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Geologic Map of the Durango East Quadrangle, La Plata County, Colorado

Description of Map Units, Fracture Data and Analysis, Economic Geology, and References

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INTRODUCTION

Geologic mapping of the Durango East 7.5-minute quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Act. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic-hazards assessment, mineral-resource development, oil and gas development, and ground-water exploration. Mapping in the Durango region also contributes to the understanding of the fracture network through which natural gas may migrate.

Figure 1 shows the status of geologic mapping of 7.5-minute quadrangles in the Durango area. The Rules Hill and Ludwig Mountain quadrangles were mapped by the CGS during previous STATEMAP projects. The Durango West and Durango East quadrangles, both of which were mapped during fiscal year 1998-1999, were the third and fourth quadrangles to be mapped by the CGS in the area. This map was prepared by interpretation of color aerial photographs at a nominal scale of 1:24,000, taken during 1992, by field verification throughout the quadrangle, and by intensive field work in selected areas.

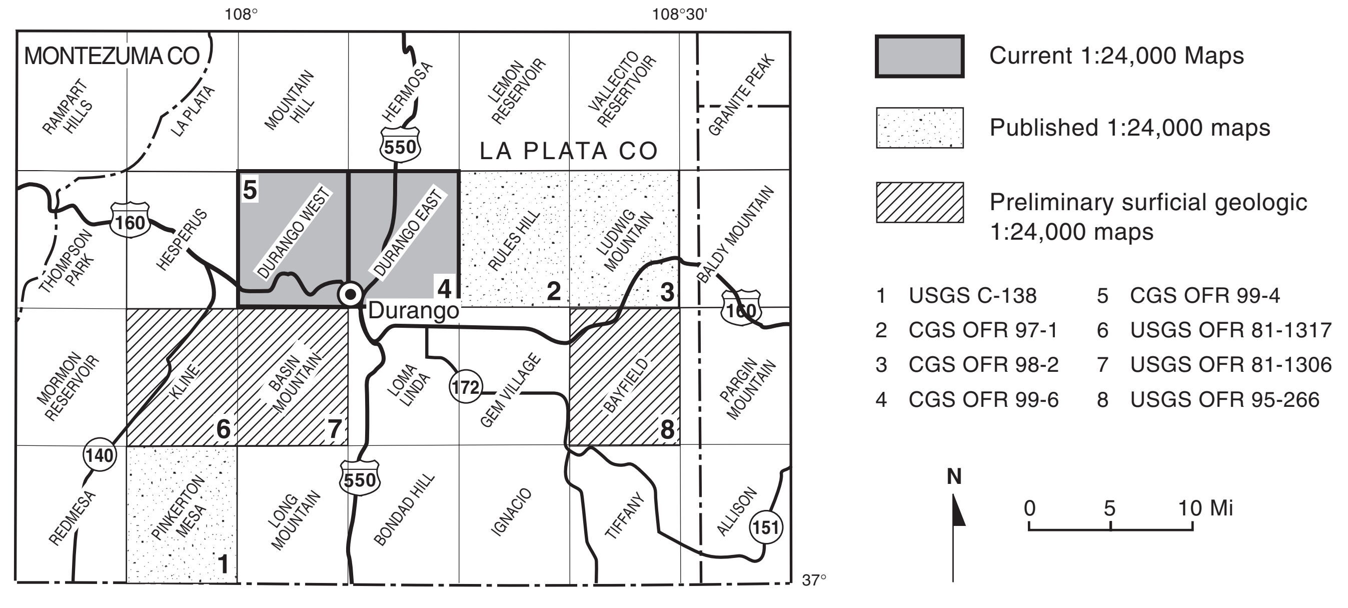

Figure 1. Status of geologic mapping of 7.5-minute quadrangles in the Durango area.

EXPANDED DESCRIPTION OF MAP UNITS

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SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than 5 ft thick but may be thinner locally. Residuum and artificial fill of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally may include deposits of another type. Divisions of the Pleistocene used herein correspond to those of Richmond and Fullerton (1986a). Relative age assignments for surficial deposits are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, and degree of weathering and soil development. The terrace stratigraphy along the Animas River used in this study was established by Gillam (1998), following work by Johnson and Gillam (1995), Gillam and others (1984; 1985), and Moore and Gillam (1984). Although the terrace nomenclature used in this report is different from that in Gillam (1998), the age assignments made by Gillam for terraces along the Animas River are used here with only minor modification. Some of the surficial deposits are calcareous and contain varying amounts of both primary and secondary calcium carbonate.

HUMAN-MADE DEPOSITS—

af

Artificial fill (latest Holocene)—Consists of waste rock and fill placed during construction of roads, buildings, and dams; also includes coal cinders from steam locomotives. Composed mostly of unsorted silt, sand, rock fragments, and construction materials. Artificial fill that forms the dam across Falls Creek in the northwest part of the quadrangle may be partially composed of lateral moraine material. The maximum unit thickness is about 30 ft. Artificial fill may be subject to settlement when loaded, if not adequately compacted.

cmw

Coal mine waste (latest Holocene)— Includes rock debris and coal refuse placed in dump piles near underground coal-mine shafts, adits, and strip mines. Maximum thickness about 30 ft. Unit may be prone to settlement or to ignition.

ALLUVIAL DEPOSITS—Silt, sand, and gravel deposited in stream channels, flood plains, glacial-outwash terraces, and sheetwash areas along the Animas and Florida Rivers and tributary drainages. Terrace alluvium along the Animas and Florida Rivers was deposited as glacial outwash mainly during late-glacial and early-interglacial stages. Most alluvium of tributary streams was probably deposited approximately the same time as outwash of the larger rivers. Individual units locally include sheetwash, colluvium, or loess that overlies alluvial deposits but cannot be mapped separately at this scale. The approximate terrace heights reported for each unit are the elevation differences measured between the modern river bed and the top of the original or remnant alluvial surface near the river side edges of the terraces. Terrace alluviums of similar age along the Animas and Florida Rivers are included in the same units.

Qa

Stream-channel, flood-plain, and low terrace deposits (Holocene)— Includes modern stream channel deposits of the Animas and Florida Rivers, adjacent flood-plain deposits, and low-terrace alluvium that is up to 8 ft above modern stream level. Unit may include deposits of terrace alluvium one (Qt_1) along Spring Creek and at the mouth of Junction Creek where human activities have disturbed the natural terrace surfaces. The unit consists of poorly to moderately sorted, clast-supported, unconsolidated bouldery and cobble gravel in a sandy or silty matrix. Locally the gravel is interbedded with or overlain by sandy silt and silty sand. Clasts are well rounded to subangular. Deposits along the Animas and Florida Rivers contain clasts with diverse lithologies, reflecting the wide variety of bedrock formations that crop out within their respective drainage basins. Clasts along the Florida River are generally derived from local sandstone with lesser amounts of igneous and metamorphic rocks. Clasts along the Animas River consist of more equal percentages of sandstone, igneous and metamorphic rock type, and reflect a larger, more diverse provenance area. The maximum thickness of alluvium in the Animas River Valley in the northern part of the quadrangle is 70 ft (water well records, Colorado Division of Water Resources, 1999) and more than 250 ft deep just north of the Animas City end moraines. Thickness is typically less than 20 feet south of the Animas City end moraines. Thickness of alluvium along the Florida River is estimated at less than 20 ft. Low-lying areas are subject to flooding. Unit is a source of sand and gravel and is currently being mined (1998) at two pits in the northern part of the quadrangle.

Qsw

Sheetwash deposits (Holocene and late Pleistocene)— Includes deposits that are transported by sheet-flow alluvial processes and deposited in valleys of ephemeral and intermittent streams, on gentle hillslopes below landslides or alluvial fans, and in basin areas. These deposits are locally derived from weathered bedrock, typically on Florida Mesa. Sheetwash deposits consist of pebbly, silty sand, sandy or clayey silt, and sandy, silty clay. Locally they grade to and interfinger with colluvium on steeper hillslopes and with lacustrine or slackwater deposits in closed depressions. Sheetwash deposits are relatively common within landslides. The maximum thickness is about 25 ft but may be greater in Horse Gulch. Unit may be prone to hydrocompaction, settlement, and piping where fine-grained and low in density.

Qt_1
Qt_{1u}
Qt_{1l}

Terrace alluvium one (late Pleistocene)—Chiefly stream alluvium that underlies several terraces from about 20 to 100 ft above the Animas River; terraces are graded to the Animas City moraines (Qma). The unit is poorly sorted, clast-supported, locally bouldery, pebble, and cobble gravel in a sandy matrix. It may include fine-grained overbank or overlying sheetwash deposits. Clasts are mainly subround to round and are composed of varied lithologies that reflect the diverse rock types in drainage basins. Clasts are generally unweathered or only slightly weathered. Terraces correlate with terrace group TG7 of Gillam (1998), which is graded to the Animas City moraines (see discussion of Animas City moraines for age determination). Terrace alluvium one is subdivided into an upper (older) unit (Qt_{1u}) which is graded to the Animas City outer moraine (Qmao) and a younger or lower unit (Qt_{1l}) which is graded to the Animas City middle and inner moraines (Qmam and Qmai). The thickness averages about 20 to 30 ft, but the maximum thickness may exceed 70 ft. This unit is a source of sand and gravel. Terrace alluvium one has not been recognized along the Florida River in the Durango East quadrangle, possibly because associated terraces are very low and have been included in stream-channel, flood-plain, and low-terrace deposits (Qa). Alternatively, terrace alluvium one may form terraces that are concealed by younger fan deposits (Qfy).

Qt_2

Terrace alluvium two (late? and late middle Pleistocene)— Chiefly stream alluvium that underlies one terrace remnant 180 ft above the Animas River and several terraces from 70 to 130 ft above the Florida River. Along the Animas River, terrace alluvium two underlies a single bench south of the junction with Spring Creek. In contrast, terrace alluvium two is locally well preserved along the Florida River. This unit is more common and underlies terraces with a larger height range (110 to 180 ft) in the adjacent Durango West quadrangle (Kirkham and others, 1999) and other quadrangles to the south (Gillam, 1998). Along the Animas River, the unit is similar in texture and lithology to terrace alluvium one (Qt_1) but is slightly more weathered. In comparison, deposits along the Florida River rarely contain small boulders, have a siltier matrix, and typically are capped by thicker loess as much as 5 ft. In both areas, mapped deposits locally may include overlying sheetwash deposits, colluvium, and loess ranging from several feet to tens of feet thick. Deposits along the Florida River contain mostly pebble- and cobble-sized clasts (3 inch to 9 inch diameter), have a silty matrix, and are capped by a 5-ft thick reddish-brown loess.

These terraces correlate with terrace group TG6 of Gillam (1998), which are graded to the Spring Creek moraines (Qms) in the Animas River Valley. The thickness ranges up to about 45 ft along the Animas River and 25 ft along the Florida River. Unit is a potential source of sand and gravel.

Qt_3
Qt_{3u}
Qt_{3l}

Terrace alluvium three (middle Pleistocene)— Chiefly stream alluvium that underlies terraces which are 290 to 450 ft above the Animas

River (Gillam, 1998) and only 100 to 180 ft above the Florida River (D.W. Moore, written communication, 1995). Along the Animas River, terrace alluvium three is subdivided into an upper (older) unit (Qt$_{3u}$) that projects to the Durango outer moraines (Qmdo) across an erosional gap, and a lower (younger) unit (Qt$_{3l}$) that is graded to the Durango inner moraine (Qmdi). The upper unit (Qt$_{3u}$) consists of a single fill terrace, whereas the lower unit (Qt$_{3l}$) includes a fill terrace and several lower cut terraces. These terraces correlate with terrace group TG5 of Gillam (1998). Most of the unit is texturally and lithologically similar to terrace alluvium one and alluvium two, but it is moderately weathered.

Along the Animas River, the basal part of the lower unit (Qt$_{3l}$) contains mostly sedimentary clasts derived from Pennsylvanian through Lower Cretaceous rocks that locally crop out in the valley sides. Although this basal section has previously been interpreted as a landslide deposit (G. R. Scott, in Gillam and others, 1984), the sediment is clast-supported and may have been reworked by fluvial processes. Locally, the unit also includes overlying sheetwash deposits, colluvium, and loess up to several tens of feet thick. Maximum thickness of terrace alluvium three along the Animas River was measured at 80 ft in this quadrangle, but approaches 150 ft within a short distance south of the Durango East quadrangle. Maximum thickness of terrace alluvium three along the Florida River is estimated at 25 ft. This unit is a potential source of sand and gravel (pits on this quadrangle are inactive in 1998, but several active pits are just south of the quadrangle).

Qt$_4$

Terrace alluvium four (middle Pleistocene)—Chiefly stream alluvium that underlies at least two terraces 530 to 640 ft above the Animas River and one or two terraces 180 to 200 ft above the Florida River. Along the Animas River, the highest terrace caps four hills near the mouth of Horse Gulch and the lower terrace is expressed as a short, narrow bench. An intermediate terrace is also suggested locally by slight slope changes at the same height as larger terrace remnants south of the quadrangle. Along the Florida River, one or two correlative terraces are present on Florida Mesa but it is concealed in most places by older fan alluvium (Qfo). Deposits of terrace alluvium four are texturally and lithologically similar to those of terrace alluvium one (Qt$_3$) but are strongly weathered. The mapped unit may include overlying sheetwash deposits, colluvium, and loess up to several tens of feet thick.

These terraces are correlated with terrace group TG4 of Gillam (1998), which projects above the Durango moraines to possible older moraines that are not preserved. Since the two highest terraces of TG4 are overlain by the Lava Creek B ash in the adjacent quadrangles (Gillam, 1998), part of terrace alluvium four was deposited before about 600 ka and part was deposited later (refer to the unit description of volcanic ash, Qva, for a discussion on the age of the ash). Maximum thickness of terrace alluvium four deposits in this quadrangle may locally exceed 60 ft. However, to the south, in Loma Linda quadrangle, the maximum thickness is about 200 ft. In contrast, the maximum thickness is approximately 20 ft along the Florida River. This unit is a potential but small source of sand and gravel in the Durango East quadrangle, but larger volumes are present and have been mined farther south.

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

Qrf

Recent rockfall (latest Holocene)—Deposits of debris from the Dakota Sandstone and Burro Canyon Formation that suddenly broke loose from a cliff as a rock topple on July 5, 1998. Located on the east wall of the Animas River Valley in the center of the NW 11⁄44 sec. 2, T. 35 N., R. 9 W., the rockfall debris chokes the headwall of a steep drainage basin. An estimated 50,000 cubic yards of debris fell downslope and came to rest on the Jurassic Morrison Formation hillside at an angle of 50°. Unit consists mostly of boulder- and cobble-sized angular blocks, some up to 40 ft in length, in a gravelly, sandy matrix. Unit is finer grained at the distal end, where siltstone and mudstone of the Morrison Formation were incorporated into the matrix. Unit is very unstable and may be a source of future debris flows, rock avalanches and landslides.

Qlsr

Recent landslide deposits (latest Holocene)— Includes recently active landslides with fresh morphological features that suggest movement during the past few decades. Most recent landslides occurred on steep north-facing hillslopes underlain by the Lewis and Mancos Shales. However, a recent landslide on the east side of Animas City Mountain involved material derived from Dakota Sandstone and Burro Canyon Formation that overlie the Morrison Formation. Recent landslide deposits are heterogeneous and consist of unsorted, unstratified rock debris, clay, silt, and sand. Texture and clast lithology depend upon provenance area. Maximum thickness is about 30 ft. These deposits are prone to renewed or continued landsliding, and they may be susceptible to settlement when loaded. Shallow groundwater may be present within areas mapped as recent landslide deposits.

Qt

Talus (Holocene and late Pleistocene?)— Angular, cobbly, and bouldery rubble on moderate to steep slopes that was derived from prominent outcrops of Dakota Sandstone and Burro Canyon Formation, Morrison Formation, or Junction Creek Sandstone, and transported downslope primarily by gravity during rockfalls, rockslides, or rock topples. Unit commonly lacks matrix and locally is underlain by or incorporated into landslides. Unit may grade into boulder-field deposits farther from the talus source. Maximum thickness estimated at 60 ft. Areas mapped as talus are subject to severe rockfall, rockslide, and rock-topple hazards. May be a source of riprap.

Qc

Colluvium (Holocene and late Pleistocene)—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy or silty matrix to matrix-supported gravelly sand or clayey silt. Colluvium is derived from weathered bedrock and surficial deposits and is transported downslope primarily by gravity but sometimes partly by sheetwash. Locally it grades to sheetwash deposits on flatter slopes and to debris-flow deposits in some drainages. Deposits are usually coarser grained in upper reaches and finer grained in distal areas. Clast lithology is variable and depends on locally exposed material. Deposits derived from thick, shaly bedrock tend to be clayey and matrix supported. Colluvial deposits are unsorted or poorly sorted with weak or no stratification. Clast lithology is variable and depends on locally exposed material. Locally the unit may include talus, landslide deposits, sheetwash deposits, and debris-flow deposits that are too small or too indistinct on aerial photographs to be mapped separately. Colluvium grades into younger fan deposits (Qfy), alluvium and colluvium, undivided (Qac), and sheetwash deposits (Qsw) in some tributary drainages. Maximum thickness is probably about 40 ft. Areas mapped as colluvium are susceptible to future colluvial deposition and locally subject to sheetwash, rockfall, small debris flows, mudflows, and landslides. Fine-grained, low-density colluvium may be prone to collapse.

Qls

Landslide deposits (Holocene and Pleistocene)— Highly variable deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes. Deposits range from active, slowly creeping landslides to long-inactive, middle or perhaps even early Pleistocene landslides. Most landslides involve the Mancos Shale, Dakota Sandstone, Burro Canyon Formation, or Morrison Formation. Several large landslides are located on the Dakota Sandstone hogback north of Spring Creek and the Florida River. These landslides result from slip planes developed along claystone beds in the Morrison Formation. These deposits have been described as a slope failure complex (Miller, 1977). Large boulders up to 20 ft in size derived from the Dakota Sandstone and Burro Canyon Formation lie at the foot of the landslide at secs. 7 and 8, T. 35 N., R. 8 W. Landslide deposits may also include boulder-rich areas that are winnowed of fine material.

Maximum thickness may exceed 200 ft at landslide toe regions. Landslide deposits may be subject to future movement, but deeply dissected deposits may be more stable. Foundation excavations within landslide deposits should be individually evaluated for stability. Large blocks of rock within many of these deposits may hinder excavation. Deposits may be prone to settlement when loaded. Shallow groundwater may occur within landslide deposits.

Qco

Older colluvium (middle and early Pleistocene?)—Occurs on hillslopes, ridgelines, and drainage divides as erosional remnants of formerly more extensive deposits that were transported primarily by gravity and partly by sheetwash processes. Texture, bedding, and clast lithology resemble those of colluvium (Qc). Maximum thickness probably is about 50 ft. Older colluvium rests on moderately steep ridges between drainages on the Lewis Shale in Horse Gulch. Unit includes material eroded from beds of Upper Cretaceous sandstone and shale that crop out along the Hogback Monocline on Florida River. Unit may be subject to collapse, piping, and settlement where fine grained and low in density.

ALLUVIAL AND COLLUVIAL DEPOSITS— Silt, sand, gravel, and clay in debris fans, stream channels, flood plains, and adjacent hillslopes along tributary valleys. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheetwash processes prevail on alluvial fans, on hillslopes, and along the hillslope/valley floor boundary.

Qfy

Younger fan deposits (Holocene and late Pleistocene)—Includes hyperconcentrated-flow, debris-flow, alluvial, and sheetwash deposits in fans and tributary drainages. Locally may include earthflows or landslides. Consists of poorly stratified deposits that range from poorly sorted, clast-supported, pebble, cobble, and boulder gravel in a clayey silt or sand matrix to matrix-supported, gravelly, clayey silt. Unit is frequently bouldery, particularly near the heads of fans. Deposits tend to be finer grained in the distal ends of fans, where sheetwash and mudflow processes become more common. Younger fan deposit in First Fork is derived from large-scale mass wasting in its headwaters. Clasts range from angular to subround. Maximum thickness is about 40 ft. Numeric subscripts in the unit symbol indicate relative ages of younger fans in sec. 19, T. 35 N., R 9 W., along the Florida River. Deposits labeled Qfy_1 are younger than those labeled Qfy_2. Younger fans are subject to flooding and to future debris-flow, hyperconcentrated-flow, and alluvial deposition. Fine-grained, low-density younger fan deposits may be prone to settlement, hydrocompaction, piping, and landsliding.

Qac

Alluvium and colluvium, undivided (Holocene and late Pleistocene)—Unit consists chiefly of stream-channel, low-terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and colluvium and sheetwash along valley sides. Locally includes debris-flow deposits. The alluvial and colluvial deposits commonly are interfingered. Unit is poorly sorted to well sorted and ranges from stratified pebbly sand and sandy gravel interbedded with sand (the alluvial component) to poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt (the colluvial component). Clast lithologies reflect the rocks within the provenance area. Thickness is commonly 5 to 30 ft; maximum thickness is estimated at about 50 ft. Low-lying areas are subject to flooding. Valley sides are prone to colluvial processes, sheetwash, rockfall, and small debris flows. Unit may be subject to settlement, collapse, or piping where fine grained and low in density. Unit is a potential source of sand and gravel. In Hidden Valley, a local term for the small valley west of the Animas River Valley and north of Animas City Mountain, the unit has a maximum thickness of 15 ft and may include lacustrine deposits, and may overlie outwash gravels resembling those of terrace alluvium one (Qt_1).

