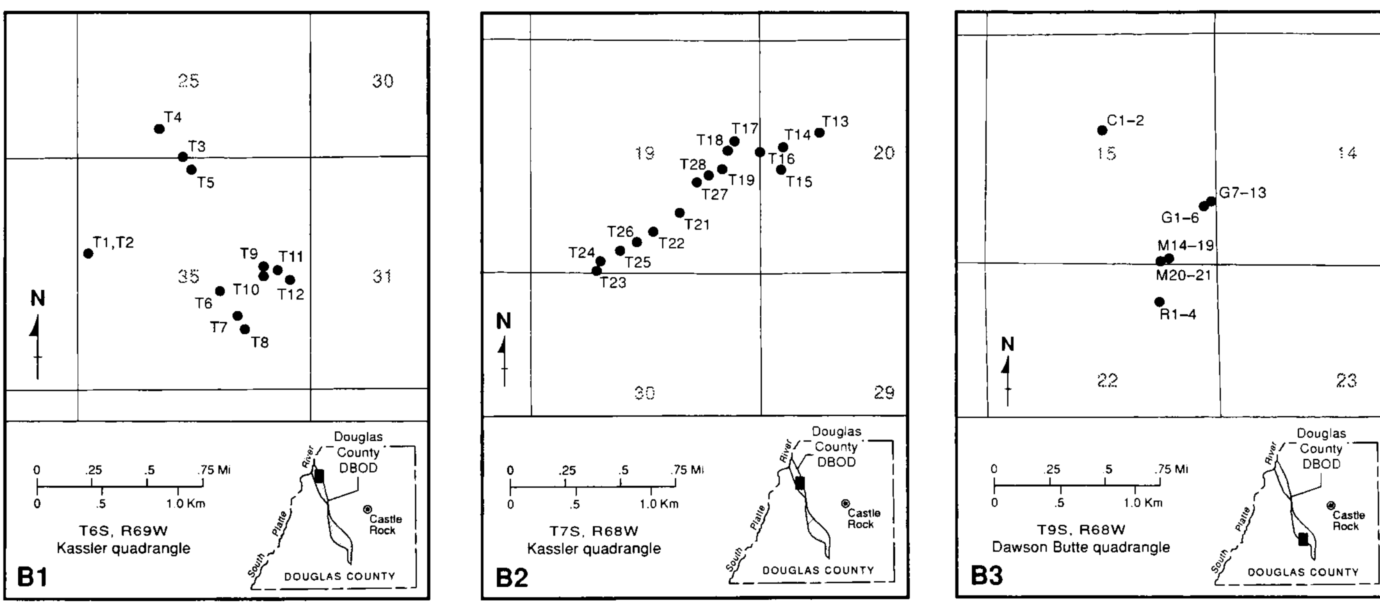


Figure B1.–B3. Maps showing bedrock sample locations in study area.

Table B2. Summary of laboratory test results.

Sample Number	Natural Water Content[1] (%)	Natural Dry Density (pcf)	Grain Size Gravel (%)	Grain Size Sand (%)	Grain Size Fines (%)	Atterberg Limits Liquid Limit (%)	Atterberg Limits Plasticity Index (%)	USCS Classification	Material Description	Geologic Unit[2]
T1 S1	19.0 (21.8)	97							Claystone, plastic, brown	Kpu
T1 S2	19.9					76.8	54.3	CH	Claystone, plastic, brown	Kpu
T2 S1A	16.4 (23.4)	95							Claystone, green-gray	Kpu
T2 S1B	16.7 (16.4)	96							Claystone, green-gray	Kpu
T2 S2	15.0					46.5	29.0	CL	Claystone, green-gray	Kpu
T2 S3	30.8					89.5	43.8	MH	Bentonite, extremely plastic clay, light gray	Kpu
T3 S1	7.9					50.2	33.3	CH–CL	Claystone, light brown	Klu
T3 S2	9.3 (9.8)	106							Claystone, light brown	Klu
T4 S1	9.6 (10.6)	89							Claystone, brown	Klu
T4 S2	17.4					49.5	30.0	CL–CH	Claystone, brown	Klu
T5 S1	11.8 (12.6)	118							Claystone, silty and sandy, yellow-brown	Klu
T5 S2	11.4					56.0	37.4	CH	Claystone, silty and sandy, yellow-brown	Klu
T5 S3	14.4					85.0	68.8	CH	Claystone, plastic, trace of v. fn. sand, grn.-brn.	Klu
T5 S4	8.8					62.5	42.5	CH	Claystone, silty, gray	Klu
T6 S1	28.5 (30.7)	85							Claystone, silty, light brown	Kll
T6 S2	15.7					42.0	19.9	CL	Claystone, silty, light brown	Kll
T7 S1	7.5					24.9	5.3	CL–ML	Claystone, silty and sandy, gray	Kll
T8 S1	11.3					45.7	28.5	CL	Claystone, silty, light yellow-green	Kll
T9 S1	10.6		0.1	97.1	2.8			SP	Sandstone, medium course, white	TKda
T11 S1	8.7		0.9	95.4	3.7			SP	Sandstone, medium course, white	TKda
T12 S1	15.5					75.0	52.0	CH	Claystone, plastic, dark gray	TKda
T12 S2			9.3	88.0	2.7			SW	Sandstone, medium course, with gravel, white	TKda
T13 S1	3.9					32.8	16.2	CL	Claystone, silty, fine sand, light brown	TKda
T13 S2	13.3					46.8	25.9	CL	Claystone, siltstone, gray	TKda
T13 S3	10.0					34.5	15.3	CL	Claystone, siltstone, gray	TKda
T13 S4	12.0					45.2	17.3	ML	Claystone, siltstone, chocolate brown	TKda
T13 S5	8.9					52.8	30.5	CH	Claystone, very plastic, gray	TKda
T13 S6	8.8					29.5	12.2	CL	Claystone, very sandy, gray	TKda
T14 S1	5.9		1.4	97.8	0.8			SP	Sandstone, medium course, light gray	TKda
T14 S2	14.0					55.5	33.9	CH	Claystone, siltstone, gray	TKda
T14 S3	1.2		4.3	92.6	3.1			SP	Sandstone, medium course, white	TKda
T15 S1	14.8 (13.7)	97							Siltstone, clayey, fine sandy, light gray	Kll
T15 S2	9.7					28.0	5.3	ML	Siltstone, clayey, fine sandy, light gray	Kll
T16 S1	14.2 (17.9)	103							Claystone, silty, sandy, gray	Kll
T16 S2	14.2					33.5	16.3	CL	Claystone, silty, sandy, gray	Kll
T17 S1	16.9					50.2	28.6	CH-CL	Claystone, plastic, green-gray	Kpt
T18 S1	14.8 (17.2)	106							Claystone, plastic, green-brown	Kpt
T18 S2	14.8					60.8	42.8	CH	Claystone, plastic, green-brown	Kpt
T19 S1	15.5					47.0	25.8	CL	Claystone, silty, light brown-gray	Kpu
T19 S2	14.7					48.5	28.7	CL-CH	Claystone, plastic, olive green-gray	Kpu
T19 S3	14.7					33.6	12.5	CL	Claystone, silty, light gray	Kpu
T20 S1	12.3					60.0	37.6	CH	Claystone, plastic, olive green-gray	Kpu
T21 S1	14.9					41.9	22.7	CL	Claystone, silty, green-gray	Kph
T22 S1	26.2 (31.3)	85							Claystone, plastic, olive green-gray	Kpl
T22 S2	26.2					81.1	51.3	CH	Claystone, plastic, olive green-gray	Kpl
T23 S1	19.1					40.5	20.9	CL	Claystone, silty, gray	Kcg

Table B2. Continued.

Sample Number	Natural Water Content[1] (%)	Natural Dry Density (pcf)	Grain Size Gravel (%)	Grain Size Sand (%)	Grain Size Fines (%)	Atterberg Limits Liquid Limit (%)	Atterberg Limits Plasticity Index (%)	USCS Classification	Material Description	Geologic Unit[2]
T25 S1	16.3					54.5	31.8	CH	Claystone, some siltstone, light brown	Kns
T25 S2	26.0					50.2	21.7	MH–ML/ CH–CL	Siltstone, clayey, yellow-brown	Kns
T25 S3	16.8					45.2	21.7	CL	Claystone, occasionally silty, light brown	Kns
T25 S4	(27.1)	86							Claystone, occasionally silty, light brown	Kns
T26 S1	19.3 (22.5)	78							Claystone, plastic, olive green-gray	Kpl
T26 S2	19.3					63.5	36.1	CH	Claystone, plastic, olive green-gray	Kpl
T27 S1	17.9 (20.0)	71							Claystone, plastic, olive green-gray, waxy	Kpu
T27 S2	17.9					75.0	43.0	CH	Claystone, plastic, olive green-gray, waxy	Kpu
C S1	20.0					60.5	30.8	CH	Claystone, silty, light brown-gray	Kcg
C S2	12.8					50.2	25.6	CH–CL	Claystone, occ. silty, light yellow-brown	Kcg
G S1	35.7								Bentonite, light. gray, very pure	Kcg
G S2	39.3								Bentonite, light. gray, pure	Kcg
G S3	25.0					73.5	31.9	MH	Silty, clayey, very dark gray	Kcg
G S4	36.6								Bentonite, light. gray, slightly silty	Kcg
G S5	40.4								Bentonite, light. gray, slightly silty	Kcg
G S6	13.6					61.0	25.7	MH	Silty, clayey, occasional sandstone, dk. gray	Kcg
G S7	38.6								Bentonite, light. gray	Kcg
G S8	20.4					51.5	19.0	MH-ML	Claystone, siltstone, dark gray	Kcg
G S9	36.6								Bentonite, light. gray	Kcg
G S10	40.9					100.0	52.0	MH	Bentonite, light gray, extremely plastic clay	Kcg
G S11	20.3					51.6	27.1	CH–CL	Claystone, occ. silty and fine sand, dk. gray	Kcg
G S12	35.8								Bentonite, light. gray	Kcg
G S13	22.4					54.3	27.0	CH	Claystone, occ. silty and sandy, dk. gray	Kcg
M S14	21.1					87.5	56.2	CH	Claystone, plastic, slightly silty, light gray	Jm
M S15	19.3					53.1	30.9	CH	Claystone, plastic, silty, light brown-gray	Jm
M S16	27.5					73.2	44.5	CH	Claystone, siltstone, light green-gray	Jm
M S17	30.8					117.8	71.0	MH–ML	Claystone, plastic, occ. silty, waxy, lt. gray	Jm
M S18	30.3					71.0	34.1	MH	Claystone, plastic, with siltstone, lt. brown-gray	Jm
M S19	38.1					131.5	89.9	CH	Claystone, plastic, occ. silty, lt. gray	Jm
M S20	35.0					79.5	36.9	MH	Claystone, plastic, occ. silty, lt. brown-gray	Jm
M S21	37.0					144.5	114.1	CH	Claystone, plastic, occ. silty, lt. gray	Jm

1. Values in parentheses represent natural water contents determined from natural dry density samples.

2. The following symbols represent geologic units: Jm = Morrison Formation; Kcg = Carlile Shale, Greenhorn Limestone, and Graneros Shale; Kns = Smoky Hill Shale Member of Niobrara Formation; Kpl = lower shale unit of Pierre Shale; Kph = Hygiene Sandstone Member of Pierre Shale; Kpu = upper shale unit of Pierre Shale; Kpt = upper transition zone of Pierre Shale; Kll = lower part of Laramie Formation; Klu = upper part of Laramie Fm. TKda = lower part of Dawson Formation.

