U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Great Sand Dunes National Park and Preserve

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Great Sand Dunes National Park and Preserve

grsa_geology.pdf

Version: 8/21/2018

Geologic Resources Inventory Map Document for Great Sand Dunes National Park and Preserve

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Geologic Resources Inventory Map Document

Great Sand Dunes National Park and Preserve, Colorado

Document to Accompany Digital Geologic-GIS Data

grsa_geology.pdf

Version: 8/21/2018

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Great Sand Dunes National Park and Preserve, Colorado (GRSA).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.

2) **GRI Digital Maps and Source Map Citations** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.

3) **Digital Geologic-GIS Map of Great Sand Dunes National Park and Preserve**

   a) **Map Unit Listing** – A listing of all map units present on the Digital Geologic-GIS Map of Great Sand Dunes National Park and Preserve.

   b) **Map Unit Descriptions** – Descriptions for all map units for the Digital Geologic-GIS Map of Great Sand Dunes National Park and Preserve.

   c) **Ancillary Source Map Information** – Additional source map information present on the Digital Geologic-GIS Map of Great Sand Dunes National Park and Preserve.

4) **Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve**

   a) **Map Unit Listing** – A listing of all map units present on the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve.

b) **Map Unit Descriptions** – Descriptions for all map units present on the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve.

c) **Geologic Cross Sections** – Geologic cross section graphics present on the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve.

d) **Ancillary Source Map Information** – Additional source map information for the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve.

5) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

For information about using GRI digital geologic-GIS data contact:

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage: http://go.nps.gov/gri_products

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: https://www.nps.gov/subjects/geology/gri.htm, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS maps for Great Sand Dunes National Park and Preserve, Colorado (GRSA):

Digital Geologic-GIS Map of Great Sand Dunes National Park, Colorado (*GRI MapCode GRSA*)

Source digital GIS data (see source citation immediately below), as well as prominent map components present on the source map (e.g., related report, unit colors, unit descriptions, and other ancillary map graphics and text) were incorporated into this GRI digital geologic-GIS dataset and product.

> Madole, R.F., VanSistine, D. P., and Romig, J.H., 2016, Geologic Map of Great Sand Dunes National Park, Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3362, scale 1:35,000 (Great Sand Dunes National Park). (*GRI Source Map ID 76089*).

The full extent of the source map above was used and all geologic features present on the map and source digital data were captured.

In addition to the above map of the park the GRI also produced a map for parts of the park and preserve that encompasses more of the Sangre de Cristo Mountains on the eastern edge of the park and preserve, as well as the areas to the immediate northeast, east and southeast of the park and preserve.

Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve (Sange de Cristo Mountains and part of the Dunes), Colorado (*GRI MapCode GSAM*)

The above map was compiled from several component maps that are listed below. For each of these maps the source map citation is also listed. The full extent of each source map was used and all geologic features present on each map including mine point features (e.g., adits, shafts, prospects, mines etc.) were captured. In addition, prominent map components present on each source map (e.g., unit colors, unit descriptions, geologic cross sections and other ancillary map graphics and text) were also incorporated into this GRI digital geologic-GIS dataset and product.

Component maps that comprise the compiled Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve and their source map citations.

Digital Geologic-GIS Map of Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle, Colorado (*GRI MapCode BEMO*)

> Lindsey, D.A., et. al., 1986, Geologic Map of the Beck Mountain, Crestone Peak and Crestone Quadrangles, Custer, Huerfano and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1878, scale 1:24,000 (Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle). (*GRI Source Map ID 78*).

Digital Geologic-GIS Map of Medano Pass Quadrangle and parts of the Liberty Quadrangle, Colorado (*GRI MapCode MEPA*)

> Johnson, B.R., Bruce, R.M., and Lindsey, D.A., 1989, Reconnaissance Geologic Map of the Medano Pass Quadrangle and Part of the Liberty Quadrangle, Alamosa, Huerfano and Saguache Counties, Colorado: U.S. Geological Survey, MF-2089, scale 1:24,000 (Medano Pass Quadrangle and parts of the Liberty Quadrangle). (*GRI Source Map ID 80*).

Digital Geologic-GIS Map of Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle, Colorado (*GRI MapCode RIAL*)

Lindsey, David A., et. al., 1985, Geologic Map of Rito Alto Peak and Northeastern Part of the Mirage Quadrangles, Custer and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1787, scale 1:24,000 (Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle). (*GRI Source Map ID 81*).

Digital Geologic-GIS Map of parts of the Twin Peaks and Blanco Peak Quadrangles, Colorado (*GRI MapCode TPBP*)

Johnson, Bruce R., and Bruce, Robert M., 1991, Reconnaissance Geologic Map of Parts of the Twin Peaks and Blanco Peak Quadrangles, Alamosa, Costilla and Huerfano Counties, Colorado: U.S. Geological Survey, MF-2169, scale 1:24,000 (Parts of the Twin Peaks and Blanco Peak Quadrangles). (*GRI Source Map ID 83*).

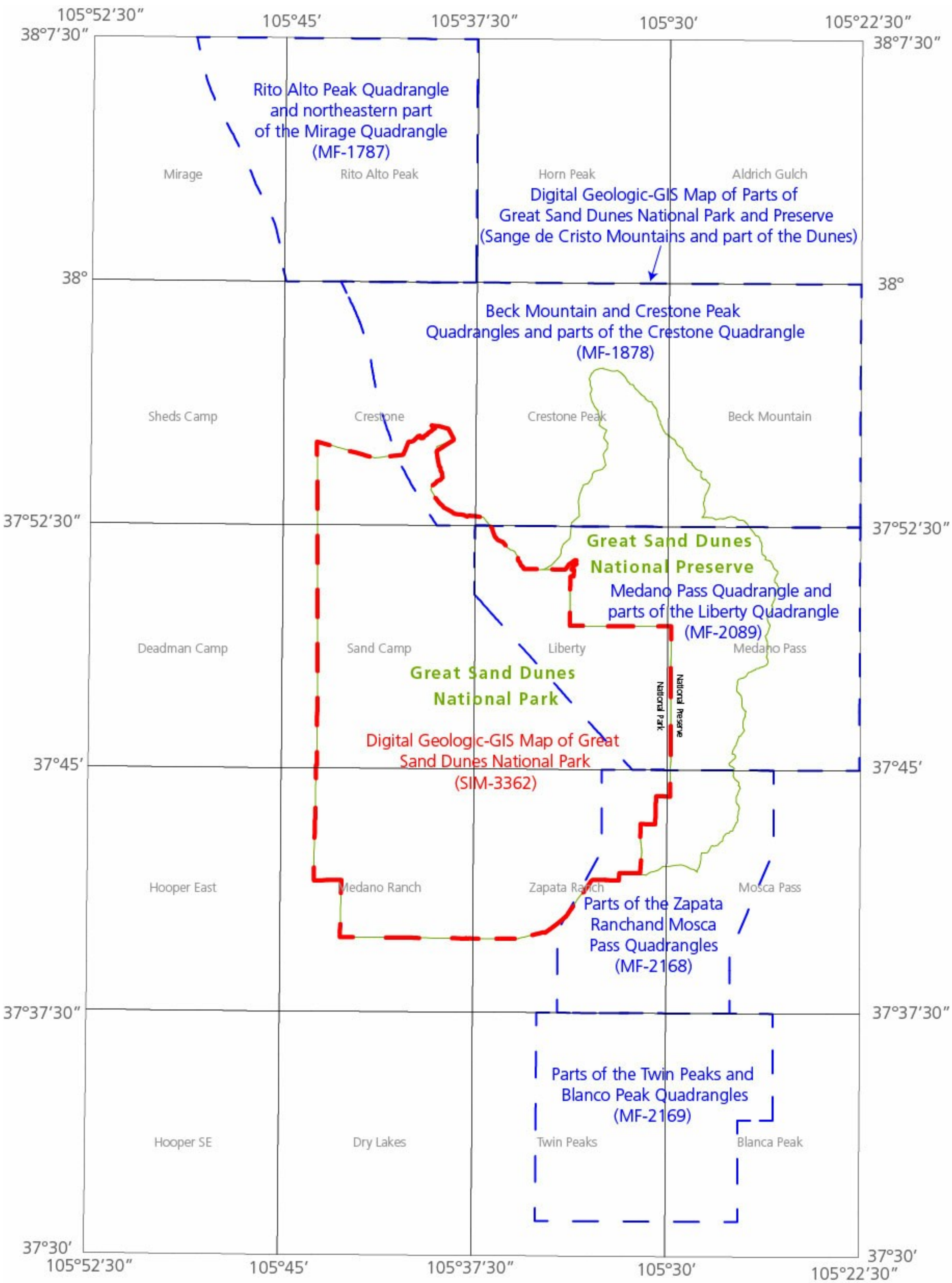
Digital Geologic-GIS Map of parts of the Zapata Ranch and Mosca Pass Quadrangles, Colorado (*GRI MapCode ZARA*)

Bruce, R.M., and Johnson, B.R., 1991, Reconnaissance Geologic Map of Parts of the Zapata Ranch and Mosca Pass Quadrangles, Alamosa and Huerfano Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2168, scale 1:24,000 (Parts of the Zapata Ranch and Mosca Pass Quadrangles). (*GRI Source Map ID 84*).

Additional information pertaining to each source map is also presented in the GRI Source Map Information (GRSAMAP) table included with the GRI geologic-GIS data.

Index Map

The following index map displays the extent of GRI digital geologic-GIS maps produced for Great Sand Dunes National Park and Preserve. The extent of the GRI Digital Geologic Map of Great Sand Dunes National Park is outlined with a dashed red line. The extent of the GRI Digital Geologic Map of Parts of Great Sand Dunes National Park and Preserve, as well as its component maps, are outlined with a dashed blue line. The title or abbreviation for each map is also indicated, as is its source map series number (e.g., SIM-3362). The boundaries for Great Sand Dunes National Park and Preserve (as of August, 2018) are outlined in green.



Index map produced by James Winter (Colorado State University).

Digital Geologic-GIS Map of Great Sand Dunes National Park

Map Unit Listing

The geologic units present in the Digital Geologic-GIS Map of Great Sand Dunes National Park (*GRI MapCode GRSA*) are listed below. Units are listed with their assigned unit symbol and unit name (e. g., Qafi - Artificial fill). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (GRSAUNIT) table included with the GRI geologic-GIS data. Some source unit symbols, names and/ or ages may have been changed in this document and in the GRI digital geologic-GIS data. Unit symbols, names and/or ages in unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary Period
Qafi - Artificial fill
Qes1 - Eolian sand unit one
Qea1 - Younger eolian sand and alluvium
Qgsd - Great Sand Dunes
Qa1 - Younger alluvium
Qa2 - Older alluvium
Qau - Alluvium, undivided
Qes2 - Eolian sand unit two
Qea2 - Older eolian sand and alluvium
Qai - Alluvium of groundwater discharge streams
Qw - Wet-meadow sediment
Qt1 - Lower terrace alluvium
Qes3 - Eolian sand unit three
Qdf - Debris-flow deposits
Qbf - Basin-floor sediment
Qaf - Alluvium-fan deposits
Qpf - Piedmont-fan deposits
Qps - Ponded sediment
Qt2 - Middle terrace alluvium
Qt3 - Upper terrace alluvium

Paleozoic Era

Pennsylvanian Period
PNm - Minturn Formation

Precambrian Eon

Xgn - Mixed gneiss

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. All unit descriptions were taken from the source map: Great Sand Dunes National Park. For references to figures in the unit descriptions, see the pamphlet that accompanied the source map and digital data for these figures.

Qafi - Artificial fill (latest Holocene)

af - Artificial fill (latest Holocene)
Earth materials emplaced or shaped by humans, principally to construct earthen dams, roadbeds, embankments, and well-drilling sites.

Qes1 - Eolian sand unit one (latest Holocene)

Active, loose, noncalcareous sand mostly in the form of dunes that have well-defined crests, flanks, and slip faces, and are between 3 and 8 m high. Deposits of this unit are devoid of vegetation except for the odd tuft of Indian ricegrass (Achnatherum hymenoides) or wild prairie sunflowers (Helianthus petiolaris) because it is difficult for plants to become established on active sand (fig. 18). Because the sand is active, unit boundaries have changed slightly in some places since the imagery used to map the area was acquired, and doubtless, some boundaries will continue to change. Stratigraphic relations in the western part of the map area, and in the vicinity of Big Spring Creek (fig. 7), indicate that most Qes1 sand was derived from older sand deposits, namely, units Qes3 and Qes2. In most places, Qes1 sand is loose and particularly difficult to traverse by vehicle.

Qea1 - Younger eolian sand and alluvium (latest Holocene)

Eolian sand overlying alluvium mostly in the run-out zones of Sand Creek and Medano Creek, the two largest drainage basins on the west flank of the Sangre de Cristo Range in the map area. As used here, run-out zone refers to places where annual snowmelt-driven peak flows and floods caused by severe thunderstorms dissipate due to infiltration and development of distributary channels. Floods transport sand to the run-out zones, sometimes in such quantities that dam-like masses are left on the channel floor when floodwaters dissipate. For most of the year, however, stream channels are dry and susceptible to wind erosion. Sand eroded from dry channels is deposited over older alluvium in areas near the channels. In some places, unit Qea1 includes active dunes overlying unit Qa1 on channel floors, particularly along Medano Creek. The distribution of unit Qea1 is particularly complex and dynamic in the run-out zone of Sand Creek. Thus, it is impractical to map unit Qea1 in detail in this area.

Qgsd - Great Sand Dunes (middle Pleistocene to latest Holocene)

Well-sorted eolian sand in dunes that have the following characteristics: they are more than 10 m high, contiguous, presently active, have identifiable slip faces, and contain bedding that dips at greater than 20°. Dunes at the edge of the active sand mass that do not quite meet these criteria are included in the Great Sand Dunes if they are contiguous with them. The exceptional heights of the Great Sand Dunes are due mostly to (1) their proximity to a sand source that was replenished periodically (the trough, fig. 2), (2) a complex wind regime, and (3) the Sangre de Cristo Range, which prevented continued eastward migration of dune sand by prevailing southwesterly and westerly winds. Although the sand on the surface of the Great Sand Dunes is presently active, the boundary of the unit has not changed appreciably since the first aerial photographs of the area were taken in 1936. The sand at and near the surface of the Great Sand Dunes is equivalent in age to unit Qes1 (latest Holocene), but most of this massive body of sand (volume estimated to be between 10 and 13 billion m3±430 million m3, Madole and others, 2008) is a complex of deposits that accumulated episodically for more than 130,000 yr (Madole and others, 2008, 2013). The onset of dune formation occurred sometime after Lake Alamosa began to drain, which according to Machette and others (2007) was about 440 ka. The elapsed time between the end of Lake Alamosa and the beginning of the Great Sand Dunes is unknown. However, it was long enough for a thick wedge of piedmont-slope deposits to prograde westward over sediment of Lake Alamosa for a distance of at least 23 km. This wedge was as much as 60 m thick at a point 10 km west of the Sangre de Cristo Range (Madole and others, 2013).

Qa1 - Younger alluvium (latest Holocene)

Alluvium deposited by streams draining from the Sangre de Cristo Range. In mountain canyons, unit Qa1 consists of clast-supported gravel ranging in size from pebbles to boulders. Westward from the mountain front, the larger streams continue to flow on gravel, but clast size decreases progressively in a downstream direction. The distance to the point where gravel ceases to be a constituent is proportional to drainage basin size. The transition from gravel bed to sand bed is abrupt. Downstream from where gravel ends, unit Qa1 consists of sand derived mostly from the eolian sand that bounds it. In some places, most notably along Deadman Creek in the northern part of the map area, deposits of unit Qt1 are included in map unit Qa1 because although the terrace deposits are morphologically distinct and extensive, they are too narrow to show separately at the scale of this map. During floods, Sand Creek commonly entrains more sand in its upper reaches than it can transport through its lower reaches because of the reduction in stream energy resulting from diminished discharge. Stratigraphic and geomorphic relations indicate that at times Sand Creek, and to lesser extent Medano Creek, were self-damming and prone to avulsion, which is one reason why unit Qa1 occupies multiple channels in the lower reaches of both streams.

Qa2 - Older alluvium (latest Holocene)

Alluvium that is physically similar to unit Qa1 because it was derived from the same source areas. Deposits of unit Qa2 are mainly in abandoned paleochannels in the lower reaches of Sand Creek. Most paleochannels are 1.0–1.5 m higher than the present channel of Sand Creek. The distribution of these deposits indicates that in its lower reaches Sand Creek occupied a broad range of locations during Holocene time. Stream avulsion likely accounts for most of the changes in channel location, and most changes likely occurred during exceptionally large floods.

Qau - Alluvium, undivided (Holocene and late Pleistocene)

Deposits of mostly sandy alluvium that are correlative with units Qa1, Qa2, Qt1, and Qt2, but are undifferentiated because they are either too small to show separately at the scale of this map, or are too difficult to distinguish because of the basinward (westward) convergence of their surfaces. These limitations apply only in valleys that originate in small canyons in the northern part of the map area.

Qes2 - Eolian sand unit two (late Holocene)

Noncalcareous sand in sheets and dunes, mostly parabolic forms, that are between 3 and 8 m high and have well-defined, narrow crests and steep flanks (figs. 6 and 9). The stipple pattern overlain on deposits of unit Qes2 along the mountain front northwest of the Great Sand Dunes denotes areas where the unit is not thick enough to conceal the hummocky debris-fan deposits that it overlaps. Although soil maps (Pannell and others, 1973; Yenter, 1984) indicate that soils of the Cotopaxi series are developed in unit Qes2, in most places evidence of soil formation is negligible. Where preserved, the Cotopaxi soil consists simply of an A/C-horizon profile wherein the A-horizon is generally less than 15 cm thick. Unit Qes2 supports a thin, relatively continuous cover of vegetation that contrasts with the much thicker, shrub-dominated vegetation cover on deposits of unit Qes3 (see figs. 8 and 19). Vegetation on unit Qes2 is composed chiefly of grasses, forbs, and rabbitbrush. Unit Qes2 was derived primarily by re-activation of unit Qes3; thus in most places, it is downwind (east and northeast) from deposits of unit Qes3. Most re-activation of unit Qes3 is inferred to have occurred when the water table lowered faster than plant roots could grow downward. Even shrubs like greasewood and saltbush, which have root systems that can penetrate several meters below the ground surface, die off when the decline in water-table level outpaces root growth (see the section on "Hydrogeology, Vegetation, and Sand-Surface Stability" for references and a more detailed discussion of this process). Unit Qes2 is noncalcareous, except locally in the southwestern part of the map area. Here, slightly calcareous deposits of unit Qes2 are depicted using a broken-block pattern. These deposits are slightly calcareous for two reasons: (1) calcium carbonate-rich sediment from adjacent basin-floor deposits was blown onto them, and (2) in some places Qes3 sand was reshaped into new bed forms, but the sand was not transported far enough for ballistic impacts and abrasion among moving sand grains to completely remove the films of calcium carbonate that coated them. Deposition of this unit began sometime between 1,500 and 1,300 cal yr BP and likely ended with the onset of the Little Ice Age in the 16th century. Although bulk densities were not measured, it is obvious that Qes2 sand is much less compact than Qes3 sand and is thus more difficult to traverse by vehicle.

Qea2 - Older eolian sand and alluvium (late Holocene)

Eolian sand in dunes and sheets overlying alluvium on the floor of a prominent paleochannel formerly occupied by Medano Creek. The channel floor is as much as 400-m-wide near its upstream (northeast) end and tapers to a width of 150 m over a distance of about 5 km. Alluvium is within 0.5 to 1.5 m of the ground surface near the upstream end of the paleochannel, but Qes2 sand thickens downvalley and completely buries the west (downstream) end of the channel (fig. 6). Either stream piracy or avulsion (an abrupt change in course) or a combination of these processes likely caused Medano Creek to abandon its former course. The alluvium underlying the paleochannel floor consists of interbedded sand and fine to coarse gravel. The gravel consists mostly of Precambrian granitic and gneissic rock derived from the core of the Sangre de Cristo Range. The thickness of the alluvium is unknown beyond the fact that where augured near the upstream end of the paleochannel it is greater than 1 m.

Qai - Alluvium of groundwater discharge streams (late Holocene)

Alluvium deposited primarily by streams that flowed from springs and marshes. Most deposits consist of poorly sorted stratified sand and a few thin, discontinuous beds of dark-gray, organic-rich mud. The mud accumulated in slack-water areas along stream margins (for example, see figs. 8, 10A, and 20A). Typically, these beds are composed of mixtures of sand (38–59 percent), silt (35–60 percent), and clay (7–9 percent).The age of unit Qai is uncertain beyond the fact that it postdates unit Qt1.

Qw - Wet-meadow sediment (late Holocene)

Chiefly sand, silty sand, and thin beds of very dark-gray to black clayey silty sand. Unit Qw is present in areas where groundwater discharge sustains or formerly sustained wetlands and sub-irrigated meadows (fig. 16). Fluctuations in water-table level during Holocene time caused the locations of groundwater discharge points to shift. They shifted upslope (northeast in most places) when the water table rose and downslope when the water table lowered. Thus, deposits of unit Qw are present in a zone that is 3–6 km wide. The zone trends roughly northwest–southeast across the topographically lowest (southwestern) part of the map area. Deposits of Qw are common at the upslope (northeast) ends of several now defunct instream wetlands (unit Qai). Soils of the Medano series are developed in unit Qw (Pannell and others, 1973; Yenter, 1984). These soils are the only Mollisols—thick dark-colored soils typically associated with lush grasslands—present in the map area. Their contrast in color and character with the generally pale brown and brown sandy Aridisols that dominant the area is noteworthy.

Qt1 - Lower terrace alluvium (late Holocene)

Alluvium underlying a terrace that is about 1 m higher than channel level along all streams regardless of whether they drain from the mountains or from springs (figs. 10A and 10B). Many deposits of unit Qt1, particularly along Deadman Creek and Big Spring Creek, are either too small or too narrow to show at the scale of the map. However, examples of this unit are visible in figures 7 and 8. Near the mountain front, Qt1 alluvium consists chiefly of cobble and pebble gravel, but farther west it is made up mostly of fine- to medium-size sand. Stratigraphic and geomorphic relations suggest that Qt1 alluvium began to accumulate sometime about or after 3,500 yr BP and ceased to accumulate by or about 1,500 yr BP. Several radiocarbon ages indicate that most aggradation occurred between about 2,900 and 1,700 cal yr BP (figs. 10A and 15).

