OPEN-FILE REPORT 04-9

Geologic Map of the Vallecito Reservoir 7.5-Minute Quadrangle, La Plata County, Colorado

Geologic Report and Unit Descriptions

Bill Owens, Governor,
State of Colorado

Russell George, Executive Director,
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This geologic mapping project was funded jointly by Fort Lewis College, the U.S. Geological Survey Educational Mapping Program under Agreements No. 02HQAG0070 and No. 03HQAG0045, and the Colorado Geological Survey and U.S. Geological Survey through the National Cooperative Geologic Mapping Program under STATEMAP Agreement 03HQAG0095).

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FOREWORD

The purpose of Colorado Geological Survey Open File Report 04-9, *Geologic Map of the Vallecito Reservoir Quadrangle, La Plata County, Colorado* is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located in south-west Colorado. Consulting geologists David A. Gonzales, Jedediah D. Frechette, Donald W. Stahr III, Todd Osmera, Nathan Morse, and Kristopher Graham completed the field work on this project during the summer of 2003.

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Vince Matthews
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INTRODUCTION

This project was funded by Fort Lewis College, the Education Mapping Program (EDMAP) of the U.S. Geological Survey (agreements No. 02HQAG0070 and No. 03HQAG0045), and jointly by the Colorado Geological Survey (CGS) and U.S. Geological Survey as part of the National Cooperative Geologic Mapping Program (STATEMAP Agreement 03HQAG0095).

David Gonzales and students from Fort Lewis College conducted the geologic mapping in the Vallecito Reservoir 7.5-minute quadrangle for the Colorado Geological Survey. Geologic maps produced by the CGS through the STATEMAP program provide geologic information for land-use evaluation and planning, design and construction of infrastructure such as utility lifelines and transportation corridors, geotechnical engineering, geologic-hazards assessment, analysis and mitigation of environmental problems, and exploration and development of mineral and water resources. The maps portray the geology of the quadrangle at a scale of 1:24,000 and serve as a basis for more detailed earth-science research, and for more regional, broad-scale investigations. The only previous geologic maps that include the Vallecito Reservoir quadrangle are 1:250,000 geologic maps compiled by Larsen and Cross (1956) and Steven and others (1974).

Figure 1 shows the current status of geologic mapping of 7.5-minute quadrangles in La Plata County. The Rules Hill, Ludwig Mountain, Durango East, Durango West, Hesperus, Basin Mountain, Hermosa, and Electra Lake quadrangles were mapped and published by the CGS during previous STATEMAP projects (Carroll and others, 1997, 1998, 1999; Kirkham and others, 1999, 2000; Kirkham and Navarre, 2001; Gonzales and others, 2002, 2003b). The mapping done in the Hesperus and Electra Lake quadrangles were funded in part by the EDMAP program.

Field studies and research for this project were done between March and September of 2002 and 2003. The first year of field work resulted in the compilation of the northern quarter of the quadrangle, and the unfinished part of the quadrangle was mapped and compiled in the summer of 2003. During these mapping periods nearly all of the outcrops and landforms in the map area were inspected and mapped for rock or deposit type, geologic structures, and resource information. Interpretation of aerial photography and previously published geologic investigations were used to delineate unit contacts in areas not visited by the authors. Black and white and color 1:15,000-and 1:24,000-scale aerial photograph coverage was used for the entire quadrangle. Compilation of the digital map from the field geologic map was done by Jason Wilson of the Geotechnical Support Group of the Colorado Geological Survey.

ACKNOWLEDGMENTS

We acknowledge the support and assistance throughout this mapping project from Vince Matthews (Colorado State Geologist and Director) of the Colorado Geological Survey, and Butch Knowlton (Director Building Department) and Joe Crain (Director Planning Services) of La Plata County. We thank all of the landowners who permitted access to their property during this project. Loren Wickstrom of the Bureau of Land Management provided assistance in obtaining a record of mining claims on public lands in the Vallecito Reservoir quadrangle. We are grateful to Robert J. Thompson for his discussions on the geology in the quadrangle, and for informing us of the exposed charcoal deposits within old alluvial fans on the west side of Vallecito Reservoir following the 2002 Missionary Ridge fire. Finally, we thank the Geotechnical Support Group of the CGS, and especially Jason Wilson, for creating the digital map and report.

GEOLOGIC SETTING

The Vallecito Reservoir 7.5-minute quadrangle includes about 60 square miles of chiefly mountainous terrain within the northeastern part of La Plata County in southwestern Colorado (fig. 1). The west and east boundaries of the quadrangle lie at longitudes of 107° 37’ 30” W and 107° 30’ 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 25 miles northeast of the town of Durango, and about 12 miles north of Bayfield (fig. 1). The quadrangle lies near the transition of the east-central part of the Colorado Plateau physiographic province and western edge of the Southern Rocky Mountains (Fenneman, 1931) (fig. 2). The terrain in the mapping area varies from an elevation of about 7,500 ft above sea level along the shores of Vallecito Reservoir to the rugged surrounding mountainous terrain, where the elevation is more than 11,600 ft above sea level. Vallecito Creek drains much of the southeastern Needle Mountains, and flows across the quadrangle along a north and south line into Vallecito

Reservoir. Nearly 5,000 ft of rock record that spans about 2 billion years of geologic time is exposed in the quadrangle (fig. 3).

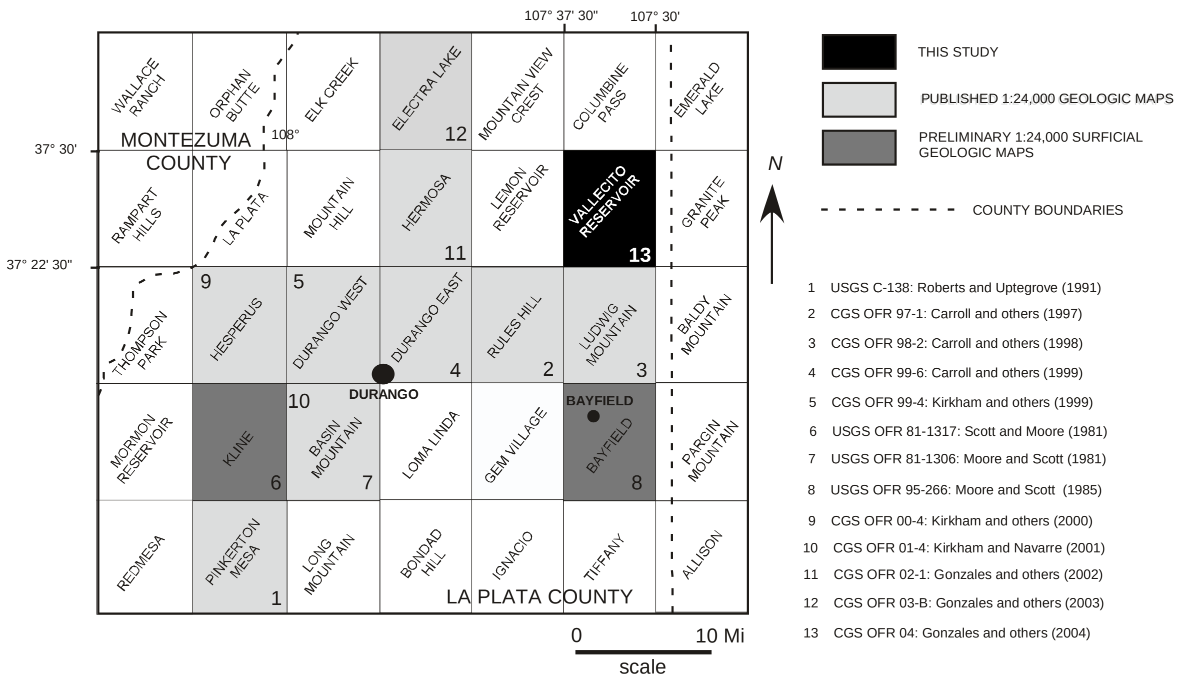

Figure 1: Published 1:24,000-scale geologic maps of 7.5-minute quadrangles in southwestern Colorado.

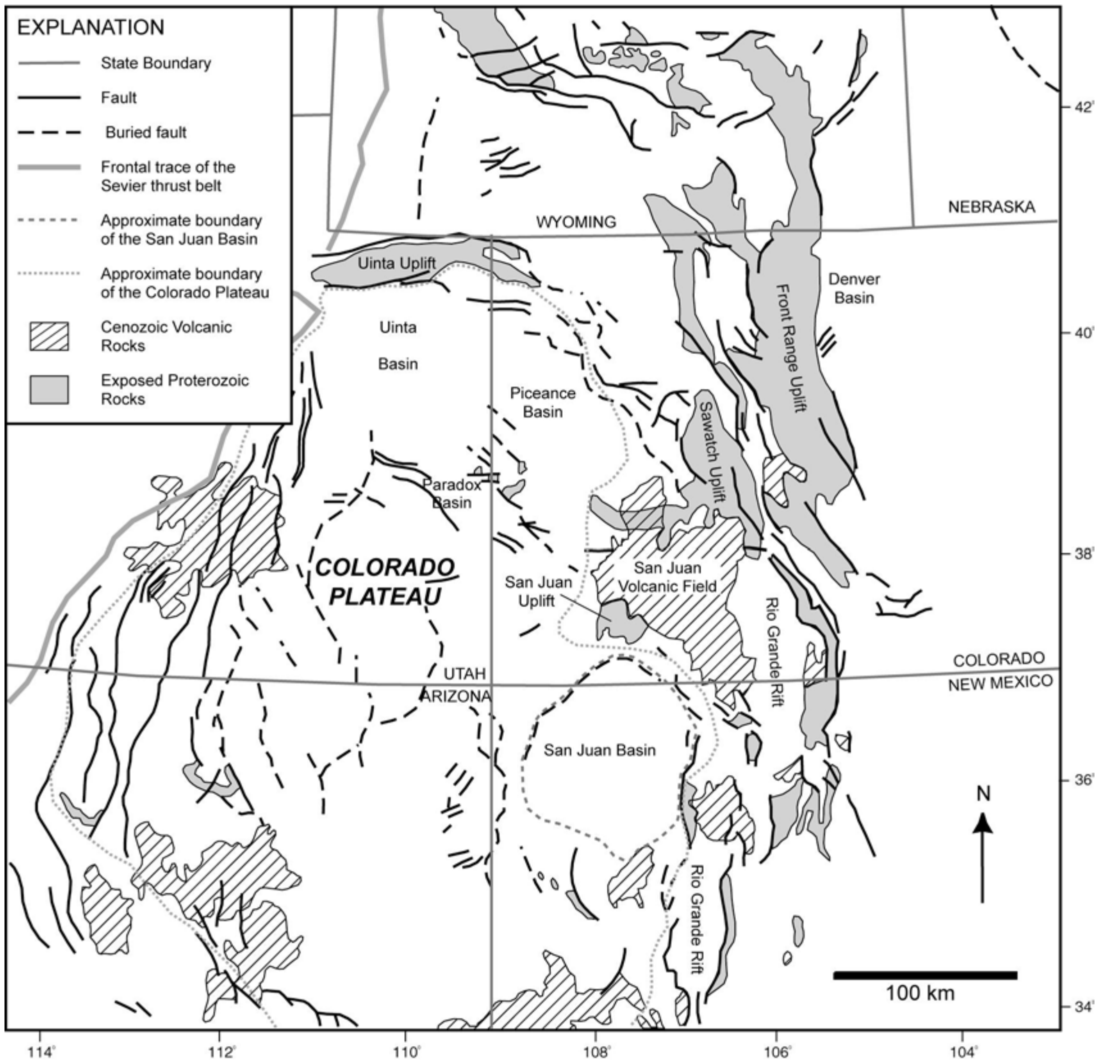

Figure 2: Generalized map of the Southern Rocky Mountains with major physiographic divisions. Figure was modified from Oldow and others (1989).

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

The oldest rocks in the map area are exposed in the precipitous canyons and ridges in the northern part of the quadrangle. Proterozoic rocks in the Vallecito Reservoir quadrangle include 1,800-million-year-old metamorphosed volcanic arc rocks of the Irving Formation (Gonzales, 1988a, 1988b). The Irving Formation underwent upper greenschist to amphibolite facies metamorphism and multiple phases of deformation prior to erosion and deposition of the thick succession of fluvial deposits of the conglomerate of Fall Creek and Vallecito Conglomerate. Deposition of these siliciclastic sedimentary rocks was followed by greenschist facies metamorphism and polyphase deformation. Granitic plutonic rocks of the Eolus Granite were emplaced at around 1,400 million years ago (Gonzales and others, 1994; Gonzales, 1997). Exposures of the Eolus Granite form the rugged terrain in the northwestern part of the quadrangle. Proterozoic rocks in the Vallecito Reservoir quadrangle are the foundation upon which Paleozoic sedimentary rocks were deposited in marine to continental environments. Vallecito Creek 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 Vallecito Reservoir 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 preserved in the rock record is as follows:

1. Formation, metamorphism, and deformation of volcanic and intrusive rocks in a volcanic arc system at around 1800 million years ago. This was followed by an extensive period of uplift and erosion. A thick succession of quartz-rich alluvium was deposited on this eroded surface by streams and alluvial fans, and these rocks were then deformed and metamorphosed during a regional orogenic event. Granitic and minor gabbroic intrusive rocks intruded into the older metamorphic complex at around 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. Gravel-rich stream alluvium was deposited upon the Proterozoic rocks. This was followed by deposition of a thick succession of fluvial, shallow to deep marine, and deltaic carbonate and clastic rocks, with minor local uplift and erosion, between 550 and 320 million years ago.

