OPEN-FILE REPORT 03-15

Geologic Map of the Taylor Ranch Quadrangle, Costilla County, Colorado

By
Robert M. Kirkham, Kenneth C. Shaver,
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RECLAMATION•MINING SAFETY•SCIENCE

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 03-15, *Geologic Map of the Taylor Ranch Quadrangle, Costilla County, Colorado.* Its purpose is to describe the geologic setting, structural geology, and geologic hazards of this 7.5-minute quadrangle located in south-central Colorado, southeast of the town of San Luis. Robert M. Kirkham, former staff geologist with the Colorado Geological Survey; Kenneth C. Shaver, consultant; Neil R. Lindsay, Adams State College, and Alan R. Wallace, U.S. Geological Survey completed the field work on this project in the summer of 2002.

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds are competively awarded through the STATEMAP component of the National Cooperative Geologic Mapping Program (Agreement No. 02HQAG0050). The program is authorized by the National Mapping Act of 1997. The CGS matching funds come from the Severance Tax Operational Account that is funded by taxes paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
Senior Science Advisor

Ronald W. Cattany
Interim State Geologist
Director, Division of Minerals and Geology

ACKNOWLEDGMENTS

Thanks to Vince Matthews, Jim Cappa, Dan Miggins, Ren Thompson, and Rob Benson for their discussions and advice. A team of soil scientists led by Alan Steube and working for the U.S. Department of Agriculture, Natural Resource Conservation Service shared their unpublished soil maps and information. Brian Brister, New Mexico Bureau of Mines and Mineral Resources, discussed the stratigraphy and structure of the Alamosa Basin on several occasions and supplied a copy of his in-press paper (Brister and McIntosh, in press).

The authors appreciate the cooperation of the landowners in the quadrangle. The Culebra Ranch (formerly called the Taylor Ranch), especially Jim Barron, Ed Sanchez, and Carlos DeLeon, granted access onto the ranch, advised about road conditions, and provided us with accommodations for part of the field season. Julio Madrid, Matt Lucero, and Bill Lyttle, with Battle Mountain Resources, Inc., provided data and gave permission to conduct field work on the mine property. Ty Ryland granted permission to work on the Forbes Trinchera Ranch.

This map was improved by the review comments of Mike Machette and Ren Thompson. Jane Ciener served as the technical editor. The authors thanks Matt Morgan for training the senior author to use the ERDAS photogrammetric system. Jason Morgan prepared the digital maps for peer review by modifying the files compiled on the ERDAS photogrammetric system. Cheryl Brchan produced the final map and booklet for publication, and Larry Scott drafted the figures.

INTRODUCTION

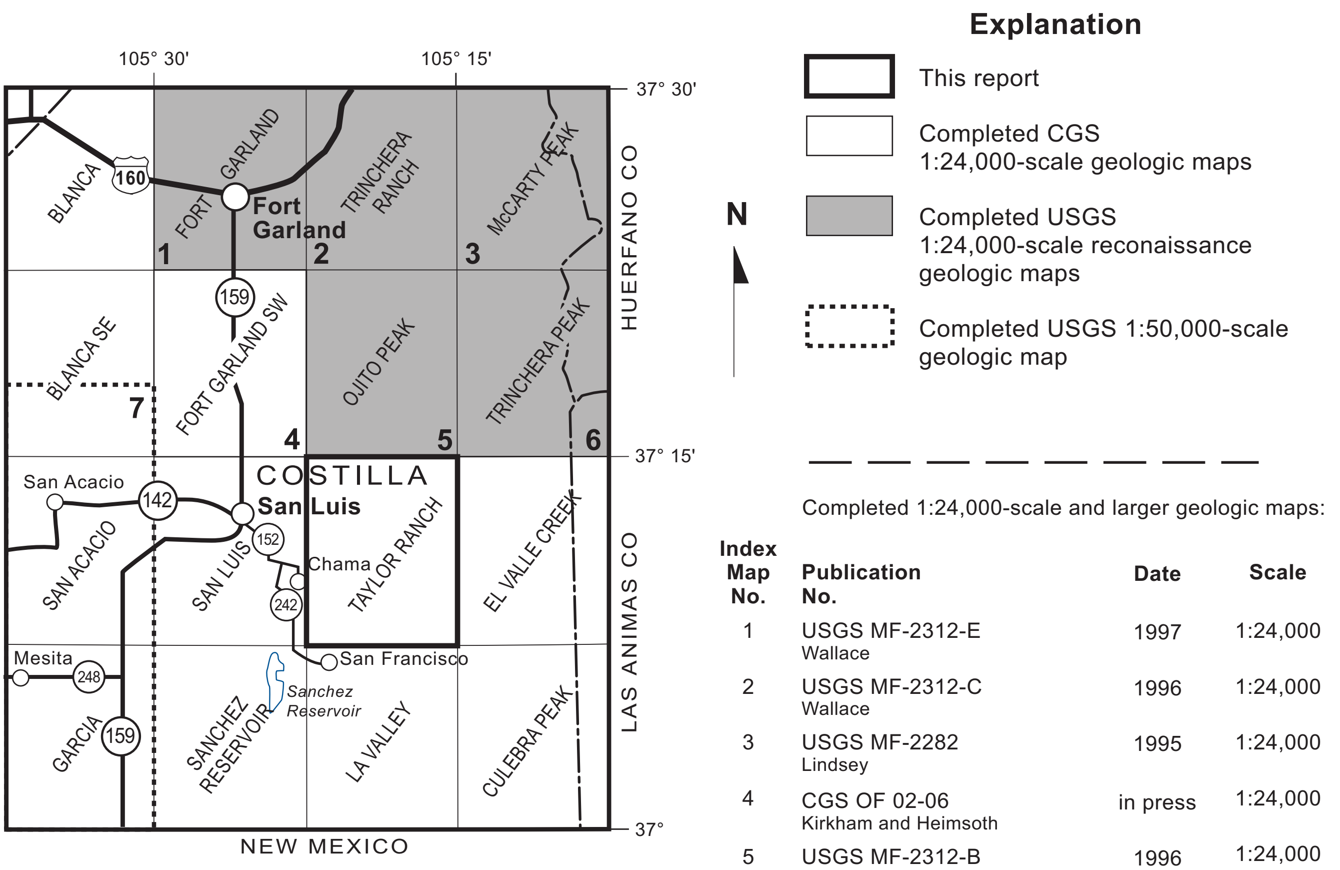
INTRODUCTION

OVERVIEW

The Taylor Ranch 7.5-minute quadrangle covers about 60 sq mi of Costilla County in south-central Colorado, east of the town of San Luis (Fig. 1). The quadrangle is in the southeastern part of San Luis Valley, a large, high-elevation, intermontane valley whose floor is at an average elevation of about 7,500 ft. The 1:24,000-scale topographic base map of the quadrangle was based on aerial photographs taken in 1965; therefore, anthropogenic features created during the past three or four decades are not depicted on the base map.

Geologic mapping of the Taylor Ranch quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Program. This program, which is administered by the U.S. Geological Survey (USGS), provided approximately one-half of the funding needed to map this quadrangle. This map of the Taylor Ranch quadrangle is the second 7.5-minute quadrangle in Costilla County to be mapped by the CGS; the Fort Garland SW quadrangle (Kirkham and Heimsoth, 2003) was the first map.

The collection of structural and stratigraphic data is an important element of the CGS mapping effort in Costilla County. This information will improve our understanding of earthquake hazards



Completed 1:24,000-scale and larger geologic maps:

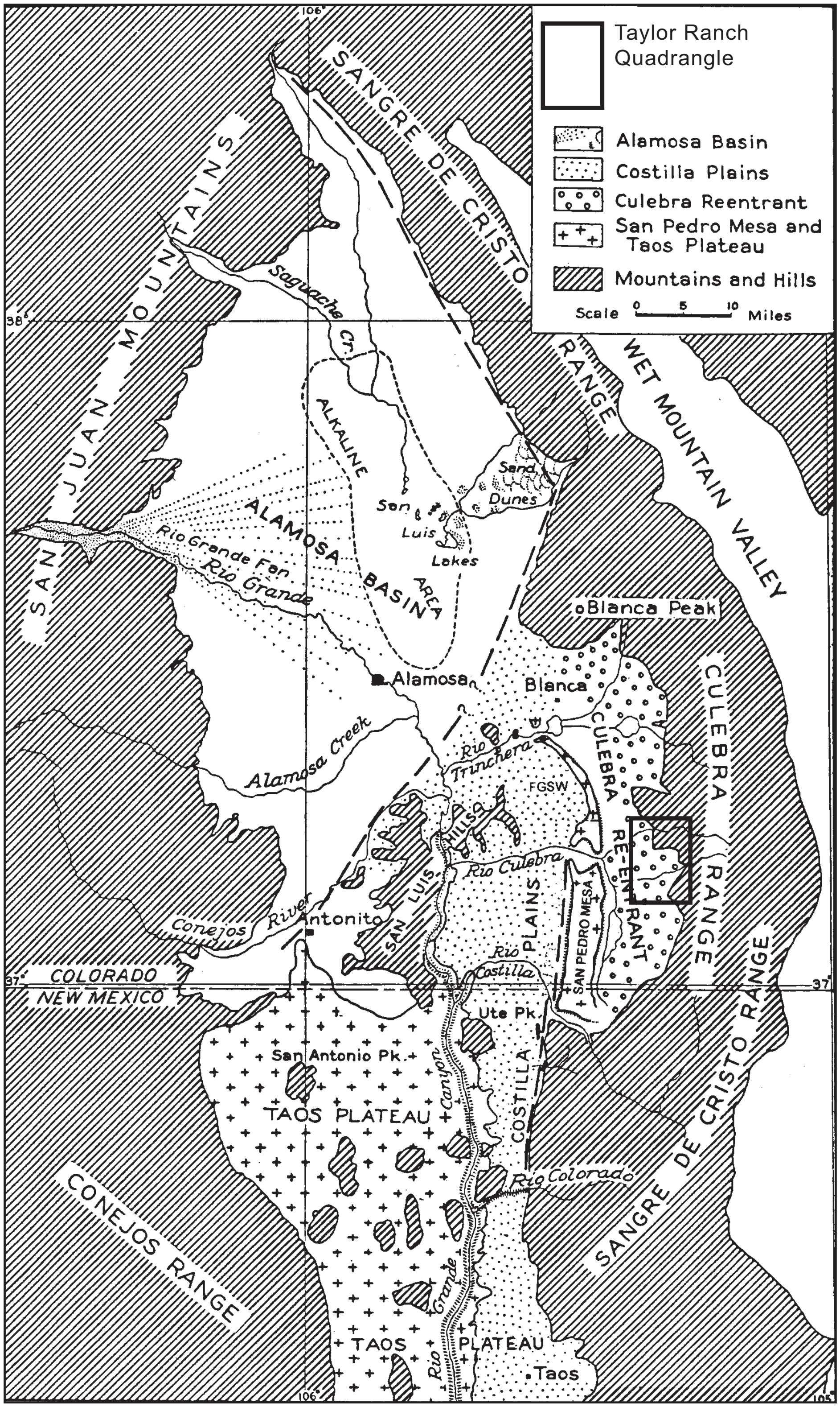
Index Map No.	Publication No.	Date	Scale
1	USGS MF-2312-E Wallace	1997	1:24,000
2	USGS MF-2312-C Wallace	1996	1:24,000
3	USGS MF-2282 Lindsey	1995	1:24,000
4	CGS OF 02-06 Kirkham and Heimsoth	in press	1:24,000
5	USGS MF-2312-B Wallace and Soulliere	1996	1:24,000
6	USGS MF-2312-A Wallace and Lindsey	1996	1:24,000
7	USGS I-1906 Thompson and Machette	1989	1:50,000

Figure 1. Location map of the Taylor Ranch quadrangle, and status of geologic mapping in adjacent areas.

and ground-water resources in the San Luis Valley. Crosscutting relations between young faults and Quaternary deposits (younger than about 1.8 million years) provide constraints on the timing and size of prehistoric earthquakes. The 1:24,000-scale geologic mapping lays the ground work required for future detailed earthquake-hazard investigations. Tertiary sediments and volcanic rocks exposed in the quadrangle, and strata that are correlative to them, serve as major aquifers in the San Luis Valley. The structural features identified by mapping have a profound effect on the geometry and connectivity of the aquifers. The maps describe the geology of the quadrangle at a scale valuable to many map users, and they also serve as good starting points for regional and site-specific studies.

GEOGRAPHIC SETTING

San Luis Valley lies in the Southern Rocky Mountain physiographic province as defined by Fenneman (1931). It is one of a series of linear valleys stretching from west Texas, through New Mexico, and into Colorado nearly to the border with Wyoming (Tweto, 1978, 1979a). The Sangre de Cristo Mountains are on the eastern side of San Luis Valley, and the San Juan Mountains form the western side of the valley in Colorado. A prominent block of steep, rugged, mountainous terrain in the Sangre de Cristos north of the quadrangle, which includes the 14,345-ft-high Blanca Peak (Fig. 2), is referred to as the Blanca Massif.



Modified from Upson (1939, 1971)

Figure 2. Physiographic subdivisions of San Luis Valley. The Taylor Ranch quadrangle is shown by the bold-outlined rectangle at right center of figure.

Upson (1939, 1971) subdivided the San Luis Valley into five distinct physiographic subdivisions (Fig. 2). The northern part of the valley, which Upson referred to as the Alamosa Basin, is north of a roughly southwest-oriented line that runs the Blanca Massif to Antonito. The San Luis Hills, which are relatively low and subdued compared to the Sangre de Cristo Mountains, are south of this line and have almost 1,000 ft of local topographic relief. The San Luis Hills separate most of the Alamosa Basin from the remainder of the valley. To the south, in New Mexico, a broad undulatory surface with local rounded hills and mountains and steep-walled, narrow, incised valleys characterizes the Taos Plateau. The eastern margin of San Luis Valley forms a reentrant from south of the Blanca Massif to a short distance south of the Colorado-New Mexico state line. Upson (1939) named this recessed area the Culebra Reentrant. The portion of the Sangre de Cristo Mountains that is east of the reentrant is called the Culebra Range. The geographic boundary between the Culebra Reentrant and the Culebra Range extends roughly north to south through the quadrangle (Fig. 2).

The Taylor Ranch quadrangle extends from the subdued foothills of the western side of the Culebra Range eastward nearly to timberline. Culebra Creek flows from east to west across the central part of the quadrangle. El Poso Creek, a major tributary to Culebra Creek, enters the quadrangle near its northeastern corner and flows southwestward to its confluence with Culebra Creek near the center of the quadrangle. North Vallejos Creek flows westward along the southern edge of the quadrangle. All three creeks have headwaters that extend to the crest of the Culebra Range. Rito Seco (Creek) obliquely crosses the northwest corner of the quadrangle.