Qcs

Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene?)— Composed of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. This unit is mapped where contacts between the two types of deposits are very gradational and difficult to identify. Located primarily on north-facing slopes of the Lewis Shale in Horse Gulch and Mancos Shale along Spring Creek. Refer to unit descriptions for colluvium (Qc) and sheetwash deposits (Qsw) for genetic, textural, and lithologic characteristics and for engineering properties and geologic hazards. Colluvial and sheetwash deposits locally include debris-flow deposits. Thickness averages 10 to 30 ft, but may be greater locally.

Qfo

Older fan deposits (middle Pleistocene)— Occurs as remnant of a long-inactive, formerly extensive fan complex on Florida Mesa west of the Florida River, and also below landslide deposits on the ridge between Spring Creek and Florida River.

The latter unit has been described as a pediment surface (D.Moore, 1998 personal comm.) but is shown on this map as a 5 to 15 ft thick fan covering outwash gravel terraces. This unit consists chiefly of sediment derived from exposures of Cretaceous bedrock located one to two miles to the northwest. It ranges in texture from poorly sorted, clast-supported, locally bouldery, cobble and pebble gravel in a sandy matrix, to silty sand. Clasts are composed mostly of Cretaceous sandstone but also of older volcanic rocks, chert, and quartzite that have been reworked from Cretaceous conglomerates. Rare clasts of granitic rocks and limestone may have been reworked either from Cretaceous conglomerates or from unpreserved terrace alluvium older than terrace alluvium four (Qt$_4$). Clasts are generally subangular to angular, but many reworked pebbles are very well rounded. Lenses of the middle Pleistocene Lava Creek B ash bed (Qva, described below) are locally interbedded within the deposits, which lie about 150 to 300 ft above the Florida River and are roughly 5 to 50 ft thick. The head of the fan complex has been completely eroded in most places where it formerly contacted its Cretaceous source rocks, and the remainder is moderately dissected by stream incision. This unit also overlies terrace alluviums three and four (Qt$_3$ and Qt$_4$) on parts of Florida Mesa and is locally overlain by several feet of loess or sheetwash alluvium. Unit may be a source of sand and low-quality gravel.

EOLIAN DEPOSITS—Silt, sand, and clay deposited by wind on level to gently sloping surfaces.

Qlo

Loess (Holocene to middle Pleistocene)— Clayey, sandy silt and silty, very fine to fine grained sand deposited by wind and preserved on level to gently sloping surfaces. Typically is unstratified, cohesive, and plastic or slightly plastic when wet. Sand grains are sometimes frosted. Where loess has been mapped as a separate unit, its thickness ranges from about 5 to 15 ft. Deposition generally occurred during several periods of eolian activity, as indicated by buried soils within some deposits (Gillam, 1998). Loess covers the Durango moraines (Qmd), indicating that deposition of preserved deposits in the Durango East quadrangle began during middle Pleistocene time. The mapped distribution of loess is very approximate due to its poor geomorphic expression. However, loess also covers many other areas where it has not been mapped separately, either because it is not as thick (as on younger moraine and terrace deposits) or because its distribution is patchy (as on some older fans). Loess that is low in density may be prone to settlement when loaded and to piping and hydrocompaction when wetted.

EOLIAN AND ALLUVIAL OR LACUSTRINE DEPOSITS—Volcanic ash deposited by wind and reworked by alluvial or lacustrine processes.

Qva

Volcanic ash (middle Pleistocene)—White to light-gray or light-brown, bedded, volcanic ash with low to moderate amounts of locally derived, non-volcanic sediment. Occurs at three locations, one on the hillslope north of Animas City Mountain (N ½ NE ¼ sec.5, T. 35 N., R. 9 W.) and two on Florida Mesa (NE ¼ SW ¼ NE ¼ sec. 36 and NW ¼ SE ¼ SW ¼ sec. 36, T.35 N., R. 9 W). Woolsey (1906) originally reported the first locality and one on Florida Mesa, which cannot be identified, but may have been the second one described there.

The ash bed north of Animas City Mountain generally rests unconformably on the Morrison Formation, but locally overlies an intervening gravel lens and is overlain by landslide deposits (Qls). This ash is thinly laminated, yielded a fossil aquatic snail (Gyraulus sp.), and may be as much as 50 ft thick, suggesting deposition in a lacustrine environment (Gillam, 1998). Kirkham and others (1999) proposed that the thin gravel lens beneath the ash bed might correlate to terrace alluvium four (Qt$_4$) near Junction Creek and that an ancestral Junction Creek flowed around the north side of Animas City Mountain during early middle Pleistocene time.

The ash beds on Florida Mesa are within older fan alluvium (Qfo). Both are poorly exposed, but the first appears to be several feet thick and at least 300 ft long and the second about 2 ft thick and at least 30 ft long. Gillam (1998) suggested that these deposits are composed of Lava Creek B ash from the Yellowstone caldera because of their similarity to other ash beds on nearby quadrangles that were identified by petrographic methods (Izett and Wilcox, 1982) or by chemical analysis (Gillam, 1998). Recent ^{40}Ar/^{39}Ar dating of 24 sanidine crystals from the Lava Creek B tuff near Yellowstone, using single-crystal laser-fusion methods, yielded an average age of 602 ± 4 ka (Gansecki and others, 1998). Previous studies by Izett and Wilcox (1982) reported an age of 620 ka for the Lava Creek B ash, a value that has been widely cited in the literature. Volcanic ash deposits are low in density and may be prone to compaction or settlement problems. They were mined for use as household abrasives during the early 20th century and could be mined in the future.

SINTER DEPOSITS—Chemical sediment deposited by a mineral spring.

Qtu

Tufa (latest Holocene)—Low density, porous chemical precipitate consisting of calcium carbonate deposited historically from a mineral-charged hot spring on the east side of the Animas River Valley in sec, 10, T. 35 N., R. 9 W. The hot springs emanates from a collapsed mine tunnel driven into the Pony Express Limestone. Since 1990 the hot spring has increased in temperature from 90° F to 132° F and its flow has risen from 2 to approximately 10 gallons per minute (W. Holland, personal communication, 1997). This increase in flow has caused the water to overflow the owner's water system and drain over the hillside to a canal below. As a result, tufa has been deposited on the hillside for the last ten years. Historic deposits of tufa occur near this deposit but are covered by vegetation.

GLACIAL DEPOSITS—Silt, sand, gravel, cobbles, and boulders deposited by or next to glacial ice in the Animas River Valley. End moraines in the northern Durango area were deposited during one of several glacial periods when the ice front was at or near its farthest down-valley position. Unlike end moraines, lateral moraines have not been subdivided according to the glacial period when they formed, and some may have formed soon after the ice began to recede. Individual units locally include overlying colluvium and loess that are mapped separately on the larger moraines. The approximate moraine crest heights reported for each unit are the elevation differences estimated between the modern riverbed and the top of the original or remnant surface. Age assignments by Gillam (1998) for moraines along the Animas River are used here with only minor modification.

Qkd

Kame deposit (latest Pleistocene)—Sandy gravel that formed against stagnant ice while the latest Animas glacier receded. Unit consists mainly of crudely bedded, clast-supported pebbles and cobbles in a sandy matrix, but unit also contains a few boulders. A single deposit occurs near the north edge of the quadrangle, where the deposit lies against the west side of the Animas Valley roughly 40 feet above the valley floor. The location of this deposit, up-valley from the Animas City end moraines and below nearby lateral moraines, suggests that it is a glaciofluvial feature which formed after ice had stagnated and partly melted, probably when sediment filled a small depression between remaining ice and the valley side. Its uniqueness indicates that it is not a remnant of a widespread deposit like the terrace alluviums described below. Thickness ranges from a few feet to about 30 ft. Unit is a potential source of sand, gravel, and decorative boulders for landscaping, but its volume is small. Excavation may be difficult where large boulders occur.

Qma
Qmai
Qmam
Qmao

Till and diamicton of Animas City moraines (late Pleistocene)—Heterogeneous, mainly silty to bouldery sediments deposited next to or by glacial ice. Unit forms three nested end moraines at the south edge of the broad Animas River Valley in northern Durango. These are the Animas City inner moraine (Qmai), which is the youngest and farthest up-valley, Animas City middle moraine (Qmam), and Animas City outer moraine (Qmao). The Animas City inner and middle moraines are well preserved as nearly continuous ridges with arcuate planforms, narrow irregular crests, and a few undrained depressions. In contrast, the older Animas City outer moraine is mostly eroded and both remnants were excavated recently for building sites. Crest heights range from 80 to 200 ft above the Animas River; unexposed moraine deposits are found in water wells below river level. Moraine locations appear to be structurally controlled by outcrops of Junction Creek Sandstone and Entrada Sandstone west of the Animas River and outcrops of Dakota Sandstone and Burro Canyon Formation east of the river (Johnson and Gillam, 1995).

The Animas City moraines and associated glaciers were described or mapped in many earlier studies (Howe and Cross, 1906; Atwood and Mather, 1932; Richmond, 1965; Gillam and others, 1984, 1985; Leonard, 1984; Johnson and Gillam, 1995; Gillam, 1998). The late-Pleistocene Animas City glacier was the largest and longest in the San Juan Mountains, with an area of about 230 square miles and length of about 50 miles. The moraine deposits vary greatly in texture, bedding, structure, and origin (Johnson, 1990; Johnson and Gillam, 1995). Most deposits consist of pebbly, sandy silt or silty sand with few to abundant cobbles and boulders. Individual lenses are usually very poorly sorted and matrix supported but locally are moderately sorted and clast supported. Crude bedding and down-valley dips suggest that much of the sediment accumulated from debris flows and meltwater streams in the form of proglacial aprons. However, some faulted melt-out till, which indicates deposition over stagnant ice, and folded lake silts, evidence of re-advancing ice, are present on the up-valley sides of the moraines. Clast lithology is highly varied and represents the many bedrock types that crop out in the Animas River drainage. These rocks range from Pre-Cambrian igneous rocks to metamorphic and sedimentary rocks of all types. Clasts are generally unweathered or only slightly weathered. The Animas City moraines are probably close in age to Pinedale and other late-Wisconsin moraines elsewhere in the Rocky Mountains (Richmond, 1965), which formed roughly between 12 and 35 ka (Richmond and Fullerton, 1986a). However, the Animas City moraines probably formed during the later part of this period because meltwater streams very likely destroyed slightly older moraines of late-Wisconsin age (Johnson and Gillam, 1995). Maximum thickness may be 150 to 200 ft. Unit is a potential source of sand, gravel, and decorative boulders for landscaping (aggregates were extracted from several pits before urban growth reached these areas). Excavation may be difficult where large boulders occur.

Qms	Qmsi
	Qmso

Till and diamicton of Spring Creek moraines (late? and late middle Pleistocene)—Heterogeneous, mainly silty to bouldery sediment deposited next to or by glacial ice. Unit caps several small, rounded hills that appear to be remnants of two moraines which are very poorly preserved. These are the Spring Creek inner moraine (Qmsi), which is younger and farther up-valley, and the Spring Creek outer moraine (Qmso). The highest (least eroded) parts of the moraines are 200 to 350 ft above the Animas River. Deposits are similar in texture and lithology to those of Animas City moraines (Qma) but are slightly more weathered.

Richmond (1965) first mapped these hills as early and late Bull Lake moraines; but Gillam and others (1984) proposed the local name “Spring Creek”. The moraines probably correlate with Bull Lake, Eowisconsin, and other moraines of similar age that formed during marine oxygen-isotope stages 6 and 5d-5b (Richmond and Fullerton, 1986b) elsewhere in the Rocky Mountains. Gillam (1998) suggested an age range of 85 to 160 ka based on dates for deposits in other areas (as summarized by Richmond and Fullerton, 1986a; see also Sturchio and others, 1994, and Chadwick and others, 1994). This age range is supported by approximate, amino-acid-racemization dates for fossil snails in alluvium overlain by the Spring Creek 1 moraine (in SW 1⁄4 NW 1⁄4 sec. 14, T. 35 N., R. 9 W; analyses by A.R. Nelson, U.S. Geological Survey reported by Gillam, 1998). Thickness ranges up to about 55 ft. Unit is a potential source of sand, gravel, and decorative boulders. Excavation may be difficult where large boulders occur.

Qmd	Qmdi
	Qmdo

Till and diamicton of Durango moraines (middle Pleistocene)—Heterogeneous, mainly silty to bouldery sediment deposited next to or by glacial ice. Unit forms several broad, smooth ridges on College Mesa (local name for the high mesa where Fort Lewis College is built), but a deeply eroded remnant also occurs on the south end of Animas City Mountain along the boundary with the Durango West quadrangle (Kirkham and others, 1999). The younger Durango inner moraine (Qmdi) forms a prominent ridge along the north edge of College Mesa. Several shorter segments are included in the older Durango outer moraine group (Qmdo). The highest (least eroded) parts of the moraines are 450 to 510 ft above Animas River. Their deposits are poorly exposed but appear similar to those of Animas City moraines except for moderate weathering and strong soils.

The moraines, first mapped by Atwood and Mather (1932), were later associated with the Sacagawea Ridge Glaciation by Richmond (1965). The Sacagawea Ridge name was later substituted for the local name Durango moraines and subdivided as shown here (G. R. Scott, in Gillam and others, 1984). Gillam (1998) suggested that the Durango inner moraine formed during marine oxygen-isotope stage 8, possibly about 250 to 275 ka, and that the Durango outer moraine group formed during stage 10, possibly about 340 to 360 ka. These stage assignments are based on calibrated river-incision rate ages for related outwash terraces. Moraines from stage 10 are rare in the United States (Richmond and Fullerton, 1986b).

The maximum unit thickness is about 200 ft. The moraines are overlain by loess that is typically from several feet to 20 ft thick, but may be thicker in depressions where the loess has been reworked by slopewash processes. On College Mesa the loess is noted by a fractional symbol. Unit is a potential source of sand, gravel, and decorative boulders. Excavation may be difficult where large boulders occur.

Qlm

Lateral moraines (late and middle Pleistocene)—-Heterogeneous deposit of mainly cobble-boulder gravel in a sandy matrix. Unit was deposited next to glacial ice emplaced on bedrock along the valley sides. Lateral moraines are located on both sides of the Animas River Valley in the valley walls. Lateral moraines cover lesser slopes near Haflin Canyon and are emplaced on the east side of the ridge between Hidden Valley and the Animas River Valley. The highest parts of the moraines are 400 to 650 ft above the Animas River. Deposits are similar in texture and lithology to those of Animas City moraines (Qma) but are slightly more weathered. Lateral moraine deposits range from 10 to 40 ft thick.

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q

Surficial deposits, undifferentiated (Quaternary)—Shown only on cross section. May include any of the above surficial deposits

BEDROCK

TKi

Monzonite and monzodiorite porphyry dikes (Lower Tertiary or Upper Cretaceous)—Purple to reddish-brown to medium-gray igneous dike along the Florida River and a medium to dark gray dike on the east side of Animas City Mountain. Both dikes are moderately to highly weathered or altered. The dike along the Florida River is exposed along a canal at SE 11⁄44 SE 11⁄44 sec. 24, T. 35 N., R. 9 W. This dike is intruded through the McDermott Member of the Animas Formation and has a fracture pattern similar to regional fractures in the area (see Fracture Data and Analysis section). This dike is 8 ft thick and trends vertically. The mapped location of the dike is based on a projection of the apparent trend from its limited exposure. A sample of the dike was submitted for dating but a precise age could not be determined. Based on field relationships and ideogram for the geochronology the dike is roughly 40 to 60 Ma, slightly younger than deposition of the McDermott Member of the Animas Formation and older than the development of fractures associated with the Laramide Orogeny.

Whole-rock analyses were performed on the Florida River dike (Table 1). This rock is subalkaline to alkaline with abundant pyroxenes and felty plagioclase crystals. The silica content suggests the rock is monzonite to diorite in composition.

Another igneous dike was discovered on the east side of Animas City Mountain. This medium-gray igneous rock was discovered in float within the Morrison Formation. A trend of N10E was implied from the observation that the dike acts as a groundwater barrier and from a linear zone of unusually large trees. Exposed dike rocks around Durango are often less resistant to erosion and do not typically form good outcrops. A smaller dike has been reported near Fort Lewis College in the Mancos Shale (R. Blair, 1999, personal comm.).

Animas Formation (Paleocene and Upper Cretaceous)—Includes the main body of the formation (TKa), the basal McDermott Member (Kam), and the interfingering parts between the two units.

TKa

Main body—Gray-green to olive-brown and light- to dark-brown volcaniclastic conglomerate, tuffaceous sandstone, lithic tuff, and shale. Sandstones are fine- to medium- grained, quartzose, and include accessory minerals such as magnetite. Sandstone beds are mostly crossbedded in sets of variable thickness ranging from 0.5 ft to 15 ft in height. Sandstone beds range from well sorted to poorly sorted, have well-rounded grains, and are cemented with silica.

Reeside (1924) suggested that the main body of the Animas Formation is unconformable with all underlying units. Zapp (1949) interpreted the main body of the Animas Formation as an intertongue with the McDermott Member east of the Florida River in secs.19 and 20, T.35 N., R 8 W., a conclusion supported by this project and by Carroll and others (1997) on the adjacent Rules Hill quadrangle. Fassett (1987) suggested that a regional unconformity occurs at the boundary between Tertiary and Cretaceous rocks in the San Juan Basin. The McDermott Member was mapped in Rules Hill quadrangle as an eastward thinning tongue in the lower part of the main body of the Animas Formation which pinches out near Rules Hill (Carroll and others, 1997). East of the Florida River the lower part of the main body of the Animas Formation thickens eastward to about 80 ft on the eastern edge of the quadrangle. Since the lower Animas Formation is Upper Cretaceous in age (Barnes and others, 1954) we herein describe the Animas Formation in the quadrangle as being both Paleocene and Upper Cretaceous. The upper or Paleocene part of the Animas Formation correlates with the Nacimiento Formation in northern New Mexico. Palynomorphs from the Animas Formation immediately above the McDermott Member in an outcrop along the Animas River indicate an early Maastrichtian age (Newman, 1985). The contact with the underlying Kirtland Shale is unconformable and distinguishable by an abrupt presence of light colored sandstone in the upper Kirtland Shale Member.

The Animas Formation is a fluvial, volcanogenic clastic deposit (Condon, 1990). Prominent sedimentary features such as trough crossbedding and clay rip-up clasts in the Animas Formation indicate deposition in a high-energy fluvial environment. Volcanic clasts were probably eroded from uplands to the north and northwest, possibly from around the La Plata Mountains area (Zapp, 1949). Maximum preserved thickness in the quadrangle is about 900 ft, on the basis of subsurface information from gas wells drilled in the southern part of the quadrangle.

Kam

McDermott Member—Member consists of purple, purplish-green, gray to grayish-white volcaniclastic conglomerates and sandstones, and lesser white-gray claystone. Clasts are cobble and pebble sized, well rounded and volcanic in origin (andesitic). The basal part is conglomeratic sandstone, mostly unsorted, and is in part matrix-supported, suggesting deposition as debris flows or lahars. The upper part is more laminar bedded, lithologically similar to the main part of the Animas Formation. Lithologically it is similar to the Animas Formation but is usually coarser clastic and purple in color. D. Gonzales (personal comm., 1998) suggested that the purple color be due to the presence of manganese in the rocks.

Reeside (1924) named the unit the McDermott Formation for exposures 15 miles southwest of Durango. The Upper Cretaceous age assignment was due primarily to dinosaur bones found within the member there. The McDermott Member may record an early outburst of volcanism during the Laramide Orogeny (Barnes and others, 1954). The McDermott Member is a restricted member of the basal Animas Formation only found between the La Plata River and Rules Hill. The McDermott Member is up to 280 ft thick in the southwest part of the quadrangle.

Kirtland Shale (Upper Cretaceous)—Consists of three members: an upper member, the Farmington Sandstone Member, and a lower member. Thickness of the entire formation is about 650 ft.

Kku

Upper member—Light-yellow, gray, and whitish-tan sandstone interbedded with olive-green and olive-blue shale. The sandstone beds are fine to medium grained, crossbedded, and include thin beds that are well indurated. Occasional massive beds form rounded ledges with distinctive honeycomb weathering that crop out as a minor ridge in the quadrangle. The sandstones are well sorted, cemented with silica, have rounded grains, and fine upward within short sequences. Shale beds are sometimes carbonaceous with coalified plant and tree impressions. The upper member of the Kirtland Shale is a fluvial deposit. The presence of feldspar and mafic minerals suggests erosion of upland areas and is interpreted as the beginning of the Laramide Orogeny (Barnes and others, 1954). Contact with the underlying Farmington Sandstone Member is gradational. As shale beds within the upper member thin to the west, the contact with the Farmington Sandstone Member becomes difficult to recognize and may be arbitrary. The upper member of the Kirtland Shale is poorly exposed except where well-indurated massive sandstones crop out, such as those found along a canal just west of the Florida River. Maximum thickness is 300 ft on the east side of the quadrangle.

