OPEN-FILE REPORT 03-21

Geologic Map of the Electra Lake 7.5-Minute Quadrangle, La Plata County, Colorado

By

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COLORADO GEOLOGICAL SURVEY

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 03-21, *Geologic Map of the Electra Lake Quadrangle, La Plata County, Colorado.* Its purpose is to describe the geologic setting, structural geology, thermal springs, and mining history of this 7.5-minute quadrangle located north of Durango.

David Gonzales, professor at Fort Lewis College in Durango; Donald Stahr III, Jedediah D. Frechette, Franklin Dorin,Kathleen Costello, Cathy Cullicott, Rebecca Kolody, Kendra Remley, and Kristopher Graham, undergraduate students at Fort Lewis College completed the field work on this project in the summers of 2000, 2001, and 2002.

This project was funded by Fort Lewis College, the Education Mapping Program of the U.S. Geological Survey (agreements No. 00HQAG0082 and No. 01HQAG0144), and jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program which is authorized by the National Geologic Mapping Act of 1997, Agreement No. 02HQAG0050, and the Colorado Geological Survey (CGS) using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

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We appreciate the thorough review of Clay Conway of the report and map. A gracious thanks goes out to all of the landowners who permitted us access to their property during this project. We are especially grateful to the Board of Directors for Electra Lake for permitting access to the area around Electra Lake.

Allen Andrews in the La Plata County GIS Department provided us with a property map of the Electra Lake quadrangle. We want to thank Loren Wickstrom of the Bureau of Land Management for providing us with a record of mining claims on public lands in the Electra Lake quadrangle.

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INTRODUCTION

David Gonzales and students from Fort Lewis College conducted the geologic mapping in the Electra Lake 7.5-minute quadrangle for the Colorado Geological Survey. Geologic maps produced by the CGS through the STATEMAP program are useful for many purposes, including land-use planning, geotechnical engineering, geologic-hazards assessment, analysis and mitigation of environmental problems, and mineral-resource and ground-water exploration and development. The maps portray the geology of the quadrangle at a scale of 1:24,000 and serve as a basis for more detailed research and for regional, broad-scale studies.

Figure 1 shows the current status of geologic mapping of 7.5-minute quadrangles in the Durango area. The Rules Hill, Ludwig Mountain, Durango East, Durango West, Hesperus, Basin Mountain, and Hermosa quadrangles were mapped and published by the CGS during previous STATEMAP projects (Carroll and others, 1997, 1998, 1999; Kirkham and others, 1999, 2000; Kirkham and Navarre, 2001; Gonzales and others, 2002). The Hesperus quadrangle was supported in part by the EDMAP program.

Field studies and research in the Electra Lake quadrangle were done between March and September of 2000 and 2001. David Gonzales, Don Stahr, and Kendra Remley mapped the southern one-third of the quadrangle in the summer of 2000. In the summer of 2001, the unfinished parts of the quadrangle were mapped and compiled by Kathleen Costello, Cathy Cullicott, Franklin Dorin, Jed Frechette, and Rebecca Kolody. David Gonzales and Don Stahr conducted field checking and additional geologic mapping during the summer of 2002. During these mapping periods nearly all of the outcrops and landforms in the map area were inspected and mapped for rock or deposit type, geologic structures, and resource information. Interpretation of aerial photography and previously published geologic investigations were used to delineate unit contacts in areas not visited by the authors. Black and white 1:40,000-scale and color 1:24,000-scale aerial photographs are available for the entire quadrangle. Map preparation and digitization were completed following field mapping by the authors and the GIS and Technical Services Section of the Colorado Geological Survey.

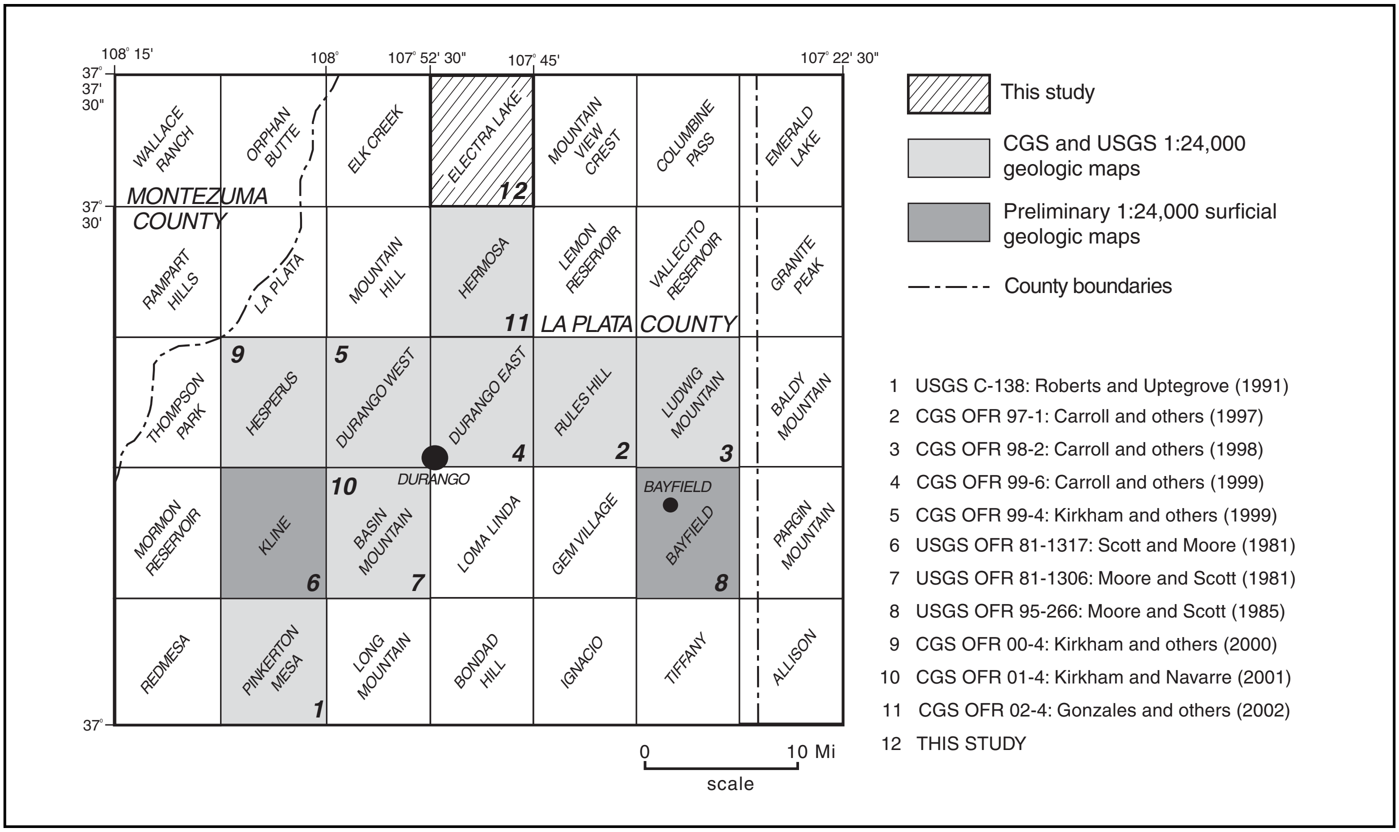

Figure 1. Published 1:24,000-scale geologic maps of 7.5-minute quadrangles in southwestern Colorado.

GEOLOGIC SETTING

The Electra Lake 7.5-minute quadrangle includes about 60 square miles of chiefly mountainous terrain within the northern part of La Plata County in southwestern Colorado (Fig. 2). The west and east boundaries of the quadrangle lie at longitudes of 107° 52' 30" W and 107° 45' 00" W, respectively. The south margin of the map is at latitude 37° 30' 00" N and the north margin is at latitude 37° 37' 30" N. The southern margin of the quadrangle lies about 20 miles north of the city of Durango (Fig. 1). The quadrangle lies near the transition of the east-central part of the Colorado Plateau physiographic province and western edge of the Southern Rocky Mountains (Fenneman, 1931) (Fig. 3). The terrain in the mapping area varies from an elevation of about 7,000 ft above sea level along the Animas River to the rugged surrounding mountainous terrain, where the elevation is more than 10,000 ft above sea level. The Animas River, a major south-flowing river that drains much of the southwestern San Juan Mountains, flows across the quadrangle from north to south along the eastern margin. Nearly 3,000 ft of rock record that spans about 2 billion years of geologic time is exposed in the quadrangle.

The mountains within the map area form part of the southern flank of the Laramide San Juan uplift, which has a core of 1,800 to 1,400 million-year-old Proterozoic crystalline rocks mantled by south-dipping strata of Paleozoic to Mesozoic sedimentary rock units (Figs. 2 and 4). Phanerozoic strata on the south flank of the dome define the northern margin of the San Juan Basin (Fig. 3).

The oldest rocks in the map area are exposed in the precipitous walls of the Animas River canyon. Proterozoic rocks in the Electra Lake quadrangle include 1,800-million-year-old metamorphosed volcanic arc rocks of the Irving Formation and 1,780- to 1,760-million-year-old metamorphosed intermediate to mafic plutonic rocks of the Twilight Gneiss (Gonzales, 1997). The Irving Formation and Twilight Gneiss underwent amphibolite facies metamorphism and multiple phases of deformation prior to emplacement of plutonic igneous rocks of the 1,700-million-year-old Bakers Bridge Granite, 1,400-million-year-old Eolus Granite and Electra Lake Gabbro (Gonzales, 1997), and swarms of Proterozoic mafic dikes whose absolute age is uncertain. The Irving Formation, Twilight Gneiss, Bakers Bridge Granite, Eolus Granite, and Electra Lake Gabbro form the eroded basement on which Paleozoic sedimentary rocks were deposited in marine to continental environments. The Animas River and its tributaries, assisted by intense glacial erosion, have carved the deep canyons and steep ridges in the map area, producing the spectacular landscape seen today.

The geologic framework of the Electra Lake quadrangle is the product of a long and complex history of metamorphic and igneous events, deformation, sedimentation, uplift, and erosion. The general sequence of events that is preserved in the rock record of the mapping area are as follows:

(1) Formation, metamorphism, and deformation of volcanic and intrusive rocks in a volcanic arc system between 1,800 and 1,750 million years ago. Intrusion of granitic and minor gabbroic rocks into the older metamorphic complex between 1,700 and 1,400 million years ago.

(2) A major gap in the rock record for about the next 900 million years because of erosion or nondeposition. Mafic dikes that cut the Irving Formation, Twilight Gneiss, Bakers Bridge Granite, and Eolus Granite may have been emplaced during this period of time.

(3) Deposition of a thick succession of marine and deltaic carbonate and clastic rocks with minor local uplift and erosion between about 550 and 320 million years ago.

(4) Tectonic uplift in the Late Pennsylvanian that produced a northwest-southeast trending belt of mountains referred to as the ancestral Rocky Mountains.

(5) Erosion of the uplifted region by streams and rivers and deposition of this material as "redbed" clastic sedimentary rocks about 300 million years ago. There are younger units exposed in the region but they are not exposed within the map area.

(6) Renewed tectonic uplift caused by compressional forces during the Laramide orogeny producing the San Juan uplift. This event was accompanied by intrusion of ore-bearing igneous rocks in the La Plata Mountains about 75 to 65 million years before present.

(7) Quaternary glaciation, alluviation, and other surficial processes that formed the present-day landscape.

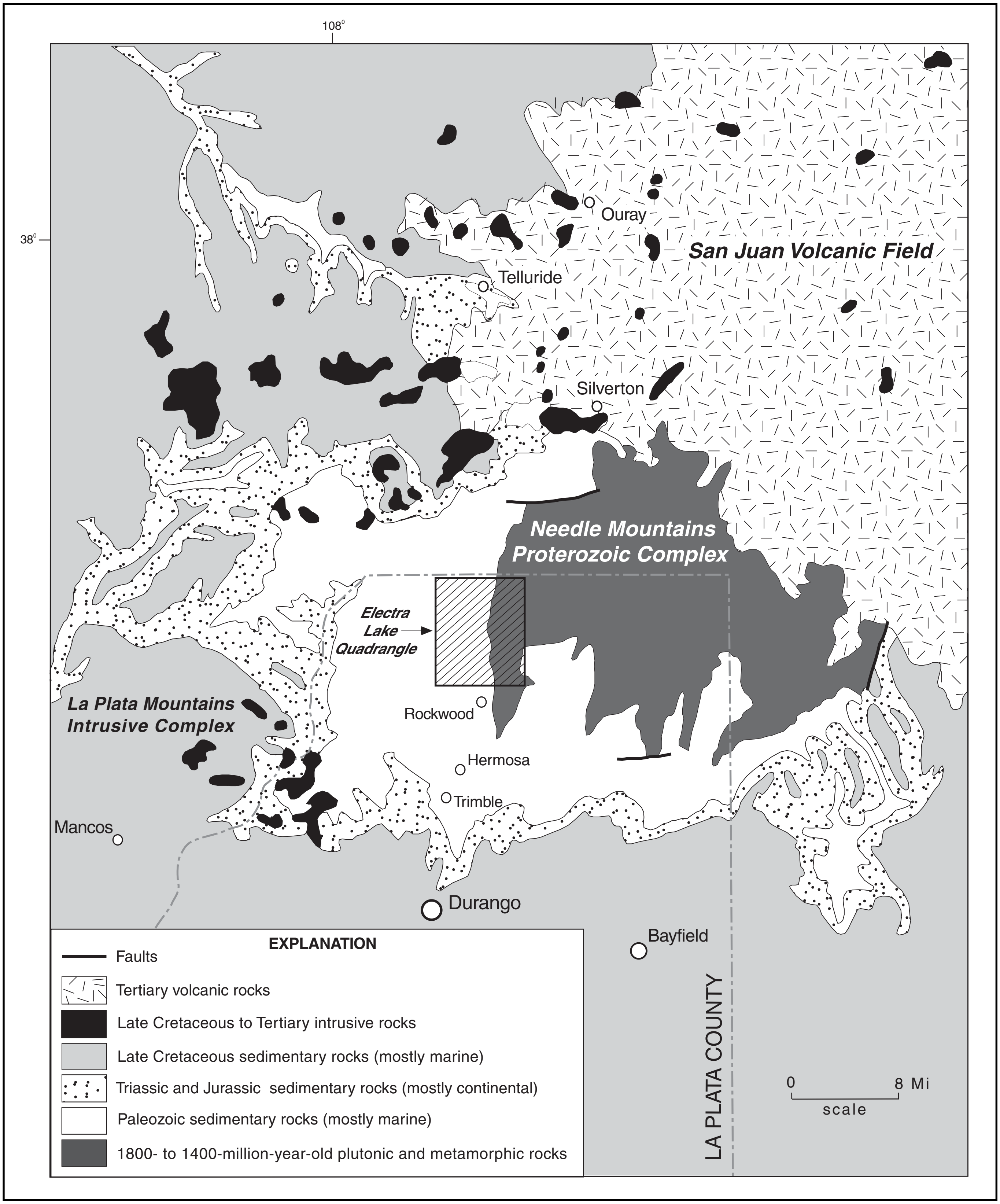

Figure 2. General geologic map showing the principal rock units in southwestern Colorado. (modified version of the Colorado Geologic Highway Map, 1991). The area of the Electra Lake 7.5 minute quadrangle is outlined. The broken line indicates the boundaries of La Plata County.