4. Late Paleozoic tectonic uplift produced a northwest-southeast trending belt of mountains referred to as the ancestral Rocky Mountains.

5. Erosion of the uplifted highlands by streams and rivers, and deposition of this material as "redbed" clastic sedimentary rocks about 300 to 250 million years ago. These sediments would be transformed into the rocks that make up the Cutler Formation. This was followed by the accumulation of river alluvium, mudflats, swamp deposits, and lake sediments between 250 and 205 million years ago (Dolores Formation).

6. Deposition of sediments in arid to semi-arid environments adjacent to the Ancestral Rocky Mountains uplift between 200 and 150 million years ago. This includes dune deposits that form the Entrada Sandstone and Junction Creek Sandstone, as well as the interstratified lake, swamp, and stream deposits preserved in rocks of the Wanakah Formation.

7. Renewed tectonic uplift caused by compressional forces during the Laramide orogeny produced the San Juan uplift that is rimmed by steep-dipping sedimentary rocks within the Vallecito Reservoir quadrangle. Tectonism during and after the Laramide orogeny caused the formation of fault systems, and the reactivation of older faults.

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

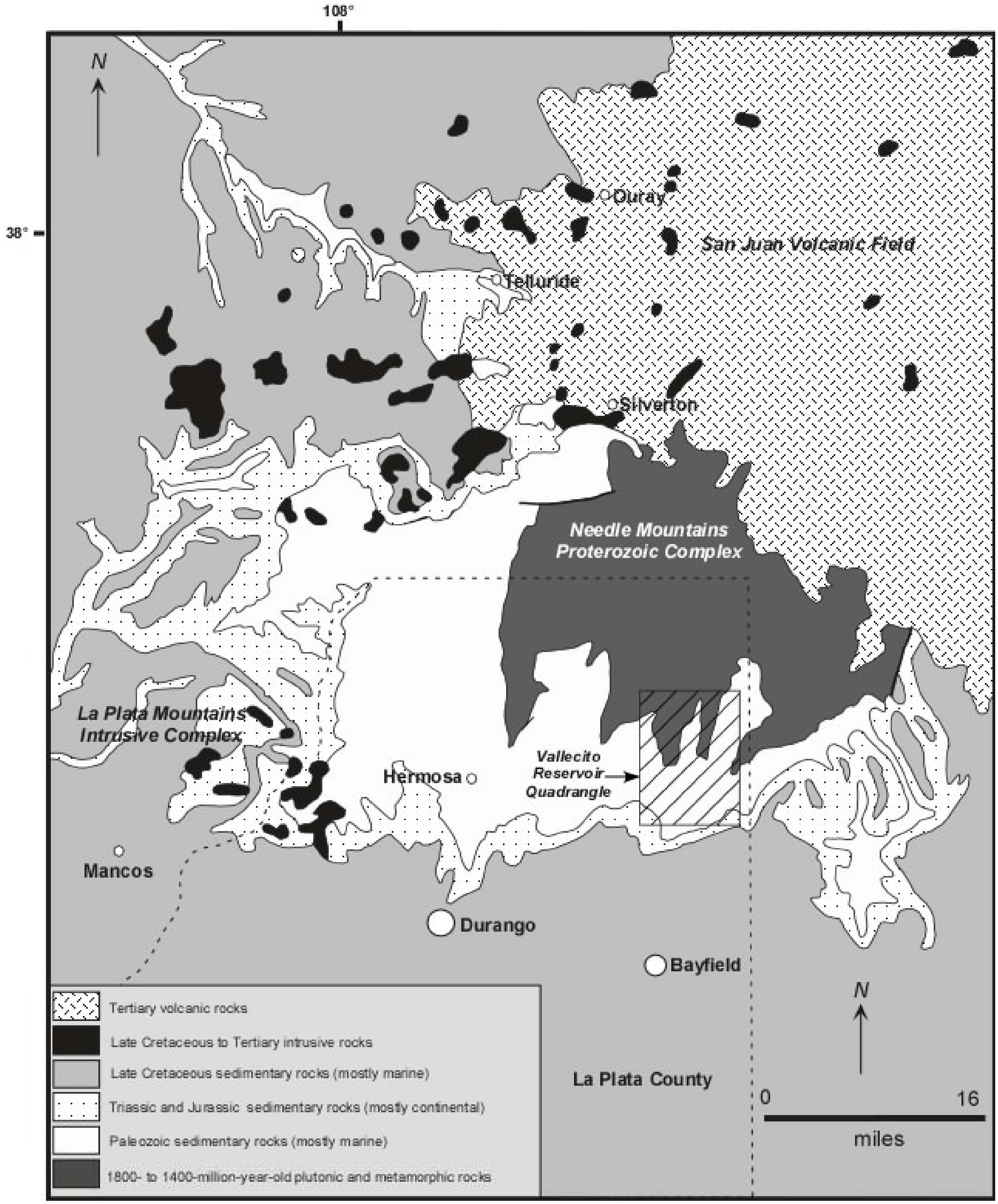

Figure 3: General geologic map showing the principal rock units in southwestern Colorado (modified version of the Colorado Geologic Highway Map, 1991). The area of the Vallecito

Reservoir quadrangle is indicated by the ruled box. The broken line indicates the boundaries of La Plata County.

PREVIOUS GEOLOGIC MAPPING STUDIES

The United States Geological and Geographical Survey conducted the first geologic studies in the Needle Mountains during reconnaissance surveys between 1869 and 1875 (Endlich, 1876). Comstock (1883, 1887) and Van Hise (1890) provided cursory descriptions of some rocks units in the region. The United States Geological Survey initiated the first comprehensive geologic mapping studies in the Needle Mountains in 1895 under the direction of Whitman Cross. By 1910 Cross and his colleagues had compiled 1:62,500 geologic maps for seven 15-minute quadrangles and published the results in a series of folios in the Geologic Atlas of the United States. The folios that were produced by this work include the Silverton (Cross and others, 1905a), Needle Mountains (Cross and others, 1905b), and Engineer Mountain (Cross and Hole, 1910) 15-minute quadrangles. The northern part of the 7.5-minute Vallecito quadrangle is within the Needle Mountains 15-minute quadrangle.

Regional investigations of the entire San Juan Mountains by Cross and Larsen (1935) and Larsen and Cross (1956) summarize much of the early work by Cross and his colleagues. In 1964 a 1:250,000-scale-mapping project of the Durango 1º x 2º quadrangle was initiated by the United States Geologic Survey (Steven and others, 1974). Kelley (1957) provided a synopsis of the geologic events and history in the region. The Proterozoic rocks exposed in the northern quarter of the Vallecito Reservoir 7.5-minute quadrangle were included in the 1:24,000- and 1:15,000-scale geologic maps compiled by Gonzales (1988a, 1988b). No other previous mapping studies of the geology in the Vallecito Reservoir quadrangle have been done.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits are widespread in the Vallecito Reservoir quadrangle, especially where Paleozoic and Mesozoic sedimentary rocks are exposed. Most of the surficial deposits are masked by heavy vegetation and are not well exposed. Descriptions of the thickness, texture, stratification, and composition of these units are therefore based on observations made where the deposits are exposed in drainages and roadcuts. Landforms associated with the surficial deposits often provide critical data on which interpretations of their genesis are made. 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 less than 5 ft thick. Because of the scale of the map, the minimum width of surficial deposits shown on the map is about 75 to 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 1964, consequently, cultural features that post-date the base map are not depicted.

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

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

ANTHROPOGENIC DEPOSITS

af

Human-made deposits (late 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 concrete and other construction materials. Maximum thickness is about 200 ft at the dam of Vallecito Reservoir. Artificial fill may compact when loaded, if not adequately compacted at the time it is deposited.

ALLUVIAL DEPOSITS—Alluvial deposits are formed of gravel, sand, silt, and clay deposited by flowing water in stream channels and flood plains along Vallecito Creek and its tributaries, and by slope runoff or sheet flow. Terrace alluvium along Vallecito Creek is chiefly glacial outwash that was probably deposited during late-glacial and early-interglacial stages. Deposits produced by sheet flow are mapped as sheetwash. Alluvial deposits include colluvium that is too small to be mapped at a scale of 1:24,000.

Qa

Stream-channel, flood-plain, and low terrace deposits (Holocene and late Pleistocene)—Includes modern stream-channel deposits of the Vallecito Creek and its tributary streams, adjacent flood-plain deposits, and low-terrace alluvium at or near the modern stream level. Sediment is generally deposited in active stream channels and overbank deposits on adjacent terraces less than 4 ft. above channel retreat. These deposits are poorly sorted and generally clast supported. Most of these deposits consist of unconsolidated, clast- to matrix-supported pebbles to boulders within a sandy or silty matrix. In some locations, gravel deposits are interbedded with or overlain by bars and sheets of sandy silt and silty sand, and locally, deposits of silty and sandy sediment are dominant. Gravel deposits in this unit contain subround to round clasts of the bedrock lithologies exposed in the Vallecito Creek drainage basin; granite and quartzite clasts are especially common. A weak imbrication of clasts is developed in some of the gravel deposits.

Glacial moraine and outwash deposited along Vallecito Creek and the area of Vallecito Reservoir were reworked and incised by post-glacial stream action. A large proportion of the alluvium exposed in the valley of Vallecito Creek consists of reworked and remobilized glacial debris. Where it was not possible to distinguish between reworked glacial ground moraine and alluvium, all of these deposits are mapped as Qa.

Maximum thickness of Qa in most areas is about 15 feet, but in the Vallecito Creek valley these deposits may be as thick as 100 feet. Low-lying areas underlain by unit Qa are subject to flooding, and deposits in this unit are a source of sand and gravel for artificial fill and aggregate for construction.

Qta

Terrace alluvium undivided (early Holocene and late Pleistocene)—This unit is composed chiefly of stream alluvium deposited as glacial outwash that was incised and terraced by later fluvial action. These deposits are only exposed in the area west of the dam at Vallecito Reservoir. Terrace surfaces are flat and generally parallel to the modern stream channel with terrace heights from 10 to 65 ft above the Los Piños River. The lower and upper terrace levels indicated on the map correspond to units Qt_1 and Qt_2 of Carroll and others (1998), respectively. The various terrace levels mapped in this investigation were not differentiated, but are shown as dotted lines to indicate the elevation of the older alluvial deposits above the modern stream channel.

The majority of these deposits are clast-supported, boulder- to pebble-sized gravels with a silty to sandy matrix. The gravels are poorly sorted and contain subround to round clasts of the bedrock units that crop out in the Vallecito Creek and Los Piños River drainage basins; quartzite makes up a high proportion of the clast populations. Clasts are up to several feet in diameter and are generally unweathered or slightly weathered. Gravel deposits in Qta locally contain thin beds of silty sand, and may also include fine-grained overbank deposits. The upper terrace surface is covered with a thin veneer of sheetwash deposits and silty soils formed by the erosion of the Cutler Formation and Dolores Formation. This unit is a potential source of sand and gravel.

Atwood and Mather (1932) mapped the gravel deposits of Qta as moraine and associated outwash deposits of the "Durango stage." Richmond (1965) mapped these terrace deposits as outwash terrace "bg" and proposed that they are Bull Lake age, making them between 140 to 300 ka (Pierce and others, 1976; Pierce, 1979; Richmond and Fullerton, 1986).

COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay that mantle valley sides and floors, and the flanks of ridges and hillslopes. This material was mobilized, transported, and deposited primarily by gravity.

Qc

Colluvium (Holocene and late Pleistocene)—Deposits included in this unit range from unsorted, clast-supported gravel with pebble- to boulder-sized rock fragments in a sandy or silty matrix, to matrix-supported gravelly sand or clayey silt. Colluvium is 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 slope on which colluvium is the predominant material. As a result, many deposits mapped as colluvium will include minor amounts of materials of varied genesis that are too small in area or too indistinct on aerial photographs to be mapped separately, including talus, landslide deposits, creep, and debris-flow deposits. Most deposits of colluvium are heavily vegetated, and are only well exposed along road cuts, drainage channels, and construction trenches.