Kkf

Farmington Sandstone Member—Yellowish-brown and tan to light-orange sandstone and greenish-gray shale. The sandstone is fine to medium grained, crossbedded, well sorted, silica cemented, and has subrounded to rounded grains. It forms a small hogback that parallels the Hogback monocline southeast of the prominent hogback formed by the Pictured Cliffs Sandstone. Along the west side of the Florida River the unit is well exposed in a canal bank and contains occasional palm-frond fossil impressions. The gradational contact with the lower member of the Kirtland Shale (Kkl) is rarely well exposed. In this quadrangle we chose to use the base of the lowest one-ft thick sandstone bed within the unit as the contact. The Farmington Sandstone Member was deposited in fluvial channels shoreward from the Fruitland coastal plain (Fassett and Hinds, 1971; Aubrey, 1991). Maximum thickness is about 150 ft. Unit may be prone to rockfall where exposed in steep cliffs. Locally it may be difficult to excavate.

Kkl

Lower member—Greenish-gray to dark-olive-gray shale and thin lenses of dark-brown to greenish-gray sandstone and silty shale beds. The dark color in the sandstone beds is due to the presence of chlorite. Hematite oxidation and bulbous partings or spheroidal weathering is common. Unit is not well exposed in the quadrangle. The contact with the underlying Fruitland Formation is conformable and gradational; it is placed at the top of the highest Fruitland Formation channel sandstone or coal bed (J. Fassett, oral comm., 1998). The lower member of the Kirtland Shale was deposited in overbank and channel areas on the Late Cretaceous coastal plain between the Fruitland Formation coal swamps and the Farmington Sandstone Member fluvial channels (Fassett and Hinds, 1971). Thickness ranges from 50 to 80 ft, thinning to the east. Engineering problems associated with the lower member of the Kirtland Shale include poor foundation soils and possible shrink-swell potential. Landsliding on steeper slopes is possible, although the unit characteristically forms saddles between ridgelines and is rarely topographically high.

Kf

Fruitland Formation (Upper Cretaceous)—Unit consists of interbedded sandstone, shale, coal, and altered volcanic ash. The sandstone is light gray, light brown to olive brown, well indurated, fine to medium grained, crossbedded, well sorted, and consists of predominantly subangular quartz grains. Interbedded shale is dark gray to black, carbonaceous, locally sandy, and contains several interbedded coal and altered volcanic ash beds. Coal beds are prevalent in the basal part of formation.

The upper part of the Fruitland Formation is a sequence of fluvial sandstones and shales. The lower part consists predominantly of sandstone, bituminous coal beds with well-developed cleats, and shale. The channel sandstones are lenticular and usually pinch out within a few hundred feet. Individual coal seams extend for thousands of feet across the quadrangle and thicken to the west. The lower part of the Fruitland Formation was deposited in non-marine brackish-water lagoonal and swampy coastal-plain environments; it grades upward into well-drained coastal-plain environments (Condon, 1990).

Historic coal mining of the Fruitland Formation occurred in the quadrangle. Measured sections of coalbeds by Zapp (1949) indicate that the Fruitland Formation has three main coal seams in the Durango East quadrangle. The middle or upper Fruitland "Peacock" seam has an aggregate thickness of 8.8 ft. (The "Jumbo" bed is a middle Fruitland Formation coal with an aggregate thickness of 20 ft). The basal Fruitland Formation coal, termed the "Fairmont" bed in a coal mine on the west side of the quadrangle (Zapp, 1949), has a measured aggregate thickness of 22.9 ft, and an aggregate thickness of 15.0 ft in the Florida Grange Mine. Combined thickness of the coal beds is as much as 60 ft in the quadrangle. Total thickness of the Fruitland Formation ranges from 250 to 350 ft.

The Fruitland Formation is the main source of San Juan Basin coalbed methane production. Fourteen of the sixteen producing gas wells located on Florida Mesa are coalbed methane wells. Seven underground coal mines or open pit mines in the map area worked Fruitland Formation coalbeds. Geologic hazards include methane gas leakage along the Fruitland outcrop, including local explosive or toxic conditions along the Florida River. Methane contamination of water wells has also been reported (W. Holland, oral communication). Lister (1996a,b) described the geologic conditions relating to these methane gas problems. The Fruitland Formation is also prone to landsliding and rockfall on steeper slopes.

Kpc

Pictured Cliffs Sandstone (Upper Cretaceous)—Light-gray to white, tan and grayish-orange sandstone interbedded with dark-gray shale in lower part. The sandstone has siliceous cement, is well sorted, and has rounded to subrounded sand grains. In the Durango East quadrangle two distinct units are noted: an upper, thick, massive sandstone sequence overlying a thinner bedded, stacked sequence of shale and sandstone. Locally the formation contains abundant *Ophiomorpha* burrows that are characteristic of the unit (Fassett and Hinds, 1971; Aubrey, 1991; Pemberton and others, 1992). The formation extends northeast-southwest across the quadrangle as a steep cliff-forming hogback. The outcrops are rounded and occasionally have honeycomb texture with large grottos.

The Pictured Cliffs Sandstone was deposited in shallow-marine water as a shoreface deposit (Fassett and Hinds, 1971; Aubrey, 1991). While the Pictured Cliffs Sandstone was deposited in a regional regression, minor transgressive sequences were deposited locally. These sandstone buildups are associated with the Fruitland Formation tongue deposition. The Pictured Cliffs Sandstone locally intertongues with the basal Fruitland Formation. The underlying Lewis Shale interfingers with the Pictured Cliffs Sandstone, but the contact between them is mostly covered. Thickness of the lower part is 215 ft near Durango (Zapp, 1949) while the upper part is up to 150 ft thick. The formation rises stratigraphically about 1,100 ft in a southwest to northeast direction across the San Juan Basin (Fassett, 1988). The Pictured Cliffs Sandstone may pose rockfall hazards where exposed in high cliffs. It is a reservoir for natural gas in the San Juan Basin.

Kft

Fruitland Formation Tongue (Upper Cretaceous)— Unit consists of coal, carbonaceous shale, clinker, and altered volcanic ash. The coal is black, subbituminous B in rank (Ayers and others, 1994), low to medium ash, and the interbedded shale is dark gray to black, carbonaceous, locally ashy with several thin tonsteins. Unit locally includes burnt rock and clinker from burning coal beds.

The Fruitland Formation tongue is part of the basal Fruitland Formation coal that overrides a tongue of Pictured Cliffs Sandstone locally. This tongue of coal is denoted on the map by a special line symbol and is labeled Kft. The Fruitland Formation tongue is 9.4 ft. thick in sec. 33, T. 35 N., R. 9 W. near the southwest corner of the quadrangle. It runs from the southern quadrangle boundary for approximately 5 miles northeast where it pinches out within the Pictured Cliffs Sandstone in sec. 24, T. 35 N., R. 9 W. The Fruitland Formation tongue consist of a coal stringer that splits from the basal Fruitland Formation coal bed and is stratigraphically limited in extent. The Fruitland

Formation tongue is genetically related to the Pictured Cliffs Sandstone tongues developed by minor transgressive sequences (Ayers and others, 1994). Recent coal mining of the Fruitland Formation tongue occurred in the southwest corner of the quadrangle, at the Carbon Junction Strip Mine which operated until 1988 (see Economic Geology Section).

Kl

Lewis Shale (Upper Cretaceous)—Dark-gray, fissile shale containing thin sandstone beds at top and gray, bluish-gray limey shale in the lower part. Altered volcanic ash beds, most notably the Huerfanito bentonite bed, have been used as time-stratigraphic markers throughout the San Juan Basin (Fassett and Hinds, 1971, Fassett and Steiner, 1997). This bentonite bed is not easily distinguished in the field but has been recognized and correlated between 600 and 850 ft below the Pictured Cliffs Sandstone on electric wireline logs in the quadrangle (Sandberg, 1986). The unit weathers easily, is generally covered by surficial deposits, and is poorly exposed in the quadrangle. The contact with the underlying Cliff House Sandstone is conformable and somewhat gradational. The Lewis Shale was deposited in a low-energy, offshore, marine environment (Fassett and Hinds, 1971). Total thickness averages about 1,800 ft in the Durango area. It is a reservoir for natural gas in the San Juan Basin. The Lewis Shale may be prone to landsliding and is susceptible to shrink-swell problems where it contains expansive clays.

Kmvu

Mesaverde Group (Upper Cretaceous)— Consists of three mappable formations in the Durango East quadrangle which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone. These formations are distinguished primarily by the presence of coal beds within the Menefee Formation. The Point Lookout Sandstone and some sandstone beds in the Menefee Formation are resistant to erosion and form a prominent ridge, locally called Raider Ridge, that lies southeast of the Durango Municipal Golf Course. The Mesaverde Group, undivided, is shown only on the cross-section.

Kch

Cliff House Sandstone— Interbedded sequence of thin beds of moderately indurated, yellowish-orange to white, gray, very fine- to medium-grained calcareous sandstone and softer light-gray mudstone and silty shale. Sandstone beds frequently contain abundant *Ophiomorpha* burrows. They weather to yellow brown or light reddish brown and form a rusty-colored outcrop that sharply contrasts with the drab colors of the underlying Menefee Formation. The Cliff House Sandstone is usually poorly exposed except in road cuts and other excavations. Contact with the underlying Menefee Formation is conformable and gradational and is placed below the lowest *Ophiomorpha*- bearing bed in the Cliff House Sandstone and above the highest coal bed in the Menefee Formation. The Cliff House Sandstone is a transgressive, shallow-marine unit deposited on the upper shoreface zone of a barrier-island beachfront (Siemers and King, 1974). Thickness in the quadrangle is usually less than 100 ft. Shale beds in the Cliff House Sandstone may have moderate to high swell potential. The formation is an important natural gas reservoir and producer in the San Juan Basin.

Kmf

Menefee Formation—Interbedded, lenticular, light-gray, brown, and orange-brown sandstone, gray, brown, and black shale, and coal. Locally includes burnt rock and clinker resultant from burning of coal beds within the formation. Sandstone beds are often well cemented and locally form prominent cliffs. They also contain ripple marks and sometimes have abundant organic debris. Contact with the underlying Point Lookout Sandstone is conformable, and often sharp. It is placed at the base of the lowest coal or carbonaceous shale.

Thickness is highly variable, ranging from about 200 to 350 ft. The variation in thickness is probably a result of several factors, including differential compaction of the sand, clay, and peat beds during lithification and thickness reduction due to burning of coal beds. Individual coal beds are up to 7 ft thick, but typically are a maximum of 3 to 4 ft thick. The combined thickness of all Menefee Formation coalbeds in the quadrangle is 22.1 ft thick along the Florida River, and 18.4 ft along the Animas River (Zapp, 1949). The Menefee Formation was deposited in a coastal plain environment (Aubrey, 1991). Subsidence of the land surface may occur above underground mines where coal was extracted from the Menefee Formation. Thick sandstone beds on high ridges pose rockfall hazards.

Point Lookout Sandstone—Consists of two members, a basal member and an overlying massive member. The contact with the underlying Mancos Shale is conformable and gradational. The sandstone beds in the Point Lookout Sandstone become thinner and shale becomes more common as it grades into the Mancos Shale. For this study the contact is placed at the base of the lowest one-ft thick sandstone bed or where the strata contain more than 50 percent shale over a 6 ft stratigraphic interval. The formation was deposited in a coastal shoreline environment It represents a regressive littoral marine unit deposited during final retreat of the Cretaceous epeiric sea in the San Juan Basin region (Wright-Dunbar and others, 1992). The Point Lookout Sandstone represents an eastward-prograding shoreline between the sea in which the Mancos Shale was deposited and the coastal plain where the Menefee Formation was accumulating. Thickness ranges from about 310 to 400 ft. The Point Lookout Sandstone is an important reservoir and producer of natural gas in the San Juan Basin.

Kplm

Massive member—Thick beds of light-gray to yellowish-gray or brown quartzose sandstone, and very minor interbeds of dark-gray shale. The sandstone is fine to medium grained, cross laminated, well sorted, and cemented with calcite. Locally it contains abundant *Ophiomorpha* and *Thalassinoides* burrows. The massive member of the Point Lookout Sandstone commonly forms prominent cliffs. Thickness ranges from about 60 ft along the Florida River to 100 ft along the Animas River. In Horse Gulch, the massive member represents the sandy mouth-bar facies overlying a shaly distal delta front (Wright-Dunbar, personal communication, 1997).

Kpl

Basal member—Sequence of interbedded thin sandstone and shale beds that are gradational between the massive member of the Point Lookout Sandstone and the Mancos Shale. Sandstone beds are commonly less than one ft thick and consist of light-gray to yellowish-gray or brown, quartzose sandstone. Shale beds are light to dark gray, fossiliferous, and carbonaceous, and become more common towards the base of the member. Contact with underlying Mancos Shale is conformable. Thickness averages 250 to 300 ft. Shale beds in the basal or transition member may have high swell potential.

Km

Mancos Shale (Upper Cretaceous)—Dark-gray to black shale and silty shale, dark-gray to blue-gray argillaceous limestone, and calcarenite with thin beds of bentonite. Yellowish-brown to dark-brown weathered concretions form within the calcareous basal part of the formation. The Mancos Shale is generally very poorly exposed in the region, but parts of the formation are locally well exposed within the quadrangle. Along Spring Creek the basal calcareous part of the Mancos Shale forms prominent round hills and ridgelines.

West of the quadrangle, in and near Mesa Verde National Park, Leckie and others (1997) subdivided the Mancos Shale into eight members. In ascending order, these members are the Graneros, Bridge Creek, Fairport, Blue Hill, Juana Lopez, Montezuma Valley, Smoky Hill, and Cortez members. Some of these members were recognized in Durango East quadrangle but were not mapped separately. Leckie and others (1997) described 188 bentonite beds, most of which were less than 4 inches thick, within the Mancos Shale west of the quadrangle. They occur throughout the formation, but are most abundant in the basal part of the formation.

The contact with the underlying Dakota Sandstone is conformable with local transgressive intertongues. The main body of the Mancos Shale was deposited in a low-energy, marine environment. The basal part of the Mancos Shale was deposited in a near-shore environment that interfingers with subaerially exposed beds in the upper part of the Dakota Sandstone. Fossil clams and oysters were found within the Juana Lopez member.

Total thickness of the Mancos Shale is about 2,000 to 2,200 ft. The Mancos Shale is prone to landsliding. Bentonitic beds may cause expansive soil and heaving bedrock problems. Unit is rich in sulfate, which can be corrosive to concrete and can impact the quality of groundwater. Several oil and gas fields in New Mexico produce from sandstone members of the Mancos Shale that are not recognized in Colorado. A fractured shale gas play in the Mancos Shale may have a major hydrocarbon potential in the map area.

Kd

Dakota Sandstone (Upper Cretaceous)—Dark-brown, tan to yellowish- brown quartz arenite sandstone with carbonaceous shale partings and siltstones at the top. The basal part is a high-energy fluvial unit of trough-cross-bedded, fine- to medium-grained sandstone with some conglomeratic beds, which was deposited as a valley-fill sequence (Aubrey, 1991). The unconformity surface on which it was deposited cuts into the underlying Burro Canyon Formation. The Dakota Sandstone fills those channel cuts with mostly coarse-grained sandstone, and is fining upward. Often the basal channel sandstones of the Dakota Sandstone, called the Encinal Member (Aubrey, 1991), fill valleys that previously truncated parts of the Burro Canyon Formation. Inasmuch, the Dakota Sandstone is typically conglomeratic and appears very similar to but darker than the Burro Canyon rocks.

The Dakota Sandstone is a transgressive unit of mostly continental rocks deposited shoreward of the Mancos seaway. The contact with the underlying Burro Canyon Formation is difficult to identify. The formations are differentiated based on color, amount of carbonaceous material, and texture. The Burro Canyon is distinctly white to buff colored, while the basal Dakota Sandstone is light brown. The Dakota Sandstone is generally finer grained and contains carbonaceous shales and thin coal beds, whereas the Burro Canyon has none. The alluvial part of the Dakota Sandstone is overlain by fine-grained beds deposited in deltaic and marginal-marine environments (Aubrey, 1991). The Burro Canyon Formation and Dakota Sandstone are separated by a disconformity. The channel sandstones in the Dakota Sandstone are tabular planar-crossbedded, fine grained, and overlain by overbank deposits of gray to black mudstone, carbonaceous shale, and thin, discontinuous coal beds. The Dakota Sandstone becomes increasingly more marine toward the top. Trace fossils such as *Diplocraterion* were found which indicate a sandy shoreface environment near the top of the formation. Fossil palm fronds were also found in the upper part of the formation. The Dakota Sandstone and Mancos Shale interfinger in the quadrangle in N^{1}¼2 NW^{1}¼4 of sec.14, T. 35 N., R. 9 W. A calcareous siltstone overlies carbonaceous shale, which may be the Polotti Sandstone Member of the Dakota Sandstone and the Clay Mesa Member of the Mancos Shale respectively (D. Owen, oral communication, 1998). The Twowells Tongue has also been reported locally in southwestern Colorado (Aubrey, 1991; Landis and others, 1973), but was not reported in the Durango East quadrangle. The Dakota Sandstone is an oil and gas reservoir in parts of the San Juan Basin. In the Durango area the Dakota Sandstone is about 80 ft thick. The Dakota Sandstone is a significant rockfall hazard where exposed in steep cliffs. Significant landslide hazards exist on the Dakota Sandstone dipslope in Durango East quadrangle. The Dakota Sandstone is 200 ft. thick.

Kbc

Burro Canyon Formation (Lower Cretaceous)—White or buff-colored, coarse- to very coarse-grained sandstone, and conglomeratic sandstone. The Burro Canyon Formation contains chert-pebble clasts and green claystone. Erosion-resistant beds of the Burro Canyon Formation commonly crop out as locally prominent ledges on the dipslope north of Spring Creek. In places much and perhaps all of the Burro Canyon was erosionally removed prior to deposition of the valley-fill sequences in the lower part of the Dakota Sandstone. The Burro Canyon Formation generally is a competent foundation material. Construction activities such as excavations may require blasting. Where exposed in steep hillslopes, this unit may be prone to causing rockfall hazards. Shear fractures commonly act as the failure planes for rockfall and rock topples. The unit is prone to block landsliding when slip planes develop within shale beds below the formation.

Kdb

Dakota Sandstone (Upper Cretaceous) and Burro Canyon Formation, undivided (Lower Cretaceous)—The two formations are mapped as a single unit where the contact between the two is difficult to recognize or to show at the map scale. The combined thickness of the two formations averages 180 to 250 ft in the quadrangle.

Jm

Morrison Formation (Upper Jurassic)— Greenish-gray, occasionally reddish-brown, bentonitic mudstone and claystone containing thin beds of very fine- to fine-grained sandstone and rare conglomeratic sandstone in the upper part. The lower part is light-gray to white, mostly silicified, fine- to medium-grained, lenticular sandstone interbedded with thin beds of greenish-gray mudstone. The Morrison Formation consists of an upper member called the Brushy Basin Member and a lower member known as the Salt Wash Member, which were not mapped separately. The Brushy Basin Member conformably overlies and perhaps intertongues with the Salt Wash Member (Condon, 1990). Thickness of the Brushy Basin Member is estimated at 150 to 200 ft, while the Salt Wash Member is about 200 to 300 ft thick.

The Salt Wash Member unconformably overlies the Junction Creek Sandstone at a regionally traceable sequence boundary (J5 unconformity of Pipiringos and O'Sullivan, 1978). Lucas and Anderson (1997a) suggest that the basal Salt Wash Member in the Durango region is the Recapture Member of the Bluff Sandstone, thus placing the J-5 unconformity within the basal Morrison Formation. Field evidence for this was uncertain in the Durango East quadrangle. Turner and Fishmann (1991) suggested that much of the Brushy Basin Member was deposited in a single ancient, alkaline, saline lake called Lake Tóódichí, Anderson and Lucas (1997a) preferred a depositional model involving numerous smaller lakes on a vast flood plain.

Bentonitic beds within the formation may be prone to swelling soil problems. The Brushy Basin Member may be subject to landsliding where exposed on steep slopes or on dip slopes. Much of the landsliding has occurred within the Morrison Formation on the slopes north of Spring Creek. A large landslide on the east side of Animas City Mountain is within the Brushy Basin Member.

