

OPEN-FILE REPORT 02-1

Geologic Map of the Hermosa Quadrangle, La Plata County, Colorado

**By David A. Gonzales,
Donald W. Stahr III, and Robert M. Kirkham**



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State of Colorado**

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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 02-1, *Geologic Map of the Hermosa 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 Ft. Lewis College in Durango; Donald Stahr III, undergraduate student at Ft. Lewis College; and Bob Kirkham, staff geologist with the Colorado Geological Survey completed the field work on this project in the summer of 2001.

This mapping project was funded 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. 00HQAG0119, 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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ACKNOWLEDGMENTS

We would like to thank the following people for giving us access or assisting us in gaining access into various sections of the map area: Marion Carnes (Hermosa Creek), Milburn Colley (East Animas), Mr. and Mrs. Leroy English (Shalona Lake), Laura Kennedy (Tierra Hermosa Ranch), Michael McQuinn (Falls Creek), Tom Phelps (Missionary Ridge), Ed Ruwaldt (Highland Meadows Ranch), and Geof Schlittgen (Redtail Development).

Allen Andrews in the La Plata County GIS Department provided us with a very useful property map of the Hermosa 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 Hermosa quadrangle. Mona Charles, Fort Lewis College, shared unpublished radiocarbon ages of deposits in the Durango East quadrangle, which aided our work in the Hermosa quadrangle. Charlie Smith shared information on the history of Trimble Hot Springs.

INTRODUCTION

Geologic mapping of the Hermosa 7.5-minute quadrangle was conducted by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Co-operative Geologic Mapping Program. This program is administered by the United States Geological Survey (USGS). 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. Geologic maps of 7.5-minute quadrangles describe the geology at a scale of 1:24,000. These maps serve as a good basis for more detailed research and are useful for regional geologic studies. Published maps of the Durango East (Carroll and others, 1999) and Durango West (Kirkham and others, 1999) 7.5-minute quadrangles cover the area to the south and southwest of the area mapped in this study (Figure 1). The only previous geologic map that includes the Hermosa quadrangle is the Durango 1:250,000 quadrangle mapped by Steven and others (1974).

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, and Basin Mountain 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).

The authors conducted field studies and research between March and September of 2001. During this period 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. Map preparation and digitization were completed during a one-year period following field mapping. Black and white 1:40,000-scale and color 1:24,000-scale aerial photographs are available for the entire quadrangle.

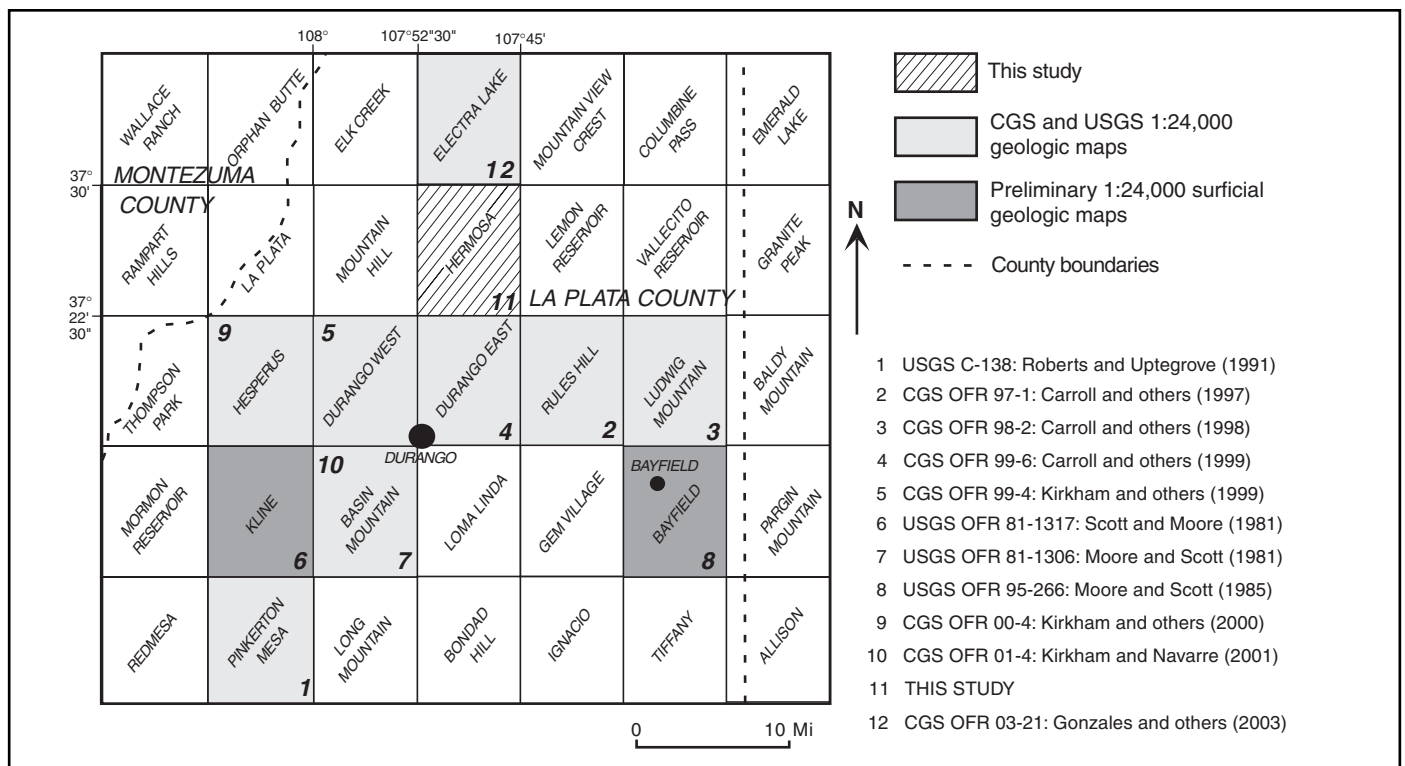


Figure 1. Published 1:24,000-scale geologic maps of 7.5-minute quadrangles in southwestern Colorado.

GEOLOGIC SETTING

The Hermosa 7.5-minute quadrangle includes about 60 sq mi of chiefly mountainous terrain within the central part of La Plata County in southwestern Colorado. 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°22'30" N and the north margin is at latitude 37°30'00" N. The southern margin of the quadrangle lies about 8 mi north of the town of Durango (Figure 2 and Figure 3). The quadrangle lies on the transition of the east-central part of the Colorado Plateau physiographic province and western edge of the Southern Rocky Mountains (Fenneman, 1931). The terrain in the mapping area rises from an elevation of about 6,500 ft above sea level along the Animas River to the rugged surrounding mountainous terrain, where the elevation is more than 9,500 ft above sea level. The Animas River, a major south-flowing river that drains much of the southwestern San Juan Mountains, bisects the quadrangle along a north and south line. Nearly 3,000 ft of rock record is exposed in the walls of Animas River canyon.

The mountains within the map area form part of the southern flank of the Laramide San Juan Uplift, which has a core of 1,800–1,400 million year old Proterozoic crystalline rocks that are mantled by south-dipping strata of Paleozoic to Mesozoic sedimentary rock units (Figure 2 and Figure 4). The oldest rocks in the map area are exposed on either side of the Animas River canyon at the north edge of the quadrangle. These Proterozoic rocks include 1,800 million year old metamorphosed volcanic arc rocks of the Irving Formation, which are intruded by plutonic igneous rocks of the 1,700-million year old Bakers Bridge Granite and 1,400 million year old Eolus Granite (Gonzales, 1997). The Irving Formation, Bakers Bridge Granite, and Eolus Granite form the foundation for sedimentary rocks that 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 Hermosa 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 of volcanic and intrusive rocks in a volcanic arc system between 1,800 and 1,750 million years ago. These ancient rocks were metamorphosed and deformed and then intruded by granitic and minor gabbroic rocks 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.
- 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) Late Paleozoic tectonic uplift that produced a northwest-southeast trending belt of mountains that includes the ancestral Uncompahgre Uplift.
- 5) Erosion of the uplifted Uncompahgre block by streams and rivers and deposition of this material as "redbed" clastic sedimentary rocks about 365–300 million years ago.
- 6) Deposition of Mesozoic clastic sediments in fluvial and eolian systems until about 200 million years ago to form the youngest strata in the area. There are younger units exposed in the region but they are not exposed within the map area.
- 7) Renewed tectonic activity caused by shortening forces during the Laramide orogeny produced the San Juan Uplift. This event was accompanied by intrusion of ore-bearing igneous rocks in the La Plata Mountains about 75–65 million years before present.
- 8) Quaternary glaciation, alluviation, and other surficial processes that formed the present-day landscape.