Colluvium is usually coarser grained in upper reaches and finer grained in distal areas. Most of these deposits are unsorted or poorly sorted with weak or no stratification. Rock clasts in this unit are generally angular to subangular, but colluvium can contain a minor amount of fluvial gravels with well-rounded clasts. Clast types in this unit are variable, as they depend on the type of material exposed in the source area. Maximum thickness is estimated at about 50 ft, but the unit commonly is much thinner. Thick deposits of colluvium exist on slopes and ridges underlain by the Cutler Formation and Hermosa Group.

Areas mapped as colluvium are susceptible to future colluvial deposition and are locally subject to sheetwash, rockfall, small debris flows, mudflows, and landslides. Fine-grained, low-density colluvium may be prone to collapse upon wetting or loading.

Qrf

Rockfall deposits (Holocene or late Pleistocene)—Tongue-shaped deposit composed of unconsolidated and unstratified angular blocks of surrounding bedrock units.

Qls

Landslide deposits (Holocene and late Pleistocene)—Heterogeneous hummocky deposits composed of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Unit includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes. Landslide deposits in parts of the quadrangle may have resulted from slope failures in glacial moraine, some of which involve underlying or adjacent bedrock. On the east side of the Vallecito Creek, along the flanks of South Bear Creek, there are several large aprons and tonques that formed from collapse of glacial moraine.

Maximum thickness of landslide deposits may exceed 100 ft. Landslide deposits may be subject to future movement. Large blocks of rock that are found locally in these deposits may hinder excavation. Landslide deposits may be prone to settlement when loaded, and shallow groundwater may occur within them.

Qt

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

ALLUVIAL AND COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay deposited as alluvium and colluvium 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.

Qfm

Fan deposits (modern)—Following the Missionary Ridge Fire in 2002, rainfall in the area triggered debris flows and hyperconcentrated flows in several tributary drainages within the map area. Most of these deposits are relatively small and confined to narrow channels, forming thin fan-shaped deposits at their terminus. Remobilized colluvium and moraine constitute a large amount of the material in these deposits.

These fan deposits are unconsolidated deposits and consist of poorly sorted, clast-supported, pebble- to boulder-sized rock fragments in a matrix of silt and sand. At the distal ends of the fans the deposits are typically finer grained and matrix supported with pebble-sized fragments in ash- and charcoal-rich clayey silt or sand. The channel of the modern fan deposit near the northwest end of Vallecito Reservoir incised older fan deposits that contained up to ten distinct layers of charcoal ranging from 130 to 4000 years BP (Frechette and others, 2003; Gonzales and others, 2003a). Maximum thickness is estimated at about 15 ft.

Qf

Fan deposits (Holocene and late Pleistocene)—Includes hyperconcentrated-flow, debris-flow, alluvial, and sheetwash deposits in fans and tributary drainages. Sediment is supplied by streams and debris flows in confined and commonly braided channels by seasonal high-discharge events. Locally the unit may include earthflows or landslides too small to map separately at a scale of 1:24,000. Fan development post-dates glaciation in the map area.

These deposits form fan-shaped landforms at the mouths of streams where stream gradient and velocity decreases and where topography widens from confined channels to open valleys. Gradients on the surface of the fans are generally less than 20º.

Fan deposits consist of crudely stratified unconsolidated material. The deposits range from very poorly sorted, clast-supported, pebble- to boulder-sized rock fragments in clay-rich silt or sand matrix to matrix-supported, gravel in clay-rich silt and sand. These deposits typically contain a high proportion of boulder-sized fragments, 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, and there is generally a high fraction of remobilized glacial moraine that was transported down slope by fluvial action. Maximum thickness of these fan deposits is estimated at about 40 ft.

Alluvial fans are subject to future debris flows, hyperconcentrated flows, and alluvial deposition and 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 is exposed on the west side of Fall Creek near the north margin of the map. It contains stream-derived sediment and subordinate colluvium deposits that are between 5 and 20 ft thick. Alluvial and colluvial deposits are mapped as a single unit because they are gradational and have boundaries that are difficult to discern. These sediments are very poorly exposed and heavily vegetated, but the upper exposed surface is mostly poorly- to moderately-sorted silt, sand, and pebbly sand. Along the margin of the deposit are chiefly colluvium composed of poorly sorted, unstratified to poorly stratified, silty sand with angular fragments of surrounding bedrock.

Qsw

Sheetwash (Holocene and late Pleistocene)—This unit includes materials transported chiefly by sheet flow and deposited on gentle slopes along the lower margins of the valleys of the Los Piños River and Vallecito Creek. These deposits are derived from weathered bedrock and surficial materials, and contain pebbly silty sand, sandy or clay-rich silt, and sandy to silty clay. Sheetwash deposits are gradational and interstratified with colluvium (Qc) on their upslope margins, and the contacts between sheetwash and colluvium are not well defined. The maximum thickness of sheetwash deposits is about 15 ft. Areas mapped as sheetwash are subject to future sheet-flow deposition, and these deposits may be prone to hydrocompaction, settling, and piping where fine grained and low in density.

Qcm

Colluvium and remobilized glacial moraine, undivided (Holocene and late Pleistocene)—Along with colluvium, this unit also includes a high proportion of glacial moraine transported down slope chiefly by sheet flow and gravity. These deposits contain numerous cobbles and boulders of subrounded to rounded fragments derived from glacial moraine exposed on the higher slopes. The contacts between this unit and colluvium are gradational and approximate.

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.

Qgds

Glacial-dammed lake sediments (Holocene, late Pleistocene, and late middle Pleistocene?)—Unit includes sand, gravel, silt, clay, and peat deposited in stream valleys dammed by lateral moraines or in elongate topographic depressions formed along the edges of the moraines. These deposits occur on the west flank of the valley of Vallecito Creek at Lake Eileen, Freeman Park, and Dunsworth Park. They are very poorly exposed, therefore their physical characteristics are not well known. The lateral moraines continue to dam tributary valleys, forming small lakes and wetlands. 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 to 150 ft.

Qk

Kame deposits (late and late middle? Pleistocene)—Crudely bedded to well stratified, moderately to well sorted, silt-rich sand and pebbly sand exposed in the roadcuts on the north side of the Los Piños River valley. Locally these glacio-fluvial deposits are gradational and interbedded with glacial-derived gravels. Kame deposits probably accumulated beneath or along the edges of valley glaciers that retreated or stagnated.

The age of the kame deposits is uncertain. Most of the exposed kame deposits are near the elevation of the Los Piños River. Glacial scour would probably have removed any unconsolidated surficial deposits encountered by the ice as it moved down valley. 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. Maximum observed thickness is about 50 ft. Unit Qk is a potential source of sand and silt.

Qm **Morainal deposits (late and late middle? Pleistocene)--**Heterogeneous deposits of unconsolidated to compacted clay- to boulder-sized sediment deposited by, adjacent to, or beneath glacial ice at ice margins along the valleys of Vallecito Creek and Los Piños River. Lateral moraines form hummocky linear ridges up to 1200 ft above the current river levels. Ground moraine is extensive in the floor of the valleys, and may be over 100 ft thick. A well preserved terminal moraine is exposed across Vallecito Reservoir about mile east of the dam; this terminal moraine is shown on the regional map of surficial deposits compiled by Atwood and Mather (1932). The morainal deposits in the map area are predominantly matrix-supported gravels with subround to subangular clasts of all bedrock units. Clasts are unweathered to moderately weathered, and are up to several feet in maximum dimension. Blocks of bedrock up to 20 ft in diameter occur locally within these deposits.

Most morainal deposits in the map area are probably close in age to Pinedale and other late-Wisconsin moraines that formed in the region about 12 to 35 ka (Richmond, and Fullerton, 1986). The last vestiges of glaciers in the area were between 12 and 15 ka (Maher, 1972; Carrara and others, 1984; Gillam, 1998).

The morainal deposits have an estimated maximum thickness of about 80 to 120 ft and may be a source of sand and gravel. In some parts of the quadrangle these deposits were remobilized as landslides and debris flows, and adjacent to the modern channel of the Vallecito Creek these glacial deposits were dissected and reworked in Strath terraces.

PHANEROZOIC BEDROCK UNITS

Jjc

Junction Creek Sandstone (Middle Jurassic)—The only exposure of the Junction Creek Sandstone is in the southwestern corner of the quadrangle where it caps the point at elevation 8810 feet and conformably overlies the Wanakah Formation. At this location the exposed part of the unit is about 20 ft thick. The Junction Creek Sandstone is tan to grayish brown and fine- to medium-grained. It is comprised mostly of subround to round grains of quartz set in silica-rich cement. The only exposure of this unit is massive or has a crude lamination and bedding, but lacks the pronounced cross stratification that is characteristic of exposures of this unit in the Animas River valley.

The Junction Creek Sandstone was deposited in a predominantly eolian environment (Peterson, 1972) and is correlative with the Bluff Sandstone in the Four Corners area and southeastern Utah (Baars and Ellingson, 1984; O'Sullivan, 1997; Lucas and Anderson, 1997).

Jw

Wanakah Formation Undifferentiated (Middle Jurassic)—The Wanakah Formation contains a basal member of dark-gray to black limestone that makes up the Pony Express Limestone. The limestone is no more than 8 feet thick. Sedimentary structures are noticeably absent from this unit. It is thin- to medium-bedded, thinly laminated, or massive without noticeable bedding. The Pony Express Limestone is a fine-grained micritic to oolitic limestone with minor sandstone lenses and partings composed of subangular to subrounded quartz grains up to 10 mm in length. The unit is generally highly fractured due to its brittle nature and in some locations is a breccia with fractures that are filled with sparry calcite veinlets. Excellent exposures of the Pony Express Limestone occur on ridge tops west of Vallecito Reservoir.

The Pony Express Limestone is overlain by about 150 ft of reddish brown to maroon and greenish-gray shale, claystone, siltstone, and fine-grained sandstone that weather to horizontal-ribbed cliffs and slopes. Near the center of the upper member there is about 25 feet of massive to thick-bedded white to tan sandstone. This medial sandstone is referred in some published works as the Bilk Creek Member (Eckel, 1949; Baars and Ellingson, 1984).

The Wanakah Formation is correlative with the Summerville Formation in the Four Corners region, and the Pony Express Limestone is correlative with the gypsiferous Todilto Limestone in New Mexico (Lucas and Anderson, 1997). It has been proposed that the upper members of the Summerville Formation and Wanakah Formation are sabkha to marginal marine deposits whereas the basal limestone members are restricted marine deposits (Condon, 1990; Lucas and Anderson, 1997). It has also been noted that the Pony Express might have been deposited in a lacustrine system (Baars and Ellingson, 1984; Condon and Huffman, 1984, p. 98).

Je

Entrada Sandstone (Middle Jurassic)—The Entrada Sandstone is light-gray, grayish white, or light brown on fresh and weathered surfaces. This unit is comprised chiefly of fine- to medium-grained quartz arenite with calcium carbonate cement, but in some locations the base of the unit is very coarse-grained to conglomeratic.

Most of the grains in the Entrada Sandstone are rounded to subrounded and are chiefly quartz and chert. The rock also contains minor amounts of perthitic feldspar, microcline, plagioclase, iron-strained chlorite-rich rock fragments, micaceous iron-strained polygranular quartz-rich rock fragments, and carbonate fragments. In addition, there is a small percentage of fine-grained, subangular rock fragments that contain very small angular grains of quartz in a weak laminated matrix. These fragments may be pieces of laminated siltstone or perhaps flow-foliated volcanic tuff.

The Entrada Sandstone achieves a maximum thickness of about 250 ft on the west side of the map area. This unit generally has a distinct large-scale cross stratification, and in some sections it contains thin lag deposits of granule to pebble conglomerate that cap the upper surfaces of truncated cross strata. Planar bedding and lamination are dominant in parts of the unit. Where well exposed, the Entrada Sandstone is weathered into smooth, undulating surfaces.

The Entrada Sandstone is the basal unit of the San Rafael Group in the Four Corners region. This formation was deposited as a vast erg that developed on an emergent arid coastal plain during regression of the shallow Curtis-Sundance seaway (Lucas and Anderson, 1997). The lower part of the Entrada Sandstone may be a transitional interfluvial to lacustrine sequence that was deposited in a dune field. The J-2 regional disconformity marks the boundary between the Entrada Sandstone and the underlying Dolores Formation.

₸d

Dolores Formation (Upper Triassic)—The Dolores Formation is a succession of clastic sedimentary rocks with a maximum thickness of about 350 ft in the map area. Sedimentary structures and features in mudstone, sandstone, and conglomerate of the Dolores Formation indicate deposition in fluvial channel, overbank to floodplain, swamp, and lacustrine environments (Baars and Ellingson, 1984; Blodgett, 1984; Condon, 1990). Blodgett (1984) noted that these deposits were transported by a series of streams that were flowing west and southwest from the eroded Uncompahgre highlands to the northeast.

