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Collapsible Soils and Evaporite Karst Hazards Map of the Roaring Fork River Corridor, Garfield, Eagle, and Pitkin Counties, Colorado

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MAP SERIES 34
PLATE 1 OF 1
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DISCUSSION

INTRODUCTION

The Lower Roaring Fork River Corridor between Glenwood Springs and Basalt (herein referred to as the Corridor) comprises a broad river valley eroded into Mesozoic to upper Paleozoic sedimentary and Tertiary basalt formations. Sequences of alluvial terraces, underlain by Pleistocene glacial outwash, are well preserved in this corridor. The floors, terraces, and walls of the valley and its tributaries, and the surrounding low hills, are variably mantled with Holocene to late Pleistocene deposits derived from alluvial/debris fan, sheet wash, gravity, and wind-blown depositional environments. These surficial deposits can pose potentially significant hazards from collapsible soils, also known as hydrocompactive or hydrocompressible soils. Large parts of the corridor are underlain by the Eagle Valley Evaporite. Ground subsidence related to dissolution of the evaporite bedrock and the subsequent formation of karst morphology also creates hazards in the area. Collapsible soils and evaporite karst hazards manifest themselves as ground settlement, regional and localized subsidence, dissolution voids, and sinkholes. These hazards present potential risks to certain types of land development within the Corridor.

The Roaring Fork River valley trends northwest from its headwaters in the Sawatch Range to its confluence with the Colorado River at the mouth of Glenwood Canyon. The Corridor extends from near the town of Basalt in northwestern Pitkin County, at an elevation of 6,700 ft (2,042 m), to Glenwood Springs in Garfield County at 5,700 ft (1,737 m). State Highway 82, the main transportation route in the corridor, follows the river valley to its confluence with the Colorado River, where it joins Interstate 70. The climate is semi-arid with annual rainfall of 12 to 15 in. on the valley floor. Historically, ranching was the dominant land use in the area and the hazards listed above caused only relatively minor problems. Recently, rapid development of the valley and its surroundings has fundamentally changed traditional land uses, resulting in higher public exposure to these hazards. To reduce the associated risks, it is necessary to understand these hazards and where they occur. Appropriate levels of investigation, engineering design, and maintenance practices are needed to mitigate these hazards for existing structures and new property and infrastructure development.

ABOUT THIS MAP AND ITS USES FOR LAND-USE PLANNING

This map identifies locations that may be susceptible to collapsible soils and subsidence related to dissolution of evaporite minerals. The map units and their related hazards include the following:

1. Surficial soil deposits that have demonstrated collapse susceptibility and ground settlement hazards;
2. Collapse debris areas, underlain by disturbed Tertiary volcanic rocks, where deeper, differential evaporite dissolution or flowage has occurred.
3. Eagle Valley Formation bedrock, in surface exposures, that may exhibit karst morphology and sinkhole formation;
4. Eagle Valley Evaporite bedrock, in surface exposures and where overlain by thin surficial deposits, that may exhibit karst morphology and sinkhole formation;
5. Known sinkholes and other subsidence hazard features.

See the Explanation below for more detailed descriptions of these map units, and the Geologic Index Map for the 1:24,000-scale CGS (Colorado Geological Survey) geologic maps that were used in this 1:50,000 scale map compilation.

This map is meant as a guide for landowners, planners, municipal and county land-use regulators, and the geotechnical and civil engineering community. Its limitations relate to the scale at which the mapping was conducted, geologic uncertainty, and unknown variability of surficial-soil thickness. The map should not be used to assign risk for a particular area and is not a substitute for professionally prepared, site-specific geologic hazard studies and designs.

For existing developed areas located within the mapped hazard areas, maintenance and mitigation techniques mentioned in the following sections are available to mitigate the hazard, if it exists, and reduce the level of risk. For new-development planning purposes, this map should not be used to determine specific land suitability, but used as a tool to formulate appropriate and proper types of investigation. These site-specific investigations should identify whether the hazards exist, the level of their severity, the risks to the proposed development, and whether mitigation plans are warranted. To minimize risk, the planning and design process should include a multi-disciplinary approach that includes geologic and geotechnical investigations and foundation and infrastructure design by geologists and engineers experienced in collapsible soil and karst terrains, and subsequent work by knowledgeable civil and structural engineers, building contractors, and landscape designers.