Qes3 - Eolian sand unit three (late Holocene? and middle Holocene)

Sand in sheets, clusters of low (3–6 m high) dunes, and a small number of oval sand mounds (a few of which are 9–10 m high and more than 1 km long) in the southwestern part of the map area. Typically, Qes3 dunes have broader crests and flatter side slopes than Qes2 dunes because they have been inactive for a longer time during which erosion, deposition, and creep modified their form (figs. 12 and 17). Besides topographic expression, the most diagnostic properties of unit Qes3 are (1) the presence of calcium carbonate in the upper 1.0–1.5 m of sediment (fig. 14), and (2) it supports a relatively dense plant cover dominated by halophytic (salt tolerant) woody shrubs, notably greasewood and saltbush, which generally grow in thick stands (fig. 8). Neither of these shrubs is common on deposits of unit Qes2. Soils of the Space City series are developed in unit Qes3 (Pannell and others, 1973; Yenter, 1984). Typically, soil profiles consist of a weakly developed A-horizon, 9–20 cm thick, overlying a calcareous C-horizon that is 100–150 cm thick. This unit is present mainly in the topographically lower parts of the map area, which mostly border the trough and areas flanking instream wetlands in the southwestern part of the map area (figs. 2 and 8). Comparable deposits of Qes3 sand are not present along the western (upwind) margin of the trough, which indicates that Qes3 sand was transported from the trough by southwesterly and westerly winds. Deposition of unit Qes3 began about 7,200 yr BP and ended about or before 3,500 yr BP. Unlike younger sand units, unit Qes3 is compact and easily traversed by vehicle or on foot.

Qdf - Debris-flow deposits (late Pleistocene? to late Holocene)

Nonsorted, heterogeneous mixtures of surficial materials and fragmented rock debris in a wide range of sizes, including large boulders. The deposit matrix (material less than 2 mm in size) and the lithologies and sizes of rock fragments vary according to the kind of bedrock from which the debris was derived. Levees formed by recent small debris flows (too small to show at the scale of this map) are visible in several places along Colorado Highway 150. Debris-flows occur frequently along the mountain front and sediment transported by them is present on both units Qaf and Qpf. Only large debris-flow deposits are mapped separately. These deposits are estimated to be less than 40 m thick.

Qbf - Basin-floor sediment (middle Pleistocene to late Holocene)

Chiefly poorly sorted sandy alluvium, some thin beds of clayey silt, and minor amounts of gravelly sand. The unit is at the surface only in the topographically lowest (southwestern) part of the map area (figs. 6 and 12). Thin beds of loess consisting mostly of windblown silt and very fine sand derived from dry playas and lakes during the Holocene cover unit Qbf in some places, as do thin deposits of silty and clayey lacustrine sediment, also of Holocene age. Both the loess and lacustrine deposits are too small or thin to show at the scale of this map. Deposits of loess typically are 50–80 cm thick and highly calcareous. The upper part of the Laney soil series is developed in loess and the lower part is developed in alluvium. The soil profile typically consists of an A/AC/C/ B2b/B3b/IIC2/IIIC3 horizon sequence (Pannell and others, 1973). Most lacustrine deposits also are 1 m or less thick. They are the parent material of the Hooper clay loam, which unlike other soils in the map area includes a heavy clay loam Bt horizon that typically is 20–25 cm thick (Pannell and others, 1973; Yenter, 1984). According to well-log data, unit Qbf is several tens of meters thick.

Qaf - Alluvial-fan deposits (early Pleistocene? to late Holocene)

Chiefly coarse-grained alluvium composed of gravel and sand, interbedded with debris-flow deposits and sheetwash alluvium. Cobbles of all sizes are the dominant constituents, but boulders also are abundant in many places. The deposits were derived primarily from Precambrian gneiss and granitic rock in canyons on the west flank of the Sangre de Cristo Range. Fans emanate from canyons and merge laterally with other fans to form a nearly continuous zone of bouldery detritus along the mountain front (fig. 6). Fans south of the map area contain large amounts of clast-supported gravel of glaciofluvial origin, but those in the map area do not contain glaciofluvial sediment because here the range was not high enough to be glaciated. At the mountain front, unit Qaf is at least 330–460 m thick based on the difference in altitude between the tops of fans and the basin floor to the west. However, the full thickness and maximum age of unit Qaf are unknown because the position of its basal contact has not been determined (Brister and Gries, 1994). At the surface, deposits range in age from late Holocene to middle Pleistocene. However, the stratigraphic relations of unit Qaf and the underlying deposits of the upper Santa Fe Group (Pleistocene to Miocene) are unknown.

Qpf - Piedmont-fan deposits (early Pleistocene? to late Holocene)

Sediment underlying the piedmont fan (that is, the merged lower slopes of adjacent mountain-front alluvial fans) consists chiefly of alternating beds of poorly sorted sand and gravel. The quantity and size of gravel clasts decrease downslope. Well-log data indicate that at times clasts as large as 6.5 cm were transported as far as 10 km from the mountain front. In much of the map area, eolian sand buries the lower piedmont slope (fig. 6). Well-log data suggest that alluvium underlying the lower piedmont slope is at least 60 m thick. The unit is presumed to be of the same age as unit Qaf.

Qps - Ponded sediment (Holocene)

Well-sorted fine sand, chiefly of eolian origin, and variable amounts of extremely poorly sorted sand and matrix-supported gravel that are of fluvial and mass-wasting origin. Unit is present in small areas along the mountain front north of Medano Creek where ridges of eolian sand dam the mouths of minor canyons (fig. 23). Only the upper 2 m (the depth limit of auguring) of unit Qps were examined. Given the porous nature of unit Qps, impoundment of runoff in areas underlain by it is likely short-lived and episodic, occurring mainly during and for a short time after thunderstorms and periods of heavy snowmelt.

Qt2 - Middle terrace alluvium (latest Pleistocene? to middle and early Holocene)

Alluvium underlying a terrace that, depending on drainage basin size and distance from the mountain front, is 1.7–3 m higher than adjacent stream channels (figs. 20A, 20B, and 20C). Terrace height is higher near the mountain front and in large drainage basins. This unit is most extensive along Deadman Creek and similar valleys (Cottonwood Creek, for example) north of the park. In this area, runoff from the cluster of high peaks east of Crestone (some of which have altitudes in excess of 4,000 m) is sufficient to maintain channels westward all the way across the map area. Deposits of unit Qt2 also exist along Sand Creek but are more difficult to discern because eolian sand overlies them in most places. The same is true along Medano Creek, where eolian sand buries nearly all terrace deposits. Cottonwood Creek, Deadman Creek, and an unnamed channel draining from Cedar Canyon (fig. 21) are underfit streams; that is, they appear to be too small to have eroded the valleys in which they presently flow. Also, the discharges required to form such broad valleys were too great to have occurred in the Holocene, yet the lack of a distinct weathering profile and the presence of calcium carbonate indicates that most of the Qt2 alluvium exposed in cutbanks is Holocene (fig. 20C). However, the gravel in the lower part of the unit suggests that it might have begun to accumulate during latest Pleistocene time when stream discharge was greater. Aggradation likely was in progress prior to 9,490±30 cal yr BP and continued at least until 7,350±70 cal yr BP (fig. 13, table 1).

Qt3 - Upper terrace alluvium (middle Pleistocene)

Chiefly poorly sorted sand, gravelly sand, and gravel in terrace remnants that are 10–11 m higher than the floors of Sand Creek, Cold Creek, and Deadman Creek (figs. 11, 22A, and 22B). In some places near the mountain front, this unit also includes debris-flow deposits. The number and thickness of gravel beds, gravel size, and height above stream level all decrease with increased distance from the mountain front. Deposits of Qt3 alluvium along Sand Creek are at least 11 m thick near the mountain front, but only about half as much Qt3 alluvium is exposed 7 km west of the mountain front (fig. 11). Eolian sand overlies unit Qt3 in much of the area; thus, in some places, unit boundaries are based on terrace morphology. For example, the morphology of Qt3 alluvium at the confluence of Cold Creek and Sand Creek is clearly visible on lidar imagery even though it is blanketed by eolian sand that, except for a few small dunes, is 1.0–1.5 m thick (fig. 9). A pit near the south side of Sand Creek about 3.5 km downstream from the mountain front exposes a 6-m-thick section of Qt3 gravel. The gravel consists of cobbles and lesser amounts of pebbles and a few small boulders in a coarse sandy matrix. The gravel is deeply oxidized (1–2 m) and clasts are highly weathered. This depth of oxidation contrasts markedly with the 1–36 cm depth of oxidation on nearby alluvial fans that are correlated with the Pinedale (latest Pleistocene) glaciation (McCalpin, 1982). Therefore, unit Qt3 is most likely of middle Pleistocene age.

PNm - Minturn Formation (Middle Pennsylvanian)

Chiefly gray arkosic sandstone, conglomerate, siltstone, shale, and minor limestone (Bruce and Johnson, 1991) that crops out in a small area along the park boundary in the southeastern part of the map area. These sedimentary rocks are relics of sediment eroded from the Ancestral Rocky Mountains (Kluth and Coney, 1981).

Xgn - Mixed gneiss (Paleoproterozoic)

Unit consists chiefly of interlayered mafic and felsic gneisses, and micaceous schist that are intruded by several bodies of non-foliated igneous rocks of unknown age. Layering is complex, variable in proportion, discontinuous, and rarely traceable in outcrop for more than 0.5 km (Johnson and others, 1989; Bruce and Johnson, 1991). These authors determined that unit Xgn was of Early Proterozoic age, which the updated International Chronostratigraphic Chart (Cohen and others, 2015) reassigns to Paleoproterozoic time.

Ancillary Source Map Information

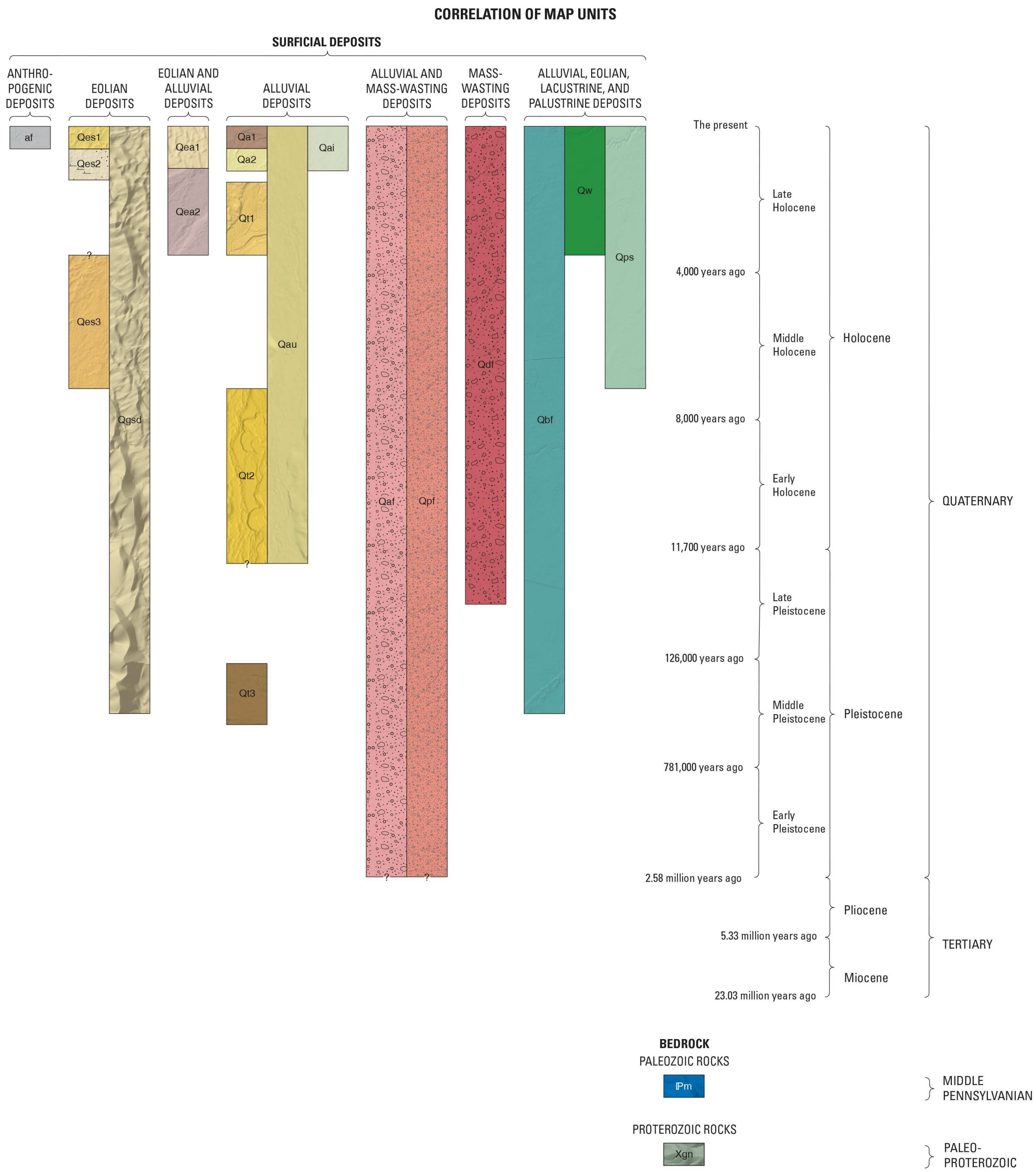
The following section presents ancillary source map information associated with source map used for this project.

The formal citation for this source.

Madole, R.F., VanSistine, D. P., and Romig, J.H., 2016, Geologic Map of Great Sand Dunes National Park, Colorado: U.S. Geological Survey, Scientific Investigations Map SIM-3362, scale 1:35,000 (*GRI Source Map ID 76089*).

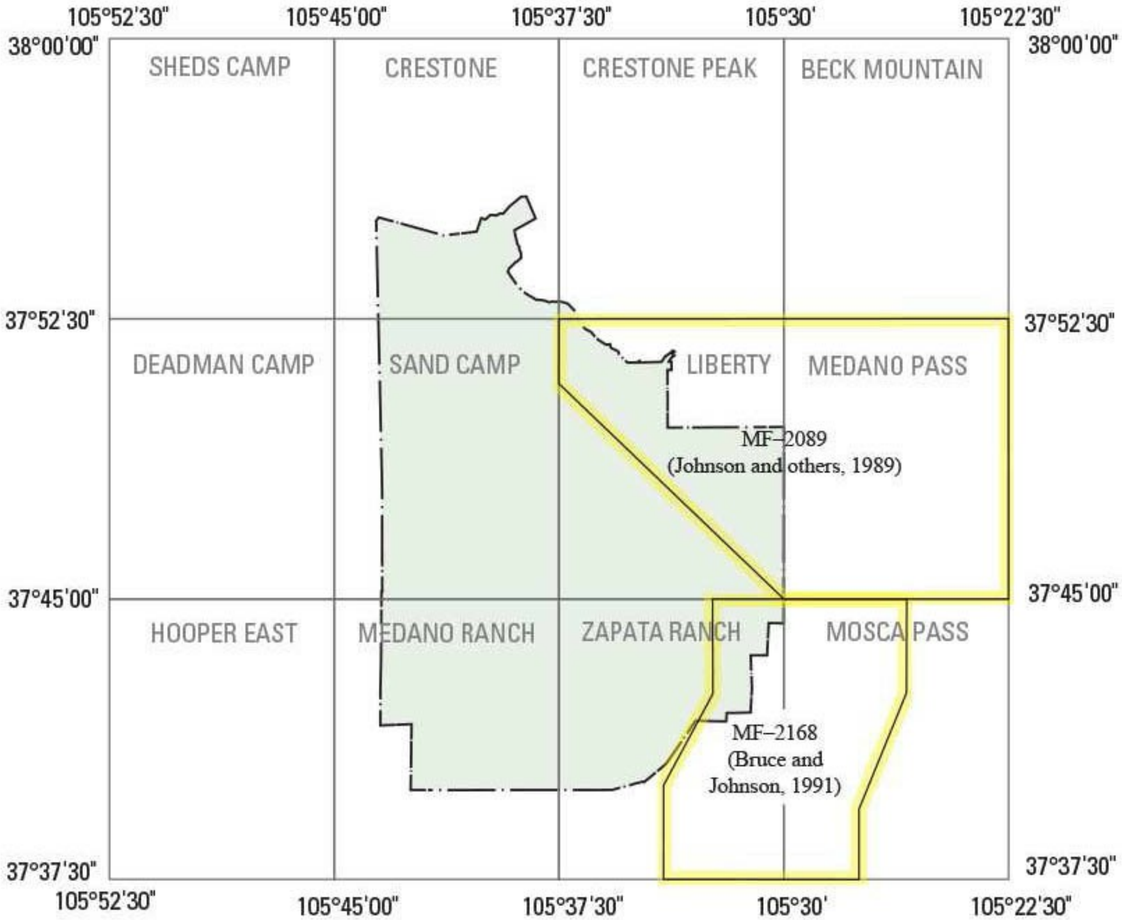
Prominent graphics and text associated with this source are presented below.

Correlation of Units



Graphic from source map: Great Sand Dunes National Park.

Index Map

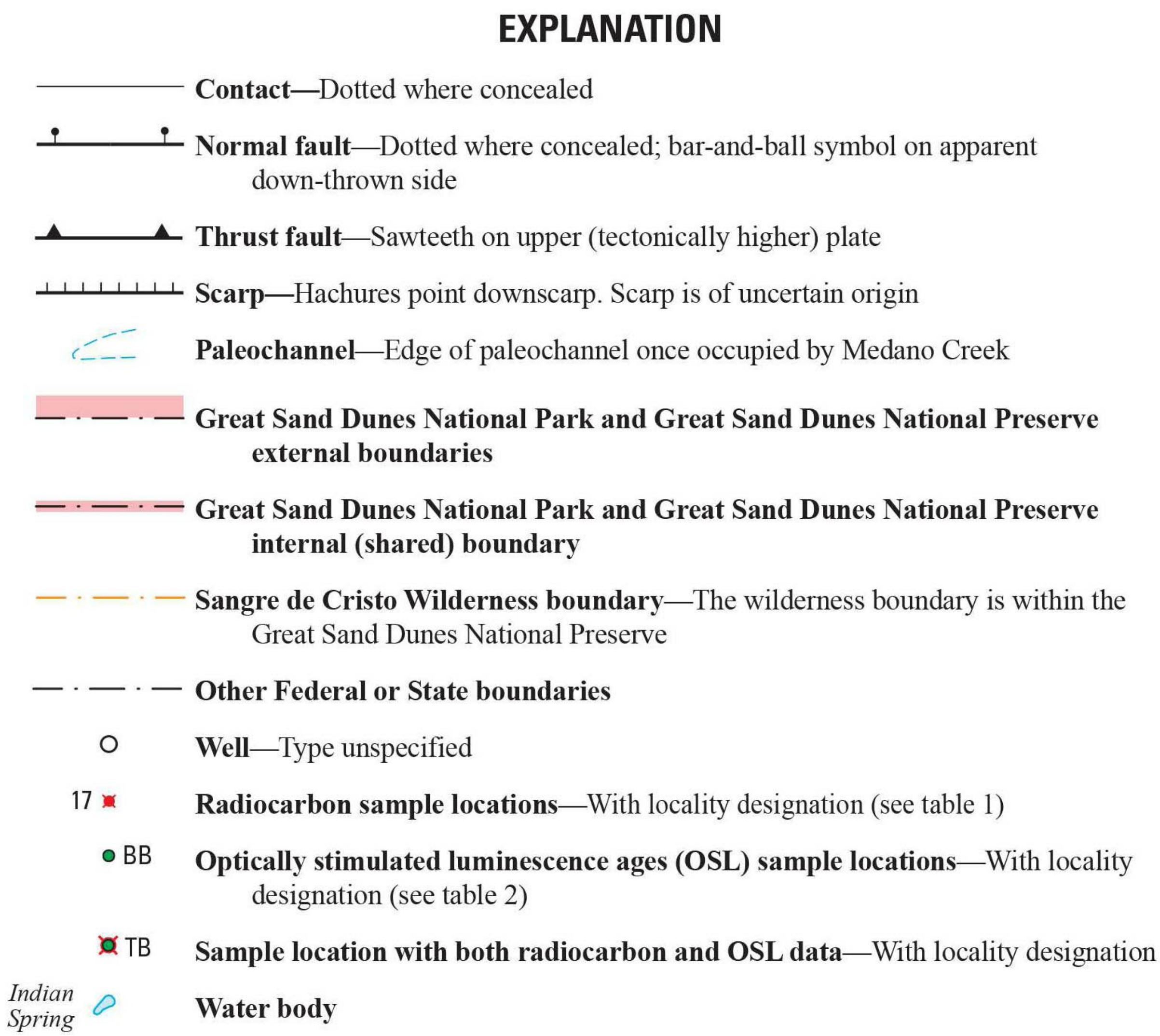


Index map showing U.S. Geological Survey 7½-minute maps in the vicinity of Great Sand Dunes National Park and Preserve (in green), and the geologic map data sources used in map compilation. U.S. Geological Survey publications show the publication number, author(s), and year of publication.

Graphic from source map: Great Sand Dunes National Park.

Map Legends

Geologic Symbols



Graphic from source map: Great Sand Dunes National Park.

Infrastructure Symbols

Graphic from source map: Great Sand Dunes National Park.

Map Introduction

The Great Sand Dunes are the tallest dunes in North America (maximum height about 750 feet, or 230 m). These dunes cover an area of 72 square kilometers (28 square miles) and contain an estimated 10-13 billion cubic meters (2.4-3.1 cubic miles) of sand. The dunes accumulated in an embayment in the mountain front formed where the trend of the Sangre de Cristo Range changes from southeasterly to southwesterly They owe their exceptional height to a combination of factors including range-front geometry, topography, an abundant sand supply from the nearby basin, a complex wind regime, and the Sangre de Cristo Range, which prevents continued eastward migration of dune sand deposited by the prevailing southwesterly and westerly winds. Although the sand at the surface of the Great Sand Dunes is presently active, most of this massive sand body is a complex of deposits that accumulated episodically for more than 130,000 years.

Geologic mapping of what is now the Great Sand Dunes National Park began after a range fire swept the area in April 2000. The park spans an area of 437 square kilometers (or about 169 square miles), of which 98 percent is blanketed by sediment of Quaternary age; thus, the geologic map of the Great Sand Dunes National Park is essentially a surficial geologic map. The surficial deposits are diverse and include sediment of eolian (windblown), alluvial (stream and sheetwash), palustrine (wetlands and marshes), lacustrine (lake), and mass-wasting (landslides) origin. Sediment of middle and late Holocene age, dating from about 8,000 years ago to the present covers about 80 percent of the park.

During Holocene time, fluctuations in groundwater level caused wetlands within and adjacent to the park on the west to alternately expand and contract. These fluctuations controlled the stability or instability of eolian sand deposits on the downwind (eastern) side of the lowland. When the groundwater level rose, playas became lakes, wet or marshy areas formed in many places, and the channels and valley floors of spring-fed streams filled with sediment. Conversely, when the groundwater level fell, spring-fed streams incised their valley floors, and lakes, ponds, and marshes dried up and became sources of windblown sand.

Discharge in streams draining the west flank of the Sangre de Cristo Range is controlled primarily by snowmelt, and flow is perennial until it reaches the mountain front beyond which streams begin losing water at a high rate as the water sinks into the gravelly stream beds and the eolian sand that bounds them. Even streams originating in the larger drainage basins, such as Sand and Medano Creeks, generally do not extend much more than 4 kilometers (about 25 miles) beyond where they exit the mountains.