In many locations in southwestern Colorado the Dolores Formation and Cutler Formation are separated by a gentle angular unconformity, but in the Vallecito area the contact is disconformable. Lucas and others (1997) correlated the Dolores Formation 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 on the Colorado Plateau.

The Dolores Formation is composed chiefly of green, gray, tan, light brown, reddish brown to maroon, reddish-brown, and grayish white shale, siltstone, and fine- to medium-grained subfeldsarenite, sublitharenite, lithic arkose, and feldsarenite. Sections of shale and siltstone are up to tens of feet thick and are generally thin- to medium-laminated or thin bedded. Layers of siltstone generally exhibit thin bedding that breaks into irregular slabs and some siltstones contain high concentration of muscovite along bedding planes. Beds of arkosic and lithic sandstone in the Dolores Formation range from thin to very thick and are massive to planar bedded and can contain low-angle planar-tabular or tangential cross stratification. The siltstones and sandstones generally have a carbonate-rich matrix that contains subrounded to angular grains of quartz and plagioclase along with muscovite, chlorite, lithic fragments, and zircon.

A variety of sedimentary structures are in the shale, siltstone, and sandstone beds including tangential cross-lamination, tangential and planar-tabular cross strata, asymmetrical ripples, ball and pillow structure, mudcracks, plant impressions and macerated plant fossils, subelliptical to elliptical calcareous nodules up 5 inches in maximum dimension, and mesoscopic soft-sediment related faults and fractures.

The Dolores Formation contains numerous thin to thick beds and lenses of limestone-pebble conglomerate. This conglomerate is one of the most characteristic and conspicuous rock types in the Dolores Formation and in some locations is up to 20 feet thick. The conglomeratic beds typically lack sedimentary structures but locally are cross or thinly laminated. In some outcrops the limestone-pebble conglomerate contains very thin to thin beds of white to greenish-gray, fine- to medium-grained sandstone and thinly laminated siltstone.

The limestone-pebble conglomerate in the Dolores Formation is clast to matrix supported with abundant subrounded to angular fragments that are chiefly greenish-tan to gray limestone, sandy limestone, and brown, tan, green, and reddish-brown siltstone. Chert clasts occur in some outcrops but are rare. Clasts in the conglomerate are typically less than several inches in maximum dimensions but in some outcrops the fragments are up to a foot in dimension. Conglomerate layers contain between 10 to 60 percent clasts that are set in a silty to sandy to carbonate-rich matrix that contains subrounded to angular grains of quartz along with opaque minerals and minor muscovite. In some outcrops a small proportion of the siltstone clasts are concentrically layered or are cored by star-shaped fractures that are filled with sparry calcite similar to septarian nodules.

The limestone-pebble conglomerate locally contains teeth and bone fragments of *Phytosaurus* (crocodilian-like reptile), and carbon-rich impressions of plant fossils. At one location a crocodile tooth nearly two inches in length was found.

In some areas the Dolores Formation contains layers of white to grayish brown medium- to coarse-grained quartz arenite that are up to 30 feet thick and form prominent cliffs and ribs in the less competent siltstone and shale layers. These coarser-grained quartz arenites are massive, lenticular bedded, to laminated and generally lack the sedimentary structures observed in the lithic and arkosic arenites.

Pc

Cutler Formation (Lower Permian)—The Cutler Formation in the map area is comprised of interbedded fluvial clastic sedimentary rocks ranging in color from medium- to dark-reddish brown, grayish brown, medium to dark brown, and maroon. This unit contains up to 1000 feet of interbedded feldsarenite and subfeldsarenite, arkosic pebble to cobble conglomerate, thin-bedded to thinly laminated shale and siltstone, siltstone with gray limestone nodules, and rare beds of massive limestone up to several feet thick. Bedding in this unit is thin to very thick with alternating ledges and slopes.

Interbedded fine- to medium-grained sandstones, siltstones, and shales in the Cutler Formation range from red to maroon and grayish green. These rocks are mostly medium bedded to thickly or thinly laminated, and weathered surfaces are broken into thin slabs in most outcrops. Siltstones and shales are characterized by bluish-green to grayish-green reduction spots up to at least 2 inches in diameter. In some outcrops the siltstone contain gray, irregular to branching limestone nodules up to 8 inches in length that grade into limestone beds up to 6 inches thick. These limestone-rich zones have a knotty and irregular pattern on weathered surfaces.

The Cutler Formation contains numerous white, reddish brown, and grayish brown beds of medium- to coarse-grained arkosic sandstone and matrix-supported pebble- to cobble-conglomerate. These rocks are poorly sorted but in some outcrops have a crude normal grading, and typically have a pronounced low-angle, tangential to trough cross stratification. Soft-sediment deformation and mud rip-up clasts occur in some outcrops of these rocks. Beds of sandstone and conglomerate range from thin to very thick with some reaching up to 20 feet in thickness, and they form prominent ledges and cliffs within the unit. Granule- to cobble-sized clasts in these rocks are subrounded to subangular and are composed chiefly of quartz, quartzite, quartz arenite, limestone, siltstone, arkosic sandstone, chert, gneiss and schist, and granite. The matrix of these rocks is arkosic sandstone with grains of angular to subrounded quartz, perthitic microcline, perthite, biotite, muscovite, opaque minerals, and zircon that are in calcareous hematitic cement.

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). This unit may be prone to rockfall hazards where exposed in steep cliffs, and was a major source of material in debris flows that followed the 2002 Missionary Ridge Fire.

Ph

Pennsylvanian Hermosa Group (Middle Pennsylvanian)—Franczyk and others (1995) assigned a Desmoinesian age to the Hermosa Group on the basis of its brachiopod faunas, and subdivided the section exposed near Hermosa in the Animas River valley into a lower Pinkerton Trail Formation and an overlying undifferentiated part. They identified four different carbonate lithofacies in the Hermosa Group that were interpreted to represent various marine depositional environments. These lithofacies were established on the basis of mineral assemblages, textures and structures, biotic assemblages, and inferred depositional environments.

In the undifferentiated part of the Hermosa Group there are stacked carbonate-clastic depositional cycles that are dominated by carbonate units at the base and grade upward into coarsening clastic cycles. These cyclic deposits were interpreted as marine deltaic, and nonmarine deltaic and alluvial systems (Franczyk and others, 1995). At least 28, and possibly 40, of these depositional cycles in the Hermosa Group were defined. In the Vallecito quadrangle the Hermosa Group contains a similar succession of rocks as those exposed in the western Needle Mountains and Animas River valley.

Lithofacies 1 in the Hermosa Group corresponds to the Pinkerton Trail Formation (Franczyk and others, 1995). 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). The Pinkerton Trail Formation crops out in drainages and steep slopes on the west and east side of the Vallecito Creek valley, and is especially well exposed in Grimes Creek.

Carbonate lithofacies in the undifferentiated part of the Hermosa Group above the Pinkerton Trail Formation contain thin to thick bedded dolostone, dolomitic limestone, calcareous shale, dolomitic siltstone, calcareous shale with about 40%

limestone pebbles and cobbles, fossiliferous limestone, limey mudstone, packstone, grainstone, and wackestone. Faunal assemblages noted by Franczyk and others (1995) in these lithofacies include crinoid columns, echinoderm plates, brachiopod shells and spines, algal laminations, stromatolitic structures, fusilinids, foraminifera, phylloid algae, ostracods, monaxon sponge spicules, gastropods, and pelecypods.

Clastic lithologies in the Hermosa Group include very thin to very thick beds of mudstone that locally contain organic debris, micaceous siltstone, fine- to very coarse-grained sandstone, and pebble to cobble conglomerate. Beds of mudstone and siltstone beds are commonly thinly to thickly laminated, whereas the sandstone and conglomerate layers vary from massive, planar laminated to bedded, or cross stratified. Siltstones and sandstones are mostly quartz arenite, subfeldsarenite, sublitharenite, and feldarenite that are composed chiefly of subangular to subrounded grains of quartz, plagioclase, perthite, perthitic microcline, biotite, muscovite, and rock fragments in calcareous cement.

Granule to cobble-sized rock fragments in pebbly sandstones and conglomerates include milky quartz, brown to tan quartzite, sandstone, granite, reddish-brown siltstone, very fine-grained black to green shale, gray limestone, and gray to brown chert. Fragments up to eight inches in maximum dimension occur in some outcrops. Sandstone beds locally contain slender fragments of carbonized material up to 4 inches in length that are interpreted as fossilized flora. There are also worm burrows in many sandstone layers.

IPm

Molas Formation (Lower Pennsylvanian)—The Molas Formation is a karst breccia with fragments of micritic to sparry limestone and minor coarse-grained sandstone up to several feet in length that are set in a fine-grained matrix of red to maroon siltstone and claystone. Limestone breccia in this unit commonly contains angular to subangular clasts of black to brown chert, brown chalcedony, and agate up to 5 inches in maximum dimension. The matrix between clasts is typically fine-grained, hematitic claystone or shale containing grains of quartz and chert. Brachiopod fossils were found in the Molas Formation in the drainage of South Bear Creek.

The Molas Formation formed as a regolith on the weathered and brecciated upper surface of the Mississippian Leadville Limestone. In the map area the Molas Formation is up to 50 ft thick and locally occurs as pipes and fracture filling in the underlying Leadville Limestone. Excellent exposures of this unit occur in Carbonate Basin and in drainage of D Creek.

Ml

Leadville Limestone (Lower Mississippian)—The Leadville Limestone is a succession of interbedded marine rocks composed chiefly of limestone, sandy to silty limestone, black to gray shale, and stromatolitic dolomite. This unit has a maximum thickness of about 150 ft. In some outcrops bedding is prominent and ranges from thin to thick; shale layers are generally thin to medium laminated. Near the top of this unit the bedding is commonly not as distinct and the unit has a more massive appearance.

In many localities the base of the Leadville Limestone is defined by a layer of red to green shale, siltstone, and sandstone up to 15 ft thick that has abundant salt casts with edges up to 1 inch long. The base of the Leadville Limestone is defined by the start of a distinct slope above well-defined benches at the top of the Ouray Limestone. The top of the Leadville Limestone is irregular due to karstic erosion prior to deposition of the Molas Formation.

Limestone in this unit is generally gray to grayish brown massive to laminated micrite, dolomicrite, and sparrite that commonly contain fossils and oolites. Fossils that are common in rocks of the Leadville Limestone include abundant crinoid columns, brachiopods, rugose corals, syringoporid corals, bryozoa, and endothyrid foraminifera, and gastropods (Baars and Ellingson, 1984). Nodules and layers of chert occur in the basal part of the unit at Endlich Mesa.

The Leadville Limestone on the north side of D Creek contains massive to thick-bedded limestone at the base. About 15 to 20 feet above the limestone there is a 1- to 2-foot-thick zone of thinly laminated red to green and bluish-green shale. The shales are either in direct contact or separated by thin beds of limestone. The shale zone is overlain by about 20 feet of sandy to silty limestone with lenticular ribbons of hematite-rich calcareous siltstone. The hematitic ribbons are up to several inches thick and several feet in length, and give the rock a banded or lenticular appearance.

At Carbonate Basin the Leadville Limestone locally contains limestone breccia with angular fragments up to 8 inches in maximum dimension. Fractures between the fragments are typically filled with calcite veins. The unusual aspect of this brecciation is that although the rock is highly brecciated the bedding is continuous and relatively undisturbed. Most of the breccia zones occur within a given bed of limestone adjacent to beds that are relatively unfractured.

Do

Ouray Limestone (Upper Devonian)—The Ouray Limestone is a succession of brown, reddish brown to maroon, light-gray, and grayish brown marine sedimentary rocks that were deposited in a shallow marine environment. Dolomitic rocks of this unit have been interpreted as stomatolitic and supratidal facies (Baars and Ellingson, 1984; Campbell and Gonzales, 1996). The Ouray Limestone crops out at most locations where the lower Paleozoic section is exposed, but in some areas it is either missing or indistinguishable from the Leadville Limestone. The Ouray Limestone is typically less than 20 ft in the map area, but it is thicker and best exposed on the dip slope at the mouth of D Creek. Where exposed this unit is resistant and forms a prominent bench.

The Ouray limestone is composed chiefly of thin to thick bedded, medium- to coarse-grained calcareous sandstone, sandy limestone, fossiliferous micritic limestone, and dolomitic limestone. Sandstones in this unit contain subrounded to subangular grains of quartz and sparse pebbles that are set in a sparry to micritic calcite cement. The limestones in this unit are fine-grained and thin bedded to thinly laminated. In some outcrops the lamination is wavy to irregular and resembles fossilized stomatolitic algal mats. Thin to medium beds of thinly laminated reddish-brown to green shale occur in this unit, especially in the basal part of the formation.