COLLAPSIBLE SOILS

Geologic Characteristics and Hazards

Collapsible soils are generally dry, low-density soils with high void space or air gaps between unpacked soil grains. Upon wetting, the soil particle-binding agents break, dissolve, or soften such that the soil grains shear against each other and re-orient in tighter, denser configurations. This re-configuration causes a net volume decrease in the soil mass that, in turn, results in settlement of the ground surface. This condition can occur just by the weight of the soil itself, called the overburden, or by loading from a structure that is founded on the soil. Structures and underground utilities founded on these types of soils can suffer from various forms of distress when settlement or collapse occurs. Because soils are typically heterogeneous and anisotropic, the settlement will likely be differential. If a structure or buried utility line spans soils with varying settlement rates, the resulting settlement strain can build until the structure bends, distorts, or breaks by cracking and/or shearing.

The binding agents of the collapsible soil structure can be very strong while the soil is in a dry state, and may possess bearing capacities able to support considerable foundation loads. When water is introduced, the soil's skeletal structure quickly weakens and fails. This settlement can be quite rapid, hence the term soil collapse. Because the introduction of water causes this collapse, the terms hydrocompactive and hydrocompressible are also used to describe these soils. Certain fine-grained soils can also collapse and settle by piping (i.e., the removal and suspension of soil particles in moving water), creating open soil pipes and voids that eventually cave in.

Research by the CGS (White, 1998) and others in this area (Mock and Pawlak, 1983), and in similar provinces in other semi-arid western states (Beckwith and Hansen, 1989; Rollins and others, 1994), has shown that certain types of recent surficial deposits derived from certain rock types are susceptible to collapse. The main types of surficial deposits prone to collapse include 1) windblown deposits of dust, silt, and fine sand called loess, 2) hillside gravity deposits called colluvium, 3) rapidly deposited, unsorted, water-borne material (mud and debris) in alluvial/debris flow fans or as hillside slope wash deposits, and 4) fine-grained alluvial deposits along ephemeral streams. These soils can be quite different in composition. Coarse, unsorted, silty to clayey sand with dispersed gravel and other larger rocks are commonly seen in alluvial/debris fan deposits, while fine, uniform, clayey silt, is more indicative of windblown loess deposits.

The common characteristic of these deposits is an internal soil structure with inherent unstable configurations caused by depositional dynamics. The generally dry climate conditions of the area (collapsible soils are not generally seen where annual precipitation exceeds 20 in., or 508 mm) cause these deposits to quickly desiccate (dry out) in their original condition without the benefit of further re-working or packing of the sediments by water. For most of these deposits, later ground-water levels generally never rise naturally into the soil mantle so they never become re-saturated. Development by man changes local ground-water conditions, however, raising ground-water levels or saturating soils through combinations of field irrigation, lawn and landscape irrigation, capillary action under impervious slabs, leaking water and sanitation utilities, and adversely altered surface drainage.

Recent geologic mapping of the Corridor by the CGS (see Acknowledgements) has emphasized surficial-deposit mapping. Collapsible soils are found in colluvial wedges that cover the valley sides and the base of slopes, and fill shallow drainageways and swales in the upland areas. Alluvial/debris flow fans of significant thickness, deposited out over earlier glacial outwash gravel terraces at the mouths of ephemeral streams, also contain collapsible soils. Most collapsible soils are derived from clay and silt-rich rock formations. The soils derived from Eagle Valley Evaporite and Eagle Valley Formation may also have high percentages of gypsum that, through dissolution, can contribute to soil settlement. Collapsible soils are also found in the windblown loess deposits that blanket certain areas, especially on older terraces and in swales and depressions in nearby upland areas. In some areas, a complex interlayering and mixing of soil types can occur. An example of the relationships between soil type, landforms, and topography are shown in the oblique block diagram below.

Considerations for Proposed and Existing Development

Even though certain assumptions about susceptibility to soil collapse can be made based on the character of the surficial deposits and site-specific geomorphology, a detailed site investigation that includes subsurface drilling and soil testing is essential for new development proposals. The geotechnical consultant should have experience with geotechnical design in collapsible soils, as these soils can vary widely.