APPENDIX C. JEFFERSON COUNTY DIPPING BEDROCK REGULATIONS

Appendix C contains excerpts from the Jefferson County Zoning Resolution, Land Development Regulation, Roadway Design and Construction Manual, and Building Supplement that pertain to development activities conducted within the Jefferson County Designated Dipping Bedrock Area (DDBA). This section is included in order to give Douglas County and other readers an idea of the regulatory language that was created in 1995 to address heaving bedrock hazards.

Excerpts from Jefferson County Zoning Resolution (July 1997 edition)

SECTION 46: DIPPING BEDROCK (D-B) OVERLAY DISTRICT

A. INTENT AND PURPOSE

This district is intended to promote the public health, safety and general welfare of the citizens of Jefferson County; reduce the risk to property, and encourage and regulate prudent land use by the following methods. (orig. 4-11-95)

1. Reduce the impacts to structures of hazards associated with development on dipping claystone bedrock. (orig. 4-11-95)
2. Require nonstructural uses such as agriculture and open space within areas that, given the associated hazards, are not suitable for occupied structures. (orig. 4-11-95)
3. Restrict the uses that are particularly vulnerable to dipping claystone bedrock hazards to alleviate hardship and reduce the demands for public expenditures. (orig. 4-11-95)
4. Require permitted land uses in dipping claystone bedrock areas, including public facilities which serve such uses, to protect property by providing for detailed geologic and engineering investigations and the avoidance of or mitigation of the hazards associated with such land uses. (orig. 4-11-95)
5. Regulate the area in which, or the manner in which, structures may be constructed to prevent damage to property. (orig. 4-11-95)
6. Designate, delineate and describe areas that could be adversely affected by dipping claystone bedrock, and to inform individuals purchasing or developing property of the possible hazards associated with the purchase or development of such property. (orig. 4-11-95)

B. GENERAL PROVISIONS

1. Dipping Bedrock Overlays Other Zone Districts:
   a. The Dipping Bedrock Overlay Zone District shall overlay that portion of any other zone district located in the designated dipping bedrock area. The regulations of this district do not supersede the permitted and special uses set forth in the underlying zone district. The regulations shall be construed as supplementary to the regulations imposed on the same lands by any underlying zone district or other overlay district. When the regulations of this district conflict with any provision of the underlying zone district, the provisions of the Dipping Bedrock Overlay District shall control; other wise, the provisions of any underlying district shall remain in full force and effect. (orig. 4-11-95)
   b. Applicants for rezoning shall demonstrate to the extent practicable that the proposal has been designed in accordance with the "Intent and Purpose" portion of this Section, as set forth above. (orig. 4-11-95)
2. Boundaries:

   The boundaries of the Designated Dipping Bedrock Area shall be as they appear on the official recorded Designated Dipping Bedrock Area Map as adopted by the Board of County Commissioners and kept on file with the Planning and Zoning Department. The boundary lines on the map shall be determined by the scale appearing on the map. Where there is a conflict between the boundary lines illustrated on the map and actual field conditions, or where detailed investigations show that hazardous conditions are not significant throughout the designated area, the conflict shall be settled according to the "Mapping Conflicts," portion of this Section. (orig. 4-11-95)

C. RESTRICTIONS

1. All rezoning applications submitted after the adoption of this Resolution, which propose structures not exempted in the "Permitted Uses and Activities" portion of this Section, and which fall within the Designated Dipping Bedrock Area shall be subject to the following. (orig. 4-11-95)

a. Detailed grading plans shall be submitted which show overburden soil or fill at least ten (10) feet thick beneath the anticipated level of the bottom of the structure foundation(s) and the top of bedrock. For purposes of this Section, the bottom of the structure foundation is defined as the bottom of footing/pad or bottom of grade beam, whichever is applicable. If deep (pier) foundations are proposed, the Zoning Administrator may require review of such plans by the Engineering Advisory Board. (orig. 4-11-95)

or

b. If ten (10) feet of overburden or fill are not proposed, detailed engineering plans shall be submitted to the Engineering Advisory Board. The alternate mitigation plans shall contain the information necessary to determine that potential hazards can be adequately mitigated by other methods. The recommendations of the Engineering Advisory Board shall be for warded to the Planning Commission and/or Board of County Commissioners before any decision on rezoning by each body. (orig. 4-11-95)

c. Review of alternate mitigation methods by the Engineering Advisory Board is not required if the Zoning Administrator determines that all of the following conditions are met. (orig. 4-11-95)

(1) The proposed methods are proven and have become the "standard of practice" by engineers who have substantial knowledge and expertise in the methods used to identify, investigate, mitigate and/or remediate damages due to dipping claystone bedrock. (orig. 4-11-95)

(2) The proposed methods have been previously reviewed by the Engineering Advisory Board and have been approved for similar site conditions. (orig. 4-11-95)

2. The rezoning application shall include geologic and soils/geotechnical reports prepared according to Part III, Sections 10 and 11 of the "Jefferson County Land Development Regulation." (orig. 4-11-95)

3. Foundation plans submitted with building permit applications for structures which fall within the Designated Dipping Bedrock Area, shall comply with the minimum foundation design requirements outlined in the "Jefferson County Building Code." (orig. 4-11-95)

4. Foundation plans for building permits submitted for structural or remedial repairs which fall within the Designated Dipping Bedrock Area, shall be prepared and signed by a professional engineer, specializing in the field of structural engineering, and registered in the State of Colorado. The engineer shall have substantial knowledge and expertise in the methods used to identify, investigate, mitigate, and remediate damages due to dipping claystone bedrock. At the discretion of the Chief Building Official, any such plans may be subject to review by the Engineering Advisory Board and/or the Board of Review. (orig. 4-11-95)

D. ENGINEERING ADVISORY BOARD

The recommendations of the Engineering Advisory Board shall not be binding on the Planning Commission, Board Of County Commissioners, Chief Building Official or the Board of Review. Each official or board may impose any conditions it deems necessary to mitigate the hazard caused by dipping bedrock. The Planning Commission and the Board of County Commissioners may also decide that the recommendations of the Engineering Advisory Board do not conform to, or are not compatible with other land use plans, policies and considerations. (orig. 4-11-95)

E. PERMITTED USES AND ACTIVITIES

The following uses and activities are permitted without the restrictions established by this Section. (orig. 4-11-95)

1. Structures exclusively for livestock. (orig. 4-11-95)
2. Accessory outbuildings and garages. (orig. 4-11-95)
3. All uninhabited structures. (orig. 4-11-95)
4. Additions to buildings where the existing building was constructed or issued a building permit before the adoption of this Section and where the square footage of the addition does not exceed fifty (50) percent of the original building footprint. (orig. 4-11-95)

F. WARNING AND DISCLAIMER OF LIABILITY

The degree of protection from potential hazards from dipping claystone bedrock intended to be provided by this regulation is considered reasonable for regulatory purposes, and is based on accepted geologic and scientific methods of study, as of April 11, 1995, the effective date of this Resolution. This regulation is intended to reduce the risks, costs and impacts from dipping bedrock hazards. Unforeseen or unknown conditions such as climate, ground water, irrigation or drainage may contribute to future damage to structures and land uses though properly permitted within the provisions of the Dipping Bedrock Overlay District. This regulation does not imply that areas outside the Designated Dipping Bedrock Area boundaries or land uses permitted within such areas will be free from the impact of expansive soils and bedrock hazards. (orig. 4-11-95)

G. MAPPING CONFLICTS

In all cases, a person contesting the location of the Designated Dipping Bedrock Area boundary or the severity of conditions at a specific location within the Designated Dipping Bedrock Area shall be given a reasonable opportunity to present their case to the Zoning Administrator and shall submit geotechnical and geologic evidence to support such contests. The Zoning Administrator shall not allow deviations from the boundary line as mapped or non permitted land uses within the boundary areas unless technical and geological evidence clearly and conclusively establish that the map location of the line is incorrect, or that the designated hazard conditions do not present a significant hazard to public health, safety or to property at the specific location within the hazard area boundary for the particular proposed land use. (orig. 4-11-95)

H. REVIEW FEES

All reviews costs for the Engineering Advisory Board shall be borne by the rezoning or building permit applicant. The fees shall be as established by the Board of County Commissioners. (orig. 4-11-95)

Excerpts from Jefferson County Land Development Regulation (July 1997 edition)

PART I—PLAT REQUIREMENTS

SECTION 2.—FEES

2.2. Developer fees to cover other additional costs incurred during the platting procedure shall include the following.

2.2.3. Review fees charged by a State Agency shall be made payable to the reviewing agency, based on current rates and paid at the time of plat application.

2.2.4. If applicable, review fees charged by the Engineering Advisory Board shall be made payable to Jefferson County and shall be paid prior to public hearing. Any such fees shall be in an amount established by the Board of County Commissioners.

SECTION 3.—PROCEDURE

3.2. PRELIMINARY PLAT SUBMITTAL AND REVIEW:

3.2.2. Distribution: Within three (3) working days after acceptance of the plat by the Planning and Zoning Department pursuant to 3.2.1. of this Section, the Planning and Zoning Department shall distribute the plat and appropriate documents to the following agencies, when applicable, as determined by the Planning and Zoning Department.
Colorado Geological Survey [among others].

3.2.3. Agency Response Requirement: Each agency that receives a plat referral shall respond within twenty-one (21) days from the date of mailing by the Planning and Zoning Department or within any period of extension not to exceed an additional thirty (30) days, consented to by the developer and the Planning and Zoning Department. Failure to respond within the prescribed time limit shall be deemed an approval of the plat by such agency.

SECTION 4.—PREPARATION

4.1. PLAT FORMAT REQUIREMENTS: The following plat format requirements shall be complied with by the developer at the time of filing with the Planning and Zoning Department pursuant to Section 3.2 of this Part.

4.1.2.4. Delineation of hazardous areas as identified in the appropriate document reports of Part III.

4.2. DOCUMENT REQUIREMENTS: The following supplemental documents shall accompany the preliminary plat as required by the Planning Engineer at the time of filing with the Planning and Zoning Department pursuant to Section 3.2. of this Part.

4.2.8. Geologic report prepared in accordance with Section 10. of Part III.

SECTION 5.—FINAL PLAT REQUIREMENTS

5.1. FORMAT: All final plats shall be prepared in accordance with the preliminary plat approved or conditionally approved by the Planning Commission, or the Board of County Commissioners if the Planning Commission's decision was success fully appealed, and the following format standards.

5.1.10. Hazardous areas which are to be utilized as building sites require specific abatement measures in accordance with 1.2.5. of Section 1. of Part II. Such areas shall be delineated on the final plat and shown by dashed lines. The specific abatement measures shall be placed in the note section and shall cross-reference and indicate the specific area in which the abatement action shall occur.

5.1.11. A building envelope or nonbuildable area shall be delineated on the final plat for each lot or structure, unless the Planning Director waives such requirement after making a finding that visual impact, geologic hazards, soil erosion, or wildfire hazard potential are nominal. The envelopes shall be fully dimensioned and tied to reference points and be shown by a fine, continuous line. The maximum number of units, the maximum height of the structure and the maximum square footage of the ground floor shall be placed within the envelope or a separatetable of data that cross-references the specific envelope.

5.2. REQUIRED DOCUMENTS: The following supplemental documents shall accompany the final plat as required by the Planning Engineer at the time of filing with the Planning and Zoning Department pursuant to Section 3.3.1 of this Part.

5.2.9. Geologic and geotechnical hazard abatement plans in accordance with Section 10 and Section 11. of Part III.

SECTION 6.—PLAT CERTIFICATES AND NOTES

6.1. GENERAL REQUIREMENTS: The following certificates, acknowledgments and descriptions shall be placed and appropriately signed and sealed on the final plat.