Jjc

Junction Creek Sandstone (Middle to Upper? Jurassic)—Light-gray to tan, white, highly crossbedded to massive, fine-grained eolian sandstone. It is primarily an eolianite, but interdunal deposits were noted as well. The upper part of the formation is highly crossbedded. The lower part of the Junction Creek Sandstone has less crossbedding and more variable sedimentary structures which indicate a variable wind direction. The Junction Creek Sandstone is correlative with the Bluff Sandstone in the Four Corners region and southeastern Utah (O'Sullivan, 1997; Lucas and Anderson, 1997b). Prominent uniform crossbedded sandstone at the top of the unit indicates a predominantly eastward paleotransport direction. Lucas and Anderson (1997b) interpreted this as an example of "event stratigraphy" indicating that at this time during the Jurassic the prevailing wind direction was from the west.

The Junction Creek Sandstone conformably overlies the Wanakah Formation. Thickness is about 120 ft. It may create rock-fall hazards where exposed in steep cliffs. The Junction Creek Sandstone forms mostly rounded ledges, but steep, fractured outcrops occur in the valley wall east of the Animas River. The Junction Creek Sandstone there is the source for much talus (Qt) below the outcrop.

Jw

Wanakah Formation (Middle Jurassic)— Consists of an upper member composed predominantly of white to tan, reddish-orange, and reddish-brown, very fine- to fine-grained sandstone and reddish-brown to greenish-gray mudstone; and a lower member, the Pony Express Limestone Member, consisting of medium- to dark-gray, very thin-bedded to laminated, micritic and oolitic limestone. Formation is very poorly exposed in the quadrangle; only the Pony Express Limestone Member locally forms a limited outcrop. The upper part of the Wanakah Formation is correlative with the Summerville Formation in the Four Corners region and the Pony Express Limestone is correlative with the Todilto Limestone in New Mexico (Lucas and Anderson, 1997b). Condon (1990) suggested the upper member of the Wanakah Formation was deposited in sabkha and marginal-marine environments, while the Pony Express Limestone Member was of restricted-marine origin. Lucas and Anderson (1997b) described the Summerville Formation as being deposited in quiet, ephemeral shallow water on an arid coastal plain of very low slope and relief. The Bilk Creek Sandstone is a regionally correlative 2-ft thick sandstone bed at the base of the Wanakah Formation and was found in

Hidden Valley but is usually covered east of there. Thickness of the upper part of the Wanakah is estimated at about 60 ft.

The Pony Express Limestone is only mapped separately in T. 36 N., R. 8 W., at the northern edge of the Durango East quadrangle where it forms a prominent dip-slope surface. The Pony Express Limestone is a distinctive limestone marker bed in an otherwise clastic sequence of rocks. Unit was a source of lime for early construction in Durango's history. The J-3 unconformity underlies the Pony Express Limestone (Pipiringos and O'Sullivan, 1978) at the basal contact with the underlying Entrada Sandstone. The maximum thickness measured in the Durango East quadrangle is 16.2 ft.

Je

Entrada Sandstone (Middle Jurassic)— Light-gray to white, sometimes orangish-gray, fine- to medium-grained, highly cross-bedded sandstone. Locally the unit is coarse grained or conglomeratic at the base and typically has prominent large-scale cross-bedding. The Entrada Sandstone is the basal unit of the San Rafael Group in this region. This formation has been described as a vast erg which developed on an emergent arid coastal plain during regression of the shallow Curtis-Sundance seaway (Lucas and Anderson, 1997b). Thickness averages about 250 ft but may be more than 340 ft thick east of the Animas River Valley. The basal Entrada Sandstone is orangish brown, medium grained and may be an interfluvial –lacustrine sequence of a dune field. A 20-ft-thick section of bioturbated sandstone was noted in Hidden Valley and forms a distinctive cliff throughout the area. The J-2 regional unconformity underlies the Entrada Sandstone (Pipiringos and O'Sullivan, 1978) at the contact with the underlying Dolores Formation.

TRd

Dolores Formation (Upper Triassic)—Dark-reddish-brown to purplish-red shale and siltstone, light-brown, gray, and reddish-brown lenticular sandstone and limestone-pebble conglomerate, and rare thin limestone beds. Locally the formation is well exposed on steep hillslopes, but usually is partly or completely covered on gentler slopes. A. Heckert (personal communication, 1997) suggests that this unit correlates with an upper member (Rock Point Formation), middle member (Painted Desert Member of the Petrified Forest Formation), and lower member (Moss Back Formation) of the Chinle Group in the Colorado Plateau. The Moss Back Formation, as described by Stewart and others (1972), is 75 ft of greenish-gray to tan, fine-grained quartzose sandstone and limestone-pebble conglomerate with siliceous clasts. Lithological units similar to the Moss Back Formation are present in the western part of Durango East quadrangle but were not observed on the east side. In the northeast corner of the map area the limestone pebble conglomerate beds thin and the contact with the underlying Cutler Formation is arbitrary. The Dolores Formation unconformably overlies the Cutler Formation. The Dolores Formation was deposited in fluvial and lacustrine environments (Condon, 1990). Thickness averages about 500 to 600 ft. The unit may be prone to rockfall hazards where exposed in steep cliffs.

Pc

Cutler Formation (Lower Permian)— Medium- to dark-reddish-brown, medium-gray, and medium- to dark-brown sandstone, arkosic sandstone, and arkosic conglomerate, reddish-brown to purplish-brown shale and siltstone, and rare thin limestone beds and limestone pebble conglomerate. Base of the formation is not exposed in quadrangle. The Cutler Formation was deposited in fluvial and alluvial-fan environments (Campbell, 1979). 1,900 ft of section is exposed in Haflin Canyon but the total thickness is greater than 2,000 ft. The formation may be prone to rockfall hazards where exposed in steep cliffs.

TRPdc

Dolores Formation (Upper Triassic) and Cutler Formation (Lower Permian), undivided—Unit is mapped in the north-northeastern part of the quadrangle where poor exposures limit recognition of the contact between these formations.

Table 1. Whole-rock analyses of igneous rock from the Durango East quadrangle.

PERCENT

Sample ID No.	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI*	TOTAL
DE-56	16.30	2.33	<0.01	6.62	4.24	0.86	0.06	3.61	0.21	60.93	0.64	2.89	98.69

Above analyses were performed by Chemex Labs, Inc., Sparks, Nevada.

*Loss on ignition

Trace element analysis was conducted on the same rock. Results for that test are shown in Table 2 below.

Table 2. Trace element analyses of igneous rock from the Durango East quadrangle.

PARTS PER MILLION

Sample ID No.	Ba	Ce	Cs	Co	Cu	Dy	Er	Eu	Gd	Ga	Hf	Ho	La	Pb	Lu	Nd	Ni	Nb
DE-56	1620	79	1.6	9.5	35	4.5	2.5	1.8	5.8	21	4	0.9	34.0	30	33.5	<5	0.4	12

	Pr	Rb	Sm	Ag	Sr	Ta	Tb	Tl	Th	Tm	Sn	W	U	V	Yb	Y	Zn	V
DE-56	8.3	92.6	6.6	<1	671	0.5	0.9	0.5	8	0.4	1	<1	2.0	60	2.8	22	85	60

Above analyses were performed by Chemex Labs, Inc., Sparks, Nevada.

Sample Location: DE-56: Dike exposed in cut along canal just west of the Florida River. Dike trends east-west and cuts the McDermott Member of the Animas Formation.

FRACTURE DATA AND ANALYSES

Data on minor faults and joints were collected at twenty-six fracture stations in the Durango East quadrangle to characterize the fracture network in sedimentary rocks exposed at the surface. Joints are defined as opening mode-I fractures with no offset between planes. Minor faults (shear fractures) are fractures with small (a few millimeters) displacement between two planes. This fracture analysis is useful for the evaluation of migration pathways for fluids and gasses (that is, groundwater, coalbed methane, and hydrogen sulfide), evaluation of shallow and deep water-well production and quality, as well as for identifying potential rockfall hazard areas. Fracture data is also useful for interpreting the tectonic history of the area. Recent fracture studies (Condon, 1997; Whitehead, 1997; Verbeek and Grout, 1997; Tremain and others, 1991; Laubach and others, 1991) within the San Juan Basin have hypothesized a range of origins for fractures including Laramide compression, unloading, and topographic release.

The fracture study of the Durango East quadrangle is part of a larger fracture study of joints and minor faults along the northern rim of the San Juan Basin (Ruf, in preparation). Data were collected from 412 minor faults for this investigation; data on 70 other faults are from Erslev (1997) (see Table 3 for data). Joint data were collected from 1,022 joints at 23 locations on the various Upper Cretaceous sandstone formations on Durango East quadrangle (Table 4). The locations of the 26 fracture stations are shown in Figure 2. Both joints and minor faults were also observed in older formations mapped within the Durango East quadrangle, but these were not studied.

Fault plane orientation, slickenline (a line on a fault-plane indicating the direction of motion) orientation, and sense of motion were determined in the field. Shear sense was evaluated using the methods of Petit (1987). In the lab, ideal σ_1 orientations were determined by the ideal σ_1 method (Compton, 1966). Fault-plane orientations were analyzed using rose diagrams. Joint-plane orientations (approximately 20 for each joint set) were collected in the field and then analyzed using rose diagrams to determine preferred orientations (Figure 3). Timing of joint formation was determined by abutting relationships. The oldest joints are called J1 joints, and successively younger joint sets are labeled J2 and J3. Rose diagrams of the orientation of ideal σ_1 orientations are shown in Figure 4. Figure 5 shows all of the rose dagrams for $\sigma_{1,}$ shear fractures, and joint planes.

Strike-slip fault-planes are the most common type of minor fault and are observed at every locality within the Dakota Sandstone and Burro Canyon Formations. Thrust faults are much less common and were only observed at localities FS1, FS2, FS3, and FS7 (Figure 2). Normal faults were observed at locality FS2. Fault-planes are best preserved within the upper, quartz arenite beds of the Dakota Sandstone, although faults were also observed in younger and older formations but are much less common and poorly preserved. The reason for increased preservation and abundance of minor faults in the Dakota Sandstone may be a function of the mechanical properties of the rock.

Strike-slip and thrust faults indicate multi-stage, multi-directional horizontal compression with three distinct events: N58E, N56W, and N18E. Tri-modal horizontal compression was observed at every locality except FS6. The lack of tri-modal horizontal compression at locality FS6 is thought to reflect a small sampling population. Normal faults at locality FS2 indicate a fourth event of extension.

Timing of the three compressional events and one extensional event recorded from minor fault data was determined by cross-cutting relationships. At locality FS8, strike-slip planes with a northeast σ_1 are offset by strike-slip planes with a northwest σ_1; this offset indicates northeast compression followed by northwest compression. Northeast-oriented slickenlines on thrust planes overprinted by north-northeast-oriented slickenlines were observed in the Durango West quadrangle (Kirkham and others, 1999; Ruf, in preparation), and indicate northeast compression followed by north-northeast compression. At locality FS7 on Animas City Mountain, a thrust plane with a north-northeast σ_1 cuts a strike-slip fault with a northwest σ_1, showing northwest compression followed by north-northeast compression. Normal faults at locality FS2 cut through the entire outcrop of Dakota Sandstone and Burro Canyon Formations and record the most recent stage of faulting. Overall order of σ_1 orientations is: 1) σ_1 northeast horizontal compression, 2) northwest horizontal compression, 3) north-northeast horizontal compression, and 4) extension.

Joint data collected at 23 localities in the Durango East quadrangle are shown in Figure 2 and Table 3. The J1 joint set at each of these localities was the first joint set to propagate. It forms planar, evenly spaced, through-going fractures. The J2 set is commonly observed as a cross joint; it abuts against two separate J1 planes and is interpreted as forming after the J1 joints. At most fracture stations, the J1 joint sets have an overall north-northwest orientation and the J2 joint sets have an overall east-northeast orientation, approximately perpendicular to the J1 joint sets. However, at localities FS10, FS11, FS12, and FS25 the orientations of J1 joint sets is north-northeast, and the orientations of the J2 joint set is east-southeast to southeast. These latter localities are located near normal faults in Horse Gulch.

Statistical joint data by formation are presented in Table 4. The orientation of the J1 joint set is consistently oriented between 323° to 355° and the J2 joint set is oriented between 12° to 89° for every formation except the Menefee Formation and the Cliff House Sandstone. These results are consistent with previous fracture studies in the quadrangle (Whitehead, 1997; Tremain and others, 1991; Laubach and others, 1991). There is no apparent pattern of rotation between older and younger formations.

The timing between joint propagation and fault development was determined by cross-cutting relationships of joint-planes and fault-planes. At locality FS6, the J1 joint set cut strike-slip faults. No observable offset of the J1 joints was noted. Secondly, localities that contained a high density of strike-slip faults have few joints; this sparcity suggests that strike-slip faults were reactivated as joints during extension. Both of these observations suggest that joints propagated after minor fault development.

Minor faulting in an igneous dike (Ti) cutting the McDermott Member of the Animas Formation along the Florida River was measured. The minor fault plane was oriented at 245°, 18° dip, with a trend of 185° and 10° plunge. The calculated σ_1 orientation is north-northeast. This is the youngest compressional event in the area.

The northeast (058°) σ_1 is a typical orientation for the Laramide Orogeny (Erslev, in press; Chapin and Cather, 1983) in the southern Rocky Mountains. The origin of the northwest (304°) σ_1 orientation is unclear but is observed throughout Colorado and New Mexico (E.A. Erslev and T.K. Ehrlich, written comm., 1998; Gregson and Erslev, 1996). It has been associated with a transfer of the Sevier stress field across the Paradox Basin (Gregson and Erslev, 1996). The north-northeast (018°) σ_1 direction has been observed in northern New Mexico and in north central Colorado (Erslev, in press; T.K. Ehrlich, written comm., 1998). This north-northeast σ_1 event has been documented cutting Eocene age rocks (24.1 Ma for Eagle Rock Dike south of Raton and 25 to 28 Ma for Llana Quemado Breccia and Picuris Formation south of Taos) (Erslev, in press).

Compression directions and timing of joint propagation versus minor fault development (Table 5) indicate that joints within the Durango East quadrangle are post-Laramide in age. The consistency of J1 orientations in the Durango East quadrangle and throughout the northern rim of the San Juan Basin is both spatially and stratigraphically different than the topographic origin for J1 joint propagation (Ruf, in prep.). The J1 joint set probably propagated within a post-Laramide stress field during uplift of the San Juan Basin. Changes in the J1 joint orientation near Horse Gulch within the Menefee Formation and the Cliff House Sandstone may be a result of localized normal faulting. A second possibility for the anomalous joint orientations at these localities is that the J1 joint set may have never propagated and instead an intermediate joint set formed either prior to or after the north-northwest trending J1 joint set. Variations of the north-northwest J1 orientation in different formations may be a result of slight changes in the stress field during uplift and joint propagation. Stresses associated with the Rio Grande Rift, which are similar in orientation to J1 orientation, may have influenced the stress field during uplift. The J2 joint set is younger than the J1 joint set and is a result of an interaction between the pre-existing J1 joint set. Greater variations of the J2 cross joint orientation suggests that it propagated late in the history of the basin, possibly as a result of a complex interaction of the contemporary regional stress field, topography, the J1 joint set, and bedding (Ruf, in prep.).

Table 3. Fracture station data. (Kdb, Dakota Sandstone and Burro Canyon Formation; Kpl, Point Lookout Sandstone; Kplm, massive member of Point Lookout Sandstone; Kmf, Menefee Formation; Kch, Cliff House Sandstone; TKa, Animas Formation; Kf, Fruitland Formation; Kpc, Pictured Cliffs Sandstone; Kkf, Farmington Member of the Kirtland Shale.)

Fracture Station ID. No.	Type	Number of Fractures	Formation	Location
FS1	Shear (Minor fault)	62	Kdb	Near 1998 East Animas Valley rockslide
FS1	Joint	22	Kdb	Near 1998 East Animas Valley rockslide
FS2	Minor fault	42	Kdb	NW Stock Driveway on Missionary Ridge
FS3	Minor fault	80	Kdb	Kdb outcrop near Mud Spring Creek
FS3	Joint	59	Kdb	Kdb outcrop near Mud Spring Creek.
FS4	Minor fault	58	Kdb	Kdb outcrop east of Mud Spring Creek
FS4	Minor fault	46	Kdb	Kdb outcrop east of Mud Spring Creek
FS5	Minot fault	41	Kdb	Kdb outcrop northeast of FS4
FS5	Joint	23	Kdb	Kdb outcrop northeast of FS4
FS6	Minor fault	20	Kdb	Kdb outcrop south of FS4
FS6	Joint	19	Kdb	Kdb outcrop south of FS4
FS7	Minor fault	55	Kdb	NW corner of Animas City Mt
FS8	Minor fault	53	Kdb	Roadcut on Florida River Rd.
FS9	Joint	56	Kpl	West end of Horse Gulch
FS10	Joint	47	Kmf	Raider Ridge, north of Horse Gulch
FS11	Joint	50	Kmf	Raider Ridge, northeast of FS10
FS12	Joint	50	Kch	Raider Ridge, SE of City Reservoir
FS13	Joint	53	Kch	Raider Ridge northeast of FS12
FS14	Joint	62	Kplm	Raider Ridge, Kplm dipslope pavement
FS15	Joint	55	Kplm	Corner of Florida Rd. and CR 234
FS16	Joint	21	Kpc/Kf	Contact at coal prospect pit
FS17	Joint	50	Kpc/Kf	Contact at old La Plata coal mine
FS18	Joint	52	Kpc/Kf	Contact at hogback northeast of FS17
FS19	Joint	52	Kpc/Kf	Contact at hogback south of FS18
FS20	Joint	50	Kpc/Kf	at hogback southeast of BM 8175
FS21	Joint	43	Kpc/Kf	Contact at hogback northeast of FS20
FS22	Joint	27	Kf	Junction of CR 234 and Horse Gulch Rd
FS23	Joint	54	Kkf	Kirtland hogback southeast of old La Plata Mine
FS24	Joint	45	TKa	Road cut on Waters Way
FS25	Joint	43	Kmf	East side of Animas River south of Durango
FS26	Joint	41	Kpc	Junction of CR 234 and Horse Gulch Rd

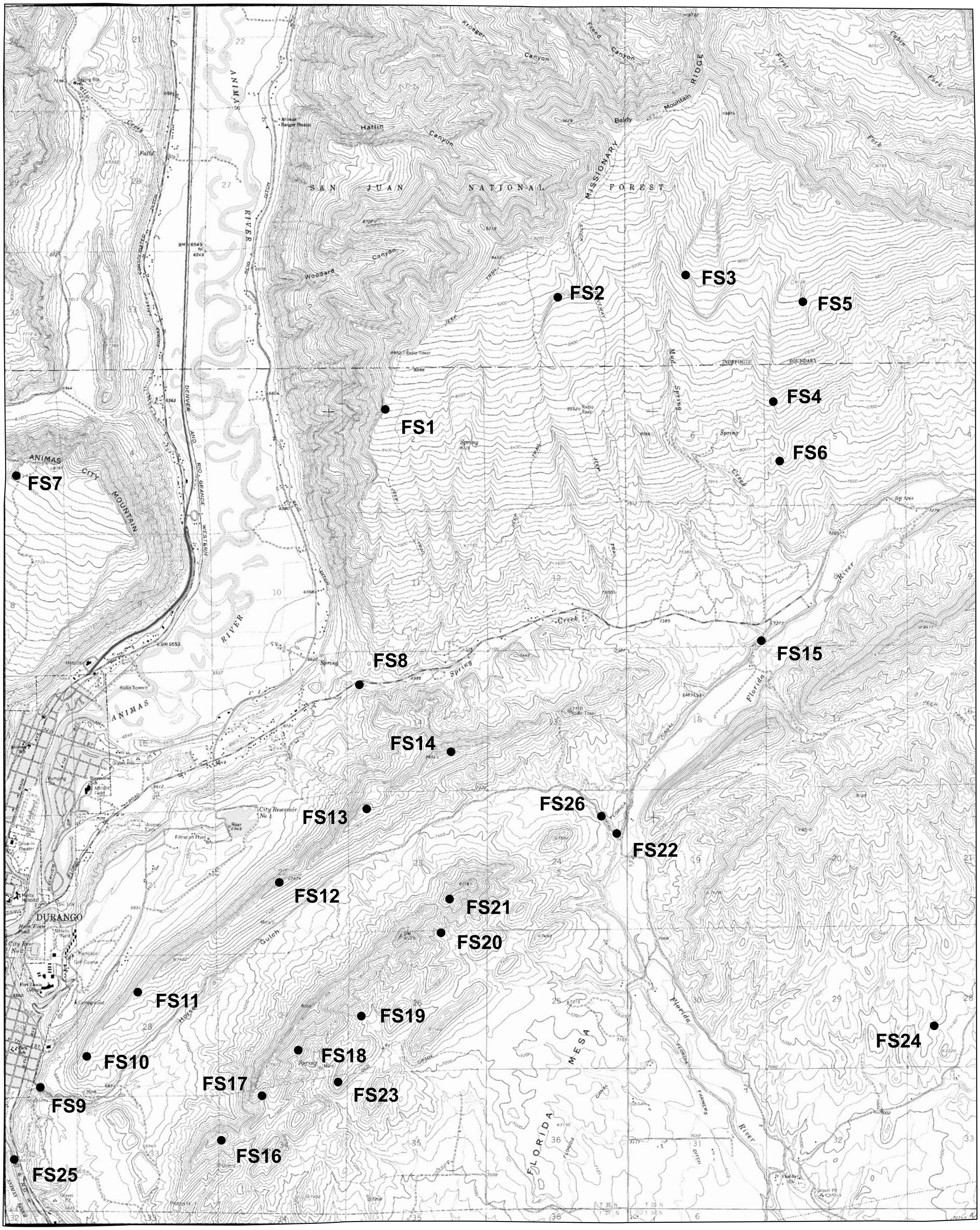


Figure 2. Locations of 26 fracture stations in Durango East quadrangle.