Collapsible soils have low densities that generally range from 75 to 105 pcf (1.2 to 1.68 g/cm^3). They also have low moisture content in their natural state and, because of the high silt content, a low plasticity index. Collapsibility is commonly determined by one-dimensional swell-consolidation tests (modified from ASTM D-2435 and D-4546 soil-testing methods). In this test an "undisturbed" soil sample is collected, generally by driving a metal cylindrical sampler into the soil mass. The samples are hydraulically jacked into a confining ring, trimmed, and inserted into a test chamber. The sample is then loaded with weights to a specific pressure, commonly 1,000 psf (47.9 kPA). The soil is then saturated and the percent collapse or swell is recorded at that constant pressure. The soil is then further incrementally loaded to determine the compression curve. Based on work by previous researchers and their own experience, Mock and Pawlak (1983) and Pawlak (1998) have established their own guidelines on severity of the potential hazard based on results of the swell-consolidation testing:

Percent Collapse	Hazard
0–1	No Problem
1–3	Low
3–5	Moderate
>5	High

Some surficial soils can be quite thick, so the above guidelines should be considered within the context of soil thickness. Even a 1 percent collapse for a 15 ft (4.5 m) depth of soil would be 1.75 in. (45 mm) of settlement, and if that settlement is differential under a structure, it could be enough to cause significant damage if mitigative measures were not taken. A limitation of this test is that some collapsible soils have high percentages of gravel-sized rocks (Rollins and others, 1994). These types of soils are not conducive to the testing described above because the gravel content prevents the reliable recovery of an undisturbed soil sample. Where critical facilities are proposed, on-site plate-load tests conducted under saturated ground conditions will more reliably indicate the collapse potential of the soil column.

There are several types of available engineering techniques to mitigate collapsible soils. They are grouped broadly into 1) ground modifications that reduces the collapse potential of the soil, 2) structural reinforcement of shallow foundations, and 3) deeper foundations that transfer building loads through the collapsible soil to a competent soil or rock layer.

Proper water and drainage management is critical in areas of collapse-susceptible soils. Collapsible soils are dry in their natural state and it is important that they remain so as much as possible. New developments located in areas of dry, collapse-susceptible soils should have a comprehensive water-management plan as part of their development plan. Landowners in existing developments should also consider site-specific water and drainage management. Property owners need to prevent undue wetting and saturation of the subsoils below structural features such as foundations, concrete slabs, retaining walls, and pavements. Irrigation pipe and sprinkler heads should not be installed near, nor allowed to splash against these structural elements. Systems should be pressure tested periodically for leakage. Depending on the severity of collapse potential, certain restrictions for lawn irrigation systems may be advisable on a site-specific basis. The amount of water needed for irrigation may be reduced by using xeriscape landscaping and soil-moisture gages. Roof gutters are essential, and splashguards or pipe extenders should be installed at downspouts to carry storm water away from building foundations. Finished grades should slope away from structures so that water cannot pond nearby. Unlined landscaping ponds should not be placed nearby or uphill from structures. Natural drainage paths and subsurface flows should not be altered in any way that would impound, delay, or back up either surface or subsurface water.

EVAPORITE KARST SUBSIDENCE

Geologic Characteristics and Hazards

A large portion of the Corridor and some other areas in the immediate vicinity are underlain by Eagle Valley Evaporite bedrock at shallow depths. This formation consists of the common evaporite minerals of gypsum ($CaSO_4*H_2O$), anhydrite ($CaSO_4$), and halite (rock salt — NaCl), and thinly interbedded fine sandstone, mudstone, and black shales. These sediments were deposited millions of years ago during the cyclic evaporation of shallow seas. As the seawater evaporated, the solution became enriched with salts. Eventually the salts precipitated out, creating thick evaporite deposits within these ancient sea basins. Subsequent to deposition, the evaporites were buried beneath thousands of feet of younger sediments. They have experienced periodic plastic deformation and flow, particularly during times of mountain building and differential un-loading by erosion and downcutting of the river valley. Over the past several million years, erosion of the uplands and downcutting of the river valley have stripped away the overlying sedimentary rock formations, eventually exposing the evaporite minerals at the ground surface.