The hills that lie between these valleys have gently to moderately steep slopes and attain a maximum elevation of about 11,300 ft in the northeast part of the quadrangle. Outcrops in the hills are relatively sparse and of limited extent. Only the more erosion-resistant igneous rocks form reasonably good, fairly continuous exposures; the sedimentary formations generally only crop out in stream banks and road cuts. The Proterozoic rocks form prominent cliffs in the glaciated upper reaches of El Poso Creek, but elsewhere they also are poorly exposed.

The southwest corner of the Taylor Ranch quadrangle lies within a prominent, regionally extensive, north-south-trending topographically low area (Fig. 3). Stevenson (1881) named this valley Culebra Park, a practice followed by Upson (1939, 1971). Culebra Park starts in New Mexico near where Rio Costilla flows out from the Sangre de Cristo Mountains (Fig. 2), runs generally northward about 25 mi, and then swings northwestward for about 20 mi, past the town of Blanca to where it merges with the Alamosa Basin. Rio Costilla has incised about 500 ft through uplifted basalt flows on the western margin of Culebra Park, but northward the park floor is generally about at the level of modern streams, including where it cuts across the southwest corner of the quadrangle.

The small villages of Chama and Los Fuertes (also called San Isidro), located in the southwest part of the quadrangle, are the only populated towns in the mapped area. Others who reside in the quadrangle live on ranches or in subdivisions. The mill and tailings impoundment for the San Luis Mine, operated by Battle Mountain Resources, Inc., is in the northwest corner of the mapped area. Production ceased here in the 1900s, and the property now is being reclaimed. Flood-irrigated fields along Culebra, El Poso, and Vallejos creeks provide forage for livestock, and much of the adjoining dry-land hill country has been grazed historically. County-maintained public roads follow the valleys of Culebra Creek, El Poso Creek, Vallejos Creek, and Rito Seco, but public access eventually ends before the roads reach the east side of the quadrangle. Unpaved subdivision roads serve portions of the western and northeastern parts of the quadrangle.

PREVIOUS GEOLOGIC MAPPING

Previously published geologic maps of the area that includes the Taylor Ranch quadrangle are regional and of small scale. No large-scale (1:24,000 or larger) geologic maps have been published for the quadrangle. Nonetheless, the geology portrayed on each small-scale map has aided our mapping of the quadrangle. A regional (scale 1:1,000,000) tectonic map of the Rio Grande Rift by Tweto (1978) covers the Taylor Ranch quadrangle, as do the 1:500,000-scale geologic maps of the entire state by Burbank and others (1935) and Tweto (1979b) and the 1:250,000-scale geologic map

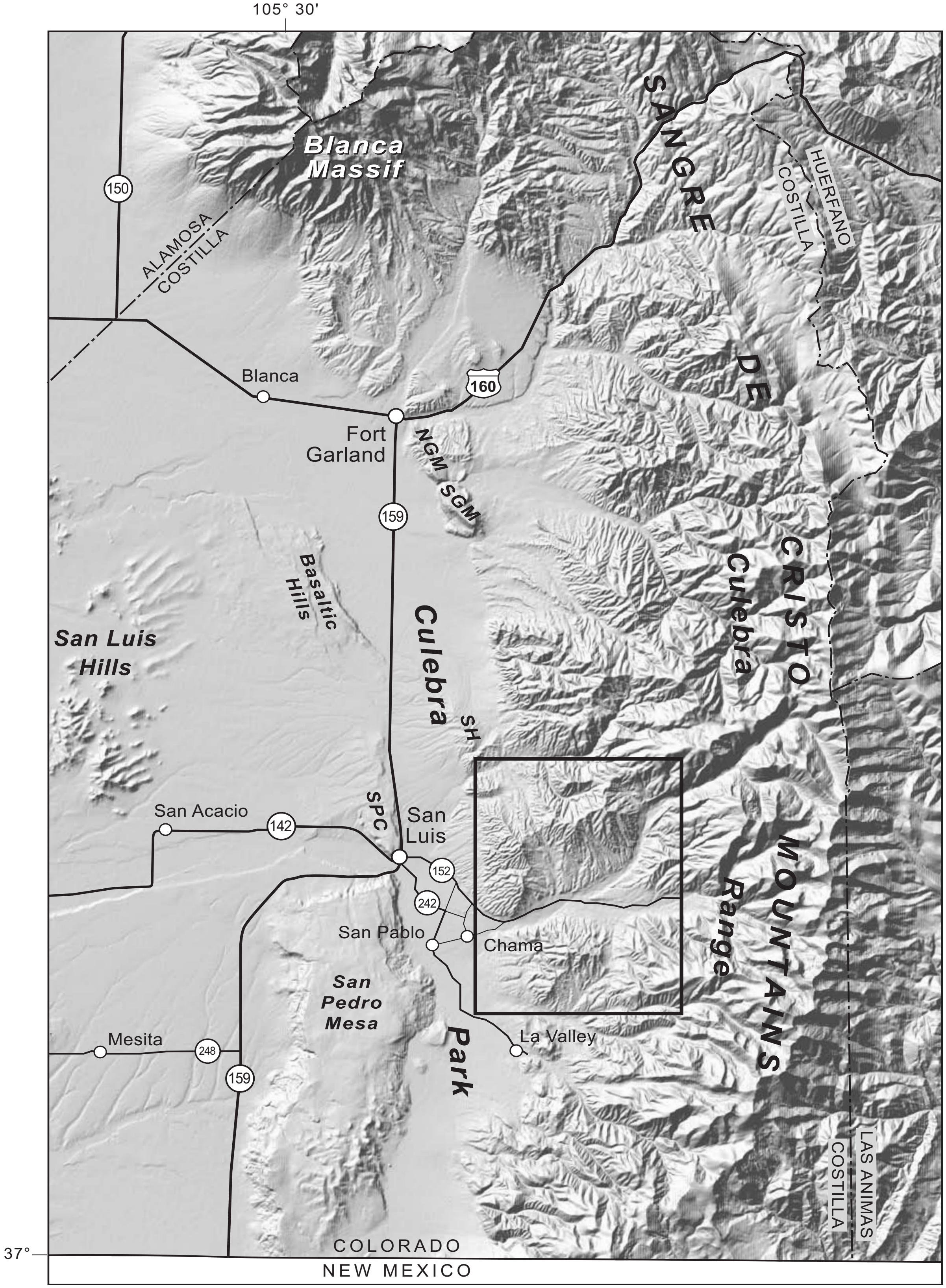


Figure 3. Selected physiographic landforms in and near the Culebra Reentrant: NGM, North Garland Mesa; SGM, South Garland Mesa; SH, Skull Hill; and SPC, San Pedro Cuesta. Rectangular box outlines Taylor Ranch quadrangle.

of the Trinidad 1° x 2° quadrangle by Johnson (1969). Upper Cenozoic strata and Quaternary faults were mapped by Colman and others (1985) at a scale of 1:125,000.

More recent and more detailed geologic mapping of adjacent areas was useful to this investigation (Fig. 1). Kirkham and Heimsoth (2003), Wallace and Soulliere (1996), and Wallace and Lindsey (1996) mapped the Fort Garland SW, Ojito Peak, and Trinchera Peak 7.5-minute quadrangles, respectively, at scales of 1:24,000. The 1:50,000-scale map of the San Luis Hills by Thompson and Machette (1989) aided stratigraphic evaluation of the Quaternary sediments and Cenozoic igneous rocks.

MAPPING METHODS AND TERMINOLOGY

Mapping responsibilities were as follows: Kirkham was responsible for mapping the Quaternary deposits and all bedrock units except for the Proterozoic rocks and the Tertiary dikes contained within them. He also led efforts to prepare the map and booklet for publication. Shaver mapped the Proterozoic rocks and igneous dikes that cut them, and helped prepare the map and booklet for publication. Lindsay assisted both Kirkham and Shaver in their mapping. Wallace conducted reconnaissance mapping in the northern part of the quadrangle for the USGS in 1995, and he provided copies of his unpublished mapping to the CGS mappers.

Field work was conducted by Kirkham, Shaver, and Lindsay from July to October, 2002. Traverses were made along all public roads and along most unimproved private roads in the quadrangle, including those accessible only to all-terrain vehicles. Nearly all arroyos and most ridgelines were walked out, and outcrops and intriguing landforms noted on aerial photography also were inspected on the ground. The best exposures of sediments in the Santa Fe Group usually were found in arroyos and road cuts.

Black-and-white aerial photography at scales of 1:53,000 (flown in 1953), 1:20,000 (1963), and 1:40,000 (1999) and color infrared aerial photography at a scale of 1:40,000 (1988) each provided complete coverage of the quadrangle. Geologic information collected in the field was inked onto the 1:20,000-scale black-and-white aerial photographs. UTM coordinates were determined using hand-held GPS receivers for most sites sampled for geochemical analysis or dating. Information drawn on the aerial photographs was compiled digitally using an ERDAS photogrammetric system; additional photogeologic interpretations also were made during this stage. The geologic map utilizes the 1:24,000-scale topographic base map of the Taylor Ranch quadrangle, which was first published by the USGS in 1967.

Grain-size terminology used herein follows the modified Wentworth scale (Ingram, 1989). This classification system describes pebbles, cobbles, and boulders as differing sizes of gravel. The general term “gravel” also is commonly used for rounded clasts that show evidence of fluvial transport. To avoid confusion, non-fluvial angular and subangular clasts ranging in size from 2–256 mm are referred to as pebble-size (small) or cobble-size (large) clasts. Terms used for sorting are those of Folk and Ward (1957). Sedimentary clasts are defined in this study as rock fragments larger than 2 mm in diameter, whereas matrix refers to surrounding material that is 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 or embedded in matrix.

GEOLOGIC SETTING

OVERVIEW

The Taylor Ranch quadrangle lies along the eastern margin of the Rio Grande Rift in south-central Colorado. It is within the southeastern part of San Luis Basin, which is a structural feature that approximately coincides with the physiographic area called San Luis Valley. Regional aspects of the rift and basin were described in numerous prior reports, books, and guidebooks, including those by Siebenthal (1910), James (1971), Tweto (1978, 1979a), Baldridge and others (1984), Chapin and Cather (1994), Brister and Gries, (1994), Kluth and Schaftenaar (1994), and Brister and McIntosh (in press).

STRATIGRAPHY

The oldest rocks in the Taylor Ranch quadrangle are Early Proterozoic basement rocks that crop out in the north-central and northeast parts of the mapped area. These crystalline rocks consist of an interlayered package of leucocratic to hornblende gneisses. Porphyroblastic, almost igneous-appearing leucrocratic augen gneiss (unit Xag) dominates in the deeply eroded and exposed sections. Locally, this unit is pegmatitic (unit Xagp). Topographically higher, and perhaps stratigraphically higher as well, these units first grade to a more equigranular leucocratic gneiss (unit Xlg), then to interlayered felsic and hornblende gneiss (units Xfh and Xhf). Because of the interlayered nature of these lithologies, map unit boundaries were determined chiefly on the basis of relative percentages of lithologies rather than sharply defined contacts.

A single gabbroic dike (unit PzZg) was observed cutting the Early Proterozoic rocks near the northeast corner of the quadrangle. Similar rocks were classified as early Paleozoic or Late Proterozoic by Wallace and Soulliere (1996) in the adjacent Ojito Peak quadrangle and by Lipman and Reed (1989) in northern New Mexico south of Taylor Ranch quadrangle. Several small dikes of latite porphyry and andesitic porphyry (unit Ti), and a rubbly outcrop of rhyolite (shown by the red square in the western part of unit Xlg near the north edge of the quadrangle) also intrude the Proterozoic crystalline rocks. The ages of these dikes are poorly constrained; they probably are Oligocene or Miocene, but could also be related to the Eocene-late Cretaceous Laramide orogeny. Whole-rock geochemical analyses of samples collected from these dikes are shown in Table 1. The rock names assigned to the dikes are based in part on where they plot on a total alkali-feldspar diagram (Fig. 4) by Le Bas and others (1986).

The oldest sedimentary rocks in the quadrangle (unit Tsr) are poorly exposed, predominantly redbeds in the southeast and north-central parts of the quadrangle. Upson (1941) included these redbeds in the Vallejo Formation, which he considered to be Eocene or Oligocene. Upson failed to report a type locality for the Vallejo Formation, but he did state that it is named for outcrops of strata exposed in the valley of Vallejo Creek (herein referred to as the type area). Following a brief reconnaissance of Upson's type area along Vallejos Creek, P.W. Lipman (1990, written commun. to B.S. Brister) concluded that the sediments described as Vallejo Formation in the type area were probably part of the Santa Fe Group. Brister and Gries (1994) also concluded that the redbeds in the type area along Vallejo Creek were Miocene or younger and that they were part of the Santa Fe Group.

Our preliminary reconnaissance work in the type area supports the conclusions that the "Vallejo" strata in the type area are Miocene or younger. North-dipping basaltic flows that appear to correlate to the Miocene-Pliocene Hinsdale Formation locally crop out low on the north valley wall of South Vallejos Creek. Therefore most and perhaps all of the sediments exposed between South and North Vallejos Creeks, which is Upson's type area for the Vallejo, are within the Santa Fe Group. Until these strata are better studied, we assign a possible age range of Miocene to Eocene to them.