At some locations the Ouray Limestone is brecciated with subangular to angular fragments of limestone that are up to an inch in size. The breccia is primarily clast supported with thin fine-grained selvages of dark red to maroon hematite-rich and calcite veinlets between the fragments.

In many outcrops the Ouray Limestone contains abundant fossils of brachiopods, pelecypods, and crinoid columns. Excellent exposure of fossiliferous beds crop out along D Creek on the west edge of Vallecito Creek valley. In this area the fossils are in such high abundance that they give the limestone a nodular to knotted texture.

D€ei **Elbert Formation (Upper Devonian) and Ignacio Formation (Upper Cambrian) undifferentiated—**The base of the Paleozoic section in the map area is diverse and different than the section exposed in the Animas River valley. No attempt was made to differentiate between the Paleozoic units that are below the Ouray Limestone. All sedimentary rocks that are exposed between Proterozoic crystalline rocks, or the Weasel Skin Conglomerate, and the Ouray Limestone are included in this map unit.

In the western Needle Mountains the lower section is typically defined by a mottled reddish-brown to grayish-brown, light-brown, white, or light-pink medium- to thick-bedded, coarse-grained quartz arenite and pebble conglomerate. These rocks are assigned to the Stag Mesa Member in the Ignacio Formation (Campbell and Gonzales, 1996) and are interpreted as shallow-marine deposits.

The Ignacio Formation is overlain in most areas by interbedded red to maroon shale, siltstone, fine- to medium-grained quartz arenite, and sandy dolomitic limestone of the Elbert Formation. In the Vallecito quadrangle the only locations where the base of the Paleozoic section is similar to that exposed in Animas River valley is in the steep canyon walls of D Creek and at the eroded edge of the basal Paleozoic section at Endlich Mesa.

In the canyon of D Creek the base of the Paleozoic contains a mottled, purplish red to maroon thin bedded to thinly laminated sandstone and siltstone that is overlain by about 60 feet of thick to very thick-bedded medium- to coarse-grained sandstone with carbonate cement, thin beds of massive white calcareous quartz arenite, and thickly laminated pink calcareous siltstone. The upper part of the section contains at least three layers of medium- to coarse-grained white to grayish-white quartz arenite up to 1 foot thick that contain subrounded grains of quartz set in calcareous cement. These sandstone layers resemble the basal McCracken Member of the Elbert Formation.

At Endlich Mesa the base of the Paleozoic section is comprised of about 60 feet of massive or planar to cross stratified, thin- to thick-bedded pebble conglomerate and fine- to very coarse-grained quartz arenite and arkosic sandstone that are similar to the Stag Mesa Member of the Ignacio Formation. Beds and lenses of conglomerate are poorly sorted in some outcrops have a crude normal grading. These rocks contain subrounded to subangular pebbles to quartz, quartzite, jasper, and banded iron formation. Beds of sandstone contain subrounded to subangular grains of quartz, potassium feldspar, and lithic fragments in hematite-rich silica cement. These conglomerates and sandstones are overlain by 30 feet of interbedded thick to thin bedded sandstone, calcareous shale, siltstone, and dolomitic limestone. Beds of sandstone are massive to cross stratified, and some layers of siltstone and shale contain mudcracks and salt casts. This upper section of rocks is similar to the Elbert Formation.

At most other locations within the quadrangle, the Ouray Limestone is generally underlain by 15 to 50 feet of thin- to thick-bedded conglomerate, sandstone, and siltstone that lie on Proterozoic rocks or the Weasel Skin Conglomerate. The conglomerates in this part of the section are massive to planar-tabular or tangential cross stratified, thin- to thick-bedded, and matrix supported with subangular to rounded clasts of quartz, quartzite, hematite-sericite rich rock fragments, granite, jasper, chert, red siltstone (?), and other lithic fragments. The clasts are set in a coarse- to very-course grained calcareous matrix containing patches of limonite and angular to subrounded grains of quartz, feldspar, muscovite, and zircon. Some of the conglomerates contain lenses of coarse-grained sandstone. In most outcrops the conglomerates are interbedded with thin- to thick-bedded, fine- to very coarse-grained, grayish-brown, reddish-brown to light brown quartz arenite and arkosic sandstone. Some outcrops also contain thin beds of light tan to grayish brown dolomitic sandstone, and beds of reddish-brown and maroon to green, thinly laminated micaceous siltstone and shale up to 6 to 8 inches thick.

In the vicinity of Bear Creek and on the ridge north of the Pine River valley the base of the Paleozoic section is marked by about ten feet of thin- to thick-bedded medium- to coarse-grained quartz arenite with silica or calcareous cement containing patches of limonite and hematite.

The rock associations and sedimentary structures in the basal section of the Paleozoic rocks in the Vallecito quadrangle reflect deposition in intertidal marine to fluvial environments (Baars and Ellingson, 1984; Campbell and Gonzales, 1996).

Ꞓw

Weasel Skin Conglomerate (Cambrian?, age uncertain)—About 2000 feet west of Vallecito Creek the Weasel Skin Conglomerate is exposed between Proterozoic rocks and the base of the Paleozoic section. The basal section of the Weasel Skin Conglomerate is a gray to light brown thick-bedded boulder to cobble conglomerate with subrounded to rounded clasts composed chiefly of quartzite and milky quartz, along with minor jasper and sandstone. This conglomerate is clast to matrix supported with the matrix consisting of very coarse-grained sandstone and pebbly sandstone. The grains in the matrix are cemented by hematite-stained silica. The matrix locally contains abundant fibrous sericite between grains, minor amounts of calcite that may be secondary, and patches of limonite. No stratification or sedimentary structures were observed in the lower section of this unit. The boulder to cobble conglomerate is up to 10 feet thick.

Overlying, and gradational with, the boulder conglomerate is a thin- to thick-bedded pebble to granule conglomerate and coarse-grained sandstone. The pebble conglomerate is grayish brown to reddish brown with local hematite-rich zones along bedding planes. Good exposures of the upper section of the Weasel Skin Conglomerate are exposed at the base of the Paleozoic section between Weasel Skin Creek and Fall Creek. The pebble conglomerate contains up to 60% subrounded to subangular clasts of gray to purplish quartzite, milky quartz, jasper, chert, sandstone, and schist; clasts of granite and red siltstone were also observed locally in the upper sections of this unit. This part of the unit is matrix supported, and the clasts are set in a matrix of coarse-grained sandstone with iron-strained silica cement and high proportions of fibrous sericite. The pebble conglomerate is well stratified and locally has a tabular cross to low-angle tangential cross stratification. Some sandy lenses in this section are thinly bedded to thinly laminated, and in some outcrops a crude normal grading is indicated by fining upward of conglomerate to very coarse-grained sandstone. This part of the Weasel Skin Conglomerate has a maximum thickness of 40 feet thick just west of Fall Creek.

Campbell and Gonzales (1996) noted that the conglomerates at the base of the Paleozoic section either are the basal member (Weasel Skin Member) of the Cambrian Ignacio Formation or are an older and separate unit. In the western

Needle Mountains coarse-grained sandstones of the upper part of Ignacio Formation that comprise the Stag Mesa Member overlie the Weasel Skin Member of the Ignacio Formation (Campbell and Gonzales, 1996). In the Vallecito quadrangle, the Late Devonian Elbert Formation or Ouray Limestone lie on the Weasel Skin Conglomerate in all outcrops, and there is no direct evidence that it Weasel Skin Conglomerate is a basal member of the Ignacio Formation. The age of the Weasel Skin Conglomerate is not constrained and this unit could be Cambrian to Neoproterozoic in age.

PROTEROZOIC BEDROCK UNITS

qp

Quartz-porphyry dikes (Mesoproterozoic)—Within the Vallecito quadrangle, porphyritic granite dikes and sills cut the Paleoproterozoic units and Eolus Granite. These dikes contain phenocrysts of subhedral to euhedral quartz, perthitic microcline, perthite, oligoclase, biotite, and hornblende that are set in a felty-microcrystalline to very fine-grained groundmass of quartz, perthite, perthitic microcline, biotite, minor hornblende, zircon, apatite, and iron oxide. Alteration of potassium feldspar to clay and plagioclase to sericite, calcite, and minor epidote is common; biotite alteration to iron oxide and chlorite is present in most samples. These rocks are brownish orange, grayish brown, and dark gray to black on fresh surfaces, and grayish brown to tan on most weathered surfaces. The most striking aspect of these rocks is the pronounced porphyritic texture defined by blocky crystals of alkali feldspar and anhedral crystals of clear to smoky quartz. Phenocrysts generally comprise about 10 to 20% of these rocks. 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 and sills are generally between 3 and 15 ft thick. In many cases these dikes terminate abruptly in country rock and can have abrupt variations in trend. On the basis of age determinations (Gonzales, 1997) and field relationships of similar intrusions in the Electra Lake quadrangle and Hermosa quadrangle (Gonzales and others, 2002, 2003b), the quartz porphyry dikes in the Vallecito quadrangle are interpreted as Mesoproterozoic in age.

g

Aplite, pegmatite, and fine- to coarse-grained granitic dikes and sills (Mesoproterozoic)—Fine-grained to pegmatitic granitic dikes and sills locally cut the Paleoproterozoic units in the Vallecito quadrangle. These intrusions are interpreted as offshoots of the Eolus Granite, although no age determinations have been done on them. They range from inches to tens of feet in thickness and can extend hundreds of feet along strike. These rocks are generally reddish orange to brownish orange and contain perthite, perthitic microcline, sodic plagioclase, quartz, biotite, primary and secondary muscovite, chlorite, and minor hornblende. These rocks also contain accessory zircon and opaque minerals.

Ye

Eolus Granite (Mesoproterozoic)—The Eolus Granite is comprised mostly of medium- to coarse-grained porphyritic, equigranular, or pegmatitic granite and monzonite with minor granodiorite and diorite.

Granite and monzonite of the Eolus Granite contain pink to salmon phenocrysts of perthitic microcline that are up to 3 inches in length. These phenocrysts are set in a medium- to coarse-grained groundmass of quartz, oligoclase, perthitic microcline, biotite, hornblende, and magnetite. Zircon, apatite, sphene, and epidote are minor accessory constituents. Zircon crystals from samples of the Eolus Granite exposed between Vallecito Reservoir and Electra Lake yield U-Pb radiometric ages of 1442 ± 3 Ma, 1435 ± 3 Ma, and 1438 ± 9 Ma (Gonzales, 1997).

Proterozoic Sedimentary Units

There is a thick succession (at least 1000 feet thick) of Proterozoic fluvial rocks exposed in the Vallecito Reservoir quadrangle. These rocks were deposited in a high-energy, subaerial fluvial systems primarily as proximal braided stream and debris flow deposits (Burns and others, 1980; Ethridge and others, 1984; Gonzales, 1988a, 1988b), following the assembly and stabilization of the older juvenile crystalline basement in the Needle Mountains (Gonzales, 1997). There is no absolute age constraint on these units, but they are similar to other syntectonic siliciclastic successions in the southwestern United States that were deposited between 1,700 and 1,650 Ma (Van Schmus and others, 1993; Williams, 2003).

Within the Vallecito Reservoir quadrangle, there are two distinct Proterozoic sedimentary map units that record polyphase ductile deformation and lower greenschist-facies regional metamorphism. Siliciclastic conglomerate and sandstone exposed in the steep canyon walls of Vallecito Creek are dominant. In the north-central section of the map, these rocks are in contact with a dark green to black conglomerate that makes up the conglomerate of Fall Creek of Gonzales (1988a, 1988b).

In previous investigations, the conglomerate of Fall Creek was interpreted as basal Vallecito Conglomerate (Cross and others, 1905b; Gonzales, 1988a, 1988b) or a wedge-shaped deposit at the base of the Irving Formation (Barker, 1969). It has been proposed that the bounding contacts of this unit are depositional surfaces (Barker, 1969; Ellingson and others, 1982; Gonzales and Ruiz, 1982; Baars and Ellingson, 1984) or a combination of depositional surfaces and faults (Cross and others, 1905b; Cross and Larsen, 1935; Burns and others, 1980; Gonzales, 1988a, 1988b). The conglomerate of Fall Creek, however, is nowhere in stratigraphic continuity with rocks of the Vallecito Conglomerate and the contact between these units is marked by an abrupt change in rock types.

Trough cross-stratification in west-dipping strata in the Vallecito Conglomerate west of Vallecito Creek generally face west, while cross-stratification preserved locally in the conglomerate of Fall Creek indicate tops to the east and west. The bedding in the Vallecito Conglomerate trends at an angle of 10º to 40º to the steep to vertical eastern contact of the conglomerate of Fall Creek. Barker (1969) noted this discordance and suggested that it might reflect "local tilting and erosion of the Vallecito before the Irving" or "folding along the contact". He felt that there was no evidence, however, of faulting between these units.