The Eagle Valley Formation, which overlies the Eagle Valley Evaporite, contains interbedded siltstone, shale, sandstone, gypsum, and carbonate rocks. Although evaporite minerals constitute a relatively minor portion of this formation, there may be local areas where there are significant gypsum-bearing strata.

Evaporite bedrock has two distinctive characteristics. One is that they can flow, like hot taffy candy, under certain pressures and temperatures. Another, and most important to land use and development, is that evaporite minerals dissolve in the presence of fresh water. It is this dissolution of the rock that creates voids, dissolution breccia zones, and fissures in the bedrock. Karst is a topographic term that refers to a type of landform where caverns and open fissures, subterranean drainage, closed depressions, and sinkholes exist that are underlain by soluble rocks. Evaporite karst refers to topography where these features develop as a result of dissolution of evaporite minerals.

The evaporite karst terrain of the Corridor is centered in an area of Late Cenozoic deformation and regional subsidence related to plastic flowage, diapiric upwelling, and dissolution of evaporite minerals. During the past several million years, many cubic miles of evaporite minerals have dissolved in this area, causing the ground surface to subside thousands of feet. Highly contorted and faulted strata, collapse debris, re-cemented breccia, regional structural depressions such as Spring Valley and Heuschkel Park, diapiric piercement structures, deformed and tilted river terraces, and river-centered anticlines are features related to the evaporite deformation in the area (Kirkham and others, 2001). High modern salinity loads in the Roaring Fork River and Glenwood Springs hot springs, along with historic sinkhole formation, indicate that evaporite deformation continues today, though the rates of this deformation are unknown.

Sinkholes are generally found in surficial deposits that overlie the Eagle Valley Evaporite. Mock (1998) has identified three basic sinkhole types in the area: 1) spontaneous roof collapse and rubble filling of existing, near-surface dissolution cavities, 2) surface collapse by downward movement of river-terrace gravel into deep bedrock voids, and 3) surface collapse by piping of fine-grained soil deposits through fissures or small pipes into underlying bedrock voids. Most of the sinkholes occur on flat-lying river terraces or slopes on the valley sides, but some of the features are fissures and caverns exposed in the actual bedrock. They more rarely form on volcanic lava flows that have collapsed into voids within the underlying evaporite; the sinkholes near Colorado Mountain College are good examples. Subsurface borings in the vicinity of sinkholes formed on river terraces indicate that the depth to bedrock can be very irregular. While the ground surface of the terrace is relatively flat, the underlying bedrock surface is likely more typical of karst topography. Such evidence is present in drainage-channel exposures west of Carbondale, where mid-Pleistocene river-gravel deposits overlie an irregular evaporite bedrock surface. The highest sinkhole densities occur between Carbondale and Glenwood Springs. Large, shallow subsidence troughs of up to several tens of acres in size most commonly occur on the Roaring Fork River valley floor, from near the confluence of Crystal Spring Creek to El Jebel.

Considerations for Proposed and Existing Development

Where the Eagle Valley Evaporite is exposed at the surface or underlies surficial soils, there is some potential that subsidence could occur in the future. The hazard is probably greater in areas with higher sinkhole densities; however, future sinkholes may not be restricted to these areas. While spontaneous collapse and openings of subsurface voids can be dangerous and life threatening, such occurrences are relatively rare in this region. More commonly, settlement subsidence and removal of fine-grained soils by piping, with the resulting differential stress and strain to rigid structures, can damage facilities that are unknowingly constructed over or near a sinkhole, subsidence trough, or near-surface underground void.

Avoidance of known subsidence features is the preferred mitigation alternative, but this is not always possible. There are ground modification and structural solutions to mitigate the threat of subsidence if avoidance is not an option. Owners and developers should consult with knowledgeable geotechnical and structural engineering firms.

Many older sinkholes have been covered with recent soil infilling, or historically filled and forgotten, and are completely concealed at the surface. Near-surface voids that have not broken through to the surface would also be similarly concealed. Subsurface inspections, either by investigative trenching, a series of investigative borings, observations made during overlot grading or utility installation, can ascertain whether filled sinkholes and near-surface voids exist within a development area. Low-altitude aerial photography, eyewitness reports, and historical records may also be helpful to identify filled sinkhole locations. There are also geophysical investigation methods that can detect shallow-subsurface voids and soil/rock property changes. If sinkholes, near-surface voids, or filled sinkholes are detected and located, an experinced geotechnical firm should be retained to evaluate the hazard and risk potential for future subsidence on the property.