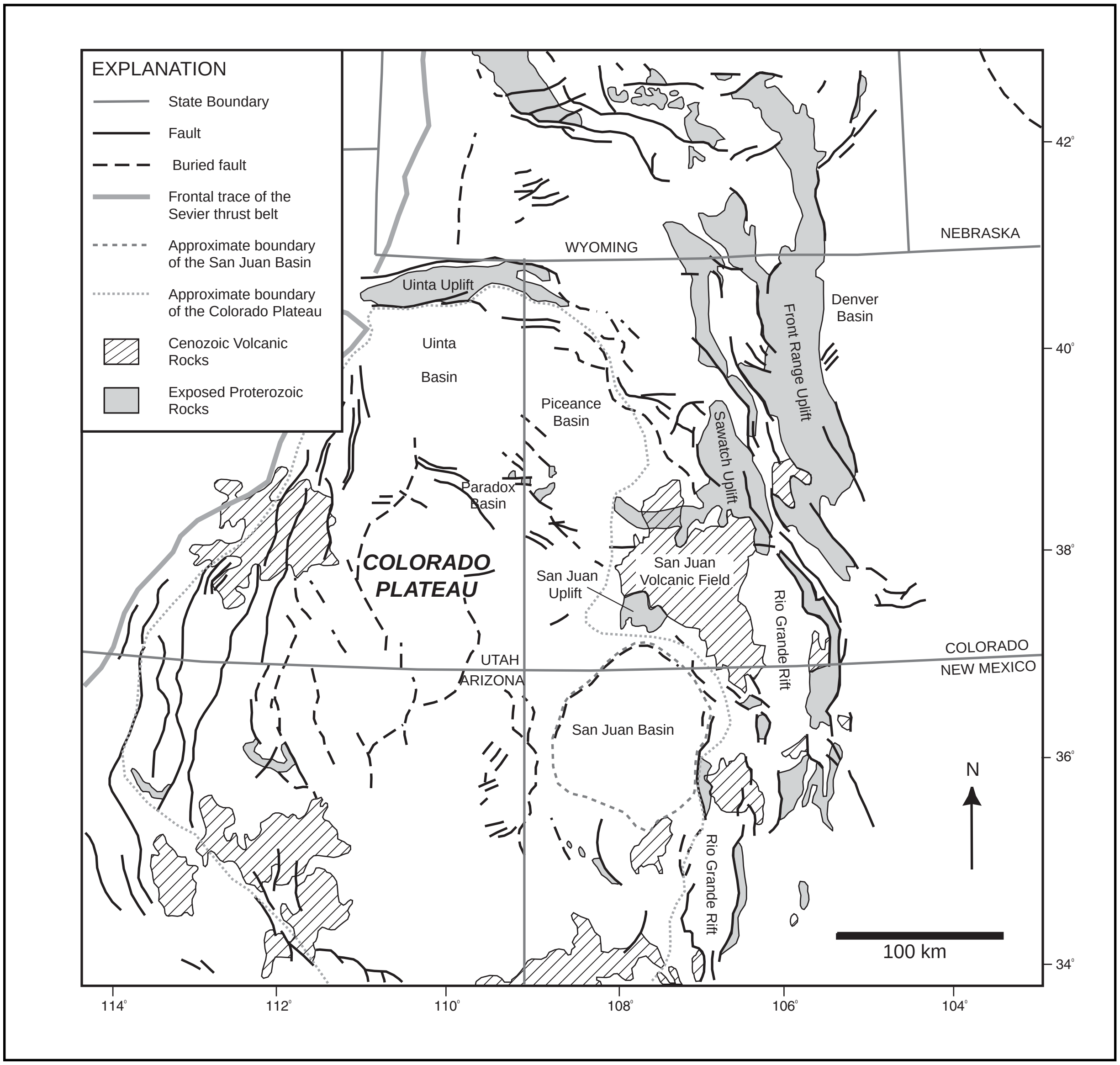

Figure 3. Generalized map of the Southern Rocky Mountains with major physiographic divisions. Modified from Oldow and others (1989).

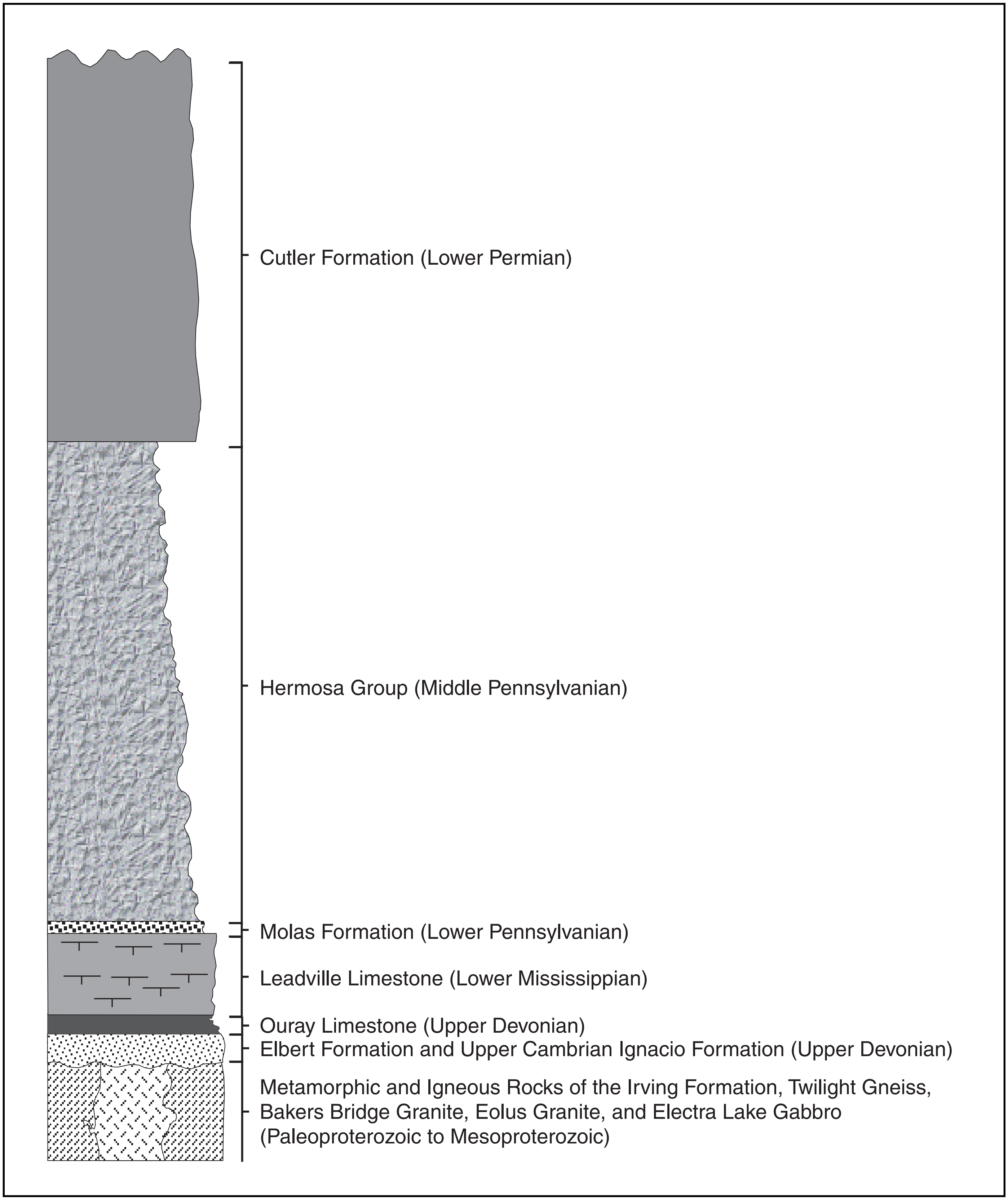

Figure 4. Generalized stratigraphic section of bedrock units in the 7.5-minute Hermosa quadranlge.

PREVIOUS GEOLOGIC MAPPING STUDIES

The United States Geological and Geographical Survey conducted the first geologic studies in the Needle Mountains during reconnaissance surveys between 1869 and 1875 (Endlich, 1876). Comstock (1883, 1887) and Van Hise (1892) provided cursory descriptions of some rocks units in the region. The United States Geological Survey initiated the first comprehensive geologic mapping studies in the Needle Mountains in 1895 under the direction of Whitman Cross. By 1910 Cross and his colleagues had compiled 1:62,500 geologic maps for seven 15-minute quadrangles and published the results in a series of folios in the Geologic Atlas of the United States. The folios that were produced by this work include the Silverton (Cross and others, 1905b), Needle Mountains (Cross and others, 1905a), and Engineer Mountain (Cross and Hole, 1910) 15-minute quadrangles. The Electra Lake 7.5-minute quadrangle is within the Needle Mountains 15-minute quadrangle.

Regional investigations of the entire San Juan Mountains by Cross and Larsen (1935) and Larsen and Cross (1956) summarize much of the early work by Cross and his colleagues. Kelley (1957) provided a synopsis of the geologic events and history in the region. In 1964 a 1:250,000-scale-mapping project of the Durango 1° x 2° quadrangle was initiated by the United States Geologic Survey (Steven and others, 1974). A 1:15,000-scale geologic map was compiled for Proterozoic rocks in the vicinity of Electra Lake by Gonzales and others (1994). No other previous mapping studies have been done that included the geology in the Electra Lake quadrangle.

UNIT DESCRIPTIONS

SURFICIAL DEPOSITS

Surficial deposits blanket a large part of Electra Lake quadrangle. The described attributes of these poorly exposed units, such as thickness, texture, stratification, and composition, are based on observations made at relatively few locations. Landforms associated with the surficial deposits often provide critical data on which interpretations are developed. The surficial stratigraphic units are generally classified by genesis or, if genesis is unknown, by the type of material of which they are composed.

Surficial units shown on the map are generally not more than about 5 ft thick. In some instances, particularly for alluvial sediments, colluvium, and fan sediments, the deposits may be much thinner than 5 ft. Because of the scale of the map, the minimum width of surficial deposits shown on the map is about 75 to 100 ft. Small deposits created by the work of humans, and residuum, were not mapped. Contacts between many surficial units may be gradational and therefore should be considered as approximate boundaries. The topographic base map was published in 1960, and consequently, cultural features that post-date the base map are not depicted on the geologic map.

Clasts are defined in this study as rock fragments larger than 2 mm in diameter, and matrix refers to surrounding material 2 mm or less in diameter (sand, silt, and clay). In clast-supported deposits, the majority of the material consists of clasts that are in point-to-point contact. Material smaller than 2 mm is predominant in matrix-supported deposits, and most clasts are separated by matrix material. Grain sizes given for surficial deposits are based upon visual estimates and the modified Wentworth grain-size scale (Ingram, 1989). This classification system describes pebbles, cobbles, and boulders as differing sizes of gravel. The term "gravel" is also commonly used for rounded clasts that show evidence of fluvial transport. To avoid confusion, non-fluvial angular and subangular clasts ranging in size from 2 to 256 mm are referred to as pebble-sized or cobble-sized clasts.

Divisions of the Pleistocene used herein correspond to those of Richmond and Fullerton (1986). Characteristics such as the degree of erosional modification of original surface morphology, height above modern stream levels, and relative degree of weathering and soil development were used to estimate the relative ages of the surficial deposits.

HUMAN-MADE DEPOSITS

af

Artificial Fill—Consists of fill and waste rock placed during construction of dams and roads. It is composed mostly of unsorted silt, sand, and rock fragments but may include construction materials. Maximum thickness is about 50 ft at the dam of Electra Lake. Artificial fill may compact when loaded, if not adequately compacted during construction.

ALLUVIAL DEPOSITS—These units consist of gravel, sand, silt, and clay deposited by flowing water in stream channels and flood plains along the Animas River and its tributaries and by slope runoff or sheet flow. Terrace alluvium along the Animas River is chiefly glacial outwash that was probably deposited during late-glacial and early-interglacial stages. Deposits resulting from sheet flow are called sheetwash. Alluvial deposits locally include colluvium that is too small to be mapped at a scale of 1:24,000. The approximate terrace heights given below indicate the elevation of the deposit above the modern stream channel.

Qa

Stream channel, flood-plain, and low-terrace alluvium (Holocene and late Pleistocene)—Includes modern stream-channel deposits of the Animas River and its tributary streams, adjacent flood-plain deposits, and low-terrace alluvium that is at or near the modern stream level. Sediment is generally deposited in active stream channels and as overbank deposits on adjacent terraces that are less than 4 ft above channel retreat. These deposits are poorly sorted and generally clast supported. They consist of unconsolidated, pebble to boulder gravel with a sandy or silty matrix locally interbedded with or overlain by beds and lenses of sandy silt and silty sand. Some clasts in the gravel are imbricated. Gravel deposits in this unit contain subround to round clasts with diverse lithologies such as amphibolite, gneiss, schist, granite, quartzite, sandstone, limestone, monzonite porphyry, and ash-flow tuff. The variety of clast lithologies reflects the wide range of rocks that crop out within the Animas River drainage basin. Some deposits of Qa in the vicinity of Electra Lake and Haviland Lake are composed principally of silty and sandy sediment that is heavily vegetated, locally forming wetlands and marshes. Maximum thickness of Qa is about 15 ft. Low-lying areas underlain by unit Qa are subject to flooding. Unit Qa is a source of sand and gravel for artificial fill.

