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

Description of Map Units, Fracture Data and Analysis, Mineral and Energy Resources, and References

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INTRODUCTION

Geologic mapping of the Durango West 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, which is administered by the U.S. Geological Survey. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps potentially useful for land-use planning, geotechnical engineering, geologic-hazards assessment, mineral-resource 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 depicts the current status of geologic mapping of 7.5-minute quadrangles in the Durango area. The Rules Hill and Ludwig Mountain quadrangles were mapped and published by the CGS during previous STATEMAP projects in 1997 and 1998 (Carroll and others, 1997; 1998). The Durango West quadrangle and Durango East quadrangle (Carroll and others, 1999) were mapped during fiscal year 1998-1999.

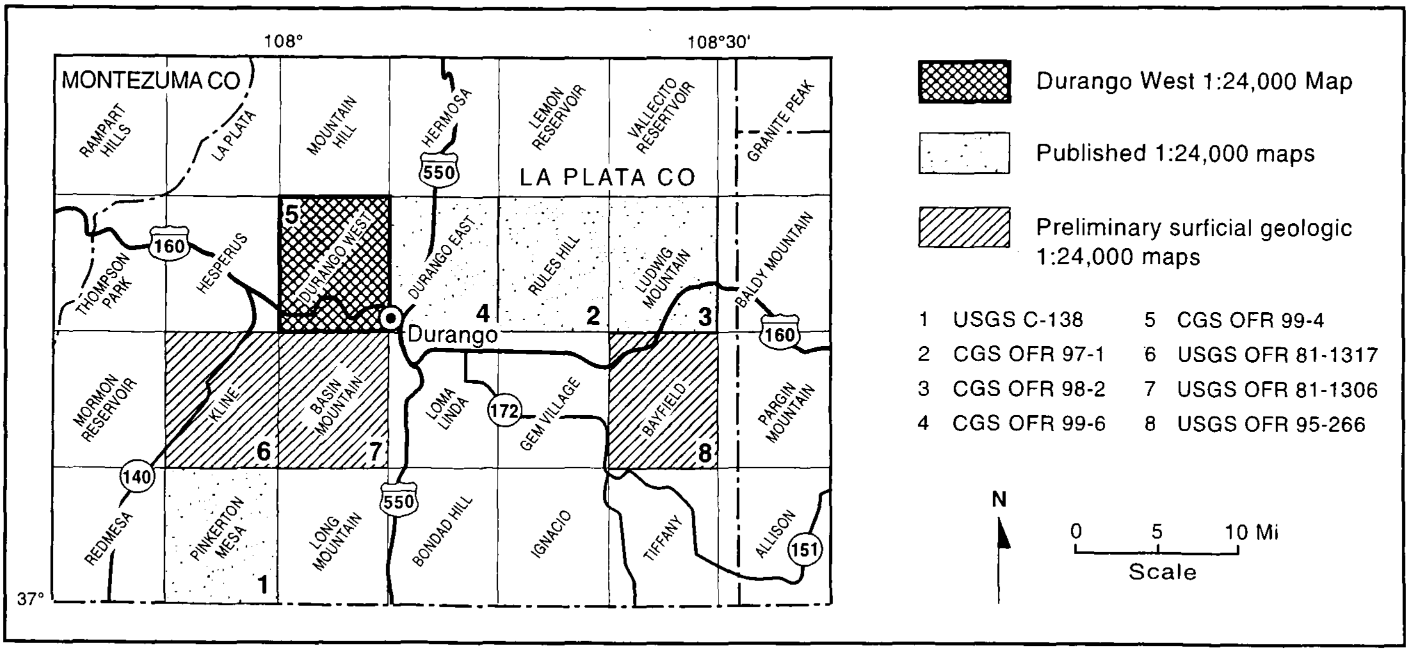


Figure 1. Status of 1:24,000-scale geologic mapping of 7.5-minute quadrangles near Durango, Colorado.

Due to access limitations, geologic mapping in the west-central part of the quadrangle (see figure 2) was based mostly upon prior published geologic studies, interpretation of aerial photography, and visual inspection from a distance using binoculars. The mapping in this area should be considered reconnaissance or preliminary.

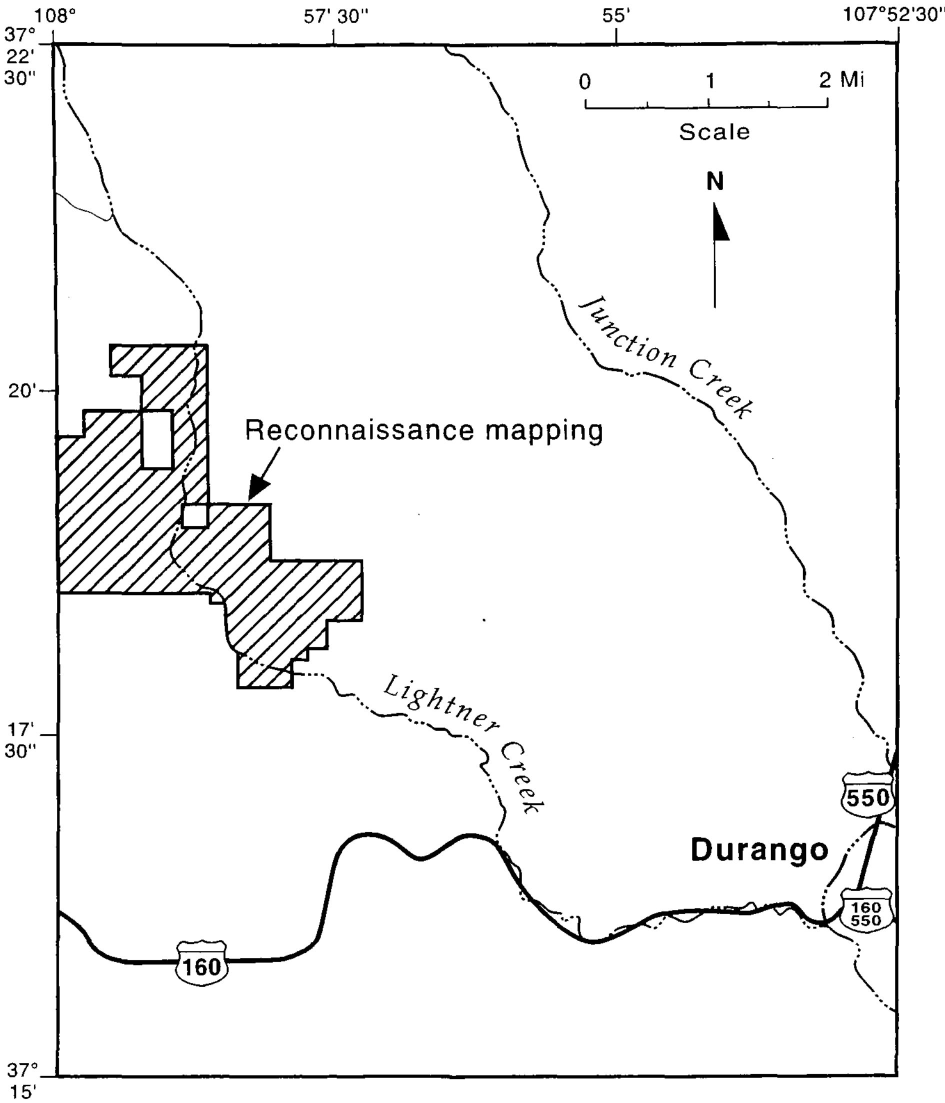


Figure 2. Approximate extent of area where only reconnaissance mapping was conducted due to restricted access. Highway locations are based on the U. S. Geological Survey 1963 Durango West topographic base map.

EXPANDED DESCRIPTION OF MAP UNITS

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. Where two symbols separated by a horizontal line are shown for a unit, a thin layer of the unit represented by the upper symbol overlies the unit indicated by the lower symbol. Some of the surficial deposits are calcareous and contain varying amounts of both primary and secondary calcium carbonate. Divisions of the Pleistocene used herein correspond to those of Richmond and Fullerton (1986). 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 relative degree of weathering and soil development. The terrace stratigraphy along the Animas River used in this study was established by Gillam (1998), which is largely based upon work by Gillam and others (1984; 1985) and Moore and Gillam (1984). Although the terrace nomenclature used in this report differs from that in Gillam (1998), the ages assigned by her to terraces along the Animas River are used with only minor modification. Correlation of terraces in Junction Creek and Lightner Creek to those in the Animas River valley is uncertain, because most terraces of these tributary streams are poorly preserved, and because channel diversion and headward extension have changed the courses and lengths of tributary streams. The latter factor altered channel gradients and relative terrace heights, which complicates correlation of the terraces.

HUMAN-MADE DEPOSITS—

af — **Artificial fill (latest Holocene)**—Consists of fill and waste rock placed during construction of roads, buildings, and dams, and also coal cinders from steam locomotives. Unit is composed mostly of unsorted silt, sand, rock fragments, and coal cinders, but may include construction materials. Maximum thickness is about 40 ft. Artificial fill may be subject to settlement when loaded, if not adequately compacted.

lf — **Landfill (latest Holocene)**—Consists of household, agricultural, and commercial refuse placed by humans in a landfill west of Durango. Maximum thickness is about 30 ft. Area is subject to severe settlement. Materials placed in landfills may generate biogenic methane gas as organic materials decay, which can create explosive hazards.

mw — **Mine waste (latest Holocene)**—Includes rock debris and coal refuse in dump piles near underground coal mines. Maximum thickness about 40 ft. Coal mine waste may be prone to settlement or to ignition.

rm — **Reclaimed mine or mill waste (latest Holocene)**—Consists of rock debris and soil that have been reclaimed at three mining and milling sites. Deposits in Coal Gulch are the result of a Colorado Division of Minerals and Geology project to reclaim coal mines. Deposits southwest of Durango at the northeast end of Smelter Mountain are reclaimed uranium and vanadium mill tailings, while the deposits south of Durango on the east end of Smelter Mountain are reclaimed raffinate ponds associated with the Durango uranium and vanadium mill. The U.S. Department of Energy reclaimed the latter two areas in the mid-1990s as part of the Durango Uranium Mill Tailings Remedial Action Project. Radioactive materials from these sites have been relocated to the Bodo Canyon disposal site at the southern edge of the Durango West quadrangle. Waste materials remaining at these two reclaimed sites are generally thin, but the disturbed area is a prominent human-created landform. Reclaimed materials may be prone to settlement or erosion.

umtra — **Bodo Canyon uranium mill tailings disposal site (latest Holocene)**—Includes low-level radioactive materials that were removed from the Durango mill site and raffinate ponds as part of the Durango Uranium Mill Tailing Remedial Action Project and placed in the Bodo Canyon Disposal Site. Maximum thickness is about 30 ft. According to signs posted around the disposal site, the materials pose a low-level radiation hazard.