Drainage issues and proper water management are as important in evaporite karst terrains as they are for collapsible soils. Because the bedrock and gypsiferous soils derived from them are soluble, changed hydrologic conditions and increases in fresh water may destabilize certain subsidence areas, rejuvenate older sinkhole locations, or cause new dissolution to occur.

The modern subsidence rate of the regional collapse area and the hazard of related ground movements are presently unknown, and are not reflected on the map. The risk, while likely very low for current or planned developments (for normal 50- to 100-year residential structures), is also unknown. The rate over geologic time, ranging from hundreds to thousands of years, is significant (Kirkham and others, 2001). Deformation rates related to regional collapse may present undefined long-term risk for development at structural margins where deformation may be highest. This includes areas located near late Quaternary faults and hinge zones of structural basins (such as Spring Valley and Heuschkel Park, for example), flexural edges and interiors of depressions, synclinal sags, sinkholes, and areas underlain by mapped Collapse Debris. Structural delineations are not shown on this map.

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REFERENCES

Beckwith, G.H., and Hansen, L.A., 1989, Identification and characterization of the collapsing alluvial soils of the western United States, *in* Foundation Engineering: Current principles and practices, v. 1: American Society of Civil Engineers, p. 153–160.

Kirkham, R.M., Streufert, R.K., Budahn, J.R., Kunk, M.J., and Perry, W.J., 2001, Late Cenozoic regional collapse due to evaporite flow and dissolution in the Carbondale collapse center, west-central Colorado: The Mountain Geologist, v. 38, no. 4, p. 193–210.

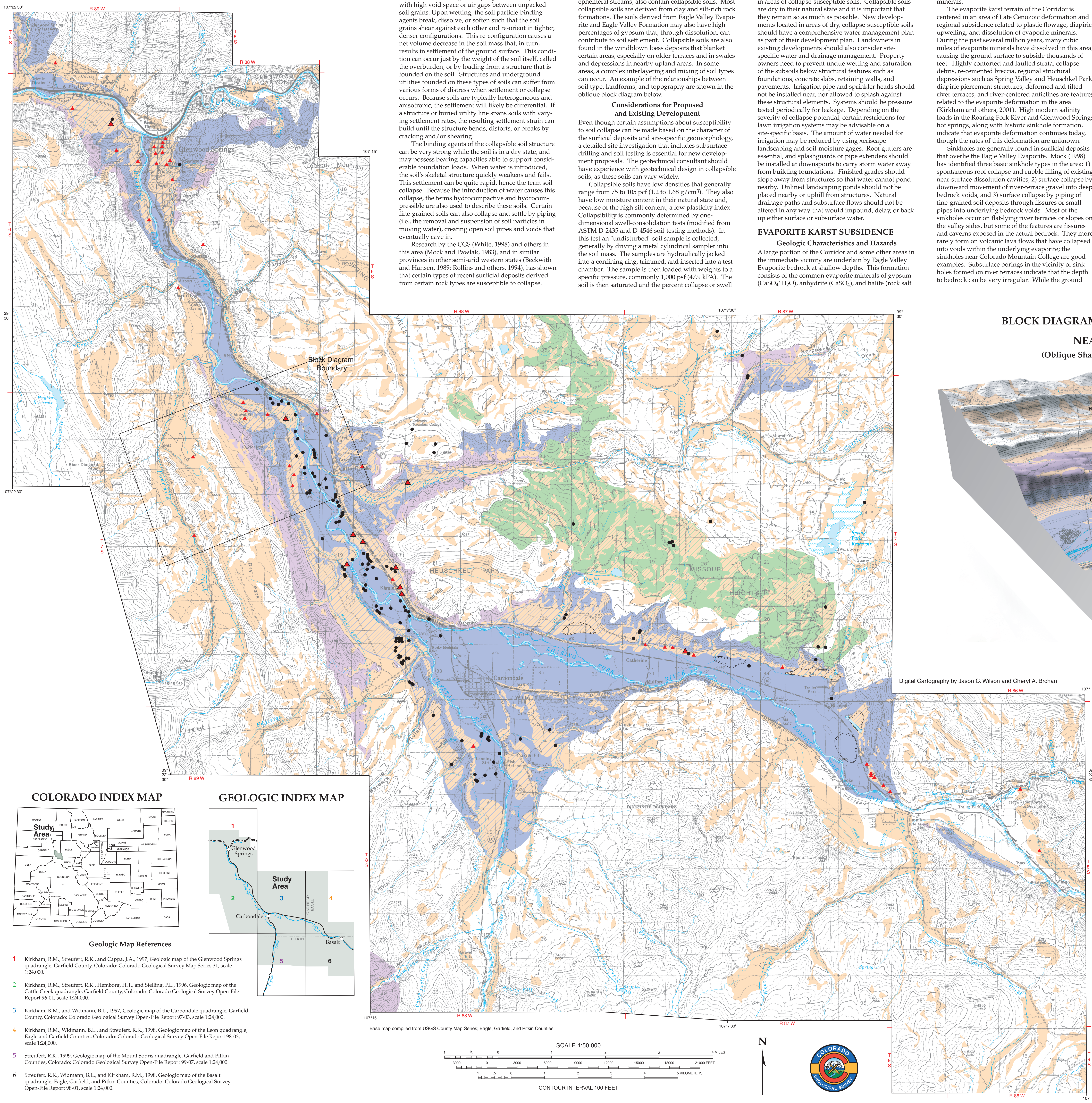
Mock, R.G., 1998, Geologic setting and hazard evaluation for sinkholes in evaporite areas in northwestern Colorado, *in* Extended abstracts, Conference on geologic hazards and engineering practices in western Colorado: October 29 and 30, 1998: Colorado Geological Survey, p. 85–94.