6.1.13. The following plat restriction shall be placed on the first sheet of the final plat where the presence of expansive soils has been identified in site specific soils reports or in publications from the United States Geological Survey or Colorado Geological Survey.

Prior to the issuance of each building permit, a geotechnical engineer, licensed in the State of Colorado and experienced in design and construction of structures on expansive soils, shall certify to the County the following.

1. That a subsurface soils investigation, including a test boring, has been conducted on the specific lot to which the building permit references and that a determination has been made as to the design criteria necessary to assure the safety and structural integrity for all buildings and structures as defined in Section 1 of the Jefferson County Zoning Resolution.
2. That proper subsurface drainage has been designed for the specific lot to which the building permit references and that a determination has been made as to the design criteria necessary to assure the safety and structural integrity for all buildings and structures as defined in Section 1 of the Jefferson County Zoning Resolution.
3. That the plans submitted to Jefferson County Building Department have been reviewed and/or prepared by subject engineer and that he has verified that said plans meet or exceed the criteria set forth in paragraphs (1) and (2) above.

Before the County performs a final inspection pursuant to the County Building Code, an engineer, licensed in the State of Colorado and experienced in the field of design and construction of structures on expansive soils, shall verify and certify that the actual construction of the foundation and subsurface drainage system meets the specification in the plans as submitted in the building permit application.

SECTION 7.—LAND REQUIREMENTS FOR SCHOOLS AND PARKS

7.2. CALCULATION OF LAND DEDICATION REQUIREMENTS: The amount of land area dedication required for park sites and public school sites shall be calculated as follows:

7.2.3.2. Land areas eligible for consideration in the evaluation of the total combined land area dedication for public school and park sites shall be based on the intended purpose of their use and are prioritized as follows.

7.2.3.2.1. Buildable Land Area: Properties located within the Dipping Bedrock Overlay District shall be considered buildable if mitigation measures, as required by the "Jefferson County Zoning Resolution" are properly addressed.

PART II—PLANNING STANDARDS

SECTION 1.—LOTS AND ENVELOPES

1.2. BUILDING ENVELOPE STANDARDS: Each building site, when applicable, shall reflect the following characteristics.

1.2.5. Building envelopes shall not encroach hazardous areas unless the hazards are abated as specified in the appropriate document plans of Part III.

SECTION 6.—UTILITIES

6.5. All proposed subdivisions in which any part is located in the Designated Dipping Bedrock Area shall have subsurface groundwater collection systems.

6.6. All subsurface groundwater collection systems shall meet the following requirements.

6.6.1. Provisions for service line connection stubouts, at each lot boundary, of individual lot foundation drains or sumps to the subsurface groundwater collection system shall be provided.

6.6.2. Water collected from individual lots or central subsurface ground water collections systems shall not discharge directly or indirectly onto a street surface or curb and gutter located within a public right-of-way.

6.6.3. Subsurface groundwater collection lines or systems located within a public right-of-way shall be located in the same trench as the sanitary sewer system.

6.7. Maintenance plans for subsurface groundwater collection systems shall be recorded with the Jefferson County Clerk and Recorder.

SECTION 9.—GEOLOGY

9.1. Building envelopes within lots and, if applicable, within tracts shall be reasonably free from geologic hazards or protected from geologic hazards. To the extent practicable, development of occupied structures in the Designated Dipping Bedrock Area shall be avoided.

9.4. All areas which fall within the Designated Dipping Bedrock Area and contain occupied structures shall be subject to the following.

9.4.1. Overburden or fill shall be at least ten (10) feet thick beneath the anticipated level of the bottom of the structure foundation(s). For purposes of this Section, the bottom of the structure foundation is defined as the bottom of footing/pad or bottom of grade beam, whichever is applicable. If deep (pier) foundations are proposed, the Geologic Coordinator may require review of such plans by the Engineering Advisory Board.

or

9.4.2. If ten (10) feet of overburden or fill are not proposed, detailed engineering plans shall be submitted to the Engineering Advisory Board. The alternate mitigation plans shall contain the information necessary to determine that potential hazards can be adequately mitigated by other methods. The recommendations of the Engineering Advisory Board shall beforwarded to the Planning Commission and/or Board of County Commissioners before any decision by each body.

9.4.3. Review of alternate mitigation methods by the Engineering Advisory Board is not required if the Geologic Coordinator determines that all of the following conditions are met.

9.4.3.1. The proposed methods are proven and have become the "standard of practice" by engineers who have substantial knowledge and expertise in the methods used to identify, investigate, mitigate and/or remediate damages due to dipping claystone bedrock.

9.4.3.2. The proposed methods have been previously reviewed by the Engineering Advisory Board and have been approved for similar site conditions.

SECTION 15.—EASEMENTS

15.4. LOCATION: Easements shall be provided in accordance with the following.

15.2.11. Subsurface groundwater collection system easements shall be provided for main collection lines, clean out ports and daylight points. Any such easement shall afford accessibility to clean out ports and daylight points from public rights-of-way and shall be of sufficient size to facilitate maintenance.

PART III—REQUIREMENTS FOR SUPPORTING DOCUMENTATION

SECTION 6.—UTILITIES

6.3. SUBSURFACE GROUNDWATER COLLECTION SYSTEM PLANS: Subsurface groundwater collection system plans, if required by Section 6. of Part II, shall be submitted. The plans shall include but not be limited to the following.

6.3.1. Subsurface groundwater collection system plans, including designs, maintenance plans, standards and specifications for clean out ports, discharge points, bedding materials, pipe materials and grade.

6.3.2. The entity/entities that will implement the plan, construct the required improvements, and be responsible for the maintenance of the improvements and appropriate easements.

6.4. REPORT AND PLAN PREPARATION:

6.4.1. The utility report(s) and subsurface groundwater collection system report shall be prepared by the developer.

6.4.2. When such plans are not prepared by the serving utility company, the plans shall be prepared and signed by a professional engineer qualified in the field of civil engineering.

SECTION 10.—GEOLOGY

10.1. GEOLOGIC MAP: A map of the area of investigation, to be included with the report and plans below, shall include, if applicable, but not be limited to the following.

10.1.1. The proposed subdivision, including lots, tracts and street/road alignments or the area to be rezoned.

10.1.2. The natural and proposed final topography as shown by contour lines.

10.1.3. Location of borings, pits, trenches, seismic traverses, etc.

10.1.4. Bedrock geology conditions discussed in 10.2. and 10.3. for this Section, including the following where applicable.

10.1.4.1. Test holes, trenches or test pits used in the investigation for this report or in Part III, Section 11—Soils/ Geotechnicial Investigation.

10.1.4.2. Sites of special geologic interest (e.g., fossil beds or unusual mineral formations).

10.1.4.3. Geologic Hazard Overlay Zone.

10.1.5. Surficial geology conditions discussed in 10.2. and 10.3 of this Section.

10.1.6. Groundwater hydrology conditions discussed in 10.2. and 10.3. of this Section.

10.1.7. Mineral resource conditions discussed in 10.2. and 10.3. of this Section.

10.1.8. Formation boundaries and outcrops.

10.1.9. Isopach map showing the thickness and distribution of surficial materials (unconsolidated natural soils and artificial fill).

10.1.10. A contour map of the top of the bedrock surface for areas of the proposed subdivision or rezoning which fall within the Designated Dipping Bedrock Area. For areas which contain claystone, the top of the weathered claystone shall be considered as the top of the bedrock.

10.2. GEOLOGIC REPORT: A report, as required by Section 4. of Part I, shall include, if applicable, the following.

10.2.1.Bedrock Geology:

10.2.1.1. Rock types present, including formation names and ages, if possible.

10.2.1.2. Bedrock characteristics including, but not limited to the following.

10.2.1.2.1. Degree of weathering, including depth of weathering, presence of expansive claystones.

10.2.1.2.2. Erodibility, including the range of normal angles of slopes.

10.2.1.2.3. Aquifer characteristics, including moisture content and permeability.

10.2.1.2.4. Shrink-swell potential, potential differential heave and range of swelling pressures.

10.2.1.2.5. Potential response to seismic activity.

10.2.1.2.6. Radioactivity (naturally occurring and man-made).

10.2.1.2.7. Slope stability in natural and excavated states, including mudflows, rockfall, creep, subsidence, settlement, and slumping.

10.2.1.2.8. Strike and dip of bedding planes, foliation, joints and faults, and the frequency and distribution of any such features.

10.2.1.2.9. Ease of excavation.

10.2.1.2..10. Well and septic system suitability.

10.2.1.2..11. Detailed description of the bedrock surface topography.

10.2.1.3. The following items may be required if any portion of the proposed subdivision or area being rezoned is located in the Designated Dipping Bedrock Area, and the plans do not conform to the provisions of Section 9 of Part II or Section 45 of the "Jefferson County Zoning Resolution," which require ten (10) feet of overburden or fill beneath the foundations of an inhabited structures.

10.2.1.3.1. Trenching or other test methods to determine attitudes of bedding planes, depth to bedrock, detailed bedrock stratigraphy, and to determine the interface between weathered claystone and clay. Where claystone or weathered claystone is present, the evaluation shall include a detailed description of discrete or zones of highly expansive claystone and/or bentonite beds, and including a detailed description of filled or open fractures.

10.2.1.3.2. Cross sections, which show subsurface bedrock relationships including depth to bedrock, dip of beds and detailed stratigraphy of the bedrock may be required. Frequency and distribution of joints and faults should be noted on the cross sections using drawings or written descriptions.

10.2.2. Surficial Geology:

10.2.2.1. Location and description of all surficial materials present, including artificial fill, utilizing unit names and ages, if possible.

10.2.2.2. A discussion of the thickness and distribution of surficial materials.

10.2.2.3. Surficial material characteristics including, but not limited to the following.

10.2.2.3.1. Erodibility.

10.2.2.3.2. Degree of weathering, including types of clay minerals.

10.2.2.3.3. Aquifer characteristics, including permeability and soil moisture.

10.2.2.3.4. Shrink-swell potential and the potential for differential heave.

10.2.2.3.5. Potential response to seismic activity.

10.2.2.3.6. Radioactivity (naturally occurring and man-made).

10.2.2.3.7. Slope stability in natural and excavated states, including mudflows, rockfall, creep, subsidence, settlement, and stumping.

10.2.2.3.8. Ease of excavation.

10.2.2.3.9. Well and septic system suitability.

10.2.2.3.10. Discussion and evaluation of the suitability of structure foundations.

10.2.2.3.11. In the Designated Dipping Bedrock Area, the geologist shall describe and map the general condition and performance of existing roads and structures within the area of investigation. Descriptions shall include degree of driveway, flatwork and road damage and/or repair, and any other evidence of ground deformation or movement such as linear heave trends. Areas of investigation shall include the site plus an outlying adjacent area of at least one-half (1/2) mile from the site boundaries in the direction of regional strike and perpendicular to the strike. The map of the area outside the proposed subdivision or rezoning may be a separate map at a scale of one (1) inch equals one thousand (1,000) feet.

10.2.2.4. A description of the surficial geomorphology.

10.2.2.5. Cross sections which show bedrock/surficial material relationships may be required in order to illustrate the depth to bedrock and any structural features such as faulting.

10.2.3. Hydrology:

10.2.3.1. Depth to groundwater, utilizing isopach map.

10.2.3.2. Perched water tables, including existing conditions and potential post-development perched water table conditions.

10.2.3.3. Expected seasonal variations in groundwater.

10.2.3.4. A description of the possible effects of surface water on structure performance, including the potential for erosion and flooding.