Qta **Terrace alluvium, undivided (early Holocene and late Pleistocene)—**Chiefly stream alluvium that underlies strath, fill, or fill-cut terrace surfaces along or near the Animas River. Surfaces are flat and generally parallel to the modern stream channel. Terrace heights range from 5 to 80 ft above the river. Five distinct terraces formed above the current level of the Animas River occur just north of the Tacoma Power Plant on the west bank of the river. The highest of these terraces is about 80 ft above the modern bank of the Animas River. Deposits in unit Qta are mostly poorly sorted and clast supported. The majority of these deposits are composed of boulder- to pebble-sized gravels that have a silty to sandy matrix and locally may include fine-grained overbank deposits or overlying sheetwash deposits. Clasts are mainly subround to round and are composed of bedrock lithologies that crop out within the Animas River drainage basin; lithologies are mostly granite, gneiss, schist, amphibolite, ash-flow tuff, sandstone, quartzite, limestone, conglomerate, and various types of hypabyssal intrusive rocks. Clasts are up to several feet in diameter, locally are imbricated, and generally are unweathered or only slightly weathered. In areas of highly mineralized bedrock, iron-oxide and iron-hydroxide form coatings and cements in these deposits. Soil developed on unit Qta has a weakly to moderately developed textural B horizon.

Terraces related to terrace alluvium may be tentatively correlated with the youngest terraces in group TG7 of Gillam (1998). The terraces in the Electra Lake quadrangle may be slightly younger, from perhaps 10 to 15 ka, because they were deposited well after the maximum advance of the Pinedale glacier. There was no attempt in this study to correlate the terraces with those defined by Gillam (1998) or Blair and others (2002) or to correlate terrace levels from one location to another on the map. The various terrace margins at a given location, however, are shown as dotted lines. The thickness of Qta varies from 5 to 65 ft in fill and fill-cut terraces. Locally Qta is absent or only a few feet thick on strath terraces, but may be over 65 ft thick in buried channels. This unit is a source of sand and gravel.

COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay that rest on valley sides, hillslopes, and valley floors and were mobilized, transported, and deposited primarily by gravity.

Qc **Colluvium (Holocene and late Pleistocene)—**Unit ranges from unsorted, clast-supported gravel consisting of pebble-sized to boulder-sized rock fragments in a sandy or silty matrix, to matrix-supported gravelly sand or clay-rich silt. Colluvium is locally derived from weathered bedrock and surficial deposits and is transported a relatively short distance downslope. As used herein, colluvium follows most aspects of the definition of Hilgard (1892), which allows colluvium to include a minor amount of sheetwash. Colluvium deposits may also contain minor amounts of surficial material from other processes, particularly debris flows, which are active at different times on the same slope on which colluvial action predominates. As a result, many deposits mapped as colluvium likely include materials of varied genesis. The unit may also include talus, landslide deposits, sheetwash, creep, and debris-flow deposits that are too small in area or too indistinct on aerial photographs to be mapped separately.

Colluvium is usually coarser grained in upper reaches and finer grained in distal areas. Colluvial deposits are generally unsorted or poorly sorted with weak or no stratification. Most rock clasts in colluvium are angular to subangular, but colluvium derived from fluvial or glacial gravels contains rounded clasts. Clast lithology is variable, as it depends on type of material exposed in the source area. Maximum thickness is estimated at about 50 ft, but the unit commonly is much thinner. Extensive deposits of colluvium occur in the area west of U.S. Highway 550 N on steep, eroded slopes of the Hermosa Formation. Areas mapped as colluvium are susceptible to future colluvial deposition and are locally subject to sheetwash, rockfall, small debris flows, mudflows, and landslides. Fine-grained, low-density colluvium may be prone to collapse upon wetting or loading.

Qrf

Rockfall deposits (Holocene or late Pleistocene)—An extensive, tongue-shaped deposit composed of unconsolidated and unstratified angular blocks from the Hermosa Group is exposed below Hermosa Cliffs directly west of the dam at Electra Lake. This deposit contains angular blocks of limestone and sandstone that are up to 30 ft in length. A good estimate of the maximum thickness of this unit was not obtained but it is at least several meters thick near the base. This deposit covers the lower terminal edges of several landslide deposits.

Qls

Landslide deposits (Holocene and late Pleistocene)—Heterogeneous hummocky deposits composed of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Unit includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes. Numerous landslide deposits have formed on the steep slopes beneath cliffs of the Pennsylvanian Hermosa Group on the west side of the quadrangle. These deposits contain blocks of the Hermosa Group that are up to tens of feet in diameter. Landslide deposits in parts of the quadrangle may have resulted from slope failures in glacial moraine, some of which involve underlying or adjacent bedrock. On the east side of the Animas River canyon between Tank Creek and Canyon Creek, several large landslides formed from collapse of moraine deposits. Maximum thickness of landslide deposits may exceed 100 ft. Landslide deposits may be subject to future movement. Large blocks of rock that are found locally in these deposits may hinder excavation. Landslide deposits may be prone to settlement when loaded, and shallow groundwater may occur within them.

Qt

Talus (Holocene and late Pleistocene)—Unconsolidated and poorly sorted angular, cobble- to boulder-sized blocks that originate as rock falls from cliffs and ledges of bedrock exposed above the talus field. Talus deposits generally blanket the topography on steep slopes at an angle of repose of 30º to 40º. Significant talus slopes occur below the Pennsylvanian Hermosa Group along the Hermosa Cliffs and also below cliffs of Proterozoic rocks in the canyon of the Animas River. Talus commonly lacks matrix and has an estimated maximum thickness of 25 ft. Areas mapped as talus are subject to severe rockfall, rockslide, and rock-topple hazards. Talus may be a source of riprap.

ALLUVIAL AND COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay deposited in alluvial and colluvial environments in fans, stream channels, flood plains, and adjacent hillslopes. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas processes on fans and adjacent hillslopes are colluvial, alluvial, or sheetwash.

Qf

Fan deposits (Holocene and late Pleistocene)—Includes hyperconcentrated-flow, debris-flow, alluvial, and sheetwash deposits in fans and drainages. The sediment in these deposits is supplied by streams and debris flows in confined and commonly braided channels by seasonal high-discharge events. Fan deposits that are composed mostly of remobilized glacial moraine that was transported down slope by fluvial action occur near the level of the Animas River just east of the Tacoma Power Plant in Canyon Creek and at the mouth of Tank Creek. Locally the unit may include earthflows or landslides too small to map separately at a scale of 1:24,000. Fan development post-dates glaciation and is therefore younger than about 15 ka. These deposits form as fan-shaped landforms at the mouths of streams where stream gradient and velocity decreases and where topography widens from confined channels to open valleys. Gradients on the surface of the fans are generally less than 20º.

Fan deposits consist of crudely stratified unconsolidated deposits that range from very poorly sorted, clast-supported, pebble-sized, cobble-sized, and boulder-sized rock fragments in a clay-rich silt or sand matrix to matrix-supported, gravelly, clay-rich silt. Unit is frequently bouldery, particularly near the heads of some fans. Deposits tend to be finer grained in the distal ends of fans, where sheetwash and mudflow processes may be more common. Clasts range from angular to subround. Maximum thickness is estimated at about 60 ft. Alluvial fans are subject to future debris flows, hyperconcentrated flows, and alluvial deposition and to flooding. Fine-grained, low-density younger fan deposits may be prone to settlement, piping, and collapse. Unit is a potential minor source of sand and gravel.

Qcs **Colluvium and sheetwash, undivided (Holocene and late Pleistocene)—**Along with colluvium, this unit also includes materials transported chiefly by sheet flow and deposited in valleys of ephemeral and intermittent streams, on gentle hillslopes, or in topographic depressions. These sheetwash deposits are locally derived from weathered bedrock and surficial materials. Sheetwash typically consists of pebbly silty sand, sandy or clayey silt, and sandy to silty clay. Locally it grades to and interfingers with colluvium (Qc) on steeper hillslopes. In many areas the contacts between sheetwash and colluvium are not well defined in Qcs. In closed depressions sheetwash may grade to lacustrine or slackwater deposits. The maximum thickness is about 25 ft, but commonly the deposits are much thinner. Areas mapped as sheetwash are subject to future sheet-flow deposition. Unit may be prone to hydrocompaction, settling, and piping where fine grained and low in density.

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)—**This unit chiefly consists of stream-channel, low-terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams and of subordinate amounts of colluvium and sheetwash along valley sides. Locally includes debris-flow deposits or small subdued hills underlain by bedrock. The alluvial and colluvial deposits are mapped as a single unit because they (1) are interbedded, (2) are gradational and have boundaries that are difficult to discern, or (3) occur side by side but are too small to show as individual polygons at the map scale. The alluvial component of the unit is poorly to well sorted and ranges from stratified fine sand to sandy gravel, whereas the colluvial component consists of poorly sorted, unstratified or poorly stratified clayey silt or sand, silty sand, bouldery sand, and sandy silt. Clast lithologies reflect the rocks within the provenance area.

Unit Qac is commonly 5 to 20 ft thick and has a maximum thickness estimated at about 35 ft. Stream channels, adjacent flood plains, and low terraces may flood. Valley sides are prone to colluvial processes, sheetwash, rockfall, and small debris flows. Deposits in unit Qac may be subject to settlement or collapse where low in density or to piping where fine grained and exposed in deep arroyo walls. These deposits are a potential source of sand and gravel.

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by glacial ice as till or by water flowing adjacent to or beneath a glacier. This unit also includes sand, gravel, silt, clay, and peat deposited in tributaries dammed by lateral moraines.

Qm **Morainal deposits (late and late middle? Pleistocene)—**Unconsolidated to compacted heterogeneous deposits of clay- to boulder-size sediment deposited adjacent to or beneath glacial ice at ice margins along the Animas River valley. Consists mostly of hummocky deposits that form lateral and ground moraine. The morainal deposits are poorly exposed but appear to be predominantly matrix-supported, pebbly, cobbly, and bouldery silt. Clasts are unweathered to moderately weathered, subround to subangular, and consist largely of Proterozoic crystalline rocks, Paleozoic sedimentary rocks, and subordinate diorite to monzonite porphyry and andesitic ash-flow tuff.

Most moraine deposits are probably close in age to Pinedale and other late-Wisconsin moraines that formed about 12 to 35 ka (Richmond, and Fullerton, 1986). The last vestiges of glaciers in the area were between 12 and 15 ka. (Maher, 1972; Carrara and others, 1984; Gillam, 1998). Most sediments in the lateral moraines that are preserved high on the valley walls probably correlate with the till of Animas City moraines in the Animas River valley (Johnson and Gillam, 1995; Gillam, 1998; Carroll and others, 1999). Some deposits in lateral moraines may be correlative with the till of the Spring Creek moraines (Johnson and Gillam, 1995; Gillam, 1998; Carroll and others, 1999), which are in the age range of 85 to 160 ka (Richmond and Fullerton, 1986). The moraine deposits have an estimated maximum thickness of about 80 to 120 ft and may be a source of sand and gravel. In some parts of the quadrangle these deposits were remobilized as landslides and debris flows, and adjacent to the modern channel of the Animas River glacial deposits were dissected and reworked in strath terraces.

BEDROCK UNITS

LATE CRETACEOUS TO TERTIARY IGNEOUS ROCKS

Tm

Mafic to intermediate dikes (Tertiary)—In the road cut of highway 550N at the north end of the quadrangle the Leadville Limestone and Molas Formation are cut by mafic to intermediate dikes up to 2 ft thick. These dikes have a very fine-grained, black to greenish-black groundmass with less than 10 percent microphenocrysts of plagioclase and augite that are extensively recrystallized and altered to chlorite, clay, and calcite. The groundmass of this rock is completely recrystallized and altered. This rock also contains less than 2 percent quartz that occurs in irregular blebs and appears to be partially resorbed xenocrysts, possibly from Cambrian Ignacio Formation or the Twilight Gneiss. There are also large angular xenoliths of Twilight Gneiss and Molas Formation in the dikes. These dikes are similar in composition and texture to fine-grained gabbroic dikes that cut the Twilight Gneiss about 2.5 mi to the east in Animas River canyon.

TKm

Quartz monzonite porphyry (middle Tertiary to Late Cretaceous)—The basal section of an eroded sill of quartz monzonite porphyry is exposed in the northwestern corner of the Electra Lake quadrangle at Lift 8 of Durango Mountain Ski Resort. A sill of this intrusive rock also cuts the Hermosa Group just west of the confluence of Elbert Creek and Line Creek.

Rock that makes up these sills is porphyritic to microporphyritic with 10 percent to 50 percent phenocrysts of sodic plagioclase (An < 30), orthoclase, resorbed quartz, biotite, and opaque minerals. Some samples also contain pseudomorphs of mafic phenocrysts that have the morphology of amphibole but are altered completely to iron oxide and clay minerals. Feldspar phenocrysts are up to 1 inch in length while phenocrysts of the other minerals are typically less than 0.2 in long. Locally, the orthoclase phenocrysts are rimmed by plagioclase forming a pronounced rapakivi texture. The groundmass of this rock is a medium- to dark-gray, fine-grained, felty mass of feldspar, iron oxide minerals, and apatite. Feldspar in the groundmass is altered to clay minerals, calcite, and sericite.

The intrusive mass at Lift 8 locally contains irregular zones of hydrothermal breccia containing angular fragments of intrusive rock with limonite staining and pervasive argillic alteration of the feldspar phenocrysts. There is no obvious mineralization in this intrusive, but within the soils and intermittent streambeds to the south and east of this stock placer gold has been found. Intrusive rocks included in TKm are similar in texture and mineralogy to late Tertiary intrusive rocks exposed at Engineer Mountain to the north and Gray Sill Mountain to the west. A potassium-argon age on feldspar from Engineer Mountain gave an age of 16.6 ± 0.5 Ma (written communication from Richard Reesman, K-Ar Laboratory Manager, Geochron Laboratories, 1998).