Pre-volcanic redbed strata in the west-central part of Ojito Peak quadrangle (Wallace and Soulliere, 1996) and in the northern part of the Trinchera Ranch quadrangle (Wallace, 1996) appear to match Upson's criteria for the Vallejo Formation. At these localities, fine- to coarse-grained redbeds rest on Proterozoic rocks and are overlain by a

Table 1. Geochemical analyses of rock samples from Taylor Ranch and La Valley quadrangles. (all analyses by ALS Chemex, except for sample 94TR29; XRF method used for major elements; ICP method used for gold; # = analysis by USGS; atomic absorption used for gold; emission spectroscopy used for other metals; %, percent; ppm, parts per million; ppb, parts per billion;<, less than)

	Major Oxides in Weight Percent														
Sample ID	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	SrO	TiO_2	LOI	Total
Taylor Ranch quadrangle															
TR16a	15.23	0.14	8.67	<0.01	8.59	2.07	4.52	0.05	4.02	0.59	49.04	0.19	1.35	4.98	99.44
TR16b	15.20	0.13	10.86	<0.01	8.19	2.06	2.79	0.11	3.59	0.62	45.16	0.18	1.36	8.42	98.67
TR16c	15.24	0.14	8.01	0.01	8.67	2.07	4.07	0.04	3.79	0.60	48.92	0.19	1.39	5.74	98.88
TR16d	15.52	0.13	8.29	0.01	8.93	2.13	4.17	0.06	3.91	0.62	49.77	0.18	1.38	4.12	99.22
TR25	15.62	0.10	7.40	0.03	9.16	2.86	7.12	0.12	3.17	0.43	49.24	0.09	1.56	3.03	99.93
TR30	16.27	0.15	6.31	0.01	7.85	2.56	2.72	0.05	4.16	0.51	54.82	0.13	1.28	2.56	99.38
TR32	15.55	0.14	2.72	<0.01	3.05	3.49	1.29	0.05	4.43	0.15	67.86	0.07	0.43	0.61	99.84
TR47	14.80	0.12	8.62	0.02	9.34	1.87	5.26	0.07	3.57	0.54	50.21	0.14	1.33	3.63	99.52
TR50	16.44	0.14	4.94	<0.01	7.26	2.78	2.37	0.05	4.09	0.48	56.24	0.12	1.23	3.35	99.49
TR63	15.26	0.08	6.71	0.03	8.31	2.33	4.49	0.11	5.90	0.54	51.47	0.12	1.32	3.46	100.13
TR86	15.21	0.08	7.80	0.04	9.40	2.64	6.26	0.15	5.30	0.43	47.61	0.06	1.72	3.35	100.05
TR87a	15.19	0.08	7.17	0.04	9.67	1.92	7.97	0.15	5.21	0.46	46.61	0.06	1.73	3.91	100.17
TR87b	15.71	0.04	7.56	0.03	9.38	2.68	6.46	0.12	4.83	0.45	48.14	0.06	1.77	2.68	99.91
TR93a	15.20	0.10	7.72	0.02	8.76	2.19	4.04	0.13	6.13	0.61	50.38	0.15	1.40	2.13	98.96
TR93b	15.40	0.12	8.02	0.02	9.85	2.01	5.84	0.16	6.06	0.69	48.85	0.18	1.60	1.40	100.20
TR194a	15.70	0.06	8.78	0.04	12.16	0.86	6.57	0.18	5.23	0.27	48.14	0.04	1.42	0.73	100.18
TR194b	16.22	0.02	9.03	0.03	12.05	0.78	6.47	0.18	5.14	0.26	47.54	0.04	1.38	0.74	99.88
TR422-1	15.26	0.09	5.81	0.02	8.09	3.56	2.82	0.10	6.02	0.49	54.64	0.10	1.09	1.90	99.99
TR422-2	15.89	0.12	4.46	0.02	8.30	4.04	2.53	0.06	6.14	0.52	55.01	0.12	1.14	1.77	100.12
TR423	14.27	0.09	5.85	0.03	6.94	2.78	4.70	0.08	5.77	0.48	54.68	0.10	1.09	3.27	100.13
TR480	16.38	0.06	8.26	0.04	12.19	0.68	6.59	0.19	4.83	0.27	46.64	0.04	1.42	2.32	99.91
TR576b	17.97	0.15	3.54	<0.01	6.26	4.64	0.55	0.01	4.42	0.57	58.16	0.14	1.10	2.26	99.77
TR578L	11.82	<0.01	0.46	<0.01	0.59	4.41	0.04	0.07	3.66	0.01	76.88	<0.01	0.04	1.53	99.51
TR578u	17.26	0.14	3.18	0.01	6.70	4.94	0.39	0.07	4.03	0.53	59.21	0.11	1.14	2.13	99.84
TR725	15.98	0.02	8.72	0.05	11.93	0.84	7.00	0.18	5.13	0.27	47.73	0.04	1.36	0.66	99.91
TR725	15.98	0.02	8.72	0.05	11.93	0.84	7.00	0.18	5.13	0.27	47.73	0.04	1.36	0.66	99.91
TRQ55	15.08	0.07	5.91	0.03	10.61	2.55	5.21	0.15	6.31	1.01	47.16	0.08	1.98	3.71	99.86
TRQ154	14.72	0.12	5.57	0.04	6.90	2.85	4.69	0.11	5.81	0.46	55.27	0.09	1.05	2.31	99.99
TRQ160	11.21	0.04	0.29	0.03	0.94	9.54	0.08	0.15	0.22	<0.01	74.85	<0.01	0.05	0.97	98.37
La Valley quadrangle															
LV1a	15.52	0.09	8.78	0.03	9.25	2.01	5.60	0.12	3.54	0.46	47.11	0.09	1.63	4.74	98.97
LV1b	15.62	0.09	6.81	0.03	9.52	1.59	7.63	0.13	3.59	0.43	47.85	0.08	1.56	4.41	99.34
LV1c	15.78	0.09	7.59	0.03	9.48	1.93	6.92	0.13	3.39	0.43	48.11	0.08	1.57	4.32	99.85
LV7	15.43	0.20	6.90	0.02	9.43	1.56	7.69	0.13	3.78	0.43	48.37	0.08	1.58	3.66	99.26
LV8	15.73	0.10	6.60	0.03	9.12	2.16	7.55	0.11	3.69	0.42	49.25	0.09	1.61	3.09	99.55
LV10	15.66	0.09	6.43	0.02	9.04	2.40	7.46	0.11	3.28	0.42	48.74	0.09	1.59	3.77	99.10
LV12a	15.52	0.09	6.55	0.03	9.47	1.86	7.74	0.12	3.88	0.42	48.00	0.09	1.61	3.66	99.04
LV12b	15.32	0.10	6.97	0.02	8.86	2.24	6.81	0.10	3.32	0.42	48.58	0.11	1.64	3.77	98.26

Taylor Ranch quadrangle

	Au ppb	Ba ppm	Ag ppm	Mn ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm	V ppm	As ppm
94TR29#	46	330	74	1300	4200	3	31	170	66	<10
TR171	<1									

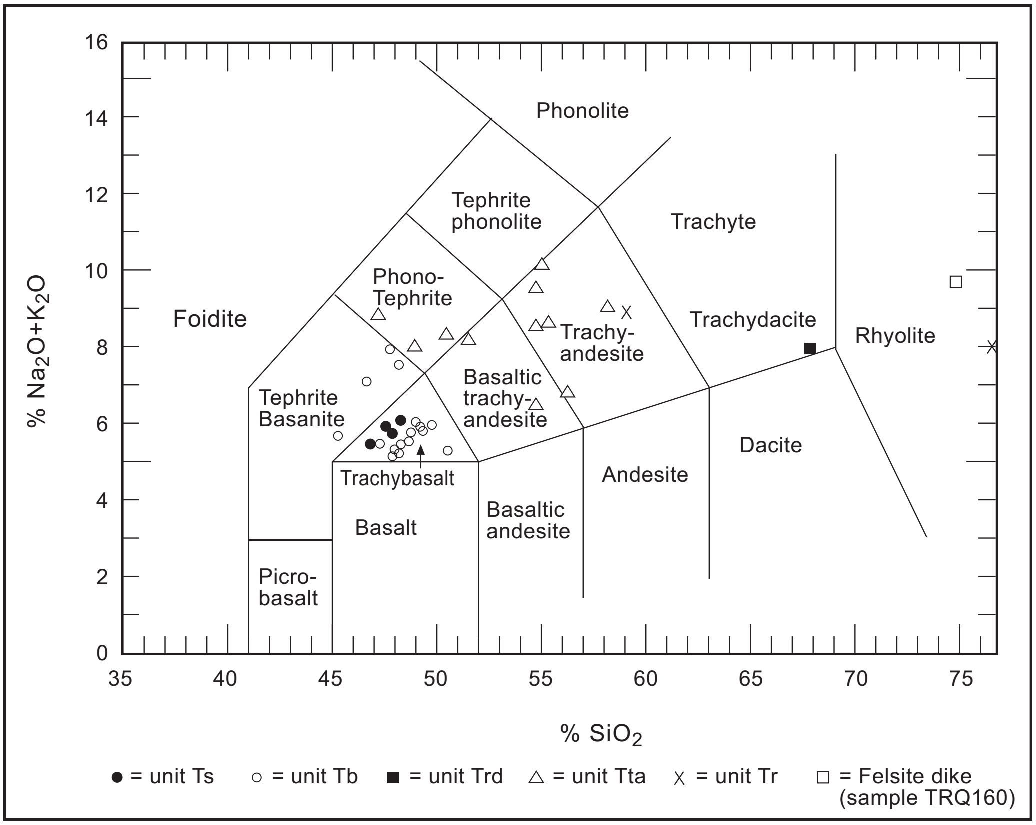


Figure 4. Graph showing total alkali and silica concentrations of igneous rock samples collected from the Taylor Ranch and La Valley quadrangles using the classification scheme of Le Bas and others (1986). Values are in weight percent. See Table 1 for geochemical analyses.

thick sequence of volcanic flows, lahars, and breccias that are correlated with the Oligocene Conejos Formation in the San Luis Hills. A tuff in the volcanic sequence overlying the redbeds in Trinchera Peak quadrangle is 29.6 ± 0.1 Ma (Wallace, 1996); therefore, the underlying redbeds could be Eocene. The conglomerates at these locations have characteristics similar to Upson's Vallejo: many conglomeratic clasts have prominent, dark-red, hematitic weathering rinds, and fractures cut through the larger clasts.

The poorly exposed, predominantly redbed sequence within the Taylor Ranch quadrangle are locally overlain by a sequence of volcanic flows that are chiefly trachyandesite (unit Tta). Samples from two of the flows (TR47 and TR423) yielded $^{40}Ar/^{39}Ar$ ages of 14.40 ± 0.12 Ma and 13.02 ± 0.06 Ma (Peters, 2003). These middle Miocene ages provide a minimum age constraint for the underlying redbeds; they must be pre-middle Miocene. However, additional absolute-age control, paleontological evidence, or stratigraphic control is needed to clearly establish the age of the redbed sequence (unit Tsr).

The Santa Fe Group is the youngest "bedrock" unit in the quadrangle. Hayden (1869) originally named the sediments exposed in the hills near Fort Garland and San Luis the Santa Fe Marls. Siebenthal (1910) called them the Santa Fe Formation. Kottlowski (1953) raised the rank to a group status on the basis of work in southern New Mexico. This practice was followed by many later workers, including Spiegel and Baldwin (1963), who favored a group ranking "that includes all the synrift basin fill, both volcanic and sedimentary, ranging in age from late Oligocene to Quaternary, but excluding deposits that postdate entrenchment of the Rio Grande in middle Pleistocene time." Following this approach, Brister and Gries (1994) included all pre-middle Pleistocene deposits in the Alamosa Basin that overlie upper Oligocene tuffs in the Santa Fe Group. They placed deposits that most prior workers called the Santa Fe Formation (e.g. Siebenthal, 1910; Powell, 1958) in the lower Santa Fe Group. The fluviolacustrine Alamosa Formation of Siebenthal (1910), which is known only in the Alamosa Basin, constituted their upper Santa Fe Group.

Although the Santa Fe Group has not been subdivided formally into formations in the Taylor Ranch quadrangle, we will follow this recent stratigraphic nomenclature and herein assign a group status to the Santa Fe. The Santa Fe Group in the quadrangle thus consists of a thick sequence of synrift sediments (unit Tsf) and intercalated volcanic flows (units Ts, Tb, Trd, Tr, and Tta) that comprise units within the group. The sequence of predominantly redbed sedimentary rock that locally underlies the middle Miocene unit Tta may or may not be part of the Santa Fe Group.

Most Santa Fe sediments in the quadrangle are Miocene and Pliocene in age, but at the base some may be upper Oligocene. This age assignment is mainly based on: (1) the middle Miocene age of the intercalated volcanic flows of units Tb and Tta, which range in age from 11.74 ± 0.51 Ma to 14.40 ± 0.12 Ma (Peters, 2003); and (2) the presence of flows in the upper part of the group that are correlated with the Servilleta Basalt (unit Ts), which in adjacent areas ranges in age from 3.66 ± 0.01 Ma to 4.75 ± 0.10 Ma (Wallace, 1997; Miggins, 2002).

Most Santa Fe sediments in the quadrangle consist of conglomerate and conglomeratic sandstone deposited in fan and stream environments proximal to sources in the tectonically rising Culebra Range. However, fine- to coarse-grained sandstone and minor mudstone are the predominant lithologies in the topographically low areas underlain by Santa Fe sediments in the south-central part of the quadrangle and in the area stretching from the northwest corner of the quadrangle to near Cañon Church. Although no mappable beds of volcanic ash were observed within the Santa Fe in the quadrangle, beds of volcanic ash likely do exist there. Pieces of volcanic ash were noted in a pile of debris dug from an animal burrow situated in the Sante Fe that is located in the south-central part of the quadrangle. A bed of volcanic ash occurring in the Santa Fe to the northwest of Taylor Ranch quadrangle that was correlated with the 11.93 ± 0.03 Ma tuff of Ibex Hollow (Kirkham and Heimsoth, 2003), along with a continuous bed of ash noted in La Valley quadrangle immediately south of the mapped area, provide additional evidence of the likely presence of ash beds within the Santa Fe Group in the Taylor Ranch quadrangle.

Lithologies of clasts in the Santa Fe sediments vary across the quadrangle. Clasts eroded from Proterozoic rocks are present everywhere, and in many locations they are the only lithology present. Paleozoic sedimentary clasts are locally the predominant clast type, and volcanic clasts locally comprise as much as half of the clasts. The percentage of volcanic clasts is noticeable higher in strata above volcanic flows that are interbedded with Santa Fe sediments, suggesting syn-deposition tectonism and uplift and local exposure of the volcanic flows to erosion.

Sediments in the Santa Fe Group are only very weakly indurated and generally do not form good outcrops. Most Santa Fe exposures are in arroyo banks or road cuts. The relatively thin sequences of volcanic rocks that are locally intercalated with the Santa Fe sediments, however, are well-indurated and sometimes form cliffy exposures. Most volcanic flows within the Santa Fe Group are trachybasalts (Table 1; Fig. 4). A single small outcrop in the north-central part of the quadrangle that appears to lie within or at the base of Santa Fe sediments (unit Tr) includes a basal devitrified rhyolitic ash flow and an overlying unit that appears to be a lahar. The outcrop pattern of rhyodacitic rocks (Trd) near the southeast corner of the quadrangle suggests these rocks are oriented in a near-vertical position. There are no nearby exposures of the sediments in which these silicic igneous rocks occur; hence, the structural attitude of the block containing the igneous rocks is unknown. Although flow structure is preserved in these silicic rocks, we are uncertain whether they are flows or dikes.