ALLUVIAL DEPOSITS—

Silt, sand, and gravel deposited in stream channels, flood plains, glacial outwash terraces, and sheetwash areas along the Animas River and its tributaries. Terrace alluvium along the Animas River is chiefly glacial outwash. The headwaters of Lightner Creek and Junction Creek apparently were not glaciated (Atwood and Mather, 1932, plates 2 and 3), but most alluvium of these streams was probably deposited during late-glacial and early-interglacial stages, as was the glacial outwash of the Animas River. Alluvial deposits locally include sheetwash, colluvium, or loess too small to be mapped at a scale of 1:24,000. The approximate terrace heights reported for each unit are the elevation differences measured between the adjacent modern stream valley and either the top of the original alluvial deposition surface near the forward edge of the terraces or the top of the preserved deposit, if eroded.

Qa **Stream-channel, flood-plain, and low terrace deposits (Holocene)**—Includes modern stream-channel deposits of the Animas River, Junction Creek, and Lightner Creek, adjacent flood-plain deposits, and low-terrace alluvium that is up to 8 feet above modern stream level. Unit may include deposits of terrace alluvium one (Qt_1) in lower Lightner Creek where human activities have disturbed the natural terrace surfaces and in upper Junction Creek where heavy vegetation obscures the terraces. These deposits are mostly poorly sorted and clast supported. They consist of unconsolidated pebble, cobble, and locally boulder gravel in a sandy or silty matrix. Locally the unit is interbedded with or overlain by sandy silt and silty sand. Clasts are well rounded to subangular. Deposits along the Animas River valley contain clasts with diverse lithologies such as sandstone, quartzite, limestone, granite, monzonite porphyry, diorite porphyry, ash-flow tuff, andesite, amphibole, schist, and gneiss, reflecting the wide variety of bedrock that crops out within the drainage basin. Clast lithology along Junction Creek and Lightner Creek includes monzonite porphyry, diorite porphyry, and lamprophyre eroded from the intrusive complex in the La Plata Mountains, and sandstone, conglomerate, siltstone, limestone, and limestone-pebble conglomerate. Maximum thickness is estimated at 15 ft. Low-lying areas are subject to flooding. Unit is a source of sand and gravel.

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Includes materials that are transported predominantly by sheetwash and deposited in valleys of ephemeral and intermittent streams, on gentle hillslopes below landslides or alluvial fans, or in topographic depressions. These deposits are locally derived from weathered bedrock and surficial materials. Sheetwash deposits typically 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 slack-water deposits in closed depressions. Sheetwash deposits commonly occur in topographic depressions within landslides. Their maximum thickness is about 25 ft, but commonly are much thinner. Area is subject to future sheetwash deposition. Unit may be prone to hydrocompaction, settlement, and piping where fine-grained and low in density.

Qt_1 **Terrace alluvium one (late Pleistocene)**—Chiefly stream alluvium that underlies several terraces from about 20 to 100 ft above the Animas River, and at least one terrace from 5 to 13 ft above Junction Creek and roughly 30 ft above Lightner Creek. Includes a fan-like deposit along Junction Creek that extends up a dry tributary (locally called "Hidden Valley") toward Chapman Lake. The unit is mostly a poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a silty or sandy matrix. It may include fine-grained overbank deposits or overlying sheetwash deposits. Clasts are mainly subround to round. In the Animas River valley these deposits are composed of varied lithologies such as sandstone, quartzite, limestone, granite, monzonite porphyry, diorite porphyry, ash-flow tuff, andesite, amphibole, schist, and gneiss that reflect the diverse rock types in its drainage basin. In contrast, deposits along Junction Creek and Lightner Creek are rich in clasts of monzonite porphyry, diorite porphyry, and lamprophyre eroded from the intrusive complex in the La Plata Mountains and contain lesser amounts of sandstone, conglomerate, siltstone, limestone, and limestone-pebble conglomerate. 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 on the adjacent Durango East quadrangle. These moraines, which formed roughly from 12 to 35 ka (Richmond, 1986), are probably equivalent to Pinedale and other late-Wisconsin moraines elsewhere in the Rocky Mountains. Related terraces in the Durango area may be slightly younger, from 10 to 20 ka, because of delays between ice retreat and terrace incision (Gillam, 1998). Thickness averages about 20 to 30 ft. This unit is a source of sand and gravel.

Qt_2 **Terrace alluvium two (late? and late middle Pleistocene)**— Chiefly stream alluvium that underlies several terraces from 110 to 180 ft above the Animas River and at least two terraces from 60 to 120 ft above Lightner Creek. The unit is preserved along Lightner Creek only in its broader reaches near Hopkins Draw and near the confluence with the Animas River. Deposits of terrace alluvium two are absent or are disturbed by landsliding along Junction Creek. They are texturally and lithologically similar to terrace alluvium one deposits (Qt_1), but are slightly weathered and locally may include overlying sheetwash deposits, colluvium, and loess ranging from several feet to tens of feet thick. Related terraces correlate with terrace group TG6 of Gillam (1998), which is graded to Spring Creek moraines on the Durango East quadrangle. These moraines probably correlate with Bull Lake, Eowisconsin, and other moraines of similar age elsewhere in the Rocky Mountains (Richmond,1986; Gillam, 1998). Gillam (1998) suggested an age range of 85 to 160 ka for Spring Creek moraines and terrace group TG6. This range is based upon poorly constrained amino-acid-racemization dates for snails in alluvium overlain by Spring Creek moraines (Gillam, 1998) and on dates for deposits in other areas (as summarized by Richmond, 1986; see also Sturchio and others, 1994; and Chadwick and others, 1994). Thickness ranges up to about 45 ft. Unit is a potential source of sand and gravel.

Qt_3 **Terrace alluvium three (middle Pleistocene)**— Chiefly stream alluvium that underlies at least two terraces along Junction Creek and Lightner Creek and one terrace along the Animas River. Several deposits of terrace alluvium three occur on the Durango East quadrangle (Gillam, 1998; Carroll and others, 1999). Along parts of Junction Creek, the terraces are moderately well preserved at heights of 250 to 450 ft above the creek, which are comparable to heights of 290 to 450 feet for terrace alluvium three (Qt_3) along the Animas River at and near Durango (Carroll and others, 1999). In contrast, deposits of terrace alluvium three are preserved along Lightner Creek only near its confluence with Hopkins Draw, and these are only 140 to 240 ft above the modern stream level. They are texturally and lithologically similar to terrace alluvium one (Qt_1), but are moderately weathered and locally include overlying sheetwash deposits, colluvium, and loess up to several tens of feet thick. Related terraces correlate with terrace group TG5 of Gillam (1998), which grades or projects to the inner (younger) Durango moraines in this quadrangle and in the Durango East quadrangle. Gillam (1998) suggested that the inner Durango moraines formed during the coldest part of oxygen-isotope stage 8 at about 250 to 275 ka. Maximum thickness of terrace alluvium three deposits in this quadrangle may locally exceed 40 ft. In nearby Loma Linda quadrangle the maximum thickness approaches 150 ft. This unit is a potential source of sand and gravel.

Qt_4 **Terrace alluvium four (middle Pleistocene)**— Chiefly stream alluvium that underlies at least two terraces along Junction and Lightner Creeks. Deposits texturally and lithologically resemble those of terrace alluvium one (Qt_1), but are moderately weathered and locally may include overlying sheetwash deposits, colluvium, and loess up to several tens of feet thick. Terrace alluvium four is moderately well preserved on the northeast side of Junction Creek northwest of Chapman Lake. Gravel deposits that underlie Lava Creek B volcanic ash (Qva) and are mapped with the ash deposit along the eastern quadrangle boundary are probably correlative with terrace alluvium four. If the gravel beneath the ash is correlative with terrace alluvium four, then Junction Creek formerly flowed around the north end of Animas City Mountain. Terrace heights along Lightner Creek are about 320 to 380 ft and about 400 to 480 ft along Junction Creek. Terrace alluvium four locally is subdivided into an older or upper unit (Qt_{4u}) and a younger or lower unit (Qt_{4l}). A south-trending remnant of the lower unit (Qt_{4l}) parallels the present course of Lightner Creek in the northwest part of the quadrangle, but a southeast-trending remnant of the upper unit (Qt_{4u}) parallels a branch of Dry Fork. The latter remnant suggests that Lightner Creek flowed between Perins Peak and Barnroof Point when the upper unit (Qt_{4u}) was deposited but shifted to its present course before the lower unit (Qt_{4l}) was deposited. Related terraces are tentatively correlated with terrace group TG4 of Gillam (1998), which projects above the Durango moraines. Since terrace deposits correlative with terrace alluvium four are overlain by the Lava Creek B ash in both the Durango West and adjacent quadrangles (Gillam, 1998), terrace alluvium four was deposited before 600 ka (refer to the unit description for volcanic ash, Qva, for a discussion of the age of the ash). Maximum thickness of terrace alluvium four deposits in this quadrangle may locally exceed 40 ft. In nearby Loma Linda quadrangle the maximum thickness is about 200 ft. The unit is a potential source of sand and perhaps gravel.

Qt_{4u} **Upper unit of terrace alluvium four**

Qt_{4l} **Lower unit of terrace alluvium four**

Qt_5 **Terrace alluvium five (early middle or early Pleistocene?)**— Includes two small, isolated remnants of probable fluvial gravel on the southeast end of the Barnroof Point cuesta. The deposits appear to be texturally and lithologically similar to terrace alluvium one (Qt_1), but the remnants may be reworked by colluvial or sheetwash processes. The deposits are about 590 to 690 ft above the valley floor of Lightner Creek and were probably deposited by ancestral Lightner Creek when it followed the course of modern Dry Creek. Correlation of terrace alluvium five to Animas River terrace deposits is uncertain; it is probably older than terrace group TG4 of Gillam (1998) and may correlate to terrace group TG3, which is preserved along the Animas River only near Farmington, New Mexico. Maximum thickness of terrace alluvium five is about 12 ft. It is a very minor potential source of sand and gravel.