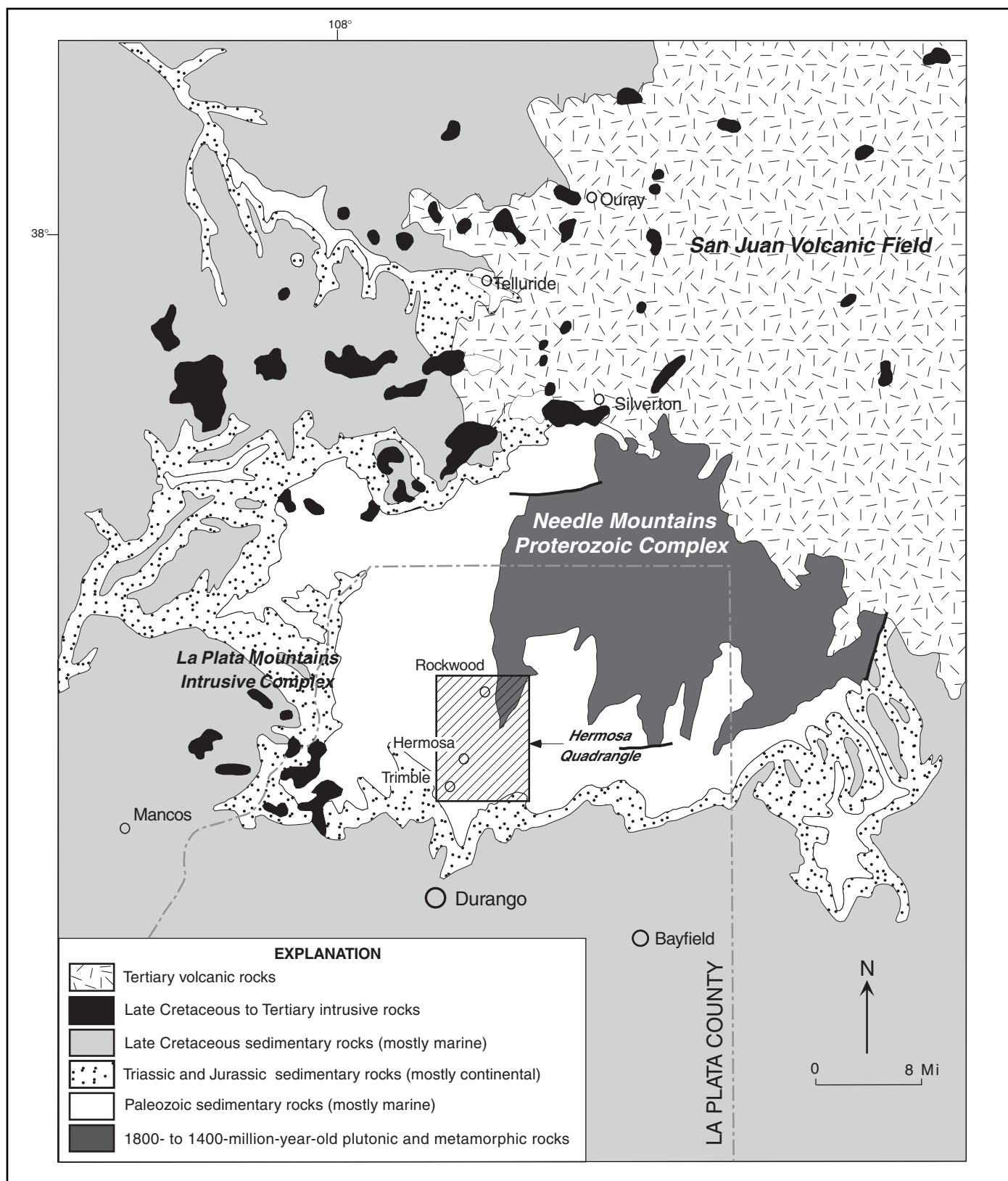


Figure 2. General geologic map showing the principal rock units in southwestern Colorado (modified version of the Colorado Geologic Highway Map, 1991). The area of the Hermosa quadrangle is indicated by the box. The broken line indicates the boundaries of La Plata County.

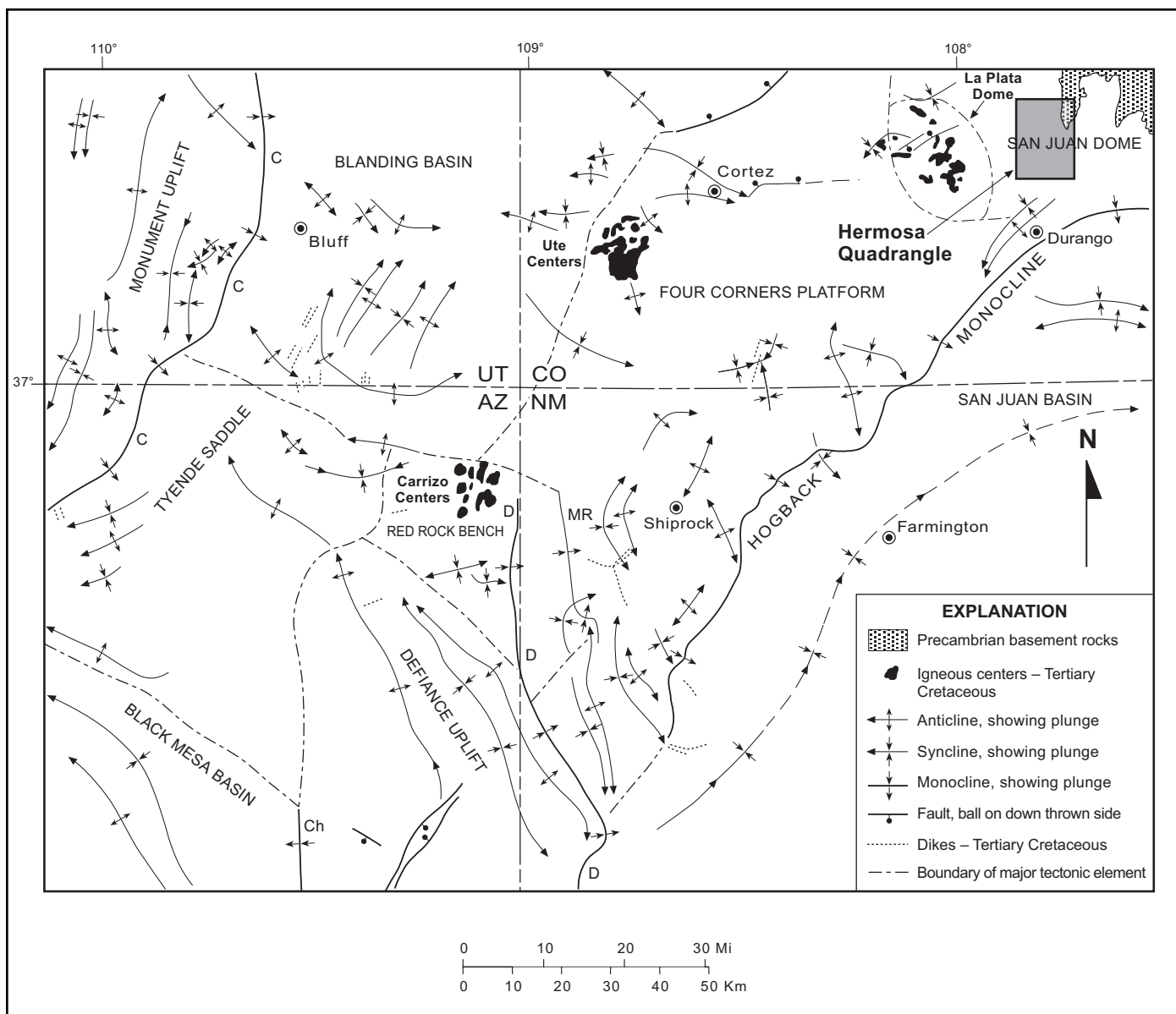


Figure 3. Generalized tectonic map of the Four Corners area showing regional structural features in the vicinity of the Hermosa quadrangle. Modified from Woodward and others (1997). C denotes the Comb Monocline, Ch refers to the Chinle Monocline, D is the Defiance Monocline, and MR refers to Mitten Rock Monocline. The general area of the Hermosa quadrangle is indicated by the box.

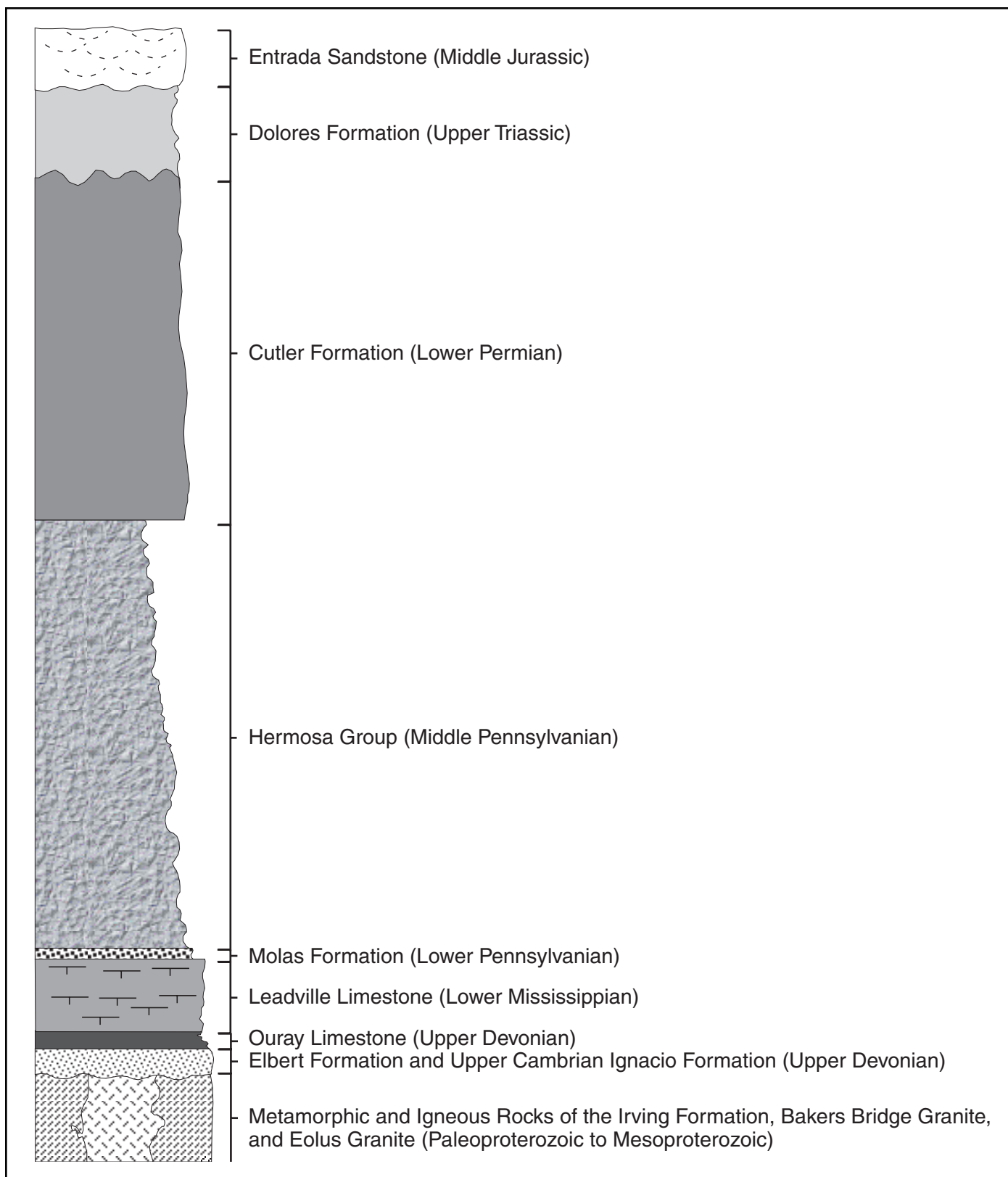


Figure 4. Generalized stratigraphic section of bedrock units in the 7.5-minute Hermosa quadrangle.