Text from source map: Great Sand Dunes National Park.

SIM-3362 Pamphlet

The following source map pamphlet, provided as an embedded PDF document, sim3362_pamphlet.pdf, can be accessed by double-clicking on the document file. The pamphlet contains additional information concerning the source geologic map, as well as a discussion of the geology pertaining to the area. The content pages in the pamphlet are presented below.

Contents

Figures

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Tables

Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve

Map Unit Listing

The geologic units present in the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve (*GRI MapCode GSAM*) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qal - Alluvium). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (GSAMUNIT) table included with the GRI geologic-GIS data. Some source unit symbols, names and/or ages may have been changed in this document and in the GRI digital geologic-GIS data. This was done if a unit was considered to be the same unit as one or more units on other source maps used for this project, and these unit symbols, names and/or ages differed. In this case a single unit symbol and name, and the unit's now recognized age, was adopted. Unit symbols, names and/or ages in unit descriptions, or on a correlation of map units or other source map figure were not edited. If a unit symbol, name or age was changed by the GRI the unit's source map symbol, name and/or age appears with the unit's source map description.

Cenozoic Era

Quaternary Period
Qal - Alluvium
Qes - Eolian sand
Qaf - Alluvial fan deposits
Qtd - Sand dune deposits, transverse dune deposits
Qld - Sand dune deposits, longitudinal dune deposits
Qpd - Sand dune deposits, parabolic dune deposits
Ql - Landslide deposits
Qrg - Rock-glaciers
Qrf - Rockfall deposits
Pinedale and Bull Lake deposits
- Pinedale deposits
  - Qpf - Pinedale deposits, fan alluvium
  - Qpl - Pinedale deposits, lacustrine clay
  - Qpo - Pinedale deposits, outwash
  - Qpt - Pinedale deposits, till
- Qg - Glacial deposits of Pinedale and Bull Lake ages
- Bull Lake deposits
  - Qbf - Bull Lake deposits, fan alluvium
  - Qbo - Bull Lake deposits, outwash
  - Qbt - Bull Lake deposits, till
  - Qbo2 - Bull Lake deposits, young outwash
  - Qbt2 - Bull Lake deposits, young till

Tertiary Period
Ts - Santa Fe Formation
Tgr - Granite and granodiorite
Ta - Andesite
Tmv - Mafic volcanic rocks
Tm - Mafic intrusive rocks
Tf - Felsic dikes and sills

Mesozoic Era

Jurassic Period

Jm - Morrison Formation
Je - Entrada Sandstone

Paleozoic Era

Permian and Pennsylvanian Periods
PPNsu - Sangre De Cristo Formation, undivided
- PPNsc - Sangre De Cristo Formation, Crestone Conglomerate Member
- PPNscd - Sangre De Cristo Formation, Crestone Conglomerate Member, marker bed of diamictite
- PPNsl - Sangre De Cristo Formation, lower member
- PPNsls - Sangre De Cristo Formation, marine limestone beds

Pennsylvanian Period
PNm - Minturn Formation, undivided
- PNmu - Minturn Formation, upper part
- PNmmls - Minturn Formation, marker limestone
- PNmcls - Minturn Formation, marker bed of crinoidal silty limestone
- PNmbls - Minturn Formation, brown-weathring limestone
- PNmpals - Minturn Formation, marker bed of phylloid algal limestone
- PNmsh - Minturn Formation, shale and siltstone member
- PNmols - Minturn Formation, marker bed of oolite limestone
- PNmlbls - Minturn Formation, lenticular biohermal limestone unit
- PNmt - Minturn Formation, main turbidite member
- PNml - Minturn Formation, lower part
- PNmq - Minturn Formation, quartoze red-beds

Mississippian, Devonian and Ordovician Periods
MDOr - Mississippian, Devonian and Ordovician sedimentary rocks, undivided

Ordovician Period
Oh - Harding Sandstone
Om - Manitou Limestone

Proterozoic Eon

PRm - Mafic dikes
Yqm - Quartz monzonite
Yqz - Vein quartz
Xp - Pegmatite
Xsm - Syenite and monzonite
Xm - Mafic intrusive rocks
Xqm - Quartz Monzonite of Music Pass
Xq - Quartzite
Xlgn - Leucocratic gneiss
Xto - Tonalite gneiss
Xg - Metagabbro
Xqd - Quartz diorite
Xdi - Diorite
Xhgn - Hornblende gneiss
Xgn - Gneiss and mixed gneiss

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qal - Alluvium (Holocene)

Qal - Alluvium (Holocene)
Sand, gravel, and clay deposited by streams; includes colluvium along valley sides; generally less than 10 m thick. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qal - Alluvium (Holocene and Pleistocene)
Sand, gravel, and clay deposited by streams. Includes Holocene stream deposits, Pleistocene glacial outwash, and, locally, colluvium. As much as several tens of meters thick. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Qal - Alluvium (Holocene)
Deposits of sorted sediment ranging from clay to boulders; along streams. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qal - Alluvium (Quaternary)
Sand, gravel, and clay deposited by streams. Includes Holocene stream deposits, Pleistocene glacial outwash, and, locally, colluvium; along east side of Sangre de Cristo Range, includes pediment deposits of Quaternary and possibly Tertiary age composed of deeply weathered detritus derived mostly from Precambrian and upper Paleozoic rocks. As much as several hundred meters thick. Description from source maps: Parts of the Twin Peaks and Blanco Peak Quadrangles and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Qes - Eolian sand (Holocene)

Qes - Eolian Sand (Holocene)
Surficial deposits of well-sorted sand; covered by sparse vegetation. Thin and discontinuous, interspersed with alluvial sand and clay north of Deadman Creek; dunes as high as 10 m south of Deadman Creek. Described in detail by Andrews (1981). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qes – Eolian Sand (Holocene)
Surficial deposits of well-sorted sand; includes dunes as much as 5 m high at the foot of the mountains. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qaf - Alluvial fan deposits (Holocene)

Qaf - Alluvial fan deposits (Holocene)
Poorly sorted, coarse sand and gravel deposited by distributary stream systems along west side of Sangre de Cristo Range. Description from source maps: Medano Pass Quadrangle and parts of the Liberty Quadrangle, Parts of the Twin Peaks and Blanco Peak Quadrangles, and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Qtd - Sand dune deposits, transverse dune deposits (Holocene)

Qtd - Transverse Sand Dune deposits (Holocene)
Asymmetrical dunes with crests oriented perpendicular to prevailing wind direction. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Qtd - Transverse Sand Dune deposits (Quaternary)
After Johnson (1967); Wind-blown dunes of sand deposited along east side of San Luis Valley (Johnson, 1967); best developed in and adjacent to Great Sand Dunes National Monument. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Qld - Sand dune deposits, longitudinal dune deposits (Holocene)

Qld - Longitudinal Dune deposits (Holocene)
Symmetrical dunes with crests oriented parallel to prevailing wind direction. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Qld - Longitudinal Dune deposits (Quaternary)
After Johnson (1967); Wind-blown dunes of sand deposited along east side of San Luis Valley (Johnson, 1967); best developed in and adjacent to Great Sand Dunes National Monument. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Qpd - Sand dune deposits, parabolic dune deposits (Holocene)

Qpd - Parabolic Sand Dune deposits (Holocene)
Scoop-shaped dunes, parabolic in plan view, with horns pointing upwind. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Ql - Landslide deposits (Holocene)

Ql - Landslide deposits (Holocene)
Deposits of angular rock debris of all sizes; typically hummocky topography. Description from source maps: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle and Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Ql – Landslide Deposits (Holocene)
Loose blocks of sandstone and soil; north of Dinick Gulch and southeast of Blind Lake. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qls - Landslide Deposits (Quaternary)
Angular rock debris at base of steep slopes, forming hummocky topography typical of landslide deposits. As much as 30 m thick. Description from source maps: Parts of the Twin Peaks and Blanco Peak Quadrangles and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Qrg - Rock-glaciers (Holocene and late Pleistocene)

Qrg - Rock Glaciers (Holocene and Late Pleistocene)
Deposits of angular blocks at the base of steep slopes and in valley floors; lobate and tongue-shaped in plan view; about 10-20 m thick. Description from source map: Beck Mountain and Crestone Peak

Quadrangles and parts of the Crestone Quadrangle.

Qrg - Rock Glaciers (Holocene and Late Pleistocene)
Deposits of angular blocks of rock extending from base of steep slopes into valley floors. Lobate flow patterns. Described in detail by Grout (1981) PINEDALE DEPOSITS (PLEISTOCENE) Description of till modified from Taylor and others (1975b). Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qrg - Rock-Glacier deposits (Quaternary)
Angular blocks at base of steep slopes and at floors of cirques. Lobate forms of deposits suggest formation by ice-cored flow. As much as 30 m thick. Description from source maps: Parts of the Twin Peaks and Blanco Peak Quadrangles and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Qrf - Rockfall deposits (Holocene and late Pleistocene)

Qrf - Rockfall Deposits (Holocene and Late Pleistocene)
Accumulations of talus below large outcrops. Description from source maps: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle, Medano Pass Quadrangle and parts of the Liberty Quadrangle, and Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Pinedale and Bull Lake deposits

Pinedale deposits

Qpf - Pinedale deposits, fan alluvium (Pleistocene)

Qpf - Pinedale Deposits, Fan Alluvium (Pleistocene)
Gray stratified alluvium composed of boulders, cobbles, pebbles, and sand. Forms mostly undissected and coalescing fans. Locally covered by thin deposits of eolian sand. Thickness unknown but may be as much as 100 m. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qpf - Pinedale Deposits, Fan Alluvium (Pleistocene)
Gray stratified alluvial fans composed of boulders, cobbles, pebbles, and sand. Thickness unknown. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qpl - Pinedale deposits, lacustrine clay (Pleistocene)

Glacial lake clay above terminal moraine on Willow Creek (Siebenthal, 1907, p. 17). Thickness unknown. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qpo - Pinedale deposits, outwash (Pleistocene)

Gray, well-washed, stratified alluvium composed of boulders, cobbles, pebbles, and sand. Below terminal moraines on South Colony Creek. Thickness about 8 m. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qpt - Pinedale deposits, till (Pleistocene)

Qpt – Till (Pleistocene)
Gray, unsorted, unstratified deposit of boulders, cobbles, pebbles, sand, and clay. Boulders as large as 3 m diameter. Rock fragments of sandstone have weathering rinds 2 mm thick or less; corners angular, surfaces not pitted. Crestlines of moraines sharp; large boulders project far above irregular surface. As much as 15 m thick. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qpt - Glacial deposits (Pleistocene)
Gray till of Pinedale age that contains boulders as much as 3 m in diameter. Moraines have hummocky topographic features and contain tillstones with thin weathering rinds typical of Pinedale moraines (Taylor, Scott, and others, 1975). As much as 30 m thick. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Qpt - Till (Pleistocene)
Gray, unsorted, unstratified deposit of boulders, cobbles, pebbles, sand, and clay derived mostly from Sangre de Cristo and Minturn Formations. Boulders as large as 3 m in diameter. Sandstone cobbles have weathering rinds 2 mm thick or less; corners angular, surfaces not pitted. Crestlines of moraines sharp; large boulders project far above irregular surface. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qg - Glacial deposits of Pinedale and Bull Lake ages (Pleistocene)

Qg - Glacial deposits (Pleistocene)
Glacial deposits (Pleistocene) — Gray till of Pinedale and Bull Lake age that contains boulders as much as 3 m in diameter. Older moraines have more subdued topographic features than do younger moraines, and contain tillstones that have thicker weathering rinds than those found in younger moraines (Taylor and others, 1975). As much as 30 m thick. Description from source maps: Parts of the Twin Peaks and Blanco Peak Quadrangles and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Bull Lake deposits

Qbf - Bull Lake deposits, fan alluvium (Pleistocene)

Qbf - Bull Lake Deposits, Fan Alluvium (Pleistocene)
Descriptions modified from Scott and Taylor (1974) and Taylor and others (1975). Sorted, stratified alluvium composed of boulders, cobbles, pebbles, and sand. Forms dissected fans. Thickness unknown but may be as much as 100 m. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qbf - Bull Lake Deposits (Pleistocene)
Descriptions of outwash and till modified from Taylor and others (1975b) Fan alluvium Sorted, stratified alluvial fans composed of boulders, cobbles, pebbles, and sand. Thickness unknown. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qbo - Bull Lake deposits, outwash (Pleistocene)

Descriptions modified from Scott and Taylor (1974) and Taylor and others (1975). Gray, sorted, stratified alluvium composed of boulders, cobbles, pebbles, and sand. Located in valleys below terminal moraines. Thickness about 10 m. Description from source map: Beck Mountain and Crestone

Peak Quadrangles and parts of the Crestone Quadrangle.

Qbt - Bull Lake deposits, till (Pleistocene)

Descriptions modified from Scott and Taylor (1974) and Taylor and others (1975). Yellow-gray, unsorted, unstratified, compact deposit of boulders, cobbles, pebbles, sand, and clay. Some boulders as large as 3 m in diameter. Sandstone cobbles have weathering rinds about 3 mm thick. Crestlines of moraines rounded; protruding stones fewer and more deeply buried than in Pinedale moraines; slopes of moraines smooth. As much as 50 m thick on South Colony and Willow Creeks. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Qbo2 - Bull Lake deposits, young outwash (Pleistocene)

Descriptions of outwash and till modified from Taylor and others (1975b)

Young outwash Gray, sorted, stratified alluvium composed of boulders, cobbles, pebbles, and sand; forms terrace about 9 m above streams. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Qbt2 - Bull Lake deposits, young till (Pleistocene)

Descriptions of outwash and till modified from Taylor and others (1975b).

Young till Yellowish-gray, unsorted, unstratified, compact deposits of boulders, cobbles, pebbles, and clay derived mostly from Sangre de Cristo and Minturn Formations. Some boulders as much as 3 n in diameter; sandstone cobbles have weathering rinds about 3 mm thick. Crestlines of moraines rounded; protruding stones fewer and more deeply buried than in Pinedale moraines; slopes of moraines smooth. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Ts - Santa Fe Formation (Pliocene and Miocene)

Ts - Santa Fe Formation (Pliocene and Miocene)
Stratified sand and gravel derived mostly from Precambrian and upper Paleozoic rocks; Overlain by deeply weathered pediment surface sloping away from mountains; equivalent to Pliocene and Miocene Dry Union Formation; as much as 400 m thick in subsurface of Wet Mountain Valley (Scott and Taylor, 1975). Description from source maps: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle and Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Ts - Santa Fe Formation (Pliocene and Miocene)
Stratified gravel, sand, and clay. As much as 50 m exposed in cliffs and small resistant hills in San Luis Valley. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Tgr - Granite and granodiorite (Pliocene, Miocene and Oligocene)

Small, irregular-shaped, locally foliated bodies of tan to light-gray, leucocratic, medium- to coarse-grained, senate granite and granodiorite. Composed of zoned plagioclase, microcline, and quartz, 1-5 percent biotite, and accessory magnetite and apatite; feldspar and biotite locally altered to muscovite and chlorite. Contains inclusions of partially resorbed xenoliths of fine-grained, crystalline rocks. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Ta - Andesite (Miocene)

Andesitic lahar, biotite latite, and dense homblende-pyroxene andesite. Correlated with the hornblende-pyroxene andesite of Scott and Taylor (1974) on the basis of lithology. About 100 m thick. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Tmv - Mafic volcanic rocks (Miocene?)

Tmv - Volcanic Rocks (Miocene?)
Description from Burford (1960, p. 105 115): exposed from Crystal Falls Creek to South Fork of Bruff Creek along the eastern side of the range; flows and flow breccias of dark-brown olivine basalt; locally vesicular. Probably erupted from a fissure; flow foliation dips into the axis of elongate bodies in Medano Pass quadrangle. More than 75 m thick. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Tmv - Mafic Volcanic Rocks (Miocene)
Black, vesicular, porphyritic olivine basalt (Burford, 1960). Contains scattered phenocrysts of olivine as much as 1 cm across set in an aphanitic groundmass. Composed of several flows probably erupted from a fissure as shown by flow foliation dipping into axis of elongate area of outcrop. Rests unconformably on Sangre de Cristo Formation. Locally 75 m thick. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Tm - Mafic intrusive rocks (Miocene or Oligocene)

Tm - Mafic Intrusive Rocks (Miocene? or Oligocene?)
Dikes and sills of lamprophyric rocks as much as 10 m thick. Dark gray-green to black, aphanitic, locally porphyritic, not foliated, composed mainly of amphibole and plagioclase, minor iron oxide minerals, and locally, biotite, pyroxene, and olivine. Sharp contacts with wall rocks. Dike near summit, east side Cleveland Peak, contains approximately 30 percent light green augite phenocrysts, 30 percent small euhedral biotite phenocrysts, and about 5 percent opaque minerals all surrounded by interlocking plagioclase; minerals unaltered except for minor sericite replacing plagioclase and sericite and chlorite replacing phenocrysts of an unidentified mineral. Lamprophyre dikes resembling the one described here cut rocks of Paleozoic age in Rito Alto Peak quadrangle (Lindsey and others, 1985a); small, unmapped bodies of lamprophyre near Independence and Deadman Creek thrusts cut lower Paleozoic carbonate rocks (Clement, 1952, p. 70 79). Queried symbol (Tm?) indicates uncertain assignment to this unit; may include some dikes and sills of unit Xm. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Tm - Mafic Dikes (Miocene or Oligocene)
Dark-gray-green to black, aphanitic to medium-grained, holocrystalline dikes as much as 3 m wide; nearly all are too small or too poorly known to show at map scale; generally massive, locally porphyritic. Identifiable minerals include subequal amounts of plagioclase and hornblende and 5-10% opaques; pyroxene- and olivine-bearing varieties occur locally. Nonfoliated; sharp contacts with host rocks. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Tm - Mafic Rocks (Miocene or Oligocene)
Dikes and sills of dark-gray to greenish-black mafic rocks. Dike of hornblende lamprophyre 1.5 km east of Blind Lake is 3-5 m thick; contains about 37 percent phenocrysts of euhedral green hornblende (30 percent), biotite (5 percent) partly altered to chlorite, and augite (2 percent); phenocrysts set in interlocking, coarsely crystalline grains of altered plagioclase; accessory magnetite, sphene, and apatite. Dike of hornblende lamprophyre south of Wild Cherry Creek, as much as 10 m thick; composed of abundant fresh, green-brown hornblende phenocrysts, smaller altered plagioclase phenocrysts, and minor euhedral magnetite in altered matrix; contains round autoclasts locally; parallel-layered dikes 1-3 m wide in wall rock. Breccia dike, 1-2 m wide and 100 m long, near mines at mountain front east of Spring Creek; contains abundant clasts of gneiss (Xgn) and feldspar

derived from wall rock, in matrix of quartz and blade-shaped hematite; mineralized with pyrite and chalcopyrite(?) and secondary limonite and malachite in fracture fillings in dike and sheared wall rock. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Tm - Mafic Dikes (Oligocene or Miocene)
Dark-gray-green to black, aphanitic to medium-grained, holocrystalline; generally massive, locally porphyritic. Identifiable minerals include subequal amounts of plagioclase and hornblende and 5-10% opaque minerals; pyroxene- and olivine-bearing varieties occur locally. Nonfoliated. Dikes have sharp contacts with host rocks. Most are too small or too poorly known to show at map scale; patterned where more than 10 m thick. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

*Unit is mapped as both an area and a linear feature in the GRI digital geologic-GIS data.

Tf - Felsic dikes and sills (Oligocene)

Tf - Felsite (Miocene or Oligocene)
Sills and dikes of light-gray to white, fine-grained igneous rock, generally 1-8 m thick. Margins generally not chilled; wall rocks not metamorphosed. Contains microphenocrysts of bipyramidal quartz, plagioclase, potassium feldspar and mica in a fine-grained matrix of same minerals. Dike in thrust fault south of Loco Hill contains abundant microphenocrysts of plagioclase and muscovite; quartz and potassium feldspar accompany these minerals in groundmass. Locally intruded along thrust and reverse faults in both Paleozoic and Precambrian rocks. Felsite dike in Horn Peak quadrangle dated at 26.4±1.1 million years by fission-track method on zircon (Lindsey and others, 1984). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Tf - Felsic Dikes (Miocene or Oligocene)
Light-gray to white, fine-grained, felsite dikes as much as 3 m wide; porphyritic; nonfoliated. Composed of microphenocrysts as much as 2 mm in diameter of quartz, feldspar, and locally sparse biotite in an aphanitic groundmass of the same minerals. Locally altered to quartz and sericite. Age based on one fission-track determination of 26.5 + 1.1 Ma on zircon from dike in Horn Peak 7 1/2-minute quadrangle (C.W. Naeser, written communication., 1982). Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Tf - Felsite (Miocene or Oligocene)
Dikes and sills of light—gray to white, aphanitic to porphyritic igneous rock; contains microphenocrysts as much as 2 mm across of quartz, plagioclase, potassium feldspar, and biotite; groundnass of quartz, feldspar, and biotite. Commonly altered; dikes in Crestone thrust contain abundant metamorphic muscovite and chlorite. Margins generally not chilled; wall rocks not contact metamorphosed. Dated at 26.5±1.1 m.y. in Horn Peak quadrangle (C. W. Naeser, written commun., 1983; Lindsey, Scott, and others, 1984) by fission-track method on zircon. As much as 10 m thick. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Tf - Felsic dikes (Miocene or Oligocene)
Light-gray to white, fine-grained granitic dikes; usually porphyritic; nonfoliated. Composed of microphenocrysts as much as 2 mm in diameter of quartz, feldspar, and locally sparse biotite in an aphanitic groundmass of the same minerals. Includes coarser grained granite and aplite dikes and quartz veins in high-angle faults. Locally altered to quartz and sericite. Age based on one fission-track determination of 26.5±1.1 Ma on zircon (C.W. Naeser, written commun., 1982). As much as 50 m thick. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Tf - Felsic Dikes (Oligocene)

Predominantly light-gray to white, fine-grained granitic dikes; usually porphyritic; nonfoliated. Composed of microphenocrysts as much as 2 mm in diameter of quartz, feldspar, and locally sparse biotite in an aphanitic groundmass of the same minerals. Includes coarser grained granite and aplite dikes and quartz veins in high-angle faults. Locally altered to quartz and sericite. Age based on one fission-track determination of 26.5±1.1 Ma on zircon (C.W. Naeser, written communication, 1982). As much as 50 m thick. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

*Unit is mapped as both an area and a linear feature in the GRI digital geologic-GIS data.

