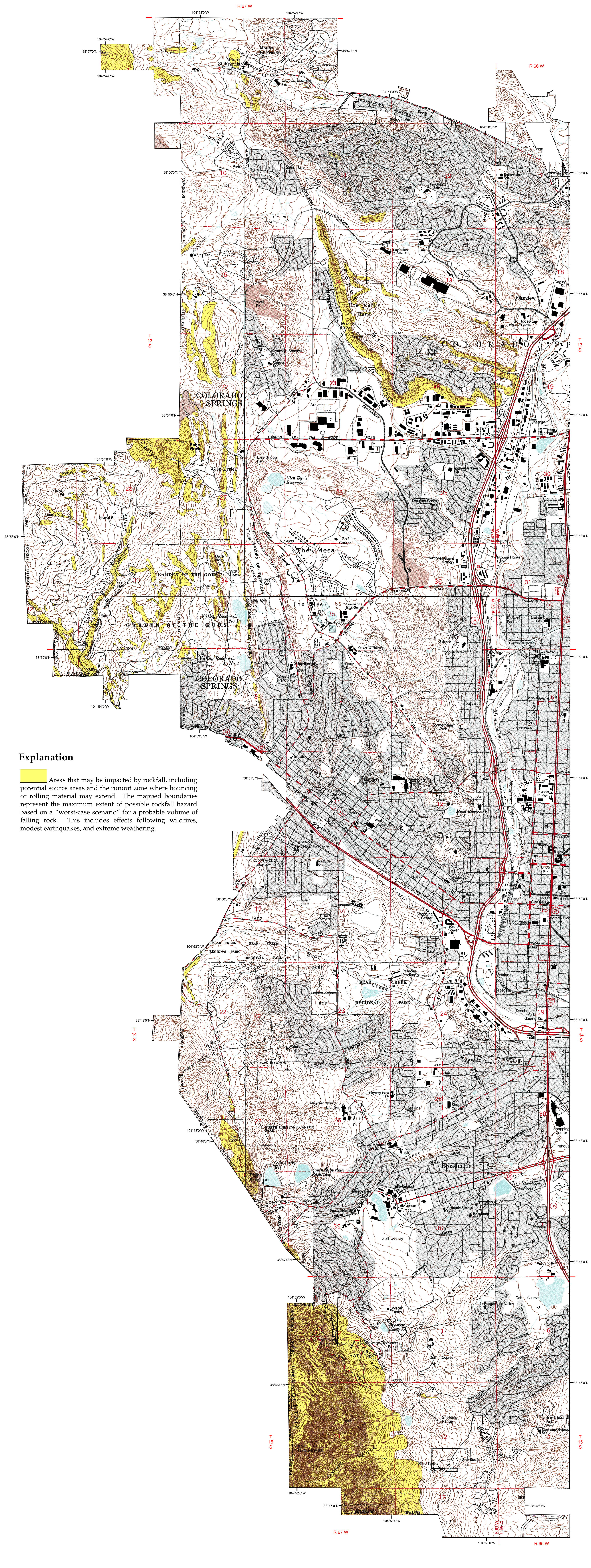
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

ROCKFALL HAZARD SUSCEPTIBILITY IN COLORADO SPRINGS, EL PASO COUNTY, COLORADO

By TC Wait and Jonathan L. White

2006

OPEN-FILE REPORT 06-3
ROCKFALL HAZARD SUSCEPTIBILITY IN COLORADO SPRINGS,
EL PASO COUNTY, COLORADO
Plate 1 of 2
2006



Explanation

Areas that may be impacted by rockfall, including potential source areas and the runout zone where bouncing or rolling material may extend. The mapped boundaries represent the maximum extent of possible rockfall hazard based on a "worst-case scenario" for a probable volume of falling rock. This includes effects following wildfires, modest earthquakes, and extreme weathering.