The opposing stratigraphic facing, abrupt lithologic changes, and angular discordance of bedding at the contact between the Vallecito Conglomerate and conglomerate of Fall Creek, provide evidence that the contact of these units is a zone of faulting. The contact between the Vallecito Conglomerate and the conglomerate of Fall Creek is defined by a zone of shearing that contains penetrative foliation, folded bedding and quartz veins, attenuated veins, deformed cross stratification, and stretched pebbles. This intense ductile deformation along the contact of these units provides supporting evidence for faulting and shearing. Ductile fabrics within this zone of shearing this contact indicate a west side is up motion.

On the basis of the evidence described above, Gonzales (1988a, 1988b) interpreted the conglomerate of Fall Creek as a basal facies of the Vallecito Conglomerate, and proposed that the conglomerate of Fall Creek was exposed in the axial zone of a faulted syncline.

There is a pronounced angular discordance between structural fabrics and unit contacts in the Irving Formation and the north-northeast trending contact of the Irving Formation and conglomerate of Fall Creek. This indicates that the contact is either a sheared angular unconformity or a fault. Gonzales (1988a, 1988b) interpreted this contact as an unconformable depositional surface that experienced shearing during deformation.

In this report, the quartz-rich conglomerate and sandstone of the Vallecito Conglomerate are mapped as Xv. The conglomerate of Fall Creek is considered to be the basal member of the Vallecito Conglomerate and is mapped as a separate unit (Xf) because of its distinct assemblage of clasts and mesoscopic features. The conglomerate of Fall Creek is not exposed outside the canyon of Vallecito Creek.

Bedding in the Proterozoic sedimentary rocks defines a series of macroscopic folds whose axial surfaces trend roughly north. The most prominent structure is an upright to steeply inclined, gently to moderately south-plunging anticline that is exposed in the Hell Canyon-Dollar Lake area, and Indian Creek area just east of the Vallecito Reservoir quadrangle. Gonzales (1988a, 1988b) argued that the conglomerate of Fall Creek is exposed in a faulted macroscopic syncline in the Vallecito Creek area and infers several other major folds in the Vallecito Conglomerate. Macroscopic folds were generated in both the Vallecito Conglomerate and Uncompahgre Formation during deformation between 1700 and 1400 Ma (Cross and others, 1905b; Barker, 1969; Tewksbury, 1981, 1982, 1989; Burns and others, 1980; Ethridge and others, 1984; Harris and others, 1986, 1987; Gibson, 1987; Harris, 1987; Gonzales, 1988a, 1988b; Gibson and Simpson, 1988; Gibson, 1990; Harris, 1990; Gibson and Harris, 1992). Due to the lack of detailed of studies, however, the structural record in the Vallecito Conglomerate is still poorly constrained.

Xv

Vallecito Conglomerate (Paleoproterozoic, absolute age not constrained)— The Vallecito Conglomerate was named by Cross and others (1905b) for the quartz-rich metamorphosed conglomerate exposed in the steep canyon walls of Vallecito Creek. This unit is a thick succession of interstratified fluvial pebble- to cobble-conglomerate and quartz-rich sandstone with subordinate amounts of mudstone and siltstone. Estimates of the thickness of this unit range from 2,000 feet (Barker, 1969) to 6,000 feet (Burns and others, 1980). The absolute age of rocks in the Vallecito Conglomerate is not constrained, but these rocks are correlative with Paleoproterozoic siliciclastic successions in New Mexico and Arizona. Williams and others (2003) hypothesized that these successions formed in syntectonic depositional basins developed on stabilizing juvenile crust by unroofing of middle crustal blocks by thrusting during collisional tectonics, and erosion of these blocks into small foreland-thrust basins.

The dominant rock types in the Vallecito Conglomerate are matrix- to clast-supported pebble to boulder conglomerate, and fine- to coarse-grained sandstone. Conglomerates contain subangular to subrounded fragments of thinly laminated to thin bedded or massive quartzite, milky quartz, chert, jasper, banded-iron formation, argillite, and metamorphosed felsic to mafic schist and gneiss that typically have relict igneous textures (Cross and others, 1905b; Barker, 1969; Burns and others, 1980; Ethridge and others, 1984; Gonzales, 1988a, 1988b). Quartzite and quartz clasts are generally dominant in any given exposure, but clasts of mafic to felsic schist and gneiss comprise between 10 to 90 percent of basal conglomeratic deposits in the Table Mountain area about 4 miles northeast in the headwaters of Deadhorse Creek. Clasts in the conglomerates range from less than 1 inch up to several feet in maximum dimensions, but generally are 2 to 6 inches in size.

Beds and lenses of sandstone, and the sandy matrix of the conglomerates, are fine- to coarse-grained and contain quartz, muscovite or sericite, epidote, biotite, chlorite, opaque oxides, lithic fragments, tourmaline, potassium feldspar, albite, amphibole, apatite, calcite, garnet, leucoxene, monazite, pyrite, rutile, silliminite, sphene, tourmaline, zircon, and andalusite (Barker, 1969; Burns and others, 1980; Gonzales, 1988a, 1988b). Silliminite and andalusite are not common in these rocks and are generally found near contacts with the Eolus Granite which suggests that they reflect local contact metamorphism at 1,400 Ma.

Bedding in the Vallecito Conglomerate is thin to very thick. Very thin to thin, parallel and contorted lamination is common in siltstone layers, and planar laminated quartz arenite is also reported (Burns and others (1980). Individual beds my be continuous for hundreds to thousands of feet along strike or form lense-shaped layers that are up to tens to hundred of feet in length and feet to tens of feet thick. Bedding planes are generally sharp, and marked by abrupt textural variations. Well-preserved primary sedimentary structures are common and include trough and planar cross stratification, normal- and reverse-graded beds, scour surfaces, contorted lamination and small-scale faulting in soft-sediment deformed siltstone, ripples, and imbricated clasts (Barker, 1969; Burns and others, 1980; Gonzales, 1988a, 1988b).

Siliciclastic rocks in the Vallecito Conglomerate are well preserved and deformation fabrics are poorly developed. Near contacts with the Irving Formation and conglomerate of Fall Creek, however, there is locally a strong penetrative tectonic foliation, stretched and rotated clasts, and mesoscopic folds that deform bedding and foliation (Gonzales, 1988a, 1988b). The Vallecito Conglomerate exposed north of the Los Piños River campground also contains a strong penetrative foliation, shear bands, deformed clasts, and folded bedding.

Barkers (1969) noted that the Vallecito Conglomerate may have been deltaic, with deposition occurring in a tectonically controlled basin. Deposition in an alluvial fan system by high-gradient, short-duration, peak discharge, braided streams and rare debris flows was proposed by Burns and others (1980) and Ethridge and others (1984). They suggest that the source area was located north of the present outcrop belt, with the proposed alluvial fan system prograding southward.

Xf

Conglomerate of Fall Creek (Paleoproterozoic, absolute age not constrained)—West of Vallecito Creek canyon, the conglomerate of Fall Creek is exposed in a northeast-trending wedge that is up to 1000 feet thick, and in most locations separates the Irving Formation from the Vallecito Conglomerate. The conglomerate of Fall Creek is distinguished by its abundant clasts of mafic and felsic metamorphic rock, dark color, and penetrative tectonic fabrics.

The conglomerate of Fall Creek is a clast- to matrix-supported polymictic conglomerate that contains a variety of subangular to subrounded, granule to boulder-sized clasts that have maximum exposed dimensions up to 2 feet. Clast types include bluish-gray to grayish-white quartzite, milky quartz, fine-grained intermediate to mafic schist and gneiss, intermediate to mafic metamorphic rocks with relict porphyritic textures, medium- to coarse-grained metamorphosed mafic rocks with relict phaneritic equigranular textures, medium- to coarse-grained quartzo-feldspathic rock, mafic to felsic gneiss, and very fine-grained felsic schist (Gonzales, 1988a, 1988b). Most of the clast types are similar in composition and texture to rocks in the Irving Formation. More competent clasts are generally subangular to angular while less competent clast lithologies are typically stretched and flattened, with their long dimensions aligned subparallel to a pronounced foliation in the matrix between the clasts.

The matrix in the conglomerate of Fall Creek is greenish-black dark gray, fine- to coarse-grained, and is composed chiefly of detrital quartz, plagioclase, and lithic fragments of polycrystalline quartz ± opaque oxides. The balance of the matrix includes actinolitic hornblende, biotite, opaque minerals, apatite, calcite, chlorite, epidote, tourmaline, and zircon (Gonzales, 1988a, 1988b).

The high proportion of incompetent clasts, and textural immaturity, of rocks in the conglomerate of Fall Creek suggests that it was deposited close to a source that contained a high proportion of mafic to felsic metamorphic rocks, and that this course debris was transported over a relatively short distance with minor reworking. The similarity of many of the clasts to rock types in the Irving Formation provides evidence that the Irving was a major source of debris. The overall poor sorting, lack of internal stratification and other primary sedimentary structures, and local lenses of sandstone suggests that this unit originated as debris flows that were incised locally by small fluvial channels.

Rocks in the conglomerate of Fall Creek typically exhibit a strong tectonic foliation, tectonic lineation defined by minerals and stretched clasts, and multiple episodes of mesoscopic folding, and ductile shearing (Gonzales, 1988a, 1988b; Gonzales and others, 1994). In many outcrops, pebble and mineral lineation are steep and plunge to the south.

Irving Formation (Paleoproterozoic) — The Irving Formation within the map area contains mafic to felsic schist and gneiss that are complexly deformed, variably foliated, and metamorphosed at upper greenschist to lower amphibolite facies. On the basis of chemical compositions and well-preserved primary features, Gonzales (1988a, 1988b) interpreted these rocks as metamorphosed volcanic and associated gabbroic intrusive rocks. Primary volcanic and intrusive textures and structures are not common in rocks of the Irving Formation within the map area, but original features are well preserved elsewhere in Irving Formation (Gonzales, 1988a, 1988b).

The metamorphosed igneous complex of the Irving Formation in the southeastern Needle Mountains is bimodal, with SiO_2 concentrations of 46 to 58 percent and 70 to 75 percent (Gonzales, 1988a, 1988b). Chemical compositions of these rocks reflect local migration of mobile elements (e.g., sodium and potassium) during deformation and metamorphism, but otherwise preserved their original chemical compositions. Mafic and intermediate rocks are predominant in the complex and are basaltic with tholeiitic to calc-alkaline affinities whereas felsic schist and gneiss are mostly rhyolitic to rhyodacitic with calc-alkaline affinities.

On the basis of field and geochemical data, Gonzales (1988a, 1988b, 1997) proposed that rocks in the Irving Formation accumulated mostly in an oceanic or continental margin arc, and perhaps in part in a back-arc basin. These rocks are part of an extensive belt of volcanic arc assemblages that accreted to the edge of the North American craton from 1,700 and 1,800 million years ago (Van Schmus and others, 1993). An age of 1787 ± 26 Ma was obtained from U-Pb analyses on zircons from felsic schist in the Irving Formation about 2 miles north of the Vallecito Reservoir quadrangle, which provides evidence that these rocks are time correlative with rocks in the western Needle Mountains that formed around 1,800 Ma (Gonzales, 1997).

Mafic schist and gneiss exposed in the Irving Formation in the Vallecito Reservoir quadrangle are greenish black to black, fine- to medium-grained, and strongly foliated. These rocks contain sparse to abundant crystals of hornblende and plagioclase (An_{25-40}) and lesser amounts of iron-rich epidote, apatite, biotite, clinozoisite, opaque oxides, quartz, sphene, and tourmaline. Subequant crystals of hornblende up to 6 millimeters in maximum dimension are common in these rocks, and in some outcrops the hornblende replaces original pyroxene crystals that define a primary subophitic texture. Relict phenocrysts and microphenocrysts of plagioclase make up 0 and 40 volume percent of these rocks, and in some outcrops the plagioclase defines a pronounced primary trachytic texture. Despite partial to complete recrystallization of epidote and sericite, the plagioclase crystals in these rocks have albite and Carlsbad-albite twinning, and rarely preserve original compositional zonation.

Mafic schist and gneiss exposed east of Fall Creek near the northern edge of the quadrangle contain ribbons and beds of massive, fine- to coarse-grained, bluish gray to light gray chert. Some beds of chert are up to five feet thick, and are composed mostly of quartz and opaque oxides with trace amounts of apatite, biotite, calcite, chlorite, epidote, and muscovite. The chert is interpreted as a product of inorganic precipitation from hydrothermal action, volcanic emanations, or alteration of volcanic glass.