Jm - Morrison Formation (Late Jurassic)

Description modified from Volckmann (1965, p. 66 67): interbedded gray and brown shale, gray to brown sandstone, and minor gray, fine grained limestone; exposed in overturned syncline at Loco Hill; about 50 70 m thick. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Je - Entrada Sandstone (Middle Jurassic)

Description modified from Volckmann (1965, p. 66 67): thin-bedded, white to tan, friable quartz sandstone; sand is fine to medium grained, well sorted, well-rounded, and frosted; exposed in overturned syncline at Loco Hill. Unconformably overlies undivided Sangre de Cristo Formation and is unconformably overlain by Santa Fe Formation; estimated at about 30 40 m thick. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PPNsu - Sangre De Cristo Formation, undivided (Permian and Pennsylvanian)

PPNsu - Sangre De Cristo Formation (Permian and Pennsylvanian)
Red arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone, arranged in fining upward alluvial cycles estimated at 1 30 m thick. Sandstone and conglomeratic sandstone crossbedded; siltstone and shale contain ripple marks and cross-laminations, mudcracks, possible raindrop impressions, and burrows. Thin (1 m) limestone beds mostly unfossiliferous, fine-grained, nodular to laminated; probably paleosol deposits. Marine limestone beds (Is) near fossil locality SC1185A on Music Creek contain abundant bryozoan fossils typical of Permian and Pennsylvanian strata, including Streblotrypa (Streblascopora) sp. (0. L. Karklins, 1983, written commun.) Unconformably overlain by Jurassic Entrada Sandstone at Loco Hill. Thickness reaches 1,400 m at Horn Peak north of map area (Lindsay and others, 1984). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PPNsu - Sangre de Cristo Formation, Undivided (Permian)
Red arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone. Exposed east of Sand Creek thrust. Maximum exposed thickness is about 1,400 m at Horn Peak (Lindsey and others, 1984), north of map area. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

PPNsu - Sangre De Cristo Formation (Permian and Pennsylvanian)
Undivided Red arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone arranged in fining upward alluvial cycles 1-30 m thick. Located entirely northeast of Spread Eagle Peak thrust. Sandstone and conglomeratic sandstone crossbedded; siltstone and shale contain ripple marks, cross-lamination, mudcracks, possible raindrop impressions, and burrows. Thin (less than 1 m) beds of unfossiliferous, fine-grained, nodular to laminated limestone; probably paleosol deposits. Conformably overlies undivided Minturn Formation in Electric Peak quadrangle, where unit is about 2,500 m thick (Lindsey, Soulliere, and Hafner, 1985); top eroded. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PPNsc - Sangre De Cristo Formation, Crestone Conglomerate Member (Permian and Pennsylvanian)

PPNsc - Sangre de Cristo Formation, Crestone Conglomerate Member (Permian and Pennsylvanian)
Red conglomerate, conglomeratic sandstone, sandstone, and minor siltstone and shale in thrust sheets (Lindsey and Schaefer, 1984). Conglomerate consists of boulders, cobbles, and pebbles of igneous and metamorphic rocks in matrix of feldspathic sand and clay; deposited by debris flows, mudflows, and streams on alluvial fans east of Uncompahgre highland of Ancestral Rocky Mountains (Lindsey and others, in press). Sandstone horizontally laminated and crossbedded, deposited by streamflow. Two lithofacies are distinguished by the presence of (1) abundant clasts of pink quartz monzonite porphyry and related rocks and (2) abundant clasts of gneiss. Clasts of quartz monzonite porphyry and related rocks are derived from rocks correlated with the Boulder Creek Granodiorite and other rocks of the Routt Plutonic Suite (Tweto, in press), including the quartz monzonite of Music Pass (Xqm). Gneiss clasts are derived from gneiss of 1,700 1,800 million years age. Quartz monzonite clast facies is mostly north of Jones Creek and Huckleberry Mountain; gneiss conglomerate facies is mostly south of Jones Creek and also between Sand Creek and Little Sand Creek. From Crestone Needle to Milwaukee Peak, the lower part of Crestone Conglomerate Member unconformably overlies Minturn Formation. On the ridge south of Spanish Creek, on the ridge between Little Sand Creek and Sand Creek, and in the Medano Pass quadrangle, Crestone rests unconformably on biotite gneiss (Xgn) and quartz monzonite (Xqm). Thickness about 2,000 m. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PPNsc - Sangre de Cristo Formation, Crestone Conglomerate Member (Permian and Pennsylvanian)
Red conglomerate, conglomeratic sandstone, and minor siltstone and shale. Exposed between Sand Creek thrust and Little Sand Creek thrust. Coarse conglomerate contains boulders and cobbles of Early Proterozoic gneiss (Xgn and Xlgn), syenite, and quartz monzonite (Xqm). Unit unconformably overlies Early Proterozoic gneiss (Xgn) near Medano Creek. Thickness approximately 2,000 m immediately north of map area. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

PPNsc - Sangre De Cristo Formation, Crestone Conglomerate Member (Permian and Pennsylvanian)
Red conglomerate, conglomeratic sandstone, sandstone, and minor siltstone and shale (Lindsey and Schaefer, 1984). Divided into two lithofacies by presence of abundant clasts of (1) red syenite (syenite clast facies) and (2) pink porphyry (quartz-monzonite clast facies) derived from quartz monzonite and syenite and monzonite (Xsm) correlated with Boulder Creek Granodiorite of Early Proterozoic age; small slices in Crestone thrust not assigned to either facies, but most probably belong to quartz-monzonite clast facies. Coarse conglomerate composed of boulders, cobbles, and pebbles of igneous and metamorphic rocks in matrix of feldspathic sand and clay-size material; deposited by debris flows, mud flows, and streams on alluvial fans. Sandstone horizontally laminated and crossbedded. Interfingers abruptly with lower member of Sangre de Cristo Formation in southeastern part of nap area. Conformably overlies lower member of Sangre de Cristo Formation except in fault slice of Crestone thrust northwest of Rito Alto Creek, where conglomerate containing abundant dolomite clasts rests in depositional contact with carbonate rocks (MDO) of Mississippian through Ordovician age. Thickness about 1,100 m at principal reference section in Groundhog basin (Lindsey and Schaefer, 1984); as much as 2,000 m on west side of Gibson Peak syncline. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PPNscd - Sangre De Cristo Formation, Crestone Conglomerate Member, marker bed of diamictite (Permian and Pennsylvanian)

d - Sangre De Cristo Formation, Crestone Conglomerate Member, marker bed of diamictite (Permian and Pennsylvanian)
From Crestone Needle to Milwaukee Peak, in lower part of Crestone Conglomerate Member, as much as 40 m thick contains distinctive clasts of amphibolite and tourmaline pegmatite. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PPNsl - Sangre De Cristo Formation, lower member (Permian and Pennsylvanian)

PPNsl - Sangre De Cristo Formation, Lower Member (Permian and Pennsylvanian)
Red arkosic sandstone, conglomeratic sandstone, siltstone, and shale, arranged in fining- upward cycles, 2 40 m thick, deposited by braided streams (Lindsey and Schaefer, 1984); crops out west of Spread Eagle Peak thrust. Sandstone contains crossbedding; siltstone and shale contain ripple marks, cross lamination, and sparse mudcracks. Contact conformable with underlying Minturn Formation. As thick as 900 m in Rito Alto quadrangle (Lindsey and others, 1985b); interfingers with Crestone Conglomerate Member in Horn Peak (Lindsey and others, 1984) and Rito Alto quadrangles. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PPNsl - Sangre de Cristo Formation, Lower Member (Permian and Pennsylvanian)
Red arkosic sandstone, conglomeratic sandstone, siltstone, and shale; arranged in fining—upward cycles, 2-40 m thick; deposited by braided streams on distal surface of alluvial fans (Lindsey and Schaefer, 1984). Located entirely west of Spread Eagle Peak thrust. Lower 300 n contains a few thin (less than 1 n) limestone beds containing crinoids, brachiopods, fusulinids, and stromatolites; beds along strike in Electric Peak quadrangle contain conodonts of Atokan or Desmoinesian age (B. R. Wardlaw, 1982, written commune.). Base placed at first fining-upward sandstone cycle above marker limestone bed (mls) of Minturn Formation (Lindsey and Schaefer, 1984). Conformably overlies Minturn Forma¬tion; interfingers upward and southward with Crestone Conglomerate Member of Sangre de Cristo Formation. Thickness about 600-900 m. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PPNsls - Sangre De Cristo Formation, marine limestone beds (Permian and Pennsylvanian)

ls - Sangre De Cristo Formation: marine limestone beds (Permian and Pennsylvanian)
Mear fossil locality SC1185A on Music Creek contain abundant bryozoan fossils typical of Permian and Pennsylvanian strata, including Streblotrypa (Streblascopora) sp. (0. L. Karklins, 1983, written commun.). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

*Unit is mapped as a linear feature in the GRI digital geologic-GIS data.

PNm - Minturn Formation, undivided (Middle Pennsylvanian)

PNm - Minturn Formation (Middle Pennsylvanian)
Gray and red arkosic sandstone, conglomerate, siltstone, shale, and marine limestone. Occurs as overturned, thrust-bounded slice on west side of range at Willow and South Crestone Creeks, and as nearly complete section above thrust on Marble Mountain, east side of range. On Marble Mountain Minturn consists of fining upward alluvial cycles of conglomerate, sandstone, and shale; conglomerate beds of probable debris flow origin; sandstone containing large deltaic foresets, deposited in standing

water; and marine limestone beds. Entire assemblage deposited on and near fan deltas (Lindsey and others, in press). From Broken Hand Peak north to Crestone Peak, unconformably overlain by Crestone Conglomerate Member; lower contact is Marble Mountain segment of Spread Eagle Peak thrust; thickness approximately 1,500 m. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PNm - Minturn Formation (Middle Pennsylvanian)
Gray arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone. Contains fossils of marine invertebrates and terrestrial plants. Some siltstone and shale in upper part is radioactive and copper bearing; marine limestone is most abundant in upper part. Located in thrust slices intercalated between Precambrian rocks; fault at base of Mintum Formation truncates bedding. As much as 500 m exposed. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

PNm - Minturn Formation (Middle Pennsylvanian)
Gray arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone. Contains fossils of marine invertebrates and terrestrial plants. Some siltstone and shale in upper part is radioactive and copper bearing; marine limestone is most abundant in upper part. Located in a thrust fault window overlain by Early Proterozoic rock; total thickness unknown. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

PNmu - Minturn Formation, upper part (Middle Pennsylvanian)

Gray and red arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestone. Located entirely west of Spread Eagle Peak thrust. Deposited by fan deltas prograding into shallow water above wave base (Lindsey, Clark, and Soulliere, 1985). Sandstone crossbedded; siltstone and shale contain ripple marks and cross lamination. Contains numerous limestone beds in upper 500 m on east side of Gibson Peak syncline and in upper 300 m on west side of syncline. Most limestone beds thin (0.5-2 m), locally continuous, and contain marine invertebrate fossils (Clark and Walz., 1985). On east side of Gibson Peak syncline, contains local units: top unit of conspicuously crossbedded conglomeratic sandstone, 40-70 m thick. Below phylloid algal limestone, upper part of Minturn on west side consists of 400-500 m of red arkosic sandstone and siltstone cut by thrusts. On east side, fossil conodonts of Middle Pennsylvanian age in marker limestone at localities D423-PC, SC-33B, and D2O3-PC (B. R. Wardlaw, written commun., 1980, 1982); beds along strike to southeast in Horn Peak quadrangle contain fusulinids (Beedeina sp.) of late Desnoinesian age (R. C. Douglass, written comnun., 1982; Lindsey, Scott, and others, 1984). Locally abundant remains of fossil land plants; some in growth position. On west side of Gibson Peak syncline, Pennsylvanian conodonts (locality D430—PC) and sparse Fusulinella? sp. (locality f14479) of late Atokan or early Desmoinesian age at top of Minturn (B. R. Wardlaw, written commun., 1982; R. C. Douglass, written commun., 1981). Total thickness about 960 n at reference section east of Eureka Mountain (Lindsey, Clark, and Soulliere, 1985). Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PNmmls - Minturn Formation, marker limestone (Middle Pennsylvanian)

mls - Minturn Formation, marker limestone (Middle Pennsylvanian)
fossiliferous in upper part, shaley and anomalously radioactive in lower part, 1—2 m thick, 40-70 m below top. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

*Unit is mapped as a linear feature in the GRI digital geologic-GIS data.

PNmcls - Minturn Formation, marker bed of crinoidal silty limestone (Middle Pennsylvanian)

cls - Minturn Formation, Crinoidal Silty Limestone Marker Bed (Middle Pennsylvanian)
About 230 m below top, 12 16 m thick, containing abundant crinoid columnals as much as 0.3 m long, brachiopods, sponge spicules, and bryozoans; shaly, carbonaceous, and radioactive in lower part. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

PNmbls - Minturn Formation, brown-weathring limestone (Middle Pennsylvanian)

bls - Minturn Formation, brown-weathering limestone (Middle Pennsylvanian)
0.5-2 m thick, fossiliferous, about 250 m below top. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

*Unit is mapped as a linear feature in the GRI digital geologic-GIS data.

PNmpals - Minturn Formation, marker bed of phylloid algal limestone (Middle Pennsylvanian)

pals - Minturn Formation, marker bed of phylloid algal limeston (Middle Pennsylvanian)
On west side of Gibson Peak syncline, about 2 m thick, located about 300 m below top. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

*Unit is mapped as a linear feature in the GRI digital geologic-GIS data.

PNmsh - Minturn Formation, shale and siltstone member (Middle Pennsylvanian)

sh - Minturn Formation, shale and siltstone member (Middle Pennsylvanian)
brown-black, fissile, 60-70 m thick, about 500 m below top. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PNmols - Minturn Formation, marker bed of oolite limestone (Middle Pennsylvanian)

mols - Minturn Formation, Oolite Limestone Marker Bed (Middle Pennsylvanian)
About 900 m below top, 4 m thick. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

*Unit is mapped a linear feature in the GRI digital geologic-GIS data.

PNmlbls - Minturn Formation, lenticular biohermal limestone unit (Middle Pennsylvanian)

bls - Minturn Formation, Lenticular Biohermal Limestone Units (Middle Pennsylvanian)
About 1,000 m below top, 300 m thick and extending 1,500 m along strike, containing abundant brachiopods, including Eomarginifera sp., typical of Atokan rocks (B. R. Wardlaw, 1979, written common.), and other marine invertebrate fossils (Berg, 1967). Bioherms contain fusulinids (Beedeina sp., localities f14566 and fl4567) of Desmoinesian age (R.C Douglass, 1982, written communication); and conodonts (localities D204PC, D205PC, D206PC, D207PC, and D208PC, representing the stratigraphic range of the south bioherm that include forms transitional between Neoginthodus roundyi Gunnell and N. dilatus Stauffer and Plummer, assigned either an Atokan or a Desmoinean age (B.R. Wardlaw, 1980, written commune). Description from source map: Beck Mountain and Crestone Peak

Quadrangles and parts of the Crestone Quadrangle.

PNmt - Minturn Formation, main turbidite member (Middle Pennsylvanian)

Gray, pebbly to medium-grained, arkosic sandstone, siltstone, and minor shale arranged in graded cycles 0.2-1.0 m thick; typical of turbidity flow deposits; interpreted as prodelta deposit (Soulliere and others, 1984). Located entirely on east side of Gibson Peak syncline and west of Spread Eagle Peak thrust. Grades upward into ridge-forming conglomeratic sandstone of the upper part of the Minturn Formation and downward into shale, siltstone, and sandstone of the lower part of the Minturn formation. Thickness 100-150 m. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PNml - Minturn Formation, lower part (Middle Pennsylvanian)

Gray arkosic sandstone, conglomeratic sand¬stone, siltstone, and shale, arranged in coarsening-upward deltaic cycles 30-300 m thick (Lindsey, Clark, and Soulliere, 1985). Located entirely east of Gibson Peak syncline and west of Spread Eagle Peak thrust. In Horn Peak quadrangle to southeast, contains fossil pelecypode, brachiopods, and fragments of land plants (Lindsey, Scott, and others, 1984). About 400 m exposed in axial zone of Cotton Lake anticline; about 1,100 m thick in Horn Peak quadrangle. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PNmq - Minturn Formation, quartoze red-beds (Middle Pennsylvanian)

Red quartz-pebble sandstone, conglomerate, siltstone, and shale; arranged in fining-upward cycles. Located entirely on west side of Gibson Peak syncline. Abundant rounded pebbles and granules of white vein quartz and pink quartz-feldspar rock; cross-bedded. Interbedded gray and tan calcareous shale and siltstone. Metamorphosed, contains muscovite and locally, chloritoid and talc (Karig, l964a), Sparse carbonized plant remains. Mapped as Kerber Formation and Sharpsdale Formation of Chronic (1958) by Karig (l964b). Incomplete section cut by thrusts; about 300 m thick. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

MDOr - Mississippian, Devonian and Ordovician sedimentary rocks, undivided (Mississippian, Devonian and Ordovician)

MDO - Undivided Sedimentary Rocks (Mississippian, Devonian and Ordovician)
Description summarized from Taylor and others (1975), Karig (1964), and Clement (1952); exposed along west side of range. In descending stratigraphic order: (1) Lower Mississippian Leadville Limestone, composed of gray, medium bedded to massive limestone, locally fossiliferous and cherty, 35 m thick. (2) Mississippian(?) to Upper Devonian Chaffee Formation, composed of yellow-gray dolomite and gray, massive sandstone and dolomite; faulted section 15 m thick reported in Alpine Creek (Clement, 1952, p. 45). (3) Upper Ordovician Fremont Dolomite, composed of dark gray crystalline dolomite; thickness unknown in map area but as much as 50 m to north. (4) Middle Ordovician Harding Sandstone, composed of pale red to white, thin bedded quartzite; 20 30 m thick. Harding unconformably overlies gneiss (Xgn) and two units of quartz monzonite (Yqm and Xqm). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

MDOr - Mississippian, Devonian, and Ordovician sedimentary rocks, undivided
Description of a full stratigraphic section in areas north of map area summarized from Taylor, Scott, and Wobus (1975), Karig (1964), and Koch (1963); in descending stratigraphic order: (1) Lower Mississippian Leadville Limestone: dark-gray, massive limestone, locally contains Limestone breccia, 70m thick; (2) Mississippian(?) to Upper Devonian Chaffee Group: Dyer Dolomite (yellow-gray, cherty

dolomite, 30 m thick) and Parting Quartzite (gray, massive quartzite and dolomite, 15m thick); (3) Upper Ordovician Fremont Dolomite: dark-gray, coarsely crystalline dolomite, 70 m thick; (4) Middle Ordovician Harding Sandstone: pale-red, thin-bedded quartzite, 30 m thick; and (5) Lower Ordovician Manitou Limestone: dark-gray, fine-grained, cherty, dolomitic limestone, 60 m thick. Rocks exposed in window of folded Deadman Creek thrust along west side of Sangre de Cristo Range, where they lie unconformably above Early Proterozoic rocks (Xgn and Xqm) and structurally below Early Proterozoic gneiss. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

MDO - Sedimentary Rocks Undivided (Mississippian, Devonian And Ordovician)
Description summarized from Taylor and others (l975a), Karig (l964b), and Koch (1963). Stratigraphic position is given in descending order: (1) Lower Mississippian Leadville Limestone: dark-gray, massive; locally contains limestone breccia and invertebrate fossils, scattered exposures on ridges northwest of Rito Alto Creek and south of North Crestone Creek; a few meters thick. (2) Mississippian (?) to Late Devonian Chaffee Formation, described from the Howard quadrangle (Taylor and others, 1975a): Dyer Dolomite Member, yellowish-gray, cherty dolomite; Parting Quartzite Member, gray, massive quartzite and dolomite, reported by Karig (1964b) but not confirmed in map area. (3) Late Ordovician Fremont Dolomite: dark-gray; coarsely crystalline dolomite, about 50 m thick on ridge north of Wild Cherry Creek and at North Crestone Creek. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

MDOr - Mississippian, Devonian, and Ordovician sedimentary rocks, undivided
Description of a full stratigraphic section in areas north of map area summarized from Taylor, Scott, and Wobus (1975), Karig (1964), and Koch (1963) Units exposed in a narrow belt near crest of Sangre de Christo Range east of Sheep Ridge, where they lie unconformably above and structurally below Early Proterozoic gneisses (Xgn and Xhgn). In descending stratigraphic order: (1) Leadville Limestone (Lower Mississippian) dark-gray, massive limestone, locally contains limestone breccia, 70 m thick. (2) Chaffee Group (Devonian-Mississippian) Dyer Dolomite - yellow-gray, cherty dolomite, 30 m thick. Parting Quartzite - gray, massive quartzite and dolomite, 15 m thick. (3) Fremont Dolomite (Upper Ordovician) dark-gray, coarsely crystalline dolomite, 70 m thick. (4) Harding Sandstone (Middle Ordovician) pale-red, thin-bedded quartzite, 30 m thick. (5) Manitou Limestone (Lower Ordovician) dark-gray, fine-grained, cherty, dolomitic limestone, 60 m thick. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Oh - Harding Sandstone (Ordovician)

Pale-red to light-gray, thin-bedded quartzite; well-sorted, pure quartz sand; lower meter contains rounded granules and pebbles of vein quartz. Conformably overlies Manitou Limestone north of Wild Cherry Creek; unconformably overlies quartz monzonite (Yqm) south of North Crestone Creek. Thickness 20-30 m north of Wild Cherry Creek; as much as 60 m thick south of North Crestone Creek. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Om - Manitou Limestone (Ordovician)

Dark-gray, fine-grained, cherty, dolomitic limestone; occurs only north of Wild Cherry Creek, where it unconformably overlies Precambrian gneiss (Xgn); about 10-20 m thick. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

PRm - Mafic dikes (Proterozoic)

Pm - Mafic dikes (Proterozoic)
Predominantly nonfoliated, dark-gray-green to black, aphanitic to coarse-grained, holocrystalline, basaltic and gabbroic dikes and sills; generally massive, locally porphyritic. Identifiable minerals include sub-equal amounts of plagioclase and homblende and 5-10 percent opaque minerals;

pyroxene- and olivine-bearing varieties occur locally. Dikes have sham contacts with host rocks; unit locally includes similar appearing Tertiary dikes; also includes numerous metagabbro dikes near contacts between metagabbro (Xg) and tonalite gneiss (Xto). Metagabbro dikes are commonly foliated parallel to foliation of surrounding gneiss. Dikes are as much as 100 m thick and those shown are representative of the mafic dike distribution, but not all dikes can be shown at this scale; patterned where more than 10 m thick. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

*Unit is mapped as both an area and a linear feature in the GRI digital geologic-GIS data.