_______, and Pawlak, S.L., 1983, Alluvial fan hazards at Glenwood Springs. in Geological Environment and Soil Properties: American Society of Civil Engineers Conference Proceedings, Houston, Texas, October 17–21, 1983, p. 221–233.

Pawlak, S.L., 1998, Evaluation, design and mitigation of project sites in collapsible soil areas in western Colorado, *in* Extended abstracts, Conference on geologic hazards and engineering practices in western Colorado: October 29 and 30, 1998: Colorado Geological Survey, pp. 78–84.

Rollins, K.M., Rollins, R.G., Smith, T.D., and Beckwith, G.H., 1994, Identification and characterization of collapsible gravels: Journal of Geotechnical Engineering, vol. 120, No. 3, p. 528–542.

White, J.L., 1998, Geology and geomorphology of collapsible soils and evaporite karst in western Colorado, an overview, in Extended abstracts, Conference on Geologic Hazards and Engineering Practices *in* Western Colorado: October 29 and 30, 1998: Colorado Geological Survey, p. 64–77.



COLORADO INDEX MAP

GEOLOGIC INDEX MAP

Geologic Map References

1 Kirkham, R.M., Streufert, R.K., and Cappa, J.A., 1997, Geologic map of the Glenwood Springs quadrangle, Garfield County, Colorado: Colorado Geological Survey Map Series 31, scale 1:24,000.

2 Kirkham, R.M., Streufert, R.K., Hemborg, H.T., and Stelling, P.L., 1996, Geologic map of the Cattle Creek quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-01, scale 1:24,000.

3 Kirkham, R.M., and Widmann, B.L., 1997, Geologic map of the Carbondale quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 97-03, scale 1:24,000.

4 Kirkham, R.M., Widmann, B.L., and Streufert, R.K., 1998, Geologic map of the Leon quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report 98-03, scale 1:24,000.

5 Streufert, R.K., 1999, Geologic map of the Mount Sopris quadrangle, Garfield and Pitkin Counties, Colorado: Colorado Geological Survey Open-File Report 99-07, scale 1:24,000.

6 Streufert, R.K., Widmann, B.L., and Kirkham, R.M., 1998, Geologic map of the Basalt quadrangle, Eagle, Garfield, and Pitkin Counties, Colorado: Colorado Geological Survey Open-File Report 98-01, scale 1:24,000.