10.2.4. Mineral Resources:

10.2.4.1. Amount and quality of any mineral resources, including, but not limited to sand and gravel, quarry aggregate, coal, limestone, mineral fuels (e.g., oil, gas, uranium), metallic resources (e.g., gold, copper), and nonmetallic resources (e.g., clay).

10.2.4.2. Existing mining site or prospects.

10.3. GEOLOGIC MITIGATION RECOMMENDATIONS: Geologic mitigation recommendations of the area of investigation, as required by Section 5. of Part I, shall assure that geologic factors affecting the planning, design, construction, operation, and maintenance of engineered structures are recognized, adequately interpreted, and presented for use in engineering practice. The recommendations shall include, if applicable, but not be limited to the following.

10.3.1. The geologic processes, constraints, and hazards which will or could affect proposed structures or the intended uses of the site. Recommendations for additional site exploration, testing, development which are necessary to assure adequate performance of mitigation methods.

10.3.2. Methods to mitigate adverse geologic conditions on proposed structures.

10.3.3. Mineral resource recovery, if applicable, in accordance with the County "Mineral Extraction Policy Plan."

10.3.4. The entity/entities that will implement the mitigation recommendations, construct required improvements, and be responsible for the maintenance of the improvements and appropriate easements, if any.

10.4. REPORT AND RECOMMENDATION PREPARATION:

10.4.1. The map, report, and recommendations (excluding plans for engineered structures) shall be prepared and signed by a qualified professional geologist, (as defined C.R.S.34-1-201, 1973, as amended) who has extensive experience in the speciality of engineering geology. If the report area is in the Designated Dipping Bedrock Area, the geologist shall have extensive first hand knowledge of and experience with the geology of eastern Jefferson County. The report should include what time of year the field work was done, and a list of references and other supportive data used.

10.4.2. Plans for engineered structures shall be prepared and signed by a professional engineer, registered in the State of Colorado and qualified in the field of civil engineering.

10.4.3. The maps, plans and reports required in this Section and in Section 11 of Part III may be combined in a single report.

10.5. APPROVALS:

10.5.1. The geologic reports and mitigation recommendations (excluding plans for engineered structures) shall be approved by the Geologic Coordinator prior to plat or rezoning approval. The plans (excluding plans for engineered structures) shall be approved by the County Planning Department Geologic Coordinator prior to plat approval.

10.5.2. Plans for engineered structures shall be approved by the Director of the Department of Highways and Transportation for structures located in public rights-of-way and by the Planning Engineer for all other such structures prior to plat approval.

SECTION 11.—SOILS/GEOTECHNICAL

11.1. SOILS AND BEDROCK MAP: A map of the area of investigation, to be included with the report and plans below, shall include, but not be limited to the following.

11.1.1. The proposed subdivision including lots, tracts, and street/road alignments or the proposed area of rezoning.

11.1.2. The natural topography as shown by contour lines.

11.1.3. Delineation and designation of soil types present.

11.1.4. Natural and artificial soil hazard areas.

11.2. GEOTECHNICAL INVESTIGATION REPORT: All sites shall be investigated to evaluate the potential impacts of adverse soil and bedrock conditions on proposed structures,pavements, drainage structures, and utilities.

11.2.1. Preliminary Geotechnical Investigation: A preliminary geotechnical investigation shall be performed under the direction of a professional engineer, registered in the State of Colorado. For areas within the Designated Dipping Bedrock Area, the professional engineer shall demonstrate substantial knowledge and expertise in methods used to identify, investigate and mitigate damages due to dipping bedrock. The objectives of this investigation shall be to establish the depth to bedrock across the site and to develop recommendations to mitigate the impacts of adverse soils and bedrock conditions and/or the impacts of steeply dipping bedrock on the proposed development. The investigation shall include the following as a minimum.

11.2.1.1. Designated Dipping Bedrock Area: At least one (1) exploratory boring shall be drilled every two hundred-fifty thousand (250,000) square feet to a minimum depth of thirty-five (35) feet, or to twenty-five (25) feet provided bedrock is found.

11.2.1.2. All Other Areas in the Plains: At least one (1) exploratory boring shall be drilled every two hundred-fifty thousand (250,000) square feet to a minimum depth of twenty-five (25) feet.

11.2.1.3. On comparatively small sites (less than five (5) acres) a minimum of four (4) borings is required. Boring locations and elevations shall be accurately located and shown on the soils and bedrock map. All borings shall be sampled at approximately five (5) foot intervals using a modified California sampler (nominal 2.0 inch inside diameter) or similar device to obtain relatively undisturbed samples. If deep cuts (in excess of 15 feet) are anticipated during site grading, the borings in cut areas shall extend at least twenty (20) feet below the anticipated cut. The depth of free groundwater shall be measured in each boring at the time of drilling and at least forty-eight (48) hours after drilling. If rain or snow melt occurs between time of drilling and subsequent measurements, these occurrences shall be noted.

11.2.1.4. For areas within the Designated Dipping Bedrock Overlay Area, if bedrock is not found within fifteen (15) feet of anticipated foundation levels (after site grading), the site or portions of the site may be exempted from further requirements for special investigation requirements, such as increased testing upon approval by the Geologic Coordinator. In order to qualify for this exemption, the geotechnical engineer shall submit findings to the Geologic Coordinator in a letter requesting exemption. The letter shall include a plan showing existing site topography and location of borings, and graphical logs of the borings. If grading plans are available, they shall also be provided. The Geologic Coordinator shall respond to this request in writing within fourteen (14) calendar days. If grading plans are not provided, exemption granted for all or a portion of a site will be subject to review upon review of grading plans by the Geologic Coordinator. The Geologic Coordinator may refer an exemption request to the Colorado Geological Survey for review and comment.

11.2.1.5. Laboratory testing of soil and bedrock shall be conducted to verify field classifications and provide indications of soil and bedrock material properties. Tests shall include the following.

11.2.1.5.1. Moisture content and a dry density profile for all intervals sampled on at least four borings.

11.2.1.5.2. Atterberg Limits and percent passing the No. 200 sieve on representative samples of each clay or claystone strata.

11.2.1.5.3. Percent passing the No. 200 sieve from representative samples of each sand or sandstone strata.

11.2.1.5.4. One dimensional swell-consolidation tests and/or soil suction tests on representative samples of each clay or claystone strata. Swell tests may be performed using a surcharge of 500 psf, 1000 psf, or the anticipated overburden pressure after site grading. Swell tests are not required for non-expansive strata provided other laboratory tests are performed to confirm classification.

11.2.1.5.5. Required test frequency per type of material sample is set forth in the following Table.

REQUIRED TEST FREQUENCY PER TYPE OF MATERIAL SAMPLED

Unified Soil Classification or equivalent classification	Moisture Content ASTM D2216-80	Dry Density	Atterberg Limits ASTM D424-59 D423-66	Passing #200 Sieve ASTM D1140-54	Hydrometer	One Dimensional Swell/ Consolidation or Soil Suction
Sand, clean to silty (SM, SW, SP)	X			X		
Sand, Clayey (SC)	X	X	X	X		X
Clay (ML, CL, MH, CH); or weathered claystone	X	X	X	X	X	X
Sandstone, clean to silty (SM, SW, SP)	X	Where poss.		X		
Sandstone, clayey (SC)	X	X	X	X		
Claystone (ML, CL, MH, CH)	X	X	X	X	X	X

Designated Dipping Bedrock Area—A minimum of two (2) test series per strata sampled for every four (4) borings, except for hydrometer tests which are required at a minimum rate of one (1) test per strata sampled for every four (4) borings.

All Other Areas In the Plains—A minimum of one (1) test series per strata sampled for every four (4) borings and hydrometer tests are not required. However, in areas of highly expansive clays, additional testing may be required.

11.2.1.5.6. For sites where sub-excavation of bedrock and construction of fill is planned, bulk samples of the cut materials shall be obtained, preferably from exploratory test pits excavated with a back hoe. Standard Proctor tests (ASTM D698) shall be performed on each of the materials. Atterberg Limits and percent passing the No. 200 sieve tests shall be performed for each sample. The proposed fill materials shall be tested for swell using samples compacted to 95 to 98 percent of maximum dry density as determined using ASTM D698 at molding moisture contents of approximately two (2) percent below optimum moisture, optimum moisture, two (2) percent above optimum moisture, and 4 percent above optimum moisture. These tests shall be performed using a surcharge of 500 psf or 1000 psf.

11.2.1.6. The geotechnical engineer shall evaluate results of the field and laboratory investigations and provide a report which shall include the following.

11.2.1.6.1. A description of the site including existing vegetation, evidence of previous construction, nearby water sources, and the slope of the existing site.

11.2.1.6.2. A description of the proposed construction, including site grading, anticipated maximum cut and fill depths, the types of structures planned, and any anticipated sources of water such as detention or retention ponds, lakes, and water features.

11.2.1.6.3. Results of field and laboratory investigations and tests. The reports shall include plans of figures showing the following:

11.2.1.6.3.1. The existing site topography; these maps shall be based upon a topographic survey performed by a professional land surveyor.

11.2.1.6.3.2. The surface elevation of the bedrock beneath the site if not already included in the geologic reports required by Section 10 of Part III.

11.2.1.6.3.3. Graphical logs of the exploratory borings. All measurements of moisture content, dry density, Atterberg Limits, percent passing the No. 200 sieve, and measured percent swell of relatively undisturbed samples shall be summarized on the graphical logs.

11.2.1.6.3.4. Results of laboratory tests in graphic or tabular form.

11.2.1.6.4. If applicable, discussion of dipping bedrock on the proposed development and the methods recommended to mitigate these impacts. If sub-excavation of bedrock and replacement by compacted fill is recommended, the recommended compaction and moisture contents for the fill shall be in accordance with Section 1 of Part V.

11.3. GEOTECHNICAL PLANS: Plans of the area of investigation, as requested by Section 5. of Part I, shall assure that soil and bedrock factors affecting the planning, design, construction, operation, and maintenance of proposed subdivision are recognized, adequately interpreted, and presented for use in engineering practice. The plans shall include, if applicable, but not be limited to the following.

11.3.1 Alternative and solutions to abate and/or minimize the adverse soil and bedrock conditions on structures.

11.3.2. The entity/entities that will implement the plan, construct required improvements, and be responsible for the maintenance of the improvements and appropriate easements, if any.

11.4. GEOTECHNICAL INVESTIGATION REPORT AND PLAN PREPARATION:

11.4.1 Any map, report and plans shall be prepared and signed by a qualified professional engineer, registered in the State of Colorado, and qualified in the field of geotechnical engineering. The report should include what time of year the field work was done, and a list of references and other supportive data used.

11.4.2. Plans for engineered structures shall be prepared and signed by a professional engineer, registered in the State of Colorado, and qualified in the field of civil engineering.

11.5. GEOTECHNICAL PLAN APPROVALS:

11.5.1. The plans (excluding plans for engineered structures) shall be approved by the County Geologic Coordinator prior to plat approval.

11.5.2. Plans for engineered structures shall be approved by the Director of the Department of Highways and Transportation for structures located in public right-of-way and the Planning Engineer for all other structures prior to plat approval.

PART IV—DEVELOPMENT AGREEMENTS AND GUARANTEES

SECTION 3.—POST PLAT APPROVAL ENFORCEMENT AND ADMINISTRATION

3.9. WARRANTY OF PUBLIC IMPROVEMENTS:

3.9.1. Warranty Period For Street/Road and Drainage Improvements:

3.9.1.1. Street/Road and Drainage Improvements Located in the Dipping Bedrock Area: The warranty period for street/road and drainage improvements which fall within the Designated Dipping Bedrock Area shall be five (5) years. Where there is ten (10) feet or more of overburden or fill between the top of the claystone bedrock and the bottom of all street/road and drainage improvements, the warranty period may be reduced to three (3) years. If at the end of the first three (3) years of the warranty period, no major repairs have been needed or are currently needed, the applicable public improvements shall be accepted by Jefferson County and the remaining two (2) year warranty period shall be waived. If major repairs have been or are currently needed, the remaining two (2) year warranty period shall not be waived.