Yqm - Quartz monzonite (Middle Proterozoic)

Yqm - Quartz Monzonite (Middle Proterozoic)
Stock of gray to pink, medium grained quartz monzonite north of Willow Creek; generally nonfoliated. According to Johnson, Lindsey, and others (in press) composed of about 35 percent plagioclase, 30 percent microcline, 30 percent quartz, 2 5 percent biotite, and accessory magnetite; extensively altered to chlorite, epidote, and muscovite (including sericitized plagioclase); scattered inclusions of mafic rock; locally, small (less than 1 m thick) pegmatite dikes. Correlated with 1,400 million year old Berthoud Plutonic Suite, which also includes Silver Plume Quartz Monzonite of central Colorado (Tweto, in press). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Yqm - Quartz Monzonite (Middle Proterozoic)
Stock of gray to pink, medium-grained quartz monzonite; generally nonfoliated. According to Johnson and others (1985), composed of approximately 35 percent plagioclase, 30 percent microcline, 30 percent quartz, 2-5 percent biotite, and accessory magnetite; metamorphosed to chlorite, epidote, and muscovite; scattered inclusions of mafic rock; locally, small (less than 1 m thick) pegmatite dikes; large pod of vein quartz (qz) in quarry along mountain front. Correlated with 1.45-b.y.-old Silver Plume Quartz Monzonite of central Colorado (Scott and Taylor, 1974; Taylor and others, l975b). Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Yqz - Vein quartz (Middle Proterozoic)

qz - Quartz monzonite, vein quartz (Middle Proterozoic)
Large pod of vein quartz (qz) in quarry along mountain front. Correlated with 1.45-b.y.-old Silver Plume Quartz Monzonite of central Colorado (Scott and Taylor, 1974; Taylor and others, l975b). Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Xp - Pegmatite (Early Proterozoic?)

Dikes as much as 15 m thick, mostly in and near gneiss (Xgn) south of Marshall Gulch. Most trend northerly and dip steeply. Composed mostly of potassium feldspar and quartz, minor muscovite, plagioclase, and black tourmaline; graphic intergrowths of potassium feldspar and quartz locally. Contacts sharp to gradational; numerous apophyses and small dikes (not shown on map). Prospected extensively. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

*Unit is mapped as a linear feature in the GRI digital geologic-GIS data.

Xsm - Syenite and monzonite (Early Proterozoic)

Stocks of reddish-pink, medium to coarse-grained porphyry of syenite to monzonite; large (1-2 cm) phenocrysts of microcline; nonfoliated to weakly foliated. According to Johnson and others (1985), composed of 50-80 percent microcline, as much as 35 percent plagioclase, 1-5 percent quartz, as much as 10 percent biotite; minor muscovite, and accessory zircon and sphene. Contains large inclusions of gneiss (Xgn), mafic dikes, and pods; large pegmatite dikes (Xp) cross contacts of gneiss (Xgn) and stocks (Xsm). Locally interlayered with gneiss. Correlated with 1.7-b.y.-old Boulder Creek Granodiorite of central Colorado (Scott and Taylor, 1974). Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Xm - Mafic intrusive rocks (Early Proterozoic)

Mafic dikes and sills of diabasic and gabbroic rocks; commonly foliated, chloritized; as much as 10 m thick. Includes dike near Music Pass, thickness variable up to 60 m, contacts sharp, composed of olivine-augite gabbro, ranging from fresh to much sheared and chloritized. Fresh gabbro near Music Pass composed of lath shaped calcic plagioclase (greater than 60 percent), partly altered to sericite; approximately equal amounts of olivine and augite; minor hornblende surrounding and replacing augite; and accessory minerals biotite, magnetite, and apatite (Volckmann, 1965, p. 23). Queried where assignment to this unit is uncertain; may include lamprophyric dikes and sills of unit Tm. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

*Unit is mapped as both an area and a linear feature in the GRI digital geologic-GIS data.

Xqm - Quartz Monzonite of Music Pass (Early Proterozoic)

Xqm - Quartz Monzonite of Music Pass (Early Proterozoic)
Summarized from Johnson, Lindsey, and others (in press). Gray to pink, coarse grained, foliated quartz monzonite porphyry; groundmass grain size averages 2 mm. White to pink, subhedral microcline phenocrysts as much as 4 cm across make up 25 45 percent of the rock; groundmass is made up of approximately 60 percent plagioclase, 20 percent quartz, 20 percent biotite, and as much as 1 percent sphene and magnetite. Apparently intrusive into gneiss (Xgn) and quartzite (Xq); mafic pods and xenoliths are common locally; sparse quartzite xenoliths in vicinity of contact with quartzite (Xq) on Snowslide Mountain. Correlated with the 1,700 million year old Routt Plutonic Suite, which also includes Boulder Creek Granodiorite of central Colorado (Tweto, in press). Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Xqm - Quartz Monzonite of Music Pass (Early Proterozoic)
Gray to pink, coarse-grained, foliated, quartz monzonite porphyry; white to pink, subhedral, microcline phenocrysts as much as 4 cm across make up 25-45% of rock; groundmass is composed of approximately 60% plagioclase, 20% quartz, 20% biotite, and as much as 1% sphene and magnetite; average grain size of groundmass is 2 mm, but monomineralic feldspar clots give an illusion of a coarser texture; rock is locally well foliated; boudinage of microcline phenocrysts accompanies increased foliation intensity, particularly near faulted contacts of unit. Entire unit weakly cataclastic. Mafic pods and large mafic xenoliths are common locally. Correlated with the 1,700-Ma-old Boulder Creek Granodiorite of central Colorado (Gable, 1980) on the basis of lithology and texture. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Xq - Quartzite (Early Proterozoic)

Black and gray to white, layered quartzite, brecciated intensely at north and south ends of outcrop; breccia fragments vary from millimeters to meters across in matrix of crushed quartzite. Quartzite composed mostly of interlocking, recrystallized quartz grains and minor amounts of iron oxide minerals and muscovite; opaque minerals concentrated in layers oriented at large angles to contacts. Quartzite occurs as 100 m wide layer and as scattered, poorly exposed xenoliths within the quartz monzonite of Music Pass; xenoliths have narrow rims of microcline and biotite replacing quartz. Contact with quartz monzonite intrusive; contact with gneiss (Xgn) possibly depositional. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Xlgn - Leucocratic gneiss (Early Proterozoic)

Xlgn - Leucocratic gneiss (Early Proterozoic)
Description modified from Johnson, Lindsey, and others (in press). White to medium gray, light pink to light-gray weathering, leucocratic gneiss of granitic to granodioritic composition. Variably massive, laminated, and layered; foliated; locally migmatitic. Layers of mafic gneiss make up about 20 percent of unit overall. Grain size varies but averages about 2 mm; locally porphyroblastic; pervasive weak cataclastic texture. Leucocratic layers contain about 35 percent plagioclase, 30 percent quartz, 30 percent microcline, 4 percent biotite, and trace of hornblende or muscovite. Mafic layers contain about 40 percent plagioclase, 25 percent quartz, 20 percent microcline, and 15 percent mafic minerals. Mafic minerals include approximately equal amounts of biotite and hornblende and accessory magnetite and sphene; mafic minerals commonly altered to chlorite. Separated from other gneiss (Xgn) by thrust faults. Possibly represents metamorphosed volcanic and Volcaniclastic rocks of rhyolitic to dacitic composition. Thickness unknown. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Xlgn - Leucocratic gneiss (Early Proterozoic)
Approximately 80% of unit is white to medium gray, light-pink- to light-gray -weathering leucocratic gneiss composed of about 30% quartz, 30% microcline, 35% plagioclase, 4% biotite, and locally trace amounts of hornblende or muscovite; texture varies from massive, near summit of Mount Seven, to finely laminated on a millimeter scale to coarsely layered on a scale of several meters; locally migmatitic; typically seriate having an average grain size of about 2 mm; locally contains porphyroblasts of feldspar as large as 5 cm. Approximately 20% of unit is gray gneiss having composition of granodiorite; composed of about 40% plagioclase, 25% quartz, 20% microcline, and 15% mafic minerals; mafic minerals consist of subequal amounts of biotite and hornblende, as much as 2% magnetite, and as much as 1% sphere; original mafic minerals are commonly altered to chlorite. These rocks are complexly interlayered with light- colored gneiss. Foliation is faint to conspicuous and is produced by subparallel alignment of micas and compositional layers and by minor pervasive cataclasis; compositional bands and laminations are sharply bounded and locally pinch and swell. Small open folds are common. Swirled, disharmonically folded migmatites and nebulites are uncommon. Quartz veins and pods and small pegmatites are common. Protolith was probably a laminated to layered mixture of felsic tuff, tuffaceous sediments, and flows of rhyolite and dacite. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Xto - Tonalite gneiss (Early Proterozoic)

Xto - Tonalite gneiss (Early Proterozoic)
White to light-gray-green, buff-weathering homogeneous gneiss of tonalite composition. Contains porphyroblastic aggregates of mafic minerals as much as 1.5 cm across set in an equigranular groundmass having grain sizes of 3-4 mm. Typically composed of approximately 60 percent plagioclase, 30 percent quartz, 8 percent mafic minerals, 2 percent or less potassium feldspar, and accessory magnetite, apatite, sphene, and sparse garnet. Weak foliation formed by alignment of mafic mineral aggregates; weak to moderate cataclasis throughout unit becomes more intense near faults and shear zones. Original mafic minerals thoroughly altered to epidote, chlorite, and muscovite; relict biotite rarely preserved; potassium feldspar content increases (to as much as 10 percent) near major faults. Unit is intruded by numerous mafic dikes as much as several tens of meters thick; dikes are most abundant near contact with metagabbro (Xg), where they form as much as 50 percent of

outcrop; abundance of dikes decreases rapidly away from metagabbro to less than 1 percent of outcrop in most areas. Contacts between metagabbro (Xg) and tonalite gneiss (Xto) are expressed by interlayering of metagabbro, dark-colored quartz diorite gneiss, and light-colored tonalite gneiss. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Xto - Tonalite Gneiss (Early Proterozoic)
White to light-gray-green, buff-weathering homogeneous gneiss of tonalite composition. Contains porphyroblastic aggregates of mafic minerals as much as 1.5 cm across set in an equigranular groundmass having grain sizes of 3-4 mm. Typically composed of approximately 60% plagioclase, 30% quartz, 8% mafic minerals, 2% or less potassium feldspar, and accessory magnetite, apatite, sphene, and sparse garnet. Weak foliation formed by alignment of mafic mineral aggregates; weak to moderate cataclasis throughout unit becomes more intense near faults and shear zones. Original mafic minerals thoroughly altered to epidote, chlorite, and muscovite; relict biotite rarely preserved; potassium feldspar content increases (to as much as 10%) near major faults. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Xg - Metagabbro (Early Proterozoic)

Dark-gray to very dark green, meta-igneous rock of gabbroic composition. Commonly porphyritic, having 3- to 7-mm phenocrysts of dark-green homblende and white to gray plagioclase in a finer grained matrix composed mainly of plagioclase. Unit composed of nearly 50 percent each of homblende and plagioclase, trace to 4 percent opaque minerals (magnetite, pyrite, and locally copper sulfides), trace to 1 percent apatite, and typically less than 1 percent quartz; contains as much as 10 percent quartz near contact with tonalite gneiss (Xto). Weakly foliated rock near contacts gives way to granoblastic interior. Commonly agmatitic, having angular blocks of dark metagabbro as much as several meters long surrounded by light-colored, tonalitic matrix. A few blocks of metagabbro display faint compositional layering. Commonly cut by thin, white, aplite dikes. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Xqd - Quartz diorite (Early Proterozoic)

Dark-gray to dark-green, predominantly medium grained, locally compositionally banded, seriate to porphyritic homblende quartz diorite. Forms pluton at Zapata Creek, which can be separated into (1) a narrow outer zone of fine-grained, commonly deformed, mafic-rich quartz diorite of variable homblende content, (2) a more uniform intermediate zone of medium-grained, spotted quartz diorite having 1 cm megacrysts and aggregates of hornblende, and (3) a core of fine-grained quartz diorite that becomes lighter colored towards center of body. Average composition (and range) is 50 (35-80) percent homblende, 40 (15-60) percent plagioclase, and 6 percent quartz; as much as 10 percent biotite is present; accessory minerals are magnetite, sphene, and zircon; alteration products are sericite, chlorite, and epidote. Contact with tonalite gneiss. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Xdi - Diorite (Early Proterozoic)

Xdi - Diorite (Early Proterozoic)
Dark-green to dark-gray, fine- to medium-grained, seriate to equigranular, locally foliated homblende diorite. Consists of 50-70 percent euhedral to subhedral homblende, 30-50 percent plagioclase, and as much as 5 percent quartz as inclusions in plagioclase; quartz averages approximately 1 percent of rock; accessory minerals (approximately 2 percent of rock) are magnetite, sphene, and apatite; unit is extensively altered to sericite, chlorite, and epidote. Fracturing and alteration increase to the east. Localities near steep northwest-trending faults are generally foliated. Body is locally injected by numerous interconnecting veins of leucocratic biotite granodiorite to tonalite in amounts of as much as 10 percent. Description from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Xdi - Diorite (Early Proterozoic)
Dark-green to dark-gray, fine- to medium-grained, seriate to equigranular, locally foliated hornblende diorite. Consists of 50-70% euhedral to subhedral hornblende, 30-50% plagioclase, and as much as 5% quartz as inclusions in plagioclase; quartz averages approximately 1% of rock; accessory minerals (approximately 2% of rock) are magnetite, sphene, and apatite; unit is extensively altered to sericite, chlorite, and epidote. Fracturing and alteration increase to the east. Localities near steep northwest-trending faults are generally foliated. Body is locally injected by numerous interconnecting veins (as much as 10% of outcrop) of leucocratic biotite granodiorite to tonalite. Description from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Xhgn - Hornblende gneiss (Early Proterozoic)

Xhgn - Hornblende gneiss (Early Proterozoic)
Schistose to massive, fine- to medium-grained, compositionally homogeneous, quartz-plagioclase-hornblende gneiss; dominantly a well-foliated, laminated gneiss, having sharply bounded, continuous, dark- and light-colored layers 1-5 mm thick. Contact with mixed gneiss (Xgn) is approximate and is placed where hornblende gneiss is dominant over more felsic rocks; thus, numerous unmapped small bodies of hornblende gneiss occur within the mixed gneiss unit (Xgn). Description from source maps: Medano Pass Quadrangle and parts of the Liberty Quadrangle, Parts of the Twin Peaks and Blanco Peak Quadrangles, and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Xgn - Gneiss and mixed gneiss (Early Proterozoic)

Xgn - Gneiss (Early Proterozoic)
Interlayered mafic and felsic gneiss; pink, gray, and black; layered, laminated, and foliated; locally migmatitic and intruded by pegmatite and mafic dikes. Mafic gneiss contains abundant quartz, plagioclase, orthoclase, biotite, and accessory magnetite and sphene; some varieties contain hornblende. Mafic gneiss medium grained, well foliated; compositionally layered on scale of a few millimeters to a meter; felsic gneiss contains greater proportion of quartz and feldspar. Extensively altered to chlorite, epidote, and sericite. Possibly represents metamorphosed sedimentary and volcanic rocks of intermediate composition. Correlated with gneiss of 1,700 1,800 million year old age (Tweto, in press). Thickness unknown. Description from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Xgn - Mixed gneiss (Early Proterozoic)
Mafic and felsic gneiss and micaceous schist, complexly interlayered in variable proportions and intruded by many bodies of unfoliated igneous rocks; layers discontinuous, rarely traceable more than 1/2 km. Unit is exposed along west side of Sangre de Cristo Range for approximately 100 km (Johnson and others, 1987); along with leucocratic gneiss (Xlgn), forms large upper thrust plate and smaller individual plates in map area and adjacent Crestone 7 1/2-minute quadrangle to north (Lindsey and others, 1986). Contains leucocratic, biotite-quartz-plagioclase-microcline gneiss and hornblende-bearing varieties of leucocratic gneiss that are interlayered with mafic quartz-plagioclase-hornblende gneiss; the leucocratic gneiss is variable in grain size, intensity of foliation, and thickness of compositional layers; the hornblende gneiss is generally fine-grained, well foliated, and thinly layered to laminated. Unit locally includes fine- to coarse-grained, weakly foliated to nonfoliated alaskitic gneiss. All varieties in this unit are extensively altered to chlorite, epidote, and sericite; alteration increases in the vicinity of range-bounding faults. Unit includes small, irregular masses of nonfoliated granite and foliated diorite. Dikes and sills ranging in composition from aplite and pegmatite to basalt cut the unit. Description from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle, Parts of the Twin Peaks and Blanco Peak Quadrangles, and Parts of the Zapata Ranch and Mosca Pass Quadrangles.

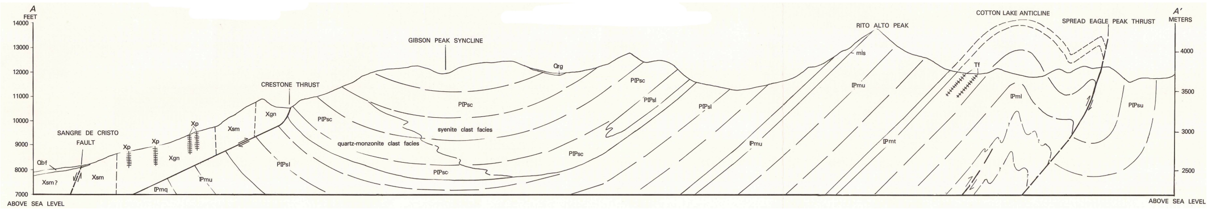
Xgn - Gneiss (Early Proterozoic)
Layered gneiss contains abundant quartz, plagioclase, potassium feldspar, biotite, and accessory

magnetite, apatite, and sphene. Pink, gray, and black, medium grained, well foliated; compositionally layered on scale of about 1 mm to 1 m. Contains mafic dikes and pods. Hydrothermally altered and mineralized locally. Description from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Geologic Cross Sections

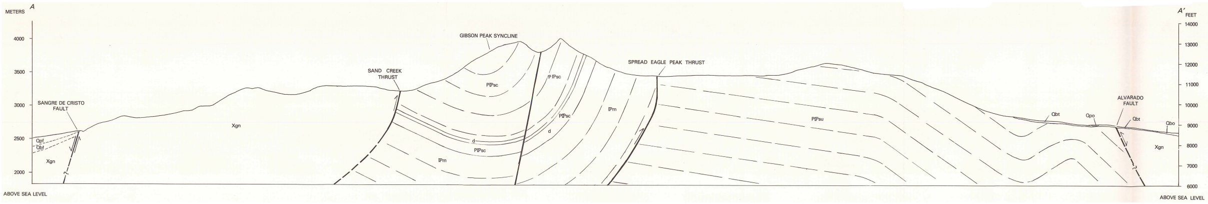
The geologic cross section graphics for the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve (*GRI MapCode GSAM*) are presented below. Note that some cross section abbreviations (e.g., A - A') may have been changed from their source map abbreviation in the GRI data so that each cross section abbreviation in the GRI data is unique. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document).

Cross Section A-A'



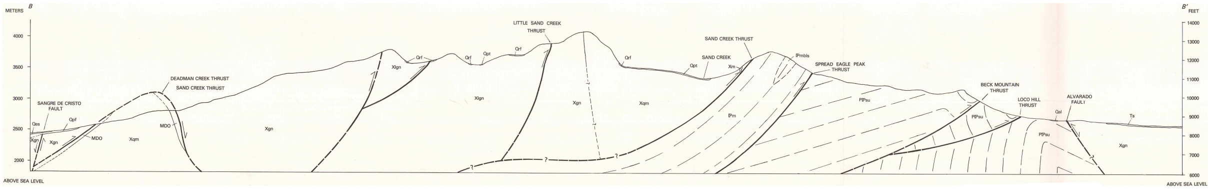
Graphic from source map: [Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle](#). No vertical exaggeration indicated on source map.

Cross Section B-B'



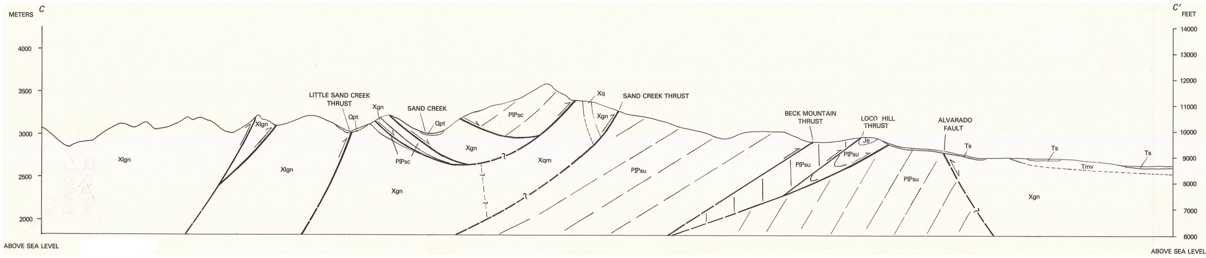
Graphic from source map: [Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle](#). Cross section abbreviation A-A' on source map. No vertical exaggeration indicated on source map.

Cross Section C-C'



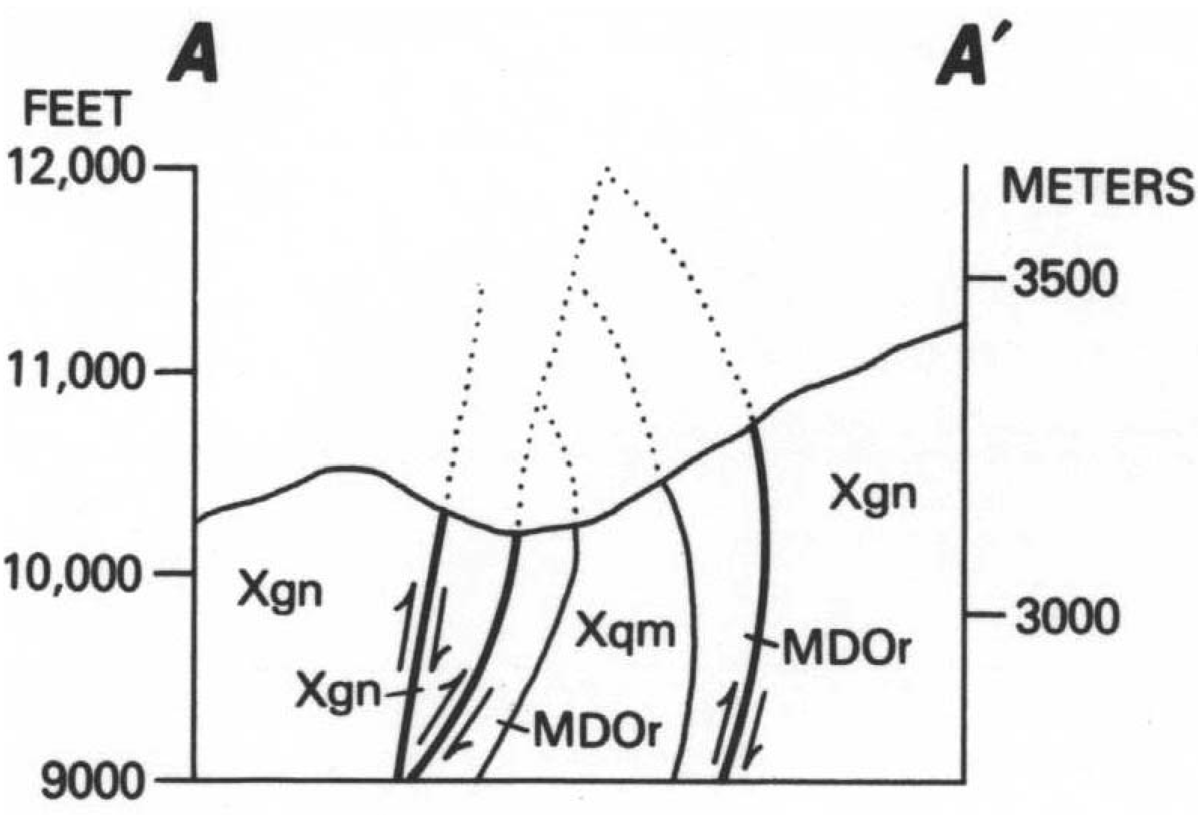
Graphic from source map: [Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle](#). Cross section abbreviation B-B' on source map. No vertical exaggeration indicated on source map.