The Colorado Geological Survey (CGS) was contracted by the City of Colorado Springs (City) to develop Geographical Information System (GIS) coverage of potential rockfall hazard areas in 2003. The scope of the project was to map potentially hazardous rockfall areas within the city limits of Colorado Springs and provide these mapped zones in digital GIS format to the City. This publication includes a map of the GIS data and a description explaining the hazard, mapping methodology, and implications to development in the area. The project was funded by the City and CGS.

Overview

Rockfall, a type of landslide, is common near cliffs of massive broken, faulted, or jointed bedrock, or where steep bedrock ledges are undercut by natural processes or development. The rockfall hazard in Colorado Springs is relatively straightforward. It occurs in steep topographic areas where rock outcrops or eroding rocky soil are exposed. Because the steep slopes are more difficult to develop, most of the areas with potential rockfall hazards have been avoided; however, as growth continues, there are some areas that have been (and are being) developed within potential rockfall hazard areas, which includes both the site of the rock failure, called the source area, and the slope below, called the runout zone.

Background

For the purposes of this project, the term "rockfall" includes modes of ground failure where weathering and gravity cause rock blocks to fall, topple, or roll down a steep slope. Depending on the quality of the rock at the source area, frequency and magnitude of rockfall can vary. A rockfall event can involve a single rock or large volumes of broken material, more properly called a rock slide.

The source areas of rockfall are hard rock formations and to a lesser extent rocky surficial deposits (soil). These materials are generally more resistant to weathering and, over geologic time and by differential erosion and removal of adjacent softer rock and soil, become landforms characterized by topographic highs such as ridges and mesas. Generally, rockfall occurs from these outcrops of more resistant rock onto the slopes below.

Resistant rocks in the Colorado Springs area include Precambrian igneous and metamorphic rocks along the mountain front, the Manitou Limestone and Leadville Limestone, the Fountain Formation sandstones and conglomerates, Lyons Sandstone, Dakota Sandstone, Niobrara limestone, Fox Hills Sandstone, and sandstones in the Laramie and Dawson Formations.

Rockfall occurrences are difficult to predict, and can range from a single rock falling or rolling to large-scale catastrophic events. The size of the falling rock depends on the source area geology (bedding thickness, bedding dip and dip direction, hardness, jointing/fracturing orientation), weathering, and position. Factors for triggering rockfall can include precipitation (water lubricates and hydraulically lifts rock joints and fractures, weakens them, and causes them to slip and/or separate), temperature extremes ("ice jacking" forces rocks apart during freeze/thaw cycles), decomposition of rock through chemical weathering, seismic activity (earthquake shaking, blasting), differential weathering and undercutting (natural or human-caused), or adverse loading (snow loads, animals, home locations, etc.) that can loosen or overturn an unstable rock.

Rockfall events are extremely rapid and can demolish structures and injure or kill people. Rocks falling on highways may strike vehicles causing accidents, block traffic, or damage highway infrastructure. However, most areas susceptible to rockfall can be identified and steps can be taken to avoid, and reduce risk by mitigating rockfall hazard.

Previous Rockfall Hazard Mapping

In 1974, passage of House Bill 1041 (C.R.S. § 24-65.1-101 through 204) provided funding to map geologic hazards; the resulting maps are commonly called "HB 1041" maps. Rockfall hazards in Colorado Springs were mapped; however, the maps concentrated on identification of rockfall source areas and did not fully identify downslope runout areas that may be subject to the impacts of rolling, bouncing, or sliding rock fragments.

Additionally, the HB 1041 maps (Cochran, 1977a-e) were mapped at a scale of 1:24,000 or 1 inch= 2,000 feet. The mapping scale made it difficult to identify historic rockfall events, and fully evaluate potential hazards. Current high-resolution aerial photography, digital elevation models (DEMs), and other digital data allow improved susceptibility mapping in a GIS framework at a scale more appropriate for community planning.

Geologic quadrangle mapping data from the CGS Statemap Program (Carroll and Crawford, 2000; Thorson and others, 2001; Madole and Thorson, 2002; Keller and others, 2004; Morgan and others, 2004), as well as geologic mapping done by CGS for the Cheyenne Mountain State Park area (Wait and White, unpublished) were also used for this project.