UNIT DESCRIPTIONS

SURFICIAL DEPOSITS

Surficial deposits blanket a large part of Hermosa quadrangle. Most are not well exposed, therefore, the described attributes of these units, such as thickness, texture, stratification, and composition, are based on observations made at only a 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 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 75–100 ft. Artificial fill of limited areal extent 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 1963, consequently, cultural features that post-date the base map are not depicted on the 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 2–256 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 ero-

sional 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 (latest Holocene)— 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 25 ft. Artificial fill may compact when loaded, if not adequately compacted.

ALLUVIAL DEPOSITS—This unit consists of gravel, sand, silt, and clay deposited by flowing water in stream channels and flood plains, hillslope runoff or sheet flow along the Animas River and its tributaries. Terrace alluvium along the Animas River is chiefly glacial outwash that was probably deposited during late-glacial and early-interglacial stages, but also includes lacustrine, deltaic, and paludal deposits associated with Glacial Lake Durango. Deposits resulting from sheet flow are called sheetwash. Alluvial deposits locally include colluvium or loess too small to be mapped at a scale of 1:24,000. The approximate terrace heights are the elevation differences between the modern stream valley and the top of the original alluvial depositional surface near the river-side edge of the terrace or the top of the preserved deposit, if eroded.

Qa

Stream channel, flood-plain, and low terrace deposits (Holocene and late Pleistocene)— Includes modern stream-channel deposits of the Animas River, Hermosa Creek, and tributary valleys, and adjacent flood-plain deposits and low- terrace alluvium that is up to about 10 ft above modern stream level. These deposits are mostly poorly sorted and clast supported. They consist of unconsolidated pebble, cobble, and locally boulder gravel in a sandy or silty matrix that is locally inter-bedded with or overlain by sandy silt and silty sand. The upper part of unit Qa is locally rich in organic material that was deposited in a

paludal environment. Gravel deposits in this unit contain round to subangular clasts with diverse lithologies such as sandstone, quartzite, limestone, granite, gneiss, monzonite porphyry, diorite porphyry, ash-flow tuff, amphibolite, and schist. The variety of clast lithologies reflects the wide range of rocks that crop out within the Animas River drainage basin.

At depth, particularly in the southern part of the quadrangle, unit **Qa** may contain fine-grained silt and clay (Butch Knowlton, 2001, oral communication) as indicated by core from a gas well drilled in 1926 in the Animas River valley about 2.5 mi south of the quadrangle. Even the name and depth of this poorly documented well are uncertain. According to records in the Denver Earth Resources Library, this well is identified as the Durango Oil and Gas Company Lattin No. 1 well. The report notes that the well was drilled to a depth of 350 ft. Gillam (1998), however, reported that the well penetrated somewhere between 440 and 900 ft without reaching bedrock, on the basis of several different sources. Much of the sediment encountered in the lower part of the well consisted of fine-grained lacustrine, deltaic, and paludal materials. As the Animas glacier retreated, late during the Pinedale glaciation, these sediments accumulated in Glacial Lake Durango, a proglacial lake that formed in a deeply scoured basin cut into bedrock (Atwood and Mather, 1932; Gillam, 1998). The lake filled with sediments (unit **Qa**), eventually creating the flat-floored valley that extends from the terminal moraines at the north end of Durango nearly to Bakers Bridge, a distance of over 11 mi. Maximum thickness near the south margin of the quadrangle may be as much as several hundred feet. In the northern part of the quadrangle and in tributary valleys to the Animas River the maximum thickness is probably tens of feet. Low-lying areas underlain by unit **Qa** are subject to flooding. Unit **Qa** is a source of sand and gravel.

Qsw

Sheetwash (Holocene and late Pleistocene)—Includes materials that are transported chiefly by sheet flow and deposited in valleys of ephemeral and intermittent streams, on gentle hillslopes, or in topographic depressions. These deposits are locally derived from weathered bedrock and surficial materials. Sheetwash typically consists of pebbly silty

sand, sandy or clayey silt, and sandy silty clay. Locally it grades to and interfingers with colluvium (**Qc**) on steeper hillslopes. In many areas the contacts between sheetwash and colluvium cannot be well defined. 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.

Qt₁

Terrace alluvium one (latest Pleistocene)—Chiefly stream alluvium that underlies several fill, fill-cut, or strath terrace surfaces along or near the Animas River. Although all these terrace deposits are included in a single unit, they are called terrace alluvium one so that the deposits can be readily correlated with map units on previously completed geologic maps of the Colorado Geological Survey. Terrace heights range from 20–65 ft above the river. The terraces rapidly converge with the river downstream of Bakers Bridge. About 1.3 mi below the bridge, the terrace on the east side of the river converges with and is buried by younger sediments deposited in Glacial Lake Durango (unit **Qa**), because the gradient of the terrace is steeper than the surface on the top of unit **Qa**. Terrace alluvium one was probably deposited at a time when sediments in the lower part of unit **Qa** were accumulating in Glacial Lake Durango upstream of Pinedale terminal moraines. Unit **Qt₁** is mostly poorly sorted, clast-supported, locally bouldery, cobble and pebble gravel in a silty or sandy matrix. It may include fine-grained overbank deposits or overlying sheetwash deposits. Clasts are mainly subround to round, and they are composed of the varied bedrock lithologies that crop out within the Animas River drainage basin, mostly granite, gneiss, schist, amphibolite, ash-flow tuff, sandstone, quartzite, limestone, conglomerate, and various types of hypabyssal intrusive rocks. Clasts are generally unweathered or only slightly weathered. Soil developed on unit **Qt₁** has a weakly to moderately developed textural B horizon.

Terraces related to terrace alluvium one are tentatively correlated with the youngest terraces in group TG7 of Gillam (1998). The **Qt₁** terraces in the Hermosa quadrangle may be related to the remnants of possible reces-

sional end moraine found northwest of Bakers Bridge, although the terraces and moraine deposits are not in physical contact. In the Durango East quadrangle Qt₁ terraces grade to the Animas City moraines (Carroll and others, 1999; Gillam, 1998). These moraines, which formed roughly from 12–35 ka (Richmond and Fullerton, 1986; Carroll and others, 1999), are probably equivalent to Pinedale and other late-Wisconsin moraines elsewhere in the Rocky Mountains. The terraces in the Hermosa quadrangle may be slightly younger, from perhaps 10–15 ka, because they were deposited well after the maximum advance of the Pinedale glacier. The thickness of Qt₁ averages about 10–65 ft in fill and fill-cut terraces. Locally it is only a few feet thick in strath terraces and 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 clayey 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. Other processes, particularly debris flows, may be active at different times on the same hillslope on which colluvium is the predominant material. As a result, many deposits mapped as colluvium likely include materials of varied genesis. The unit may also include talus, landslide deposits, sheetwash, 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 gravels will contain rounded clasts. Clast lithology is variable, as it depends on

type of material exposed in the source area. Maximum thickness is estimated at about 40 ft, but the unit commonly is much thinner. Areas mapped as colluvium are susceptible to future colluvial deposition and 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.

Qls

Landslide deposits (Holocene and Pleistocene)—Heterogeneous deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Unit includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes.

Most landslide deposits in the quadrangle resulted from slope failures in morainal deposits, some of which involve underlying or adjacent bedrock. The large landslide complex at Spud Hill involves both bedrock and morainal deposits, and it apparently includes a younger landslide that formed by partial remobilization of an older landslide. Although a prominent linear ridge in the older part of the landslide (crest of this ridge has an elevation of 8,526 ft on the topographic base map) has the geomorphology of a lateral moraine, we interpret this feature as a large landslide slump block. It is composed entirely of debris derived from adjacent Paleozoic sedimentary rocks, which contrasts with other mapped morainal deposits on the east side of the Animas River valley that are rich in Proterozoic clasts. A road cut into the lower part of the Spud Hill landslide has recently triggered local reactivation of a very small part of this landslide.

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)—Angular, cobbly, and bouldery rubble on moderate to steep slopes below some cliffs and ledges of bedrock. Talus commonly lacks matrix and has an estimated maximum thickness of 10 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 colluvial, alluvial, and sheetwash processes prevail on fans and on or adjacent to hillslopes.

Qfy

Younger fan deposits (Holocene and latest Pleistocene)—Includes hyperconcentrated-flow, debris-flow, alluvial, and sheetwash deposits in fans and tributary drainages. Locally the unit may include earthflows or landslides too small to map separately at a scale of 1:24,000. Younger fan deposits consist of crudely stratified deposits that range from very poorly sorted, clast-supported, pebble-sized, cobble-sized, and boulder-sized rock fragments in a clayey silt or sand matrix to matrix-supported, gravelly, clayey 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 50 ft. Younger 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.

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, un-stratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt. Clast lithologies reflect the rocks within the provenance area.

Unit Qac is commonly 5–20 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, rock-fall, 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.

Qfo

Older fan deposits (late Pleistocene)—Includes three remnants of a former fan complex that are below the cliffs in the Hermosa Group northwest of the town of Hermosa. Unit Qfo is both matrix- and clast-supported and is genetically and texturally similar to younger fan deposits. Clasts consist chiefly of sandstone and limestone derived from the Hermosa Group. Adjacent drainages have eroded as much as about 80–100 ft below the original depositional surface on this deposit. Older fan deposits are estimated to be a maximum of about 80–120 ft thick. Deposits in unit Qfo are a limited source of sand and gravel.

SINTER DEPOSITS—Chemical precipitate that is deposited by hot or cold mineral springs.

Qtu

Tufa (Holocene)—Low-density, porous, chemical sedimentary rocks consisting of calcium carbonate precipitated from mineral- and carbonate-charged thermal springs. Tufa commonly is light reddish brown due to its high iron content. Two relatively large deposits of tufa are associated with Trimble hot springs (NW¼ sec. 15, T. 36 N., R. 9 W.) and Pinkerton hot springs (NE¼ sec. 25, T. 37 N., R. 9 W.). Small mounds of tufa occur at the thermal springs northwest of Pinkerton hot springs. Unmapped deposits of tufa were also found along several faults and fractures within the Hermosa Group and Leadville Limestone.

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.