Qgh **High-level gravel (middle and early Pleistocene)**—Includes four remnants of high-level gravel on the saddle in Perins Peak and on the drainage divide between Lightner Creek and Coal Gulch. Unit appears to be chiefly fluvial, clast-supported, cobble and pebble gravel in a sandy or silty matrix, although matrix-supported material is locally present. Unit is moderately to strongly weathered and is poorly exposed. Clasts are round to subangular and composed mostly of sandstone and conglomeratic sandstone with lesser amounts of intrusive rocks eroded from the La Plata Mountains. High-level gravel deposits accumulated beneath at least two and probably more terrace levels. A constructional terrace surface is preserved only on the central saddle on Perins Peak. The deposits on Perins Peak suggest that ancestral Lightner Creek may have flowed through the saddle on Perins Peak during the early Pleistocene. Remnants of high-level gravel between Lightner Creek and Coal Gulch may be similar in origin to the sediments of Sheep Springs Gulch. Although all four remnants of high-level gravel occur at altitudes of 8,000 to 8,300 ft, they range from about 930 to 1,550 ft above Lightner Creek. Their elevations above Lightner Creek depend in part on the azimuths used to project these remnants toward the present course of Lightner Creek. The remnants north of Coal Gulch, at heights from 930 to 1,050 ft, might correlate with terraces of group TG3 mapped by Gillam (1998) in the Animas River valley near Farmington, New Mexico. Remnants of high-level gravel on Perins Peak lie 1,150 to 1,550 ft above Lightner Creek and probably correlate to younger terrace levels within terrace group TG2, which are preserved in the Animas River valley only near Colorado-New Mexico state line (Gillam, 1998). Maximum thickness is estimated at 40 ft. Unit may be a potential source of sand and perhaps gravel.

COLLUVIAL DEPOSITS—

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

Qlsr **Recent landslide deposits (latest Holocene)**— Includes four recently active landslides with fresh morphological features that suggest movement during the past few decades. Three are on steep hillslopes cut into the Morrison Formation. One is east of Chapman Lake, while the other two are south of the confluence of the main and south forks of Lightner Creek. The fourth recent landslide is on the Dakota Sandstone/Burro Canyon Formation dip slope along the west edge of the quadrangle in Sawmill Canyon. The three recent landslides in the northwest part of the quadrangle may be related to water saturation of surficial deposits along the Big Stick Ditch. Other recently active landslides likely exist in the quadrangle. For example, the authors were told that active landsliding reportedly sheared the casing of a water well on the west side of Animas City Mountain, but they were unable to substantiate this claim. 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 may be susceptible to settlement when loaded. Shallow groundwater may be present within areas mapped as recent landslide deposits. Soil slips (see explanation of map symbols) are thin, areally small, recent landslides that formed on steep slopes mantled by colluvium or residuum. However, they are too small to be shown as a map unit at a scale of 1:24,000.

Qt

Talus (Holocene and late Pleistocene)—Angular, cobbly, and bouldery rubble on moderate to steep slopes below cliffs of Dakota Sandstone/Burro Canyon Formation, Morrison Formation, or Junction Creek Sandstone. Unit commonly lacks matrix and locally is underlain by or incorporated into landslides. Maximum thickness estimated at 60 ft. Mapped areas are subject to severe rockfall, rockslide, and rock-topple hazards. Talus 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, sometimes aided by sheetwash. Unit includes thin, landslide deposits near Perins Peak and Barnroof Point. 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. Deposits derived from thick, shale beds 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 estimated at 40 to 60 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)—Heterogeneous deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Unit includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes. Deposits range from active, slowly creeping landslides to long-inactive, middle or perhaps even early Pleistocene landslides. Numeric modifiers used with the landslide symbol denote nested landslides with apparent age differences. Deposits labeled Qls_1 are younger than those labeled Qls_2. Most landslides involve the Mancos Shale, Dakota Sandstone/ Burro Canyon Formation, or Morrison Formation. Along Junction Creek near the U.S. Forest Service campground and along Lightner Creek southwest of Barnroof Point streams appear to have cut terraces on the landslide deposits. Rounded river gravel is often present at these locations, but it is unclear whether the gravel was deposited by the stream that cut the terrace or was part of a former terrace that was destroyed by and incorporated into the landslide. Maximum thickness may exceed 100 ft. Landslide deposits may be subject to future movement. Large blocks of rock in these deposits may locally hinder excavation. Deposits may be prone to settlement when loaded. Shallow groundwater may occur within landslide deposits.

Qpl **Deposits of the Perins Peak landslide complex (Holocene to early middle Pleistocene)**—Includes landslide deposits and colluvium of various ages around Perins Peak. These deposits formed during the destruction of the sandstone-capped mesa by mass-wasting along slip planes in the underlying Mancos Shale. Unit is unsorted, unstratified, and matrix-supported and consists of angular to subangular clasts of sandstone in a matrix of oxidized, yellow-brown silt and clay. Most of the fine-grained, clay-rich matrix is derived from the Mancos Shale, and the sandstone clasts are from the Point Lookout Sandstone and Menefee Formation. Two large toreva blocks occur within the Perins Peak landslide complex west of Perins Peak. These blocks consist of relatively intact bedrock that slid downslope and rotated. Landforms associated with deposits of the Perins Peak landslide complex range from hummocky terrain typical of recently active landslides to deeply dissected, highly eroded, narrow deposits that cap ridges.

The Perins Peak landslide complex apparently began to form at least by early middle Pleistocene time, after streams cut through the Point Lookout Sandstone and began to expose the underlying Mancos Shale. At this time, the sandstone-capped mesa was much more extensive than the present Perins Peak. Deposits from this initial phase of mass wasting apparently were graded to paleovalleys, because the contact between the landslide deposits and underlying Mancos Shale has a very low gradient. Remnants of deposits from this initial phase are preserved in several areas around Perins Peak, such as on the narrow ridge in the SW ¼ of section 19, T. 35 N., R. 9 W. As streams eroded more deeply into the Mancos Shale, parts of the original deposit were reactivated as landslides and colluvium. An example of this relationship is exposed in the steep hillslope west of the narrow, ridge-capping deposit described above. At this location the reactivated part of the deposit is graded to a topographically lower base level, and its basal contact is steeper. The triangular-shaped, erosional remnant in the NW ¼ of section 30, T. 35 N., R. 9 W. was probably formed by re-activation of the narrow, ridge-capping deposit and may correlate with the reactivated deposit across the gulch to the west. In several areas reactivated deposits of the Perins Peak landslide complex grade to modern stream channels and appear to have been active during the late Holocene.

A 15-ft-thick, deformed bed of volcanic ash (Qva), which is nearly vertical at its northeastern end, lies within deposits of the Perins Peak landslide complex southwest of Chapman Lake. The ash bed may have accumulated in a closed topographic depression within a landslide and later been deformed as the landslide was reactivated. An undisturbed remnant of terrace alluvium three (Qt_3) locally covers these landslide deposits about 100 ft northeast of the ash deposit. This relationship indicates that at this location the Perins Peak landslide complex moved after deposition of the 602 ka volcanic ash, but has been relatively stable since deposition of terrace alluvium three during middle Pleistocene time.

Maximum thickness of the deposits of the Perins Peak landslide complex locally exceeds 100 ft. The mapped area may be prone to future landslide activity.

Qco **Older colluvium (Pleistocene)**—Occurs on dissected hillslopes, ridgelines, and drainage divides as erosional remnants of formerly more extensive deposits that were transported primarily by gravity and locally by sheetwash processes. Texture, bedding, and clast lithology resemble those of colluvium (Qc). Maximum thickness probably is about 50 ft. Area generally is not subject to much future colluviation, except where adjacent to steep, eroding hillslopes. Unit may be subject to collapse, piping, and settlement where fine grained and low in density.

Qlso **Older landslide deposits (Pleistocene)**—Landslide deposits that lack distinctive landslide geomorphic features and have been moderately to deeply dissected by erosion are classified as older landslide deposits. They occur near Chapman Lake, on the southwest side of Barnroof Point, and at several locations on the Dakota Sandstone/Burro Canyon Formation dip slope. Older landslide deposits are similar in texture, bedding, sorting, and clast lithology to landslide deposits (Qls). Type of landslide movement is generally not identifiable due to partial erosion of the deposits. Maximum thickness may exceed 200 ft. Most older landslide deposits are probably not prone to reactivation unless significantly disturbed by construction activities, but each deposit should be individually evaluated for stability. Unit may be prone to settlement when loaded.

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)**—Includes hyperconcentrated-flow, debris-flow, alluvial, and sheetwash deposits in fans and tributary drainages. Locally may include earthflows or landslides. Consists of crudely 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. Frequently bouldery, particularly near the heads of fans which are rich in boulders of sandstone. Deposits tend to be finer grained in the distal ends of fans, where sheetwash and mudflow processes become more common. Clasts range from angular to subround. Maximum thickness is about 50 ft. 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, piping, and collapse. Unit may be a potential source of sand and gravel when derived from alluvial deposits.

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Unit chiefly consists of stream-channel, low-terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and of colluvium and sheetwash along valley sides. Locally includes debris-flow deposits. The alluvial and colluvial deposits commonly are interfingered. Unit is poorly 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.

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 locate. Refer to unit descriptions for colluvium (Qc) and sheetwash deposits (Qsw) for genetic, textural, and lithologic characteristics and for engineering properties and geologic hazards. Unit locally includes debris-flow deposits. Thickness averages 10 to 30 ft, but may be greater locally.

Qcso **Older colluvium and sheetwash deposits, undivided (Pleistocene)**—Includes a single deposit of colluvium and sheetwash on a ridge line west of Chapman Lake. Unit lies 200 to 400 ft above the adjacent stream valley. It resembles colluvium and sheetwash (Qcs) in texture and lithology, but is much older. Maximum thickness probably 20 to 30 ft. Mapped area is probably not subject to future deposition.

Qss **Sediments of Sheep Springs Gulch (middle Pleistocene)**—Includes gravel deposits that cap several broad benches and narrow ridges in the southwestern part of the quadrangle. Unit is chiefly fluvial, but includes deposits of sheetwash, colluvial, and debris-flow origin. It ranges from poorly sorted, stratified, clast-supported, silty, clayey, and sandy, cobble and pebble gravel to poorly sorted, unstratified, matrix-supported, gravelly clayey silt. Clasts are chiefly rounded to subangular monzonite porphyry and diorite porphyry eroded from the intrusive rocks in the La Plata Mountains, with lesser amounts of sandstone and siltstone.

The lowest surface capped by the sediments of Sheep Springs Gulch is best preserved from the southern edge of the quadrangle northward to Sheep Springs Gulch. Associated deposits range from about 10 to 150 ft above adjacent drainages and grade westward (upslope) into landslides. These landslides formed by mass wasting of Lewis Shale and overlying cobble and pebble gravel that caps Red Mesa on the adjacent Hesperus and Kline quadrangles. This physical relationship suggests that the sediments of Sheep Springs Gulch consist of reworked landslide material that was deposited in fluvial, debris-flow, and sheetwash environments. Between Sheep Springs Gulch and Cherry Gulch the sediments of Sheep Springs Gulch underlie multiple surfaces. These elongate, erosional remnants have steeper gradients at their western ends and lie about 120 to 280 ft above adjacent valleys. They cannot be directly traced to existing landslide deposits but are inferred to have been derived from former landslide deposits that have since been removed by erosion. The ridge-capping remnants between Cherry Gulch and Coal Gulch underlie another former surface about 240 to 280 ft above adjacent streams and probably formed in the same manner as topographically lower remnants to the south. A veneer of loess locally caps the sediments of Sheep Springs Gulch between Cherry Gulch and the southern quadrangle boundary.