Cross Section D-D'



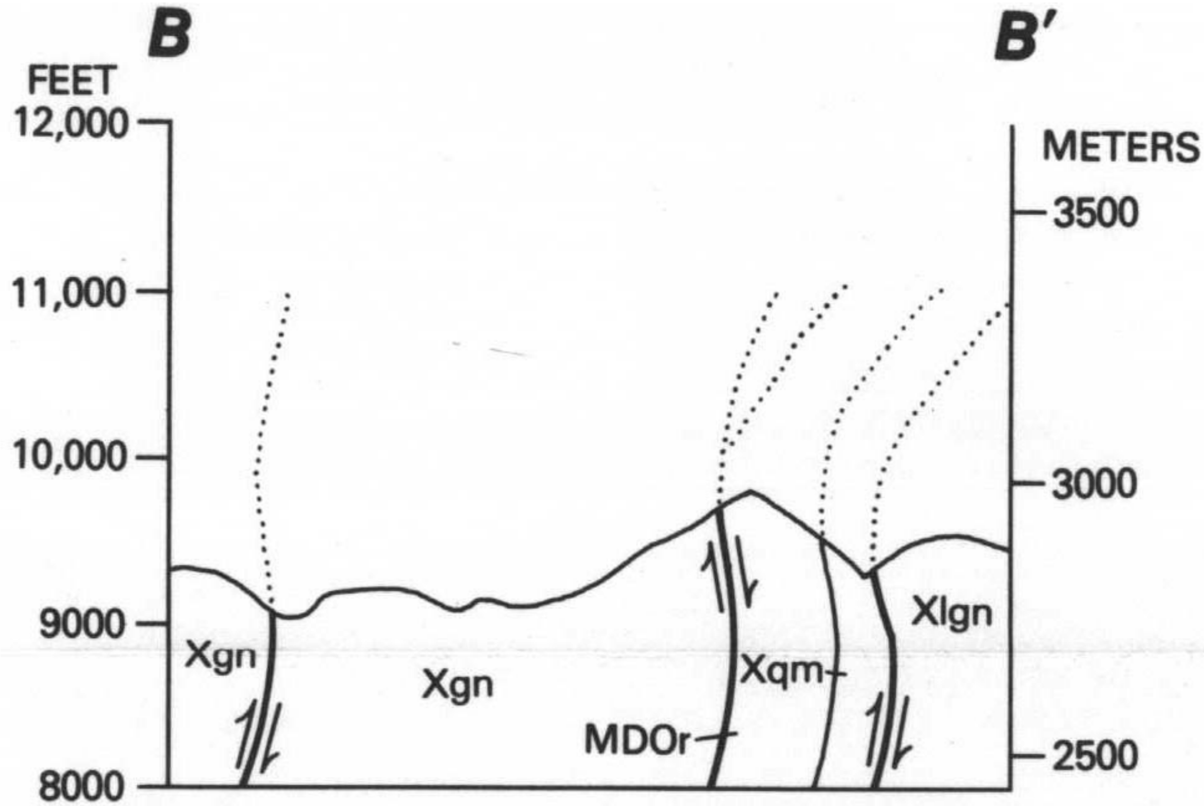
Graphic from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle. Cross section abbreviation C-C' on source map. No vertical exaggeration indicated on source map.

Cross Section E-E'



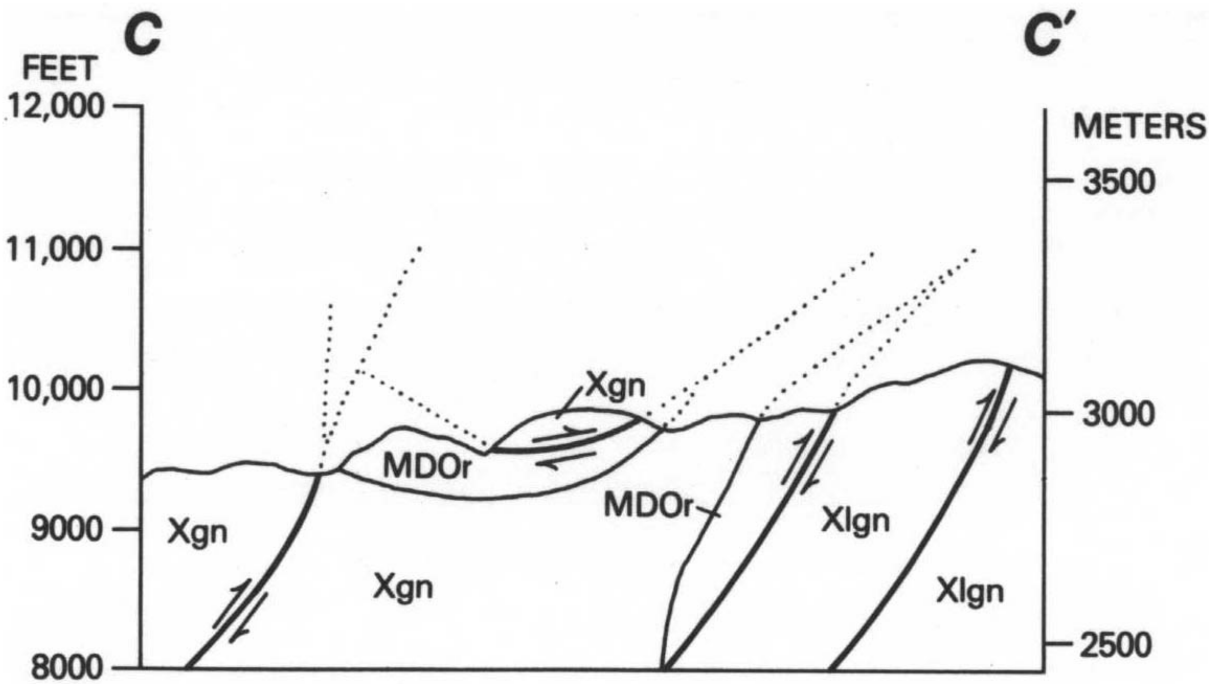
Graphic from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle. Cross section abbreviation A-A' on source map. No vertical exaggeration indicated on source map.

Cross Section F-F'



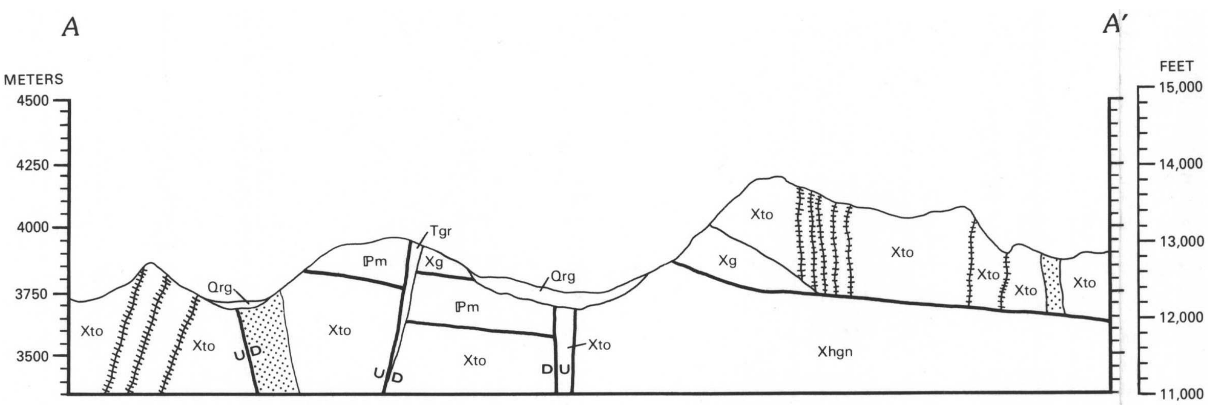
Graphic from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle. Cross section abbreviation B-B' on source map. No vertical exaggeration indicated on source map.

Cross Section G-G'



Graphic from source map: [Medano Pass Quadrangle and parts of the Liberty Quadrangle]. Cross section abbreviation C-C' on source map. No vertical exaggeration indicated on source map.

Cross Section H-H'



Graphic from source map: [Parts of the Twin Peaks and Blanco Peak Quadrangles]. Cross section abbreviation A-A' on source map. No vertical exaggeration indicated on source map.

Ancillary Source Map Information

The following sections present ancillary source map information associated with source map used for the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve, as well as its individual component maps.

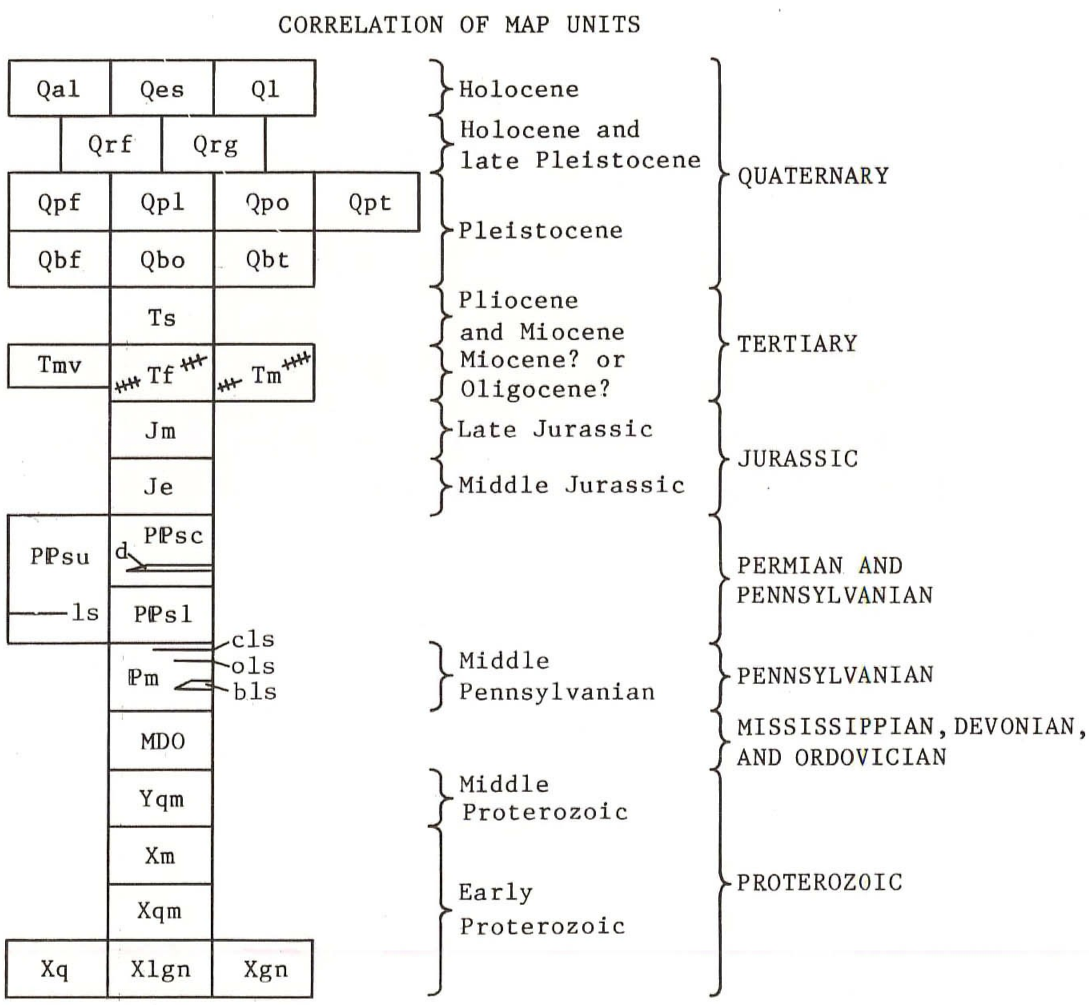
Beck Mountain and Crestone Peak Quadrangles, and parts of the Crestone Quadrangle

The formal citation for this source.

Lindsey, D.A., et. al., 1986, Geologic Map of the Beck Mountain, Crestone Peak and Crestone Quadrangles, Custer, Huerfano and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1878, scale 1:24,000. (*GRI Source Map ID 78*).

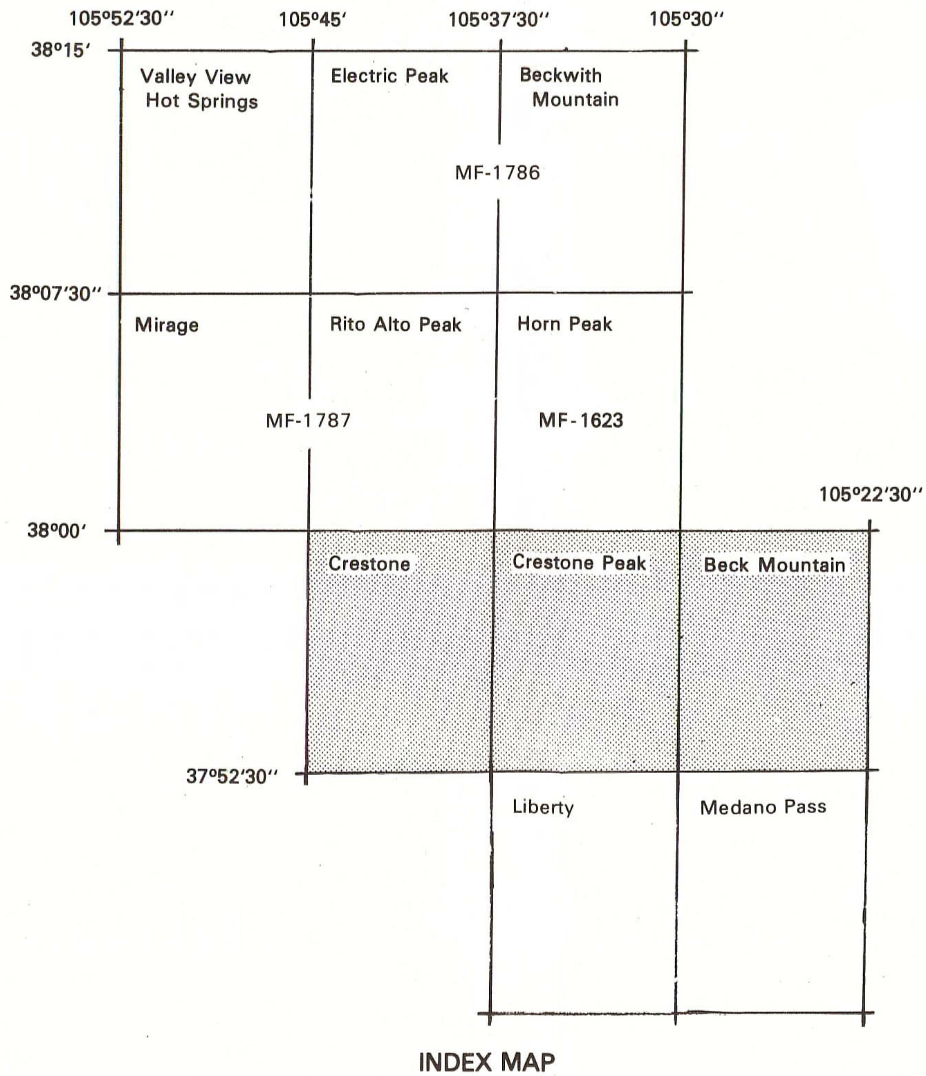
Prominent graphics and text associated with this source are presented below.

Correlation of Units



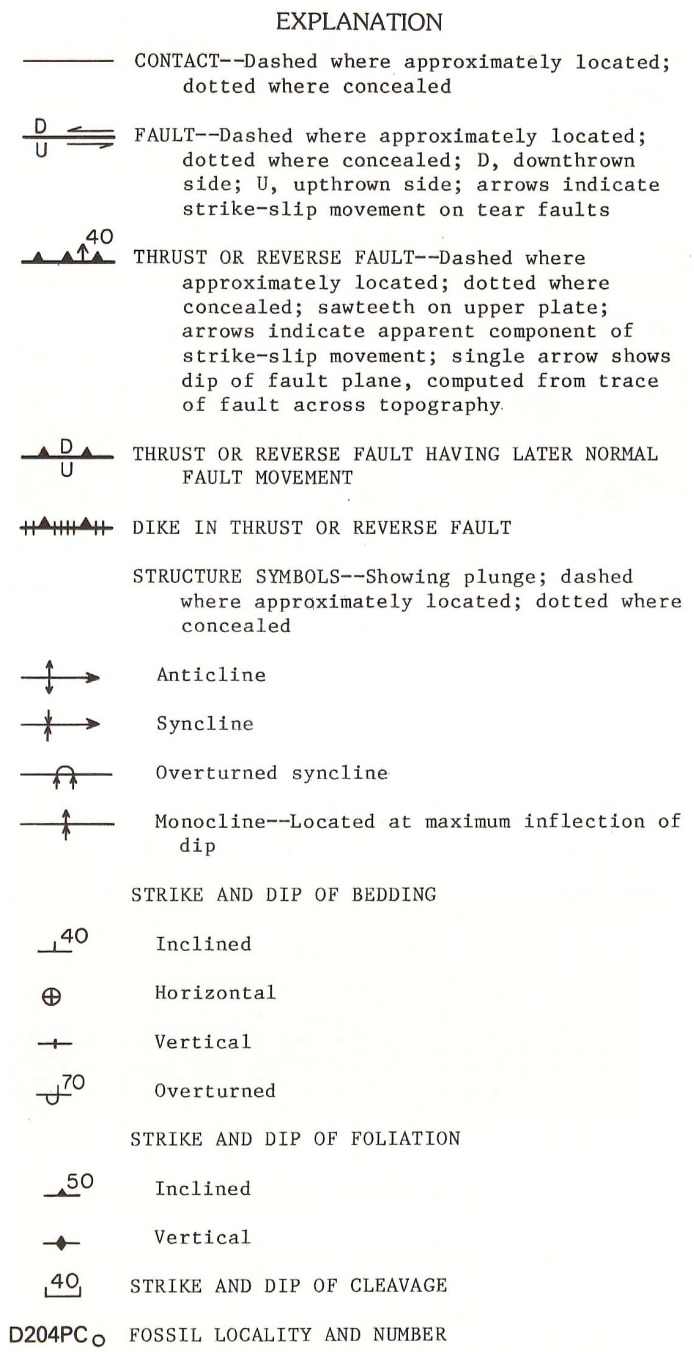
Graphic from source map: [Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle](#).

Index Map



Graphic from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Map Legend



Graphic from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

Map Text

Structure

The Sangre de Cristo Range was uplifted during Tertiary and Quaternary time. The range is bounded on the west by the Sangre de Cristo normal fault and on the east by a complex and poorly understood system of faults represented by the Alvarado fault. Segments of the Sangre de Cristo fault are well-exposed in fault scarps that cut deposits as young as Pinedale age (McCalpin, 1982). The fault downdrops the east side of the San Luis Valley, a graben formed as part of the Rio Grande rift during late Oligocene to present time. Exposed segments of the Alvarado fault are interpreted as a west-directed thrust or reverse fault, bringing Precambrian rocks up on the east against Pennsylvanian and Permian Sangre de Cristo Formation on the west (Lindsey and others, 1983).

North of the map area, different segments of the Alvarado fault exhibit features of both a Laramide thrust or reverse fault (east side up) and a Tertiary normal fault (east side down) (Lindsey and others, 1985 b). Evidently, the Alvarado fault was a zone of west-directed thrusting in Laramide time and a zone of down-to-the-east normal faulting in Tertiary time. No normal faults have been mapped along the trend of the Alvarado fault in the Beck Mountain quadrangle, but they may be concealed beneath the pediment surface that truncates the Santa Fe Formation.

Paleozoic and Precambrian rocks of the map area are cut by Laramide thrust faults that cross the range from northwest to southeast (see geologic sections A-A', B-B', and C-C'). An extensive upper plate is represented by rocks above the Sand Creek thrust and the Deadman Creek thrust. Rocks of the upper thrust plate contain a simple stratigraphic sequence of Crestone Conglomerate Member in depositional contact with Precambrian rocks; this sequence represents deposition close to the late Paleozoic Uncompahgre highland. Additional thrust plates are exposed east of the upper plate and in the window of the Deadman Creek thrust. Most of the lower plates are composed of Precambrian rocks, a veneer of lower Paleozoic rocks (Harding Sandstone through Leadville Limestone), and a thick sequence of Minturn Formation and Sangre de Cristo Formation. The lower plates sequence represents deposition in the central Colorado trough, east of the Uncompahgre highland. The lower thrust plates are interpreted to be underlain by a lower detachment surface (see Dahlstrom, 1969, 1970, for discussion of detachments). Below the level of the sections, the Spread Eagle Peak, Beck Mountain, Loco Hill, and adjacent thrusts may be splays from the lower detachment surface.

Rocks of the upper thrust plate extend over much of the map area: southwest of the Sand Creek thrust from the village of Crestone, through Music Pass, and thence south past Medano Pass (south of the map area). The upper thrust plate is itself broken by subsidiary thrusts, two of which delineate a large subplate of leucocratic gneiss (Xlgn). East of the Little Sand Creed thrust, the upper plate contains a large mass of quartz monzonite (Xqm) that may have been derived from the same rock unit below the Deadman thrust. In the upper plate southeast of Sand Creek, a large syncline of Crestone Conglomerate Member overlies gneiss (Xgn) above the Sand Creek thrust. The conglomerate-gneiss contact is faulted along the east limb of the syncline, but intervals of undoubted depositional contact are well exposed along the west limb in Little Sand Creek and southward into the Medano Pass quadrangle. At intervals this contact has been overridden by leucocratic gneiss (Xlgn) above the Little Sand Creek thrust.

The folded Deadman Creek thrust may represent a westward extension of the Sand Creek thrust. The Deadman Creek thrust is well defined by gneiss overlying small slices of Ordovician Harding Sandstone (quartzite) and Ordovician through Mississippian carbonate rocks. These lower Paleozoic formations overlie quartz monzonite (Xqm) along a depositional contact. Traces of red beds too small to map occur above the lower Paleozoic formations and below the thrust. Where the Paleozoic formations are missing, gneiss is in thrust contact with quartz monzonite. These relationships, first described by Clement (1952), are well exposed in the canyon walls of Deadman Creek. The thrust may be barely exposed as mylonite in a ravine near the mouth of Cedar Canyon (at cleavage symbol on map). Rocks above and below the Deadman Creek thrust have been folded into a north-plunging, asymmetric-to-the-east anticline that tightens southward into an isoclinal fold. On the west limb of the anticline, footwall rocks of the Deadman Creek thrust show conspicuous development of slaty cleavage that dips westerly at low to moderate angles.