Trachybasalts in the lower part of the Santa Fe Group (unit Tb), including those in the relatively long, north-south-trending outcrop in the south-central part of the quadrangle and in the small fault-bounded blocks on the north side of North Vallejos Creek, probably are age equivalent to the Hinsdale Formation in the San Luis Hills (Thompson and Machette, 1989). A sample of the Hinsdale-equivalent flows (TR87a) yielded an $^{40}Ar/^{39}Ar$ age of 11.74 ± 0.51 Ma (Peters, 2003).

Trachybasalts in the upper part of the Santa Fe Group (unit Ts) crop out in the foothills along the western edge of the quadrangle. These flows are correlated with the Pliocene Servilleta Basalt reported in nearby areas to the northwest, west, and southwest (Kirkham and Heimsoth, 2003; Miggins and others, 2002; Thompson and Machette, 1989; Lipman and Reed, 1989). The Servilleta Basalt originally was named the Servilleta Formation by Butler (1946), on the basis of exposures on the Taos Plateau in the southern part of the San Luis Basin. Initially, the formation included intercalated sediments (Butler, 1946; Montgomery, 1953). Lipman and Mehnert (1979) excluded the sediments from the formation and renamed it the Servilleta Basalt. Here, we also exclude the sediments from the unit, although in areas with poor exposure, some undetected Santa Fe sediments may be intercalated with the mapped flows.

Quaternary deposits are generally thin, but they mantle the bedrock across much of the quadrangle. Thick glacial till underlies moraines along the eastern margin of the quadrangle in the valleys of El Poso and North Vallejos creeks, and it also is found about 1 mi east of the quadrangle in Culebra Creek valley. Glacial outwash deposits form the terraces found along all three major creeks within the Taylor Ranch quadrangle. The glacial outwash terraces extend westward to the system of Quaternary faults near the western margin of the quadrangle. West of the Quaternary faults, the outwash alluvium was deposited in broad fans. Fan alluvium also was deposited by most tributary streams, including a sequence of older fans that grade to the Pleistocene outwash terraces and fans. An excellent exposure of the early middle Pleistocene Lava Creek B ash is present in a tributary drainage on the south side of El Poso Creek.

STRUCTURAL GEOLOGY

The San Luis Basin, which roughly coincides with the floor of San Luis Valley, is generally characterized as a large east-tilted half graben that began to form in late Oligocene time. It is part of the northern Rio Grande Rift, a north-south-trending continental rift that extends from west Texas at least to northern Colorado (Tweto, 1978, 1979a). Lipman and Mehnert (1975) proposed that rifting initiated around 27–26 Ma, and Miggins and others (2002) suggest the inception of extension was 27–25 Ma.

Brister and Gries (1994) and Wallace (1995) demonstrated that the northern part of San Luis Basin (or Alamosa Basin) contains a pair of half grabens (Fig. 5). Late Cenozoic sediment conceals a buried, north-trending, mid-valley structural high between the two half grabens in the Alamosa Basin (Tweto, 1978, 1979a; Brister and Gries, 1994). Oligocene and younger volcanic rocks and minor intrusive rocks in the San Luis Hills in the southern part of the San Luis Basin form another intrarift horst.

The Sangre de Cristo fault, a major north-northwest-striking, west-dipping, normal-displacement structure, forms the eastern margin of San Luis Basin. From about Blanca Peak northward to about Poncha Pass and from near the Colorado-New Mexico state line southward to beyond Taos, New Mexico, the Sangre de Cristo fault is a relatively narrow and generally linear fault zone that lies at the base of the abrupt western range front of the Sangre de Cristo Mountains (Widmann and others, 1998, 2002). Between these two end sections and within the Culebra Reentrant, the fault is geometrically complex and it consists of several en echelon strands which are at the western edge of relatively subdued foothills underlain by the Santa Fe Group. Within the Culebra Reentrant, the main range crest is set back several miles to the east relative to the range crests to the north and south. Many additional late Cenozoic, rift-related faults cut the strata exposed between the range crest and the Sangre de Cristo fault within the Culebra Reentrant.

The Taylor Ranch quadrangle straddles the structurally complex region in the Culebra Reentrant (Fig. 6). The Rito Seco strand of the San Luis section of the northern Sangre de Cristo fault (Widmann and others, 1998, 2002) cuts across the southwestern part of the quadrangle. This strand forms the eastern margin of the Culebra graben, as described by Kirkham and Heimsoth (2003). Scarps along the Rito Seco strand document late Quaternary faulting within the quadrangle. A series of subparallel structures in the footwall of the Sangre de Cristo fault system offset deposits of middle Pleistocene alluvium (unit Qfo), but are concealed by late Quaternary alluvium along the valleys of Culebra and Vallejos Creeks. Such concealment suggests that these structures are no longer active or are less active than the Rito Seco strand.

Evidence of Quaternary activity is present along other strands of the Sangre de Cristo fault system to the northwest of the Taylor Ranch quadrangle (Kirkham and Heimsoth, 2003; Widmann and others, 1998; Wallace, 1997; Colman and others, 1985; McCalpin, 1982) and to the south (Machette and others, 1998; Menges, 1988). A major late Cenozoic structure that cuts across the southwest corner of the quadrangle probably is part of the Trinchera Peak fault system of Wallace and Lindsey (1996).

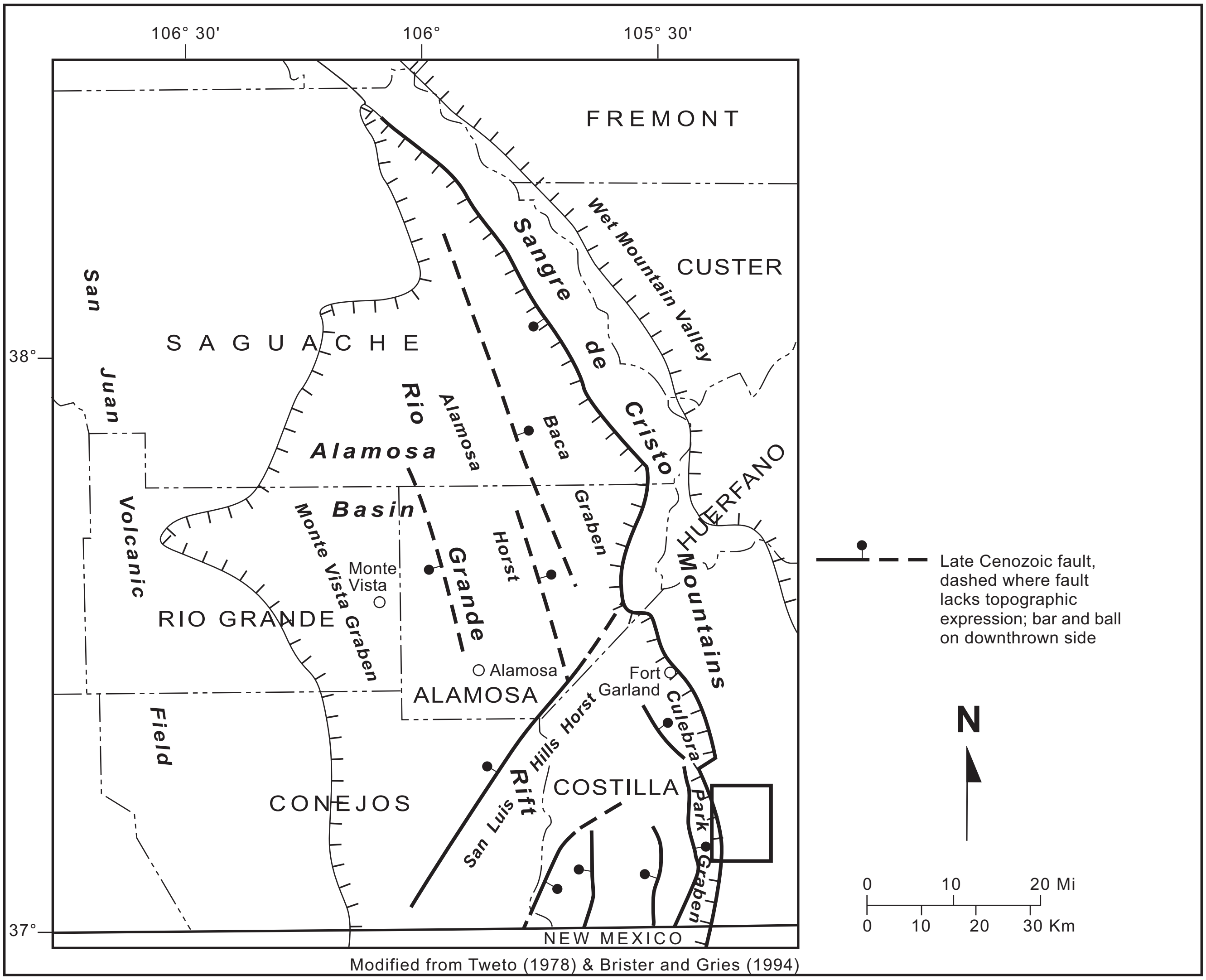


Figure 5. Simplified late Cenozoic structure of the part of the Rio Grande Rift. (Modified from Tweto [1978] and Brister and Gries [1994])

Numerous northwest- and northeast-striking faults cut the late Cenozoic deposits between the Sangre de Cristo and Trinchera Peak faults. These faults bound blocks of varying sizes and structural orientations. Most faults are downthrown to the west, and strata within the larger blocks generally dip eastward. This causes younger Santa Fe strata to crop out in the topographically lower, western part of the quadrangle in the footwall of the Sangre de Cristo fault; older Santa Fe strata crop out in the western, topographically higher parts of the mapped area.

Dip changes in the Santa Fe strata were used to define the approximate locations of many of the faults that cut only these strata. Stratal dip changes on opposite sides of the major creeks also lead us to conclude that concealed faults, perhaps Laramide tear faults that were reactivated as Neogene extensional structures, may underlie the major stream valleys in the quadrangle. This conclusion is supported by apparent down-to-southeast offset of the Proterozoic rocks by the fault beneath the valley of El Poso Creek near the edge of the mapped area (see cross section B–B'). The isolated outcrop of brecciated leucocratic gneiss (unit Xlg) on the southeast side of El Poso Creek in the east-central part of the quadrangle may support the presence of a concealed fault beneath this part of El Poso Creek valley. Because the southeast-dipping Proterozoic-Santa Fe contact does not crop out on the northwest side of the valley, a down-to-the-northwest fault could underlie the valley here, unless the

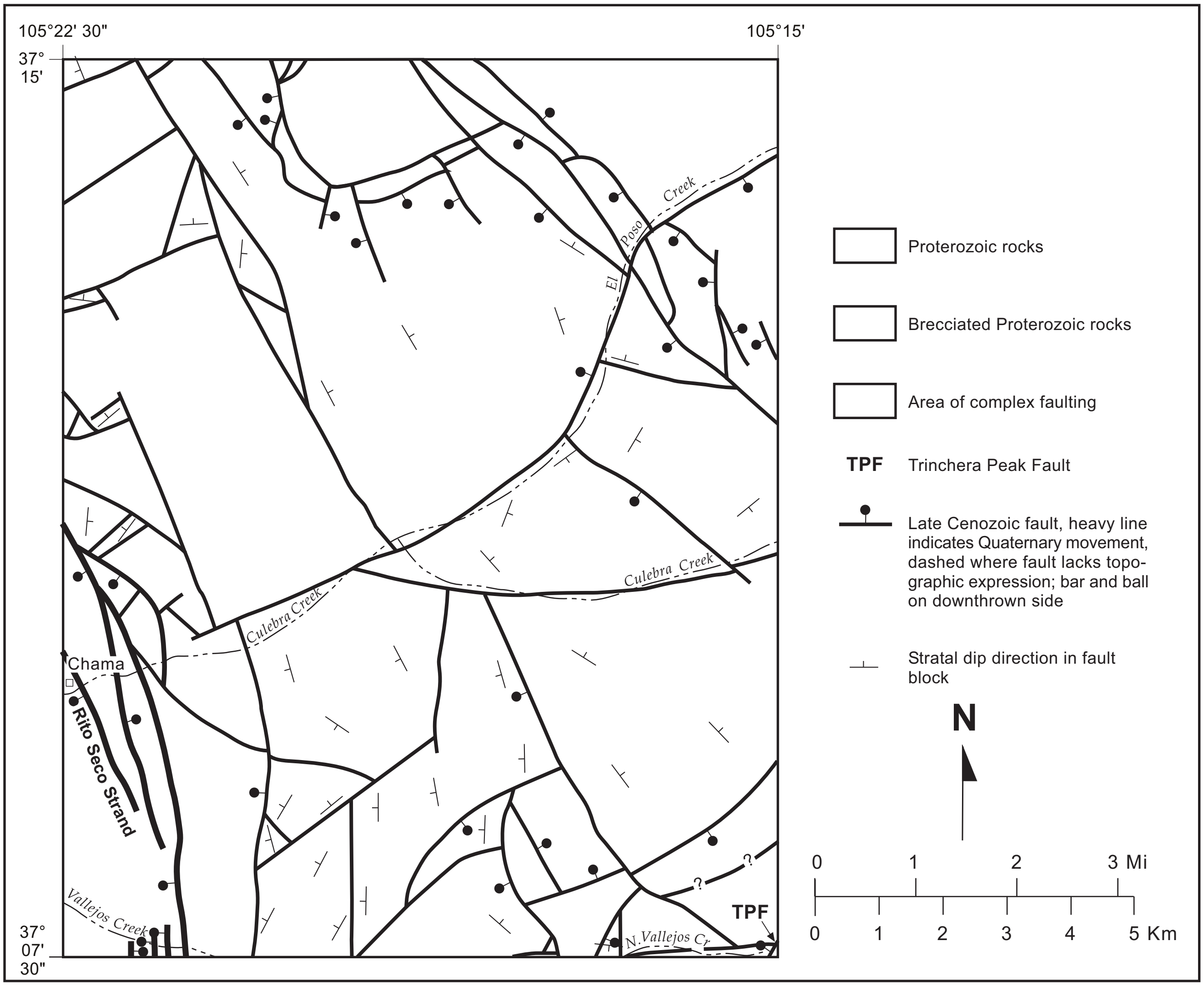


Figure 6. Simplified late Cenozoic structure of the Taylor Ranch quadrangle.

contact is highly undulatory. Crosscutting relationships depicted on the map between the concealed faults that underlie the valleys and the faults that cut obliquely across the valleys are stylized. The precise relationships of the fault intersections are unknown, and it is likely that the structural geology is more complex than depicted on the map.