The sediments of Sheep Springs Gulch may be late middle and middle middle Pleistocene in age and are tentatively correlated with terrace alluviums two and three (Qt_2 and Qt_3). Maximum thickness is about 50 ft, but typically is much less. The unit is a potential source of sand and gravel.

GLACIAL DEPOSITS—

Gravel, sand, silt, and clay deposited by ice or adjacent to ice in moraines.

Qmd **Durango moraine (middle Pleistocene)—** Unit is composed of a single eroded remnant of end moraine or perhaps lateral moraine along the east edge of the quadrangle at the southern tip of Animas City Mountain. Deposit is a heterogeneous unit consisting of cobbles, pebbles, and boulders in a sandy, silty, or clayey matrix. It is poorly sorted and matrix-supported. Gravel clasts are angular to subround, with the larger clasts usually being more angular than the smaller clasts. The varied clast lithology reflects the numerous different types of bedrock exposed in the Animas River drainage. Red sandstone and siltstone probably derived from the Cutler and Dolores Formations are most abundant.

Atwood and Mather (1932) correlated this deposit with their "Durango stage". Richmond (1965) associated it with his Illinoian "Sacagawea Ridge" glaciation. Gillam and others (1984) and Moore and Gillam (1984) described this deposit as inner (younger) Durango moraine. Gillam (1998) also reported a late Durango age for this deposit and suggested it may have formed during oxygen-isotope stage 8 about 250 to 275 ka. Maximum thickness of the Durango moraine in the Durango West quadrangle is about 60 ft.

EOLIAN DEPOSITS—

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

Qlo **Loess (late and late middle? Pleistocene)—** Slightly clayey, sandy silt and silty, very fine to fine sand deposited by wind and preserved on level to gently sloping surfaces. Typically the unit is unstratified, friable, and plastic or slightly plastic when wet. Sand grains are sometimes frosted. Thickness ranges from about 5 to 15 ft. Deposition occurred during at least one and perhaps two periods of Pleistocene eolian activity. Mapped distribution of loess is very approximate due to the poor geomorphic expression of loess. The best-preserved deposits of loess overlie the sediments of Sheep Springs (Qss) in the southwest part of the quadrangle. A small nearby remnant of loess lies on Cliff House Sandstone. The loess may have been derived from glacial outwash deposits that cap Red Mesa west of the quadrangle. Low-density loess may be prone to settlement when loaded and to piping and hydrocompaction when wetted.

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 occurs at two locations, one along the eastern boundary of the quadrangle northeast of Chapman Lake and a second on the southwest side of Junction Creek southwest of Chapman Lake. Unit also includes pebble and cobble gravel that locally underlie the ash at the first site, but is too thin to be mapped separately. Both localities were originally reported and described by Woolsey (1906).

Along the eastern boundary of the quadrangle the ash bed is concealed by a thin veneer of colluvium and is overlain by landslide deposits. At this site the ash is thinly laminated, yielded a fossil aquatic snail (Gyraulus sp.), and is perhaps as much as 50 ft thick, which suggests deposition in a lacustrine environment (Gillam, 1998). The ash rests on a thin pebble and cobble gravel that overlies the Morrison Formation and contains clasts derived from the intrusive rocks in the La Plata Mountains. This gravel lies about 320 ft above the adjacent stream valley, which is roughly the same height as nearby deposits of terrace alluvium four (Qt_4). If the gravel beneath the ash bed correlates to terrace alluvium four, then Junction Creek probably flowed north of Animas City Mountain in early middle Pleistocene time. Gillam (1998) suggested this ash deposit along the eastern boundary of the quadrangle is the Lava Creek B ash from the Yellowstone caldera in Yellowstone National Park. Recent $^{40}Ar/^{39}Ar$ dating of 24 sanidine crystals of the Lava Creek B tuff near Yellowstone using single-crystal laser-fusion methods by Gansecki and others (1998) yielded an average age of 602 ± 4 ka. Previous studies by Izett and Wilcox (1982) reported an age of 620 ka for the Lava Creek B ash, a value that is widely cited in the literature for the Lava Creek B ash.

The ash bed southwest of Chapman Lake lies within deposits of the Perins Peak landslide complex. It is up to about 15 ft thick and is highly deformed, being nearly vertical at its northeastern end. The ash contains minor sand and silt that probably were added during reworking in a sheetwash environment. The ash may have been deposited on or near a landslide, reworked and redeposited within a topographic depression on the landslide, and then deformed by subsequent reactivation of the landslide. A remnant of terrace alluvium three (Qt_3), apparently undisturbed, is preserved over these landslide deposits about 100 ft northeast of the ash deposit. Izett and Wilcox (1982) described the volcanic ash southwest of Chapman Lake as Lava Creek B ash, an interpretation supported by Gillam (1998). This indicates that at this location the landslide complex moved after approximately 602 ka, but has been relatively stable since deposition of terrace alluvium three during middle Pleistocene time.

Volcanic ash deposits are low in density and may be prone to compaction or settlement problems. They were mined for use as scouring powder during the early 20th century and potentially could be used as mineral resources in the future.

BEDROCK

Tki **Diorite porphyry and monzonite porphyry sills and dikes (Upper Cretaceous or Paleocene)**— Medium-brown to medium-gray igneous sills and dikes in the northwest and southeast parts of the quadrangle. Generally moderately to highly weathered or altered. The sills tend to be less weathered than the dikes. Petrographically the dikes appear to be mostly diorite porphyry with a color index of about 20 to 40 percent, while the sills are monzonite porphyry or diorite porphyry with a color index of about 10 to 20 percent (David Gonzales, 1999, written communication). The degree of weathering inhibits identification of some minerals and determination of rock type. The sills consist mostly of feldspar and mafic minerals, with lesser amounts of apatite, opaque minerals, quartz, and zircon. The feldspars are commonly weathered to sericite and appear to be mainly plagioclase with lesser or nearly subequal amounts of orthoclase. Hornblende altered to chlorite is the most abundant mafic mineral, although some samples may have contained pyroxene prior to alteration. The dikes appear to have higher plagioclase to potassium feldspar ratios than the sills, and the mafic minerals, which are more common in the dikes than the sills, are dominated by hornblende altered to chlorite.

Whole-rock samples from two sills and two dikes were chemically analyzed for major elements (table 1). All four samples, especially DW-112, DW-114, and DW-121, have high loss on ignition, probably a result of the high degree of alteration. These rocks are subalkaline to alkaline. On the basis of silica content, they range from diorite to monzonite in composition. The apparently high potassium and sodium concentrations suggest these rocks are more alkaline than monzonite or diorite, but the high loss on ignition raises suspicions about the validity of the potassium and sodium values. The sills were slightly enriched in silica, sodium, and potassium and slightly deficient in calcium, iron, phosphorus, and titanium relative to the dikes.

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

Sample 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 %
DW-112	16.19	4.68	<0.01	7.20	2.09	2.40	0.16	5.09	0.40	54.98	0.75	5.35	99.29
DW-114	16.06	4.90	<0.01	8.80	2.74	3.42	0.17	5.07	0.34	52.76	0.86	3.54	98.66
DW-121	15.86	3.05	<0.01	5.06	3.00	2.49	0.10	5.53	0.21	59.12	0.58	4.07	99.07
DW-143	16.11	2.69	<0.01	5.22	3.63	2.80	0.14	6.16	0.21	59.96	0.61	1.39	98.92

* Loss on ignition
Above analyses performed by Chemex Labs, Inc., Sparks, Nevada.

Sample Descriptions:

DW-112: Dike exposed in cut along old road on east side of Lightner Creek near northwest corner of quadrangle. Lat. 37.3667, Long.107.9952.

DW-114: Dike exposed in cut along old road on east side of Lightner Creek near northwest corner of quadrangle. Located about 400 ft east of DW-112. Lat. 37.3676, Long. 107.9942.

DW-121: Prominent ledge-forming sill in small unnamed drainage along northern edge of quadrangle near northwest corner of mapped area. Lat. 37.3740, Long. 107.9863.

DW-143: Subtle, ledge-forming dike that is slightly discordant with bedding in host sedimentary rocks. Lat. 37.3713, Long. 107.9749.

Thin, weathered dikes that range from a few inches to several feet thick in the southeast part of the quadrangle are within or are adjacent to the Bodo fault. Their locations along the fault are denoted on the map by the letter "d". Immediately north of Bodo Canyon road the dikes are so oxidized that they are less resistant to erosion than adjacent contact-metamorphosed sedimentary rocks. Jacobs-Weston Team (1985c) reported that a dike was offset by the Smelter Mountain fault (their Fault 2) in a gully north of Bodo Canyon road, but we did not find it during a brief reconnaissance of this area. Two dikes on the east side of Lightner Creek near the northwest corner of the quadrangle are as wide as 20 ft and are exposed only in a road cut and a stream-cut bank. The mapped locations of these dikes are based on projections of apparent trends from limited exposures.

At least three intrusive bodies crop out in the northwest corner of the quadrangle. Two appear to be sills, but the centrally located igneous body is slightly discordant with bedding in the sedimentary rocks it intrudes.

Although age dates are not available for the dikes and sills in the Durango West quadrangle, they are likely associated with the early Laramide, 60 to 70 Ma, intrusive rocks in the La Plata Mountains (David Gonzales, 1999, oral communication). These intrusive bodies typically are 25 to 30 ft thick, but the sills locally are up to 80 ft thick. Sills may be a potential source of riprap.

Kl

Lewis Shale (Upper Cretaceous)—Dark-gray, fissile shale containing thin sandstone beds at top and gray, rusty-weathering concretionary limestone in the lower part. Volcanic ash beds in the Lewis Shale, 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). The unit weathers easily and is generally covered by surficial deposits. It is exposed only at and near the southern edge of the quadrangle. The contact with the underlying Cliff House Sandstone is conformable and somewhat gradational. The Lewis Shale was deposited in a low-energy, off-shore, marine environment (Fassett and Hinds, 1971). Total thickness averages about 1,800 ft in the Durango area, although only the lower part of the formation occurs in the Durango West quadrangle. It is a reservoir for natural gas (a fracture play) in the San Juan Basin. The Lewis Shale is prone to landsliding and is susceptible to shrink-swell problems where it contains expansive clays.