Qdts

Dammed tributary sediments (Holocene, late Pleistocene, and late middle Pleistocene?)—Unit includes sand, gravel, silt, clay,

and peat deposited in valleys dammed by lateral moraines. These sediments are very poorly exposed, therefore their physical characteristics are not well known. Excellent examples of these deposits occur at Mitchell Lakes and Wallace Lake. Here, the lateral moraines continue to dam tributary valleys, forming small lakes and wetlands. Detailed studies of these locations would likely yield abundant evidence of the physical character and age of the dammed tributary sediments. At most other locations where dammed tributary sediments were identified, the morainal dams have been breached by erosion. Dammed tributary sediments range in age from latest Holocene to at least late Pleistocene; locally they may be as old as late middle Pleistocene. Maximum thickness is estimated at 100 ft.

Qk

Kame deposits (late and late middle? Pleistocene)—Sandy gravel and sand probably deposited by Hermosa Creek in a depression along the western margin of Animas River valley. These glacio-fluvial sediments may have accumulated between the western valley wall and the Animas glacier as the glacier retreated or stagnated. Unit consists of crudely bedded to well bedded, poorly to well sorted, clast-supported cobbles and pebbles in a sandy matrix and medium- to fine-grained sand that locally has sparse pebbles. Unit Qk contains boulder-sized clasts that are round to subangular and composed chiefly of sandstone, limestone, conglomeratic sandstone, shale, quartzite, hypabyssal intrusive rocks, ash-flow tuff, and andesitic rocks. Clasts are moderately weathered.

Most preserved kame deposits are at or near the elevation of the Animas valley floor. The remnant in Hermosa Creek caps a hill that is perpendicular to and nearly blocks the valley floor. The contact between these deposits and the underlying bedrock is 100–120 ft above Hermosa Creek; the contact projects to or above the base of older fan deposits across the creek. Age of the mapped kame deposits is uncertain. Glacial scour would probably have removed any unconsolidated surficial deposits encountered by the ice as it moved downvalley. Therefore, it seems likely that the kame sediments were deposited during the last glaciation, probably as the ice began to retreat up the valley or at least stagnated sufficiently to melt and create a depression along or very near the ice margin. The clast weathering and elevation of the

deposit in Hermosa Creek, however, suggests a somewhat older age. Charcoal obtained from deposits overlying correlative kame sediments in Durango East quadrangle has a radiocarbon age of about $11,435 \pm 215$ years before present and provides a minimum age for the kame deposits at that location (Mona Charles, 2001, written communication). Maximum observed thickness is about 50 ft. Unit Qk is a potential source of sand and gravel.

Qm

Morainal deposits (late and late middle? Pleistocene)—Heterogeneous deposits of chiefly silty to bouldery sediments deposited by, adjacent to, or beneath glacial ice along the Animas River valley. Unit includes sediments deposited in lateral moraines, recessional moraine, 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, along with subordinate diorite to monzonite porphyry and andesitic ash-flow tuff. As many as three nested lateral moraines, such as those at Mitchell Lakes, occur in the quadrangle. Most sediments in the lateral moraines that are preserved high on the valley walls probably correlate with the till and diamicton of Animas City moraines in the Animas River valley (Johnson and Gillam, 1995; Gillam, 1998; Carroll and others, 1999). A large remnant of moraine found between Elbert Creek and Bell Canyon northwest of Bakers Bridge was deposited during the final stages of the Pinedale glaciation. Johnson (1990) described material in the basal part of this deposit that was exposed in a road cut on County Road 250N as lodgement till. The landform and wide lateral extent of this deposit suggest it is in part a recessional moraine.

Most morainal deposits are probably close in age to Pinedale and other late-Wisconsin moraines that formed about 12–35 ka (Richmond, and Fullerton, 1986). The sediments in recessional moraines near Bakers Bridge were deposited during the final stages of the Pinedale glaciation. Some deposits in lateral moraines may be correlative with the till and diamicton of the Spring Creek moraines (Johnson and Gillam, 1995; Gillam, 1998; Carroll and others, 1999), which are in the age range of 85–160 ka (Richmond and

Fullerton, 1986). The morainal deposits have an estimated maximum thickness of about 80–120 ft. Unit Qm contains uneconomic deposits of placer gold and may be a source of sand and gravel.

Qmk

Morainal and kame deposits, undifferentiated (late and late middle? Pleistocene)—Unit is mapped where limited exposures and poorly preserved landforms prevent conclusive determination of the specific origin of these glacial deposits.

BEDROCK UNITS

TKd

Diorite Porphyry (lower Tertiary to Upper Cretaceous)—A dark grayish green to black diorite porphyry dike cuts the Cutler Formation west of Falls Creek in “Dike Creek” canyon. The dike is porphyritic to microporphyritic and is composed of less than 10 percent phenocrysts of andesine and augite that are less than 2 mm in length. The groundmass is a very fine-grained assemblage composed essentially of andesine and augite with lesser amounts of apatite, opaque minerals, biotite, and quartz. Alteration of the groundmass is extensive and consists of epidote, calcite, sericite, and chlorite. In outcrop this dike reaches a maximum thickness of about 15 ft and has a pronounced columnar jointing developed at right angles to its margins. This dike has been interpreted as the source of mineralization along the Trimble Fault (Lakes, 1906). Mineralization in the vicinity consists of native gold, telluride minerals, native mercury, and minor copper carbonate and fluorite. Though we do not have an absolute age on the rock from this dike, it is similar in texture and mineralogy to Late Cretaceous to early Tertiary dioritic intrusive rocks of the La Plata Mountains.

Je

Entrada Sandstone (Middle Jurassic)—This unit is composed mostly of light gray, white, or light brown, fine- to medium-grained, highly cross-stratified quartz arenite with a calcium carbonate cement. The Entrada Sandstone in the map area is locally coarse grained or conglomeratic at the base and commonly has a distinct large-scale cross stratification. The Entrada Sandstone is the basal unit of the San Rafael Group in the Four Corners region. It is exposed only on the southern margin of the map area. This formation was deposited as a vast erg that developed on an emergent arid coastal plain dur-

ing regression of the shallow Curtis–Sundance seaway (Lucas and Anderson, 1997). Within and near the south-central boundary of the map area the maximum thickness of the Entrada Sandstone is up to about 150 ft thick. The lower part of the Entrada Sandstone may be an interfluvial-lacustrine sequence that was deposited in a dune field. The J-2 regional unconformity marks the boundary between the Entrada Sandstone and the underlying Dolores Formation.

Rd

Dolores Formation (Upper Triassic)—Only the basal part of the Dolores Formation is exposed within the map area. This unit correlates with an upper member (Rock Point Formation), middle member (Painted Desert Member of the Petrified Forest Formation), and lower member (Moss Back Formation) of the Chinle Group in the Colorado Plateau (Carroll and others, 1999). In the map area the Dolores Formation is a light to medium gray to brownish gray limestone-pebble conglomerate and minor limestone that is overlain by a white to light tan lenticular sandstone. Hematitic sandstones and siltstones that occur in the Dolores Formation in the Durango East quadrangle were not found in the Hermosa quadrangle. Conglomerate of the Dolores Formation in the map area is clast and matrix supported and contains abundant subrounded to angular fragments of limestone in a sandy to carbonate-rich matrix. The conglomerate locally contains teeth and bone fragments from crocodilians. The limestone-pebble conglomerate forms a prominent cliff on the southern edge of the Stevens Creek canyon. The Dolores Formation unconformably overlies the Cutler Formation.

Pc

Cutler Formation (Lower Permian)—The Cutler Formation in the map area is comprised of interbedded 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 to 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 at least 2 in. in diameter. Sandstones are immature to

submature and contain high concentrations of quartz, potassium feldspar, and biotite in a 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 a calcareous cement. 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 1,800 ft thick. This unit may be prone to rock-fall hazards where exposed in steep cliffs.

Ph

Pennsylvanian Hermosa Group (Middle Pennsylvanian)—Outcrops of the Hermosa Group in the map area form the most southern 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 (refer to 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 interpret four different carbonate lithofacies in the Hermosa Group that represent various marine depositional environments. These lithofacies were established based on mineral assemblages, textures and structures, biotic assemblages, and inferred depositional environments. In the undifferentiated part of the Hermosa Group there are stacked carbonate-clastic depositional cycles which are dominated by carbonate units at the base and grade upward into coarsening clastic cycles. These cyclic deposits formed in marine deltaic and nonmarine deltaic and alluvial systems. At least 28 and possibly 40 of these depositional cycles were recognized by Franczyk and others (1995).

Lithofacies 1 corresponds to the Pinkerton Trail Formation. It is dominated by a succession of thin- to thick-bedded calcareous black 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).

Carbonate lithofacies in the undifferentiated part of the Hermosa Group above the Pinkerton Trail Formation are thin to thick bedded and contain 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, fusulinids, foraminifera, phylloid algae, ostracods, monaxon sponge spicules, gastropods, and pelecypods.

Clastic deposits in 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 in. in length that are interpreted as fossilized flora. There are also worm burrows in many sandstone layers.

Lithofacies 2 of Franczyk and others (1995) makes up part of the undifferentiated part of the Hermosa Group. This lithofacies is capped by a 25 ft thick zone of gypsum, dolomitic mudstone, and claystone. Thick beds of interbedded gypsum, shale, and claystone are exposed on the west side of the Animas River valley at the mouth of Hermosa Creek. On the southern slope of Hermosa Mountain, at an elevation of about 7,200 ft, there is a 20–25 ft thick succession of interbedded gypsum, black shale, and conglomerate or intraformational conglomerate. The con-

glomerate has a reddish to orangish brown matrix of siltstone and fine-grained sandstone. It contains subangular to angular pebble- to cobble-sized clasts of red to maroon, medium-grained sandstone, brown siltstone, brownish iron-stained medium-grained calcareous sandstone, and grayish black limestone. Beds of gypsum in this succession are up to 20 ft thick and are typically highly contorted and deformed.

Pm

Molas Formation (Lower Pennsylvanian)—

The Molas Formation is a karstic breccia with fragments of micritic to sparry limestone up to 10 in. in length which 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 in. in maximum dimension. In one outcrop of Molas Formation about 600 ft north of Coon Creek, a pod of chert and agate was found. This pod is about 1 ft thick and 3 ft long and is elongate along bedding. 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 ranges in thickness from 2–25 ft and locally occurs as pipes and fracture filling in the underlying Leadville Limestone.