3.9.3. Deposited Collateral Guarantee: A deposited collateral guarantee in the form of an irrevocable letter of credit, comple tion performance bond or cash escrow shall be required during warranty and up to two (2) months thereafter to guarantee the cost of repairs. Collateral guarantees with a one (1) year term will be accepted. However, for longer warranty periods, these guarantees will need to be renewed on an annual basis. The amount of the deposited collateral guarantee during the warranty period shall be determined in the following manner.

3.9.3.1. Street/Road and Drainage Improvements Located In the Dipping Bedrock Area:

3.9.3.1.1. One hundred (100) percent of the total cost of the street/road and drainage improvements where there is less than ten (10) feet of fill or overburden between the bottom of the street/road (bottom of base coarse) or drainage improvement and the top of claystone bedrock.

3.9.3.1.2. Fifty (50) percent of the total cost of the street/road and drainage improvements where there is ten (10) or more feet of overburden or fill between the top of the claystone bedrock and the bottom of the street/road or drainage improvement for the first three (3) years and, if applicable, twenty-five (25) percent for the last two (2) years.

PART V—CONSTRUCTION SPECIFICATIONS

SECTION 1.—EXCAVATION AND GRADING

[Section 1 is not included in this appendix; however, this section contains nine pages of specifications for excavation and grading. These specifications are applicable to operations such as those used to create overexcavations in dipping bedrock areas.]

SECTION 4.—WATER SUPPLY

4.2. CENTRAL WATER SYSTEM STANDARDS FOR SUBDIVISIONS LOCATED IN THE DESIGNATED DIPPING BEDROCK AREA: In addition to the other provisions of this Section, subdivisions which are located in the Designated Dipping Bedrock Area and have central water systems located within public rights-of-way, and the applicable water provider is not a contract distributor of the Denver Water Board, shall construct central water systems in accordance with the following standards.

4.2.1. Continuous gravel bedding shall be provided beneath the entire main service system.

4.2.2. All subdivisions where any portion of the site is located in the Designated Dipping Bedrock Area and any portion of the water system is located within four (4) feet of the top of claystone bedrock shall be subject to the following additional restrictions.

4.2.2.1. Water mains shall be constructed using Class 50 ductile iron pipe, or Class 150 or Class 200 AWWA C-900 polyvinyl chloride (PVC) pipe or pipe material of equivalent or better strength characteristics.

4.2.2.2. Bedding material and trench standards shall be as shown on (JEFFERSON COUNTY) FIGURE 8.

SECTION 5.—WASTEWATER COLLECTION

5.2. CENTRAL WASTEWATER COLLECTION SYSTEM STANDARDS FOR SUBDIVISIONS LOCATED IN THE DESIGNATED DIPPING BEDROCK AREA: In addition to the other provisions of this Section, subdivisions for which any part(s) are located in the Designated Dipping Bedrock Area and have central sewage systems located within public rights-of-way shall construct central sewage disposal systems in accordance with the following standards.

5.2.1. All segments of gravel bedding shall have positive drainage, including segments dammed by manhole bases, or the gravel bedding shall be continuous beneath manhole bases. The gravel bedding shall discharge at daylights points approved by the Director of the Department of Highways and Transportation and the applicable sanitation district.

5.2.2. All subdivisions where any portion of the site is located in the Designated Dipping Bedrock Area and any portion of the central sewage system is located within four (4) feet of the top of claystone bedrock shall be subject to the following additional restrictions.

5.2.2.1. Sanitary sewer pipelines (main and service lines) shall be constructed using AWWA C-900 Class 200 polyvinyl chloride (PVC) materials or pipe materials of equivalent or better strength characteristics.

5.2.2.2. PVC water pipe fittings shall be used to make connections between the main and service lines.

5.2.2.3.Bedding material and trench standards shall be as shown on (JEFFERSON COUNTY) FIGURE 9 or 10, whichever is applicable.

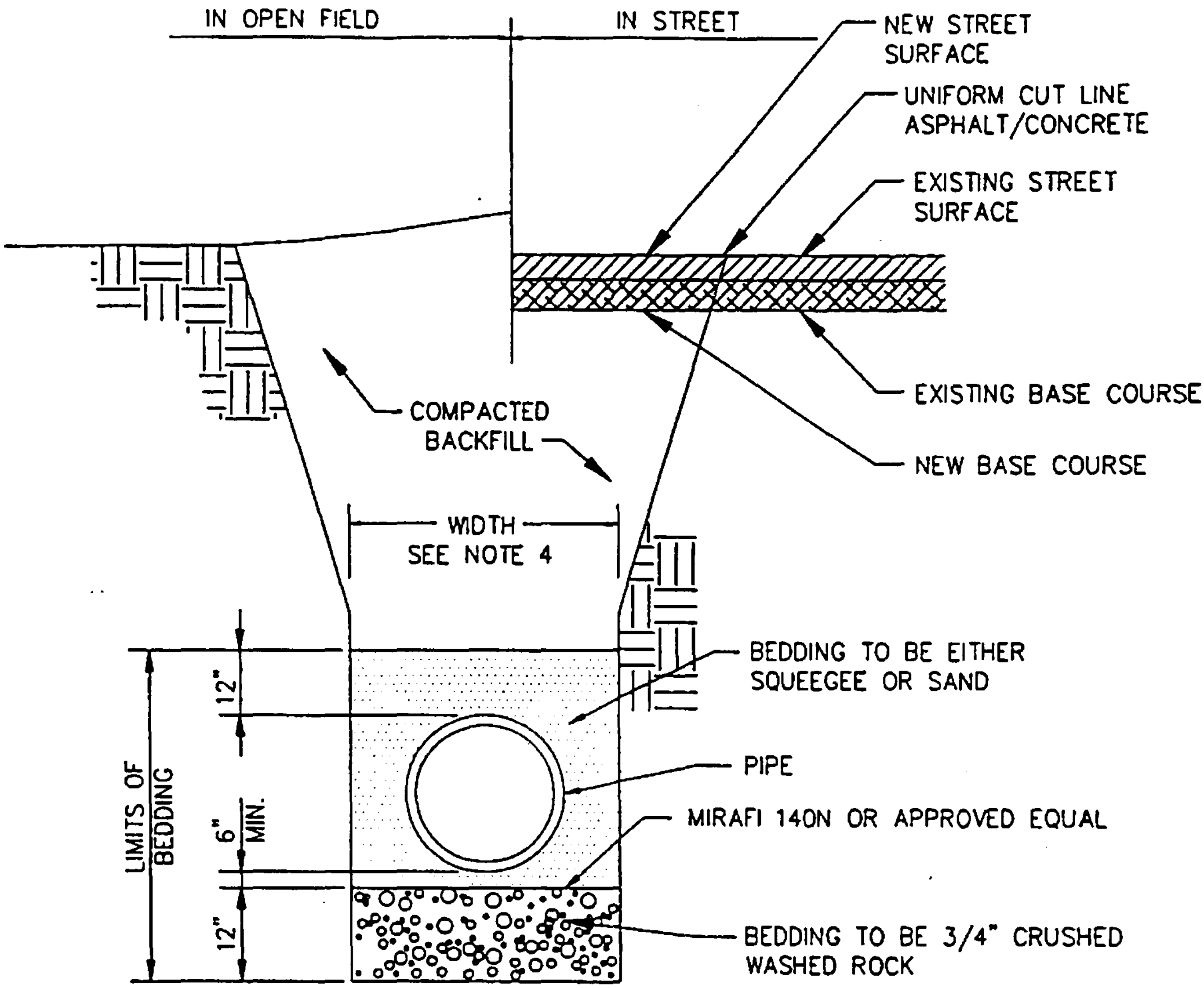
SECTION 6.—UTILITIES

6.2. SUBSURFACE GROUNDWATER COLLECTION SYSTEM STANDARDS: Construction shall be in accordance with the following.

6.2.6. All subdivisions, where any portion of the site is located in the Dipping Bedrock Area and any portion of the collection system is located within four (4) feet of the top of claystone bedrock, shall be subject to the following additional restrictions.

6.2.6.1 Pipe materials shall be constructed of solid wall AWWA C-900 Class 200 polyvinyl chloride (PVC) or pipe material of equivalent or better strength characteristics. Perforated pipe may be used for main collection lines, if approved by the applicable sanitation district. Perforated pipe may also pled be used for the service line from the lot boundary to the structure.

6.2.6.2. The main collection lines shall be installed in accordance with (JEFFERSON COUNTY) FIGURE 9.

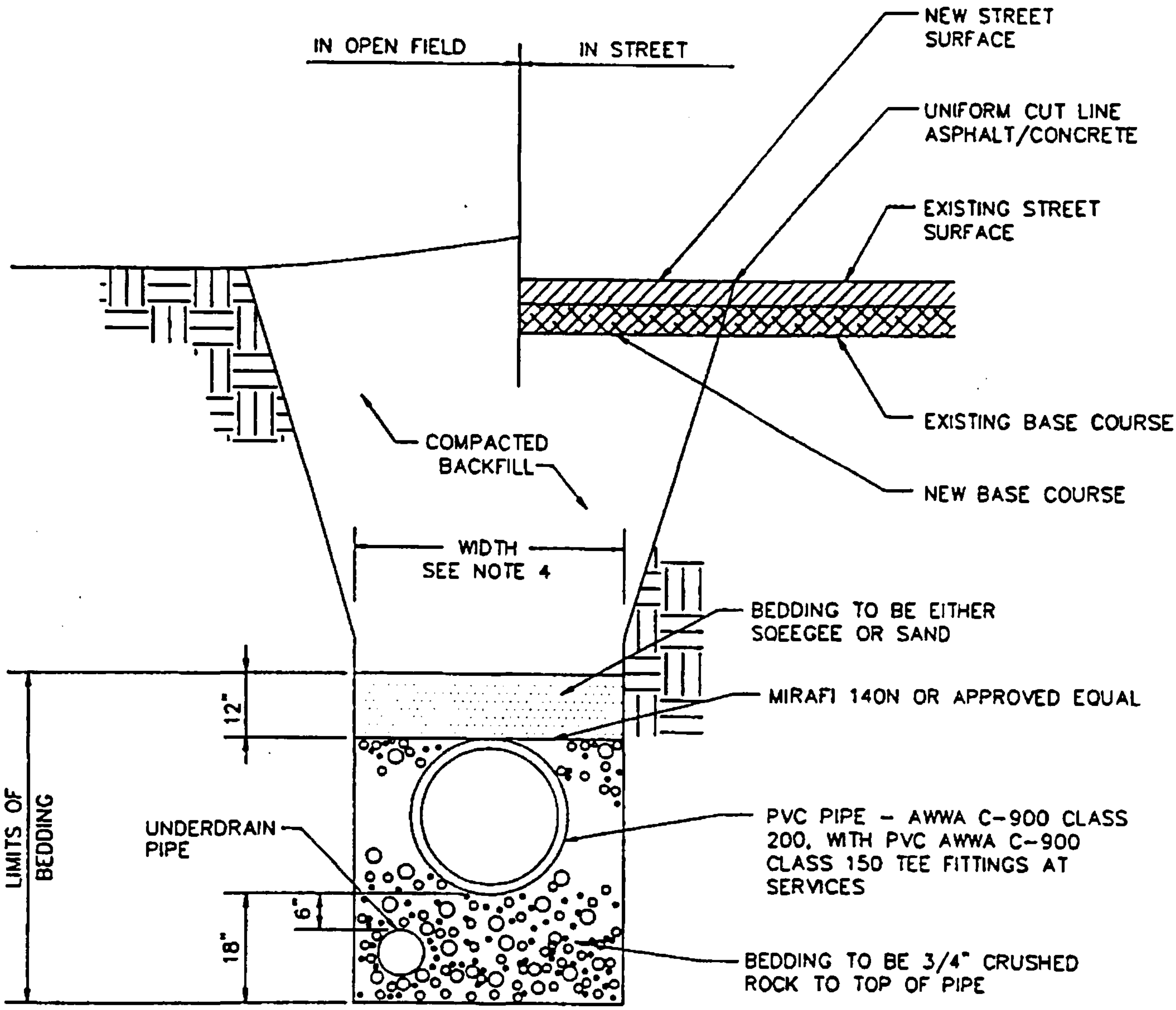


TYPICAL TRENCH SECTION

NOTES:

1. Minimum cover to be 4.5' below official street grade.
2. Trench to be braced or sheeted as necessary for the safety of the workman and protection of other utilities in accordance with applicable local, state and federal safety regulations.
3. Pipe shall be bedded from 18" below the bottom of the pipe to 12" above the top of the pipe
4. Trench width shall not be more than 16" nor less than 12" wider than the largest outside diameter of the pipe.
5. Compaction shall be as follows: Pipe zone bedding 18" under and 12" over pipe will require 90% S.P.D. or 70% relative. Trench Zone above bedding materials, full trench section in roadway or street R.O.W. limits will require 95% S.P.D. Trench zone above bedding materials, outside of street R.O.W. will require 90% S.P.D.
6. Tapping saddles required in areas where this bedding section is used.

Jefferson County Figure 8. Water line.

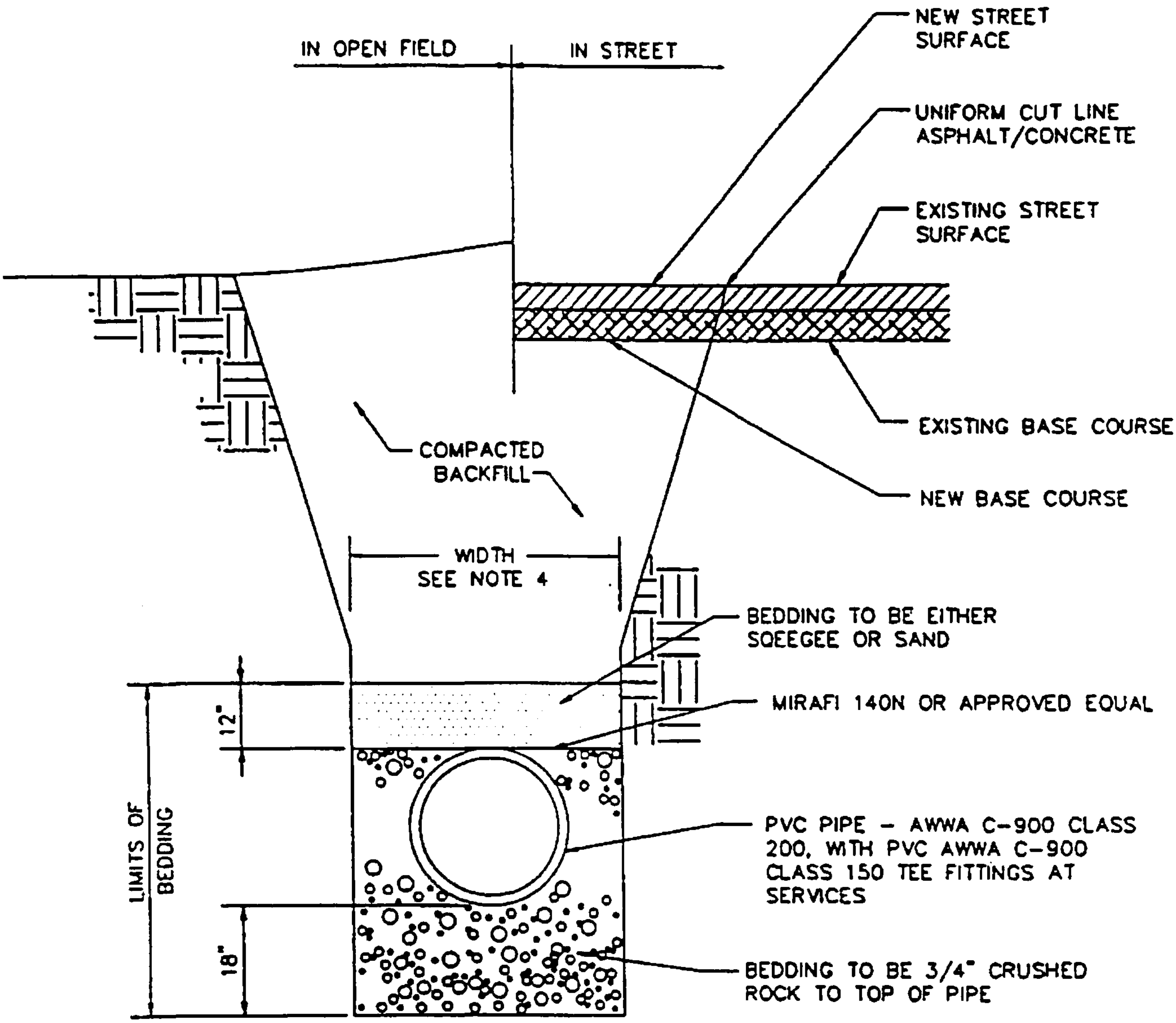


TYPICAL TRENCH SECTION

NOTES:

1. Minimum cover to be 4.5' below official street grade.
2. Trench to be braced or sheeted as necessary for the safety of the workman and protection of other utilities in accordance with applicable local, state and federal safety regulations.
3. Pipe shall be bedded from 18" below the bottom of the pipe to 12" above the top of the pipe.
4. Trench width shall not be more than 16" nor less than 12" wider than the largest outside diameter of the pipe.
5. Compaction shall be as follows: Pipe zone bedding 18" under and 12" over pipe will require 90% S.P.D. or 70% relative. Trench zone above bedding materials, full trench section in roadway or street R.O.W. limits will require 95% S.P.D. Trench zone above bedding materials, outside of street R.O.W. will require 90% S.P.D.

Jefferson County Figure 9. Sanitary sewer with underdrain.



TYPICAL TRENCH SECTION

NOTES:

1. Minimum cover to be 4.5' below official street grade.
2. Trench to be braced or sheeted as necessary for the safety of the workman and protection of other utilities in accordance with applicable local, state and federal safety regulations.
3. Pipe shall be bedded from 18" below the bottom of the pipe to 12" above the top of the pipe.
4. Trench width shall not be more than 16" nor less than 12" wider than the largest outside diameter of the pipe.
5. Compaction shall be as follows: Pipe zone bedding 18" under and 12" over pipe will require 90% S.P.D. or 70% relative. Trench zone above bedding materials, full trench section in roadway or street R.O.W. limits will require 95% S.P.D. Trench zone above bedding materials, outside of street R.O.W. will require 90% S.P.D.

Jefferson County Figure 10. Sanitary sewer without underdrain.

PART VI—DEFINITIONS

C.R.S.: Colorado Revised Statutes.

DIP OF SURFACE: The angle that a stratum or similar geological feature makes with a horizontal plane. (Slope of ground).

ENGINEER: A person possessing specialized knowledge in the applicable area, registered as a professional engineer in the State of Colorado pursuant to Title 12, Article 25, C.R.S., as amended.

GEOLOGIST: A person possessing specialized knowledge in the applicable area, meeting the definition of professional geologist pursuant to Section 34-1-201, C.R.S. as amended.

NATURAL HAZARD AREAS: Geologic Hazard: A geological phenomenon which is so adverse to past, current or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property. This includes, but is not limited to, landslide, rockfall, slope failure complex, mudflow and creep.

REMEDIATION: The action or measures taken, or to be taken, to lessen, clean-up, remove or mitigate the existence of hazardous materials existing on the property to such standards, specifications or requirements as may be established or required by federal, state or county statute, rule or regulation.

Excerpts from Jefferson County Roadway Design and Construction Manual (May 1995 edition)

CHAPTER 4—PAVEMENT DESIGN AND TECHNICAL CRITERIA

4.4—PAVEMENT DESIGN CRITERIA

4.4.3. Minimum Pavement Section.

Expansive soil subgrades shall be subexcavated and replaced with moisture conditioned fill. Minimum subexcavation require ments are listed below in Table 4.4a.

Table 4.4a. Minimum subexcavation requirement for expansive soils.

	Depth of Treatment	
Plasticity Index	Locals/Collectors	Arterials
15–20	1 foot	2 feet
20–30	2 feet	3 feet
30–40	3 feet	4 feet

NOTE: Road segments with isolated soil types may be designed separately for that individual segment.

Soil with (PI) over 40 shall be removed and wasted to a depth of five feet for any type of street.

Subexcavation in the Dipping Bedrock Overlay District, when bedrock is within 5 feet of the surface, shall be a minimum of five (5) feet.

The subexcavation areas shall be recompacted to 95% of maximum standard proctor density (ASTM D-698) at 0 to +4% above optimum moisture content, with a minimum of 12" of soil stabilization below the pavement section to be included as part of the depth of treatment.

NOTE: Subexcavation below the stabilization section may be waived by the Department of Highways and Transportation in areas where overexcavation and grading have been validated.

Excerpts from Jefferson County Supplement to the 1994 Uniform Building Code (May 1995 edition)

SECTION 1804.4.1 DESIGNATED DIPPING BEDROCK AREA

Piers:

Minimum pier length of 25 feet when bedrock is shallower than 19 feet below surface grade. For piers designed for support in bedrock, minimum 6 foot penetration into bedrock is required.

Minimum pier diameter of 10 inches.

Minimum 1.5% steel area (grade 60)

= 1.18 square inches on 10 inch diameter pier

= (2) # 7 grade 60 bars in 10 inch diameter pier.

Pier steel should extend into top row of wall steel.

Foundation Walls:

Designed for minimum 50 p.c.f. equivalent fluid pressure when house penetrates bedrock or when soils adjacent to base ment swell greater than 4% at 1000 pound surcharge or 5% at 500 pound surcharge. Higher minimum equivalent fluid pressures should be used if geotechnical report indicates.

Structural basement floor required if bedrock is encountered within 6 feet of basement floor or when soils within 6 feet swell greater than 4% at 1000 pound surcharge or 5% at 500 pound surcharge. Adjustable teleposts must be used at intermediate structural floor support.

No wall shall be greater than 25 feet in length without counterfort or buttress.

Minimum 6 inch foundation voids should be used when bedrock is encountered within 6 feet of basement or when soils with in 6 feet of basement swell greater than 4% at 1000 pound surcharge or 5% at 500 pound surcharge.

Drainage and Grading:

A foundation drain and sump pit shall be installed on all homes. If the sump pit is the sole discharge system used, an opera tional pump must be installed with adequate surface discharge or discharge into positive sloped pipe to an underdrain. If the sump pit us used as a backup to an underdrain connection, a pump is not required.