Mesaverde Group (Upper Cretaceous)—Consists of three mappable formations in Durango West quadrangle, which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone. These formations are distinguished primarily by the gray to black shale and coal beds within the Menefee Formation and the *Ophiomorpha* burrows in the Cliff House Sandstone and Point Lookout Sandstone. The Point Lookout

Sandstone and the resistant sandstone beds in the Menefee Formation form prominent cliffs around Barnroof Point, Perins Peak, and Smelter Mountain.

Kch

Cliff House Sandstone—Interbedded sequence of thin beds of moderately indurated, yellowish-orange to white, very fine to medium-grained calcareous sandstone and softer light-gray mudstone, siltstone, and silty shale. Sandstone beds frequently contain abundant *Ophiomorpha* burrows, and they weather to yellow brown or light red brown, forming a rusty-colored outcrop that sharply contrasts with the drab colors of the underlying Menefee Formation. Sandstone beds within the formation thicken westward. West of the map area Barnes and others (1954) reported rapid thickening of the sandstone beds west of longitude 108°20′. In that area the formation includes massive sandstone beds 50 to 70 ft thick, and these thicken westward in the Mesa Verde area. To the east shale and siltstone beds thicken and comprise much of the formation. The Cliff House Sandstone is usually poorly exposed except in road cuts and other excavations. Contact with the underlying Menefee Formation appears to be a minor disconformity in most of the quadrangle. To the west on Barker Dome Barnes and others (1954) described local intertonguing of the Cliff House Sandstone and Menefee Formation. The Cliff House Sandstone is a transgressive, shallow marine unit deposited on the upper shoreface zone of a barrier-island beach front (Siemers and King, 1974). Thickness in the quadrangle averages about 325 ft (Zapp, 1949). Formation thins eastward. 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 gray, brown, and black carbonaceous shale, light-gray, brown, and orange-brown, locally lenticular sandstone, and coal. Locally includes burnt rock and clinker resulting from burning of coal beds within the formation. Sandstone beds are commonly 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, but often sharp. It is placed at the base of the lowest coal or carbonaceous shale bed. The Menefee Formation was deposited in a coastal-plain environment (Aubrey, 1991). Thickness is highly variable, ranging from about 200 to 350 ft. The variation is partly due to syn-depositional factors, but also to differential compaction of the sand, clay, and especially the peat beds during lithification and, to a lesser degree, volume loss due to combustion of coal beds. Individual coal beds are up to 8.5 ft thick, but typically are a maximum of 5 to 6 ft thick. Subsidence of the land surface may occur above underground mines where coal was extracted from the Menefee Formation. Thick sandstone beds in the formation may cause rockfall hazards.

Kplu

Point Lookout Sandstone, undivided—Shown only on cross section. This formation is subdivided into two lithostratigraphic units, a massive part and lower part, based on the relative amounts of sandstone and shale, similar to the work of Zapp (1949) and Barnes and others (1954). The two sequences are mappable lithologic units in the quadrangle, each with different engineering geology characteristics. West of the map area, near the town of Mancos, Barnes and others (1954) and Condon (1990) described intertonguing relationships between the two units, including a basal tongue of the massive part that underlies the lower part.

The formation consists of lenses of sandstone that are stacked in an imbricate pattern and separated by shale and siltstone of varying thickness. The younger beds lie to the northeast. Barnes and others (1954) traced individual sandstone beds and discovered the sandstone lenses were thickest in the massive part and thinner in the lower part.

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 in the lower part of the formation. For this study the contact is arbitrarily placed at the base of the lowest 1-ft-thick sandstone bed or at the point where the strata contain more than 50 percent shale over a six ft stratigraphic interval. The formation was deposited in a coastal shoreline environment as a deltaic plain and mouthbar depositional sequence in the Durango delta (Wright, 1986, 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 300 to 400 ft. The Point Lookout Sandstone is an important reservoir and producer of natural gas in the San Juan Basin.

Kplm

Massive part of Point Lookout Sandstone— Thick, massive 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 the massive part contains *Ophiomorpha* burrows. This unit commonly forms prominent cliffs. Thickness ranges from about 60 to 100 ft. It is generally thicker in the western part of the quadrangle. The massive part of the Point Lookout Sandstone may pose rockfall hazards where exposed in steep cliffs, such as around Barnroof Point, Perins Peak, and Smelter Mountain, and along Lightner Creek and Wildcat Canyon.

Kpl

Lower part of Point Lookout Sandstone— Sequence of interbedded thin sandstone and shale beds that are gradational between the massive part of the Point Lookout Sandstone and the Mancos Shale. Sandstone beds are 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 predominant towards the base of the unit. The lower part of the Point Lookout Sandstone is usually poorly exposed. Contact with underlying Mancos Shale is conformable and is arbitrarily placed at the base of the lowest 1-ft-thick sandstone bed or where the strata contain more than 50 percent shale in a six-ft-thick interval. Thickness averages 250 to 300 ft. Shale beds in the lower part may have high swell potential. It is prone to landsliding, and soil slips are common in residuum and colluvium derived from the unit.

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. The Mancos Shale is locally overlain by unmapped landslide deposits. 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. West of the quadrangle in and near Mesa Verde National Park, Leckie and others (1997) have subdivided it 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 the Durango West quadrangle but were not mapped. Leckie and others (1997) described 188 bentonite beds, most of which are less than 4 inches thick, within the Mancos Shale west of the quadrangle. They occurred throughout the formation, but are most abundant in the lower one-fourth of the formation. The contact with the underlying Dakota Sandstone is conformable and perhaps intertongued locally. The Mancos Shale was deposited in a low-energy, marine environment. Total thickness of the Mancos Shale is about 2,000 to 2,400 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 affect the quality of groundwater.

Kdb

Dakota Sandstone (Upper Cretaceous) and Burro Canyon Formation (Lower Cretaceous), undivided—Dakota Sandstone is composed of white, light- to medium-gray, and yellowish-brown conglomeratic sandstone, fine- to coarse-grained sandstone, and conglomerate interbedded with dark- to medium-gray siltstone, carbonaceous shale, and thin coal beds. Conglomerate clasts in the Dakota Sandstone usually are granules and pebbles of chert and quartz. The Burro Canyon Formation consists of sandstone, chert-pebble conglomerate, and grayish-green, non-carbonaceous claystone. The absence of coal and carbonaceous shale in the Burro Canyon Formation is the primary characteristic used to distinguish it from the Dakota Sandstone. They are lumped into a single map unit because the contact between the two formations is commonly either concealed or is exposed in a near vertical cliff and not possible to depict at a scale of 1:24,000. Unmapped colluvium or landslide deposits locally overlie the unit. Lucas and Anderson (1997a) stated that the Burro Canyon Formation is synonymous with Cedar Mountain Formation and should be abandoned; however, we chose to apply the name Burro Canyon Formation to these rocks because of the long historical usage in Colorado. The Burro Canyon Formation and Dakota Sandstone are separated by a disconformity with local erosional relief (Aubrey, 1991). In places much and perhaps all of the Burro Canyon was erosionally removed prior to deposition of the Dakota Sandstone. The upper and middle parts of the Dakota Sandstone were deposited in coastal swamp, lagoon, and beach environments, whereas the lower part of the Dakota Sandstone and the Burro Canyon Formation were likely deposited in a fluvial environment. The combined thickness of the two formations averages 180 to 250 ft in the quadrangle.

The Dakota Sandstone and Burro Canyon Formation generally serve as good foundation material, although excavations into well-cemented beds may require blasting. Where exposed in cliffs and steep hillslopes, this unit causes rockfall hazards, including massive rock topples like the July 5, 1998 event on the east side of the Animas River valley that involved about 50,000 cubic yards of rock. Shear fractures commonly act as the failure planes for rockfall and rock topples. The unit is prone to landssliding along shale beds within the formation. The Dakota Sandstone is an oil and gas reservoir in parts of the San Juan Basin.

Jm **Morrison Formation (Upper Jurassic)**—Consists of an upper member called the Brushy Basin Member and a lower member known as the Salt Wash Member, but these were not mapped individually in this quadrangle due to poor exposures. In several areas on Barnes Mountain the Morrison Formation is overlain by thin, unmapped landslides and small soil slips. The Brushy Basin Member is predominantly greenish-gray, occasionally reddish-brown, bentonitic mudstone and claystone containing thin beds of very fine-grained sandstone and rare conglomeratic sandstone. It conformably overlies and perhaps intertongues with the Salt Wash Member (Condon, 1990). The Salt Wash Member is mainly light-gray to white, fine- to medium-grained, locally silicified, lenticular sandstone interbedded with thin beds of greenish-gray mudstone. The Salt Wash Member conformably overlies the Junction Creek Sandstone.

The Brushy Basin Member was deposited in shallow lacustrine and fluvial environments (Condon, 1990). Turner and Fishmann (1991) suggested that much of the Brushy Basin was deposited in a single ancient, alkaline, saline lake called Lake T'oo'dichi', although Anderson and Lucas (1997a) preferred a depositional model involving numerous smaller lakes on a vast floodplain. Thickness of the Brushy Basin Member is estimated at 150 to 200 ft. The Salt Wash Member was deposited in a fluvial environment (Condon, 1990) and is about 200 to 300 ft thick. 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. The Salt Wash Member has yielded large amounts of uranium in the region.

Jjc **Junction Creek Sandstone (Middle Jurassic)**—Light-gray to tan, highly cross-bedded to massive, fine-grained eolian sandstone. Although the type section of the Junction Creek Sandstone is in the quadrangle, it is commonly poorly exposed and is mapped jointly with the underlying Wanakah Formation and Entrada Sandstone in some areas. It is correlative with the Bluff Sandstone in the Four Corners Region and southeastern Utah (O'Sullivan, 1997; Lucas and Anderson, 1997b). The Junction Creek Sandstone conformably overlies the Wanakah Formation. It was deposited in a predominantly eolian environment (Peterson, 1972). Thickness averages about 100 ft. It may pose rockfall hazards where exposed in steep cliffs.

Jw **Wanakah Formation (Middle Jurassic)**—Consists of two members, 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 outcrops. The upper member of the Wanakah Formation and the Pony Express Limestone Member are probably correlative with the Summerville Formation in the Four Corners region and in part with the Todilto

Formation in New Mexico. The gypsiferous part of the Todilto is not present in the Durango West quadrangle. The Wanakah Formation conformably overlies the Entrada Sandstone. Condon (1990) suggested the upper member of the Wanakah Formation was deposited in sabkha and marginal marine environments, and the Pony Express Limestone Member was of restricted marine origin. Lucas and Anderson (1997b) described the upper member (Summerville Formation) as being deposited in quiet, ephemeral shallow water on an arid coastal plain of very low slope and relief. Thickness of the upper member ranges from about 40 to 70 ft, while the Pony Express Limestone Member is about 3 to 7 ft thick. North of Durango this member is represented by a 2- to 5-ft-thick oolitic limestone (Baars and Ellingson, 1984), whereas to the south Condon (1990) describes it as including a 5- to 15-ft-thick limestone bed and a bed of gypsum up to about 15 ft thick.