Methodology

In order to map the potential rockfall hazard boundaries, existing data, including 2-foot contour data, aerial photographs, and digital geologic data, were compiled using ArcMap GIS version 8. These initial data were used during the field-checking process and adjusted as field observations were made to more accurately reflect the observed rockfall potential.

The Colorado Rockfall Simulation Program (CRSP) version 4.0 (Jones and others, 2000) was also used on a limited basis to model rockfall for comparison to field evidence of rockfall run-out zones. Project funding did not allow for extensive CRSP use but two topographic cross-sections were chosen to run CRSP modeling profiles: an area in the vicinity of the Cheyenne Mountain Zoo and one on the western side of Pope's bluff. The CRSP modeling was useful in identifying areas that could be impacted by various rockfall events and subsequent downhill bouncing and rolling, allowing for a better determination of runout boundaries.

During the field investigation, areas that had been identified as potentially having geologic and topographic conditions that might produce a rockfall event were visited. Observations made regarding the extent of the runout area, size of the blocks that could fall, and topographic features that could affect rockfall were used to refine the mapped boundaries.

The mapped boundaries include potential source areas and the runout area where bouncing or rolling material may extend. The mapped boundaries represent the maximum extent of possible rockfall hazard based on a "worst-case scenario" for a probable volume of falling rock. This includes the effects following wild fires, modest earthquakes, and extreme weathering. Effects from large-volume "catastrophic" events such as large earthquakes and catastrophic rock failures from the flank of Cheyenne Mountain were not included in this map.

Mapping Results

The rockfall susceptibility data was developed at a mapping scale of 1 inch = 800 feet (1:9,600) to discern rockfall areas identified during this study.

In this study, five general types of rockfall areas were identified within the City of Colorado Springs:

STEEP SLOPES AND FRACTURED OUTCROP AREAS IN PRECAMBRIAN ROCKS ALONG THE MOUNTAIN FRONT. These areas include the Peregrine/Dry Creek area, Old Stage Road area, Cheyenne Canyon, and Cheyenne Mountain. Typically the landforms here are large cliffy outcrops of rocks, steep chutes, and talus slopes (rocky colluvial soil derived from rockfall). The rockfall that occurs in these mountain front areas is often from the more-resistant granitic rock outcrops.

Areas where resistant, highly fractured Precambrian outcrops are located above steep slopes (>60% grade) can produce rockfall wherein rocks may bounce or roll a long distance. Most rockfall in such areas is produced by the rock mass failing along prominent joints or fractures by the mechanisms that were listed earlier. A minority of rockfall can be caused from weathering and undercutting, or sloughing of rocks in chutes or partially embedded in colluvial soil. The falling rocks tend to break up into talus slopes below the source outcrops, but can also bounce erratically and launch onto flatter adjacent terrain. In some areas, tree-covered slopes are currently acting as rockfall barriers, however, should this forest cover burn, rollout zones may extend further down the slopes.

Some areas in the Precambrian mountain front are not as prone to rockfall, based on the rock mass characteristics. Highly weathered granites (grus) tend to decompose, ravel and erode like soils instead of producing rockfall.

STEEPLY DIPPING SEDIMENTARY BEDROCK. This includes areas around the Garden of the Gods, Glen Eyrie, Cedar Heights, Black Canyon, Mt. St. Francis, Peregrine/Dry Creek, and Bear Creek. Rockfall occurs in these areas when sedimentary rock layers (such as the Fountain, Niobrara, and Dakota Formations and resistant beds in the Morrison, Laramie, and Lyons Formations) are more resistant to weathering and create steep spines and ridges of rock. Toppling and sliding failure along joints and discontinuities predominates in these areas. Most of the potential hazard zones occur along the back slope (typically western slope) of the hogbacks and terminates at the base of the slope or where there are valleys, drainages, or road cuts. Areas potentially impacted by rockfall can occur on either side of a resistant ridgeline, especially if the beds are overturned or near vertical, such as in the Garden of the Gods area.