Felsic schist and gneiss is exposed in the Irving Formation just east of Fall Creek. Fine-grained, muscovite and biotite bearing quartzo-feldspathic schist with a weak to prominent tectonic foliation is the dominant felsic rock type, but in some areas there are outcrops of banded gneiss with alternating quartzo-feldspathic and amphibole-rich layers up to 3 inches thick. On the basis of composition, texture, and geochemical affinities, Gonzales (1988a, 1988b) interpreted these rocks as metamorphosed rhyolitic to dacitic tuffs and reworked volcanic deposits.

Felsic lithologies are monotonous and typically do not exhibit pronounced variations in color, composition, and fabrics. These rocks are grayish white to dark grayish brown on fresh and weathered surfaces, and commonly contain medium- to coarse-grained quartzo-feldspathic stringers and ribbons that are less than 1 to 4 inches thick. These stringers and ribbons generally trend subparallel to compositional layering and S_1-S_2 tectonic foliation, and locally define tight to isoclinal F_1 and F_2 folds. Transposition and detachment of stringers in some outcrops form augen and boudin structures in which quartzo-feldspathic "eyes" and ribbons are set in a groundmass of finer grained rock. In some outcrops the felsic rocks have a pronounced layering that may be primary bedding and lamination.

Felsic schist and gneiss are generally composed of an equigranular assemblage of quartz, oligoclase and andesine, microcline, biotite, and muscovite. Accessory minerals include apatite, calcite, iron-rich epidote, opaque oxides, perthite, sphene, tourmaline, and zircon. Outcrops of biotite schist locally contain garnet. Retrograde alteration of biotite to chlorite and plagioclase to sericite is common. Mineral assemblages in the felsic gneisses of this unit are similar to schistose rocks, but the gneisses contain higher concentrations of hornblende in mafic bands. Felsic rocks of the Irving Formation have color indices ranging from 5 to 50%.

Crystals of feldspar and quartz in felsic schist and gneiss in the Irving Formation are anhedral and less than 0.1 to 5 mm in size, whereas biotite and muscovite form subhedral blades up to 1.5 mm in length. The fine grain size of these rocks probably reflects the original grain size of the protolith, but in part could also reflect extensive granulation and grain-size reduction from ductile deformation and recrystallization.

Rocks in the Irving Formation record several phases of deformation. The earliest phases of deformation are F_1 and F_2 tight to isoclinal folds defined by quartz stringers and folded S_1 foliation. Foliations developed during the first and second phases of folding are generally steep dipping and trend roughly north-south. In some outcrops the S_1-S_2 foliations are refolded into F_3 folds (and related S_3 foliation) that are tight to open with variable trends. The F_1-F_3 folds are interpreted as different phases of folding that developed during the same deformational event between 1,800 and 1,760 Ma.

On the basis of work on the metamorphic assemblages in the Irving Formation near its contact with the Eolus Granite, Silva and others (2003) proposed that the Irving Formation was thermally metamorphosed by the intrusion of the granite at distances from the contact of 0.8 miles. They argue that the rocks pre-intrusion assemblages contain actinolite, chlorite, and biotite with actinolite recrystallizing to hornblende due to thermal effects of the pluton during its emplacement margin. Detailed petrographic studies by Gonzales (1988a, 1988b), however, indicate that all of the rocks in the Irving Formation were recrystallized to upper greenschist- to lower amphibolite-facies prior to intrusion of the Eolus Granite with local static recrystallization of hornblende to clinopyroxene near the pluton as a result of its emplacement. Lower greenschist facies retrograde recrystallization is preserved in the Irving Formation, but peak prograde metamorphism was at upper greenschist to lower amphibolite facies.

STRUCTURAL GEOLOGY

The dominant structures in the map area are faults and sets of brittle faults that cut the Proterozoic basement and Paleozoic to Mesozoic sedimentary cover rocks. Displacement on these faults varies from several feet to hundreds of feet. Many faults in the area have an east-west or north-south trend, but some of the structures trend northeast or northwest. The east-west and north-south trending faults, in part, are probably reactivated Proterozoic structures that also have these dominant trends. In most cases the orientations of the fault surfaces in the area could not be determined or measured. Most of the eroded fault and related fracture planes that were observed, however, are vertical or steep. The interpretation of the apparent displacement on these faults is therefore based on disruption of the stratigraphic section, fault-line scarps, and other evidence such as breccia zones and mineralization. The reader should note that in some cases the interpretation as to whether a given fault is normal or reverse is tentative due to the lack of evidence for net slip. The ball and bar shown on the trace of faults on the map indicate the downthrown side of the fault, but dips of the fault planes are not known for most of these structures.

Vallecito Creek valley is defined by a graben structure whose western margin is delineated by a network of north-south trending faults that extend from Dunsworth Park northward to Weasel Skin Creek. Faults in this system are subvertical to vertical with east dips, and most disrupt the Paleozoic and Mesozoic sedimentary strata which are rotated and tilted steeply to the east in the hanging walls of the faults.

The eastern margin of the graben is bounded by a north-south trending set of faults with apparent displacements that are down to the west. The best exposed fault in this system cuts beds in the Hermosa Group immediately east of Vallecito Reservoir. This structure has down to west displacement as evidenced by steep-dipping beds on the downthrown and rotated hanging wall of the fault. Juxtaposition of the Cutler Formation and Hermosa Group on either side of the reservoir was also used to infer a major structure along the length of the valley. This structure was also shown on the 1:250,000-scale geologic maps of Larsen and Cross (1956) and Steven and others (1974). The northern extension of this fault is uncertain as no evidence of its trace was found further to the north on the flanks of the canyon.

The north-south trending faults that bound the graben structure are cut by series of east-west trending faults whose displacements are mostly down to the south on the west side of Vallecito Reservoir and down to the north on the east of the reservoir. These east-west structures are marked by breccia zones, tilted and disrupted sedimentary strata, and local zones of quartz stockwork and sulfide mineralization. In the vicinity of Carbonate Basin this east-west fault system is cut by a series of northwest trending faults whose apparent displacement is chiefly down to the south.

Between Carbonate Basin and Endlich Mesa the Eolus Granite and Paleozoic strata are cut by a system of branching and cross cutting normal faults with variable trends. These faults have displacements of feet to tens of feet but there is no consistent relative displacement of rocks along these faults.

At several locations the Hermosa Group are in direct contact with the Vallecito Conglomerate. The absence of the lower Paleozoic section in these areas suggests that they were topographically high blocks during deposition of Cambrian to Lower Pennsylvanian rocks. These blocks may have been high due to differential erosion or uplift along faults. The Hermosa Group was mapped in direct contact with the Vallecito Conglomerate just north of Dark Canyon and on the eastern margin of the quadrangle between about 0.5 to 2 miles north of the Los Piños River valley. Further study of these areas is warranted to perhaps gain insight into the Paleozoic tectonics and structural architecture.

A CHONICLE OF FIRE HISTORY

Wildfires in southwestern Colorado in the summer of 2002 had a tremendous impact on the environment. The damage was not only from fire but also from the subsequent erosion and land degradation because of conditions created by the fires. There has been a great deal of speculation on the occurrence and frequency of fires and related events in the past. A record of past events and insight into the history of fires was established during this investigation from a study of ancient charcoal layers exposed in a small drainage basin on the western edge of Vallecito Creek valley approximately 0.75 miles south the mouth of Lost Creek, west of Country Road 501 (fig. 4). This research provides important insight into the history of fires, the relationship of past wildfires to climatic conditions and land erosion, and geomorphologic development of a region (e.g., Meyer and others, 1992; Meyer and others, 1995; Meyer and others, 1997).

Modern debris flows following the 2002 Missionary Ridge Fire incised older alluvium in the drainage basin outlined in figure 4. The surface debris in this area was subsequently remobilized during periods of rainfall over the burned area and this created a series of modern alluvial fans. Stream erosion and alluvial fan development in the drainage basin exposed a succession of ancient alluvial fan deposits that preserved up to twelve distinct layers of charcoal, some of which are several inches thick and contained burned logs and debris (fig. 5). Charcoal

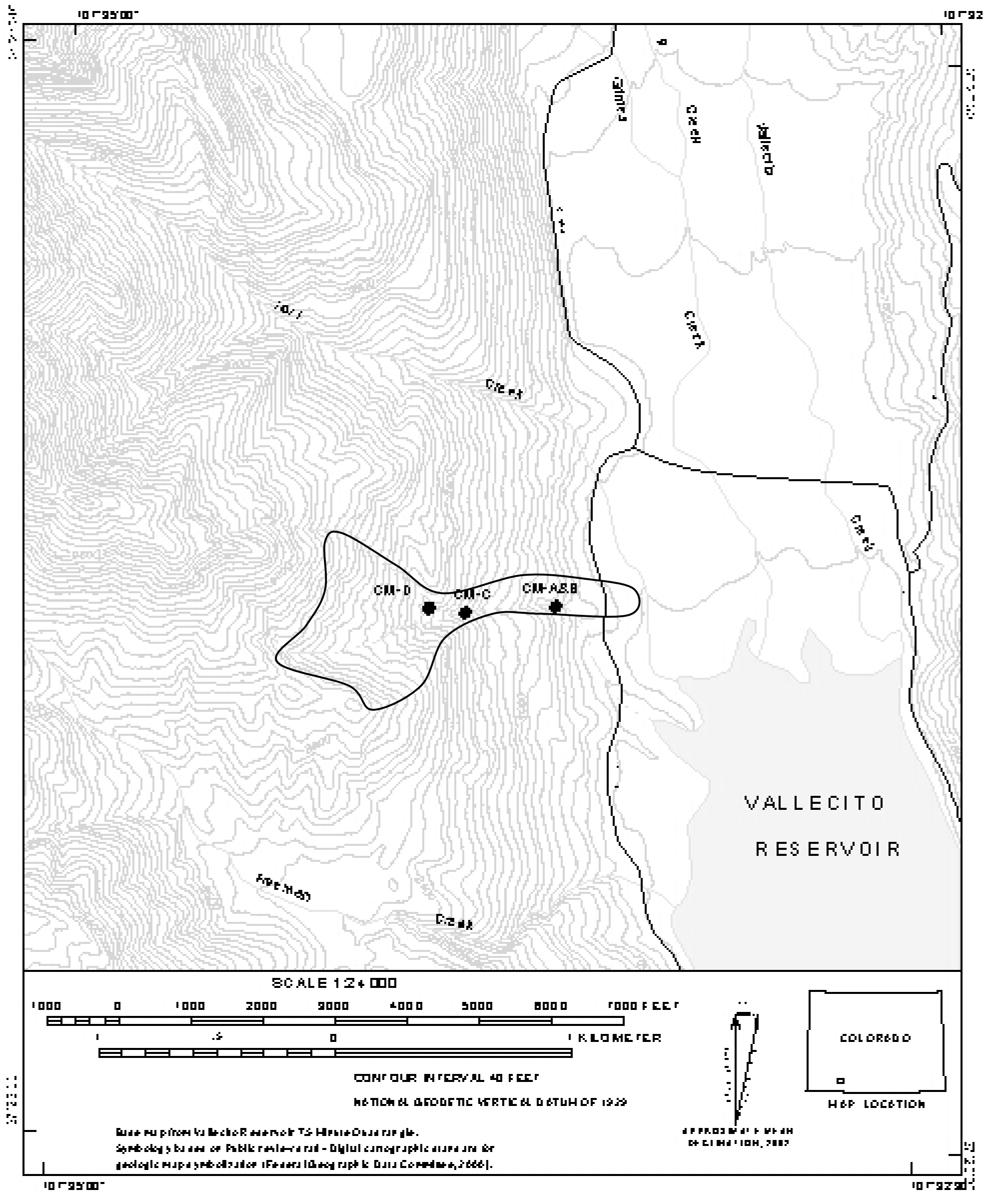

Figure 4: Location of sample sites where charcoal was collected from older debris flows that were incised by modern debris flows following the 2002 Missionary Ridge Fire. The black line delineates the margins of the drainage basin.

layers were also found in older alluvial fan deposits near Lemon Reservoir and have been noted from similar deposits in the Animas River valley. The possible link between fires and related geologic events in the past was tested with field studies and radiocarbon age determinations to establish a chronology of events and stratigraphic records in these deposits.

A detailed investigation of the stratigraphy of the older fan deposits was conducted at four separate locations in the older fan deposits (fig. 4). The alluvial sediments exposed in these sections consisted of layers and lenses of silt and sand that contain pebbles and boulders of bedrock and glacial material. This older alluvium also contained layers and pieces of charcoal at various stratigraphic horizons. Charcoal layers generally bound distinct cycles of alluvium that were indicative of debris flow and sheet flow deposits.