Je

Entrada Sandstone (Middle Jurassic)—Light-gray to white, sometimes orangish-gray, fine- to medium-grained, highly cross-bedded sandstone that is locally coarse grained or conglomeratic at the base of the formation. The Entrada Sandstone typically has prominent large-scale cross bedding. It occasionally forms good outcrops, such as in the valley east and north of Chapman Lake, but commonly is veneered by colluvium or residuum. Locally it includes a sequence of sandstone beds at the base of the formation that may correlate with the Wingate Sandstone (Jack Campbell, 1998, oral communication) The Entrada Sandstone unconformably overlies the Dolores Formation and was deposited in an eolian environment. Thickness averages about 250 ft. Where exposed in cliffs, the Entrada Sandstone may cause rockfall hazards. It has yielded uranium and vanadium in the quadrangle.

Jje

Junction Creek Sandstone, Wanakah Formation, and Entrada Sandstone, undivided (Middle Jurassic)—Mapped in the north-central part of the quadrangle where poor exposures limit recognition of contacts.

T̵d

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 containing rare thin limestone beds. Locally is well exposed on steep hillslopes, but usually is partly or completely covered on gentler slopes. Lucas and others (1997b) correlated this unit with an upper member (Rock Point Formation), middle member (Painted Desert Member of the Petrified Forest Formation), and lower member (Moss Back Formation) of Chinle Group strata on the Colorado Plateau. The Dolores Formation unconformably overlies the Cutler Formation. Although the contact between the Dolores and Cutler is a major unconformity, it is not easily recognizable. In the Durango area it generally occurs within a bleached zone of varying thickness. During a field review of the problem with Jack Campbell and Dave Gonzales, Fort Lewis College, it was agreed to place the contact at the base of the first limestone-pebble conglomerate that contains teeth and bone fragments from crocodilians above the highest arkosic bed in the Cutler Formation. The Dolores Formation was deposited in fluvial and lacustrine environments (Condon, 1990). Thickness averages about 500 to 600 ft. The Dolores Formation 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 and reddish-brown to purplish-brown shale and siltstone containing occasional limestone-pebble conglomerate and rare thin limestone beds. Base of formation is not exposed in quadrangle. The Cutler Formation was deposited in fluvial and alluvial-fan environments (Campbell, 1976; 1979; 1980). Total thickness is estimated at about 2,000 to 2,500 ft. The formation may be prone to rockfall hazards where exposed in steep cliffs.

FRACTURE DATA AND ANALYSIS

Analysis of fracture data is potentially useful in evaluating migration pathways for fluids and gases, including ground water, coalbed methane, and hydrogen sulfide gas. Fracture analysis can also provide insight into the tectonic history of an area. Recent fracture studies within the San Juan Basin (Condon, 1997a, b; Whitehead, 1997; Verbeek and Grout, 1997) have hypothesized various ages and origins for fractures, ranging from Laramide compression to Quaternary topographic release.

Fracture data were collected at thirteen sites (fracture stations) in the Durango West quadrangle to characterize the fracture network in sedimentary rocks exposed within the quadrangle. The fracture studies were conducted both as part of this mapping project and as part of a larger fracture study of joints and shear fractures along the northern rim of the San Juan Basin by Ruf (in preparation). Data on 233 shear fractures (including 51 measurements by Erslev, 1997) and on 284 joints are reported in table 2. The shear fracture data were collected at six fracture stations in the Dakota Sandstone/Burro Canyon Formation and one in the Morrison Formation. The joint data are from six sites at three fracture stations in the Menefee Formation, two sites in the massive members of the Point Lookout Sandstone, and one site in the lower member of the Point Lookout Sandstone. The locations of the thirteen fracture stations are shown in figures 3 and 4.

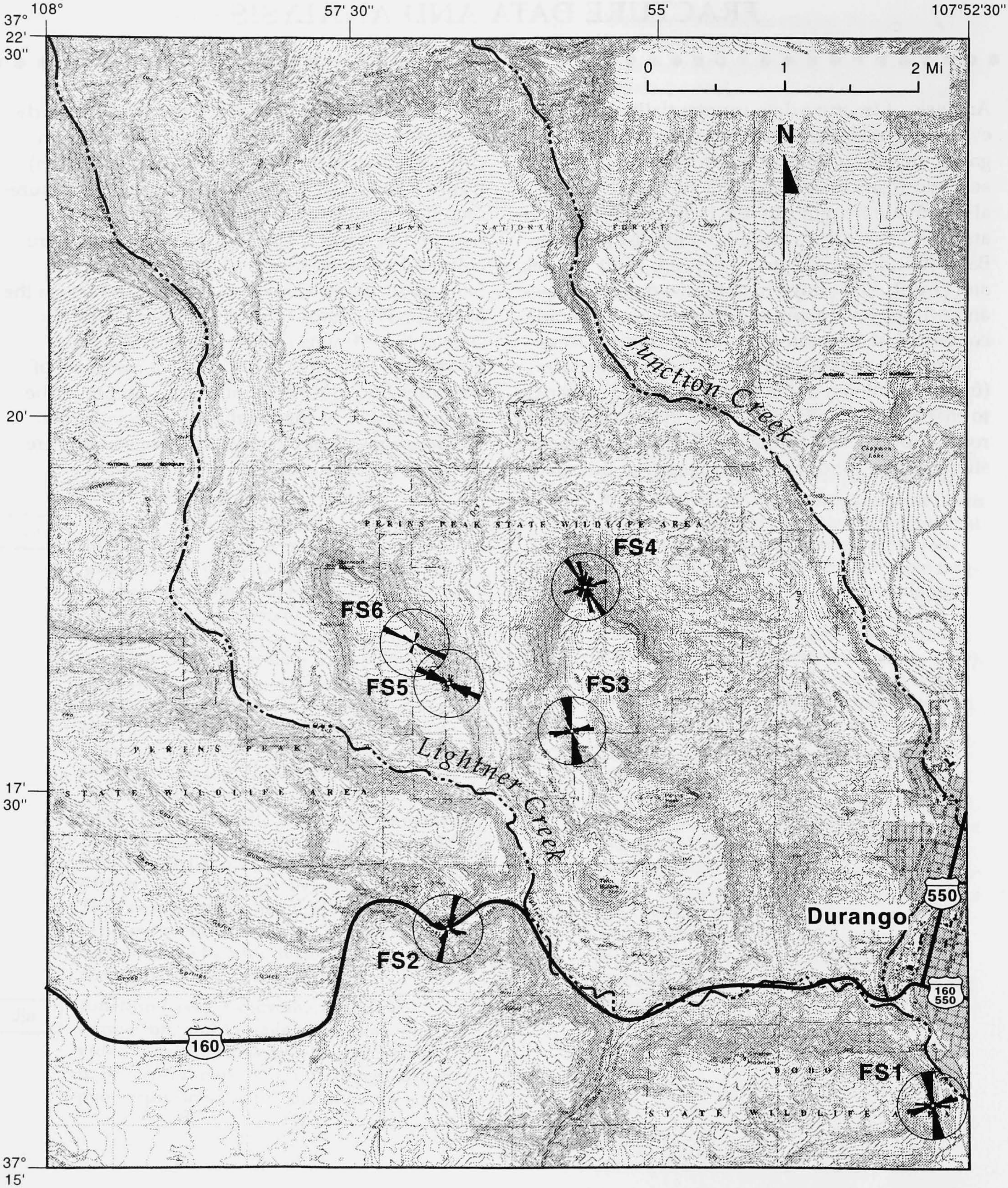


Figure 3. Location of fracture stations with joint measurements in Durango West quadrangle. Rose diagrams for joint planes are centered on each fracture station.

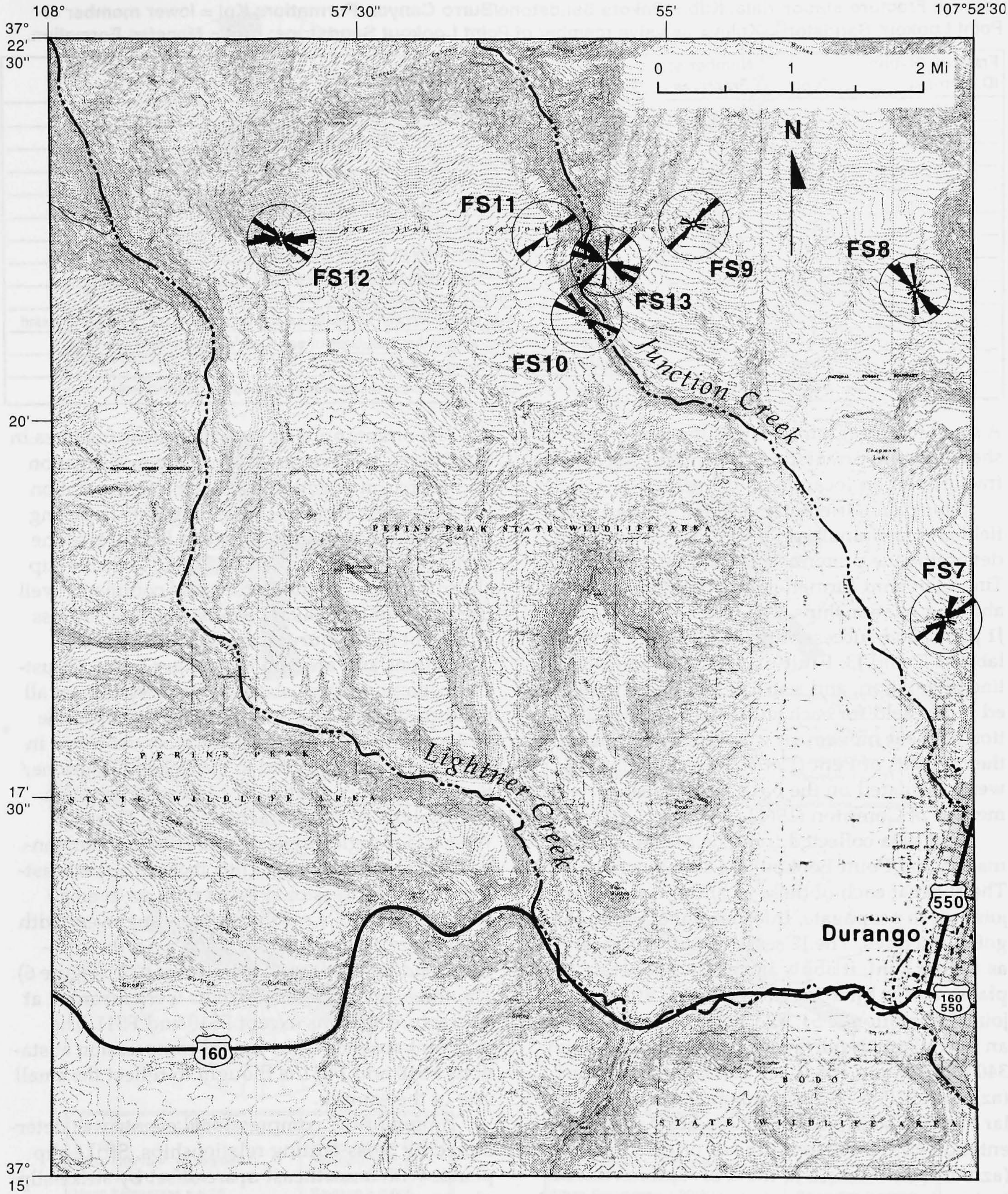


Figure 4. Location of shear fracture measurements in Durango West quadrangle. Rose diagrams for shear fracture measurments are centered on each fracture station.