An area of complex faulting is on the eastern side of the Sangre de Cristo fault system. Small faults were noted in many of the outcrops examined in this area, but only those that can be seen in more than one outcrop, coincide with topographic lineaments, or cut volcanic flows are shown on the map. Stratal dips rapidly change within the area of complex faulting, and the few outcrops of Servilleta Basalt, which in nearby areas is very continuous laterally (Kirkham and Heimsoth, 2003; Wallace, 1997; Thompson and Machette, 1989), are in discontinuous, small fault blocks.

Brecciated leucocratic gneiss underlies a large hill along the northern edge of the quadrangle. This thick sheet of breccia is petrologically similar to and adjacent to a sub-horizontal breccia zone in the Ojito Peak quadrangle (Benson and Jones, 1996; Wallace and Soulliere, 1996). However, the two bodies of breccia are separated by an east-west-trending fault along Rito Seco (Wallace and Soulliere, 1996). Futhermore, the breccia north of the creek was mineralized to form the San Luis gold deposit, but the breccia south of Rito Seco is apparently less mineralized (Benson and Jones (1996). Benson (1997) and Benson and Jones (1996) interpreted the breccia zone as a detachment sheet that presumably slid westward from the Culebra Range early during rifting. The overall geometry of the breccia zone in Taylor Ranch quadrangle suggests that it is a west-dipping structure with low to moderate dip, but exposures are inadequate to provide additional evidence for or against an interpretation as a low-angle detachment structure. The breccia sheet north of Rito Seco is locally overlain by tilted Santa Fe sediments (Wallace and Soulliere, 1996), and trachyandesite flows that dip 16° north locally overlie the breccia sheet in Taylor Ranch quadrangle. Therefore, the present configuration of the breccia sheet on both sides of Rito Seco does not exactly match its original orientation (Wallace and Soulliere, 1996).

A prominent, large-displacement normal fault truncates the western end of the breccia zone and ore body at Battle Mountain Gold Company's San Luis Mine in the Ojito Peak quadrangle. The fault is well exposed in the western end of the reclaimed open pit, less than 1 mi north of the map area. In the reclaimed pit, this N15 to 20°W-striking, 55 to 65° west-dipping fault juxtaposes Santa Fe sediment against Proterozoic rock that is shattered and rich in clay gouge in a 25- to 30-ft-wide zone that is adjacent and subparallel to the fault. The Santa Fe sediment in the footwall adjacent to the fault is part of an east-tilted fault block that dips 30 to 35° east. An exploration drill hole for the gold mine penetrated about 1,000 ft of Santa Fe sediments on the west side of the structure (R.G. Benson, 2001, oral commun.). The drill hole did not reach the base of the Santa Fe sediments, but it demonstrates that the vertical displacement on the fault exposed in the pit at San Luis Mine may exceed 1,000 ft.

The fault that truncates the west side of the breccia sheet in Taylor Ranch quadrangle may be a southward continuation of the fault exposed in the open pit at the San Luis Mine. The fault trends south-southeast for about 0.5 mi from the edge of the quadrangle. We infer that the fault gradually bends eastward, following the arcuate valley cut into brecciated Proterozoic rocks. A subparallel system of faults lies about 1,000 ft south and southwest of the fault along the Forbes Road. This fault places brecciated gneiss against the Santa Fe Group, a relationship well exposed along Skidmore Road at UTM coordinates 470,085 E and 4,120,970 N (zone 13, NAD27). Here, the fault plane, which is marked by a dark red-brown clay gouge that separates Proterozoic rocks from Santa Fe sediments, strikes N10 to 20°W and dips 70 to 72°W. The fault geometry in this part of the quadrangle likely is more complex than shown on the map. Undetected faults may extend southward from the mapped bends in these faults, into an area underlain by the Santa Fe Group that lacks exposures.

GEOLOGIC HAZARDS AND ENGINEERING CONSTRAINTS

Geologic hazards and engineering constraints present in Taylor Ranch quadrangle include sediment-laden flooding, debris flows, earthquakes and surface rupture of faults, rockfall, landslides, and problematic soils. Areas underlain by alluvial unit one (Qa_1) and younger fan deposits (unit Qfy) are prone to flooding, including sediment-laden flood waters, debris flows, and mud flows. Sheet flooding may be expected to occur in areas mapped as sheetwash (unit Qsw).

Potentially catastrophic damage may result from fault rupture within or adjacent to the quadrangle. Faults that displace Quaternary deposits, particularly late Quaternary deposits, have experienced movement during the recent geologic past and are probably capable of future movement. Future earthquakes as large as about magnitude 6 3/4 to 7 1/4 may occur on these faults, causing tens of miles of surface rupture and several feet of differential displacement of the ground surface along these faults. Structures built on and near the faults can be damaged by rupture of the ground surface, but the ground shaking generated by the earthquakes poses a more far-reaching threat. Earthquakes can also trigger secondary effects, such as liquefaction, rockfall, and landsliding, which potentially can cause great damage.

Rockfall is a hazard on and beneath cliffs of hard rock, such as those found in Proterozoic rocks in El Poso Creek valley, and where ledges of Cenozoic volcanic rocks crop out across the quadrangle. Areas mapped as talus (unit Qta), and some areas mapped as colluvium (unit Qc), are particularly prone to rockfall. Although landslides are not common in the quadrangle, a few are present in areas underlain by the Tertiary redbeds (unit Tsr) and morainal deposits, and in Santa Fe sediments along incised drainages.

Fine-grained sediments deposited in fan environments and on colluvial slopes may create conditions favorable for hydrocompaction and piping. Such sediments may be found in units Qfy, Qa_1, Qa_2, Qa_3, Qa_4, Qc, Qcs, and Qcf.

MINERAL RESOURCES

Potential sand and gravel resources occur in most Quaternary alluvial deposits and in the Santa Fe Group in much of the map area. There are no permitted sand and gravel operations in the quadrangle (Colorado Division of Minerals and Geology, 2003, http://mining.state.co.us/operatordb/report.asp), but evidence of past sand and gravel mining was noted in several areas. Several of the volcanic units, for example units Ts, Tb, and Tta, and talus (unit Qta), may be suitable for moderate to high-quality riprap.

The gold deposit at the San Luis Mine, which was operated by Battle Mountain Resources, Inc., is located in Ojito Peak quadrangle immediately to the north. The mill, tailings pond, and several waste rock piles and soil stockpiles associated with this mine are located in the northwest part of the quadrangle. Most mineralization in the San Luis deposit took place in brecciated Proterozoic biotite gneiss in a low-angle fault zone; minor mineralization was hosted in an underlying biotite gneiss cataclasite (Benson, 1997). An assay on a sample collected from a small mine dump in the brecciated leucocratic gneiss in the north-central part of the Taylor Ranch quadrangle contained over 4 percent copper, 460 ppb (parts per billion) gold, 74 ppm (parts per million) silver, and 170 ppm zinc (Table 1). A sample of silicified breccia from leucocratic gneiss on the south side of El Poso Creek contained less than 1 ppb of gold.

No petroleum exploration wells have been drilled in the quadrangle (Colorado Oil and Gas Conservation Commission (http://cogccweb.state.co.us). Only four wells have been drilled in all of Costilla County; all four were drilled and abandoned.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits blanket much of Taylor Ranch quadrangle, effectively concealing the underlying bedrock. Most of the surficial deposits in the quadrangle are not well exposed due to vegetative cover and limited outcrops. The best exposures occur in the eroded banks of arroyos and road cuts. Because of the limited exposures, the attributes of these units, such as thickness, texture, stratification, and composition, are based on observations made at only a few locations, whereas their origin is often based only on geomorphic characteristics. Since many of the intended users of this map will be interested in unconsolidated surficial materials and active surficial processes, the surficial deposits are subdivided into a relatively large number of map units compared to traditional bedrock-oriented geologic maps.

Most of the surficial map units are classified by genesis and relative age. Surficial units shown on the map generally are more than about 3 ft thick. Deposits associated with distinct landforms may locally be thinner than 3 ft. Map units shown as fractions (such as Qfy/Qgds) indicate that a thin mantle of material, in this case younger fan alluvium, overlies another deposit (glacially dammed sediments-unit Qgds). Surficial deposits with a mapped width of about 75 to 100 ft or less cannot be depicted on the 1:24,000-scale map. 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.

Divisions of the Quaternary used herein correspond to those summarized by Madole and Thorson (2003) and are presented in Figure 7. Characteristics such as the position in the landscape, degree of erosional modification of original surface morphology, and relative degree of weathering and soil development were used to estimate the relative ages for the surficial deposits. Differences in the soil development were only sometimes useful, because: (1) good exposures of well-preserved soil profiles are relatively rare in the quadrangle; (2) limited field time prevented the excavation of numerous soil pits; and (3) the available soil exposures were difficult to interpret because deposits that were suspected of being late and middle Pleistocene commonly had only weakly developed soil profiles. The latter factor may result from a number of causes, including the complicating effects of erosion and eolian deposition and the fact that many surficial deposits are composed of very granular sediments with few fine-grained particles.

Soil-horizon names used here are those of the Soil Survey Staff (1975) and Guthrie and Witty (1982), and the stages of secondary carbonate morphology are from Gile and others (1966), with the modifications of Machette (1985). Concurrent soil mapping by the U.S. Department of Agriculture's Natural Resource Conservation Service aided our attempt to use pedogenic soil development as a tool to determine relative ages of the surficial map units.

QUATERNARY TIME CHART

Formal Time Divisions		Informal Time Divisions	Age (Sidereal Years)
Quaternary Period	Holocene Epoch		~11,500
	Pleistocene Epoch	late Pleistocene	~127,000
		middle Pleistocene	~778,000
		early Pleistocene	~1,806,000
Tertiary Period (part)	Pliocene Epoch		

Figure 7. Quaternary time chart (from Madole and Thorson, 2003).

HUMAN-MADE DEPOSITS—Materials placed by humans

af

Artificial fill (Historic)—Consists of fill and waste rock associated with irrigation canals and dams. This unit is composed mostly of unsorted silt, sand, and rock fragments but may include construction materials. Maximum thickness unit af is about 30 ft. If not adequately compacted, artificial fill may settle when loaded.

m

Mine and mill waste (Historic)—Includes materials along the Rito Seco drainage that were deposited by mining and milling associated with Battle Mountain Resources, Inc., San Luis Mine (all in the northwest corner of the quadrangle), and a reclaimed test heap-leach operation in the late 1970s by Earth Science, Inc. (R.G. Benson, 2002, personal commun.) that is located in a tributary valley along the northern edge of the quadrangle near the tick mark on the base map for the UTM coordinate 470,000E. Mine and mill waste associated with the San Luis Mine are currently being reclaimed. The large deposit of mine and mill waste along the western edge of the mapped area includes the tailing pond and the embankment for the pond. Tailings material range from granular sandy deposits to clayey "slimes". The boot-shaped deposit northeast of the tailings pond is associated with the mill facility and adjacent waste piles. Other nearby deposits mapped as unit m include both coarse-grained material in waste-rock piles and topsoil piles. In that reclamation was underway at the time of our mapping, the configuration of some area mapped as mine and mill waste may change, as topsoil is removed from the soil piles and placed over the waste-rock piles. The Earth Science, Inc. test heap-leach site was completely regraded and reclaimed prior to field investigations; therefore, little information about these deposits was obtained by our field work. Mine and mill waste locally exceed a thickness of 50 ft. Fine-grained materials within the tailings pond may be subject to compaction when loaded or prone to stability problems if disturbed by future grading activities. Environmental aspects of the mine and mill waste were not investigated.

ALLUVIAL DEPOSITS—Gravel, sand, silt, and clay deposited by flowing water in channels and on flood plains and fans along Rito Seco, Culebra, El Poso, Vallejos, and North Vallejos creeks, or as sheet flow in tributary valleys. Deposits resulting from sheet flow are referred to as sheetwash. The pre-Holocene units along the main valleys were deposited as outwash carried by melt water from glaciers in the Culebra Range to the east. These deposits are subdivided chiefly on the basis of their position in the landscape and, to a lesser extent, on the pedogenic soil formed on the surface of the deposits.

Qal

Alluvium of Rito Seco (Holocene)—Chiefly silty sand and sandy gravel in the modern channel of Rito Seco and in an adjacent low terrace . Most sandy beds are very fine to medium grained; gravel clasts are predominantly subround to subangular and range from granule to small pebble sizes. Unit Qal is moderately well to well bedded and moderately well to poorly sorted. The lithologies of clasts within unit Qal are predominantly gneiss, quartz, and feldspar; sparce clasts of sedimentary rocks, basalt, andesite, felsite, and gabbro are also present. The clasts are commonly fresh and sound; weathered clasts probably were recycled from conglomerate beds in the Santa Fe Group. Unit Qal is well exposed in cut banks along Rito Seco. Multiple, thin, very weakly developed azonal soils (A horizons) present within the unit suggest a Holocene age. Maximum exposed thickness is about 20 ft. Unit is a source of sand and fine gravel.

Qa_1

Alluvial unit one (Holocene)—Mainly poorly sorted, clast-supported, unconsolidated, sandy pebble and cobble gravel, gravelly sand, silty sand, and sandy silt. Locally alluvial unit one includes silt and boulder-sized material. The unit contains channel, flood-plain, fan, and low-lying terrace deposits along Culebra, El Poso, Vallejos, and North Vallejos creeks, whose headwaters were glaciated. Strata in alluvial unit one range from poorly bedded to well bedded and may have cut-and-fill channels. Locally the unit includes very poorly sorted, matrix-supported gravelly silt and sand that probably were deposited by debris flows from tributary drainages. Deposits of alluvial unit one may grade to alluvium and colluvium, undivided (unit Qac) in tributary drainages.

Sediment contained in unit Qa_1 includes material eroded from Proterozoic crystalline rock, Paleozoic sedimentary rock, and Santa

Fe Group sediment and volcanic flows. Lithologies of clasts within the unit are predominantly gneiss, feldspar, and quartz, although clasts of sandstone, conglomeratic sandstone, conglomerate, limestone, basalt, and andesite are locally common. Most clasts in unit Qa_1 are subround to subangular; a small percentage is round or angular. Many clasts are fresh and sound; weathered clasts probably were recycled from conglomerate beds in the Santa Fe Group.

Deposits of unit Qa_1 usually lack any appreciable soil development or have only weakly developed, sometimes stacked, A horizons. Some deposits of unit Qa_1 are historical. Because the base of unit Qa_1 is not exposed in the quadrangle, the thickness of this unit is unknown. It probably is 5 to 20 ft thick, but locally could be thicker. Topographically low areas mapped as unit Qa_1 are prone to flooding. Deposits of unit Qa_1 are a good source of unweathered sand and gravel.