Base map compiled from USGS County Map Series; Eagle, Garfield, and Pitkin Counties

Digital Cartography by Jason C. Wilson and Cheryl A. Brchan

SCALE 1:50 000

1 ½ 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET

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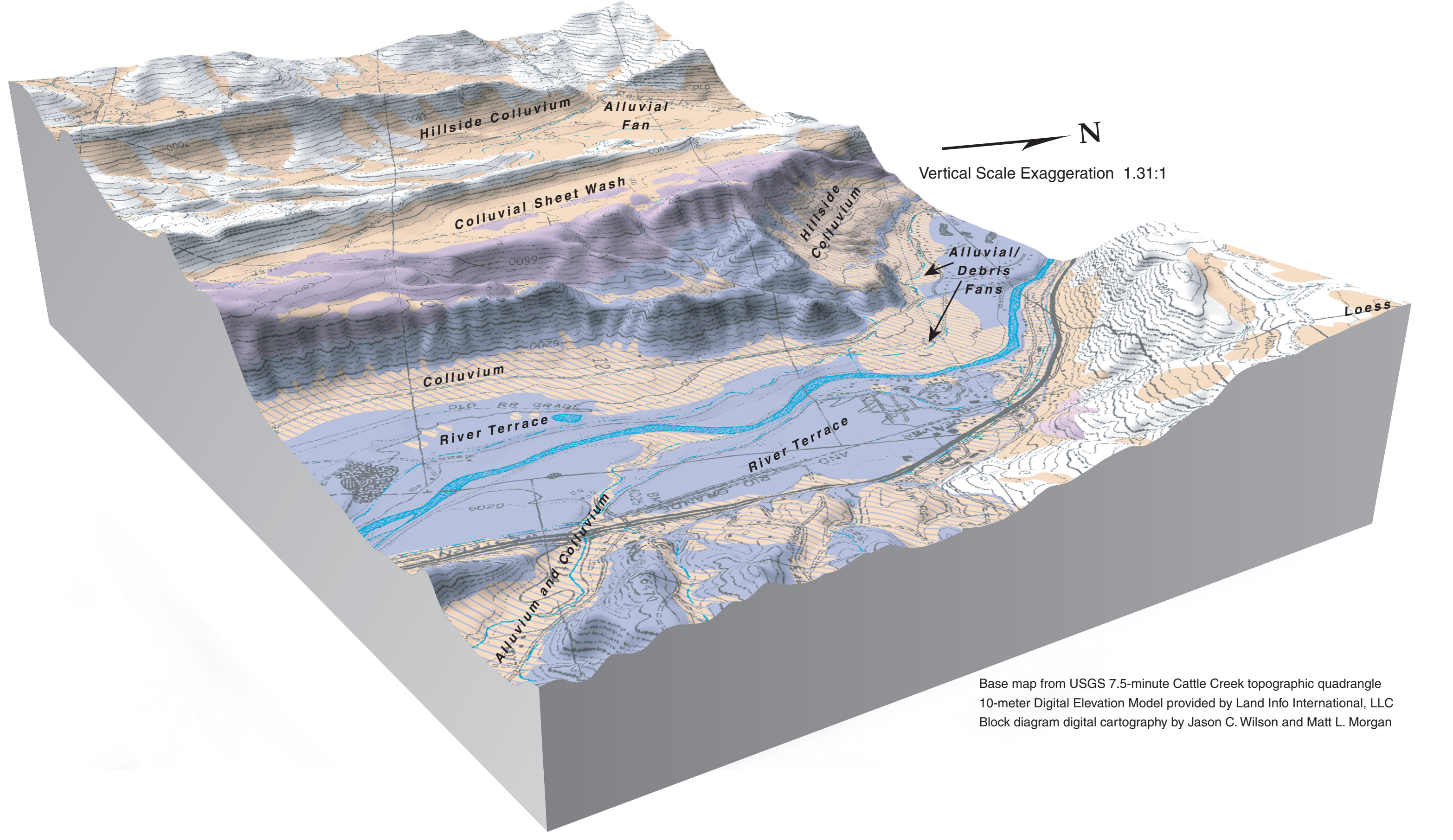
BLOCK DIAGRAM OF PART OF THE ROARING FORK RIVER VALLEY NEAR CONFLUENCE WITH CATTLE CREEK