RESISTANT, GENTLY TO MODERATELY DIPPING, SEDIMENTARY BEDROCK. Sandstones and conglomerates in the Dawson and Laramie Formations and moderately dipping bedrock of the Manitou Springs and Fountain Formations may also be susceptible to rockfall. The Dawson and Laramie Formations can be found under the majority of the northern and eastern portions of Colorado Springs. Resistant conglomerate layers that form cliffy areas with rockfall potential occur at Popes Bluff, Pulpit Rock, Austin Bluffs, Palmer Park, Payton Circle, and along portions of Jimmy Camp Creek. Moderately dipping Manitou Limestone and Fountain Formation underlie the foothills of west-central Colorado Springs. The beds here generally dip moderately to the northeast and east, making the exposed rock outcrops on the western and southern sides more prone to rockfall. Canyon walls and road cuts in these formations can also produce falling rock. Rockfall sources are found in the cliffs around Manitou Springs (outside of the study area), Cedar Heights, and in Queens Canyon. In both gently and moderately dipping sedimentary rocks, failure occurs when differential weathering or stream erosion accelerates erosion of underlying weaker beds and undercuts the resistant layers. Undercut rock blocks on the leading edge of the bluff, ridge, or canyon outcrop may begin to slump and tilt away from the rock face. Rockfall results when these blocks ultimately separate along pre-existing joints and fractures and topple from the rock face .

EROSIONAL REMNANTS AND HOODOOS. This type of rockfall is mostly found in the Woodman Valley and Palmer Park areas. Differential erosion and sporadic resistant lenses lead to the creation of pillar-like hoodoos, or erosional remnants, which can topple to produce localized rockfall hazards. These types of rockfall areas are difficult to map due to their localized nature and isolated lithology. Rocks that fall generally do not roll beyond the base of the outcrop if the surrounding terrain is relatively flat.

Base map compiled from USGS 7.5 minute topographic quadrangle maps:
Cascade, Cheyenne Mountain, Colorado Springs, Manitou Springs, Pikeview

SCALE 1:24,000

1 0.5 0 1 Miles

4,000 2,000 0 4,000 Feet

1 0.5 0 1 Kilometers

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

OTHER ROCKFALL TYPES. Potential rockfall areas related to downcutting streams and the associated loosening and falling of individual rocks incorporated in rocky pediment deposits were observed during the field investigation. These areas include younger drainage ways and stream banks (including Jimmy Camp Creek) and areas where steep slopes are exposed in older pediment gravel deposits (especially the Verdos Alluvium). Many of these steep cut slopes are man-made excavations. Generally these areas produce a local risk of rockfall, but may be difficult to map, because of the variable occurence of boulder and cobble-sized rocks within the pediment deposit. Ongoing erosion in these areas may contribute to isolated and site-specific potential for rockfall that is not shown on this map.

Development Considerations and Mitigation

Human activities can create rockfall hazards or cause rocks to fall sooner than they would naturally. Vibration from trains or blasting can trigger rockfall, as can development-related changes in surface and ground water conditions.

Excavations, such as road cuts, often remove support for overlying or overhanging rock and create rockfall risks. Talus (loose rock fragments) on steep slopes is often the result of numerous small rockfall events. Talus, by definition, is at the angle of repose and potentially unstable if disturbed. Excavations on talus slopes can increase rockfall risks by destabilzing over-steepened cutslopes above and below. These can be common and dangerous areas for rockfall events.

Hazard avoidance is by far the simplest, most effective, and least costly mitigation strategy. However, other forms of mitigation can reduce, but not eliminate, rockfall risk. Rockfall mitigation falls into two major catagories:

- Rock Stabilization at the Source Area
  - Stabilization of rocks by removal of unstable rocks (scaling), rock bolting, or installation of buttress walls
- Rockfall Prevention Systems
  - Rock fences, screens, berms or ditches to slow or divert moving rocks
  - Impact barriers or covered galleries placed around vulnerable structures and facilities
  - Strategic home design - locating heavily occupied living spaces away from potential impact direction

All these measures are expensive, require regular maintenance, and do not eliminate the risk of rockfall. For example, complete removal of all potentially unstable rocks is often not possible; berms, ditches, and fences fill with fallen rock; concrete barriers and galleries deteriorate, from weathering and rock impact damage and require replacement.