PALEOZOIC SEDIMENTARY ROCKS

Pc

Cutler Formation (Lower Permian)—The Cutler Formation is comprised of clastic sedimentary rocks ranging in color from medium- to dark-reddish brown, grayish brown, medium to dark brown, and maroon. This unit is composed mostly of interbedded sandstone, feldspathic sandstone, arkosic conglomerate, limestone-pebble conglomerate, thin-bedded to thinly laminated shale and siltstone, and rare beds of massive unfossiliferous and fossiliferous limestone up to 2 ft thick. Siltstones and shales in the Cutler Formation are characterized by bluish-green to grayish-green reduction spots up to several inches in diameter. Sandstones are immature to submature and contain high concentrations of quartz, potassium feldspar, and biotite in hematitic cement. Beds of conglomerate are dominated by subangular to subrounded granule- to pebble-sized clasts of quartz, quartz arenite, granite, biotite gneiss, and arkosic sandstone in calcareous matrix. Limestone conglomerate in the Cutler Formation generally contains subangular fragments of limestone in a sandy matrix. Bedding in this unit is thin to very thick with alternating ledges and slopes. Sandstone and conglomerate beds typically have a pronounced low-angle, tangential to trough cross stratification. Siltstones are mostly thin bedded to thickly laminated, and weathered surfaces are broken into thin slabs in most outcrops. The Cutler Formation was deposited in fluvial and alluvial-fan environments in the Paradox Basin during erosion of the adjacent Ancestral Rocky Mountains (Campbell, 1979, 1980). Within the mapping area the Cutler Formation is up to 700 ft thick. This unit may be prone to rockfall hazards where exposed in steep cliffs.

IPh **Hermosa Group (Middle Pennsylvanian)—** Outcrops of the Hermosa Group in the map area form the southernmost exposures of Pennsylvanian strata on the eastern side of the Paradox Basin. On the basis of its brachiopod faunas, the Hermosa Group was assigned a Desmoinesian age (Franczyk and others, 1995). The Hermosa Group in the map area was subdivided into a lower Pinkerton Trail Formation and an overlying undifferentiated part by Franczyk and others (1995). They identify four different carbonate lithofacies in the Hermosa Group that they interpret to represent various marine depositional environments. These lithofacies were established on the basis of mineral assemblages, textures and structures, biotic assemblages, and inferred depositional environments. In the undifferentiated part of the Hermosa Group, stacked carbonate-clastic depositional cycles are dominated by carbonate units at the base that then grade upward into coarsening clastic cycles. These cyclic deposits formed in marine deltaic and nonmarine deltaic and alluvial systems. Franczyk and others (1995) recognized between 28 and 40 of these depositional cycles.

Lithofacies 1 corresponds to the Pinkerton Trail Formation. It is dominated by a succession of black to dark-gray, thin- to thick-bedded calcareous shale, wackestone, packstone, rare grainstone, and dolomitic limestone. Carbonate lithologies in this formation contain crinoid stems, brachiopod shells and spines, fusulinids, monaxon sponge spicules, and bryozoa (Franczyk and others, 1995). The Pinkerton Trail Formation is exposed in road cuts along U.S. Highway 550 and is especially well exposed in the road cut at the south end of the quadrangle.

Carbonate lithofacies 2 to 4 in the undifferentiated part of the Hermosa Group above the Pinkerton Trail Formation contain thin to thick beds of dolostone, dolomitic limestone, calcareous shale, dolomitic siltstone, calcareous shale with about 40 percent limestone pebbles and cobbles, fossiliferous limestone, limey mudstone, packstone, grainstone, and wackestone. Faunal assemblages noted by Franczyk and others (1995) in these lithofacies include crinoid columns, echinoderm plates, brachiopod shells and spines, algal laminations, stromatolitic structures, fusilinids, foraminifera, phylloid algae, ostracods, monaxon sponge spicules, gastropods, and pelecypods.

Clastic deposits within the stacked successions include very thin to very thick beds of mudstone that locally contain organic debris, siltstone, fine- to coarse-grained sandstone, and pebbly conglomerate. These beds vary from massive to cross stratified. Siltstones and sandstones observed during this study ranged from mature quartz arenites to immature micaceous siltstones. Detrital minerals include quartz, feldspar, mica, glauconite, and fossil fragments (Franczyk and others, 1995). Rock fragments in pebbly sandstones and conglomerates include milky quartz, very fine-grained black to green shale, amphibolitic and granitic gneiss, granite, gray limestone, brown to tan quartzite, and gray to brown chert. Sandstone beds locally contain slender fragments of carbonized material up to 4 inches in length that are interpreted as fossilized flora. There are also worm burrows in many sandstone layers.

IPm **Molas Formation (Lower Pennsylvanian)—** The Molas Formation is a karstic breccia with fragments of micritic to sparry limestone up to 10 in long that are set in a fine-grained matrix of red siltstone and claystone. Limestone breccia in this unit commonly contains angular to subangular clasts of chert, chalcedony, and agate that are up to 5 inches in maximum dimension. In the roadcut on U.S. Highway 550 at the north end of the area, chert forms irregular masses and thin beds in the Molas Formation. The Molas Formation formed as regolith on the underlying brecciated and weathered top of the Mississippian Leadville Limestone. The Molas Formation in the map area is up to 25 ft thick and locally occurs as pipes and fracture filling in the underlying Leadville Limestone.

Ml **Leadville Limestone (Lower Mississippian)—** The Leadville Limestone crops out along the central to southeastern edge of the map area as well as on the east side of Highway 550 through the central part of the map area. This unit contains interbedded marine rocks that include limestone, black to gray shale, intraformational limestone conglomerate, limestone breccia, and stromatolitic dolomite.

Limestone in this unit is generally gray to grayish-brown, dolomitic micrite or sparrite that commonly contains fossils and oolites. In the drainage of Elbert Creek the Leadville Limestone contains a layer of coarse quartz sandstone up to a meter thick. Thin beds and lenses of chert are interbedded with limestone in the upper part of the Leadville Limestone at the southern edge of the quadrangle. In some outcrops bedding is prominent and ranges from thin to thick with shale layers that are thin to medium laminated. Near the top of this unit the bedding is generally not distinct, and the unit has a more massive appearance. Fossils found in this unit include abundant crinoid columns, brachiopods, rugose corals, syringoporid corals, bryozoa, and endothyrid foraminifera (Baars and Ellingson, 1984).

In many localities the base of the Leadville Limestone is defined by a layer of red to green shale, siltstone, and sandstone up to 15 ft thick that has abundant salt casts with edges up to 0.5 in long. The base of the Leadville Limestone is generally marked by a distinct slope above well-defined benches at the top of the Ouray Limestone. The top of the Leadville Limestone is irregular due to karstic erosion prior to deposition of the Molas Formation. The Leadville Limestone reaches a maximum thickness of about 150 ft.

Do

Ouray Limestone (Upper Devonian)—The Ouray Limestone crops out along the central to southeastern edge of the map area as well as on the east side of Highway 550 through the central portion of the map area. The contact between the Ouray Limestone and underlying Elbert Formation was placed where the red clastic rocks and minor limestone of the Elbert Formation grade into dolomitic limestone with minor clastic rocks of the Ouray Limestone.

The Ouray Limestone is comprised chiefly of brown to light-gray dolomitic limestone, micritic limestone, and sandy dolomite that were deposited in shallow marine environments; dolomitic rocks are mostly stomatolitic and supratidal in origin (Campbell and Gonzales, 1996). Thin to medium beds of thinly laminated reddish-brown, black, or green shale occur in this unit, especially in the basal part of the formation. In some outcrops the shale layers show soft sediment deformation structures such as pinch and swell. Lenticular limestone nodules were also observed in some of the shale layers. Occasional thin to medium beds of light-brown sandy micrite near the top of the unit have intraclasts of dolomitic limestone. Subrounded to rounded grains of quartz and feldspar were observed in some of the sandy micrite beds. A bed of quartz-rich sandstone up to 6 ft thick is exposed above the basal micrite of the Ouray Limestone south of Columbine Lake near the Two Dogs Subdivision. Limestone breccia is locally present near the base of the Ouray Limestone. On the west side of Columbine Lake, the basal portion of the Ouray Limestone contains three parallel layers of chert, 1 in to 4 in thick, within a dense micrite approximately 3 ft thick. These chert layers were observed along the entire length of the western side of Columbine Lake although they are traceable only at outcrop scale in any one area. Bedding in this unit is poorly developed, but where apparent it ranges from thin to thick. Laminar features that could be fossilized algal mats occur in some places within the Ouray Limestone, but otherwise no fossils were observed in this unit within the map area. The Ouray Limestone is generally less than 100 ft thick but it reaches its maximum thickness on the eastern side of the Animas River. This unit is resistant and forms prominent cliffs and benches.

DCei

Elbert Formation (Upper Devonian) and Ignacio Formation (Upper Cambrian), undifferentiated—The Elbert Formation is interbedded red to maroon shale, siltstone, fine- to medium-grained quartz arenite, and sandy dolomitic limestone that lies unconformably on the Ignacio Formation. Rocks in the Elbert Formation formed in an intertidal marine environment (Baars and Ellingson, 1984; Campbell and Gonzales, 1996). Iron staining is present in most outcrops of this unit. The upper member of the Elbert Formation is thin-bedded to thinly laminated and is no more than 15 ft thick. This part of the unit is slope forming and typically covered by heavy vegetation. Shales and siltstones in the Elbert Formation can be micaceous and locally contain salt casts and trace fossils. The base of the Elbert Formation is a white to tan quartz arenite and pebbly conglomerate that comprises the McCracken Member (Baars and Ellingson, 1984; Campbell and Gonzales, 1996). There has been some controversy over the distinction between the

McCracken Member of the Elbert Formation and the Ignacio Formation (Baars and Knight, 1957; Baars, 1966; Baars and See, 1968; Baars and Ellingson, 1984; Campbell and Gonzales, 1996). In most instances the McCracken Member cannot be distinguished from the underlying Ignacio Formation and the ca. 125-million-year disconformity between these units is generally unrecognizable in the field. Therefore, in this study the Elbert Formation and Ignacio Formation are not differentiated and collectively form the lowermost unit of the Paleozoic section. All sedimentary rocks that are exposed between Precambrian crystalline rocks and the Ouray Limestone are included in this map unit. Locally, the Elbert Formation is not preserved.

The Ignacio Formation is a mottled reddish-brown to grayish-brown, light-brown, white, or light-pink coarse-grained quartz arenite and pebble conglomerate. The Stag Mesa Member (Campbell and Gonzales, 1996) is medium- to thick-bedded shallow-marine quartz arenite with lenses of pebble conglomerate up to 1.5 ft thick. Quartz arenite in the Stag Mesa Member has silica cement that makes it extremely resistant to weathering and erosion; minor hematitic cement gives these rocks their characteristic mottled appearance.

The base of the Ignacio Formation contains lenses and beds of matrix- to clast-supported pebble conglomerate on the western and northern edges of Columbine Lake, on the western shore of Electra Lake, south of Haviland Lake, and the eastern canyon walls of the Animas River. The basal conglomerate contains rounded to subrounded clasts of quartzite, milky quartz, and rare granite. Angular fragments of potassium feldspar are found in some lenses of the conglomerate. Interbedded with this conglomerate are thin beds of coarse-grained quartz arenite with hematitic silica cement. Beds of sandy dolomitic limestone up to 3 ft thick occur in the upper part of the Stag Mesa Member of the Ignacio Formation in the Rockwood area. These limestone beds also contain limestone fragments and patches of sparry calcite. Pronounced tabular to low-angle tangential cross stratification is visible in most outcrops of the Stag Mesa Member, as well as blocky and rectangular fractures. The Stag Mesa Member is up to 100 ft thick and forms a prominent cliff at the base of the Paleozoic section.

PROTEROZOIC CRYSTALLINE ROCK UNITS

gb

Gabbro dikes (Neoproterozoic to Mesoproterozoic, absolute age uncertain)—Black to greenish-black gabbroic dikes intrude the Irving Formation, Twilight Gneiss, Bakers Bridge Granite, and quartz-porphyry dikes of the Eolus Granite. Cambrian strata of the Ignacio Formation overlie and are younger than these gabbroic dikes. A sample from a gabbro dike exposed in the Rockwood area was submitted to the New Mexico Geochronological Research Laboratory for analysis. Hornblende from this sample was initially step-heated as a bulk separate and yielded a highly disturbed age spectrum with apparent ages between 800 Ma and 1627 Ma. An integrated age of 1067.5 ± 7.5 Ma was calculated for this sample (written communication with Lisa Peters, April 15, 2002). The sample was reanalyzed as single crystals in an attempt to assign a more precise age. Twenty six single crystals of hornblende were fused with the CO2 laser. The hornblende crystals yielded a range of ages from 666.7 ± 28.0 Ma to 4,369.3 ± 350 Ma with the apparent ages of all but the oldest crystal being evenly distributed between 666.7 ± 28.0 Ma and 1,407.4 ± 619.0 Ma (written communication with Lisa Peters, June 20, 2003). No correlation between radiogenic yield or K/Ca value and apparent age was determined, but the ages suggest that the dikes are probably Proterozoic.

Most of the dikes trend east-west, subparallel to felsic dikes of the Eolus Granite, and they commonly dip between 60° and 90°. The dikes are generally equigranular, fine to coarse grained or microporphyritic. Lath-shaped phenocrysts of plagioclase up to 2 in. in length comprise up to 10 percent of the interior parts of some dikes, giving the rock a pronounced porphyritic texture. Essential constituents of these gabbros are subophitic to ophitic assemblages of hornblende and andesine. Some samples contain clinopyroxene that is mantled by hornblende, but pyroxene is not common. Other constituents in these rocks include opaque minerals, apatite, and minor quartz. Plagioclase crystals are generally altered to masses of epidote, sericite, and calcite; hornblende is commonly altered to chlorite and biotite. Minor to extensive alteration in these rocks appears to be related to late-stage magmatic fluids. At some contacts with country rocks the mafic dikes have chilled and sheared margins. Along the cut of the Durango and Silverton Narrow Gauge Railroad north and east of Rockwood, these gabbroic dikes appear to have caused minor melting of the Bakers Bridge Granite. Most of these dikes are less than 6 ft thick, but some are up to 30 to 45 ft thick. They have a tendency to fill pre-existing fractures in older crystalline rocks.