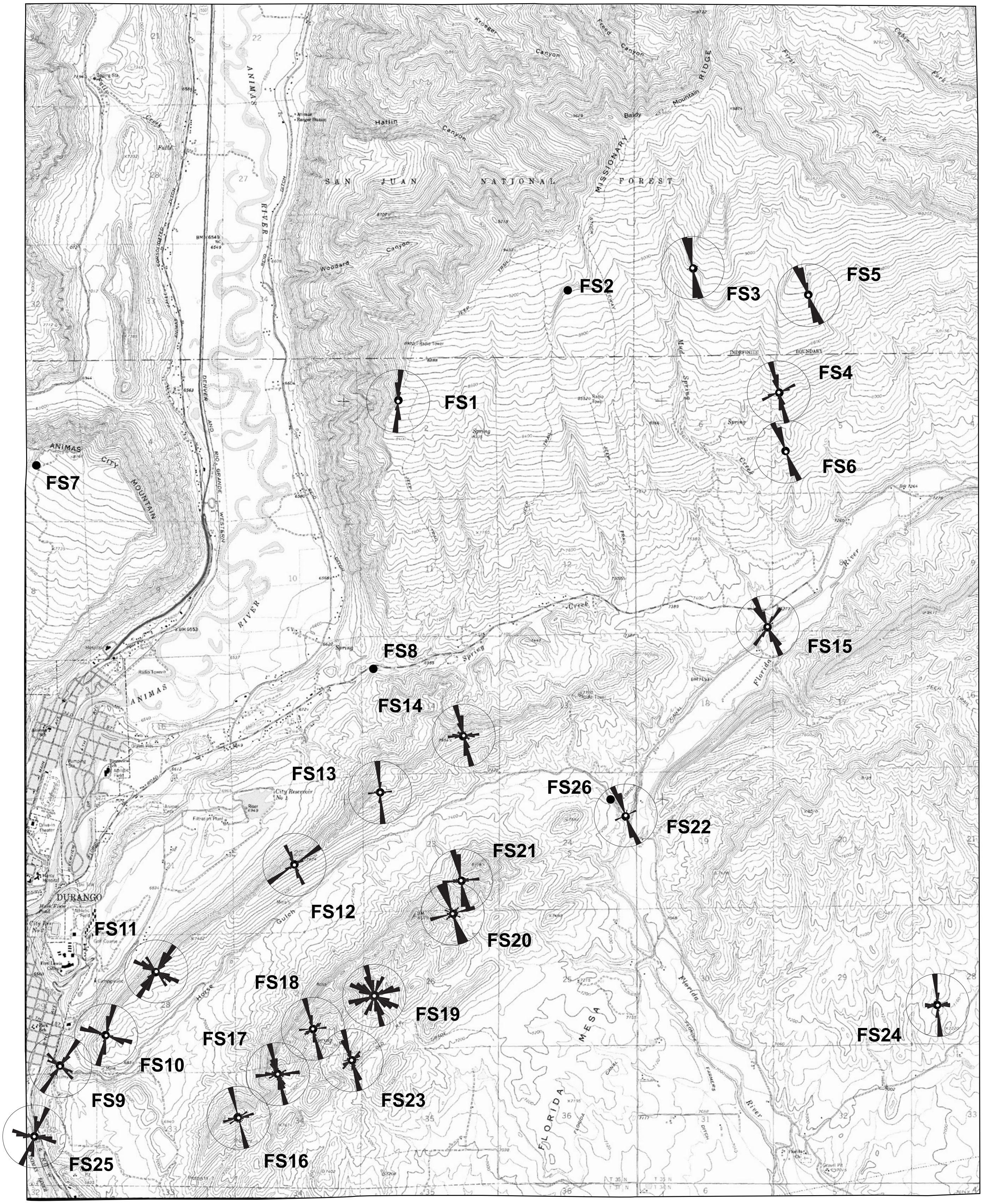


Figure 3. Rose diagrams of joint fractures in Durango East quadrangle. Details are shown in Figure 6.

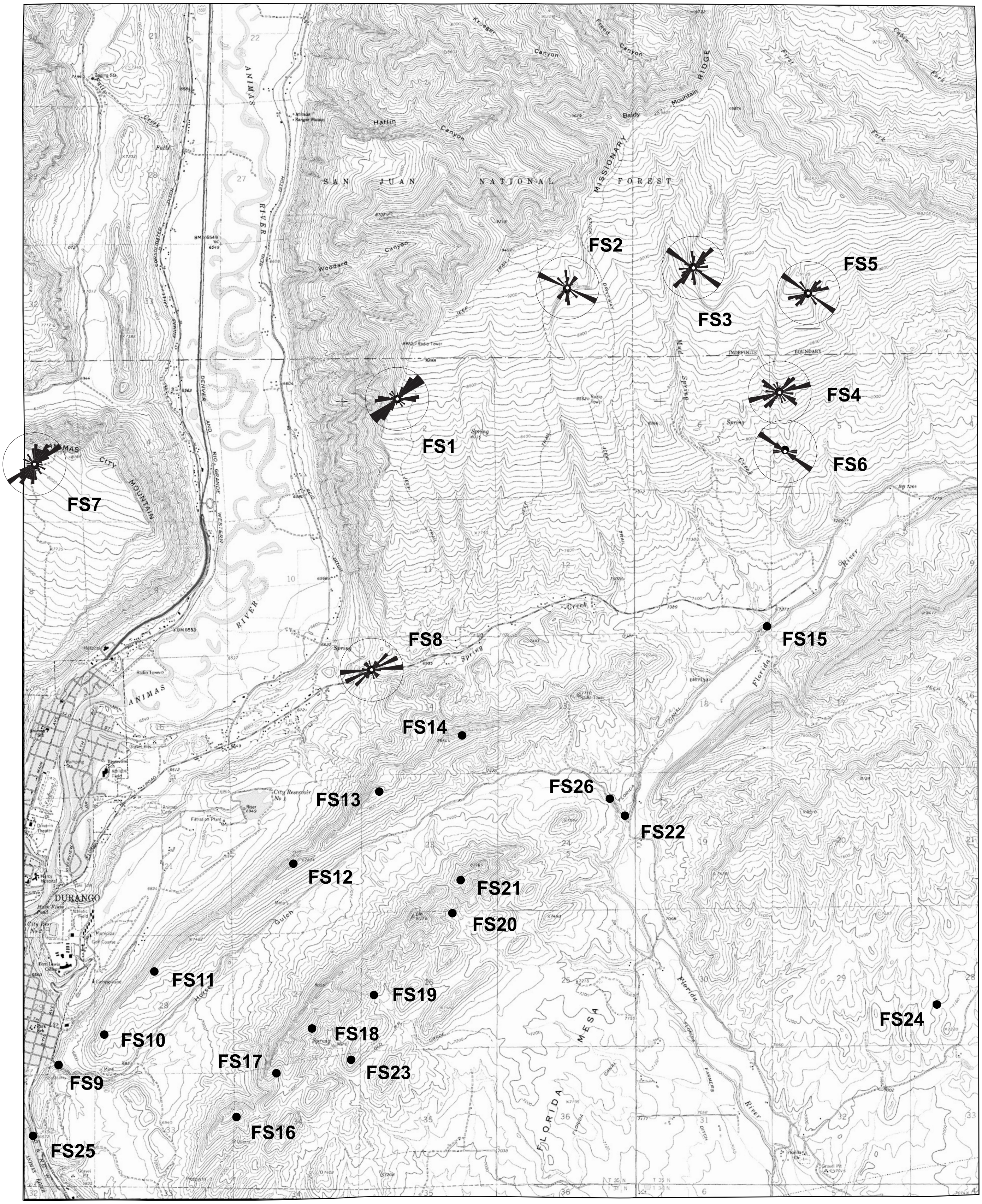


Figure 4. Rose diagrams of minor faults in Durango East quadrangle. Details are shown in Figure 6.

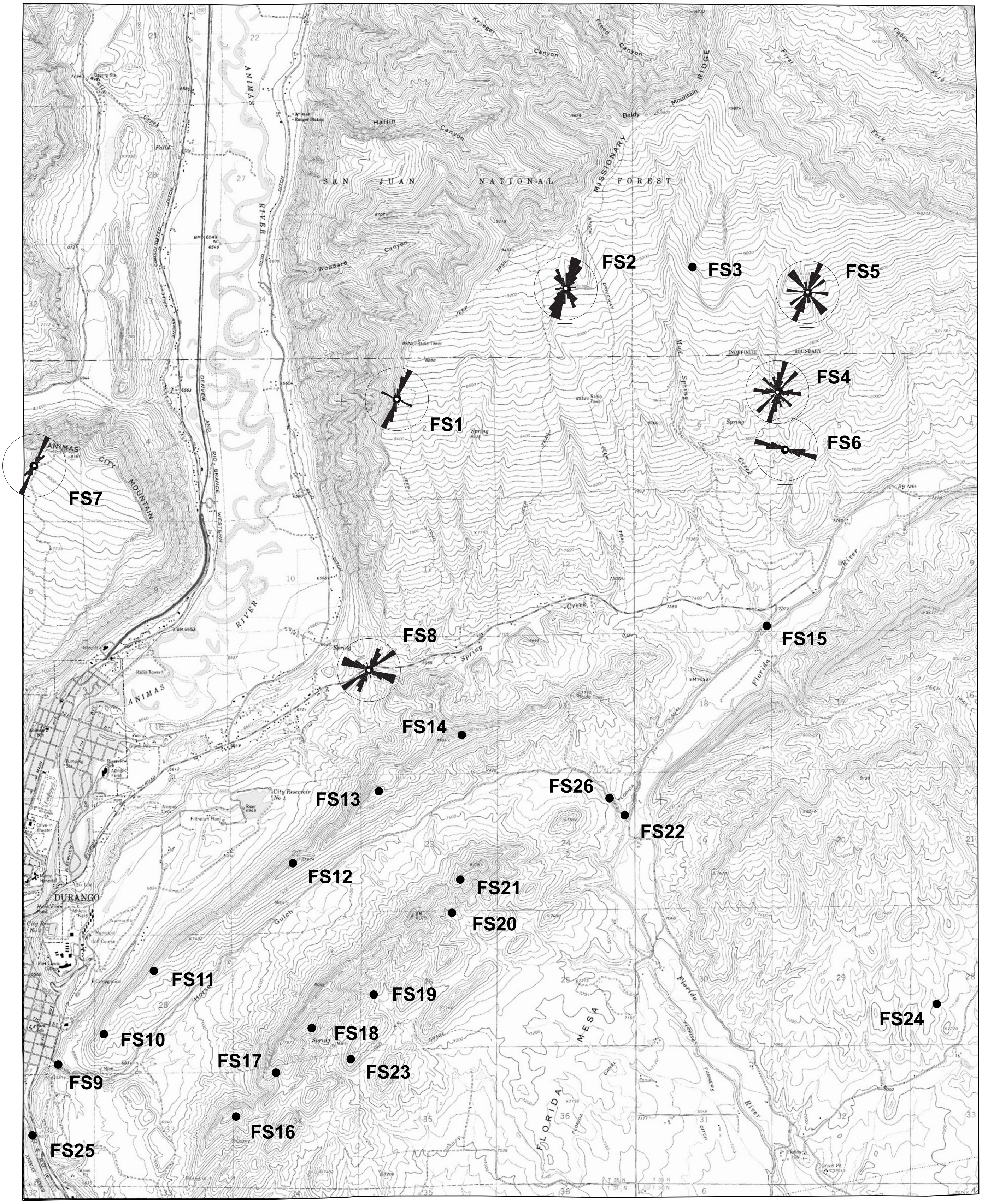
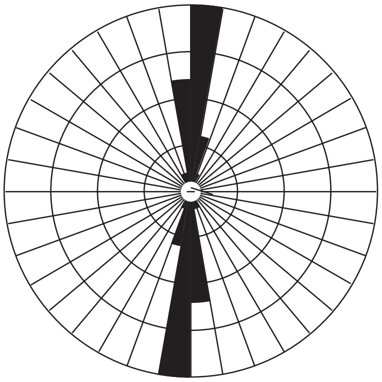
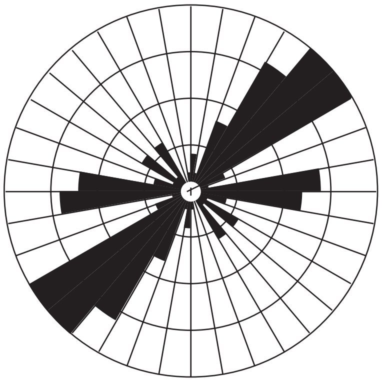


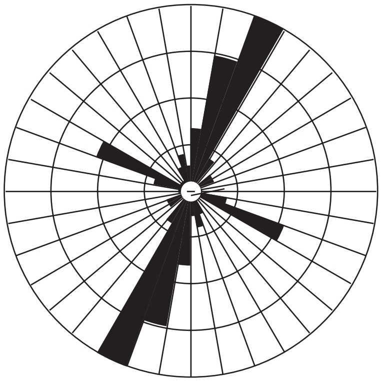
Figure 5. Rose diagrams of Sigma 1 (σ_1) orientations in Durango East quadrangle. Details are shown in Figure 6.



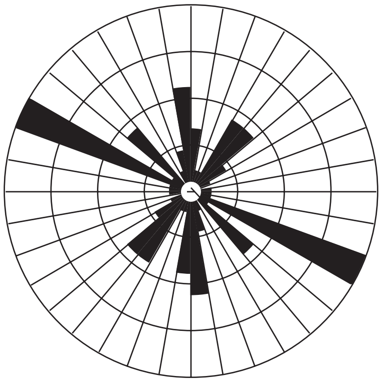
FS1; Kdb; Joint planes	Statistics
N = 22	Vector Mean = 359.3
Class Interval = 10 degrees	Std. Error = 4.28
Maximum Percentage = 45.4	R Magnitude = 0.944
Mean Percentage = 16.66 Standard Deviation = 15.90	Rayleigh = 0.0000



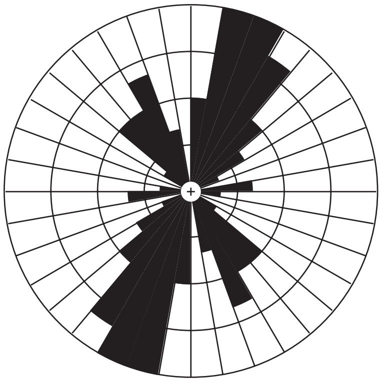
FS1; Kdb; Shear fracture planes	Statistics
N = 62	Vector Mean = 56.2
Class Interval = 10 degrees	Std. Error = 11.11
Maximum Percentage = 16.1	R Magnitude = 0.436
Mean Percentage = 6.24 Standard Deviation = 5.17	Rayleigh = 0.0000



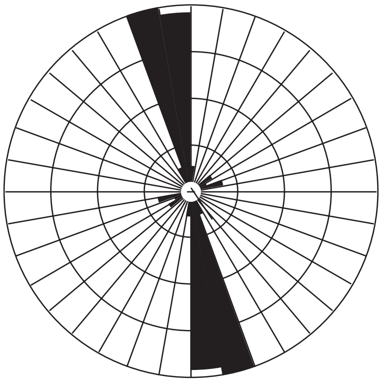
FS1; Kdb; Sigma 1 orientations	Statistics
N = 62	Vector Mean = 13.9
Class Interval = 10 degrees	Std. Error = 13.46
Maximum Percentage = 24.1	R Magnitude = 0.366
Mean Percentage = 6.19 Standard Deviation = 6.50	Rayleigh = 0.0002



FS2; Kdb; Shear fracture planes	Statistics
N = 42	Vector Mean = 341.6
Class Interval = 10 degrees	Std. Error = 57.80
Maximum Percentage = 21.4	R Magnitude = 0.105
Mean Percentage = 6.17 Standard Deviation = 5.23	Rayleigh = 0.6256

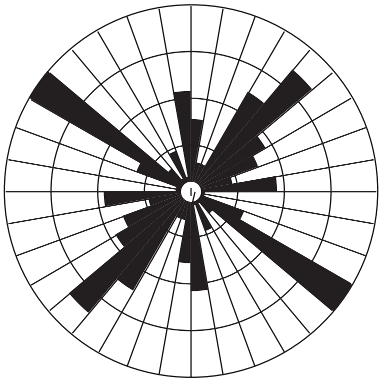


FS2; Kdb; Sigma 1 orientations	Statistics
N = 42	Vector Mean = 13.9
Class Interval = 10 degrees	Std. Error = 15.39
Maximum Percentage = 14.2	R Magnitude = 0.389
Mean Percentage = 7.14 Standard Deviation = 3.99	Rayleigh = 0.0017

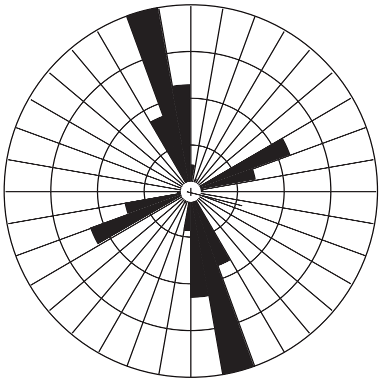


FS3; Kdb; Joint planes	Statistics
N = 59	Vector Mean = 350.3
Class Interval = 10 degrees	Std. Error = 6.42
Maximum Percentage = 37.2	R Magnitude = 0.689
Mean Percentage = 12.50 Standard Deviation = 14.35	Rayleigh = 0.0000

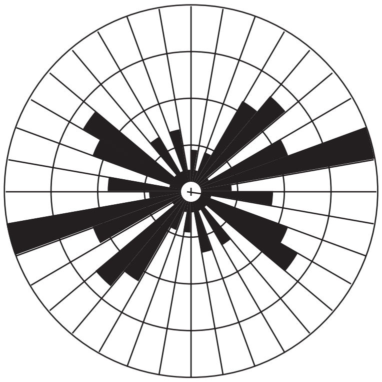
Figure 6. Detailed rose diagrams for joint planes, minor faults, and Sigma 1 (σ_1) orientations measured at fracture stations FS1 through FS26.