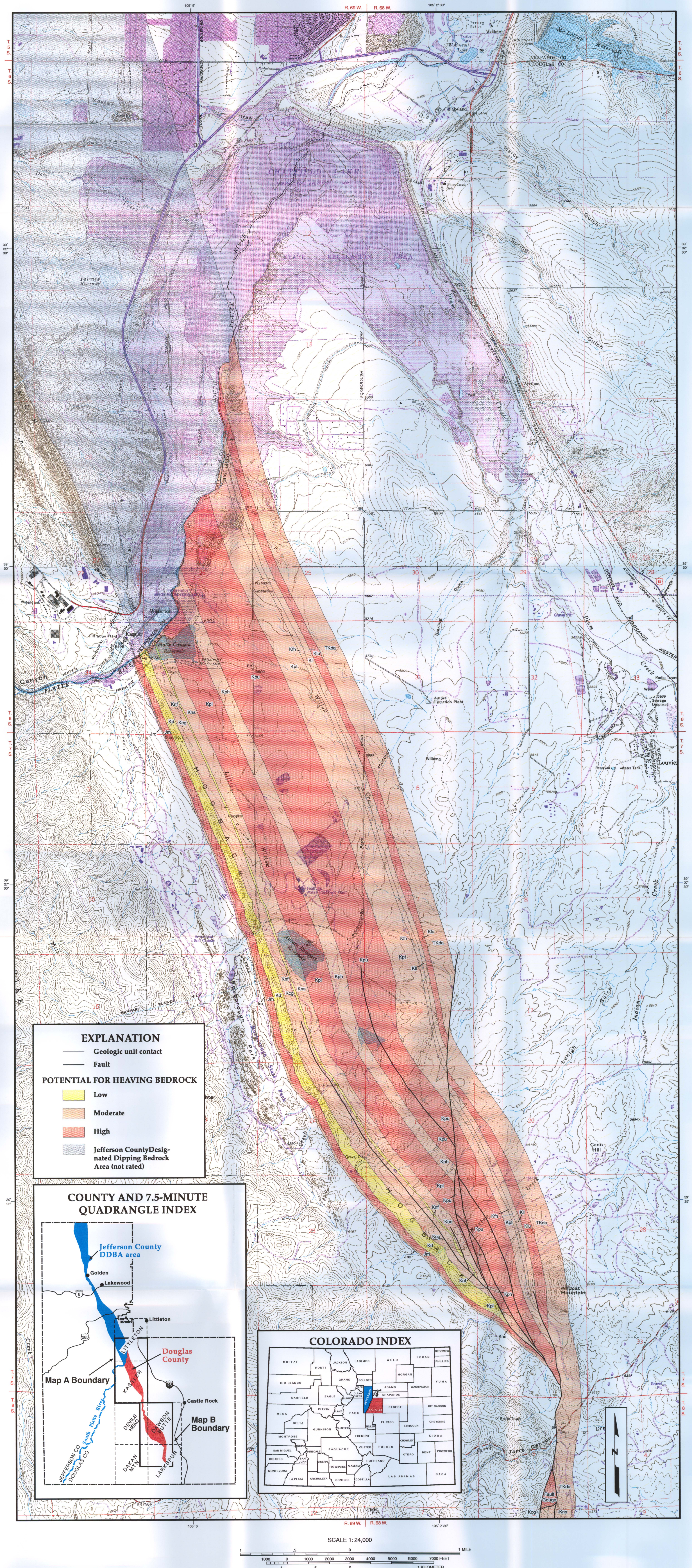
Foundation drains shall have a minimum 1% fall with the low point at the discharge connection.

COLORADO GEOLOGICAL SURVEY
VICKI J. COWART, DIRECTOR
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

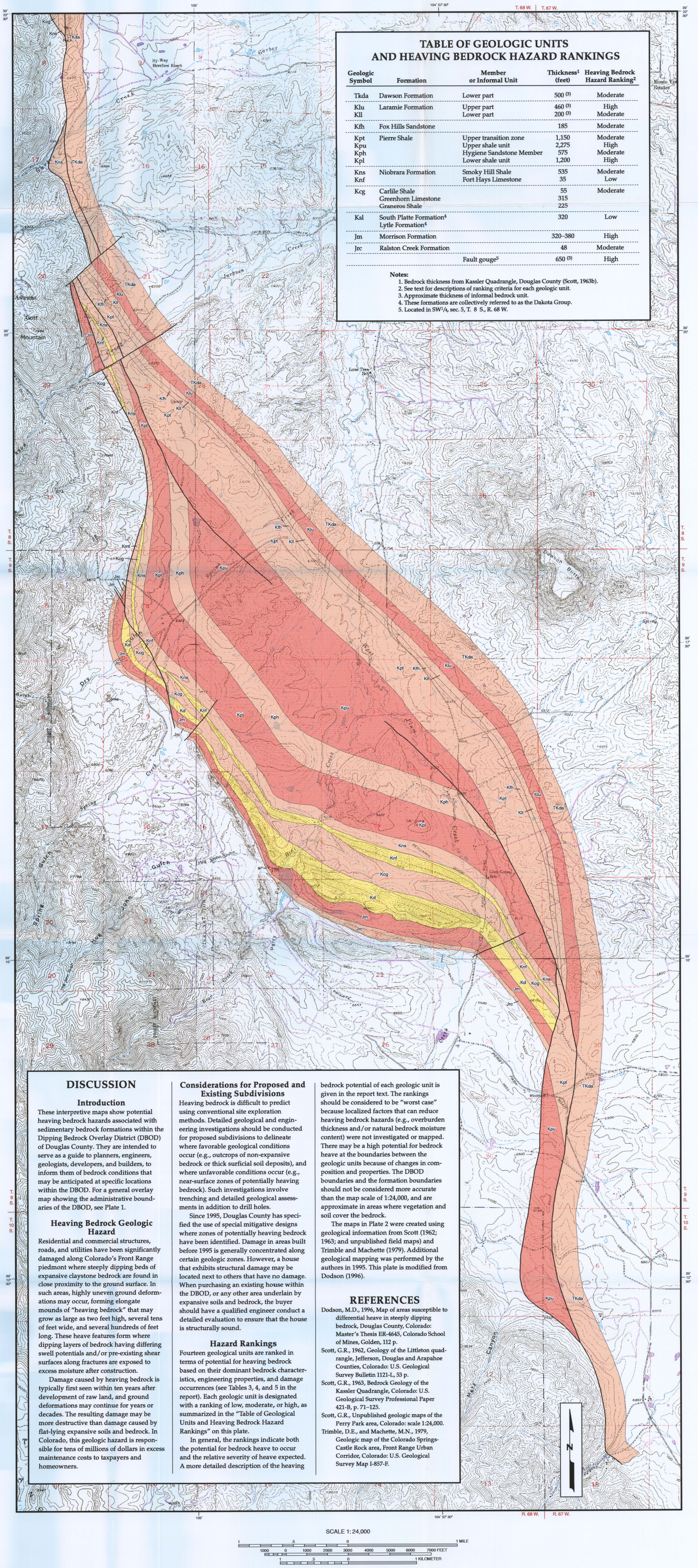
HEAVING BEDROCK HAZARDS MAP, DOUGLAS COUNTY, COLORADO

By David C. Noe and Marilyn D. Dodson

SPECIAL PUBLICATION 42
PLATE 2
1999



Map A. Roxborough Park Area



Map B. Perry Park Area

TABLE OF GEOLOGIC UNITS AND HEAVING BEDROCK HAZARD RANKINGS

Geologic Symbol	Formation	Member or Informal Unit	Thickness[1] (feet)	Heaving Bedrock Hazard Ranking[2]
Tkda	Dawson Formation	Lower part	500 (3)	Moderate
Klu	Laramie Formation	Upper part	460 (3)	High
Kll		Lower part	200 (3)	Moderate
Kfh	Fox Hills Sandstone		185	Moderate
Kpt	Pierre Shale	Upper transition zone	1,150	Moderate
Kpu		Upper shale unit	2,275	High
Kph		Hygiene Sandstone Member	575	Moderate
Kpl		Lower shale unit	1,200	High
Kns	Niobrara Formation	Smoky Hill Shale	535	Moderate
Knf		Fort Hays Limestone	35	Low
Kcg	Carlile Shale		55	Moderate
	Greenhorn Limestone		315	
	Graneros Shale		225	
Ksl	South Platte Formation[4]		320	Low
	Lytle Formation[4]			
Jm	Morrison Formation		320–380	High
Jrc	Ralston Creek Formation		48	Moderate
		Fault gouge[5]	650 (3)	High

Notes:
1. Bedrock thickness from Kassler Quadrangle, Douglas County (Scott, 1963b).
2. See text for descriptions of ranking criteria for each geologic unit.
3. Approximate thickness of informal bedrock unit.
4. These formations are collectively referred to as the Dakota Group.
5. Located in SW1/4, sec. 5, T. 8 S., R. 68 W.

DISCUSSION

Introduction

These interpretive maps show potential heaving bedrock hazards associated with sedimentary bedrock formations within the Dipping Bedrock Overlay District (DBOD) of Douglas County. They are intended to serve as a guide to planners, engineers, geologists, developers, and builders, to inform them of bedrock conditions that may be anticipated at specific locations within the DBOD. For a general overlay map showing the administrative boundaries of the DBOD, see Plate 1.

Heaving Bedrock Geologic Hazard

Residential and commercial structures, roads, and utilities have been significantly damaged along Colorado's Front Range piedmont where steeply dipping beds of expansive claystone bedrock are found in close proximity to the ground surface. In such areas, highly uneven ground deformations may occur, forming elongate mounds of "heaving bedrock" that may grow as large as two feet high, several tens of feet wide, and several hundreds of feet long. These heave features form where dipping layers of bedrock having differing swell potentials and/or pre-existing shear surfaces along fractures are exposed to excess moisture after construction.

Damage caused by 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 may be more destructive than damage caused by flat-lying expansive soils and bedrock. In Colorado, this geologic hazard is responsible for tens of millions of dollars in excess maintenance costs to taxpayers and homeowners.

Considerations for Proposed and Existing Subdivisions

Heaving bedrock is difficult to predict using conventional site exploration methods. Detailed geological and engineering investigations should be conducted for proposed subdivisions to delineate where favorable geological conditions occur (e.g., outcrops of non-expansive bedrock or thick surficial soil deposits), and where unfavorable conditions occur (e.g., near-surface zones of potentially heaving bedrock). Such investigations involve trenching and detailed geological assessments in addition to drill holes.

Since 1995, Douglas County has specified the use of special mitigative designs where zones of potentially heaving bedrock have been identified. Damage in areas built before 1995 is generally concentrated along certain geologic zones. However, a house that exhibits structural damage may be located next to others that have no damage. When purchasing an existing house within the DBOD, or any other area underlain by expansive soils and bedrock, the buyer should have a qualified engineer conduct a detailed evaluation to ensure that the house is structurally sound.

Hazard Rankings

Fourteen geological units are ranked in terms of potential for heaving bedrock based on their dominant bedrock characteristics, engineering properties, and damage occurrences (see Tables 3, 4, and 5 in the report). Each geologic unit is designated with a ranking of low, moderate, or high, as summarized in the "Table of Geological Units and Heaving Bedrock Hazard Rankings" on this plate.

In general, the rankings indicate both the potential for bedrock heave to occur and the relative severity of heave expected. A more detailed description of the heaving bedrock potential of each geologic unit is given in the report text. The rankings should be considered to be "worst case" because localized factors that can reduce heaving bedrock hazards (e.g., overburden thickness and/or natural bedrock moisture content) were not investigated or mapped. There may be a high potential for bedrock heave at the boundaries between the geologic units because of changes in composition and properties. The DBOD boundaries and the formation boundaries should not be considered more accurate than the map scale of 1:24,000, and are approximate in areas where vegetation and soil cover the bedrock.

The maps in Plate 2 were created using geological information from Scott (1962; 1963; and unpublished field maps) and Trimble and Machette (1979). Additional geological mapping was performed by the authors in 1995. This plate is modified from Dodson (1996).