Yel

Electra Lake Gabbro (Mesoproterozoic)— Fine- to very coarse-grained subophitic to ophitic gabbro, diorite, and granodiorite. This unit locally contains irregular zones of gabbroic pegmatite that crop out over areas of several to tens of square feet. Rocks in the Electra Lake Gabbro are generally massive but locally have a weak to strong northwest- to southeast-trending primary flow foliation defined by subparallel aligned blades of pyroxene and laths of plagioclase. Essential constituents in the Electra Lake Gabbro in a general paragenetic sequence are clinopyroxene and orthopyroxene, andesine to labradorite, hornblende, biotite, and quartz. Pegmatitic phases also contain perthitic microcline. Accessory minerals include apatite, deuteric epidote, magnetite, and zircon; secondary alteration of plagioclase to sericite and mafic minerals to chlorite is common in these rocks. Zircons from a sample of pegmatitic gabbro collected at Electra Lake give a U-Pb age of 1,435 ± 2 Ma (Gonzales, 1997).

Approximately 1 mile southeast of Haviland Lake the Irving Formation is intruded by several irregular masses of pegmatitic gabbro (shown as pattern on the map) that are interpreted as offshoots of the Electra Lake Gabbro. These bodies are exposed over areas that are up to 300 square ft. They contain large anhedral mafic and felsic clots that give the rock a mottled appearance. Mafic clots are composed essentially of hornblende altered to chlorite. Felsic clots are subequant crystals of andesine to bytownite recrystallized to epidote and sericite. Accessory minerals include apatite, zircon, sphene, and opaque minerals.

qp

Quartz-porphyry dikes (Mesoproterozoic)— Porphyritic granitic dikes are exposed within the older crystalline rocks in the northeastern part of the map area. These dikes contain phenocrysts of subhedral to euhedral quartz, perthitic microcline, perthite, oligoclase, biotite, and hornblende that are set in a felty-microcrystalline to very fine-grained groundmass of quartz, perthite, perthitic microcline, biotite, minor hornblende, zircon, apatite, and iron oxide. Alteration of potassium feldspar to clay and plagioclase to sericite, calcite, and minor epidote is common; biotite alteration to iron oxide and chlorite is present in most samples. These rocks are brownish orange, grayish brown, and dark gray on fresh surfaces and grayish brown to tan on most weathered surfaces. The most striking aspect of these rocks is the pronounced porphyritic texture defined by blocky crystals of alkali feldspar and anhedral crystals of clear to smoky quartz. Phenocrysts generally comprise about 10 to 15 percent of the rock, but in some outcrops the phenocrysts make up about 50 percent of the rock. These dikes locally have a flow foliation developed parallel to their margins as a result of shearing during emplacement. A striking rapakivi texture is visible in most exposures with alkali feldspar phenocrysts mantled by white albite. Quartz crystals in some samples are embayed, indicating disequilibrium crystallization during emplacement. In thin section, some samples have micrographic texture and myrmekitic intergrowths. These quartz-porphyry dikes are up to 150 ft thick, though most are 3 to 15 ft thick. In many cases these dikes terminate abruptly in country rock and locally can have abrupt variations in trend. A U-Pb zircon age of about 1,400 Ma was obtained from a sample of quartz-porphyry dike about 1 mile south of Shalona Lake in the Hermosa quadrangle (Gonzales, 1997).

Ye

Eolus Granite (Mesoproterozoic)—The Eolus Granite is comprised mostly of medium- to coarse-grained porphyritic or equigranular granite and monzonite, and pegmatitic granite. Granodiorite and dioritic phases occur in the intrusive complex but they are minor. Granite and monzonite of the Eolus Granite contain pink to salmon phenocrysts of perthitic microcline that are up to 3 inches in length. These phenocrysts are set in a medium- to coarse-grained groundmass of quartz, oligoclase, perthitic microcline, biotite, hornblende, and magnetite. Zircon, apatite, sphene, and epidote are minor accessory constituents. Zircon crystals from samples of the Eolus Granite exposed between Vallecito Reservoir and Electra Lake yield U-

Pb radiometric ages of 1,442 ± 3 Ma, 1,435 ± 3 Ma, and 1,438 ± 9 Ma (Gonzales, 1997).

g

Aplite, pegmatite, and fine- to coarse-grained granitic dikes and sills (Mesoproterozoic to Paleoproterozoic)— These dikes are interpreted as offshoots of the Bakers Bridge Granite or Eolus Granite, although no age determinations have been done on them. In some localities these dikes cut the Irving Formation and Bakers Bridge Granite in the map area. They range from inches to tens of feet in thickness and can extend hundreds of feet along strike. Locally they have a weak to strong east-trending foliation that may be related to deformation that occurred about 1,435 Ma (Gonzales and others, 1995). Granite dikes in the map area generally trend east-west and erosion along these dikes has locally created steep valleys of intermittent streams which are tributary to the Animas River. These rocks are generally reddish orange to brownish orange and contain perthite, perthitic microcline, sodic plagioclase, quartz, biotite, and minor hornblende.

Xb

Bakers Bridge Granite (Paleoproterozoic)— The Bakers Bridge Granite is exposed only along the southern margin of the Electra Lake quadrangle where it intrudes the Irving Formation. The main phase of the Bakers Bridge Granite is a relatively homogeneous, medium- to coarse-grained, equigranular to seriate porphyritic, biotite-hornblende-magnetite granite. Barker (1969) also reported alaskite and quartz monzonite phases in the pluton. A stock of biotite-muscovite granite cuts the main pluton near its southern exposed end (Bickford and others, 1969) that is outside the map area. Gonzales (1997) reported U-Pb ages on zircon of 1,698 ± 4 Ma for the biotite-hornblende-magnetite granite and 1,695 ± 2 Ma for the biotite-muscovite granite.

In the map area the Bakers Bridge Granite is composed mostly of a coarse-grained assemblage of perthitic microcline, perthite, quartz, albite to oligoclase, hornblende, and biotite with accessory zircon, apatite, magnetite, calcite, and epidote. Potassium feldspar is commonly altered to clay, plagioclase to sericite, and mafic minerals to iron oxide. Some samples contain veinlets of calcite, muscovite, and quartz that fill microfractures. Porphyritic phases contain phenocrysts of perthitic microcline up to 3 in. in length. Associated with the coarser grained granite are aplitic to granitic dikes that in some outcrops are quite abundant. In the northern part of the pluton, particularly near the contact zone with the Irving Formation, the granite commonly has a pronounced rapakivi texture in which alkali feldspar phenocrysts are mantled by rims of sodic plagioclase. The predominant lithology in the Bakers Bridge Granite is a reddish- brown granite with no discernible tectonic fabrics. The part of the pluton that is exposed in map area, however, locally has a pronounced lenticular foliation that defines isoclinal and tight folds. This deformation fabric is developed in the outer 30 to 45 ft of the pluton, suggesting that strain developed along the margin of the pluton during its emplacement or that a regional tectonic strain was imparted to the magma during emplacement. The pluton truncates layering and deformational fabrics in the Irving Formation and contains numerous amphibolite xenoliths within about 0.75 mi of its northern margin. The xenoliths are in various stages of assimilation in this zone. Geochemical analyses from samples of the Bakers Bridge Granite (Barker, 1969, and this report) show that these rocks are relatively low in Ca and Mg and high in Na and K. These signatures are similar to high-crustal-level 1,700 Ma granitoids that are widespread in central Arizona and that occur locally in northern New Mexico and southern Colorado (Conway and others, 1987; Conway, 1995).

Xt

Twilight Gneiss (Paleoproterozoic)—The Twilight Gneiss is composed mostly of concordant layers of gneiss that are tonalitic, trondjhemitic, and granodioritic in composition. The metamorphosed intermediate rocks in the Twilight Gneiss contain layers of fine- to coarse-grained, strongly foliated to massive amphibolite that are typically 3 to 10 ft thick and continue along strike for tens to thousands of feet. At most locations the different rock types in this unit cannot be mapped separately and are undifferentiated, except in the area immediately east of Electra Lake. Although individual layers of these intermediate to mafic rocks are generally not shown on the map the trend of S_0 defined by these layers is indicated by map symbols. All rocks in the Twilight Gneiss contain F_1 and F_2 tight to isoclinal folds defined by quartz stringers and folded S_1 foliation. Foliations developed during the first and second phases of folding are generally steep dipping and trend roughly parallel to compositional layering in the Twilight Gneiss.

Gonzales (1997) interpreted the Twilight Gneiss as an intermediate plutonic complex that was cut by swarms of gabbroic sills or dikes prior to or during compressional deformation and amphibolite-facies metamorphism. Radiomentric age determinations indicate that these rocks crystallized between 1,775 and 1,755 Ma (Gonzales and others, 1994; Gonzales, 1997). The intrusive origin of these rocks was made on the basis of the lithologic associations, gross mineralogy, rock textures and structures, geochemical affinities, and primary intrusive relationships and features. The trondhemite-tonalite-gabbro suite is typical of plutonic complexes in orogenic belts at continental margins (Barker, 1979).

Intermediate gneisses in the Twilight Gneiss have rather homogeneous compositions and textures (Gonzales, 1997). These rocks are mostly medium- to coarse-grained and equigranular, but in some areas they contain relict porphyritic textures defined by 10 to 50 percent flattened phenocrysts of quartz and plagioclase in a fine-grained groundmass. Primary features in the tonalitic and trondhjemitic gneisses that support of an intrusive origin include offshoots of the tonalitic layers that crosscut trondhjemitic host rocks, relict chill margins in some layers of tonalitic gneiss, and zones of lenticular mafic xenoliths in the tonalitic gneisses (Gonzales, 1997).

Trondhjemitic gneiss is the dominant rock type of the Twilight Gneiss within the Electra Lake quadrangle. It is fine- to coarse-grained, grayish-white to tan gneiss that typically contains subequant to lenticular plagioclase crystals and ellipsoidal polygranular aggregates of quartz that are set in a finer grained groundmass composed largely of quartz, plagioclase, biotite, hornblende, epidote, garnet, muscovite, apatite, opaque minerals, and zircon with secondary chlorite and sericite. Polygranular quartz aggregates are from 1 to 40 mm long and impart a prominent ribbony foliation to most outcrops. Locally, the quartz aggregates and plagioclase crystals define relict porphyritic textures. The color index of these rocks is less than 25 percent.

Amphibolite layers in the Twilight Gneiss generally trend subparallel to compositional layering and foliation in the intermediate gneisses. The layers of amphibolite are texturally and compositionally homogeneous, being composed mostly of hornblende, plagioclase, quartz, epidote, and garnet along with accessory sphene, apatite, opaque minerals, and secondary chlorite and sericite. Relict chill margins and porphyritic textures were observed in some amphibolite layers (Gonzales, 1997). Original intrusive relationships of the mafic layers with the intermediate gneisses are preserved in some outcrops (Gonzales, 1997; Gibson, 1987), and crosscutting relationships reveal that the mafic layers were cut by sills and dikes of tonalite.

Partial melting of trondhjemitic gneiss in the Twilight Gneiss during emplacement of the Electra Lake Gabbro produced melt-filled fractures and breccia zones within 1.5 miles of the pluton margins. The spatial distribution of the granitic partial melt that was generated by this melting suggests that wall rocks form a shallow carapace around the pluton. An absolute age of the partial melt that fill fractures in an aureole of the Electra Lake Gabbro has not been obtained, but field relationships clearly link them with deformation at ca. 1,435 Ma (Gonzales and others, 1995). The degree of partial melting and brittle deformation increases gradually in the country rocks toward the main mass of the gabbro. Zones composed of variably rotated angular blocks of amphibolite in a matrix of nonfoliated to weakly foliated trondhjemite are common within 0.5 km to 1 km of the pluton. These zones resemble intrusive breccia and the felsic component grades from strongly foliated trondhjemitic gneiss to undeformed trondhjemite that has undergone nearly complete recrystallization and fabric annealing. The rotation of amphibolite fragments and local folding of elongate blocks reflects flow of magma produced by melting of trondhjemitic gneiss during emplacement of the gabbro.

Undeformed granitoid dikelets fill brittle fractures in the country rocks within 1 km to 2 km of the main mass of the Electra Lake Gabbro. These dikelets and stringers generally emanate from trondhjemitic gneiss layers that were penetratively deformed during pre-1,700 Ma metamorphism and deformation (Gibson and Simpson, 1988). Although melt-filled fractures are typically concentrated in more competent, amphibolite layers, they also cut tonalitic and trondhjemitic gneisses.

Locally within the contact aureole of the

Electra Lake Gabbro, stringers from granite dikes from the Eolus Granite fill brittle fractures in amphibolite layers in the Twilight Gneiss and Irving Formation. In some outcrops of melt breccia these dikes are intimately mixed with the trondhjemitic dikelets from partial melting and show a pronounced tectonic foliation. The involvement of Eolus Granite dikes in the melting and deformation further constrains the timing of this event at ca. 1,435 Ma. Offshoots of Electra Lake Gabbro also cut deformation and zones of melting in the pluton aureole, but penetrative ductile fabrics were not observed in these dikes.

Granulite-facies metamorphism near the margins of the gabbro is indicated by pyroxene-bearing amphibolite layers in the Twilight Gneiss. In addition, andalusite-, sillimanite-, and staurolite-bearing assemblages are widespread in Paleoproterozoic metasedimentary rocks within several kilometers of the Eolus Granite batholith (Barker, 1969; Burns and others, 1980). These mineral assemblages record an increase in thermal gradient toward the pluton margins. Distribution of thermal aureoles around ca. 1,435 Ma plutons in the Needle Mountains suggests that thermal metamorphism during their emplacement was subregional and not confined to narrow contact zones.

Xtt

Tonalitic gneiss—Medium- to coarse-grained, dark-gray gneiss with a pronounced ribbony foliation defined by alternating quartzo-feldspathic and mafic ribbons. A pronounced mineral lineation is visible in most outcrops. Principal constituents are quartz, plagioclase, biotite, hornblende, epidote, and garnet with accessory opaque minerals, apatite, zircon, and sphene. Most samples show partial replacement of mafic minerals and garnet by chlorite, and plagioclase by sericite. The color index of these rocks ranges from 30 percent to 80 percent. Zircons sampled from this unit on the east side of Electra Lake yielded a U-Pb age of 1,759 ± 6 Ma (Gonzales, 1997).

Xta

Amphibolite—A layer of amphibolite up to 75 ft thick is exposed on the southeast side of Electra Lake. This layer is similar in composition and texture to thinner amphibolite layers in the Twilight Gneiss and to mafic schist and gneiss in the Irving Formation. The other possible interpretation for this layer is a pendant of Irving Formation, but there is no compelling field and petrographic evidence to support this interpretation.