MI

Leadville Limestone (Lower Mississippian)—

Interbedded marine rocks that include gray fossiliferous and oolitic limestone, black to gray shale, intraformational limestone conglomerate, limestone breccia, and stromatolitic dolomite. Thin beds and lenses of chert occur within limestone beds in the upper part of the Leadville Limestone. 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, syringoporida 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 siltstone up to 15 ft thick which has abundant salt casts with edges up to 0.5 in. long. The Leadville Limestone reaches a maximum thickness of about 100 ft just east of Tamarron Resort.

Do

Ouray Limestone (Upper Devonian)—This unit is comprised chiefly of brown to light

gray dolomitic limestone, micritic limestone, and sandy dolomite. Thin to medium beds of thinly laminated reddish brown to 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. Limestone breccia is locally present near the base of the Ouray Limestone. Bedding in this unit is poorly developed, but where apparent it ranges from thin to thick. Fossils were not observed in the Ouray Limestone within the map area. The Ouray Limestone is a resistant unit and forms prominent cliffs and benches. The bench formed by the top of this unit underlies Highway 550 from west of Bakers Bridge to beyond the northern boundary of the map area. The Ouray Limestone formed in shallow marine environments; dolomitic rocks are mostly stromatolitic and supratidal in origin (Campbell and Gonzales, 1996).

D-Cei

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. These rocks 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. 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). In most instances the McCracken Member cannot be distinguished from the underlying Ignacio Formation and there has been some controversy over the distinction of these two units (Baars and Knight, 1957; Baars, 1966; Baars and See, 1968; Baars and Ellingson, 1984; Campbell and Gonzales, 1996). In this study, however, these two units are not differentiated and collectively form the base of the Paleozoic section. Locally, the

Elbert Formation is not preserved in the stratigraphic section.

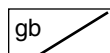
The Ignacio Formation is a mottled reddish brown to grayish brown, light brown, white, or light pink coarse-grained quartz arenite and pebble conglomerate. The Stag Mesa Member (Campbell and Gonzales, 1996) is medium- to thick-bedded shallow-marine quartz arenite with lenses of pebble conglomerate up to 1.5 ft thick. Clasts in the conglomerate are predominantly milky quartz and quartzite but angular fragments of potassium feldspar are found in some lenses of the conglomerate. 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.

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. South of Shalona Lake, along the railroad cut, the Stag Mesa Member contains a lens of matrix- to clast-supported, pebble- to boulder conglomerate that is up to 100 ft long and 4 ft thick. Clasts in this conglomerate are mostly subangular to angular fragments of dolomitic limestone, but there are also subangular to angular fragments of red siltstone and rounded to subrounded fragments of milky quartz. This conglomerate also contains very thin, discontinuous lenses and beds of reddish siltstone. The matrix of this lens of conglomerate is coarse sandstone composed mostly of subrounded quartz grains in a silica cement. Iron oxide stain and patches and veins of sparry calcite are prevalent throughout this unit.

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 50 ft thick and forms a prominent cliff at the base of the Paleozoic section.

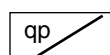
On the tracks of the Durango and Silverton Narrow Gauge Railroad south of Rockwood, quartz arenite of the Stag Mesa Member overlies lenses of matrix- to clast-supported boulder conglomerate that contains rounded to subrounded clasts of quartzite, milky quartz, and rare granite. Interbedded with this boulder conglomerate are

thin beds of coarse-grained quartz arenite with hematitic silica cement. This conglomerate and minor quartz arenite exposed beneath the Stag Mesa Member correspond to the Weasel Skin Member of the Ignacio Formation, which is interpreted as braided-stream deposits (Campbell and Gonzales, 1996).



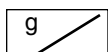
Gabbro dikes (age uncertain)—Black to greenish black gabbroic dikes intrude the Irving Formation, Bakers Bridge Granite, and quartz-porphyry dikes of the Eolus Granite. Cambrian strata of the Ignacio Formation overlie and are younger than these gabbroic dikes. Most of the dikes trend east-west, subparallel 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 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 30–45 ft thick. They have a tendency to fill pre-existing fractures in older crystalline rocks.

PROTEROZOIC CRYSTALLINE ROCK UNITS



Quartz-porphyry Dikes (Mesoproterozoic) — Granitic dikes are exposed within the older crystalline rocks in the northeastern part of the map area. These dikes contain phenocrysts of sub-hedral to euhedral quartz, perthitic microcline, perthite, oligoclase, biotite, and hornblende which 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 10–15 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 3–15 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 (Gonzales, 1997).



Aplite, pegmatite, and fine- to coarse-grained granitic dikes and sills (Paleoproterozoic to Mesoproterozoic)—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 E–W 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.

Xbt

Xt

Xb

Bakers Bridge Granite (Paleoproterozoic)—

The Bakers Bridge Granite consists of two phases, a biotite-magnetite-hornblende granite and a younger biotite-muscovite granite.

Biotite hornblende granite and two-mica granite of the Bakers Bridge Granite—

This map unit includes undifferentiated bodies of both phases of the Bakers Bridge Granite. Within these zones there is an intimate association of the two phases where the biotite-muscovite granite forms fingers and ribbons in the biotite-magnetite-hornblende granite.

Biotite-muscovite granite phase of the Bakers Bridge Granite—A stock of biotite-muscovite granite cuts the main pluton near its southern exposed end (Bickford and others, 1969). This phase of the pluton is light gray to grayish white and contains less than 5 percent dark minerals. It is medium to coarse grained and equigranular with related aplitic offshoots. The rock is composed essentially of quartz, microcline, perthite, albite to oligoclase, biotite, muscovite, and accessory zircon and iron oxide. Dikes and offshoots of the biotite-muscovite granite cut the biotite-hornblende-magnetite granite. This cross-cutting relationship is supported by U-Pb ages on zircon of $1,698 \pm 4$ Ma for the biotite-hornblende-magnetite granite and $1,695 \pm 2$ Ma for the biotite-muscovite granite (Gonzales, 1997). The biotite-muscovite granite phase of the Bakers Bridge pluton is devoid of xenoliths and deformation fabrics and is cut by quartz porphyry dikes (map unit qp). The margin between the biotite-hornblende-magnetite granite and biotite-muscovite granite is about 200 ft wide and is a zone where the former is cut by many dikes and stringers of the biotite-muscovite granite.

Biotite-hornblende-magnetite granite phase of the Bakers Bridge Granite—

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. This unit 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. At the northern margin of the pluton in the map area, however, the granite locally has a pronounced lenticular foliation that is folded. This deformation fabric is developed in the outer 30–45 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 (Dr. Clay Conway, United States Geological Survey, 1994, oral communication).

Xi

Irving Formation (Paleoproterozoic)—This unit contains polyphase deformed, middle to upper amphibolite-facies mafic to felsic volcanic and sedimentary rocks, and associated mafic intrusive rocks. A U-Pb age of

1,795–1,805 Ma was obtained on zircons from a sample of fine-grained felsic schist about 5 mi north of the Hermosa quadrangle (Gonzales, 1997).

The Irving Formation contains mafic to felsic schist and gneiss. Mafic lithologies are fine- to coarse-grained, strongly foliated to massive amphibolite that is interpreted as metamorphosed basaltic volcanic rocks and associated gabbroic intrusive rocks. Metamorphosed gabbro is the predominant rock type of this unit in the map area. The amphibolite 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.

The Irving Formation within the map area also contains fine- to medium-grained felsic to intermediate schist and gneiss interlayered with fine- to coarse-grained amphibolite. Layers are one to tens of feet thick. Felsic and intermediate lithologies are interpreted as metamorphosed rhyolitic to dacitic tuffs and reworked volcanic deposits. These rocks are locally cut by swarms of medium- to coarse-grained quartzo-feldspathic stringers and ribbons that are less than 1–4 in. thick. These stringers and ribbons commonly trend subparallel to compositional layering and S1-S2 tectonic foliation and locally define tight to isoclinal F1 and F2 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. Amphibolite layers in this unit are composed of hornblende, oligoclase to andesine, epidote, quartz, and garnet. Felsic to intermediate rocks of this unit are composed largely of quartz, feldspar, biotite, muscovite, and garnet. These rocks have color indices ranging from 5–50 percent. In some outcrops these rocks have a pronounced layering that is interpreted as primary bedding and lamination.

The earliest phases of deformation in the Irving Formation are F1 and F2 tight to isoclinal folds defined by quartz stringers and folded S1 foliation. Foliations developed during the first and second phases of folding are gen-

erally steep dipping and trend roughly east-west. In some outcrops the S1-S2 foliations are refolded into F3 folds (and related S3 foliation) that are tight to open with variable trends. The F1-F3 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 S4 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 1,720–1,730 Ma (Gonzales, 1997). Superimposed on F1 to F3 folds are F4 pygmatic folds that deform the granitic intrusives.

STRUCTURAL GEOLOGY

INTRODUCTION

The dominant structures in the map area are faults that cut Proterozoic and younger rocks. Many of these structures have an east-west trend but some of the structures trend more northeast or northwest; structures with north-south trends are subordinate. 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 we observed, however, are vertical or steep. Interpretations 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, mineralization, and hot springs. The reader should note that on the map 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 generally not known.

TRIMBLE FAULT ZONE

In this report the roughly ENE-WSW trending faults and fractures that cut the Hermosa Group and Cutler Formation west of Trimble Hot Springs make up the Trimble Fault zone. This zone of faulting and fracturing has an apparent displacement that is predominantly north-side-down and right lateral. On the basis of displacement and meager control on the dips of the faults within the zone, we interpret this fault zone as a north-dipping normal fault. Apparent right-lateral displacement is inferred on the basis of offset of the contact between the Hermosa Group and Cutler Formation immediately west of Trimble Hot

Springs. About 0.5 mi west of Trimble Hot Springs this fault zone is mineralized and has been prospected and mined for gold. Dips on fault planes in this zone were not measurable, but they were observed in the cliffs of Cutler Formation west of Fall Creek subdivision where the faults dip steeply to the north and have obvious down-to-the-north displacement. The Trimble Fault zone is mentioned by Lakes (1906), Kilgore (1955), Kilgore and Clark (1961), and Moyer and others (1961) but has not been previously mapped. On the basis of offset strata in the Cutler Formation, this fault has a maximum apparent throw of about 200 ft; minor related faults have displacements of several feet to tens of feet. The Trimble Fault zone may have influenced the location of the Late Cretaceous to early Tertiary dike exposed to the northwest. The dike does not extend into the fault zone on the surface, but the projected intersection of the dike and fault is mineralized.