Qa_{2r} Qa_{2b} Qa_2 Qa_{2a}

Alluvial unit two (late Pleistocene)—Alluvial unit two contains sandy cobble and pebble gravel, gravelly sand, silty sand, and sandy silt that underlies and forms glacial outwash terraces along El Poso, Culebra, and Vallejos creeks. These terraces are formed in valleys with restricted widths. West of the foothills near Chama and Los Fuertes, the unit underlies broad alluvial fans. Unit Qa_2 locally is divided into an older and topographically higher deposit (unit Qa_{2a}) and a younger and topographically lower deposit (unit Qa_{2b}), chiefly on the relative positions of these deposits within the landscape. In El Poso Creek, near the east edge of the quadrangle, the unit includes a single deposit of outwash that grades to a recessional late Pleistocene moraine (unit Qa_{2r}). Unit Qa_2 is mainly poorly sorted and clast supported. Most clasts contained within unit Qa_2 are unweathered or very slightly weathered; the few strongly weathered clasts probably are reworked from conglomerate beds in the Santa Fe Group. Pedogenic soils formed on unit Qa_2 locally have thin to moderately thick A horizons, weak clayey (argillic) Bt horizons, and calcareous Cca horizons with stage I to weak stage II carbonate morphology. Deposits of unit Qa_2 locally grade upstream to morainal deposits of unit Qm_1, which are Pinedale in age and generally considered to be about 12-35 ka (Richmond, 1986). Thickness of this unit is unknown. Alluvial unit two is a good source of unweathered sand and gravel.

Qa_3 Qa_{3b} Qa_{3a}

Alluvial unit three (late middle Pleistocene)—Sediment in unit Qa_3 is similar to that contained in unit Qa_2, but is older and higher in the landscape where present beneath terraces. Most gravel clasts contained within unit Qa_3 are slightly to moderately weathered; strongly weathered clasts within unit Qa_3 deposits probably are reworked from conglomerate beds in the Santa Fe Group. Unit Qa_3 underlies and forms glacial outwash terraces along El Poso, Culebra, and Vallejos creeks. The terrace along Vallejos Creek spreads out into a fan near Los Fuertes. East of Chama, unit Qa3 is divided into an older and topographically higher deposit (unit Qa_{3a}) and a younger and topographically lower deposit (unit Qa_{3b}), chiefly on the relative positions of these deposits within the landscape. The strongest soils present on deposits of unit Qa_3 usually have moderate to strong A horizons, and moderate to well-developed argillic Bt horizons that sometimes have blocky or weak prismatic structure and stage I carbonate morphology. The Cca horizon, which is not present everywhere, has stage II to weak stage III morphology. Unit Qa_3 deposits are correlated with morainal deposits of unit Qm_2, which are interpreted as Bull Lake moraines deposited about 140–150 ka (Pierce and others, 1976; Pierce, 1979) or about 130-350 ka (late middle Pleistocene; Richmond, 1986). Thickness of alluvial unit three is unknown. Unit Qa_3 is a potential source of moderate-quality sand and gravel.

Qa_4

Alluvial unit four (middle Pleistocene)—Sediment in unit Qa_4 is similar to that contained in unit Qa_2. Most gravel clasts contained within unit Qa_4 are slightly to strongly weathered. Some strongly weathered clasts within unit Qa_4 deposits may be reworked from conglomerate beds in the Santa Fe Group, but others reflect the antiquity and length of exposure of this deposit to weathering. A nearly continuous deposit of unit Qa_4 is preserved along the southeast side of El Poso Creek and near the confluence of El Poso and Culebra creeks. These deposits underlie and form a terrace in parts of this area; elsewhere they are overlain by thick, locally derived fan deposits. Scattered remnants of alluvium beneath a terrace along the north side of North Vallejos Creek are correlated with the extensive Qa_4 deposits along El Poso Creek. Pedogenic soils preserved on unit Qa_4 are similar to those on unit Qa_3, except the A horizons are commonly thinner and the Cca horizons are locally slightly better developed. The early middle Pleistocene Lava Creek B ash (639 ± 2 ka; Lanphere and others, 2002) rests on unit Qa_4 in two tributary arroyos on the southeast side of El Poso Creek. Unit Qa_4 is assigned a middle Pleistocene age, because it must be older than the ash bed; however, it could be significantly older than the ash. Unit Qa_4 probably correlates with morainal deposit Qm_3, but the units do not physically grade to one another within the mapped area. The base of unit Qa_4 ranges from about 120–150 ft above El Poso Creek in upstream areas to about 80–120 ft above the creek near the confluence with Culebra Creek in the central part of the quadrangle. The base of the unit is only 40–60 ft above Culebra Creek in the western part of the quadrangle. Maximum thickness of unit Qa_4 is estimated at 40–60 ft. The unit is a potential source of moderate-quality sand and gravel.

Qau

Alluvium, undivided (Pleistocene)—Undifferentiated, gravelly outwash deposits on the south side of El Poso Creek near its confluence with El Pedregoso Creek. Unit is correlative to units Qa_3 and Qa_4, and perhaps to unit Qa_2, and it has characteristics similar to these units.

MASS-WASTING DEPOSITS—Sand, gravel, silt, and clay on hillslopes and adjacent valley floors that were transported downslope primarily by gravity. In contrast to other forms of material transport, the debris carried by mass-wasting processes is not transported within, on, or under another medium such as flowing water or wind (Jackson, 1997). Water can be an important element in mass wasting, and it commonly triggers the movement. However, water is merely a part of the moving mass, not the transporting agent. Landslide deposits, colluvium, and talus are the principal types of mass-wasting deposits in the Taylor Ranch quadrangle.

Qc

Colluvium (Holocene and late Pleistocene)—Deposits of poorly sorted, sandy or silty, fine to coarse gravel and gravelly sand and silt that are on or at the foot of hillslopes. As used here, colluvium generally follows the definition of Hilgard (1892) in that it: (1) is derived locally and transported only short distances; (2) is not distributed by channelized water flow; (3) contains clasts of varying size; (4) has little or no sedimentary structures or stratification, which are typically caused by channelized flow of water; and (5) may include minor amounts of sheetwash and debris-flow deposits.

The lithology of clasts within colluvial deposits depends on the source area. Most clasts are Proterozoic gneiss, but clasts of Paleozoic sandstone, conglomeratic sandstone, and limestone, and Tertiary basalt and andesite are abundant locally. Colluvium containing subround to subangular clasts may be derived from conglomeratic beds in the Santa Fe Group. Colluvial deposits contain abundant angular and subangular volcanic clasts where the source area includes outcrops of the volcanic flows. In the northeastern and north-central parts of the quadrangle where Proterozoic rocks crop out, the clasts in colluvium are chiefly subangular gneiss. Where derived from surficial deposits, the clasts in colluvium reflect those in the original surficial deposit. Maximum thickness of colluvium is estimated to be 25 ft. Areas mapped as colluvium may be prone to rockfall hazards.

Qta

Talus (Holocene and late Pleistocene)—Crudely sorted and stratified, angular, bouldery to pebbly rubble on and below steep slopes in Proterozoic rocks on the valley walls of upper El Poso Creek. Talus was transported downslope by gravity, as rockfalls, rockslides, or rock topples. The unit typically lacks matrix material. Maximum thickness of talus is about 30 ft. Areas mapped as talus deposits have high rockfall potential. Talus deposits are a source of high quality riprap.

Qls

Landslide deposits (Holocene and late Pleistocene)—Heterogeneous, mostly unsorted and unstratified debris that commonly is characterized by hummocky topography and lobate form. Most landslides in the mapped area are rotational slumps. Although the topography in the quadrangle is steep, landslides are relatively rare, probably because much of the quadrangle is underlain by either permeable, well-drained materials in the Santa Fe Group or by hard, well-indurated Proterozoic rocks. A few small landslides were mapped in the Santa Fe Group where incision along arroyos has oversteepened hillslopes. The largest landslides in the quadrangle formed in glacial deposits in the prominent lateral moraine on the north side of El Poso Creek or in the Tertiary redbeds (unit Tsr). An odd, rounded hill along the eastern edge of the quadrangle about 0.5 mi south of El Pedregoso Creek is inferred to be underlain by landslide deposits. Although no exposures of the material underlying this hill were found, we conclude it is a result of landsliding, perhaps as an earth flow, because: (1) the hill is part of a lobate, somewhat hummocky landform that obliquely crosses a Neogene fault that created a fault-line scarp in adjacent areas; (2) float on the hill is monolithologic, consisting of leucocratic gneiss similar to that exposed to the east, not the various lithologies found in the conglomerates of the Santa Fe Group; (3) if the fault-line scarp is projected through the hill, then the hill should be underlain by the Santa Fe Group; and (4) Proterozoic rock in the footwall of the Neogene fault may be highly fractured and prone to slope instability. Landslide deposits may exceed 50 ft in thickness, but most are thinner. Landslide deposits may be prone to future movement, particularly if disturbed by human activities, and they are indicative of an environment favorable for slope instability.

ALLUVIAL AND MASS-WASTING DEPOSITS—Although fan deposits in the quadrangle consist mainly of alluvium, some fan deposits contain sediment from debris flows, which are considered to be a form of mass wasting by Cruden and Varnes (1996) and Hungr and others (2001).

Qfy **Younger fan deposits (Holocene and late Pleistocene?)—**Includes sediment in small, geomorphically distinct fans at the mouths of tributary valleys and large coalesced fan complexes along the larger valleys. Unit Qfy is chiefly moderately well sorted to poorly sorted, clast-supported, alluvial sandy gravel and gravelly sand, but locally it includes matrix-supported debris-flow deposits that are generally gravelly silt. Most younger fan deposits consist of material eroded from the Santa Fe Group, therefore the clasts within the deposits reflect those contained within the Santa Fe Group in the provenance of each fan. Younger fan deposits commonly either interfinger with or are deposited over units Qa_1, Qal, and Qac. In some narrow valleys, younger fan deposits include colluvium at the base of the valley wall. Maximum thickness of unit Qfy is estimated at 60 ft, but commonly the deposits are thinner. Areas mapped as younger fan deposits have high potential for future flooding and rapid sediment deposition. Fine-grained beds with unit Qfy may be prone to hydrocompaction. Deposits of unit Qfy may contain high-quality sand and gravel.

Qfm_1 **Middle fan deposits, unit one (late Pleistocene)—**Sediments are similar in genesis and sedimentological properties to younger fan deposits (Qfy). These deposits are part of inactive fans and fan complexes that commonly grade to, project to, or overlie late Pleistocene outwash deposits (unit Qa_2). Pedogenic soils formed in unit Qfm_1 are similar to those associated with unit Qa_2. Estimated maximum thickness of unit Qfm_1 is 40 ft, but commonly it is much thinner. The unit is a potential source of good-quality sand and gravel.

Qfm_2 **Middle fan deposits, unit two (late middle Pleistocene)—**Sediments are similar in genesis and sedimentological properties to younger fan deposits (Qfy). These deposits are part of inactive fans and fan complexes that commonly grade to, project to, or overlie late middle Pleistocene outwash deposits (unit Qa_3). Pedogenic soils developed in unit Qfm_2 are similar to those formed in unit Qa_3. Estimated maximum thickness of unit Qfm_2 is 50 ft but commonly is much thinner. The unit is a potential source of moderate-quality sand and gravel.

Qfm **Middle fan deposits, undifferentiated (late and late middle Pleistocene)—**Mapped where limited exposures, poorly preserved landforms, and uncertainties in projecting the deposit to the alluvial units preclude distinction of the units Qfm_1 and Qfm_2. Undifferentiated middle fan deposits are a potential source of moderate-quality sand and gravel.

Qfo_1 **Older fan deposits, unit one (middle Pleistocene)—**Sediments are similar in genesis and sedimentological properties to younger fan deposits (unit Qfy). Older fan deposits underlie inactive fans and fan complexes that commonly grade to, project to, or overlie middle Pleistocene outwash deposits of unit Qa_4. In many exposures, erosion has completely or partially removed the pedogenic soils developed in unit Qfo_1; where preserved, the soil is similar to the soil formed on unit Qa_4. Estimated maximum thickness of unit Qfo_1 is 30 ft, but commonly it is thinner. The unit is a potential source of moderate-quality sand and gravel.

Qfo_2 **Older fan deposits, unit two (middle Pleistocene)—**Sediments are similar in genesis and sedimentological properties to younger fan deposits (unit Qfy). These deposits underlie inactive fans and fan complexes that project above the middle Pleistocene outwash deposits of unit Qa_4. In many exposures, erosion has completely or partially removed the pedogenic soils developed in unit Qfo_2; where preserved, the soil is similar to or stronger than the soils present on unit Qa_4. Estimated maximum thickness of unit Qfo_2 is 25 ft, but commonly it is thinner. Older fan deposits are a potential source of low- to moderate-quality sand and gravel.

Qfo **Older fan deposits, undifferentiated (middle Pleistocene)—**Mapped where limited exposures, poorly preserved landforms, and uncertainties in projecting the deposit to the alluvial units preclude assignment to older fan deposits Qfo_1 or Qfo_2. Locally, unit Qfo may include deposits that are older than unit Qfo_2.

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene?)—**Unit mainly consists of stream-channel, low-terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and of subordinate amounts of colluvium and sheetwash along valley margins and sideslopes. Unit Qac locally includes debris-flow deposits. Small subdued hills underlain by bedrock also may be included in the mapped unit locally. The alluvial and colluvial deposits are mapped as a single undifferentiated unit where they: (1) are interbedded; (2) are gradational and have boundaries that are difficult to discern; or (3) are side by side but too small to show as individual deposits at the map scale. The alluvial component of the unit is poorly to well sorted and ranges from stratified fine sand to sandy gravel, whereas the colluvial component consists of poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt. Clast lithologies reflect the rocks within the drainage provenance. The unit grades into younger fan deposits in some drainages.

Unit Qac is commonly 5 to 20 ft thick. Stream channels, adjacent flood plains, and low terraces included in map unit Qac may flood. Valley sides are prone to colluvial deposition, sheetwash, rockfall, and small debris flows. Deposits of Qac may be subject to settlement or collapse where low in density or to piping where fine grained and exposed in deep arroyo walls. These deposits are a potential source of good-quality sand and gravel.