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

Map Usage and Limitations

The map area includes the extent of the Colorado Springs city limits (as of 2002) and was mapped on a 1 inch = 800 feet (1:9,600) scale. Inclusion of properties within the mapped boundaries does not imply that rockfall events will impact that particular property at any given time - only that the property has a higher risk compared to areas not included in the mapped area, based on the geologic and topographic conditions. Conversely, areas that are not identified in the rockfall boundaries could be exposed to potential rockfall occurrences if adverse blasting, grading, excavation, or wildfire occurs. Isolated areas of localized rockfall hazard potential outside of the mapped boundaries may include the areas surrounding smaller hoodoos and erosional remnants, as well as ongoing excavation and grading activities within the city limits.

This study does not consider or include the potential of very large, catastrophic failures of mountainside rock outcrops that could result in a large volume rock avalanche, as described by Hill (1974) and mapped by Scott and Wobus (1973). Such failures may be related to severe earthquake shaking. Detailed investigations of the rock mass structure and the evaluation and integrity of large-scale mountainside rock exposures were beyond the scope of this study.

The potential rockfall hazard areas shown on this map were constructed qualitatively using the available geologic, topographic, and field evidence. No levels of risk assessment were made within the mapped boundaries, which include not only source areas, but also down-slope run-out zones. Appropriate geologic and geotechnical studies should be conducted to determine what mitigation, if any, should occur, and appropriate disclosure should be made to prospective property buyers.

A qualified engineering geologist should further evaluate the areas that are identified on this map during any additional development, renovations, ground alterations, road alignments, and residential resale. These investigations should include consideration of the geologic conditions present within the site, and also how the proposed development might impact other properties in the vicinity. Mitigative measures may need to be implemented to reduce the risk from potential rockfall events.

References

Carroll, C.J. and Crawford, T.A., 2000, Geologic map of the Colorado Springs Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report 00-3, scale 1:24,000.

Cochran, D.M., 1977a, Map of potential geologic hazards and surficial deposits, Cascade Quadrangle, El Paso County, Colorado: Charles S. Robinson & Associates, Inc., scale 1:24,000.

_______, 1977b, Map of potential geologic hazards and surficial deposits, Cheyenne Mountain Quadrangle, El Paso County, Colorado: Charles S. Robinson & Associates, Inc., scale 1:24,000.

_______, 1977c, Map of potential geologic hazards and surficial deposits, Colorado Springs Quadrangle, El Paso County, Colorado: Charles S. Robinson & Associates, Inc., scale 1:24,000.

_______, 1977d, Map of potential geologic hazards and surficial deposits, Manitou Springs Quadrangle, El Paso County, Colorado: Charles S. Robinson & Associates, Inc., scale 1:24,000.

_______, 1977e, Map of potential geologic hazards and surficial deposits, Pikeview Quadrangle, El Paso County, Colorado: Charles S. Robinson & Associates, Inc., scale 1:24,000.

Hill, J.J., 1974, Environmental resource study for Teller and El Paso Counties, Colorado, Part B: Geology, Pikes Peak Area Council of Governments, 73 p. (authors note: The original Hill study includes various map plates that were missing from the text that was available for this study)

Jones, C.L., Higgins, J.D., and Andrew, R.D., 2000, Colorado Rockfall Simulation Program, version 4.0: Colorado Geological Survey Miscellaneous Investigations MI-66, 127 p., CD-ROM.

Keller, J.W., Morgan, M.L., Siddoway, C.S., Route, E.E., Grizzell, M.T., Scerdoti, R., and Stevenson, A., 2004, Geologic map of the Manitou Springs Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report 03-19, scale 1:24,000.