An east-west trending fault that is exposed about 0.5 mi south of the mouth of Stevens Creek on the east side of the Animas River valley may be the eastward extension of the Trimble Fault zone. Drag and warping of beds in the Hermosa Group in the area north of this fault suggest that displacement is down to the north. The trace and apparent displacement of this fault zone is consistent with it being an extension of the Trimble Fault, but additional evidence is lacking.

TRIPP GULCH FAULT

About 2 mi north of the Trimble Fault zone there is a WNW-ESE trending fault zone whose trace follows Tripp Gulch. This fault zone was not mapped or described in previous studies. Stratigraphic displacement on the fault indicates about

50 to 100 ft of apparent down-to-the-south movement. This indicates that the Tripp Gulch Fault forms the northern structure of a broad graben that is bounded on the south by the Trimble Fault Zone. The trace of the Tripp Gulch Fault is heavily vegetated and very little information about the fault was obtained in our mapping of this structure.

On the east side of Animas River valley a NNW-SSE trending fault was located in Freed Canyon. The trace of this fault has a similar trend as the Tripp Gulch Fault, to which it may be related. Apparent displacement determined solely on stratigraphic offset suggests that the fault zone in Freed Canyon is down to the north. The fault in Freed Canyon is poorly exposed, but the contact between the Hermosa Group and the Cutler Formation is clearly disrupted in this zone. The contact on the north side of the fault zone dips to the southeast into Freed Canyon and extends to the level of the creek. The contact on the south side of the fault is located about 200 ft higher and dips gently to the south. If the fault zone in Freed Canyon is related to the Tripp Gulch Fault, then it appears that the motion has reversed and the system is a scissors fault.

JONES CREEK-BEAR CREEK FAULT SYSTEM

An extensive system of faults and fractures occurs on the northern edge of the Hermosa quadrangle. The western extension of this system is comprised of a NNE-SSW trending fault whose trace lies within Jones Creek. The Jones Creek Fault is heavily vegetated and evidence for its motion is based chiefly on stratigraphic offset. The western part of the Jones Creek Fault is exposed in the steep cliffs of Hermosa Creek where the trace of the fault in the cliffs is vertical to near vertical with a steep north dip. West of Hermosa Creek the Jones Creek Fault is intersected by several NNW-SSE-trending faults that locally contain extensive zones of breccia injected with veins containing calcite, pyrite, and iron oxide. In this same area there is a sliver of Cutler Formation that is juxtaposed against the Hermosa Group in what we interpret to be a small graben. About four miles northeast there is also a block of Cutler Formation that is adjacent to rocks of the Hermosa Group. The contact between the Hermosa Group and Cutler Formation north of

the fault dips gently to the south and lies about 200 ft lower than the south-dipping contact on the south side of the fault. Collectively, the evidence suggests that the northern block of this fault has dropped down relative to the southern block.

A 100 ft long segment of the Jones Creek Fault is exposed in a road cut near Rockwood. This segment of the fault is shown on the geologic map of Atwood and Mather (1932). Along the road cut the fault places the Proterozoic Bakers Bridge Granite against the Mississippian Leadville Limestone along a steep north-dipping fault. This is consistent with our interpretation that the dominant fault motion is down to the north. About 2 mi to the east there are several prospects and mines along this fault zone where it is adjacent to the Animas River. From Rockwood to the Animas River this fault system is expressed by a steep and prominent depression in the topography.

Immediately east of the Animas River the Jones Creek Fault splits into a wishbone-shaped system of faults that make up the Bear Creek Fault system. The southern splay of this system is shown on the geologic map of Atwood and Mather (1932) but was not connected with the Jones Creek Fault. Bickford and others (1969) mapped the Bear Creek Faults on their geologic map of the Bakers Bridge Granite. The northern splay of the Bear Creek system cuts the contact between the Irving Formation and Bakers Bridge Granite in an apparent left-lateral direction. This fault extends further to the northeast into the Electra Lake quadrangle where it bends to the north and extends into Canyon Creek. Near Canyon Creek this fault zone is mineralized, and there are numerous prospects along the trace of the fault where it displaces the Cambrian Ignacio Formation several hundred feet down against the Irving Formation.

The southern splay of the Bear Creek Fault system extends into the upper reaches of Bear Creek. This fault displaces the contact between the Irving Formation and Bakers Bridge Granite and the quartz-porphyry dikes that intrude both units. An apparent left-lateral motion is inferred from this displacement. Though the dip of this fault was not constrained at any location, near the eastern edge of the quadrangle it does drop the Paleozoic strata exposed in the block north of the fault down relative to the south block of the fault.

CARSON CREEK FAULT

Between Bear Creek and Carson Creek several faults displace the contact between the Irving Formation and Bakers Bridge Granite, and cut the lower Paleozoic rocks. Traces of these faults generally trend east–west and show either apparent dextral or sinistral strike-slip motion. The southernmost of these faults also displaces the Ignacio Formation and Ouray Limestone down against the Bakers Bridge Granite.

The Carson Creek Fault is an east–west trending structure whose trace extends from the upper part of Carson Creek westward towards the mouth of Bell Canyon. A relative right-lateral displacement of nearly 0.5 mi is suggested by offset of the contact between the Bakers Bridge Granite and lower Paleozoic strata. Immediately east of Smith Lake the Ignacio Formation is juxtaposed against the Bakers Bridge Granite. The western extension of the Carson Creek Fault is speculative. The fault is poorly exposed, and there is no field evidence that accurately constrains the position of the fault trace west of the Animas River.

SPUD HILL FAULT ZONE

The Spud Hill Fault is a complex system of small east–west trending faults and fractures that are exposed just west of Spud Hill. The northernmost fault of this system cuts the lower Paleozoic section with a down-to-the-south vertical displacement of 50–100 ft. About 300 ft to the south, a series of small faults and fractures displace the Paleozoic strata in a step-wise fashion. In this zone there are numerous steeply north-dipping antithetic normal faults that have vertical offsets ranging from 1 ft to around 15 ft. There are also

south-dipping synthetic normal faults with apparent vertical displacements of several feet. Locally within this fault zone there are also reverse faults with displacements up to several feet. Collectively, these structures form a half graben in which the lower Paleozoic strata have been bent, fractured, and warped into a monoclinical structure that dips to the north. Proterozoic basement structures may have had some control on the formation of this monoclinical structure.

The Spud Hill Fault zone is on trend with a set of small faults exposed west of Highway 550 on the west side of Animas River valley. We suspect that these small faults are part of the same system and that they may control the thermal springs that issue from the area west of Highway 550. In the vicinity of the thermal springs the faults form a series of steeply dipping to vertical structures that cut strata as young as the Hermosa Group. These faults form a small horst that is marked by tufa deposits. McCarthy and others (1982) suggested that the traces of these faults trended NW–SE based on reconnaissance surface mapping and geophysical data. Our field mapping provided no evidence to support this interpretation.

The Spud Hill Fault zone is intersected by a NNW–SSE trending fault that extends southeast to the area west of Wallace Lake. This fault drops rocks as young as the Hermosa Group down to the west and is exposed in a road cut about 0.5 mi north of Coon Creek. The rocks and surfaces in the fault zone along the road cut are unstable in places causing slumping and small slides. About 100 ft north of Coon Creek there is a landslide that developed along the scarp of this fault. Rotation of large blocks and hummocky topography occur throughout the landslide zone.

THERMAL SPRINGS

INTRODUCTION

Within the study area there are several natural thermal springs that discharge at the surface and are referred to as “hot” springs. Within the quadrangle, thermal springs are confined to the western side of Animas River valley. A thermal spring does, however, issue from the Pony Express Limestone on the east side of the valley (Entrada seep) in the Durango East quadrangle (Carroll and others, 1999). These thermal springs and associated deposits include Trimble Hot Springs, Tripp Hot Springs, Stratten Warm Springs, and Pinkerton Hot Springs. Barrett and Pearl (1978) and McCarthy and others (1982) provide more extensive descriptions and a history of studies on these springs.

All of the thermal springs in the map area have mounds and platforms of calcareous tufa (unit Qtu). These tufa deposits often have a reddish brown to orangish red coloration due to the presence of iron oxides and hydroxides. These springs lie on or near fault and fracture zones that trend roughly east–west. The fact that the thermal springs in the map area are confined to the west side of the Animas River valley may indicate that the faults and fractures are acting as discharge zones from a source to the west. There may, however, be additional conduits along the edge of the valley. There has also been speculation that some of the thermal waters in the Animas River valley originate at depth in the San Juan Basin and migrate from south to north due to pressure created by coal-gas water injection wells in the Entrada Sandstone and other units (Debbie Baldwin, written communication with Jim Cappa, 1997).

Assuming a geothermal gradient of 35°C/km would require that waters must circulate to a depth of between 5,000 and 9,000 ft without an additional heat source (McCarthy and others, 1982). McCarthy and others (1982) proposed the La Plata Mountains intrusive complex was the source of heat for the thermal springs in the map area. We suggest that this is unlikely because intrusive activity in the La Plata Mountains ceased about 65 million years ago. Middle Tertiary mantle magmas emplaced about 30 mi south and west of the study area in Mancos River canyon might, however, be a potential source of heat.

PINKERTON HOT SPRINGS

The northernmost of the thermal springs in the map area is the Pinkerton Hot Springs, located about 14 mi north of Durango (Figure 1). This site is a thermal complex consisting of several springs and associated tufa-mound deposits (Barrett and Pearl, 1978). The primary spring at this site originally discharged to the surface at a broad, flat tufa mound located at the site of the old Pinkerton Hot Springs resort, established by homesteader Judge Pinkerton. The Colorado Mountain Academy currently owns the location of the original primary spring. During construction and modification of U.S. Highway 550N in the late 1970s a conduit carrying thermal water was intercepted in a road cut about 800 ft west of the original resort site, causing the original primary spring to dry up. Presently, the thermal water intercepted in the road cut issues from the top of a pile of rocks placed on the east shoulder of Highway 550N. A road cut to a new home site on the banks of the Animas River exposes the southern edge of the large tufa mound at Colorado Mountain Academy and intersected a conduit of a thermal spring about 300 ft south of the Academy. Warm water issues from the culvert at a rate of approximately 10–20 gallons per minute (gpm). Three other distinct springs and related tufa mounds are located about 1,500–2,000 ft northwest of Colorado Mountain Academy.