Xi

Irving Formation (Paleoproterozoic)—This unit contains polyphase deformed, middle to upper amphibolite-facies basaltic flows and tuffs, rhyolitic to dacitic tuffs and reworked volcanic deposits, and associated mafic intrusive rocks (Barker, 1969; Gonzales and others, 1994; Gonzales, 1997). A U-Pb age of 1,801 ± 6 Ma was obtained on zircons from a sample of metamorphosed rhyolite exposed about 1,500 feet east of Electra Lake (Gonzales, 1997).

Mafic rocks in the Irving Formation are fine- to coarse-grained, and strongly foliated to massive. Metamorphosed gabbro is the predominant mafic rock type of the Irving Formation in the map area. Mafic schist and gneiss in the Irving Formation is composed chiefly of hornblende, oligoclase to andesine, epidote, quartz, and garnet. Primary features such as pillow structures, pillow breccias, porphyritic and amygdaloidal textures, subophitic to ophitic textures, and additional features that support a volcanic or intrusive origin are preserved in exposures of the Irving Formation elsewhere in the Needle Mountains, but these features were not observed in the map area.

Felsic to intermediate rocks in the Irving Formation are fine- to medium-grained, and schistose to gneissic. They are composed largely of quartz, feldspar, biotite, muscovite, and garnet with color indices ranging from 5 to 50 percent. In some outcrops these rocks have a pronounced layering that is interpreted as primary bedding and lamination. Locally these felsic schists and gneisses are cut by swarms of medium- to coarse-grained quartzo-feldspathic stringers and ribbons that are less than 1 to 4 in. thick, generally trend subparallel to compositional layering and S_1-S_2 tectonic foliation, and define tight to isoclinal F_1 and F_2 folds. Transposition and detachment of quartz stringers locally form augen and boudin structures in which quartzo-feldspathic "eyes" and ribbons are set in a groundmass of finer grained schist. In some locations, felsic schist and gneiss in the Irving Formation contains layers of fine- to coarse-grained amphibolite that are up to 15 ft thick.

The earliest phases of deformation in the Irving Formation are F_1 and F_2 tight to isoclinal folds defined by quartz stringers and folded S_1 foliation. Foliations developed during the first and second phases of folding are generally steep dipping and trend roughly east-west. In some outcrops the S_1-S_2 foliations are refolded into F_3 folds (and related S_3 foliation) that are tight to open with variable trends. The F_1 to F_3 folds are interpreted as different phases of folding that developed during the same deformational event between 1,800 and 1,760 Ma. A pronounced east-west trending S_4 foliation is developed in granitic sills and stringers that cut the Irving Formation. U-Pb age determinations on zircons from these granitic intrusives yielded ages of 1,720 to 1,730 Ma (Gonzales, 1997). Superimposed on F1 to F_3 folds are F_4 p tygmatic folds that deform the granitic intrusives.

STRUCTURAL GEOLOGY

The dominant structures in the map area are brittle faults that cut Proterozoic and younger rocks. Many of these faults have an east-west trend but some trend northeast or northwest, and a few trend north-south. In most cases the orientations of the fault surfaces could not be determined or measured. Most of the eroded fault and related fracture planes that were observed, however, are vertical or steep. The interpretation of the apparent displacement on these faults is therefore based on disruption of the stratigraphic section, fault-line scarps, and other evidence such as breccia zones and mineralization. In some cases the interpretation as to whether a given fault is normal or reverse is tentative due to the lack of evidence for net slip. The ball and bar shown on the trace of faults on the map indicate the downthrown side of the fault, but dips of the fault planes are not known for all fault systems.

COLUMBINE LAKE-CASCADE CREEK FAULT SYSTEM

A complicated system of faults extends from east of the confluence of the Animas River and Cascade Creek to the Columbine Lake area. Scott (1983), Van Loenen and Scott (1983), and Van Loenen (1985) mapped part of the fault that cuts across Cascade Creek, but these structures are not shown on any other previous maps. The dominant structures in this system are northwest- trending faults that are intersected by a smaller system of northeast-trending faults near Columbine Lake. Good exposure of these smaller structures occurs in the road cut on Highway 550N near Silver Pick Resort. At this location these structures display both normal and thrust motions. The location of the Columbine Lake-Cascade Creek fault system in the Hermosa Cliffs was not determined due to heavy vegetation and poor exposure.

Zones of fault breccia with iron oxide and hydroxide coating and cement occur locally along the fault zones. The Columbine Lake-Cascade Creek fault system is mineralized at several points, most notably near the Silver Star Extension Mine and in the vicinity of Columbine Lake where numerous prospects and small mines were developed along the traces of these faults.

Evidence for the relative displacement of blocks juxtaposed on the faults is mostly from offset of layers in the lower Paleozoic section on the west side of Columbine Lake. In this area the dip of the faults were observed to be mostly steep to the north with displacements that are down to the north. The large fault that cuts across Cascade Creek dips to the south and displacement is down to the south. The two northwest-southeast faults of this system probably represent reactivation of Proterozoic fabrics and structures in the Twilight Gneiss. The Columbine Lake-Cascade Creek fault system locally provides the paths for tributaries of the Animas River, and numerous small springs have formed along the traces of these faults.

ELBERT CREEK FAULT

Cross and others (1905a) mapped northwest-southeast trending faults in the area just north of Elbert Creek which terminate in a series of faults at Hermosa Park to the west. Steven and others (1974) also mapped this fault as a normal fault with a south dip. Prior to this project the trace of the Elbert Creek fault was not mapped east of the Hermosa Cliffs. The surface trace of the Elbert Creek fault extends from Butler Creek eastward to Castle Rock where it is exposed in the steep cliffs of the Hermosa Group. The local relative displacement along this fault west of Hermosa Cliffs and its northern dip were used to interpret this structure as a normal fault with a north dip. A series of related synthetic structures are also developed in the area around Castle Rock. In the area between Castle Rock and Grasshopper Creek, east of the Animas River, the Elbert Creek fault displaces lower Paleozoic rocks and Proterozoic crystalline rocks of the Twilight Gneiss. Just west of Little Cascade Creek along the northern edge of Electra Lake, the Elbert Creek fault offsets the lower Paleozoic section and its contact with the Electra Lake Gabbro. Breccia zones were found in many places along the trace of the Elbert Creek fault. In the area between Castle Rock and Electra Lake there is an extensive zone of quartz veins and stockwork breccia occur along the fault. The stockwork breccia contains angular blocks of

Paleozoic country rock in a network of massive milky quartz veins that in some places have well-developed vugs with crystals of quartz up to 1 inch in length. Several small prospect pits were found along the fault within these breccia zones. Iron-oxide alteration and minor sulfide mineralization occurs in this fault zone along its trace within the Twilight Gneiss.

DUTCH CREEK FAULT

Two east-west trending faults are developed immediately north of Dutch Creek in the northwest quarter of the map area. The gently south-dipping contact of the Hermosa Group with the Cutler Formation is cut by these faults, and at several points along the trace of these structures the Cutler Formation is juxtaposed against rocks of the Hermosa Group. This pair of faults is exposed in the Hermosa Cliffs to the east where south dips of between 70º and 90º were observed. Cross and others (1905a) mapped this set of faults as a single structure but did not provide evidence of relative movement along the fault. Steven and others (1974) also show this map on the 1º x 2º Durango quadrangle with a down-to-the-south motion. There is no good evidence to establish the extent of the Dutch Creek fault east of Electra Lake. It is possible, however, that the steep and nearly linear Sawmill Canyon is the eroded trace of this fault.

CANYON CREEK FAULT SYSTEM

The Canyon Creek fault system is an extension of the northern branch of the Bear Creek Fault system that is mapped in the Hermosa quadrangle (Gonzales and others, 2002). The northern branch of the Bear Creek fault system trends northeast near the northern margin of the Hermosa quadrangle where it then curves into a north-south system of faults that dip steeply to the west with displacements that is down to the west. This system of faults splays just south of Canyon Creek and are either buried beneath Paleozoic and younger cover or the displacement along these faults diminishes, probably because of the branching of the fault system. Just south of Canyon Creek these faults dissect the west edge of the Paleozoic section and displace slivers of Ignacio Formation down to the west with up to 200 ft of apparent vertical offset. Several mineralized prospects were found along the trace of faults in the Canyon Creek fault system. The north-trending structures of the Canyon Creek fault system are intersected by a northwest- trending fault that dips north, juxtaposes the Eolus Granite against rocks of the Irving Formation, and offsets the intrusive contact between these units.

GOULDING CREEK FAULT SYSTEM

An extensive system of east and northeast-trending faults and fracture system occurs in the vicinity of Goulding Creek in the southern and central part of the Electra Lake quadrangle. This system is intersected by a set of north-trending faults. Erosion of these two systems of faults and fractures has created depressions and valleys that have influenced stream flow and springs in the area. Apparent vertical displacement of the Paleozoic strata that is cut by this system is generally not more than several hundred feet.

The east and northeast-trending faults of this system have steep dips to the south and relative vertical displacements of 5 ft to 50 ft. The eastern part of this system splays into a series of en-echelon fractures that displace the edge of the Paleozoic section and forms a series of south-stepping blocks. Further to the west these faults are anastomosing and branch into a set of faults with decreasing displacement.

The north-trending faults that intersect this fault system dip between 70º and 90º. Dips of fault planes in the north-trending system were difficult to measure or observe, but displacement of strata and drag folds along the faults provided evidence of relative movements of the blocks along the faults. Although apparent vertical displacement along most of the faults is down to the west, on several faults the displacement is down to the east, and locally the relative motion appears to be scissors-like. A good example of scissors motion can be observed along the road towards Chris Park. The northern extent of the fault has down-to-the-west displacement and places the Pennsylvanian Molas Formation down against the Upper Devonian Ouray Limestone. About 1 mile southeast, the fault is exposed in the road cut where a drag fold developed in the Elbert Formation and Ouray Limestone indicates that the western block moved up relative to the eastern block.

This Goulding Creek fault system probably developed, in part, by reactivation of Proterozoic structures during Cenozoic uplift. The northeast- and north-trending structures form a crude conjugate fracture system that may have developed at about the same time from regional strain related to uplift.

PROSPECTS AND MINES

Prospecting and mining have been conducted in the region around the La Plata Mountains and San Juan Mountains for more than 120 years. Several sites within the Electra Lake quadrangle have surface evidence of prospecting and/or mining for lode and placer deposits. There are no active mines within the map area. The principal goal of this section is to briefly discuss the mineralized areas that were identified during mapping and to summarize the history of claimed areas on public lands within the Electra Lake quadrangle.

The mineral resource potential in the Electra Lake quadrangle is low. Most of the potential precious- and base-metal resources are in hydrothermal fissure and load veins that have limited extent and low tonnage. These deposits have been fully explored and there is no current mining activity or prospecting. County records of mining activity were examined at the San Juan Public Lands Information Center and the United States Bureau of Land Management (BLM LR2000 database as of 2002) in Durango, Colorado, in order to determine the locations of patented and unpatented claims and prospects. This information was combined with existing published information and field observations as part of the assessment of mines in this quadrangle.

The area between the Animas River and Columbine Lake contains several small zones of precious- and base-metal deposits (Fig. 5). In the West Needle Mountains Wilderness area (Birmingham and Van Loenen, 1983; Scott, 1983; Van Loenen and Scott, 1983; Van Lonen, 1985) on the north side of Cascade Creek in sec. 28, 30, 31, 32, and 33, T39N, R8W there are a large number of unpatented lode and placer mining claims. Resource records indicate that most of these claims are closed but some remain active. Most of these claims are on quartz fissure veins that contain trace amounts of precious and base metals, but these deposits have a low potential for mineral resources. Evidence of past mining was not found in most of these areas.

A large group of claims (outlined on the maps in Birmingham and Van Loenen, 1983; Scott, 1983; Van Loenen and Scott, 1983; Van Lonen, 1985) is located just north of the confluence of Cascade Creek and the Animas River in the SW ¼ of sec. 32; among these is the Lost Lode mill site. Another set of claims are on the mineralized deposits in and around the Silver Star Extension Mine in the NE ¼ of sec. 31 and NW ¼ of sec. 32. The Silver Star Extension Mine is developed in the Proterozoic Twilight Gneiss along a northeast-trending fracture system that contains discontinuous mineralized fissure veins. Though this fracture system is adjacent to an east-trending fault system it does not appear to have any relationship to the larger structure. The intersection of these two systems, however, may have created pathways that were favorable for the migration of ore fluids. The portal of the Silver Star Extension Mine has collapsed and little remains of the original mine. The fracture into which the mine was driven contains sulfide-bearing quartz veins, zones of hydrothermal breccia, as well as iron oxide and hydroxide coatings and fillings within the mineralized zone. A small tram house is located near the collapsed portal that was used to transport ore from the mine to a road that is about 1000 ft downslope. Around the portal and the road there are small dump piles that contain pieces of ore. The ore contains galena, tetrahedrite, sphalerite, pyrite, and chalcopyrite dispersed in veins of milky quartz and calcite. Some of the ore is composed almost entirely of sulfide minerals. Two samples (EL-336a-2002 and EL-336b-2002) of dump ore were sent to ACTLABS/SKYLINE-TUSCON for base- and precious-metal analyses. Results of aqua regia-ICP and fire assay analyses on these samples are shown in table 1. Concentrations of 20 ppm silver, 0.95 ppm gold, 300 ppm cadmium, 15000 ppm lead, and 20000 ppm zinc were previously reported for samples of rock from the Silver Star Extension vein system (Birmingham and Van Loenen, 1983; Van Loenen, 1985). The geochemical data suggest that the vein system of the Silver Star Extension Mine contained ore with high silver and base metal concentrations.