Morgan, M.L., Rowley, P.D., Siddoway, C.S., Temple, J., Keller, J.W., Archuleta, B.H., and Himmelreich, J.W. Jr., 2004, Geologic map of the Cascade Quadrangle, El Paso County, Colorado: Colorado Geological Survey, Open-File Report 03-18, scale 1:24,000.

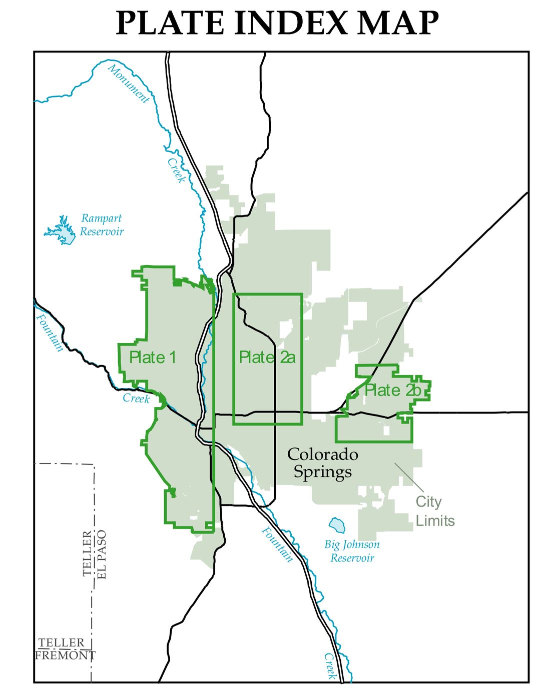
Rowley, P.D., Himmelreich, J.W. Jr., Kupfer, D.H., and Siddoway, C.S., in publication, Geologic map of the Cheyenne Mountain Quadrangle, El Paso County, Colorado: Colorado Geological Survey, scale 1:24,000.

Scott, G.R. and Wobus, R.A., 1973, Reconnaissance geologic map of Colorado Springs and vicinity, Colorado: United States Geological Survey MF-482, scale 1:62,500.

Thorson, J.P., Carroll, C.J. and Morgan, M.L., 2001, Geologic map of the Pikeview Quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 01-3, scale 1:24,000.

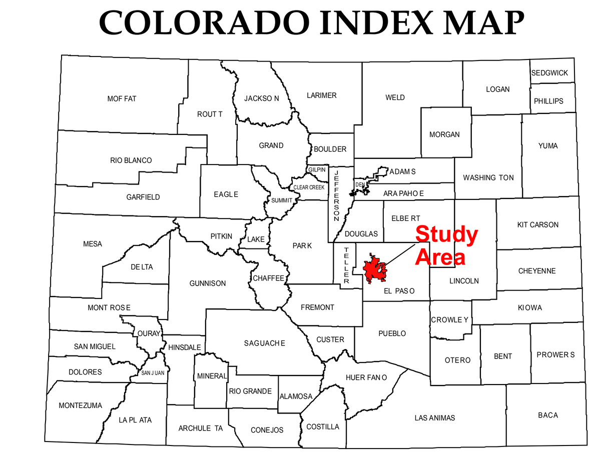
Wait, T.C. and White, J.L., unpublished, Geology and geologic map of the Cheyenne Mountain State Park, El Paso County, Colorado: Colorado Geological Survey unpublished map and report prepared for Colorado State Parks, scale 1:6,000.

PLATE INDEX MAP



NOTE: Only areas within the Colorado Springs city limits that have rockfall hazard susceptibility are shown on these plates. Rockfall areas adjacent to, but outside of, Colorado Springs city limits were not mapped.

COLORADO INDEX MAP



COLORADO DEPARTMENT OF NATURAL RESOURCES

COLORADO GEOLOGICAL SURVEY

Bill Owens, Governor,
State of Colorado

Russell George, Executive Director,
Department of Natural Resources

Vincent Matthews,
State Geologist and Division Director,
Colorado Geological Survey