Barrett and Pearl (1978) and McCarthy and others (1982) report that the thermal waters at Pinkerton springs are a mixed sodium and calcium chloride-bicarbonate type with high concentrations of dissolved iron. Total dissolved solids (TDS) were measured between 3,770 and 3,800 mg/l. Discharge at the springs and mounds ranged between 2 to 60 gpm, and temperatures varied from 26°C to 33°C (84°F to 91°F).

The Pinkerton thermal springs system discharges from the Leadville Limestone. McCarthy and others (1982) inferred a set of northwest trending faults in the area on the basis of reconnaissance mapping and geophysical data, and they suggested that these structures were the conduits of this system. Our mapping, however, identified a set of E–W trending structures in the area

which appear to be an extension of the fault system exposed in the Paleozoic cliffs on the east side of the valley, due east of Pinkerton Hot Springs. In the vicinity of the Pinkerton springs these E–W trending structures bound a small horst block of Leadville Limestone with a thin cover of Molas Formation. Numerous small fractures and breccia zones that would provide pathways for fluid flow characterize this fault system. Two tufa mounds and related springs (Mound Spring and Little Mound Spring of McCarthy and others, 1982) discharge on either side of the horst structure, and one of the faults can be traced on the steep hillside to the west.

STRATTEN WARM SPRINGS

McCarthy and others (1982) noted the occurrence of a thermal spring at the mouth of Tripp Gulch. At the time of their publication they indicated that the spring was unused. Our survey of the area indicates that the spring is still not being used and that there is no surface evidence of flow. The Stratten springs are located in the vicinity of the Tripp Gulch Fault, which has apparent down-to-the-south displacement. No large tufa deposits were identified in the area of the Stratten Warm Springs. McCarthy and others (1982) reported a discharge of 10 gpm at the Stratten springs, a temperature of 28°C (82°F), and a TDS of 1,300 mg/l.

TRIMBLE-TRIPP HOT SPRINGS

A fault extends southwest from near Trimble Hot Springs to the area immediately west of Falls Creek development about 1.5 mi to the west. This fault system has a down-to-the-north apparent movement and together with the Tripp Gulch Fault forms a broad graben. Numerous fractures

and minor faults associated with this system have localized gold-telluride-mercury mineralization (Lakes, 1906) and thermal fluids. The slope to the west of Trimble Hot Springs is heavily vegetated, so it is difficult to identify controlling structures, but further to the west the fault zone is highly fractured and brecciated. Thermal fluids that flow from the Trimble-Tripp springs discharge from colluvium and alluvium at the stratigraphic level of the Hermosa Group.

Trimble Hot Springs is located about 300 ft south of the main fault zone and is currently used as a public swimming pool, spa, and private spa. The water in the spring must be pumped to obtain sufficient water for the facility (oral communication with Charlie Smith, 2001). There is a large apron of calcareous tufa that is exposed on the west side of the swimming pool area. Tripp Hot Springs was located about 200 ft north of the original Trimble Hot Springs site (Barrett and Pearl, 1978), but it was apparently plugged in the early 1980's (McCarthy and others, 1982). The location noted for Tripp Hot Spring is currently near the private spa at Trimble.

Barrett and Pearl (1978) and McCarthy and others (1982) reported discharge rates at the Trimble-Tripp thermal-springs complex of 1 to 10 gpm and temperatures of 36°C (96°F) to 44°C (111°F). Measured TDS ranged from 3,240 to 3,340 mg/l and the fluids associated with these springs were identified as calcium- or calcium-sodium sulfate type. McCarthy and others (1982) reported that since 1875 the temperature, discharge, and dissolved solids have changed dramatically at Trimble Hot Springs. The temperature had decreased about 35°F, the discharge had dropped about 190 gpm, and the TDS increased about 2,000 mg/l.

GEOCHEMISTRY OF IGNEOUS ROCKS

Bondar Clegg Analytical Laboratories analyzed representative samples of the Bakers Bridge Granite, rhyolite porphyry dikes, and gabbroic dikes for major oxides using X-ray fluorescence spectrometry. Information on the analytical process, detection limits, standard data, and precision tolerance of reported results are available upon request from the authors or from Bondar Clegg.

Major oxide and trace element geochemical data are reported in Table 1. No FeO data was obtained for any of the samples and all iron is reported as Fe₂O₃. Concentrations of Ba, Nb, Rb, Sr, Y, and Zr were also obtained for selected samples. Geochemical analyses for two samples of Electra Lake Gabbro (NM272 and NM293) obtained from the U.S. Geological Survey analytical laboratories are included in Table 1 to allow comparison with samples of gabbroic dikes that were collected and analyzed in this study. Normative mineralogies were determined for all of the samples from the Hermosa quadrangle in order to generate geochemical plots (Table 2). Since FeO was not reported in the analyses normative values for clinopyroxenes, magnetite, ilmenite, and hematite could not be accurately determined and the data were not compiled.

All samples analyzed are subalkaline. Granitic rocks are calc alkaline and the gabbroic dikes are primarily tholeiitic. The subalkaline signature of these rocks is consistent with results of previous geochemical analyses of Proterozoic rocks in the Needle Mountains (Barker, 1969; Gonzales, 1988, 1997).

Geochemical signatures of the biotite-hornblende-magnetite and biotite-muscovite phases of the Bakers Bridge are similar in most respects (Table 1 and Barker, 1969). Samples of biotite-muscovite granite, however, have higher SiO₂ and lower Fe₂O₃, MgO, CaO, and K₂O. The biotite-hornblende-magnetite granite has notably higher Ba that probably reflects higher fractionation of barium-rich mineral phases such as alkali feldspar, biotite, hornblende, and plagioclase. Higher Sr in the biotite-hornblende-magnetite samples is attributed to fractionation of plagioclase in the magma during emplacement. All samples of Bakers Bridge Granite are potassic, with

K₂O/Na₂O ratios between 1 and 2, and are either metaluminous to slightly peraluminous. Initial ⁸⁷Sr/⁸⁶Sr ratios of 0.7012 (Bickford and others, 1969) and ε_{Nd(t)} values of +4.6 to +3.8 (Gonzales, 1997) are consistent with formation of the Bakers Bridge Granite by partial melting of juvenile crust composed mostly of mafic to intermediate igneous rocks. Geochemical data for the samples analyzed in this study are consistent with this hypothesis.

Quartz porphyry dikes that cut the Bakers Bridge Granite show similar geochemical trends (Table 1 and Barker, 1969). These rocks are characterized by SiO₂ of 73 to 76 weight percent, high K₂O and Na₂O, and relatively low CaO, MgO, and Fe₂O₃. These trends are consistent with the low color index of these rocks and the high proportions of quartz, alkali feldspar, and oligoclase. The Ba, Rb, and Sr concentrations in these rocks reflect the fractionation and concentration of these minerals. The quartz porphyry dikes are metaluminous to slightly peraluminous. A U/Pb age of 1,481 ± 47 million years obtained for a sample of one of the quartz-porphyry dikes (Gonzales, 1997) indicates that they are coeval with the Eolus Granite. Bickford and others (1969) reported initial ⁸⁷Sr/⁸⁶Sr ratios of 0.7058 based on whole-rock and mineral-separate data from rhyolite porphyry dikes in the Bakers Bridge Granite and samples of Trimble Granite. Gonzales (1997) reported ε_{Nd(t)} values of +1.8 to +0.9 for samples of Eolus Granite. Collectively, the isotopic and geochemical data for the Eolus Granite support either partial melting of mantle-derived basaltic rocks or Paleoproterozoic continental crust, followed by magmatic differentiation that generated the dioritic to granitic compositions of the Eolus Granite.

Gabbro dikes that cut the Bakers Bridge Granite are gabbroic to dioritic in composition, with SiO₂ between 49 and 57 weight percent. These rocks are metaluminous and relatively high in Ba and Sr. Since the age of these dikes is unknown, one possible hypothesis is that they are related to intrusion of the 1,430 million year old Electra Lake Gabbro. The mafic dikes and samples of Electra Lake Gabbro have some distinct geochemical differences (Table 1). In general, samples

Table 1. Whole-rock XRF chemical analyses (performed by Bondar Clegg Analytical Laboratories).

Sample Number	Rock Type	Major Oxides in Weight Percent												Minor Element in Parts per Million					
		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total	Ba	Sr	Y	Nb	Zr	Rb
Detection Limits		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-2.00		50	5	5	5	5	5
HM6	quartz porphyry	75.03	0.12	12.24	1.91	0.04	0.22	1.04	3.45	4.64	0.02	0.56	99.39	612	98	54	26	227	143
HM7	quartz porphyry	73.34	0.20	12.98	2.13	0.04	0.28	0.95	3.43	5.14	0.04	0.60	99.26	565	58	45	24	256	170
HM22	quartz porphyry	74.86	0.08	12.31	1.55	0.02	0.10	0.43	3.07	5.29	0.02	0.69	98.44						
HM28	quartz porphyry	73.85	0.20	12.82	2.21	0.04	0.28	0.91	3.37	4.93	0.04	0.66	99.43	440	51	49	29	252	186
HM11	gabbro	50.52	1.82	14.67	14.47	0.18	4.73	5.99	2.91	1.73	0.29	2.20	99.50						
HM20	gabbro	52.75	1.38	14.66	12.84	0.24	4.03	6.77	3.57	1.73	0.23	1.30	99.49						
HM21a	gabbro	55.16	2.17	13.90	12.74	0.20	2.57	5.64	3.28	2.25	0.56	1.14	99.75	675	261	36	10	203	71
HM24	gabbro	49.84	1.76	14.68	14.40	0.21	4.58	7.11	2.89	1.55	0.26	2.04	99.42	525	244	25	< 5	126	52
HM30	gabbro	56.23	0.80	14.81	7.51	0.13	6.39	6.00	3.04	2.04	0.16	1.90	99.17	653	328	22	11	147	96
NM272	Electra Lake gabbro	49.2	1.60	17.6	12.1	0.17	5.02	8.73	3.09	0.69	0.13	1.31	99.76	260	75	18	< 10	75	16
NM293	Electra Lake gabbro	50.3	1.33	15.3	13.5	0.19	6.16	9.93	2.81	0.56	0.12	0.06	99.69	235	310	24	<10	69	13
HM12	bio-hbl-mag granite	67.78	0.54	14.00	5.16	0.14	0.35	1.60	3.56	5.26	0.10	0.61	99.47	2366	157	56	31	744	100
HM14	bio-hbl-mag granite	70.04	0.42	13.55	3.98	0.08	0.36	1.10	3.44	5.28	0.07	0.60	98.94						
HM16	bio-hbl-mag granite	71.75	0.30	12.86	3.39	0.08	0.19	1.15	3.38	5.19	0.05	0.43	98.80						
HM25	bio-hbl-mag granite	72.01	0.29	13.05	3.13	0.08	0.22	0.83	3.17	5.63	0.05	0.46	99.24	2257	123	37	17	501	114
HM18	bio-musc granite	75.95	0.04	12.72	1.22	0.02	0.06	0.44	3.77	4.67	0.02	0.79	99.79	< 50	6	131	70	171	306
HM31	bio-musc granite	75.95	0.08	12.04	1.52	0.02	0.07	0.60	3.60	4.75	0.01	0.54	99.30	117	14	148	54	192	237