Qaco **Older alluvium and colluvium, undivided (Holocene? and Pleistocene)—**Unit includes dissected valley-fill deposits and remnants of mixed alluvium and colluvium that cap hilltops and drainage divides. Physical characteristics of this unit are similar to those of unit Qac. Thickness of the unit ranges up to about 20 ft. Unit Qaco may be a potential source of moderate-quality sand and gravel.

Qcs **Colluvium and sheetwash, undivided (Holocene and late Pleistocene)—**Mapped where these deposits are gradational and have boundaries that are difficult to discern or where they occur side by side but are too small to depict individually at the map scale. Refer to the description of unit Qc for the characteristics of colluvium. Sheetwash typically consists of pebbly silty sand, sandy or clayey silt, and sandy silty clay. It ranges from well sorted to poorly sorted, and commonly is moderately well or well bedded. The estimated maximum thickness of unit Qcs is about 20 ft. Fine-grained deposits may be prone to hydrocompaction or piping.

Qcf **Colluvium and younger fan deposits, undivided (Holocene and late Pleistocene)—**Mapped where colluvium (Qc) and younger fan deposits (Qfy) are gradational and have boundaries that are difficult to discern, or where they occur side by side but are too small to depict as individual deposits at the map scale. The unit includes two deposits in the southwest part of the quadrangle south of Culebra Creek.

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by glacial ice. These deposits also include clastic sediments and organic-rich materials in tributaries that were dammed by lateral moraines. The lower limit of glacial deposits is at an elevation of about 9,000 ft in the quadrangle. Relative ages of the morainal deposits are based mainly on geomorphic relationships and on weathering characteristics of the landform and the deposits. No exposures of the pedogenic soil formed on the deposits were observed.

Qm_{1r}
Qm_1

Morainal deposits, unit one (late Pleistocene)—Heterogeneous deposits of mostly silty to bouldery sediments deposited by or adjacent to glacial ice along El Poso Creek. Although poorly exposed, the deposits appear to be dominantly matrix-supported, pebbly, cobbly, and bouldery silt and silty cobble and boulder gravel. Clasts contained with units Qm_1 and Qm_{1r} are unweathered to slightly weathered, subangular to subround, and consist of Proterozoic lithologies. Boulders with only minor pitting are common on the surface of the moraines underlain by units Qm_1 and Qm_{1r}. The crests of moraines underlain by the unit are fairly sharp. Unit Qm_1 forms the prominent, well-preserved lateral moraines on both the northwest and southeast sides of El Poso Creek, as well as a small area of ground moraine overlying a window of Proterozoic rocks on the north side of El Poso Creek. The downstream end of the moraine on the south side of the c reek (at an elevation of about 9,000 ft) slightly bends towards the creek and probably represents a small remnant of an end or terminal moraine. Late stage recessional morainal deposits (unit Qm_{1r}) are upvalley and younger than the deposits of unit Qm_1 that are contained in the prominent lateral moraines. The deposits in units Qm_1 and Qm_{1r} likely are equivalent in age to Pinedale morainal deposits, which formed about 12 to 35 ka (Richmond, 1986) during oxygen isotope stage II. The unit is as much as about 400 ft thick. It is a source of boulders, gravel, and perhaps minor sand.

Qm_2

Morainal deposits, unit two (late middle Pleistocene)—Heterogeneous deposits of chiefly silty to bouldery sediment deposited by or adjacent to glacial ice along El Poso Creek. Unit underlies a remnant of a lateral moraine at the mouth of El Pedregoso Creek and a bench-like landform on the southeast side of the late Pleistocene moraine formed by unit Qm_1. The deposit under the bench is included in unit Qm_2 because of its position between the late Pleistocene and middle Pleistocene moraines (units Qm_1 and Qm_3) and because it is less weathered than the middle Pleistocene morainal deposits. The deposit underlying the bench may be a debris flow from the adjacent tributary valley.

Although poorly exposed, morainal deposit two appears to be sedimentologically similar to unit Qm_1. However, the crests of moraines underlain by unit Qm_2 are more rounded and subdued than the crest of the late Pleistocene lateral moraines, and the boulders on the surface of the moraine are fewer in number and more weathered than those on moraines underlain by unit Qm_1. Morainal deposit Qm_2 is tentatively correlated with Bull Lake morainal deposits, which are late middle Pleistocene in age and may be about 140–150 ka (Pierce and others, 1976; Pierce, 1979), having been deposited during oxygen isotope stage VI or about 130–350 ka (Richmond, 1986). Morainal deposit Qm_2 has an estimated maximum thickness of about 80 ft. It is a potential source of moderate-quality gravel and sand.

Qm_3

Morainal deposits, unit three (middle Pleistocene)— Heterogeneous deposits of chiefly silty to bouldery sediments deposited by or adjacent to glacial ice along El Poso Creek. Unit Qm_3 underlies a single lateral moraine between El Poso and El Pedregoso creeks. Although poorly exposed, the deposits appear to be sedimentologically similar to unit Qm_1. However, the crest of the moraine underlain by unit Qm_3 is very subdued, and very few boulders are preserved on the moraine crest and sides. Morainal deposit Qm_3 is tentatively correlated with the middle Pleistocene alluvial unit Qm_4, which is overlain by the Lava Creek B ash (dated at 639 ± 2 Ma by Lanphere and others, 2002). Maximum thickness of morainal deposit Qm_3 is estimated at about 100 ft. The unit is a potential source of low- to moderate-quality gravel and minor sand.

Qm

Morainal deposits, undifferentiated (late and middle Pleistocene)—Mapped where the age of the morainal deposit is questionable. Unit Qm includes units Qm_1, Qm_2, and possibly Qm_3.

Qgds

Glacially dammed sediments (Holocene and late Pleistocene)—Unit includes sand, gravel, silt, clay, and peat in tributary valleys dammed by lateral moraines in upper El Poso Creek. These sediments are poorly exposed and no drill-hole data are available for them, therefore their physical characteristics are not well known. The sediments probably accumulated in alluvial, paludal, lacustrine, and deltaic environments after the tributary valleys were dammed by lateral moraines during the late Pleistocene. Erosion and mass wasting have breached the glacial dams, effectively terminating continued deposition of the sediments. Maximum thickness is estimated at 40 ft.

EOLIAN DEPOSITS—Sediments deposited chiefly by wind

Qva

Lava Creek B volcanic ash (early middle Pleistocene)—White to very light-brown volcanic ash crops out in two arroyos on the southeast side of El Poso Creek about 2 mi upstream from its confluence with Culebra Creek. In the southwestern of the two arroyos, the ash bed is spectacularly well exposed and underlies an area sufficiently large to be shown as a map unit. The ash bed in the northeastern arroyo is less well exposed and is shown by a line symbol on the geologic map. Near the head of the southwestern arroyo, the ash bed is more than 8 ft thick and is well sorted. It has been reworked, but contains only minor amounts of clastic materials, particularly when compared with the ash bed exposed in the lower end of the arroyo. The relatively clean tephra bed is correlated with the Lava Creek B ash on the basis of microprobe analysis of glass fragments contained in the ash (N.W. Dunbar, 2003, written commun.). The Lava Creek B ash erupted from the Yellowstone caldera at 639 ± 2 Ma (Lanphere and others, 2002).

An angular unconformity is cut across the clean ash bed, and a long, continuous bed of reworked ash with appreciably more clastic sediment, including rip-up clasts of ash, extends down the arroyo from the unconformity. In much of the arroyo, this ash bed rests on cobble gravel, sandy pebble gravel, or sandy silt contained in unit Qa_4. The ash is only an estimated 120–160 ft above El Poso Creek. Volcanic ash deposits are low in density and may be prone to compaction or settlement problems. They were mined for use as scouring powder during the early 20th century and potentially could be used as mineral resources in the future.

BEDROCK

Santa Fe Group (late Oligocene?, Miocene, and Pliocene)—The Santa Fe Group consists of a thick sequence of consolidated clastic sediments and several intercalated, relatively thin, apparently discontinuous, volcanic flows. The group also includes at least one minor bed of volcanic ash, in that pieces of ash were observed in a pile of debris that was dug from an animal burrow in the south-central part of the mapped area (location shown by special symbol on map). The presence of ash beds in the Santa Fe Group to the northwest in the Fort Garland SW quadrangle (Kirkham and Heimsoth, 2003) and to the south in La Valley quadrangle supports the likely existence of thin ash beds in the Santa Fe Group within the quadrangle. In the Taylor Ranch quadrangle, units mapped as Santa Fe Group include Tsf, Ts, Tb, Trd, and Tta.

Tsf

Santa Fe Group sediments (late Oligocene?, Miocene, and Pliocene)—Chiefly weakly lithified, light-brown, light- to medium-yellow-brown, and light- to medium red-brown, sandy cobble and pebble gravel, fine- to very coarse-grained sandstone, and conglomeratic sandstone. The unit contains minor light-brown or light- to medium-reddish-brown mudstone and shale in the western part of the quadrangle, and it is locally rich in boulders where adjacent to Proterozoic rock. Santa Fe sediments are predominantly conglomerates and conglomeratic sandstones in areas with greater topographic relief and chiefly sandstone in areas with modest topographic relief, such as the valley that leads north-northwest from Cañon Church and the low areas that are southwest and south from the buildings labeled Taylor Ranch on the base map. Conglomeratic beds range from about 0.5 to over 10 ft thick; sandy beds can be thin bedded or massive. Gravelly channel deposits, cut-and-fill structures, and graded bedding are present locally. Locally, clast imbrication is developed enough to be used as a paleocurrent indicator. In the southern and western parts of the quadrangle, flow directions were generally westerly, whereas in the north-central and northeast parts the flow direction was southwesterly.

Most clasts in Santa Fe sediments are subround to subangular. Clast lithology varies across the mapped area, indicating multiple source areas with different types of bedrock. Clasts of gneiss, quartz, and feldspar are always present, and in some areas in the northern part of the quadrangle they comprise all the clasts. Clasts of Paleozoic sandstone, conglomeratic sandstone, limestone, and conglomerate are locally abundant in the southern part of the quadrangle and rare in the northern part. At least a few clasts of Tertiary volcanic rocks are present in most outcrops, and they are commonly abundant in strata overlying intra-Santa Fe volcanic flows and in the hills in the west-central part of the mapped area. Volcanic clasts are usually angular to subangular in the strata that overlie volcanic flows.

The age of the Santa Fe sediments is not well constrained within the quadrangle. The onset of rifting, which triggered deposition of the syn-rift Santa Fe Group, is generally considered to be late Oligocene (summarized by Chapin and Cather, 1994). Sediments of the Santa Fe overlie Oligocene volcanic rocks north of the quadrangle (Wallace, 1996, 1997; Wallace and Soulliere, 1996). Volcanic flows locally intercalated with the sediments of the Santa Fe Group in the quadrangle are middle Miocene (Peters, 2003); therefore, the age of the sediments at these locations is middle Miocene or younger. The sediments, however, may be older in other parts of the quadrangle. Basalt flows intercalated with sediments in the upper part of unit Tsf in the western part of the quadrangle are correlated with the Servilleta Basalt, which is Pliocene. Middle Pleistocene surficial deposits unconformably overlie the sediments of the Santa Fe Group and are excluded from the group in this study. These surficial deposits provide a minimum age for unit Tsf.

Sediments of the Santa Fe Group crop out in a series of generally east-dipping blocks that are downthrown on their western margins; therefore, the oldest Santa Fe sediments crop out in the blocks in the eastern and north-central parts of the quadrangle. Santa Fe sediment either directly overlies Proterozoic rock or it rests on volcanic flows that overlie Proterozoic rock in two areas. One area is on the north edge of the mapped area, west of the large hill of brecciated gneiss; a second is near the good exposure of volcanic ash along El Poso Creek. These strata represent the basal sediments of the unit at these locations, but they may or may not be the oldest Santa Fe strata in the quadrangle. The youngest Santa Fe strata are exposed in the western parts of the quadrangle. See an earlier section on Stratigraphy for a more complete description of the age of the Santa Fe Group.

Total thickness of the Santa Fe Group sediments in the quadrangle is unknown. The entire section is not preserved in any one location, no drill holes penetrate the entire unit in the quadrangle, and the complex faulting complicates efforts to measure the thickness. The quadrangle is located southeast of a major Santa Fe depocenter (Wallace, 1995) that may contain over 8,000 ft of Santa Fe sediments (Keller and others, 1984). The Santa Fe Group sediments may exceed a thickness of a few thousand feet in the quadrangle. Because the gravel clasts are commonly decomposed, unit Tsf is a source of low-to moderate-quality sand and gravel.

Ts

Servilleta Basalt (Pliocene)—Medium- to dark-gray tholeiitic flows of Servilleta Basalt are the youngest volcanic rocks intercalated with sediment of the Santa Fe Group. Distinguishing characteristics of Servilleta flows include small olivine phenocrysts, diktytaxitic texture, and locally common vesicle pipes and segregation veins (Lipman and Mehnert, 1979; Thompson and Machette, 1989; Burroughs, 1971). The olivine phenocrysts commonly are slightly altered to iddingsite. Phenocrysts of plagioclase and clinopyroxene also are present.

Servilleta flows were found in three areas of the quadrangle: on the north and south sides of Culebra Creek about 1 mi upstream from Chama, and on the west edge of the quadrangle about 2.5 mi north of Chama. Generally, only a single flow was observed in outcrop, and the outcrops are discontinuous laterally. The original distribution of Servilleta flows may have been limited to these three outcrop areas, but because they are preserved in areas of complex faulting, the flows may be cut out by post-eruption faulting. Four samples were collected from Servilleta flows within the quadrangle and submitted for geochemical analysis (samples TR194a, TR194b, TR480, and TR725; Table 1). All plot in the trachybasalt field of Le Bas and others (1986) (see Fig. 4).

No age determinations are available for Servilleta flows within the quadrangle. However, Miggins (2002) and Miggins and others (2002) reported $^{40}Ar/^{39}Ar$ plateau ages of 4.37 ± 0.17 Ma, 4.55 ± 0.15 Ma, and 4.59 ± 0.02 Ma, and an isochron age of 4.75 ± 0.10 Ma for nearby flows to the northwest and west of the mapped area. A Servilleta flow to the north in the Fort Garland quadrangle had an $^{40}Ar/^{39}Ar$ age of 3.66 ± 0.01 Ma (Wallace, 1997). These recent $^{40}Ar/^{39}Ar$ ages are similar to those of other Servilleta flows in nearby areas dated using K/Ar methods (Aoki, 1967; Lipman and Mehnert, 1979; Thompson and Machette, 1989). Servilleta flows in the quadrangle range up to about 30 ft thick. Servilleta Basalt is difficult to excavate and can pose rockfall hazards where exposed in cliffs. It probably is suitable for use as riprap.