Distinct differences were observed between the alluvial sediments deposited near the bottom of the basin (refer to section CMC-B in fig. 5) and those deposited farther upstream (refer to section CMC-D in fig. 5). The alluvial fan material near the head of the drainage (e.g., section CMC-D in fig. 5) contained much more fine-grained material and all of the conglomerates were clast supported with most clasts less than 1 inch in diameter. The conglomerates were well sorted and in some cases were normal graded, and were interbedded with thinly laminated organic-rich sand- and mud-rich facies. This section contained at least three smaller scale fining upwards sequences that were interpreted as a series of progressively more dilute sediment-laden flows that were deposited after a period of fire.

Ancient alluvial deposits in the medial and distal parts (e.g., section CMC-B in fig. 5) of the drainage contained a much greater percentage of coarse material. Silt- and sand-sized material is almost completely lacking except where it forms the matrix of conglomerates. The conglomerates are dominant in these parts of the fan complex. They are generally poorly sorted to unsorted and matrix to clast supported with a high proportion of granule- to boulder-sized fragments. Locally, the entire section of alluvium fines upward with the lowest deposits resting on bedrock and consisting primarily of boulder to cobble conglomerates while the upper deposits are dominated by poorly-sorted silt- and sand-sized material. The overall fining of sediments upward in this section possibly reflects a change in the source material in this basin over time.

The overall stratigraphy of the fan deposits at this site reflects the mobilization and reworking of glacial debris and colluvium in a succession of alluvial fans from about 4300 years

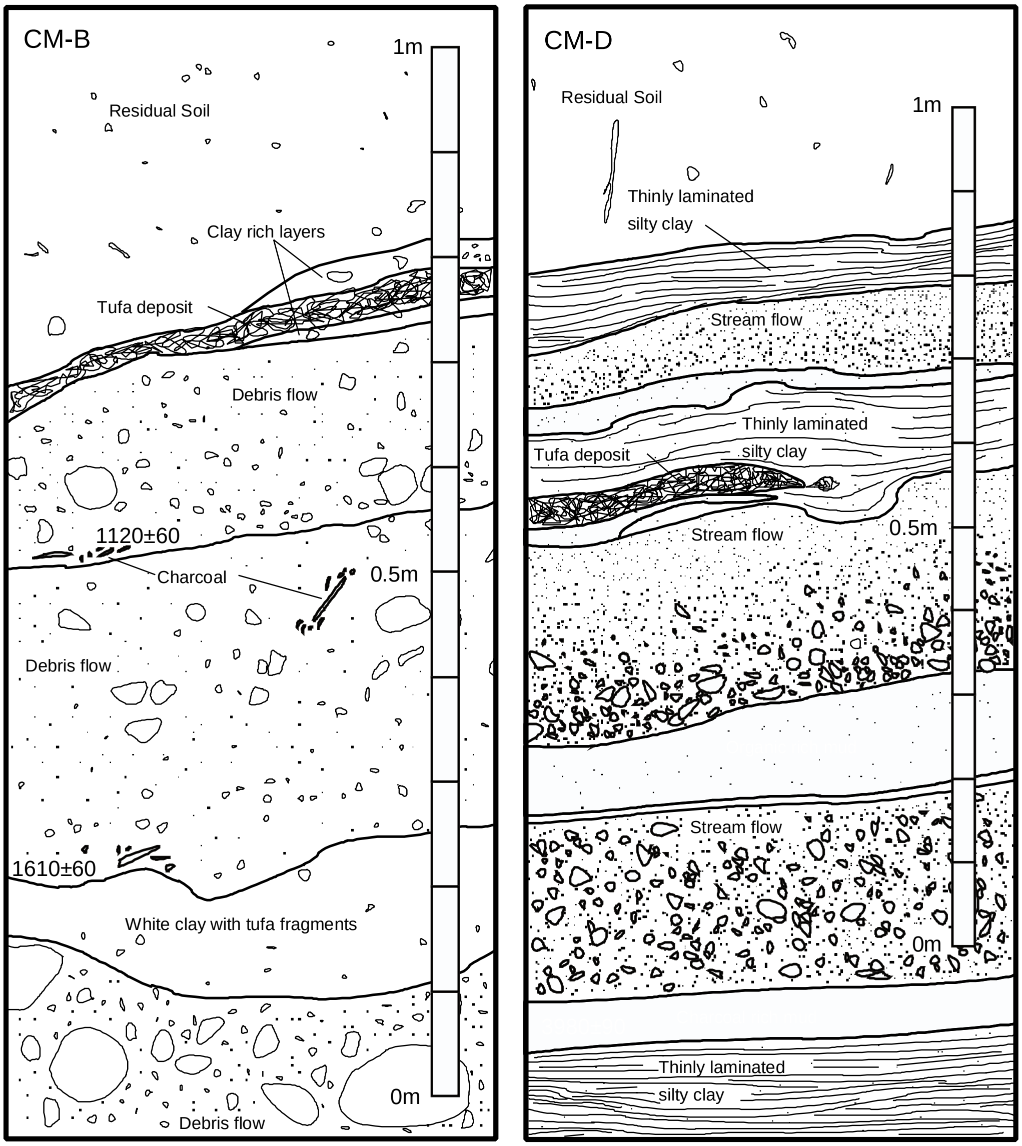

Figure 5: Partial stratigraphic sections measured in older incised alluvial fan deposits showing variations in the stratigraphy of deposits near the head (CMC-D) and mouth CMC-B) of the fan deposits on the west side of Vallecito Reservoir.

before present. Periods between debris flows were marked by normal stream flow and sheetwash that transported and reworked finer material. Successive alluvial fans reworked older gravel deposits in the channel, leading to an overall fining upward succession of sediment over time. Variations in the deposits from the head of the fan to the mouth probably reflect variations in source material and energy of the system in different parts of the basin.

Charcoal samples were collected from all four sites in the incised channel at Vallecito Reservoir, as well as from another location (LMC-MR) to the west of the study area near Lemon Reservoir (Table 1). Selected samples were sent to Geochron Laboratories in Cambridge, MA for radiocarbon age determinations. The bulk samples were typically aggregates of charcoal fragments mixed with sand, silt, rootlets, and other foreign material. Charcoal from thirteen samples was prepared using standard methods and dated using beta counting and accelerator mass spectrometry (Table 1) (Dickin, 1997). Figure 6 shows the variation in age of charcoal layers at site CMC-B.

The fluvial facies and stratigraphy of these older fan deposits exposed in the wash establishes a cyclic pattern of debris-flow dominated, fire-related sedimentation. Combined with ^{14}C ages of the charcoal layers these data give evidence that old debris flow deposits were triggered by major fires that occurred in the region over the past 4300 years BP, and that fire-related erosion and sedimentation constitutes an effective mechanism for landscape evolution in the area. Similar deposits of alluvium and charcoal exposed near Lemon Reservoir and Animas River valley suggests a regional pattern of fire, erosion, and landscape development.

Another interesting result of this research is the apparent connection between the cycles of major wildfires in southwestern Colorado and other climatic and fire records (fig. 7). Periods of high fire related sedimentation as determined by this study correlate well with periods of high fire related sedimentation in Yellowstone National Park (Meyer and others., 1995) and periods of drought determined locally in La Plata Mountains (Petersen, 1988). This hints that large-scale changes in climate that affect much of the western United States are an important control on the frequency of wildfires and related debris flow events in the West. Results from our study provide a better understanding of the relationship of ancient wildfire events and Holocene geologic processes in southwestern Colorado.

TABLE 1: RADIOCARBON AND CALIBRATED AGES FOR CHARCOAL SAMPLES COLLECTED AT VALLECITO RESERVOIR AND LEMON RESERVOIR.

Sample No.	*Method*	$\delta^{13}C_{PDB}$	^{14}*C Age* BP	*Calibrated Age Range*	
CMC-B0-02	E	-21.9	3190 ± 80	1680-1660 (0.008) 1660-1650 (0.007) 1640-1260 (0.985)	cal BC
CMC-B1-02	A	-22.2	3010 ± 50	1400-1110 (0.991) 1100-1090 (0.009)	cal BC
CMC-B2-02	B	-21.8	2480 ± 80	780-410 (1.000)	cal BC
CMC-B3-02	B	-21.9	1610 ± 60	260-280 (0.027) 330-600 (0.973)	cal AD
CMC-B4-02	B	-23.8	1120 ± 60	780-790 (0.031) 790-1010 (0.969)	cal AD
CMC-B5-02	B	-22.8	130 ± 60	1670-1780 (0.408) 1790-1950 (0.592)	cal AD
CMC-B6-02	E	-24.6	1170 ± 80	690-1000 (1.000)	cal AD
CMC-B7-02	B	-26	860 ± 60	1040-1270 (1.000)	cal AD
CMC-B8-02	B	-23.3	880 ± 60	1030-1260 (1.000)	cal AD
CMC-D2-02	A	-24.0	3980 ± 90	2680-2810 (0.047) 2750-2720 (0.019) 2700-2270 (0.893) 2260-2200 (0.041)	cal BC
CMC-D12-02	B	-23.4	2840 ± 120	1370-1360 (0.006) 1355-1345 (0.006) 1320-800 (0.988)	cal BC
LMC-MR2-02	E	-24.1	4340 ± 190	3510-3410 (0.037) 3390-2480 (0.963)	cal BC
LMC-MR5-02	B	-22.7	1060 ± 90	780-1190 (1.000)	cal AD

Notes:

Samples: CMC-B0-02 was collected from the remains of a burned log 12 cm above bedrock about 10 m downstream of the main section.

CMC-B5-02 and CMC-B6-02 were collected from the same stratigraphic layer.

Method: B = Beta counting, E = Beta counting with extended counting time, A = Acclerator mass spectrometry.

^{14}C Ages: Conventional radiocarbon age based on Libby half life (5570 years) and corrected for isotope fractionation. The error is 1σ measured from the analytical data alone.

Calibrated Age Range: 2σ (95.4% of area) calibrated age ranges with the relative area under the probability distribution for each range in parentheses. The ranges were calculated using the INTCAL98 calibration curve and CALIB 4.1(Stuiver and Reimer, 1993, Stuiver and others,1998).

Samples designated by LMC were collected south of Lemon Reservoir, outside the map area.

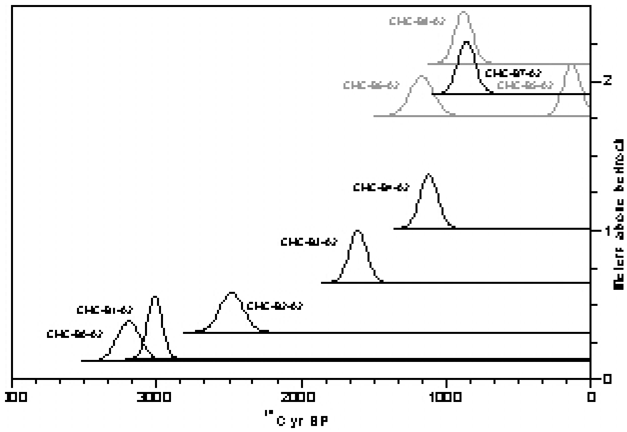

Figure 6: The stratigraphic sequence of radiocarbon ages for charcoal samples collected at site CMC-B. Discrepancies in ages for the grayed samples (CMC-B5-02, CMC-B6-02, and CMC-B8-02) suggest that the samples could possibly contain reworked material from older charcoal layers in the deposits or, in the case of CMC-B5-02, may have been contaminated. In the case of CMC-B6-02 and CMC-B8-02, 02, however, the uncertainty in the ages is not low enough to permit a critical evaluation of this possibility.

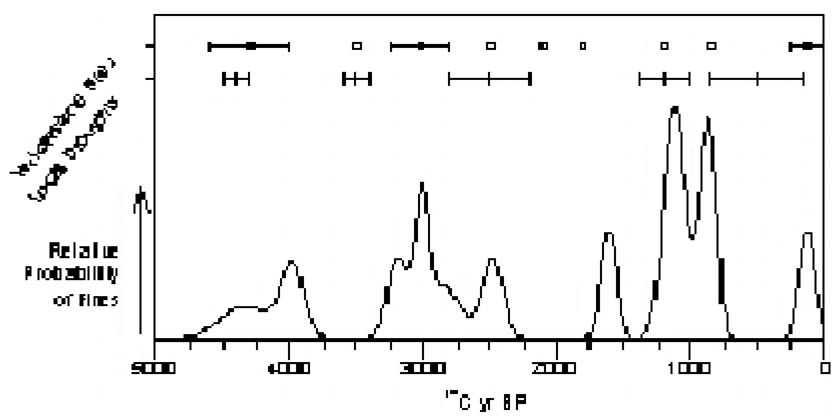

Figure 7: Periods of fire-related sedimentation over the past 5000 radiocarbon years. Probability distributions of radiocarbon ages were summed to generate a curve showing peaks that have the greatest probability of fire-related sedimentation. These curves are compared to periods of drought as established by Petersen (1988) and peak periods of fire-related sedimentation in Yellowstone National Park that were determined by Meyer and others (1995).

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