of Electra Lake Gabbro have lower SiO₂, K₂O, Ba, Sr, Zr, and Rb but higher Al₂O₃, MgO, and CaO. On several chemical- tectonic plots (Table 2), the data for the gabbroic dikes plot in fields for rift-type mafic magmas. The predominantly east-west

trend of these dikes in the Bakers Bridge Granite indicates north-south extension during their emplacement, possibly as a result of continental rifting.

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 Hermosa quadrangle have surface evidence of prospecting and/or mining for lode and placer deposits. There are no active metal mines within the map area. An active surface-pit gravel operation, however, extracts gravel from the channel of the Animas River west of Trimble Hot Springs. 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 Hermosa quadrangle.

Lakes (1906) noted the occurrence of gold, native mercury, telluride minerals, fluorite, and traces of copper carbonate in the area west of Trimble Hot Springs. Several of these prospects are marked on the map along the Trimble Creek Fault in N $\frac{1}{2}$ sec. 16, T. 36 N., R. 9 W. No open drifts were identified in this area, but Neubert and others (1992) described a mine near these prospects that they identified as the Hazel Mine. The mine consists of several east–west trending drifts that intersect a series of west–northwest trending shear zones that dip steeply north and are cut by steep northeast trending faults related to the Trimble Fault Zone. The faults dip between 60° and 85° north or south. Gold assays indicated concentrations of 0.12–0.006 oz. per ton with a weighted average of 0.03 oz. per ton gold for one sample collected over a width of 1.5 ft. Maximum concentrations of silver, tellurium, and mercury were measured at 3 ppm, 110 ppm, and 122 ppm, respectively. The Hazel Mine and related prospects appear to be the eastern extension of the Mason Mine, which consists of gold-bearing quartz veins associated with an east–west trending diorite porphyry dike. The eastern extension of this dike or dikes is exposed in “Dike Creek” canyon. The association of these lode deposits with the dike, and the association of minerals in the deposits, indicate that they are related to igneous activity and subsequent mineralization in the La Plata Mountains to the west. Data obtained from the BLM Mining Claim Geographic Index Report identifies eight active or inactive lode and

placer claims in the NE $\frac{1}{4}$ of sec. 17 immediately to the west in the vicinity of the Trimble Fault. There are also numerous previous claims in sec. 8. These claims lie northwest of the mine site in the vicinity of the early Tertiary to Late Cretaceous diorite porphyry dike.

Near the western extent of Tripp Gulch in the map area, a mine was located near the contact between the Hermosa Group and Cutler Formation at SE $\frac{1}{4}$ sec. 4, T. 36 N., R. 9 W. The mine at this site has a 150 ft long adit that extends from the surface in a southwest trend into the Cutler Formation. Pitchblende occurs in carbonaceous sandstone and shale layers. Our examination of this area showed that much of the rock has a dull black coating of pitchblende. It has been estimated that this site contains 240,000 tons of uranium at an average grade of 0.06 percent U₃O₈ and minor vanadium (Neubert and others, 1992).

The BLM record of mining claims indicates a large number of inactive lode claims in the SE $\frac{1}{4}$ sec. 27 and sec. 28 and 29, T. 37 N., R. 9 W. The only favorable zone of mineralization that was identified in this area lies along an east–west trending fault with down-to-the-north motion. Where the fault zone is exposed in Hermosa Creek, the shale and limestone of the Hermosa Group are extensively fractured, brecciated, and injected with calcite veins. The surface of these rocks has a pervasive coating of limonite indicating the presence of oxidized sulfide minerals. There is no evidence, however, of prospecting or mining in this area. Another fault that is exposed immediately to the north in section 21 has a similar state of mineralization, but only sparse and minor sulfide minerals were noted along this fault zone.

Numerous small zones of mineralization occur along the southern branch of the Bear Creek Fault zone (secs. 7, 8, 17, and 18, T. 37 N., R. 8 W.). A collapsed vertical shaft was found at Walker's Crossing on the west bank of the Animas River along the fault. Additional prospects were located along the fault to the southeast. Most of the mineralization is confined to veins of quartz and altered zones in the Bakers Bridge Granite and Irving Formation that are within or adjacent to the fault system. An extensive zone of mineralization with

Table 2. Classification of intrusive rocks in the Hermosa Quadrangle using various chemical schemes.

Geochemical Classification Scheme	Reference for Classification	Compositional Restrictions	Limits	Rock Name (No. of Points in Field) (Refer to Table 1 for explanations and abbreviations)	Classification Field
alkalies vs. silica	Irvine and Baragar (1971)	none	mafic to felsic	bio-hbl-mag granite (4) bio-musc granite (2) quartz porphyry dikes (4) gabbro dikes (5)	all samples plot in the subalkaline field
Ab'-An-Or	Irvine and Baragar (1971)	normative mineralogy	mafic to felsic	bio-hbl-mag granite (4) bio-musc granite (2) quartz porphyry dikes (4) gabbro dikes (5)	all samples plot in the potassic field
alkalies vs. silica	Cox and others (1979)	none	mafic to felsic	bio-hbl-mag granite (4) bio-musc granite (2) quartz porphyry dikes (4) gabbro dikes (5)	alkali granite (4) alkali granite (2) alkali granite (4) gabbro (3), diorite (2)
alkalies vs. silica	Le Bas and others (1986)	none	mafic to felsic	bio-hbl-mag granite (4) bio-musc granite (2) quartz porphyry dikes (4) gabbro dikes (5)	rhyolite (3), trachydacite (1) rhyolite (2) rhyolite (4) basalt (2), basaltic andesite (3)
Ab-An-Or	Barker (1979)	normative mineralogy	intermediate to felsic	bio-hbl-mag granite (4) bio-musc granite (2) quartz porphyry dikes (4)	all samples plot in the granite field
Zr/TiO ₂ vs. Nb/Y	Winchester and Floyd (1977)	none	mafic to felsic	bio-hbl-mag granite (2) bio-musc granite (2) quartz porphyry dikes (3) gabbro dikes (2)	rhyolite (2) rhyolite (2) rhyolite (3) andesite (1), trachyandesite (1)
Nb/Y	Pearce and others (1984)	none	granitic	bio-hbl-mag granite (2) bio-musc granite (2) quartz porphyry dikes (3)	all samples plot in the within-plate granite field
Rb-Y +Nb	Pearce and others (1984)	none	granitic	bio-hbl-mag granite (2) bio-musc granite (2) quartz porphyry dikes (3)	within-plate granite (2) within-plate granite (2) within-plate granite (2)
Ti/100-Zr-Y*3	Pearce and Cann (1973)	none	mafic	gabbroic dikes (4)	within-plate granite (2) calc-alkaline (1) outside of fields (1)
Ti/100-Zr-Sr/2	Pearce and Cann (1973)	none	mafic	gabbroic dikes (4)	ocean floor (2) calc-alkaline (1) outside of fields (1)
TiO ₂ -MnO*10-P ₂ O ₅ *10	Mullen (1983)	none	mafic	gabbroic dikes (5)	island arc tholeiite (3) ocean island alkaline (2)
K ₂ O-SiO ₂	Gill (1981)	none	mafic to felsic	bio-hbl-mag granite (4) bio-musc granite (2) quartz porphyry dikes (4) gabbro dikes (5)	all felsic samples plot in the shoshonitic field and all mafic samples plot in the high-potassium calc-alkaline field
Zr/4-2Nb-Y	Meschede (1986)	none	mafic	gabbro dikes (2)	normal-type mid ocean-ridge basalts and volcanic-arc basalts (2)

numerous prospects and small mines was located along the contact between the Irving Formation and Bakers Bridge Granite in S½ sec. 8 and N½ sec. 17, T. 37 N., R. 8 W. This zone is marked by extensive skarn development in the Irving Formation along with veins of quartz and granite. Mineralization in this part of the map area is contained in lode and replacement deposits in which quartz and calcite veins and altered host rock contain blebs and stringers of pyrite, chalcopyrite, and magnetite with coatings of malachite, azurite, and limonite. Large zones of mineralization were not noted, but it is highly probable that these sulfide-rich zones contain small concentrations of gold, as suggested by the 60+ inactive claims recorded in this general area.

In the vicinity of Bakers Bridge gold-placer deposits were discovered and prospected in the 1930s by Humphreys Gold Corporation (Parker,

1974). These deposits occur in glacial- and alluvial-gravel deposits located in sec. 19 and sec. 30, T. 37 N., R. 8 W., and sec. 24 and sec. 25, T. 37 N., R. 9 W. Parker (1974) notes that an unsuccessful attempt was made to change the course of the Animas River in this area in order to mine the gravels. Most of the gold recovered from the gravels was fine and generally concentrated near the granite bedrock. The highest grade gravels discovered in this area yielded 47.56–121.59 cents per cu. yd. at 1930s gold values (Parker, 1974). It was estimated that in the area south of Bakers Bridge there are nearly 15,000,000 cu. yds. of gold-bearing gravels with an average value of 26 cents per cu. yd. at 1930s value which was about \$30.00 per oz. The source of the gold in these deposits was interpreted to be from the mineralized areas to the north in the Needle Mountains, and even perhaps from the San Juan Mountains volcanic field.

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