REFERENCES

Dodson, M.D., 1996, Map of areas susceptible to differential heave in steeply dipping bedrock, Douglas County, Colorado: Master's Thesis ER-4645, Colorado School of Mines, Golden, 112 p.

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

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Trimble, D.E., and Machette, M.N., 1979, Geologic map of the Colorado Springs-Castle Rock area, Front Range Urban Corridor, Colorado: U.S. Geological Survey Map I-857-F.

COLORADO GEOLOGICAL SURVEY
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DIPPING BEDROCK OVERLAY DISTRICT (DBOD) MAP, DOUGLAS COUNTY, COLORADO

By David C. Noe and Marilyn D. Dodson

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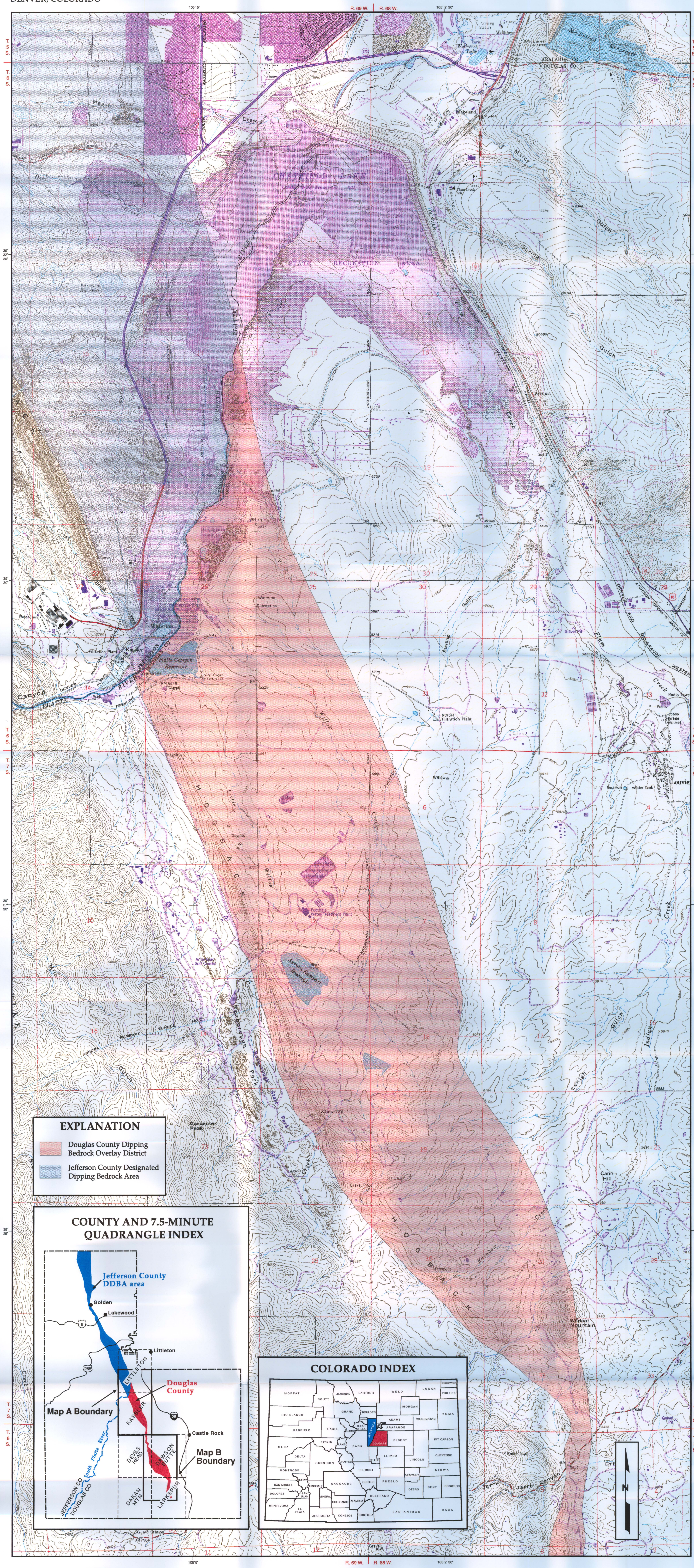
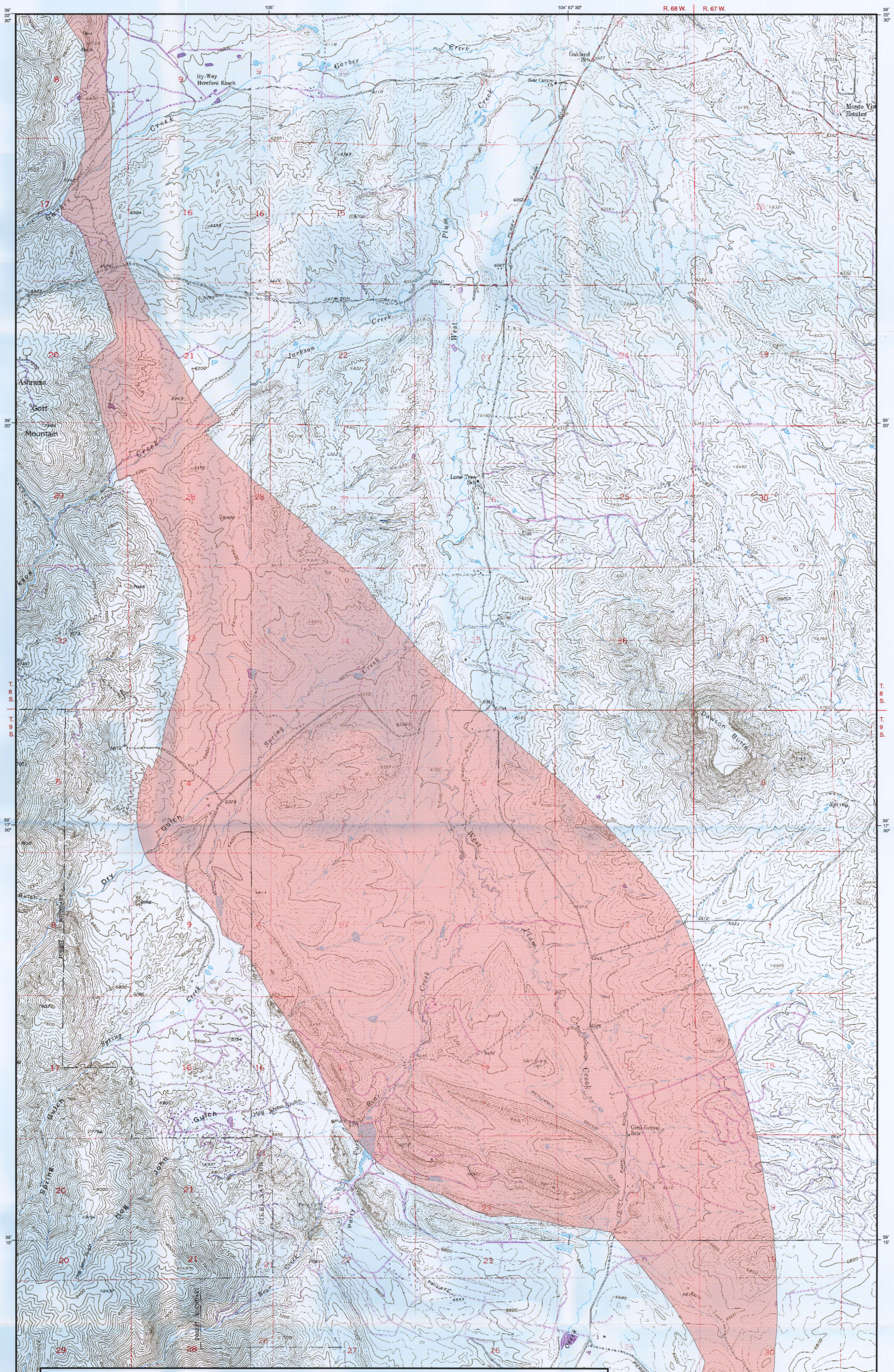
PLATE 1
1999



Map A. Roxborough Park Area



DISCUSSION

Introduction

The Dipping Bedrock Overlay District (DBOD) is an area of Douglas County where heaving bedrock hazards may exist 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 individual homeowners, homeowner's associations, utility districts, and the County within this area. The maps in Plate 1 are intended for use as an administrative tool by Douglas County for land-use planning purposes. For maps showing interpretive heaving bedrock hazard rankings for formations within the overlay area, see Plate 2.

Heaving Bedrock Geologic Hazard

Residential and commercial structures, roads, and utilities have been significantly damaged along Colorado's Front Range piedmont in areas where steeply dipping beds of expansive claystone bedrock are found in close proximity to the ground surface. In such areas, highly uneven ground deformations may occur, forming elongate mounds of "heaving bedrock" that may grow as large as two feet high, several tens of feet wide, and several hundreds of feet long. These heave features form where dipping layers of bedrock having differing swell potentials and/or pre-existing shear surfaces along fractures are exposed to excess moisture after construction.

Damage caused by heaving bedrock is typically first seen within 10 years after development of raw land, and ground deformations may continue for years or decades. The resulting damage may be more destructive than damage caused by flat-lying expansive soils and bedrock. In Colorado, 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

Heaving bedrock is difficult to predict using conventional site exploration methods. Detailed geological and engineering investigations should be conducted for proposed subdivisions to delineate where favorable geological conditions occur (e.g., outcrops of non-expansive bedrock or thick surficial soil deposits), and where unfavorable conditions occur (e.g., near-surface zones of potentially heaving bedrock). Such investigations involve trenching and detailed geological assessments in addition to drill holes.

Since 1995, Douglas County has specified the use of special mitigative designs where zones of potentially heaving bedrock have been identified. Damage in areas built before 1995 is generally concentrated along certain geologic zones. However, a house that exhibits structural damage may be located next to others that have no damage. When purchasing an existing house within the DBOD, or any other area underlain by expansive soils and bedrock, the buyer should have a qualified engineer conduct a detailed evaluation to ensure that the house is structurally sound.

Geology and Boundaries

The DBOD is underlain by sedimentary formations of Jurassic and Cretaceous age: the Ralston Creek Formation, Morrison Formation, Dakota Group, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, Laramie Formation, and the lower part of the Dawson Formation. The western boundary is mapped at the base of the Ralston Creek Formation or, where this contact is missing due to faulting, the trace of the Jarre Creek and Rampart Range Faults. The eastern boundary corresponds to the 30-degree dip axis separating moderately to steeply dipping bedrock within the DBOD from more gently dipping bedrock to the east.

Actual heaving bedrock hazards may vary considerably within the DBOD overlay area. The maps in Plate 1 do not show areas of surficial soil deposits that may cover and significantly reduce the heaving potential of the bedrock, nor do they delineate the areal distribution of formations that have high, moderate, or low heave potentials. The DBOD boundaries should not be considered more accurate than the map scale of 1:24,000, and are approximate in areas where vegetation and soil cover the bedrock.

The maps in Plate 1 were created using geological information from Scott (1962; 1963; and unpublished field maps) and Trimble and Machette (1979). Additional geological mapping was performed by the authors in 1995. This plate is modified from, and is intended to replace the 1:50,000 scale map plate shown in Noe and Dodson (1995).

REFERENCES

Noe, D.C., and Dodson, M.D., 1995, The Dipping Bedrock Overlay District—an area of potential heaving bedrock hazards associated with expansive, steeply dipping bedrock in Douglas County, Colorado: Colorado Geological Survey Open-File Report 95-5, 32 p., 1 map, scale 1:50,000.

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SCALE 1:24,000

Map B. Perry Park Area