(Oblique Shaded Relief View from the East, Boundary Lines Shown on Map)



Base map from USGS 7.5-minute Cattle Creek topographic quadrangle
10-meter Digital Elevation Model provided by Land Info International, LLC
Block diagram digital cartography by Jason C. Wilson and Matt L. Morgan

EXPLANATION

DESCRIPTION OF MAP UNITS

Surficial deposits. (Holocene to late Quaternary)— Unconsolidated deposits, generally exceeding five feet in thickness, which mantle the ground surface. These deposits include hillside colluvuim, sheet wash deposits, debris-flow deposits, alluvium along tributary and ephemeral streams, and eolian loess. The deposits, generally considered soils in civil and geotechnical engineering terms, varying from uniform loess to coarse gravel in a clay, silt and sand matrix. These soils are geologically recent, are typically loosely packed, porous, dry, and have not been subject to geologically recent saturation by ground water. While some early Holocene to late Pleistocene sediments may have developed soil horizons and limited cementation of the sediment grains, the deposits are mostly younger in age and their pedogenic development is immature. Hazards associated with this unit include potential of soil collapse (hydrocompaction) when wetted and piping collapse of fine-grained deposits in the presence of running water. Risks to structures and infrastructure include distress from adverse ground settlements and openings of piping voids. Where hachured, the underlying bedrock is Eagle Valley Evaporite or collapse debris, depending on the hachure line color.

Collapse debris (Quaternary and late Tertiary)— Heterogeneous deposits of moderately to severely deformed bedrock overlain by undeformed to moderately deformed surficial deposits north of the Roaring Fork River. Unit formed in response to differential collapse or regional subsidence resulting from dissolution of underlying thick beds of evaporite, primarily halite (rock salt), and/or flow of the evaporitic rocks out from beneath the area. Hazards include surface strain regimens related to subsidence deformation and potential of sinkhole formation. The subsidence deformation hazard is currently poorly understood and it is not presently known whether there is any structural risk.

Eagle Valley Formation (Middle? Pennsylvanian)— Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks that are gradational between and intertongue with the underlying Eagle Valley Evaporite. Soils derived from the Eagle Valley Formation can have significant gypsum content and are also known to have an elevated potential for hydrocompactive soil hazards.

Eagle Valley Evaporite (Middle Pennsylvanian)— Evaporitic sequence of gypsum, anhydrite, and halite (rock salt) interbedded with mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed. Includes areas overlain by various thin (approximately 50-ft or 15-m thick), surficial deposits. Boundaries are approximate where covered by surfical deposits. Evaporite minerals are soluble; as dissolution of the bedrock occurs, a karst morphology results. Hazards include spontaneous ground openings (sinkholes) and subsidence deformation and settlement near sinkholes and closed depressions. Soils derived from evaporite have high gypsum content and may have high potential for significant collapse upon wetting (hydrocompaction). Potential hazards from regional deformation of the evaporite and risks to structures and infrastructure are undefined. Ground water in this unit typically has a high percentage of total dissolved solids and high salinity.

MAP SYMBOLS

● **Sinkholes and subsidence features—** Ground depression areas created either by (1) piping or collapse of surficial deposits into dissolution fissures, voids, or caverns within underlying Eagle Valley Evaporite, (2) downward movement of gravel chimneys into deep bedrock voids, (3) dissolution caverns in outcrops of Eagle Valley Evaporite, or (4) large-scale collapse or settlement of low-density surficial deposits. A black dot denotes small sinkholes or clusters of small sinkholes, and closed, hatured lines denote the larger subsidence areas. Many small sinkholes in addition to those shown are probably present where the Eagle Valley Evaporite is shown, but have not been detected or mapped.

▲ **Soil-collapse locations—**Historical occurrences of soil settlement, damage to structures, and/or collapsible soils verified by soil testing. These data were compiled by CGS as part of the Statewide Collapsible Soil Study (White and Greenman, in prep.). Red triangles show approximate locations of historical occurrences of collapsible soils or damage to a structure as a result of soil collapse and settlement. A Red triangle with black edging denotes approximate locations of historical occurrences of both collapsible soils and sinkholes.