The area around Columbine Lake within sec. 25, T. 39 N., R. 9 W. contains a number of prospects, adits, and shafts on mineralized fault and fracture zones within the Twilight Gneiss and Lower Paleozoic limestones and sandstones. Van Loenen (1985) reports 0.2-28 ounces of silver per

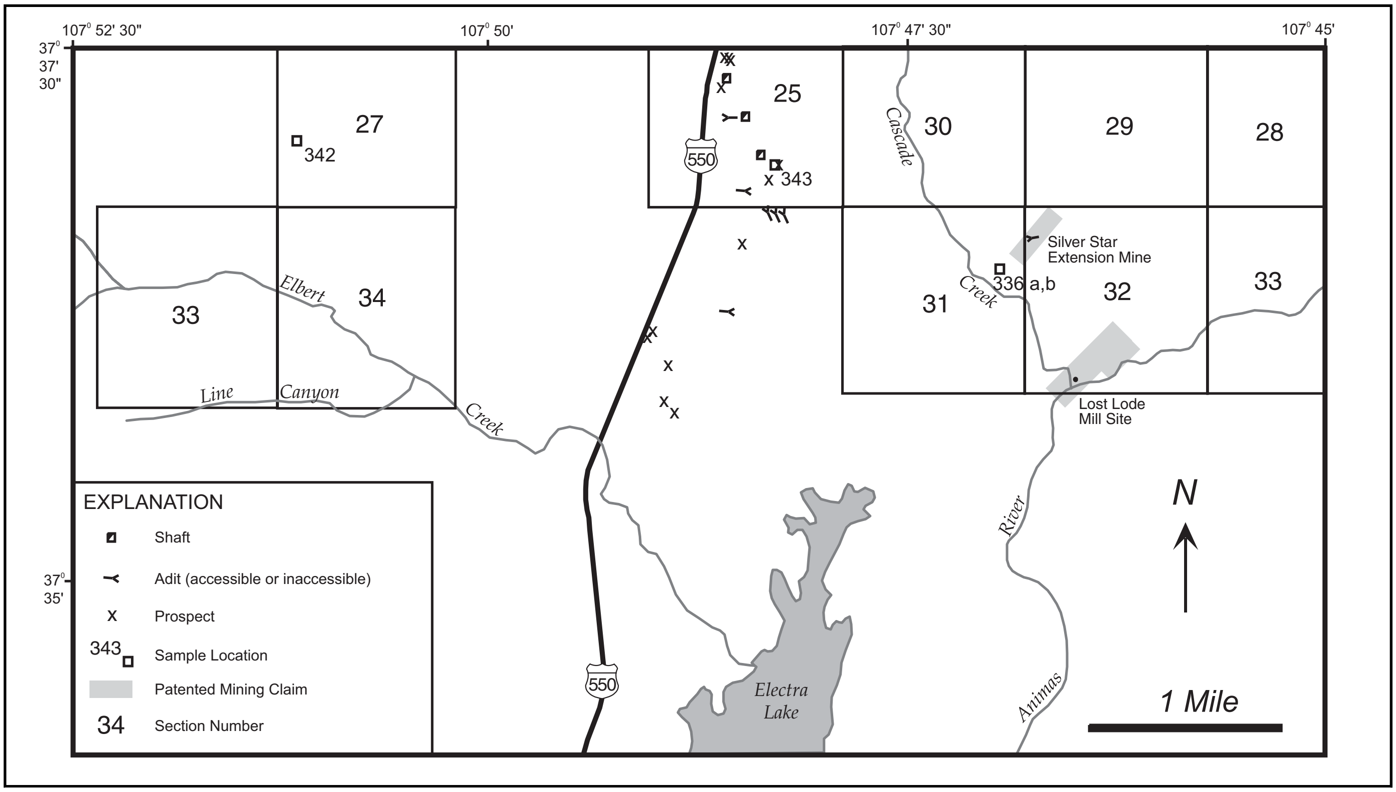

Figure 5. Generalized map showing the locations of selected mines, prospects, and mineralized zones in the Electra Lake quadrangle. Locations of samples analyzed for selected precious and base metals in this study are also indicated.

ton along with trace amounts of base metals from these veins. A sample (EL-343-2002) of vein quartz and silicified gneiss with minor iron oxide coating and specks of galena was collected at a prospect on the northwest-trending fault at the north end of Columbine Lake. The results of this analysis show that the sample contains minor amounts of precious and base metals but does not have a high potential as a mineral resource.

The Late Cretaceous to middle Tertiary quartz-monzonite porphyry stock exposed in the western part of sec. 27, T. 39 N., R. 9 W. at Lift 8 of Durango Mountain Resort contains zones of hyrothermal breccia that are silicificied and coated with iron oxide and hydroxide minerals. A sample (EL-342-2002) of oxidized and altered rock from the intrusive was analyzed for selected base- and precious-metal concentrations (Table 1). These data suggest that the intrusive has a very low potential as a mineral resource. A group of active unpatented claims are located in the SW ¼ sec. 27. These claims are concentrated on a southeast-trending tributary of Elbert Creek that contains flakes of gold in alluvial and colluvial deposits along the Elbert Creek Fault that cuts the Hermosa Group and Cutler Formation south of the monzonite stock.

In the northwestern corner of the Electra Lake quadrangle in the vicinity of Line Canyon and Elbert Creek (sec. 33 and 34, T. 39 N., R. 9 W.) there are a large number of active unpatented claims. Prospects in this area are on small and discontinuous zones of precious- and base-metal mineralization near altered Tertiary granite dikes and local fracture systems. Placer gold has been recovered from colluvium near these mineralized zones but there appears to be low potential for precious-metal mineralization in these zones.

The Elbert Creek Fault between Electra Lake and Castle Rock is injected with quartz veins. Zones in this segment of the fault are silicified and brecciated, but only minor sulfide mineralization was observed. Although there are numerous pits and prospects in the silicified zones along the Elbert Creek Fault in this area the evidence gathered in this study indicates a very low potential for precious- and base-metal mineralization.

Table 1: Selected base- and precious-metal concentrations of mineralized samples.

[Analyses were done by ACTLABS/SKYLINE TUCSON.

Ag, Cd, Cu, Mn, Mo, Ni, Pb, Zn, and S were analyzed using aqua regia ICP. Gold concentrations were determined using fire assay and atomic absorption spectrometry. Negative values indicate less than the detection limit and 99999 indicates concentrations greater than 10%.

Values for Ag, Cd, Cu, Mn, Mo, Ni, Pb, Zn are reported as part per million (ppm). Au values are in parts per billion (ppb) and S concentrations are in percentage.]

Sample	Rock type/location	Au	Ag	Cd	Cu	Mn	Mo	Ni	Pb	Zn	S
El-336a-2002	Vein/ Silver Star Extension Mine	890	72.7	1234	1418	1236	6	8	13902	99999	6.593
El-336b-2002	Vein/ Silver Star Extension Mine	1040	88.1	1267	2077	1288	6	11	12771	99999	7.744
EL-342-2002	Igneous hydrothermal breccia, Lift 8, DMR	5	-0.2	1.6	22	657	3	10	48	191	0.037
EL-343-2002	Hydrothermal breccia, Columbine Lake	120	53.8	26.2	74	136	61	8	15955	3692	1.574

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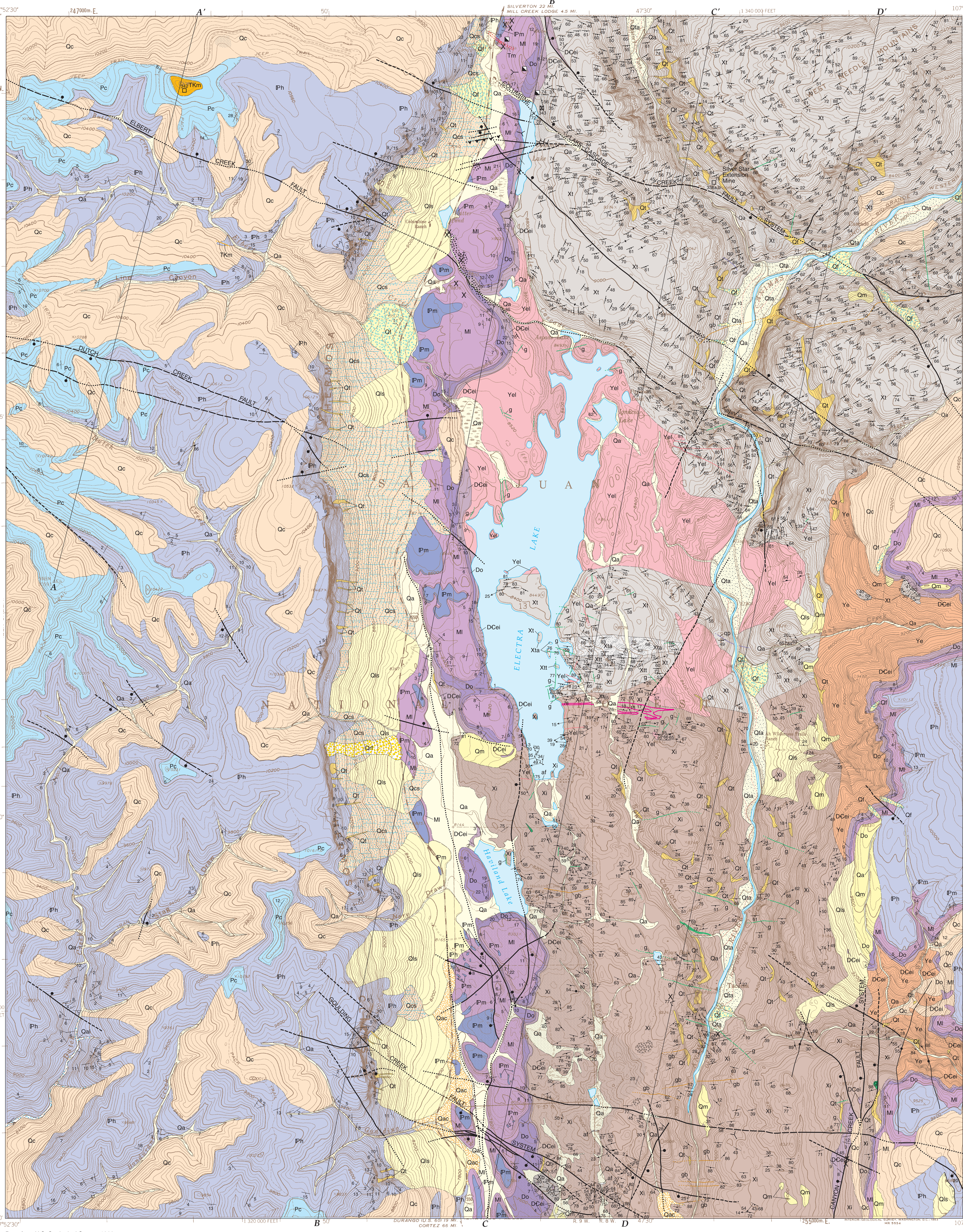
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN-FILE MAP 03-21
GEOLOGIC MAP OF THE ELECTRA LAKE QUADRANGLE,
LA PLATA COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1960
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate
system, south zone

COLORADO
QUADRANGLE LOCATION

SCALE 1:24,000
1 — 1/2 — 0 — 1 MILE
1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET
1 — 0.5 — 0 — 1 KILOMETER

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

TRUE NORTH
MAGNETIC NORTH
14°
APPROXIMATE MEAN DECLINATION, 1960

Geology mapped in 2000, 2001, and 2002
Digital map prepared by Jason Wilson

MAP UNITS

The complete description of map units and references are in the accompanying booklet.

SURFICIAL DEPOSITS

HUMAN–MADE DEPOSITS

- **af** — Human-made deposits (late Holocene)

ALLUVIAL DEPOSITS

- **Qa** — Stream channel, flood-plain, and low–terrace alluvium (Holocene and late Pleistocene)
- **Qta** — Terrace alluvium, undivided (early Holocene and late Pleistocene)

COLLUVIAL DEPOSITS

- **Qc** — Colluvium (Holocene and late Pleistocene)
- **Qrf** — Rockfall deposits (Holocene or late Pleistocene)
- **Qls** — Landslide deposits (Holocene and late Pleistocene)
- **Qt** — Talus (Holocene and late Pleistocene)

ALLUVIAL AND COLLUVIAL DEPOSITS

- **Qf** — Fan deposits (Holocene and late Pleistocene)
- **Qcs** — Colluvium and sheetwash, undivided (Holocene and late Pleistocene)
- **Qac** — Alluvium and colluvium, undivided (Holocene and late Pleistocene)

GLACIAL DEPOSITS

- **Qm** — Morainal deposits (late and late middle? Pleistocene)

BEDROCK UNITS

LATE CRETACEOUS AND TERTIARY IGNEOUS ROCKS

- **Tm** — Mafic dikes to intermediate dikes (Tertiary)
- **TKm** — Quartz monzonite porphyry (middle Tertiary to Late Cretaceous)

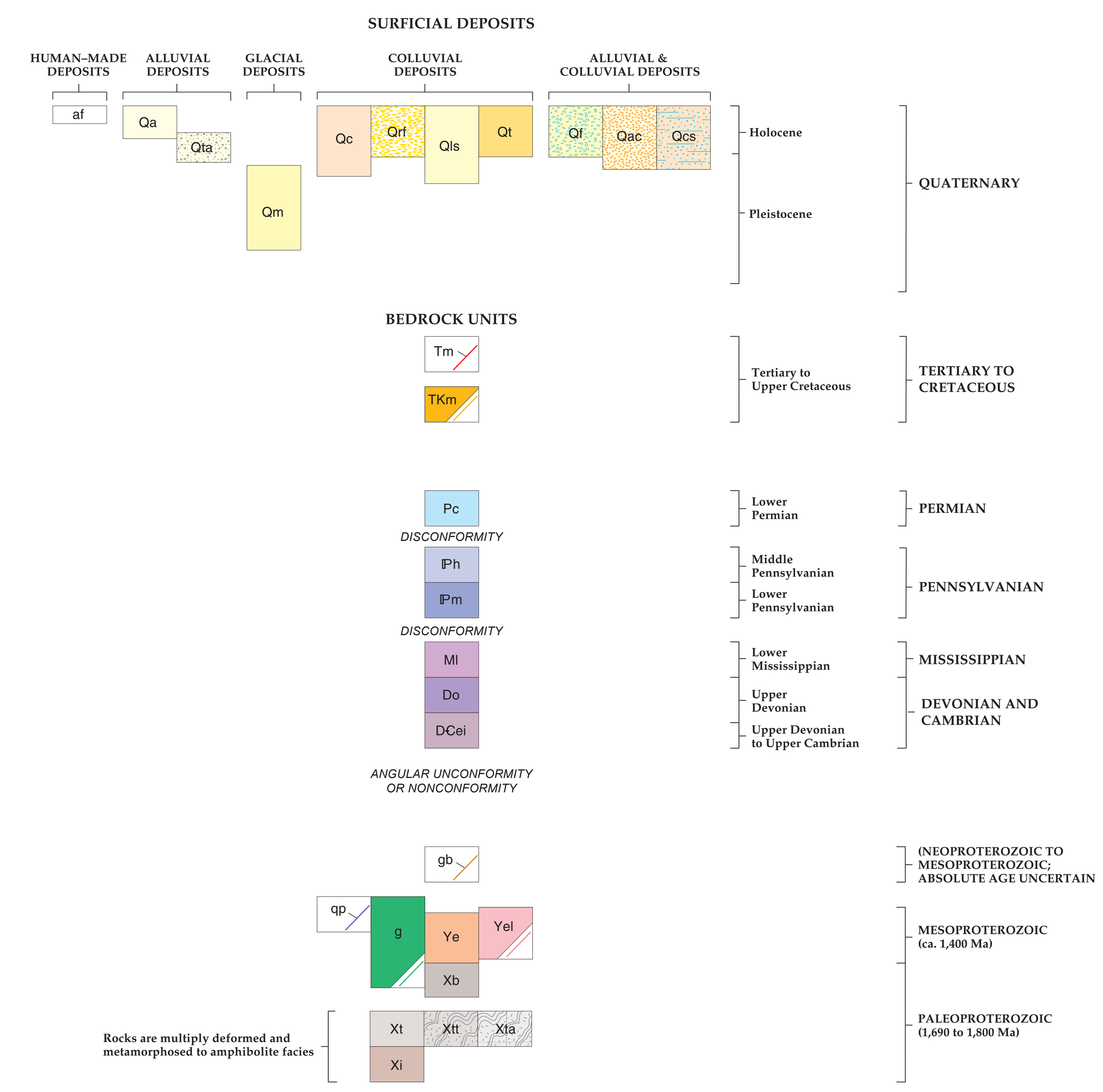
PALEOZOIC SEDIMENTARY ROCKS

- **Pc** — Cutler Formation (Lower Permian)
- **ℙh** — Hermosa Group (Middle Pennsylvanian)
- **ℙm** — Molas Formation (Lower Pennsylvanian)
- **Ml** — Leadville Limestone (Lower Mississippian)
- **Do** — Ouray Limestone (Upper Devonian)
- **DЄei** — Elbert Formation (Upper Devonian) and Ignacio Formation (Upper Cambrian) undifferentiated