Table 2. Fracture station data. Kdb = Dakota Sandstone/Burro Canyon Formation; Kpl = lower member of Point Lookout Sandstone; Kplm = massive member of Point Lookout Sandstone; Kmf = Menefee Formation.

Fracture Station ID. Number	Type	Number of Fractures	Formation	Location
FS1	Joint	45	Kmf	SW corner of Smelter Mountain
FS2	Joint	63	Kpl	Roadcut on Hwy 550 along Coal Gulch
FS3	Joint	42	Kmf	Boston Mine
FS4	Joint	56	Kmf	North end of Perins Peak
FS5	Joint	50	Kplm	East side of Barnroof Point near Kplm/Kpl contact
FS6	Joint	28	Kplm	East side of Barnroof Point near Kplm/Kmf contact
FS7	Shear	52	Kdb	Southwest side of Animas City Mtn.
FS8	Shear	39	Kdb	Southeast edge of Barnes Mountain
FS9	Shear	40	Kdb	Roadcut on Junction Creek Road on Barnes Mountain
FS10	Shear	23	Kdb	West side of Junction Creek about .5 mile northwest of USFS campground
FS11	Shear	24	Kdb	West side of Junction Creek near Gude's rest on Colorado Trail
FS12	Shear	32	Kdb	East side of Deep Creek
FS13	Shear	23	Jm	East side of Junction Creek below mouth of Quinn Creek

A small rose diagram of either the joint-plane or shear-fracture orientations is centered over the fracture station location on the map.

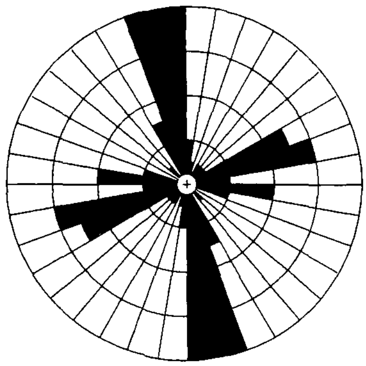
Joint-plane orientations were recorded in the field and later analyzed using rose diagrams to determine the preferred orientations of joint sets. Timing of joint formation was determined by abutting relationships. The oldest joints are called J1 joints, and successively younger joint sets are labeled J2 and J3. Fault-plane orientation, slickenline orientation, and sense of motion were recorded in the field for each shear fracture. The direction of shear movement was determined using the methods of Petit (1987). Stress orientations were calculated on the basis of the ideal σ_1 method of Compton (1966).

Joint data collected from the Menefee Formation and Point Lookout are shown on Figure 5. The J1 set at each of these localities was the first joint set to propagate. It forms planar, 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 stations FS1, FS3, and FS4 the J1 set has an overall north-northwest orientation (azimuth 340 to 350°) and the J2 set trends east-northeast (azimuth 070 to 080°) approximately perpendicular to the J1 set. Joints at station FS2 have a J1 orientation with a north-northeast orientation (azimuth 021°) and a J2 trend of west-northwest (azimuth 290°). The J1 set at stations FS5 and FS6 trend west-northwest (azimuth 295°) and the J2 joints are oriented north-northeast (azimuth 020°).

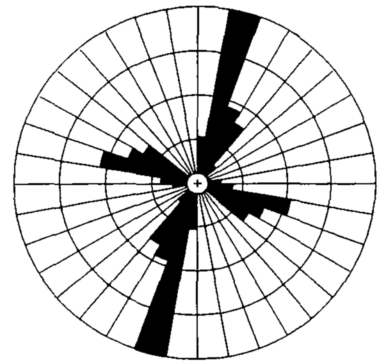
The orientations or trends of shear fractures in the Dakota Sandstone/Burro Canyon Formation and Morrison Formation at each fracture station are shown on Figure 6. Rose diagrams depicting the ideal σ_1 orientation for shear fractures at the seven stations are shown on Figure 7. Strike-slip shear fractures are numerous and commonly well preserved in the Dakota Sandstone; they are less abundant in the Burro Canyon and Morrison Formations and are rare in younger rocks. Thrust-shear fractures were observed at most, but not all fracture stations and are less numerous than the strike-slip shears. All shear fractures described in this report were confined to the Dakota Sandstone/ Burro Canyon Formation or Morrison Formation.

Analysis of shear fractures in the Durango West quadrangle suggests three distinct horizontal compression events. They include a northeast-trending compressional event with an average azimuth of 051°, a northwest-trending event with an average azimuth of 300°, and a north-northeast-trending event with azimuth of 022° (Figure 6). The three compressional events were recorded at all fracture stations except FS10 and FS11. The apparent absence of tri-modal compression at stations FS10 and FS11 is thought to reflect the small size of the sample.

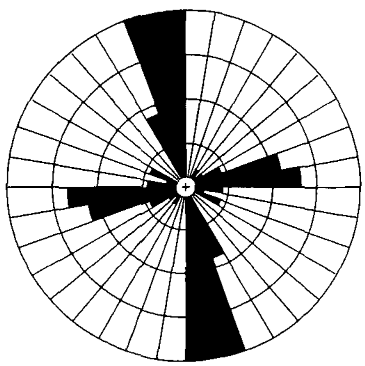
Timing of the compressional events was determined by cross-cutting relationships. Strike-slip planes with a northeast σ_1 are offset by strike-slip planes with a northwest σ_1, indicating northeast compression followed by northwest compression. (Carroll and others, 1999; Ruf, in preparation). At



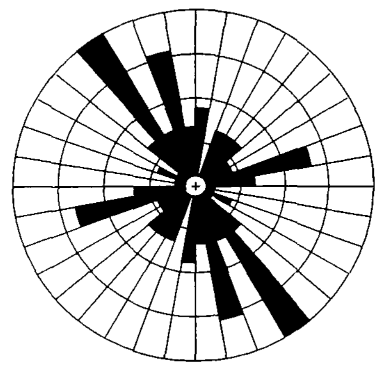
FS1; Kmf, joint planes	Statistics
N = 45	Vector Mean = 358.2
Class Interval = 10 degrees	Std. Error = 84.27
Maximum Percentage = 17.7	R Magnitude = 0.073
Mean Percentage = 7.14	Rayleigh = 0.7857
Standard Deviation = 5.62	



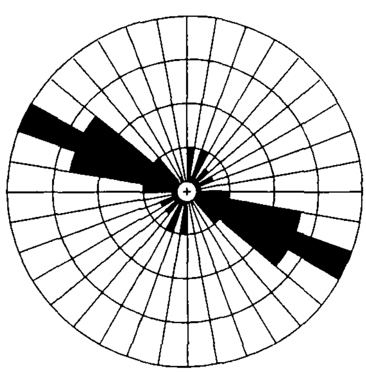
FS2; Kpl, joint planes	Statistics
N = 63	Vector Mean = 24.2
Class Interval = 10 degrees	Std. Error = 36.20
Maximum Percentage = 23.8	R Magnitude = 0.140
Mean Percentage = 6.66	Rayleigh = 0.2877
Standard Deviation = 6.01	



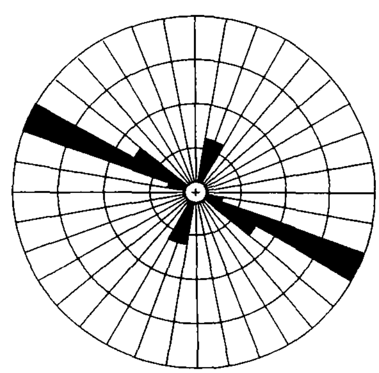
FS3; Kmf, joint planes	Statistics
N = 42	Vector Mean = 331.2
Class Interval = 10 degrees	Std. Error = 40.77
Maximum Percentage = 21.4	R Magnitude = 0.154
Mean Percentage = 9.09	Rayleigh = 0.3648
Standard Deviation = 7.11	



FS4; Kmf, joint planes	Statistics
N = 56	Vector Mean = 339.2
Class Interval = 10 degrees	Std. Error = 37.90
Maximum Percentage = 16.0	R Magnitude = 0.144
Mean Percentage = 5.88	Rayleigh = 0.3116
Standard Deviation = 3.62	



FS5; Kplm, joint planes	Statistics
N = 50	Vector Mean = 290.5
Class Interval = 10 degrees	Std. Error = 11.72
Maximum Percentage = 24.0	R Magnitude = 0.460
Mean Percentage = 6.66	Rayleigh = 0.000
Standard Deviation = 6.54	



FS6; Kplm, joint planes	Statistics
N = 28	Vector Mean = 300.9
Class Interval = 10 degrees	Std. Error = 16.85
Maximum Percentage = 46.4	R Magnitude = 0.432
Mean Percentage = 20.00	Rayleigh = 0.0053
Standard Deviation = 14.40	

Figure 5. Rose diagrams for joint planes at fracture stations FS1 through FS6.