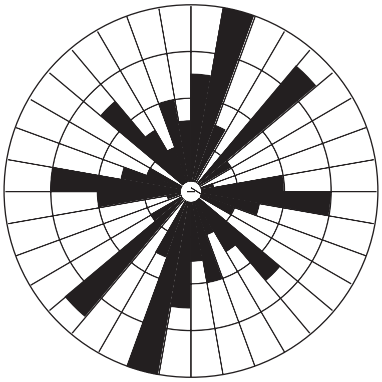
FS3; Kdb; Shear fracture planes	Statistics
N = 81	Vector Mean = 47.7
Class Interval = 10 degrees	Std. Error = 33.95
Maximum Percentage = 16.0	R Magnitude = 0.134
Mean Percentage = 5.55 Standard Deviation = 4.28	Rayleigh = 0.2333



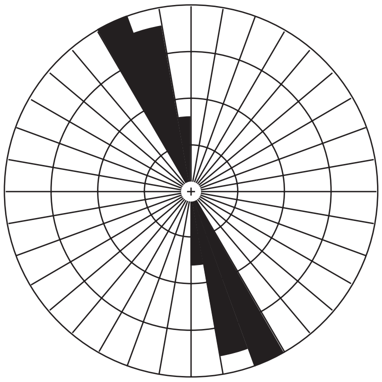
FS4; Kdb; Joint planes	Statistics
N = 46	Vector Mean = 353.1
Class Interval = 10 degrees	Std. Error = 15.55
Maximum Percentage = 30.4	R Magnitude = 0.369
Mean Percentage = 12.36 Standard Deviation = 9.21	Rayleigh = 0.0018



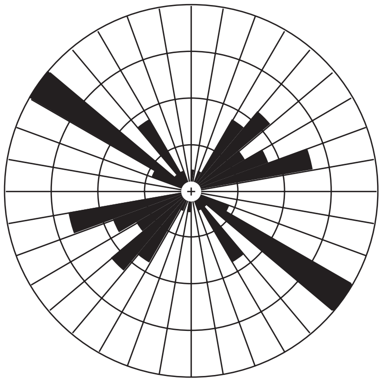
FS4; Kdb; Shear fracture planes	Statistics
N = 58	Vector Mean = 75.1
Class Interval = 10 degrees	Std. Error = 21.92
Maximum Percentage = 15.5	R Magnitude = 0.238
Mean Percentage = 5.55 Standard Deviation = 3.97	Rayleigh = 0.0372



FS4; Kdb; Sigma 1 orientations	Statistics
N = 58	Vector Mean = 2.3
Class Interval = 10 degrees	Std. Error = 40.40
Maximum Percentage = 13.7	R Magnitude = 0.132
Mean Percentage = 6.66 Standard Deviation = 3.38	Rayleigh = 0.3629

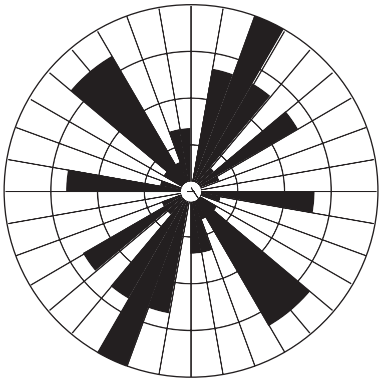


FS5; Kdb; Joint planes	Statistics
N = 23	Vector Mean = 340.6
Class Interval = 10 degrees	Std. Error = 2.95
Maximum Percentage = 43.4	R Magnitude = 0.969
Mean Percentage = 33.33 Standard Deviation = 12.50	Rayleigh = 0.0000

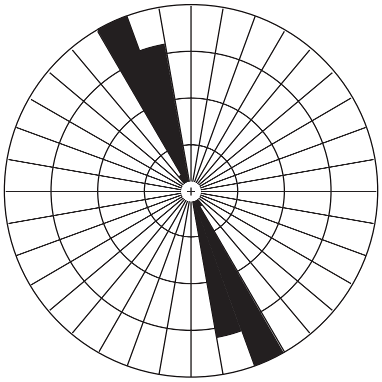


FS5; Kdb; Shear fracture planes	Statistics
N = 41	Vector Mean = 80.6
Class Interval = 10 degrees	Std. Error = 26.08
Maximum Percentage = 21.9	R Magnitude = 0.238
Mean Percentage = 8.33 Standard Deviation = 5.88	Rayleigh = 0.0980

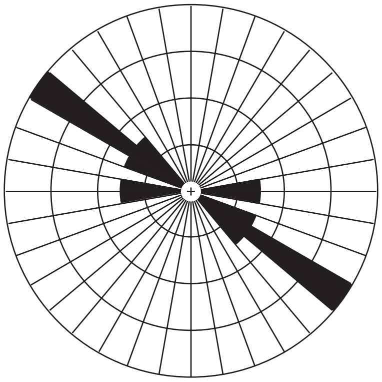
Figure 6. Continued.



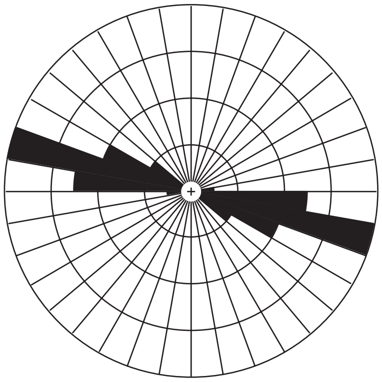
FS5; Kdb; Sigma 1 orientations	Statistics
N = 41	Vector Mean = 4.3
Class Interval = 10 degrees	Std. Error = 28.57
Maximum Percentage = 14.6	R Magnitude = 0.217
Mean Percentage = 7.14 Standard Deviation = 4.34	Rayleigh = 0.1439



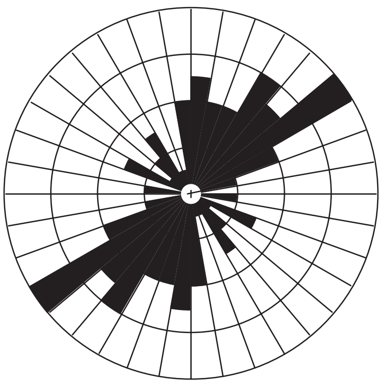
FS6; Kdb; Joint planes	Statistics
N = 19	Vector Mean = 338.4
Class Interval = 10 degrees	Std. Error = 2.64
Maximum Percentage = 52.6	R Magnitude = 0.980
Mean Percentage = 33.33 Standard Deviation = 22.24	Rayleigh = 0.0000



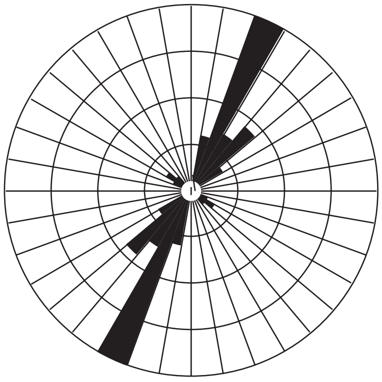
FS6; Kdb; Shear fracture planes	Statistics
N = 20	Vector Mean = 295.8
Class Interval = 10 degrees	Std. Error = 7.76
Maximum Percentage = 40.0	R Magnitude = 0.825
Mean Percentage = 19.99 Standard Deviation = 10.54	Rayleigh = 0.0000



FS6; Kdb; Sigma 1 orientations	Statistics
N = 20	Vector Mean = 283.8
Class Interval = 10 degrees	Std. Error = 4.09
Maximum Percentage = 40.0	R Magnitude = 0.952
Mean Percentage = 20.00 Standard Deviation = 12.90	Rayleigh = 0.0000

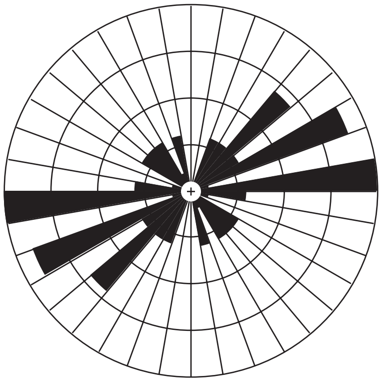


FS7; Kdb; Shear fracture planes	Statistics
N = 55	Vector Mean = 31.7
Class Interval = 10 degrees	Std. Error = 15.00
Maximum Percentage = 14.5	R Magnitude = 0.354
Mean Percentage = 6.25 Standard Deviation = 3.51	Rayleigh = 0.0009

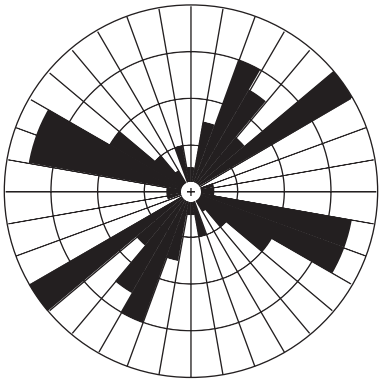


FS7; Kdb; Sigma 1 orientations	Statistics
N = 55	Vector Mean = 30.7
Class Interval = 10 degrees	Std. Error = 7.25
Maximum Percentage = 36.3	R Magnitude = 0.652
Mean Percentage = 9.99 Standard Deviation = 10.19	Rayleigh = 0.0000

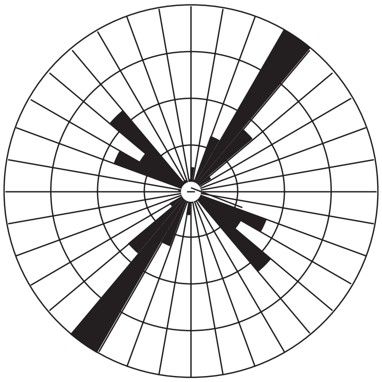
Figure 6. Continued.



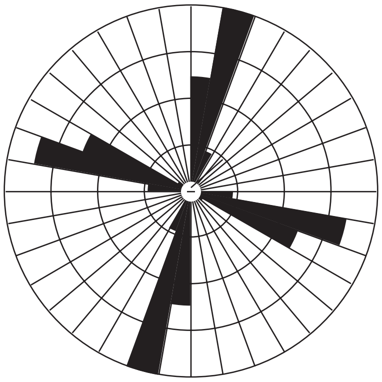
FS8; Kdb; Shear fracture planes	Statistics
N = 53	Vector Mean = 70.7
Class Interval = 10 degrees	Std. Error = 14.83
Maximum Percentage = 18.8	R Magnitude = 0.364
Mean Percentage = 7.14 Standard Deviation = 5.24	Rayleigh = 0.0008



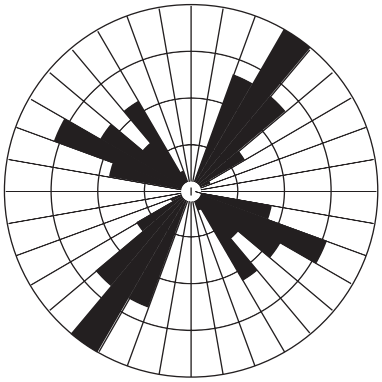
FS8; Kdb; Sigma 1 orientations	Statistics
N = 53	Vector Mean = 67.2
Class Interval = 10 degrees	Std. Error = 39.35
Maximum Percentage = 15.0	R Magnitude = 0.141
Mean Percentage = 6.25 Standard Deviation = 4.68	Rayleigh = 0.3464



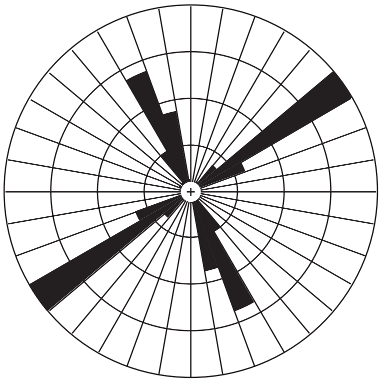
FS9; Kpl; Joint planes	Statistics
N = 58	Vector Mean = 28.9
Class Interval = 10 degrees	Std. Error = 33.39
Maximum Percentage = 27.5	R Magnitude = 0.156
Mean Percentage = 7.69 Standard Deviation = 7.54	Rayleigh = 0.2413



FS10; Kmf; Joint planes	Statistics
N = 47	Vector Mean = 341.8
Class Interval = 10 degrees	Std. Error = 72.07
Maximum Percentage = 27.6	R Magnitude = 0.083
Mean Percentage = 14.28 Standard Deviation = 9.19	Rayleigh = 0.7190

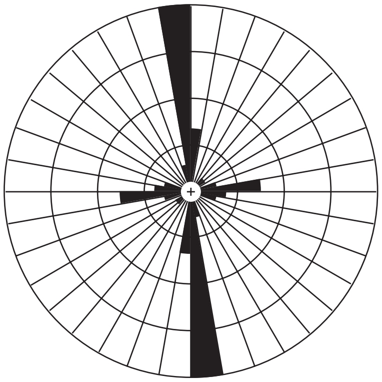


FS11; Kmf; Joint planes	Statistics
N = 50	Vector Mean = 66.8
Class Interval = 10 degrees	Std. Error = 83.04
Maximum Percentage = 18.0	R Magnitude = 0.067
Mean Percentage = 9.09 Standard Deviation = 4.80	Rayleigh = 0.7944

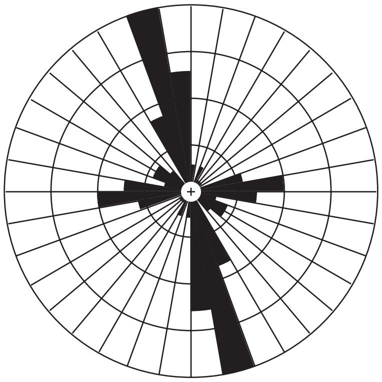


FS12; Kch; Joint planes	Statistics
N = 50	Vector Mean = 17.5
Class Interval = 10 degrees	Std. Error = 31.49
Maximum Percentage = 32.0	R Magnitude = 0.180
Mean Percentage = 9.99 Standard Deviation = 9.84	Rayleigh = 0.1946

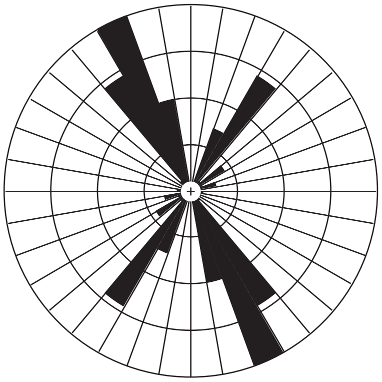
Figure 6. Continued.



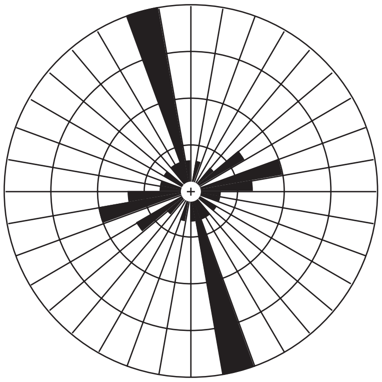
FS13; Kch; Joint planes	Statistics
N = 53	Vector Mean = 1.2
Class Interval = 10 degrees	Std. Error = 23.81
Maximum Percentage = 39.6	R Magnitude = 0.230
Mean Percentage = 11.11 Standard Deviation = 11.07	Rayleigh = 0.0591



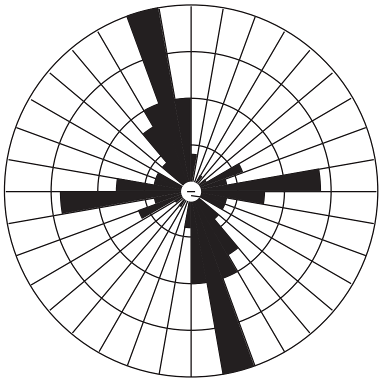
KS14; Kplm; Joint planes	Statistics
N = 62	Vector Mean = 330.9
Class Interval = 10 degrees	Std. Error = 19.49
Maximum Percentage = 22.5	R Magnitude = 0.258
Mean Percentage = 6.66 Standard Deviation = 5.74	Rayleigh = 0.0157



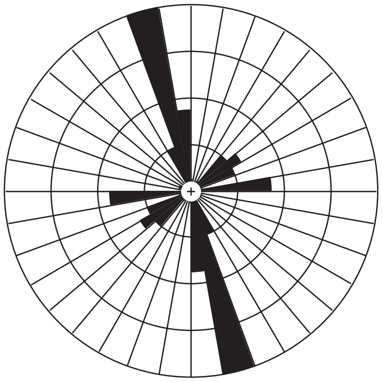
FS15; Kplm; Joint planes	Statistics
N = 55	Vector Mean = 352.3
Class Interval = 10 degrees	Std. Error = 12.99
Maximum Percentage = 25.4	R Magnitude = 0.404
Mean Percentage = 9.09 Standard Deviation = 8.16	Rayleigh = 0.0001



FS16; Kf; Joint planes	Statistics
N = 21	Vector Mean = 317.9
Class Interval = 10 degrees	Std. Error = 122.85
Maximum Percentage = 28.5	R Magnitude = 0.073
Mean Percentage = 8.33 Standard Deviation = 6.91	Rayleigh = 0.8919

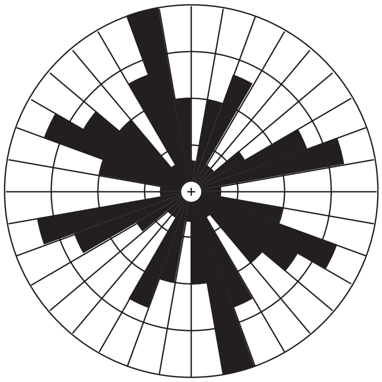


FS17; Kf; Joint planes	Statistics
N = 50	Vector Mean = 321.8
Class Interval = 10 degrees	Std. Error = 22.42
Maximum Percentage = 20.0	R Magnitude = 0.252
Mean Percentage = 7.14 Standard Deviation = 4.97	Rayleigh = 0.0410

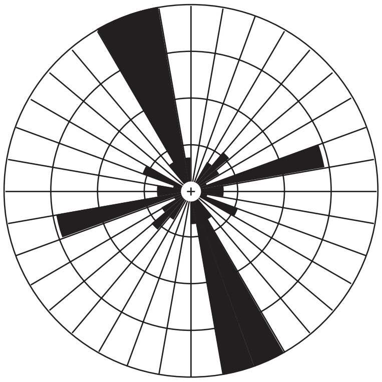


FS18; Kpc; Joint planes	Statistics
N = 52	Vector Mean = 2.7
Class Interval = 10 degrees	Std. Error = 24.07
Maximum Percentage = 30.7	R Magnitude = 0.230
Mean Percentage = 8.33 Standard Deviation = 8.15	Rayleigh = 0.0633

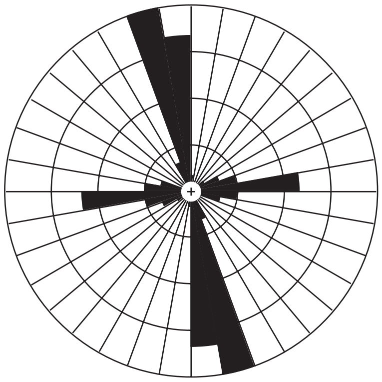
Figure 6. Continued.



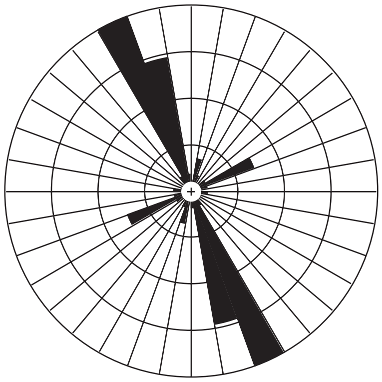
FS19; Kf; Joint planes	Statistics
N = 52	Vector Mean = 319.2
Class Interval = 10 degrees	Std. Error = 50.67
Maximum Percentage = 11.5	R Magnitude = 0.111
Mean Percentage = 5.55 Standard Deviation = 3.11	Rayleigh = 0.5266



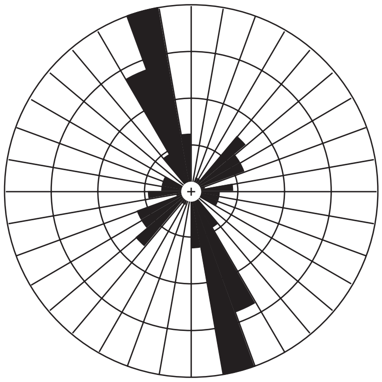
FS20; Kf; Joint planes	Statistics
N = 50	Vector Mean = 333.5
Class Interval = 10 degrees	Std. Error = 31.90
Maximum Percentage = 22.0	R Magnitude = 0.176
Mean Percentage = 7.69 Standard Deviation = 7.10	Rayleigh = 0.2114



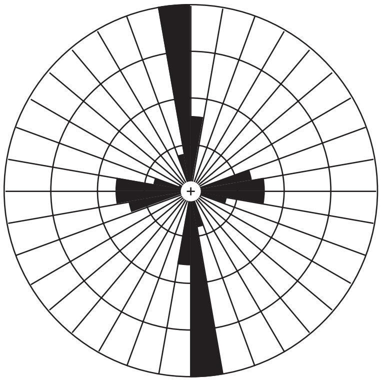
FS21; Kpc; Joint planes	Statistics
N = 43	Vector Mean = 338.2
Class Interval = 10 degrees	Std. Error = 29.20
Maximum Percentage = 27.9	R Magnitude = 0.208
Mean Percentage = 10.00 Standard Deviation = 8.93	Rayleigh = 0.1545



FS22; Kf; Joint planes	Statistics
N = 31	Vector Mean = 343.4
Class Interval = 10 degrees	Std. Error = 13.89
Maximum Percentage = 35.4	R Magnitude = 0.486
Mean Percentage = 9.99 Standard Deviation = 11.21	Rayleigh = 0.0006

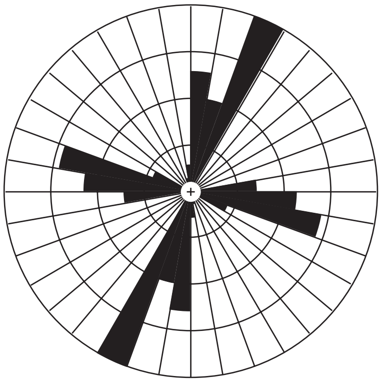


FS23; Kkf; Joint planes	Statistics
N = 54	Vector Mean = 346.0
Class Interval = 10 degrees	Std. Error = 26.25
Maximum Percentage = 24.0	R Magnitude = 0.205
Mean Percentage = 7.14 Standard Deviation = 6.12	Rayleigh = 0.1025

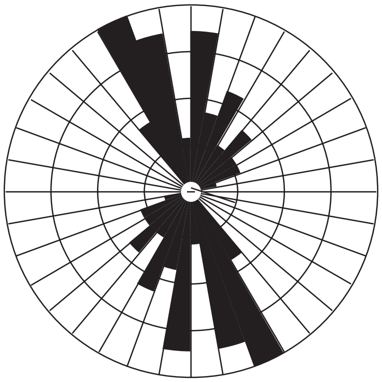


FS24; Ta; Joint planes	Statistics
N = 45	Vector Mean = 338.3
Class Interval = 10 degrees	Std. Error = 54.63
Maximum Percentage = 33.3	R Magnitude = 0.110
Mean Percentage = 12.50 Standard Deviation = 9.03	Rayleigh = 0.5777

Figure 6. Continued.