Northeast of the Sand Creek thrust fault, the Spread Eagle Peak thrust forms the exposed front of a large lower thrust plate composed mostly of Minturn and Sangre de Cristo Formations. These formations are folded into the Gibson Peak syncline, a large fold that is offset slightly by branches and tear faults that extend from the Spread Eagle Peak thrust. North of Marble Mountain, the main thrust dips steeply, but it flattens to a west dip of about 50 degrees on Marble Mountain. The syncline is bounded on the west by the west-dipping Crestone thrust. East of the Spread Eagle Peak thrust, a large block of gently folded Sangre de Cristo Formation is essentially autochthonous in the north, but the folds pass southeast into the Beck Mountain, Loco Hill, and contiguous thrusts.

The Beck Mountain, Loco Hill, and contiguous thrust faults developed in front of the eastern culmination of the Sand Creek thrust, where it overrode the Spread Eagle Peak thrust from Music Pass southward. These faults probably represent splays extending upward from a lower detachment. South of Beck Mountain, the Beck Mountain thrust dips west about 30 degrees in sandstones of the Sangre de Cristo Formation. The thrusts at Loco Hill bound a sharply overturned, nearly isoclinal syncline of Sangre de Cristo, Entrada, and Morrison Formations. Judged by the great extent of overturning of the syncline, the thrusts at Loco Hill dip moderately west, parallel to the syncline limbs. In the Beck Mountain quadrangle, the thrusts of the allochthonous terrain probably do not have great horizontal offset because they mostly involve the Sangre de Cristo Formation and they pass northward into folds. This zone of thrusts has been traced south of the map area to the Bruff Creek area of Huerfano Park, where it brings the Sangre de Cristo and Minturn Formations over formations of Mesozoic age (Burbank and Goddard, 1937).

The thrust faults of the map area are part of a larger system of thrusts that developed along the east side of the Uncompahgre highland during the Laramide orogeny (Lindsey and others, 1983). Within the map area, the Crestone and Spread Eagle Peak thrusts probably formed first, followed by emplacement of the upper plate on the Sand Creek and Deadman Creek thrusts. The upper plate overlaps and cuts off the structures of the Spread Eagle Peak plate, bringing Crestone Conglomerate Member and Precambrian rocks across almost the entire width of the range. Thrusts developed within the upper plate, possibly where it rose over ramps of thick Minturn and Sangre de Cristo Formations in the Spread Eagle Peak plate. The east-facing Little Sand Creek thrust may represent the position of a major ramp. Near the end of emplacement of the upper plate, the Beck Mountain, Loco Hill, and contiguous thrusts formed as splays extending up from a lower detachment. The Sangre de Cristo and Minturn Formations were thrust over the Sangre de Cristo and Mesozoic formations at Loco Hill and in Huerfano Park (Burbank and Goddard, 1937) as new thrusts extended the lower detachment farther east. As these rocks moved over the lower detachment, they would have carried rocks of the upper plate with them. Rocks of the upper thrust plate buckled and folded as they rode on the underlying plate, forming anticlines that could be exposed as windows by erosion. Such a window is exposed below the folded Deadman Creek thrust.

The stratigraphic level of detachment was generally near the base of Paleozoic sedimentary rocks. Shaly sedimentary rocks of Ordovician through Mississippian age may have been an important detachment control; remnants of these remain beneath the Deadman Creek thrust. Shaly beds in the lower part of the Minturn Formation provided the zone of detachment for the Spread Eagle Peak thrust. The detachment level of the Sand Creek thrust was in Early Proterozoic gneiss and quartz monzonite at or slightly below the base of the Crestone Conglomerate Member, there being no shaly beds of Minturn or lower Paleozoic formations to act as slip zones.

Text from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

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References from source map: Beck Mountain and Crestone Peak Quadrangles and parts of the Crestone Quadrangle.

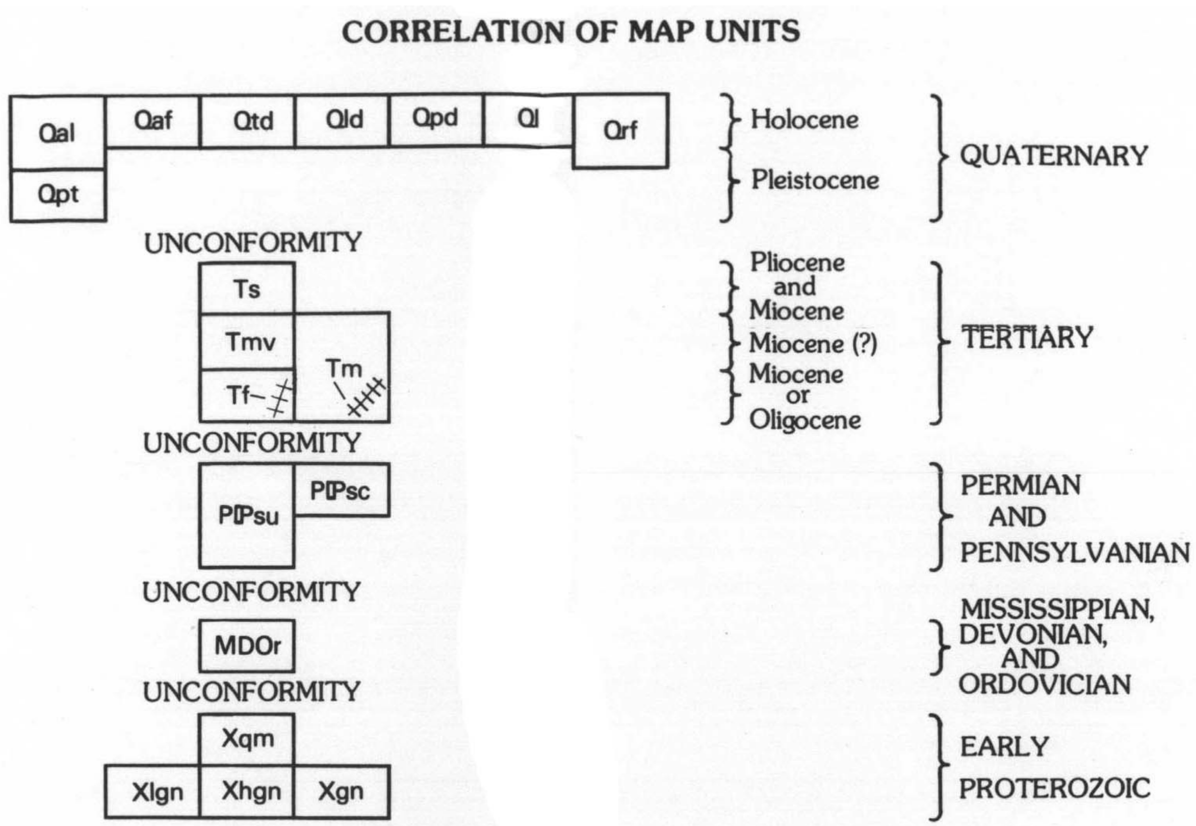
Medano Pass Quadrangle, and parts of the Liberty Quadrangle

The formal citation for this source.

Johnson, B.R., Bruce, R.M., and Lindsey, D.A., 1989, Reconnaissance Geologic Map of the Medano Pass Quadrangle and Part of the Liberty Quadrangle, Alamosa, Huerfano and Saguache Counties, Colorado: U.S. Geological Survey, MF-2089, scale 1:24,000. (*GRI Source Map ID 80*).

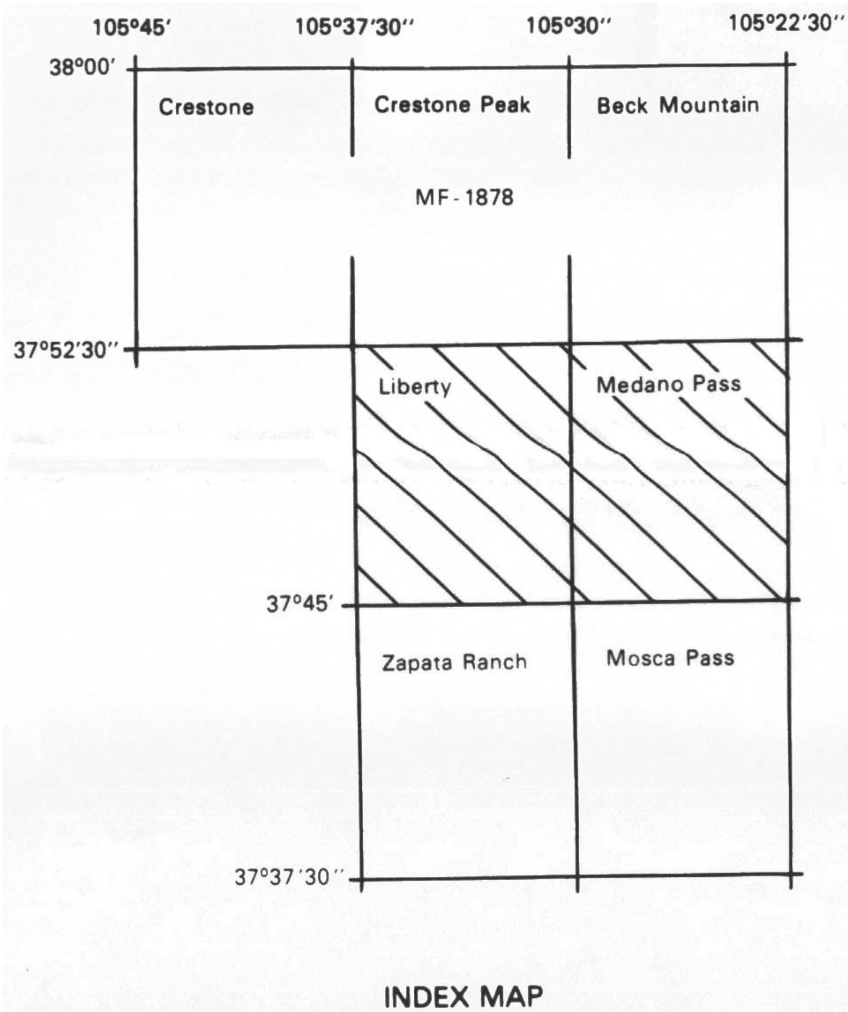
Prominent graphics and text associated with this source are presented below.

Correlation of Units



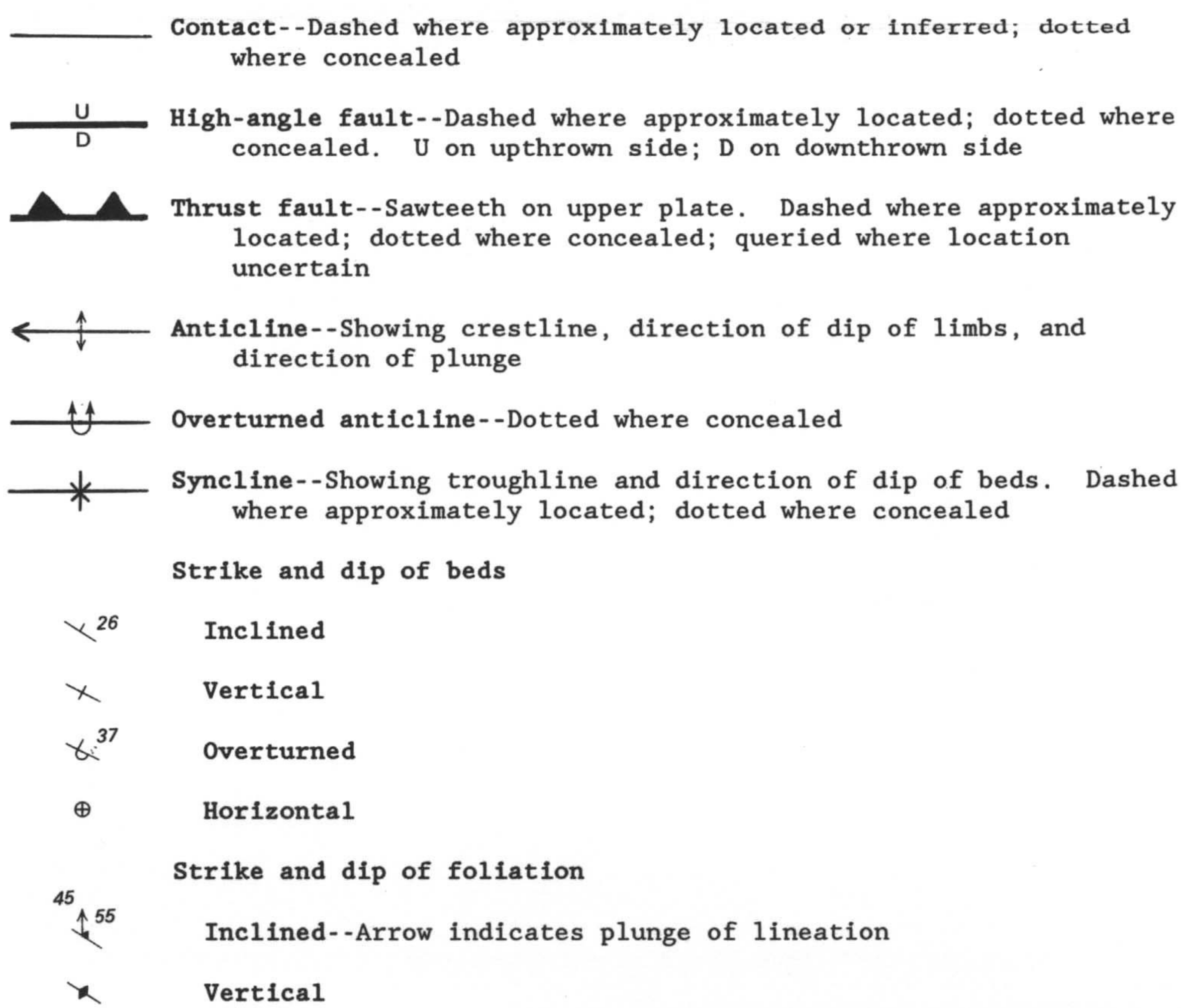
Graphic from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Index Map



Graphic from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Map Legend



Graphic from source map: [Medano Pass Quadrangle and parts of the Liberty Quadrangle].

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References from source map: Medano Pass Quadrangle and parts of the Liberty Quadrangle.

Rito Alto Peak Quadrangle, and northeastern part of the Mirage Quadrangle

The formal citation for this source.

Lindsey, David A., et. al., 1985, Geologic Map of Rito Alto Peak and Northeastern Part of the Mirage Quadrangles, Custer and Saguache Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1787, scale 1:24,000. (*GRI Source Map ID 81*).

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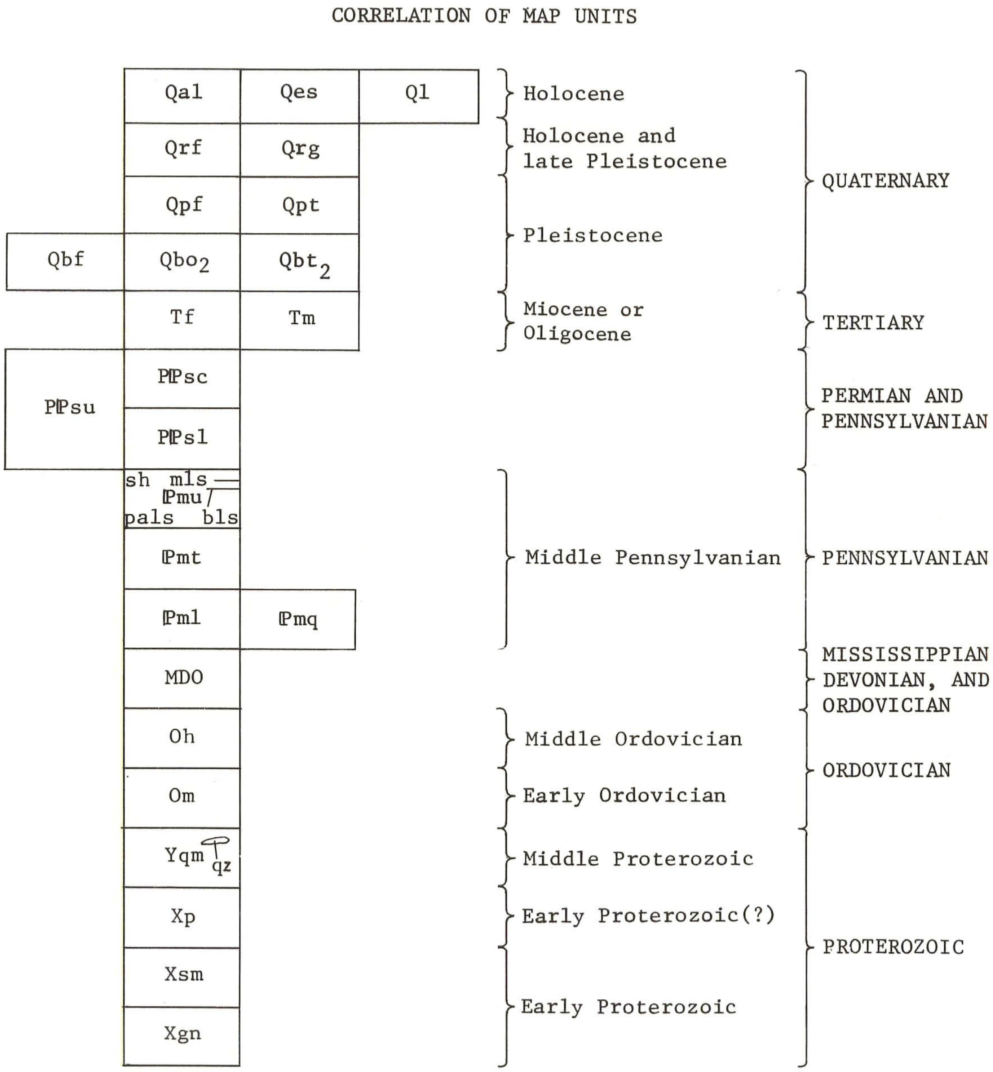
Correlation of Units



Graphic from source map: [Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle]
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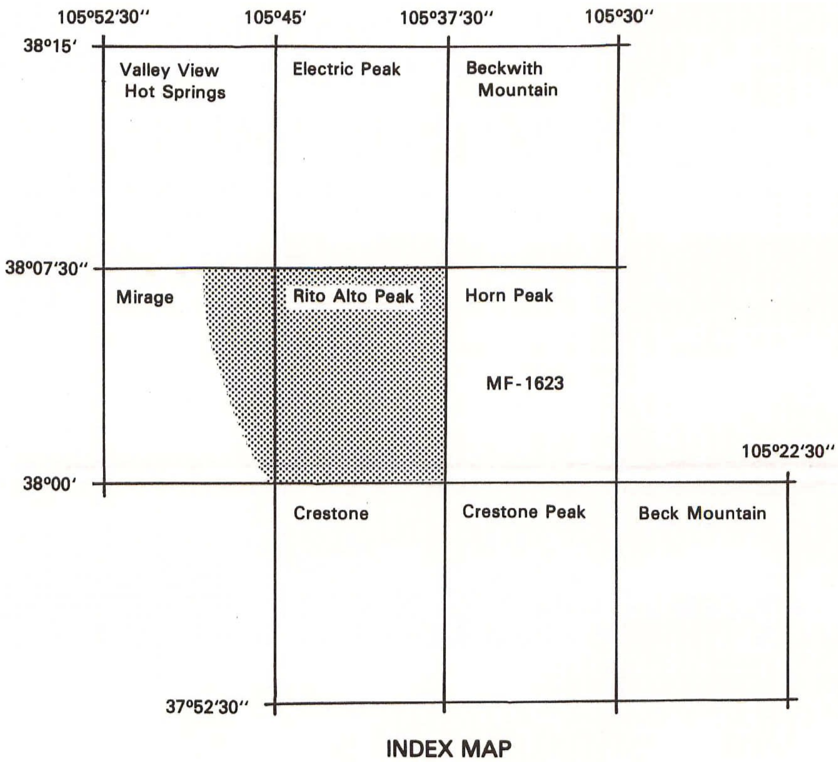
Index Map



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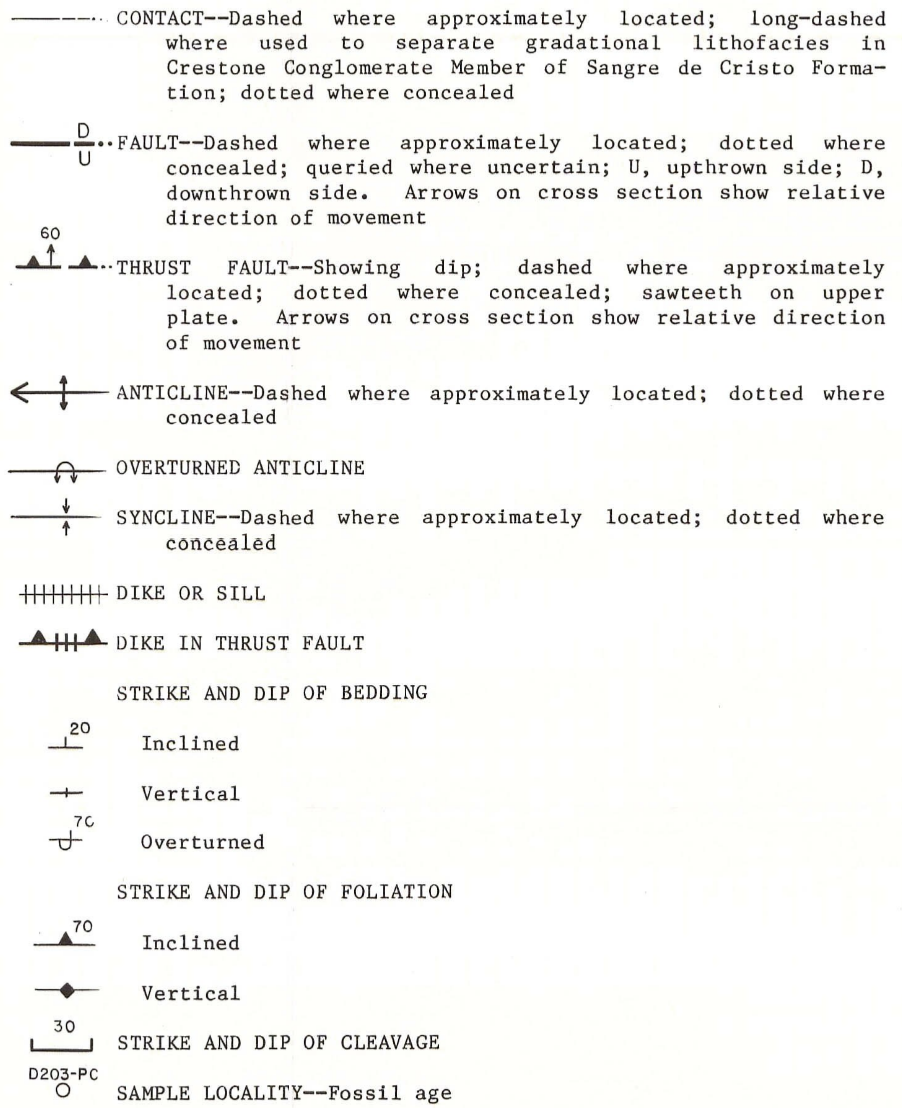
Map Legend



Graphic from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle
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Map Text

Structural Geology

Geologic structures in the map area were formed during the Laramide orogeny and Rio Grande rifting (Lindsey and others, 1983). The Crestone thrust, Spread Eagle Peak thrust, and associated folds were formed during the Laramide orogeny in latest Cretaceous to Eocene time. The Sangre de Cristo normal fault was formed during Rio Grande rifting from late Oligocene to present tine. These structures divide the map area into (1) down—faulted alluvial fill of the San Luis Valley, (2) the Crestone thrust plate of mostly Precambrian and lower Paleozoic rocks, and (3) the Spread Eagle Peak thrust plate of folded upper Paleozoic rocks. In the extreme northeastern part of the map area, autochthonous Sangre de Cristo Formation is exposed east of the Spread Eagle Peak thrust plate.