Tb

Basalt (Miocene)—Mostly dark-gray to black, fine-grained, commonly porphyritic, tholeiitic basaltic flows intercalated with sediments in the middle and/or lower Santa Fe Group. Unit Tb is found only in the southeast part of the quadrangle. It includes a sequence of flows west of the buildings labeled Taylor Ranch on the base map; these flows can be traced in outcrop for about 1.5 mi. Other exposures of unit Tb in the quadrangle are in areally small, fault-bounded blocks. Unit Tb typically includes multiple stacked flows. Pyroxene and olivine are common phenocrysts. Geochemically, the flows plot in the trachybasalt (samples TR16a, TR16c, TR16d, and TR25) and tephrite basanite (TR16b, TR86, TR87a, and TR87b) fields of Le Bas and others (1986). Samples collected from similar-looking flows in approximately the same stratigraphic position within the Santa Fe Group in La Valley quadrangle also are trachybasalts (Table 1; Fig. 4). Although the four stacked flows in a small fault-bounded block of unit Tb between North Vallejos and El Puertecito creeks (samples TR16a,b,c,d) plot as trachybasalt or tephrite basanite, they are light to medium gray and look like andesite in hand specimen.

The groundmass of sample TR87a yielded a weighted mean $^{40}Ar/^{39}Ar$ age of 11.74 ± 0.51 Ma on the basis of its age spectrum (Peters, 2003), but had very low (<20%) radiogenic yield and very large atmospheric signals. The isochron age for this sample is 11.25 ± 0.34 Ma, which is within the error range of the date calculated using the age spectrum. No other geochronologic data are presently available for this unit within the quadrangle.

On the basis of the stratigraphic position of these flows within the Santa Fe Group and on their petrology and absolute age, unit Tb may correlate with the Hinsdale Formation in the San Luis Hills (Thompson and Machette, 1989) and San Juan Mountains (Lipman and Mehnert, 1975) west of the quadrangle, where the Hinsdale Formation ranged in age from 4.4-26.8 Ma, or with the "Miocene basaltic rocks" of Lipman and Reed (1989) in the Latir volcanic field, where the formation ranged from 15 to 16 Ma. Basaltic flows from east of Sanchez Reservoir (which is south of the quadrangle) yielded ages of 10.74 ± 0.10 Ma and 11.98 ± 0.10 Ma (Miggins, 2002); they also may be correlative with unit Tb. Wallace (1996) obtained an age of 18.86 ± 0.01 Ma on a potentially correlative basalt dike to the north in Trinchera Ranch quadrangle. Individual flows are about 10–25 ft thick, and the maximum thickness of the flow sequence is estimated at 60 ft. Flows in unit Tb may be difficult to excavate and can pose rockfall hazards where exposed in cliffs. They may be suitable for use as riprap or crushed stone.

Trd

Rhyodacite (Miocene)—Includes three bodies of light-gray, porphyritic rhyodacite exposed on and near the ridgeline between North Vallejos and El Puertecito Creeks near the southeast corner of the mapped area. Unit contains abundant phenocrysts of euhedral potassium feldspar, hornblende, and biotite. It is rich in silica (67.86% SiO_2; sample TR32; Table 1) and plots essentially on the boundary between the trachydacite and dacite fields and near the rhyolite field of Le Bas and others (1986). Because of where the sample plots on this chart, we refer to unit Trd by the less specific name of rhyodacite. The bodies of rhyodacite, which form near-vertical outcrops on the hillside, lie within Santa Fe sediments, form poor natural outcrops, and are mapped chiefly on the basis of float. The best exposures of the unit are on the ridge crest where a jeep road cuts through the rhyodacite. Unfortunately, the structural attitude of the fault block containing the rhyodacite rocks is unknown, therefore it is unclear whether the unit is a flow intercalated with Santa Fe sediments or a dike that cuts them. Flow structure is locally present, but both rhyolitic flows and dikes can have flow structure. An $^{40}Ar/^{39}Ar$ date on biotite separated from sample TR32 yielded a somewhat disturbed age spectrum with climbing apparent ages and radiogenic yields, and its K/Ca ratios dropped to low values in the final heating steps (Peters, 2003). Therefore, only a minimum age of 12.99 ± 0.23 Ma could be assigned. Maximum thickness of the rhyodacite is estimated at about 70 ft.

Tta

Trachyandesite lava flows (Miocene)—Predominantly intermediate-composition volcanic flows in the southeast and north-central parts of the quadrangle. Unit includes: (1) two laterally continuous flow sequences, one that crosses Cuchilla Alta Creek and a second southeast of the large hill of brecciated leucocratic gneiss; and (2) several flows that have limited areal extent. Flows are chiefly light to medium gray and have a very fine-grained groundmass. Most flows are porphyritic and contain sparse to abundant euhedral phenocrysts of potassium feldspar, some of which are partially resorbed and may be xenocrysts. Potassium feldspar phenocrysts up to 0.5 in. long occur in the flows southeast of the large hill of brecciated Proterozoic rocks. Some flows have sparse to abundant pyroxene phenocrysts; the flows that lie on Proterozoic rocks along the north edge of the quadrangle have phenocrysts of plagioclase and clinopyroxene.

In the southeast part of the quadrangle unit Tta commonly overlies redbed sediments (unit Tsr). The sediments beneath unit Tta southeast of the large hill of brecciated leucocratic gneiss are not exposed, and the Tta flows northwest of the hill of brecciated gneiss rest directly on Proterozoic rocks. Most samples of trachyandesite lava flows (TR50, TR422-1, TR422-2, TR423) plot in the trachyandesite field of Le Bas and others (1986). Other samples are phonotephrite (TR93a, TR93b) or basaltic trachyandesite (TR30), and one plots on the boundary between the phonotephrite and basaltic trachyandesite (TR63). A single-crystal, weighted-mean, laser-fusion $^{40}Ar/^{39}Ar$ age of 13.02 ± 0.06 Ma was obtained on potassium feldspar from sample TR423. The groundmass of sample TR47 yielded a weighted-mean $^{40}Ar/^{39}Ar$ age of 14.40 ± 0.12 Ma that was calculated from approximately 80 percent of the ^{39}Ar released during heating (Peters, 2003). The isochron age of the latter sample was 14.32 ± 0.04 Ma, which is analytically indistinguishable from its weighted-mean age. All the trachyandesite lava flows within the quadrangle likely are middle Miocene in age. Individual flows are as much as 60 ft thick; the entire flow sequence is generally 50–100 ft thick or less. Unit is a potential source of riprap and crushed stone.

Tr

Rhyolite lavas and andesite lahar deposits (Pliocene, Miocene, or Oligocene)—A single, small outcrop of volcanic rocks exposed on the side of a ridge about 0.7 mi south of the top of the large hill of brecciated leucocratic gneiss (unit Xlg) in the northern part of the quadrangle. This outcrop includes two flows that appear to be intercalated with sediments of the Santa Fe Group, although the base of the flow sequence is not exposed. The lower flow is a devitrified rhyolitic ash flow or ash fall with contorted flow layering, traces of glass shard remnants and flattened pumice fragments, and clots of an unidentified material. The rock is silica rich (76.88% SiO_2; Table 1), low in iron (0.46% Fe_2O_3), and plots in the rhyolite field (Fig. 4) of Le Bas and others (1986). The upper flow is a volcanic lahar with cobble- and pebble-sized, subround to subangular clasts of porphyritic andesite. The matrix contains abundant euhedral phenocrysts of feldspar and plots in the trachyandesite field of Le Bas and others (1986). Due to the small areal extent of the andesitic lahar, it is not shown as a separate unit on the map. The age of these rocks is poorly constrained. The unit is interpreted as being within the Santa Fe Group, but it may be slightly older. Thickness of the unit is estimated at 15 ft.

Tsr

Redbed sedimentary rocks (Miocene? to Eocene?)—Predominantly weakly to moderately indurated, light-pinkish-gray to dark-red-brown mudstone, sandy siltstone sandstone, conglomeratic sandstone, and sandy pebble and cobble conglomerate. Locally unit Tsr is variegated in color, and it can consist of clast-supported deposits of angular boulders of Proterozoic rock with little matrix. The unit is mapped only where it underlies flows of unit Tta or where it can be traced from these flows. The redbed sedimentary strata are poorly exposed. In the few good exposures observed in the mapped area during this investigation, the clasts are chiefly subround to subangular, and a few are rounded. Typically, about 60–70 percent of the clasts are well indurated sandstone, conglomeratic sandstone, and limestone derived from Paleozoic formations, and about 30–40 percent are gneiss, quartzite, and pegmatite. None of the clasts are volcanic. Many of the gneiss and sandstone clasts have disintegrated. Where well exposed in an excavation about 500 ft north-northwest of the buildings labeled “Taylor Ranch” on the base map, the unit contains an intriguing deposit of clast-supported, nearly matrix-free angular boulders of gneiss. The origin of this deposit is uncertain; it may represent material from a debris avalanche or rock slide.

Upson (1941) included much of the area herein mapped as unit Tsr in his Vallejo Formation. Some characteristics of unit Tsr are similar to those described by Upson for the Vallejo Formation. However, the strata in unit Tsr are commonly much coarser grained than the Vallejo sediments described by Upson, and the conglomerate clasts in unit Tsr lack the distinctive iron-oxide rinds reported by Upson (1941), Wallace (1996), and Wallace and Soulliere (1996). The minimum age of unit Tsr is constrained by the middle Miocene flows of unit Tta that locally overlie it. Until additional absolute age control, paleontological evidence, or stratigraphic control is available, we conclude unit Tsr in Taylor Ranch quadrangle may be Miocene, Oligocene, or Eocene in age. Thickness of the redbed sedimentary strata in the quadrangle also is poorly constrained. The strata may be hundreds of feet thick.

Ti

Intermediate-composition dikes (Miocene or Oligocene)—Includes four dikes that cut Proterozoic crystalline rocks. Two gently-dipping dikes in brecciated leucocratic gneiss in the north-central part of the quadrangle are gray, fine grained, and porphyritic; they contain partially resorbed quartz and altered feldspar phenocrysts. Samples from these two dikes (TRQ154; TR576b; Table 1) plot in the trachyandesite field of Le Bas and others (1986). They are similar to felsite dikes and sills at the San Luis Mine about 2 mi north of the quadrangle. Sericitic alteration in these rocks at the mine has been dated at 24.0 ± 1.0 Ma and 24.1 ± 1.0 Ma (Benson and Jones, 1996). Wallace and Soulliere (1996) assigned an Oligocene(?) age to these felsite dikes at the mine. Unit Ti also includes two steeply dipping dikes in Proterozoic rocks near the northern boundary of the quadrangle. These dikes are dark gray, very fine grained, and porphyritic, and contain tabular phenocrysts of plagioclase feldspar. Locally these dikes are sericitic and pyritic. Sample TRQ55, collected from the northern end of the easterly of the two dikes, plots in the phonotephrite field of Le Bas and others (1986). The exact age of unit Ti is unknown, but provisionally is considered to be Miocene or Oligocene.

PzZg

Gabbro dike (Early Paleozoic or Late Proterozoic)—Includes a single coarse-grained, dark-gray, aphyric dike in the northeast corner of the quadrangle. The gabbro dike is composed chiefly of plagioclase and biotite, the latter apparently altered from hornblende. Trace amounts of magnetite also are present. Wallace and Soulliere (1996) mapped similar rocks to the north in the Ojito Peak quadrangle. The Early Paleozoic or Late Proterozoic age assigned to these rocks by Wallace and Soulliere is used herein. The gabbro dike in Taylor Ranch quadrangle is about 20 ft thick.

Xhf

Interlayered hornblende and felsic gneiss (Early Proterozoic)—Interlayered hornblende gneiss and felsic gneiss with greater than fifty percent hornblende gneiss. The hornblende gneiss is typically medium to dark gray and medium grained and consists chiefly of hornblende and plagioclase with lesser amounts of quartz, biotite, and pyroxene. Locally, the hornblende gneiss has a greenish tint due to chlorite alteration. Hornblende gneiss is moderately foliated and the segregation of light minerals (plagioclase and quartz) and dark minerals (hornblende and pyroxene) gives the rock a banded appearance. The felsic gneiss is light brown to light gray and medium grained and composed mainly of quartz, feldspar, and hornblende and/or biotite. Foliation is defined by compositional layering. Leucocratic augen gneiss (unit Xag) and pegmatitic leucocratic augen gneiss (unit Xagp) are present locally. The unit occurs in the northeast corner of the quadrangle.

Xfh

Interlayered felsic and hornblende gneiss (Early Proterozoic)—Interlayered felsic gneiss and hornblende gneiss with greater than fifty percent felsic gneiss. The felsic gneiss is light brown to light gray and medium grained, and it is composed primarily of quartz, feldspar, and hornblende and/or biotite. Foliation is defined by compositional layering. The hornblende gneiss component is typically medium to dark gray and medium grained; it consists chiefly of hornblende and plagioclase with lesser amounts of quartz, biotite, and pyroxene. Hornblende gneiss is moderately foliated with a banded appearance due to segregation of light and dark minerals. Leucocratic augen gneiss (unit Xag) and pegmatitic leucocratic augen gneiss (unit Xagp) are present locally. Unit Xfh occurs in the northeast corner of the quadrangle.

Xlg

Leucocratic gneiss (Early Proterozoic)—White to tan, medium- to coarse-grained, massive to moderately well-foliated microcline gneiss. The rock is composed primarily of quartz, microcline, and biotite. Foliation and/or mineral streaking lineations are defined by discontinuous concentrations of biotite. Leucocratic gneiss occurs in the northeast part of the quadrangle.

Xag

Leucocratic augen gneiss (Early Proterozoic)—Coarse-grained, porphyritic, leucocratic gneiss. Unit Xag is composed mainly of microcline and quartz, with accessory biotite, muscovite, and magnetite. The augen are defined by 0.4 to 0.8-in.-long microcline porphyroblasts. Leucocratic augen gneiss is well exposed in the north wall of El Poso canyon in the northeast part of the quadrangle.

Xagp

Pegmatitic leucocratic augen gneiss (Early Proterozoic)—Very coarse-grained, porphyritic, leucocratic gneiss. Unit Xagp is composed mainly of microcline and quartz, with accessory biotite, muscovite, and magnetite. It occurs in layers generally parallel to compositional layering in Proterozoic metamorphic rocks and forms large dip slopes in leucocratic gneiss terrane south of El Poso canyon in the northeast part of the quadrangle. It also is a cliff-former in a large, unnamed, side canyon north of El Poso Creek.

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