FS25; Kmf; Joint planes	Statistics
N = 59	Vector Mean = 29.5
Class Interval = 10 degrees	Std. Error = 41.08
Maximum Percentage = 23.7	R Magnitude = 0.125
Mean Percentage = 11.11 Standard Deviation = 6.93	Rayleigh = 0.3935



FS26; Kpc; Joint planes	Statistics
N = 41	Vector Mean = 1.6
Class Interval = 10 degrees	Std. Error = 10.97
Maximum Percentage = 17.0	R Magnitude = 0.529
Mean Percentage = 8.33 Standard Deviation = 4.60	Rayleigh = 0.0000

Figure 6. Continued.

ECONOMIC GEOLOGY

Known mineral resources in the Durango East quadrangle include natural gas, coal, sand, gravel, dimension stone, and volcanic ash. Locations and names of known coal mines and gas wells are shown on the geologic map. Sand and gravel mining accounts for much of the current mineral resource production in the Durango East quadrangle. Surficial units containing potentially economic deposits of sand and gravel are briefly discussed in the "Description of Map Units". Two smaller gravel pits are located along the Animas River north of Durango.

Coal mining was formerly a much larger industry in the region. Available production data for coal mines in the Durango East quadrangle are listed in Table 6. Most of the coal production in the quadrangle has been from the Menefee Formation; only a small part of the historic production was from the Fruitland Formation. Nearly all historic coal production came from underground mining, although the last operating mine in the quadrangle was a strip mine (Carbon Junction Strip Mine). The City Mines Nos. 1 and 2, which operated around the turn of the century, were the most productive coal mines in the quadrangle. These mines also had the greatest extent of mining (Sullivan and Jochim, 1984). Only one coal mine was recently active on this quadrangle, the Carbon Junction strip mine, which operated in the 1980s. It produced 21,000 tons of coal from the Fruitland Formation tongue in the southwest part of the quadrangle. It has not been active since 1988.

The Menefee Formation has low-sulfur bituminous coal that ranges from 10,860 to 14,700 Btus/pound (Tremain and others, 1995). Sulfur content generally ranges from about 0.6 to 1.3 percent, while values for ash, volatile matter, and fixed carbon average about 5 percent, 38 percent, and 55 percent, respectively. Menefee Formation coal in the Durango East quadrangle has a free swelling index around 5.0–7.0. Three main coal seams were mined in the Menefee Formation in La Plata County. These seams range from 3 to 10 ft thick. The thickness measured section of Menefee Formation coal is 21.9 ft along the Florida River. Fruitland Formation coals vary from 3 to 27 ft thick, with the basal coal usually the thickest. Fruitland Formation coal is also low sulfur, bituminous, and averages about 11,230 to 12,140 Btus/pound (Tremain and others, 1995). Sulfur content is generally about 0.7 to 0.8 percent, while values for ash, volatile matter, and fixed carbon average about 13 percent, 29 percent, and 55 percent, respectively. Fruitland Formation coal in the San Juan Basin has a free swelling index around 7.0–8.0 (Eakins and others, 1999).

Lime was mined from a number of small adits and pits along the Animas River Valley from the Pony Express Member of the Wanakah Formation. Dimension stone has been quarried from the massive member of Point Lookout Sandstone at a rock quarry in Horse Gulch. Rocks from this quarry were reportedly used for building stone at the nearby Fort Lewis College.

Two deposits of Quaternary volcanic ash crop out in the quadrangle (Woolsey, 1906; Gillam, 1998). One is along the western quadrangle boundary northeast of Chapman Lake (Kirkham and others, 1999); a second is on the west side of a small ridge in Florida Mesa near the southern quadrangle boundary. Woolsey (1906) reported a thickness of 25 to 50 ft for the ash northeast of Chapman Lake. Although exposures are poor, our field work supports this thickness estimate. This bed was reportedly explored by a 12 ft deep shaft around the turn of the century (Woolsey, 1906). A bench cut into the ash bed was noted at this location. The volcanic ash bed in Florida Mesa has a maximum thickness of about 2 feet. It is interbedded with Quaternary fan deposits derived from local bedrock, chiefly the McDermott Member of the Animas Formation. It is not well exposed and has limited economic value due to its small areal extent and high clastic content.

Geothermal resources in the Durango East quadrangle include an active hot spring in sec. 10, T. 35 N., R. 9 W. with a measured temperature of 132° F (W. Holland, personal comm. 1998). This hot spring emits from a pipe in an abandoned

Table 4. Joint data for each formation. (Kdb, Dakota Sandstone and Burro Canyon Formation; Kpl, Point Lookout Sandstone; Kmf, Menefee Formation; Kch, Cliff House Sandstone; Kpc, Pictured Cliffs Sandstone; Kf, Fruitland Formation; Kkf, Farmington Sandstone; TKa, Animas Formation).

Formation	Number of J1 Joints	J1 Preferred Azimuth (Degrees)	Number of J2 Joints	J2 Preferred Azimuth (Degrees)
Kdb	144	347	23	68
Kpl	86	332	87	48
Kmf	65	20	73	289
Kch	55	19	46	307
Kpc	47	323	54	12
Kf	105	343	100	83
Kkf	28	340	24	68
TKa	24	355	19	89

mine shaft in the Pony Express Limestone. The water was sampled in 1996 and determined to be similar in character to other sodium-rich hot springs in the Animas Valley and may be related to the sodium-rich Paradox Formation (Gibbons, 1997). The Trimble, Tripp, and Stratten hot springs just north of the quadrangle are calcium sulfate and calcium-sodium sulfate rich.

Twenty natural gas wells have been drilled within the Durango East quadrangle between 1979 and 1998. Of these, 12 produce gas from Fruitland Formation coals as part of the coalbed methane production play in the northern Ignacio-Blanco field. Two wells produce natural gas from the Dakota Sandstone and Burro Canyon Formation. Two wells were drilled and abandoned, and four were recently drilled for increased production but are only being developed now.

The Fruitland Formation wells produce methane gas from coalbeds between 1,850 ft and 2,400 ft deep. In 1997, gas production for individual coalbed methane wells range from 13,000 thousand cubic feet (Mcf) to over 172,000 Mcf (Huber-Dobbins 1–31 well). Total cumulative production for individual wells ranges from as much as 635,508 Mcf (Huber-Dobbins 1–31) to as little as 1,260 Mcf (Hallwood-Natomos State 36–1). Through 1997, cumulative coalbed methane production for all wells in the quadrangle was 2,462,409 Mcf. Recent infill drilling to 320-acre spacing has resulted in four more Fruitland Formation coal-gas wells drilled in the southwest corner of the quadrangle. Over 300,000 Mcf of cumulative gas from the two Dakota Sandstone wells has been produced since 1979. The deepest well on the quadrangle is the Hallwood (Natomas) State 36-1 with a total depth of 7,630 ft in the Morrison Formation. Table 7 shows production for all gas wells on the quadrangle.

In 1997 annual production of coalbed methane gas in La Plata County was 318.2 billion cubic ft (Bcf) of gas. The total cumulative coalbed methane production for Ignacio Blanco field coal gas through 1997 was 1.315 trillion cubic feet (Tcf). Coalbed methane resource are estimated by the Potential Gas Committee (1997) at 12.43 Tcf for the San Juan Basin. This Figure includes undiscovered and probable resources but does not include proved resources (T. Hemborg, personal comm., 1999).

In addition to coal gas, conventional natural gas has also been produced in the county. The cumulative conventional gas production for La Plata County is 1.29 Tcf. As of January 1999, total cumulative conventional and coal gas production in La Plata County surpassed 3 trillion cubic feet of gas, the first county in Colorado to reach that plateau. There is no oil production in the quadrangle, but 2,220,947 barrels of oil have been produced cumulatively through 1997 within La Plata County. The Mesaverde Group and Dakota Sandstone reservoirs have wet gas associated with production while Fruitland Formation coal gas is essentially dry gas production.

Table 5. Minor Fault (shear fracture) data for eight locations on Durango East quadrangles. (NA, Not applicable data for this fracture station.)

Location	NE σ_1 N=	NE σ_1 Azimuth (Degrees)	NW σ_1 N=	NW σ_1 Azimuth (Degrees)	NNE σ_1 N =	NNE $\sigma 1$ Azimuth (Degrees)
FS 1	8	065	19	119	35	202
FS 2	6	065	13	312	14	022
FS 3	19	239	26	116	36	200
FS 4	15	246	24	130	19	190
FS 5	8	246	19	133	14	207
FS 6	0	NA	20	107	0	NA
FS 7	18	226	7	128	30	203
FS 8	16	234	24	119	13	015

Table 6. Reported production data for coal mines within the Durango East quadrangle (from Boreck and Murray, 1979; Sullivan and Jochim, 1984; Colorado Division of Minerals and Geology, 1999). Refer to geologic map for mine locations.

Name	Formation	Coal Bed Name and Thickness (Ft)	Reported Dates of Operation	Total Known Production (Tons)
Bobcat	Upper Menefee Fm	No.1, no.2; 3.5–4.0	1928	None reported
City Mine no.1, no.2; Durango Land and Coal, no.1 later	Upper Menefee Fm	Unnamed; 2.1	1887–1893;1898–1923	338,952
Elledge; later known as Dill	Menefee Fm	Unnamed; 2.0–3.0	1932–1937; 1938–1939	1,805
Fire Glow	Menefee Fm	Unnamed; 5.0	1933–1941	6,942
Florida	Middle Fruitland Fm	Unnamed; 3.0–9.0?	1935	25
Florida Grange	Middle Fruitland Fm	Unnamed; 3.0–8.0	1922–1926	769
Florit	Menefee Fm	Unnamed; 2.0–2.5	Unknown	None reported
Horse Gulch	Menefee Fm	Unnamed; 4.0–8.0	1927	142
La Plata (Fairmont)	Menefee Fm	Unnamed; 7.0	1890–1891	81,866
La Plata (Old)	Menefee Fm	Unnamed; 8.9	1893–1902	5,447
Rainbow	Middle Fruitland Fm	Mesaverde; 3.0	1927	90
Carbon Junction Strip	Pictured Cliffs SS/ Fruitland Tongue	Fruitland; 8.0	1983–1988	21,722

Table 7. Production data for 14 gas wells on Durango East quadrangle.

Operator, Lease Name	Producing Formation (Ft)	Total Depth (Ft)	Completion Date	1997 Production (MCF)	Total Cumulative Production Through 1997 (MCF)
Huber-Culhane 29-1	Fruitland Coal	2147	May 1993	15,881	67,460
Huber-Federal 2-29	Fruitland Coal	2247	May 1993	19,709	103,871
Huber-Federal 1-30	Fruitland Coal	2056	Oct. 1991	61,860	235,960
Huber-Nelson 2-31	Fruitland Coal	2305	Feb. 1993	73,291	177,518
Huber-Dobbins 1-31	Fruitland Coal	2280	Feb. 1993	172,739	635,508
Natomas State-Chastain 1-31	Dakota/Burro Canyon	7388	Nov. 1982	15,215	297,906
Huber-Flanagan 2-32	Fruitland Coal	2197	Sept. 1991	66,197	185,499
Huber-Culhane 1-32	Fruitland Coal	2131	Oct. 1991	81,162	326,982
Huber-Johnson 1-33	Fruitland Coal	2110	Jan. 1993	86,718	311,693
Fuelco (Hallwood) Day-V-Ranch 35-2	Fruitland Coal	2315	April 1993	13,673	100,812
Allen Vince (Hallwood) Day-V-Ranch 35-1	Fruitland Coal	2200	Jan. 1987	0	1,260
Natomas (Hallwood) State 36-1 Canyon	Dakota/Burro	7630	July 1979	0	21,009
Bowen-Edwards (Hallwood) State 36-2	Fruitland Coal	2454	June 1991	210,896	326,405
Fuelco (Hallwood) State 36-3	Fruitland Coal	2443	July 1991	21,681	104,950

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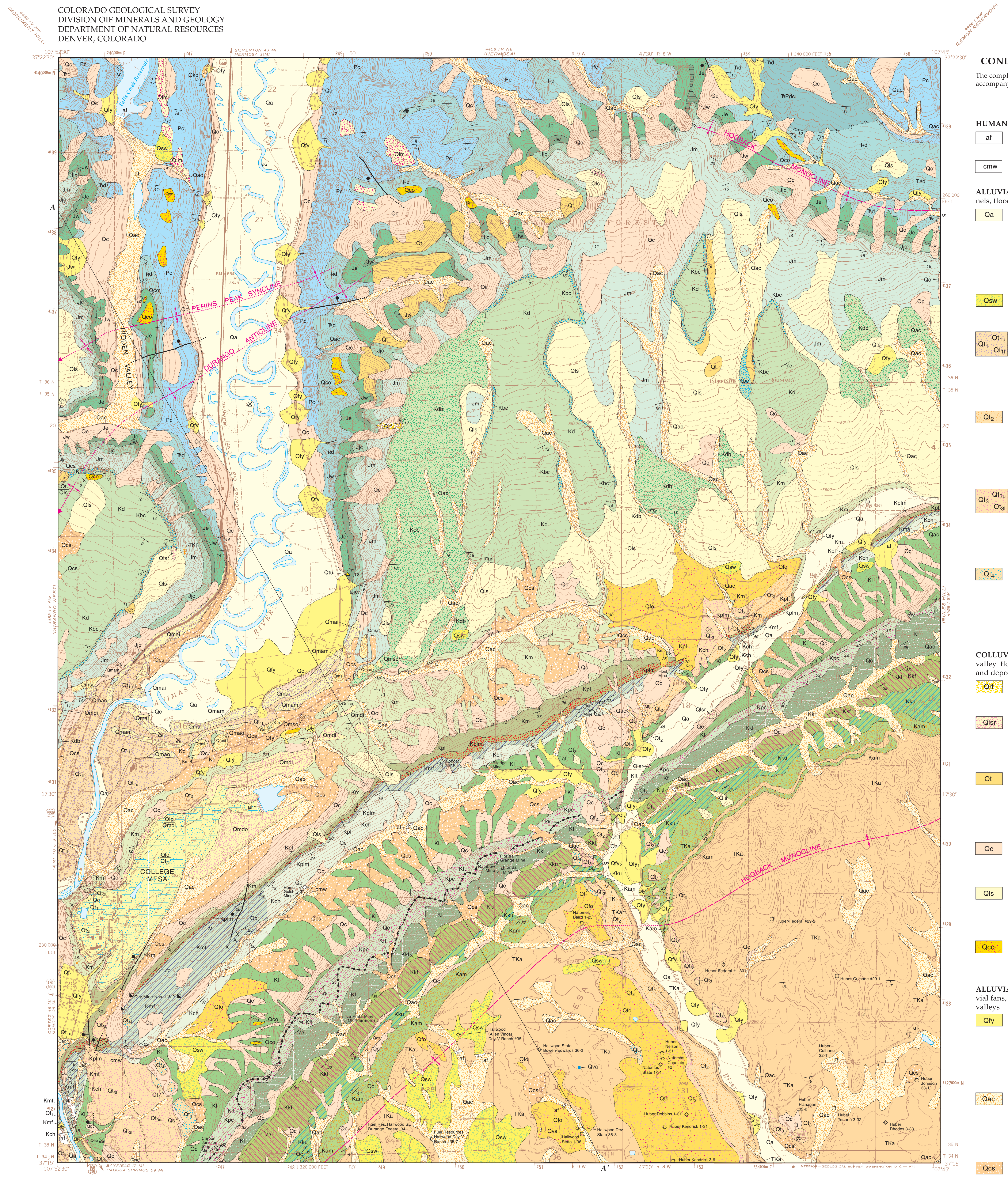
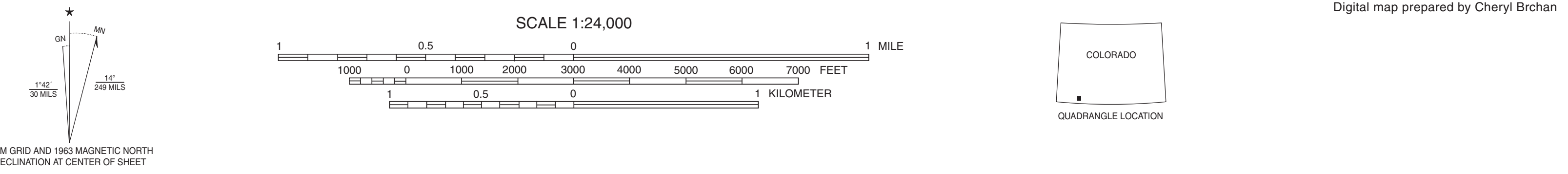
COLORADO GEOLOGICAL SURVEY
DIVISION OIF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN FILE MAP 99-6
GEOLOGIC MAP OF THE DURANGO EAST
QUADRANGLE, LA PLATA COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1963
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

Geology mapped in 1998
Digital map prepared by Cheryl Brchan



UTM GRID AND 1963 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

QUADRANGLE LOCATION

CONDENSED DESCRIPTION OF MAP UNITS

The complete description of map units and references is in the accompanying bookhlet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene)—**Fill and waste rock placed during construction of roads, buildings, and dams, and also coal cinders from steam locomotives

cmw **Coal-mine waste (latest Holocene)—**Rock debris and coal refuse placed in dump piles near underground coal mines

ALLUVIAL DEPOSITS—Sediments deposited in stream channels, flood plains, outwash terraces, and sheetwash areas

Qa **Stream-channel, flood-plain, and low-terrace deposits (Holocene)—**Poorly sorted, clast-supported gravel in a sandy, silty matrix. Includes terraces up to about 8 ft above the Animas River. Deposits along the Animas and Florida Rivers contain clasts with diverse lithologies, reflecting their respective provenances. Clasts along the Florida River are generally derived from local sandstone with lesser amounts of igneous and metamorphic rocks. Clasts along the Animas River consist of more equal percentages of sandstone, igneous and metamorphic rock types

Qsw **Sheetwash deposits (Holocene and late Pleistocene)—**Sandy, clayey silt to sandy gravel deposited in intermittent and ephemeral stream valleys, on gentle hillslopes, or in basinal areas

Qt$_1$ Qt$_{1u}$ Qt$_{1l}$ **Terrace alluvium one (late Pleistocene)—**Mostly poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel in a sand or silt matrix. May include fine-grained overbank deposits. Underlies glacial outwash terraces 20–100 ft above Animas River. Terrace alluvium one is subdivided into an older or upper unit (Qt$_{1u}$) that projects to the Animas City outer moraine (Qmao), and a younger or lower unit (Qt$_{1l}$) that is graded to the Animas City inner moraines (Qmam and Qmai)

Qt$_2$ **Terrace alluvium two (late? and late middle Pleistocene)—**Deposits similar to terrace alluvium one (Qt$_1$) but slightly more weathered. Terrace alluvium two is chiefly stream alluvium that underlies one terrace remnant 180 ft above the Animas River and several terraces from 70 to 130 ft above the Florida River. Deposits along the Florida River rarely contain small boulders, have a siltier matrix, and typically are capped by thicker loess as much as 5 ft

Qt$_3$ Qt$_{3u}$ Qt$_{3l}$ **Terrace alluvium three (middle Pleistocene)—**Deposits sim-ilar to younger terrace alluvium (Qt$_1$). Underlies terraces 290–450 ft above Animas River but only 100 to 180 ft above the Florida River. Along the Animas River, terrace alluvium three is subdivided into an older or upper unit (Qt$_{3u}$) that projects to the older Durango moraine (Qmdo) across an erosional gap, and a younger or lower unit (Qt$_{3l}$) that is graded to the younger Durango moraine (Qmdi)

Qt$_4$ **Terrace alluvium four (middle Pleistocene)—**Chiefly stream alluvium that underlies at least two terraces 530 to 640 ft above the Animas River and one or two terraces 180 to 200 ft above the Florida River. Terrace alluvium four underlies one or two correlative terraces on Florida Mesa but is mostly concealed by older fan alluvium (Qfo). Deposits of terrace alluvium four are texturally and lithologically similar to those of terrace alluvium one (Qt$_1$) but are strongly weathered

COLLUVIAL DEPOSITS—Sediments deposited on valley sides, valley floors, and hillslopes that were mobilized, transported, and deposited primarily by gravity

Qrf **Rockfall (latest Holocene)—**Includes bouldery and cobbly rubble from the Dakota Hogback on Missonary Ridge deposited during the July 5, 1998 rock topple event on the east side of Animas River Valley

Qlsr **Recent landslide deposits (latest Holocene)—**Includes recently active landslides with fresh morphological features. A heterogeneous unit consisting of unsorted, unstratified rock debris, clay, silt, and sand. Soil slips (see explanation of map symbols) are a type of recent landslide found on steep slopes of Mancos and Lewis Shales