PROTEROZOIC CRYSTALLINE ROCK UNITS

- **gb** — Gabbro dikes (age uncertain, Neoproterozoic or Mesoproterozoic)
- **Yel** — Electra Lake Gabbro (Mesoproterozoic)
- **qp** — Quartz-porphyry dikes (Mesoproterozoic)
- **Ye** — Eolus Granite (Mesoproterozoic)
- **g** — Aplite, pegmatite, and fine- to coarse-grained granitic dikes and sills (Mesoproterozoic to Paleoproterozoic)
- **Xb** — Bakers Bridge Granite (Paleoproterozoic)
- **Xt** — Twilight Gneiss undifferentiated (Paleoproterozoic)
  - **Xtt** — Twilight Gneiss (tonalitic gneiss)
  - **Xta** — Twilight Gneiss (amphibolite)
- **Xi** — Irving Formation (Paleoproterozoic)

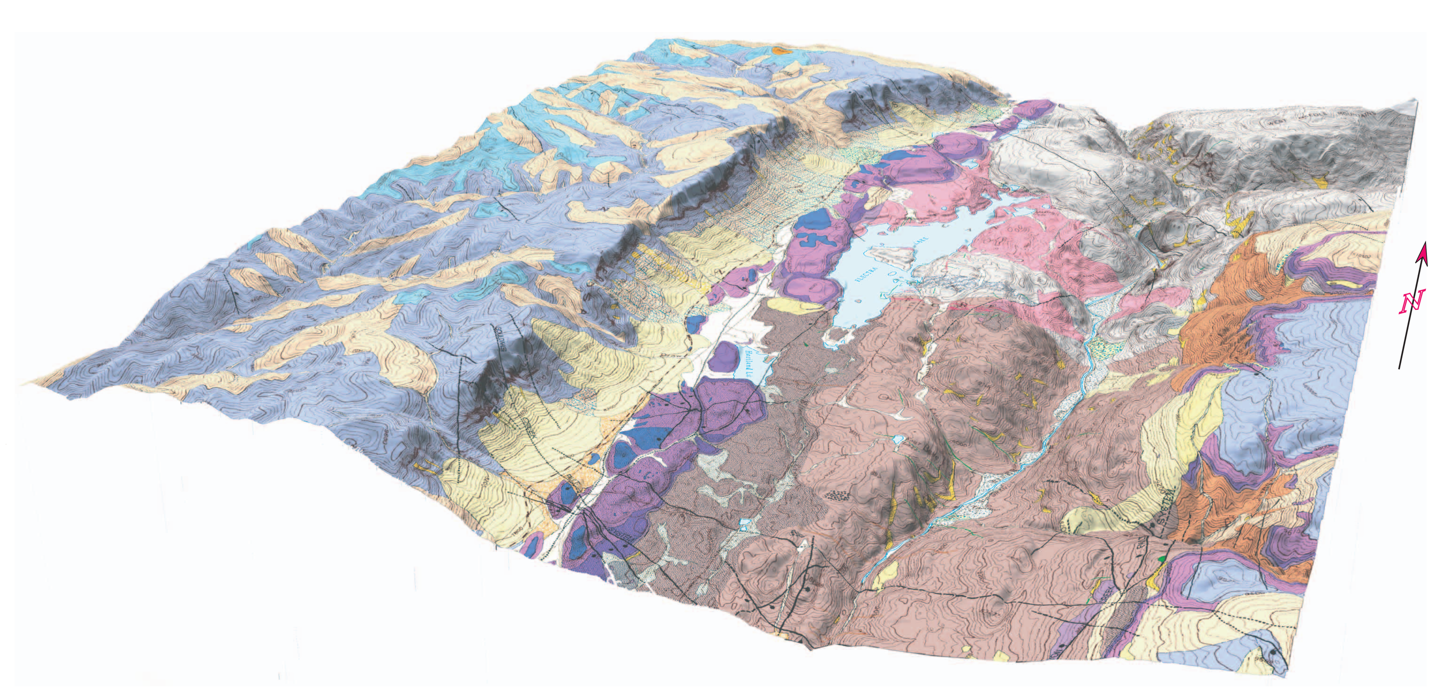
CORRELATION OF MAP UNITS

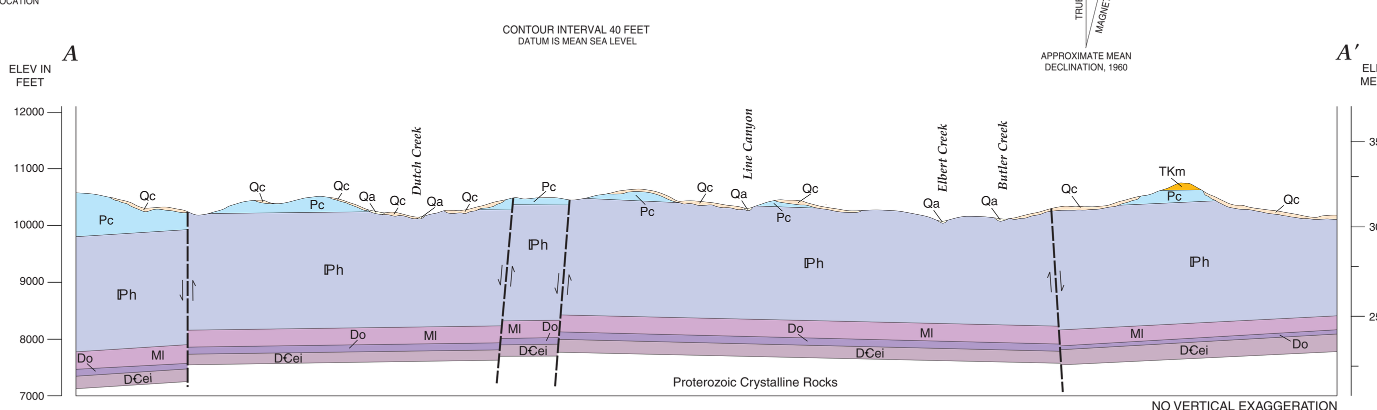


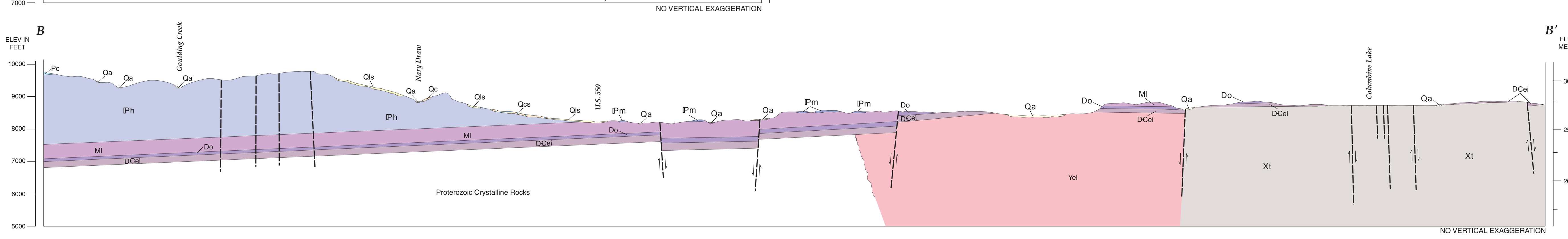
MAP SYMBOLS

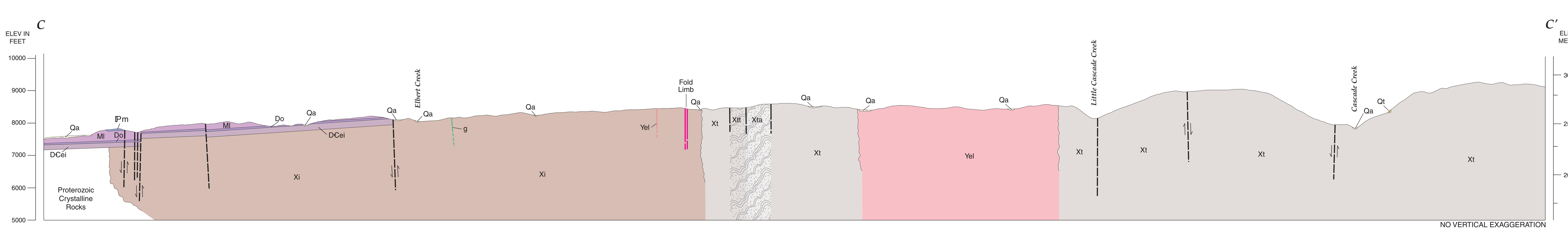
- **Contact**—Dashed where approximately located, dotted where concealed
- **Fault**—Long Dash where approximately located, short dash where inferred, dotted where concealed. Ball and bar on the actual or apparent downthrown side
- **Thrust fault**
- **Trace of isoclinal fold**
- **Landslide scarp**
- **Margins of terraces in unit Qta**
- **Shear zone**
- **Thin cover of glacial till**
- **Zone of bedrock intruded by pods and irregular mass of Electra Lake Gabbro**
- **Zone of fault breccia**
- **Strike and dip of bedding**
  - 25 **Inclined**—Showing direction and angle of dip; inclination and direction may be added to the trace of dikes
  - **Horizontal**
- **Strike and dip of tectonic foliation**
  - 75 **Inclined**—Showing direction and angle of planar feature
  - **Vertical**
- **Strike and dip of tectonic foliation that has same trend as compositional layering**
  - 80 **Inclined**—Showing direction and angle of planar feature
  - **Vertical**
- **Strike and dip of igneous flow foliation**
  - 75 **Inclined**—Showing direction and angle of planar feature
- **Strike and dip of mesoscopic joint**
  - 65 **Inclined**—Showing direction and angle of planar feature
  - **Vertical**
- **Fold**—Showing direction and angle of the axial plane
- **Drag fold**—Short arrow indicates steep limb of fold; long arrow indicates the more gentle limb of fold. Middle arrow shows the direction and amount of plunge of fold axis. Folds develop along fault traces
- **Mesoscopic fold**—May be combined with foliation symbol to show trend and dip of folded foliation
- **Bearing and plunge of mineral lineation or fold axis**—Tail of arrow at point of measurement; may be combined with foliation or fold symbols (fold axis)
- **Mine adit**
- **Prospect**
- **Shaft**
- **Location and identification of sample analyzed for selected precious and base metals**
- A ——— A′ **Alignment of cross sections**

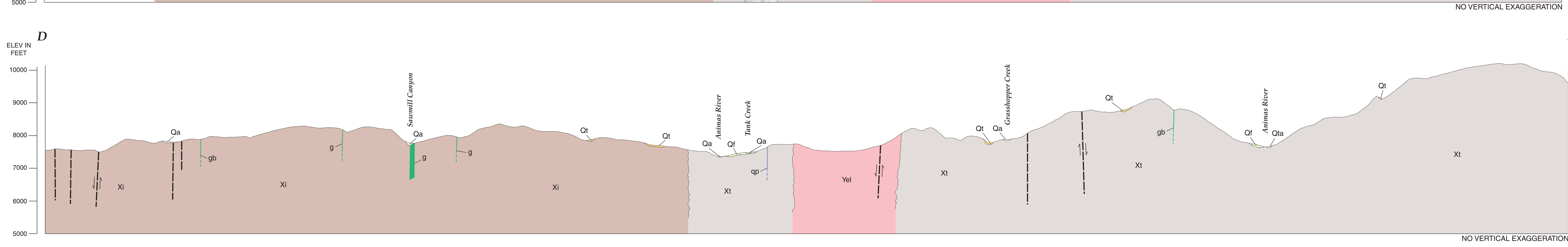
SHADED RELIEF MAP OF THE ELECTRA LAKE QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTH NORTHWEST











COLORADO
DEPARTMENT OF NATURAL RESOURCES
Bill Owens, Governor
State of Colorado

Greg Walcher, Executive Director,
Department of Natural Resources

COLORADO DIVISION OF MINERALS & GEOLOGY
RECLAMATION•MINING SAFETY•SCIENCE
Ronald W. Cattany, Director,
Division of Minerals and Geology

COLORADO GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE ELECTRA LAKE QUADRANGLE, LA PLATA COUNTY, COLORADO

By David A. Gonzales, Donald W. Stahr III, Jedediah D. Frechette, Franklin Dorin, Kathleen Costello,
Cathy Cullicott, Rebecca Kolody, Kendra Remley, and Kristopher Graham

2003