The Crestone thrust is a complex zone of imbricate thrust faults that dip west as low as 35 degrees. The thrust superposes Precambrian gneiss (Xgn) and stocks (Xsm and Yqm) over upper Paleozoic rocks. At many localities along the east side of the plate, strands of the thrust cut shaly beds between the Harding Sandstone and the upper part of the Minturn Formation. Where not faulted, the contact between the Harding Sandstone and Precambrian rocks is a near—vertical depositional contact. The vertical contact is interpreted as the remnant of the east limb of a basement—cored anticline that was thrusted over upper Paleozoic rocks. The presence of unsheared felsite dikes in the Crestone thrust indicates that no movement took place since their intrusion in Oligocene or Miocene time.

The Spread Eagle Peak thrust underlies the Minturn and Sangre de Cristo Formations in the Gibson Peak syncline and adjacent folds to the northeast. A segment of the thrust is exposed in the northeastern part of the Rito Alto Peak quadrangle. The Gibson Peak syncline occupies the main part of the thrust plate; it faces east and is locally overturned along the west limb. East of the syncline, the Cotton Lake anticline and other east—facing folds are cut off by the Spread Eagle Peak thrust. The level of exposure descends to the lower part of the Minturn Formation and the amplitude of the folds decreases as the thrust approaches the surface; thus, the thrust probably follows the level of shaly beds in the lower part of the Minturn. At the axis of the Gibson Peak syncline, the thrust probably underlies the entire section of upper Paleozoic rocks, estimated to be about 4 km.

The Sangre de Cristo fault is the major range—front structure separating the Sangre de Cristo Range from the San Luis Valley. The fault itself is not exposed in bedrock, but forms lineaments and fault scarps in alluvium of Bull Lake to Holocene age. Shears in bedrock near the trace of the fault are filled with dikes and veins; these shears probably formed before Rio Grande rifting. The topographic scarp at the foot of range is mainly a fault—line scarp, formed by retreat of scarps during erosion. Scarps in Pinedale alluvium probably represent the surface expression of the main fault; they formed as recently as 7,600 years ago (McCalpin, 1982).

Text from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

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References from source map: Rito Alto Peak Quadrangle and northeastern part of the Mirage Quadrangle.

Parts of the Twin Peaks and Blanco Peak Quadrangles

The formal citation for this source.

Johnson, Bruce R., and Bruce, Robert M., 1991, Reconnaissance Geologic Map of Parts of the Twin Peaks and Blanco Peak Quadrangles, Alamosa, Costilla and Huerfano Counties, Colorado: U.S. Geological Survey, MF-2169, scale 1:24,000. (*GRI Source Map ID 83*).

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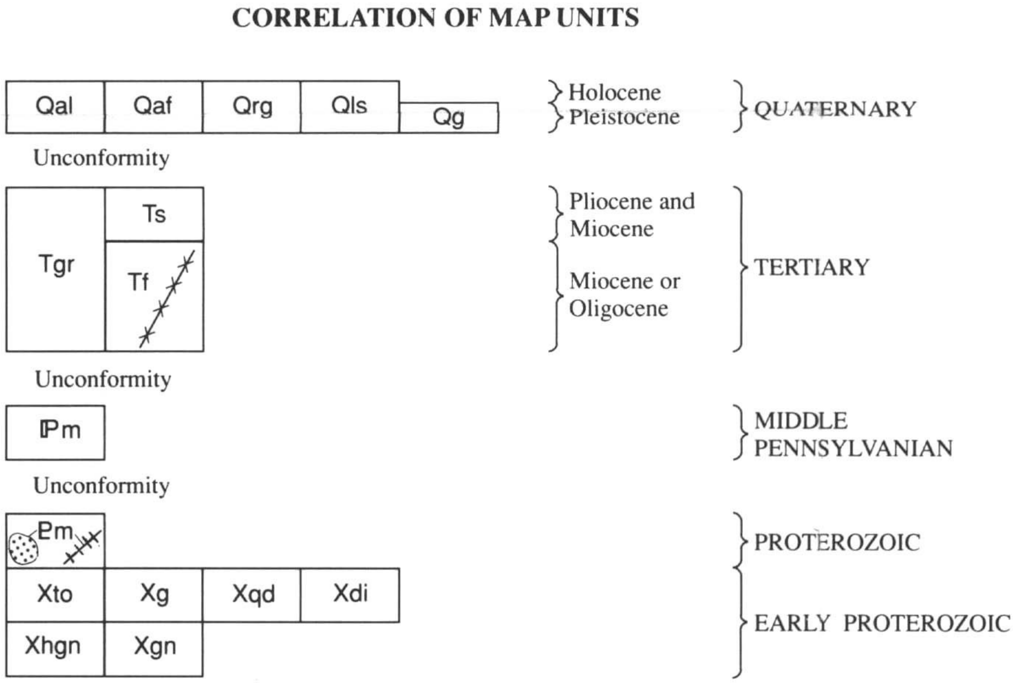
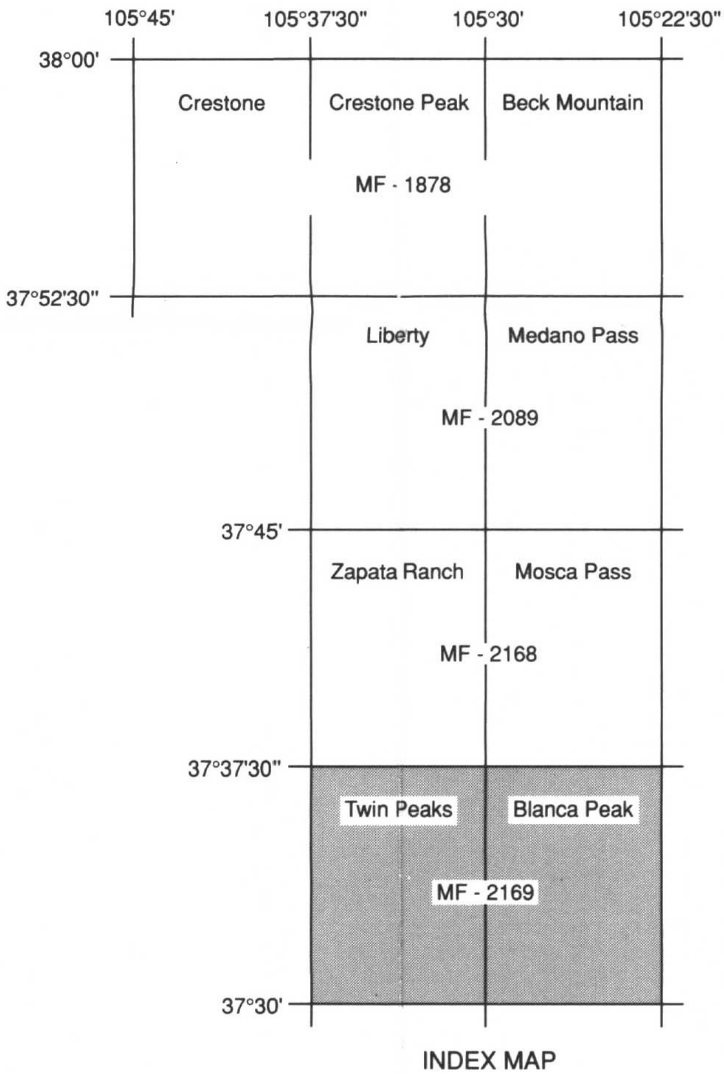


Graphic from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

Index Map



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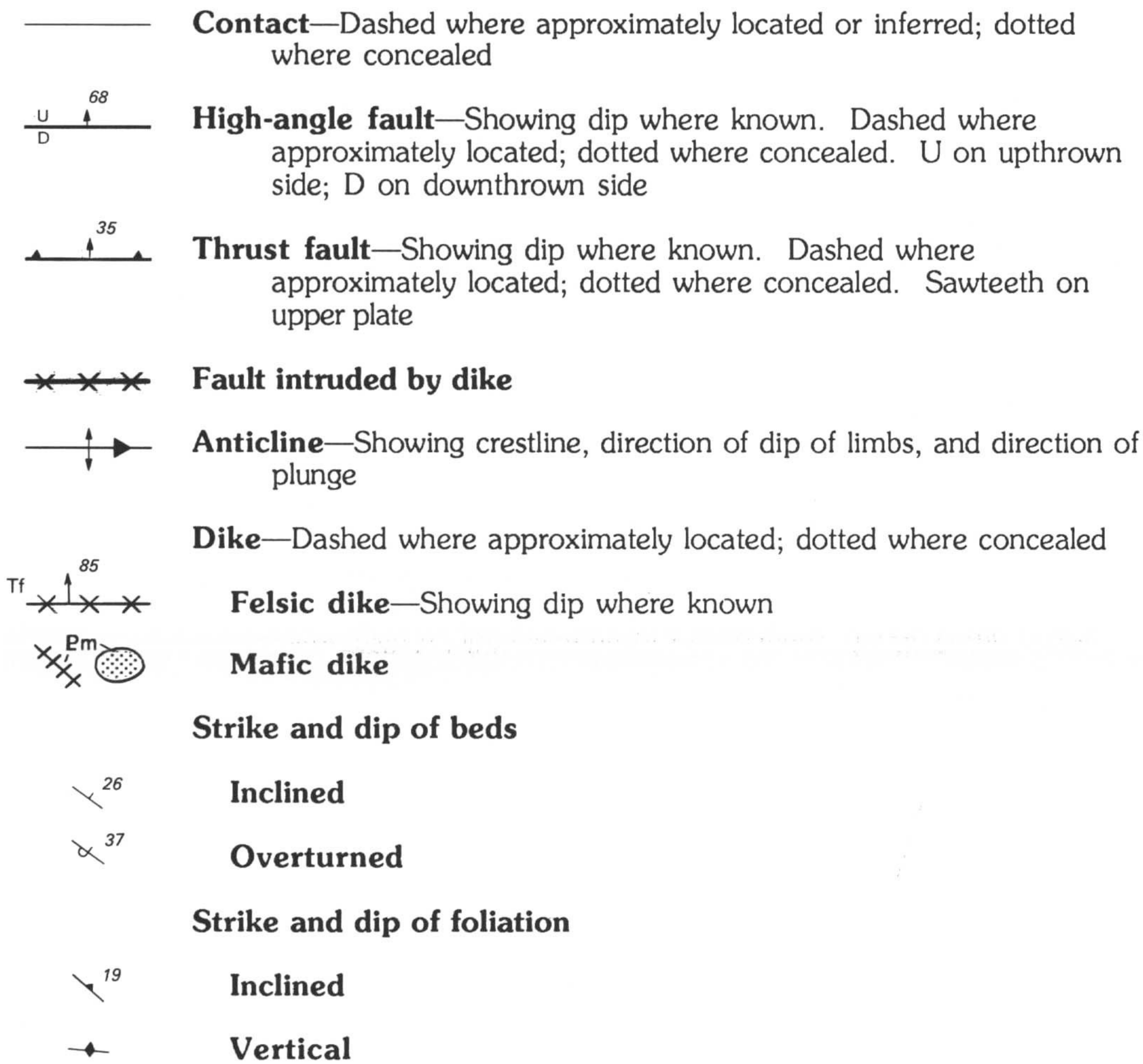
Map Legend



Graphic from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

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References from source map: Parts of the Twin Peaks and Blanco Peak Quadrangles.

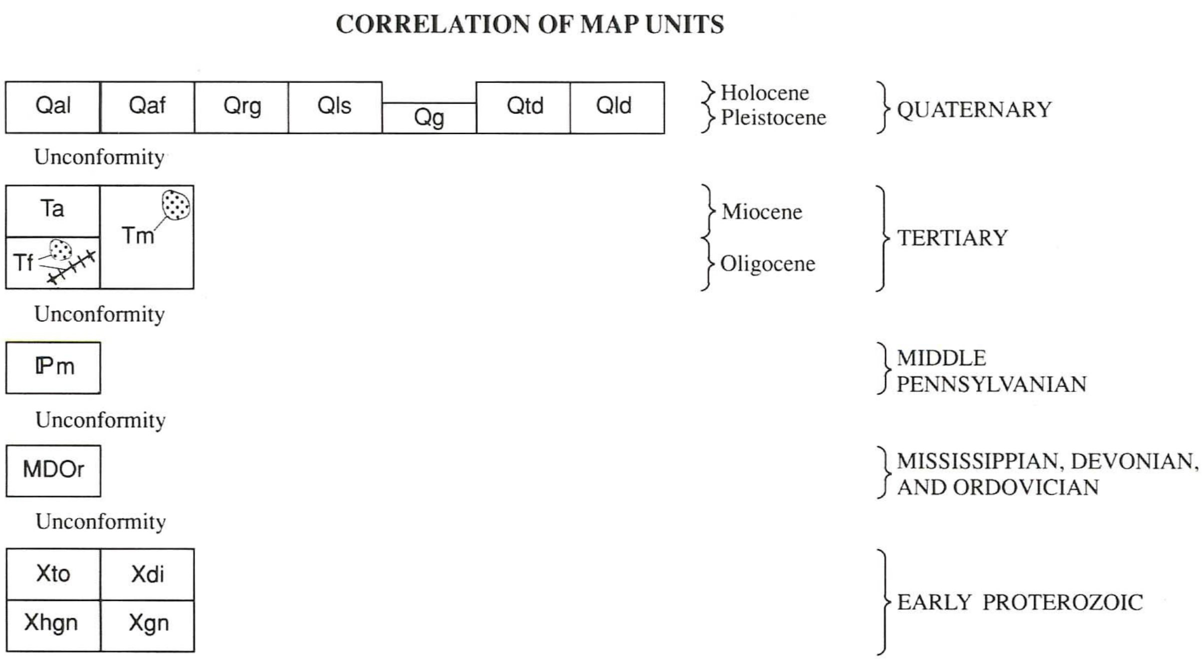
Parts of the the Zapata Ranch and Mosca Pass Quadrangles

The formal citation for this source.

Bruce, R.M., and Johnson, B.R., 1991, Reconnaissance Geologic Map of Parts of the Zapata Ranch and Mosca Pass Quadrangles, Alamosa and Huerfano Counties, Colorado: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2168, scale 1:24,000. (*GRI Source Map ID 84*).

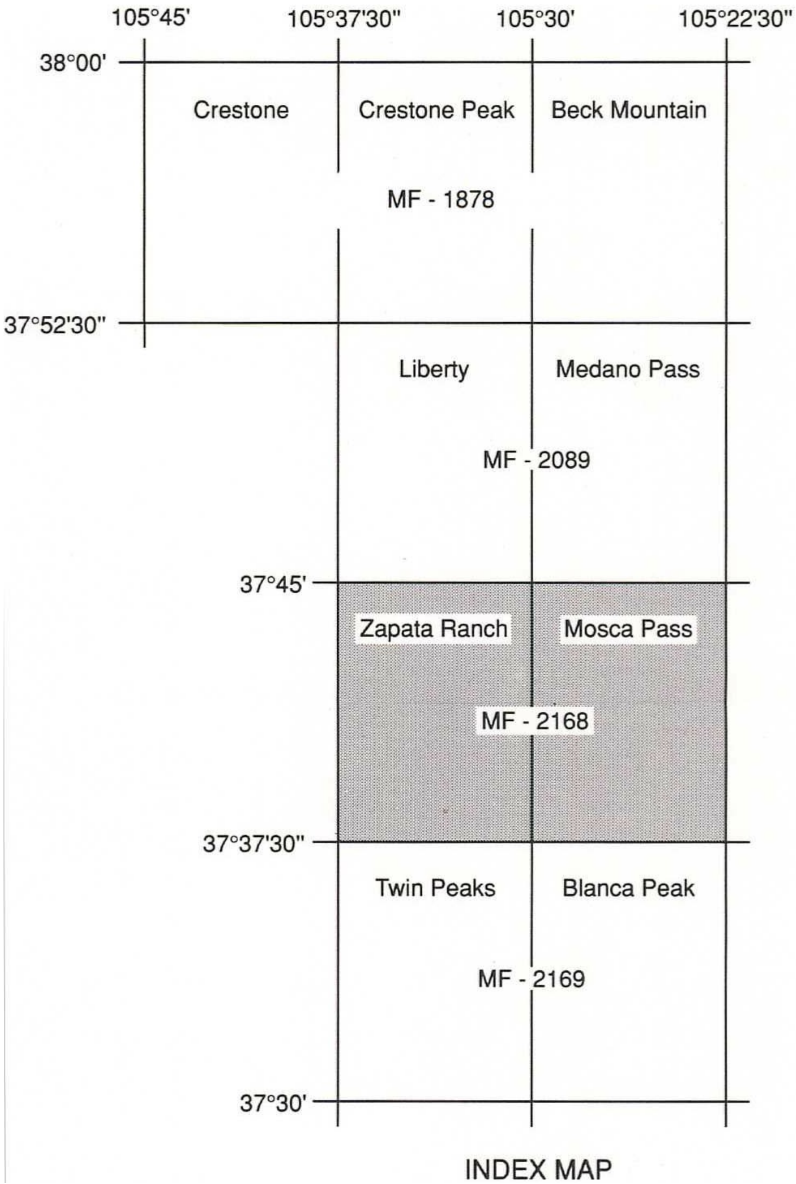
Prominent graphics and text associated with this source are presented below.

Correlation of Units



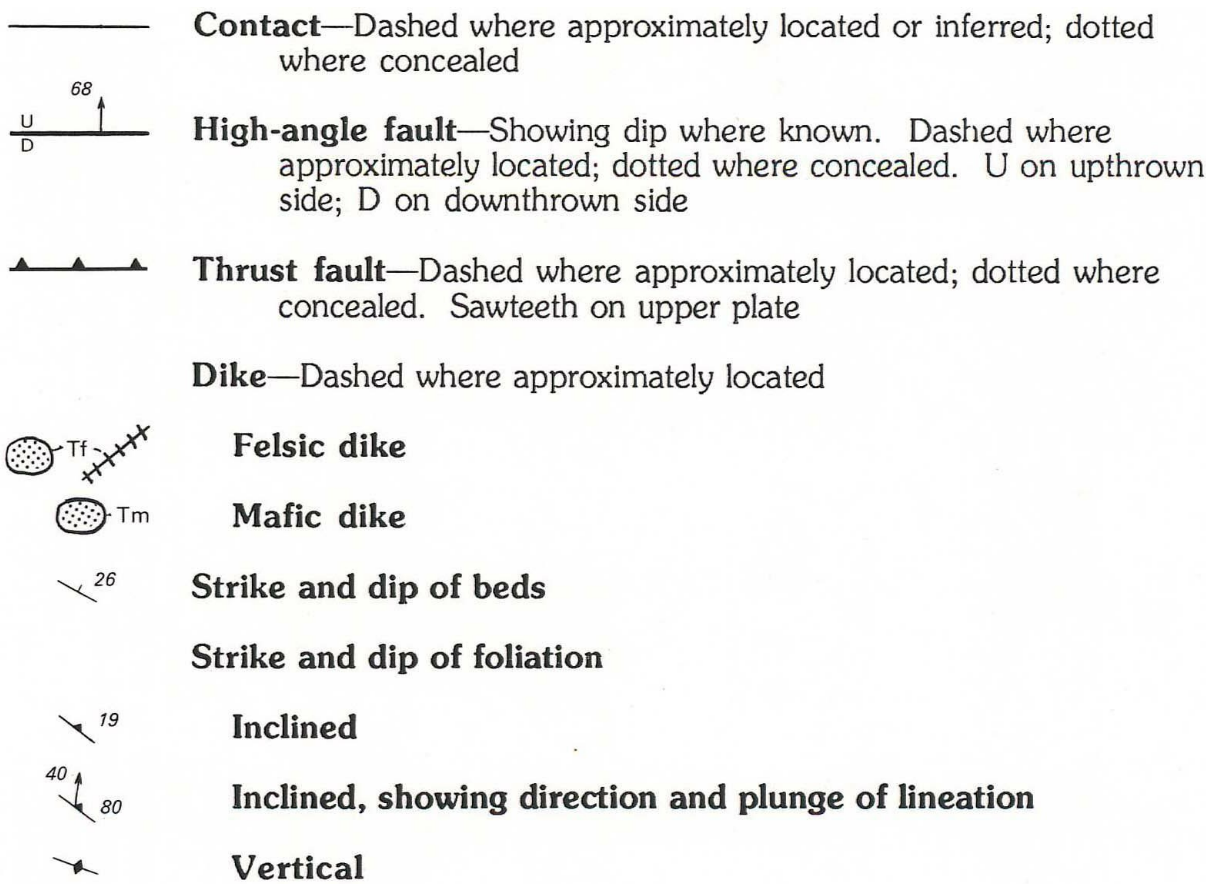
Graphic from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Index Map



Graphic from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

Map Legend



Graphic from source map: Parts of the Zapata Ranch and Mosca Pass Quadrangles.

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GRI Digital Data Credits

This document was developed and completed by Dalton Meyer and Stephanie O'Meara (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by Stephanie O'Meara, review by James Winter.

The information in this document was compiled from GRI source maps and is intended to accompany the digital geologic-GIS maps and other digital data for Great Sand Dunes National Park and Preserve, Colorado (GRSA) developed by Stephanie O'Meara, Dalton Meyer, James Winter and Dylan Rolley (Colorado State University; see the GRI Digital Maps and Source Map Citations section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS maps). Earlier GRI digital geologic-GIS datasets which served as the source for most of the digital data for the Digital Geologic-GIS Map of Parts of Great Sand Dunes National Park and Preserve and its component maps was initially produced by Stephanie O'Meara, Eileen Ernenwein, Victor deWolfe and Giorgia deWolfe (Colorado State University and NPS GRD).

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