Qt **Talus (Holocene and late Pleistocene?)—**Angular, cobbly and bouldery rubble on moderate to slopes derived from outcrops of Dakota Sandstone and Burro Canyon Form-ation, Morrison Formation, or Junction Creek Sandstone, and transported downslope primarily by gravity during rockfalls, rockslides, or rock topples. Significant talus slopes are located below the Junction Creek Sandstone in Haflin and Woodard Canyons

Qc **Colluvium (Holocene and late Pleistocene)—**Ranges from clast-supported, pebble to boulder gravel in a sandy matrix to matrix-supported, gravelly sand or clayey silt. Deposits usually coarser grained in upper reaches and finer grained in distal areas

Qls **Landslide deposits (Holocene and Pleistocene)—**Similar in texture to recent landslide deposits (Qlsr). Range from active, slowly creeping landslides to long-inactive, middle or perhaps even early Pleistocene landslides. Prominent on steep dipslopes of Dakota Sandstone north of Spring Gulch and the Florida River

Qco **Older colluvium (middle and early Pleistocene?)—**Texturally similar to colluvium (Qc) but generally not subject to future deposition. Found on ridgelines, drainage divides, and dissected hillslopes

ALLUVIAL AND COLLUVIAL DEPOSITS—Sediments in alluvial fans, stream channels, and adjacent hillslopes along tributary valleys

Qfy **Younger fan deposits (Holocene)—**Sediments deposited by debris flows, hyperconcentrated flows, and sheetwash. Range from poorly sorted, clast-supported, pebble, cobble, and boulder gravel in a clayey, sandy silt or silty sand matrix to matrix-supported gravelly, clayey silt. Frequently bouldery, particularly near the heads of fans. Deposits tend to be finer grained in the distal ends of fans. Deposits labeled Qfy$_1$, are younger than deposits labeled Qfy$_2$

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)—**Stream-channel, low-terrace, and flood-plain deposits along tributary valley floors. May interfinger with colluvium and sheetwash from valley sides. Typically composed of poorly to well-sorted, stratified, interbedded sand, pebbly sand, and sandy gravel to poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt

Qcs **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene?)—**Consists of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are gradational over shale-rich bedrock sources

Qfo **Older fan deposits (middle Pleistocene)—**Remnants of long-inactive fans found in Florida Mesa and along the ridge between Spring Gulch and the Florida River. Texturally similar to younger fan deposits (Qfy). Unit may interfinger with the Lava Creek B volcanic ash

EOLIAN DEPOSITS—Sediments deposited by wind processes

Qlo **Loess (Holocene to middle Pleistocene)—**Clayey, sandy silt and silty, very fine- to fine-grained sand deposited by wind and preserved on level to gently sloping surfaces. Loess covers the tops of Durango moraines (Qmd), indicating that loess development is mainly post-middle Pleistocene in age

EOLIAN AND ALLUVIAL/ LACUSTRINE DEPOSITS—Volcanic ash deposited by wind and reworked by alluvial or lacustrine processes

Qva ▲ **Volcanic ash (middle Pleistocene)—**White to light-gray, bedded, volcanic ash correlated with the 602 ka Lava Creek B ash. Found at three localities, one along the western quadrangle boundary north of Animas City Mountain and two on Florida Mesa

SINTER DEPOSITS—Chemical sediment deposited by a mineral hot spring

Qtu △ **Tufa (latest Holocene)—**Low density, porous chemical pre-cipitate consisting of calcareous mineral deposits. Active deposit exists near a hot spring on the east side of the Animas River Valley

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by glaciation

Qkd **Kame deposits (latest Pleistocene)—**Heterogeneous, mainly silty to bouldery sediment deposited next to or by glacial ice. Unit includes deposits on relatively gently sloping parts of the valley sides north of Durango and on the divide that separates the Animas River Valley from Falls Creek.

Qma Qmai Qmam Qmao **Till and diamicton of Animas City moraines (late Pleisto-cene)—**Unit forms three nested end moraines at the south edge of the broad Animas Valley, in northern Durango. These are the Animas City inner moraine (Qmai), which is the youngest and farthest up-valley, Animas City middle moraine (Qmam), and Animas City outer moraine (Qmao), the oldest. Heterogeneous, poorly sorted, matrix- supported units consisting of cobbles, pebbles, and boulders in a sandy, silty matrix

Qms Qmsi Qmso **Till and diamicton of Spring Creek moraines (late? and late middle Pleistocene)—**Unit caps several small, rounded hills that appear to be remnants of two moraines which are poorly preserved. These are the Spring Creek inner moraines (Qmsi), which is younger and farther up-valley, and the Spring Creek outer moraine (Qmso). These moraines are weathered, heterogeneous, poorly sorted, matrix-supported units consisting of cobbles, pebbles, and boulders in a sandy, silty, clayey matrix

Qmd Qmdi Qmdo **Till and diamicton of Durango moraines (middle Pleistocene)—**Unit forms broad, rounded ridges on College Mesa and on the south end of Animas City Mountain. The younger Durango inner moraine (Qmdi) forms a prominent ridge along the north edge of College Mesa. Several shorter segments are included in the older Durango outer moraine group (Qmdo). Both units are heterogeneous, poorly sorted, matrix-supported deposits composed of cobbles, pebbles, and boulders in a sandy, silty, or clayey matrix. Units are partly glacio-fluvial in origin

Qlm **Till and diamicton in lateral moraines (late and middle Pleistocene)—**Unit includes deposits on relatively gently sloping parts of the valley sides in the Animas River Valley north of Durango 120 to 800 ft above the river. A heterogeneous, clast-supported unit consisting of cobbles and boulders in sandy matrix

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q **Surficial deposits, undifferentiated (Quaternary)—**Shown only on cross section. May include any of the above surficial deposits

BEDROCK

TKi **Monzonite and monzodiorite porphyry dikes (Paleocene or Upper Cretaceous)—**Two separate gray to brown igneous dikes found along Florida River and on Animas City Mountain. Highly weathered or altered, the dike along the Florida River trends east-west and cuts the McDermott Member of the Animas Formation (Kam) at nearly right angles. Dike on Animas City Mountain is inferred from float rock and lineament features

TKa **Animas Formation (Paleocene and Upper Cretaceous)—**Includes two members, the main body of the Animas Formation and the McDermott Member, a lenticular unit in the basal part of the Animas Formation

Kam **Main body—**Gray-green, olive-brown to dark-reddish-brown conglomerate, sandstone, and shale. Con-glomeratic clasts derived from volcanic rocks

Kk **McDermott Member—**Purple to reddish-brown, gray volcaniclastic sandstone and conglomerate with tuffaceous interbeds. Intertongues with the basal Animas Formation east of the Florida River

Kirtland Shale (Upper Cretaceous)—Includes three members, an upper and lower member separated by the Farmington Sandstone Member. Combined thickness of the formation is about 650 ft. Shown only on cross section

Kku **Upper member—**Light-yellow to white, and whitish-tan sandstone interbedded with olive-green and olive-gray shale. Sandstone beds are fine to medium grained, crossbedded, and sometimes conglomeratic. Shale beds are sometimes carbonaceous

Kkf **Farmington Sandstone Member—**Olive-brown to yellow, and tan to light-orange sandstone and greenish-gray shale. Sandstone is well sorted, fine to medium grained and has large-scale crossbedding, silica cement, and subrounded grains

Kkl **Lower member—**Gray-green to dark-olive-gray shale containing thin lenses of dark-brown to greenish-gray sandstone and silty shale beds

Kf **Fruitland Formation (Upper Cretaceous)—**Light-gray, light-brown to olive-brown, fine- to medium-grained sandstone interbedded with dark-gray shale and coal. Coal beds are prevalent in basal part; carbonaceous shales and sandstones dominate the upper part. Net coal thickness is 60 ft

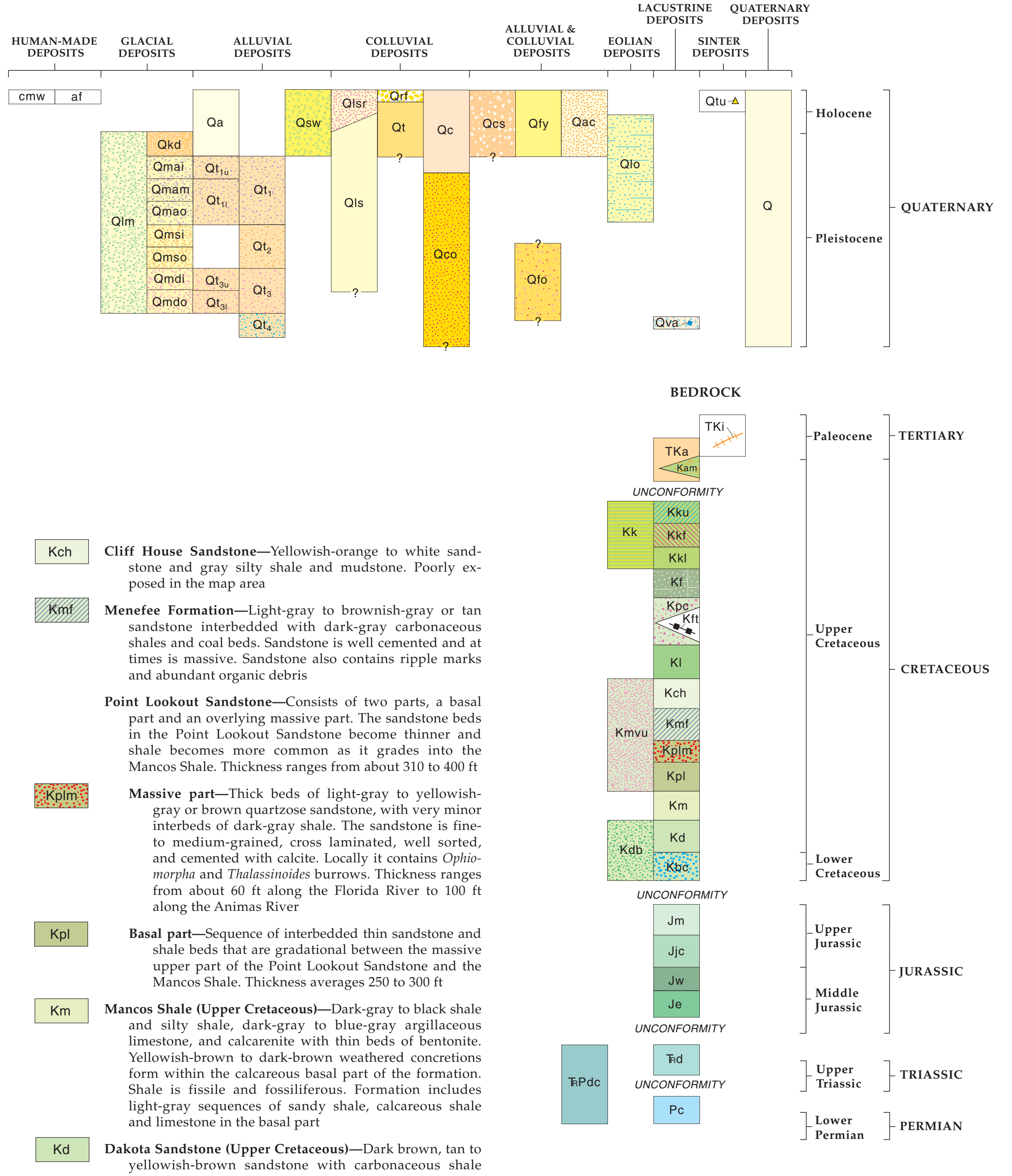
Kpc **Pictured Cliffs Sandstone (Upper Cretaceous)—**Light-gray to white, tan or grayish-orange sandstone interbedded with dark-gray shale in lower part. Sandstone is siliceous and well sorted, fine to medium grained, and has rounded grains. Contains locally abundant *Ophiomorpha* burrows. Locally intertongues with the Fruitland Formation

Kft **Fruitland Formation Tongue (Upper Cretaceous)—**Coal, carbonaceous shale, clinker, and altered volcanic ash. The coal is subbituminous B in rank, low to medium ash; the interbedded shale is dark gray to black, carbon-aceous, locally ashy with several thin tonsteins

Kl **Lewis Shale (Upper Cretaceous)—**Thick sequence of dark-gray fissile shale containing thin sandstone beds in upper part and gray, rusty-weathering concretionary limestone at base

Kmvu **Mesaverde Group (Upper Cretaceous)—**Includes three mappable formations, the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone. Menefee Form-ation coalbeds distinguish these formations apart. Shown only on cross section

CORRELATION OF MAP UNITS



Kch **Cliff House Sandstone—**Yellowish-orange to white sandstone and gray silty shale and mudstone. Poorly exposed in the map area

Kmf **Menefee Formation—**Light-gray to brownish-gray or tan sandstone interbedded with dark-gray carbonaceous shales and coal beds. Sandstone is well cemented and at times is massive. Sandstone also contains ripple marks and abundant organic debris

Point Lookout Sandstone—Consists of two parts, a basal part and an overlying massive part. The sandstone beds in the Point Lookout Sandstone become thinner and shale becomes more common as it grades into the Mancos Shale. Thickness ranges from about 310 to 400 ft

Kplm **Massive part—**Thick beds of light-gray to yellowish-gray or brown quartzose sandstone, with very minor interbeds of dark-gray shale. The sandstone is fine- to medium-grained, cross laminated, well sorted, and cemented with calcite. Locally it contains *Ophiomorpha* and *Thalassinoides* burrows. Thickness ranges from about 60 ft along the Florida River to 100 ft along the Animas River

Kpl **Basal part—**Sequence of interbedded thin sandstone and shale beds that are gradational between the massive upper part of the Point Lookout Sandstone and the Mancos Shale. Thickness averages 250 to 300 ft

Km **Mancos Shale (Upper Cretaceous)—**Dark-gray to black shale and silty shale, dark-gray to blue-gray argillaceous limestone, and calcarenite with thin beds of bentonite. Yellowish-brown to dark-brown weathered concretions form within the calcareous basal part of the formation. Shale is fissile and fossiliferous. Formation includes light-gray sequences of sandy shale, calcareous shale and limestone in the basal part

Kd **Dakota Sandstone (Upper Cretaceous)—**Dark brown, tan to yellowish-brown sandstone with carbonaceous shale partings, thin coals and siltstones at top, more conglomeratic basally. Fine- to course-grained sandstone; trace fossils and plant remains common

Kbc **Burro Canyon Formation (Lower Cretaceous)—**White to buff and tan sandstone and conglomerate with distinctive opaque chert clasts. Burro Canyon Formation is more highly crossbedded than the overlying Dakota Sandstone and usually contains grayish-green claystone

Kdb **Dakota Sandstone (Upper Cretaceous) and Burro Canyon Formation (Lower Cretaceous), undivided—**The two formations are combined where the contact between them is difficult to identify. This unit is mapped where exposures are rare or where stratigraphic relationships are uncertain

Jm **Morrison Formation (Upper Jurassic)—**Includes an upper member, the Brushy Basin Member, consisting predominantly of greenish-gray, occasionally reddish-brown claystone and mudstone; and a lower member, the Salt Wash Member, composed mostly of light-gray to white, fine- to medium-grained, lenticular sandstone and greenish-gray mudstone. Members not mapped separately

Jjc **Junction Creek Sandstone (Upper Jurassic)—**Light-gray to tan, massive, highly crossbedded to structureless, fine-grained sandstone. Forms a prominent rounded exposure across the northern part of the quadrangle. Junction Creek Sandstone is the source rock for large talus slopes

Jw **Wanakah Formation (Middle Jurassic)—**Upper unit is comprised of predominantly reddish-orange and reddish-brown, very fine- to fine-grained sandstone and reddish-brown to greenish-gray mudstone. Lower member is the medium- to dark-gray Pony Express Limestone

Je **Entrada Sandstone (Middle Jurassic)—**Light-gray to white, locally orange-gray basally, fine- to medium-grained, highly crossbedded sandstone

Ꞧd **Dolores Formation (Upper Triassic)—**Dark-reddish-brown to purplish-red shale and siltstone and light-brown, gray, and reddish-brown lenticular sandstone and limestone–pebble conglomerate; contains rare thin limestone beds. Limestone pebble conglomerates contain rare crocodilian teeth

Pc **Cutler Formation (Lower Permian)—**Medium- to dark-reddish-brown, medium-gray, and medium- to dark-brown sandstone, arkosic sandstone and limestone pebble conglomerate, and reddish-brown to purplish-brown shale and siltstone; contains rare thin limestone beds

ꞦPdc **Dolores Formation (Upper Triassic) and Cutler Formation (Lower Permian), undivided—**Unit is mapped in north central part of the quadrangle, where poor exposures limit recognition of the contacts between these formations

MAP SYMBOLS

— **Formation or unit contact—**Dashed where approximately located, queried where uncertain

Qlo/Qmdi **Fractional formation—**Indicates a thin veneer of one deposit (upper symbol) overlies another deposit (lower symbol)

Fault—Dashed where approximately located; dotted where concealed; ball and bar on downthrown side

Anticline—Showing axial trace; dashed where approximately located; dotted where concealed; arrow on end of axial trace indicates direction of plunge

Syncline—Showing axial trace; dashed where approximately located; dotted where concealed; arrow on end of axial trace indicates direction of plunge

Monocline-synclinal bend—Shorter arrow on steeper beds; dashed where approximately located; dotted where concealed; arrows point in direction of dip

Monocline-anticlinal bend—Shorter arrow on steeper beds; dashed where approximately located; dotted where concealed; arrows point in direction of dip

9 **Strike and dip of inclined beds—**Angle of dip shown in degrees

TKi **Igneous dike—**Line symbol for Lower Tertiary or Upper Cretaceous igneous dike (unit TKi)

⚒ **Rock quarry—**Sandstone used for building stone

c ⚒ **Coal mine—**Permitted strip mine

Sand and gravel pit—Active operation with reclamation permit issued by Colorado Division of Minerals and Geology

Sand and gravel pit—Formerly active gravel pits, now either reclaimed or inactive

◪ **Coal mine shaft**

≺ **Coal mine adit**

X **Coal prospect pit**

A——*A′* **Alignment of cross section**

☼ Huber Federal 33-1 **Gas well—**Producer, operator, well name

Drilled and abandoned well—With oil or gas shows

Tested and abandoned well—Used for pressure monitoring only

☼ **Development well—**Coalbed methane wells drilled in 1998

Soil slip—Thin, small, translational slope failure generally developed where thin veneer of colluvium overlies shale bedrock; tick points in direction of failure; may coincide with contact between units; common on Mancos and Lewis Shales

High level gravel—Thin remnant of a high-level Quaternary gravel at 1,850 ft above the Animas River near Haflin Canyon

■-■-■ **Fruitland Formation tongue (unit Kft)**

■ **Quaternary volcanic ash bed (unit Qva)**

△ **Sinter deposit (unit Qtu)—**Tufa with thermal spring

☰ **Pony Express Limestone—**Thin-bedded micritic and oolitic limestone. Unit is a unique marker bed found at the base of the Wanakah Formation throughout the region but only mapped on Baldy Mountain where it crops out 15 ft thick

ACKNOWLEDGMENTS

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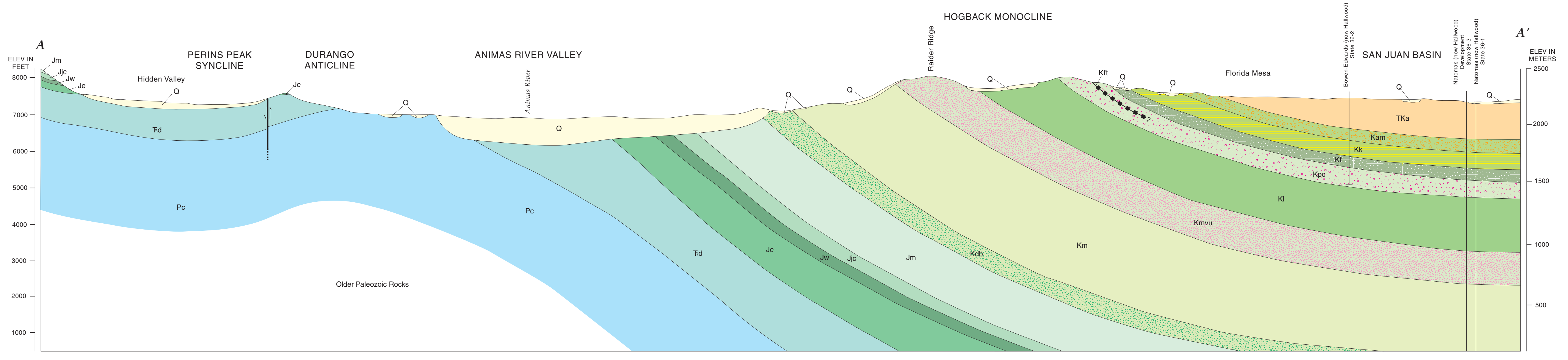

SHADED-RELIEF MAP OF THE DURANGO EAST QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTHEAST

GEOLOGIC MAP OF THE DURANGO EAST QUADRANGLE, LA PLATA COUNTY, COLORADO

By Christopher J. Carroll, Mary L. Gillam, Jason C. Ruf, Travis D. Loseke, and Robert M. Kirkham

1999