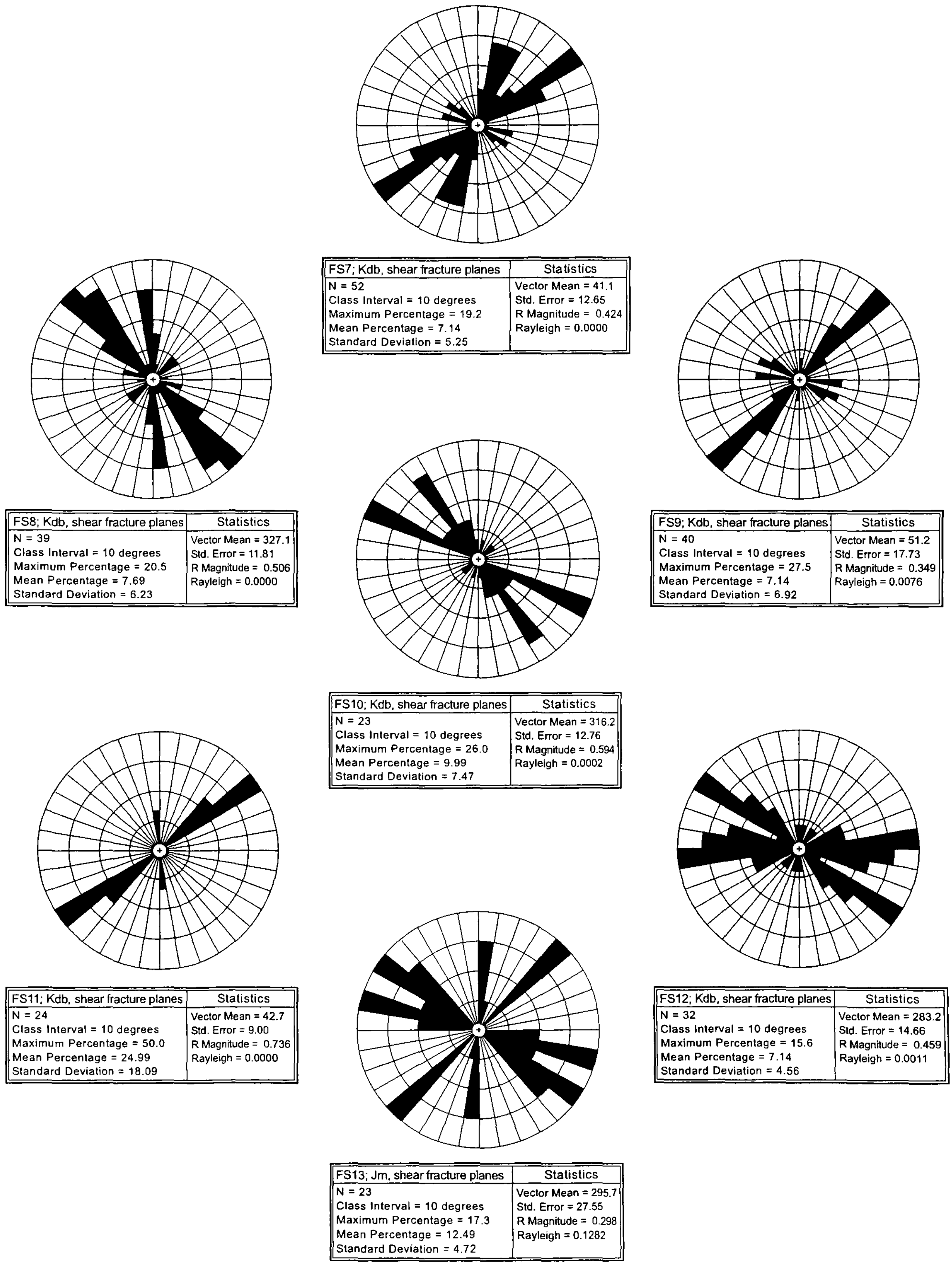


Figure 6. Rose diagrams showing orientations of shear fractures measured at fracture stations FS7 through FS13.

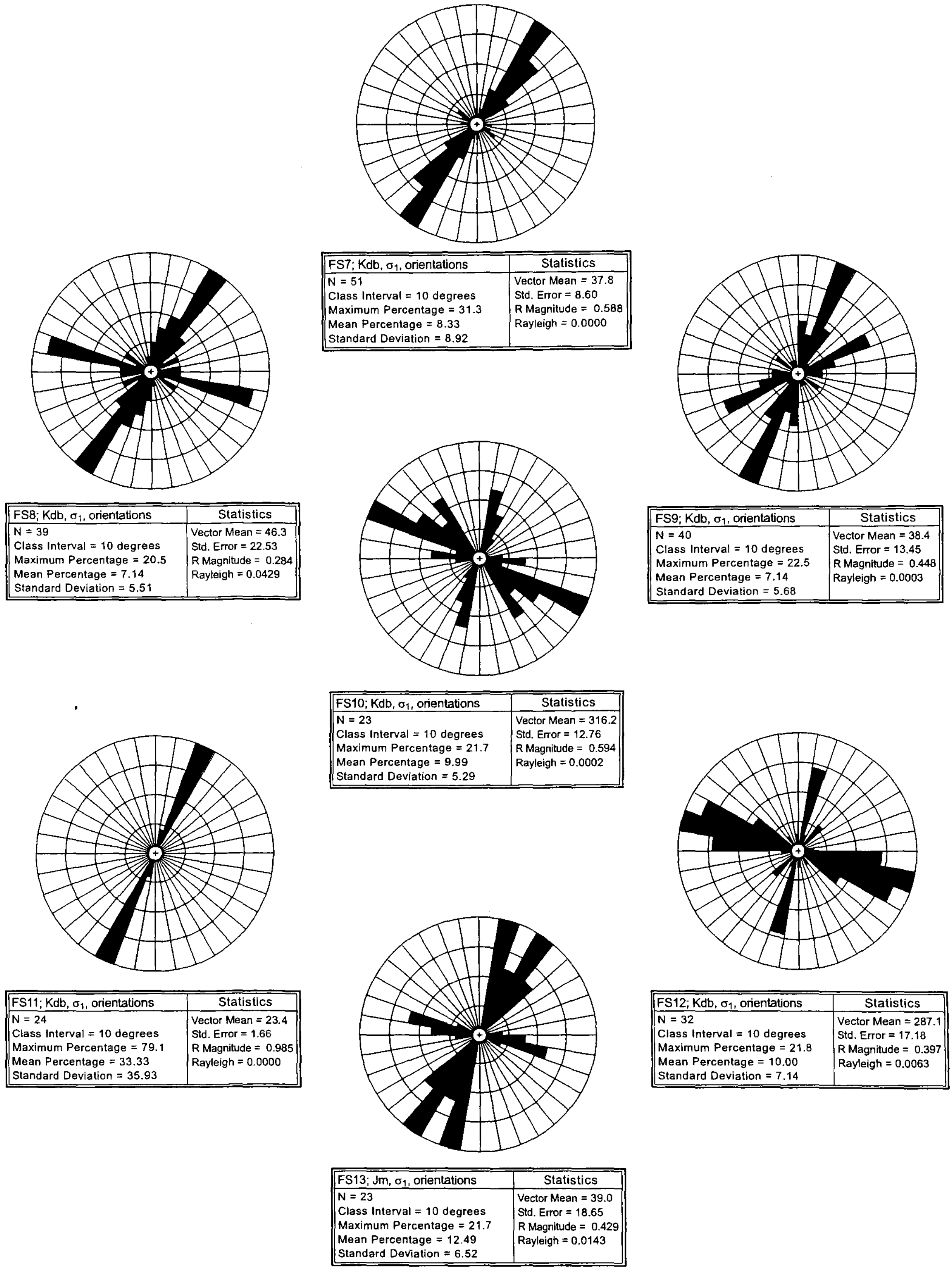


Figure 7. Rose diagrams showing preferred σ_1 orientations of shear fractures measured at fracture stations FS7 through FS13.

station FS13 the northeast-oriented slickenlines on thrust planes are overprinted by north-northeast-oriented slickenlines, suggesting the northeast compression was followed by north-northeast-compression. At station FS14 a north-northeast-oriented thrust plane cut a northwest-oriented strike-slip fault, demonstrating that the northwest compression event was followed by a north-northeast compression event. Thus, the overall order of shear fracture development in the Durango West quadrangle is (1) initial northeast compression, (2) followed by northwest compression, and (3) lastly north-northeast compression.

The relative timing of joint propagation and shear fracture development can be determined by cross-cutting relationships. At a fracture station in the Durango East quadrangle (Ruf, in preparation; Carroll and others, 1999), strike-slip faults were cut by the J1 joint set. There was no observable offset of J1 joints by the shear fractures. Fracture stations that have a high density of strike-slip shear fractures generally have few joints, suggesting that strike-slip faults may have acted as joints during extension.

The northeast-oriented shear fractures (azimuth about 051°) have a σ_1 typical of the Laramide orogeny in the southern Rocky Mountains (Chapin and Cather, 1983). The origin of the northwest-trending shear fractures (azimuth about 300°) is unclear but is observed throughout Colorado and New Mexico (E. Erslev and T. E. Ehrlich, 1998, oral communication; 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 orientation (azimuth about 022°) direction has been observed in northern New Mexico and in north-central Colorado (E. Erslev and T.E. Ehrlich, 1998, oral communication). Shears associated with the north-northeast compressional event have been observed cutting igneous rocks as young as 24.1 Ma Eagle Rock dike south of Raton, New Mexico and may record a separate post-Laramide compressional event (E. Erslev, 1998, oral communication).

Since joint propagation appears to post-date shear fracture formation and the orientation of shear fractures fits well with Laramide or Sevier Orogeny stress patterns, the age of joint development likely is post-Laramide. The consistency of J1 orientations, both spatially and stratigraphically, suggests an origin other than topographic release or exfoliation for the J1 joint set (Ruf, in preparation). The J1 joint set may have propagated within a post-Laramide stress field associated perhaps with uplift of the San Juan Basin or regional extension early during initial stages of the Rio Grande Rift. The J2 joint set is younger than the J1 set and is probably a result of a complex interaction between the pre-existing J1 joint set, contemporary regional stress field or fields, and perhaps topography. Definitive topographic-release joints were not identified at any of the fracture stations, but were noticed at a few outcrops inspected during this study.

MINERAL AND ENERGY RESOURCES

Historic mineral and energy production in the Durango West quadrangle includes coal, sand, gravel, uranium, vanadium, thorium, dimension stone, gold, silver, and volcanic ash. Locations of known mines, quarries (both for dimension stone and volcanic ash), sand and gravel pits, and petroleum test wells are shown on the geologic map. Named coal, uranium, and vanadium mines and gold and silver prospects are located on figure 8. Two petroleum test wells have been drilled in the quadrangle; both were plugged and abandoned. The Fruitland Formation, which is a major coalbed methane-producing formation in adjacent parts of the San Juan Basin, is not present in the Durango West quadrangle because it has been removed by erosion.

Sand and gravel mining accounts for the only active mineral resource production in the Durango West quadrangle and likely has generated the greatest cumulative financial yield, although historic coal mining was formerly one of the larger businesses in the region. Surficial units containing potentially economic deposits of sand and gravel are mentioned in the section on "Description of Map Units".

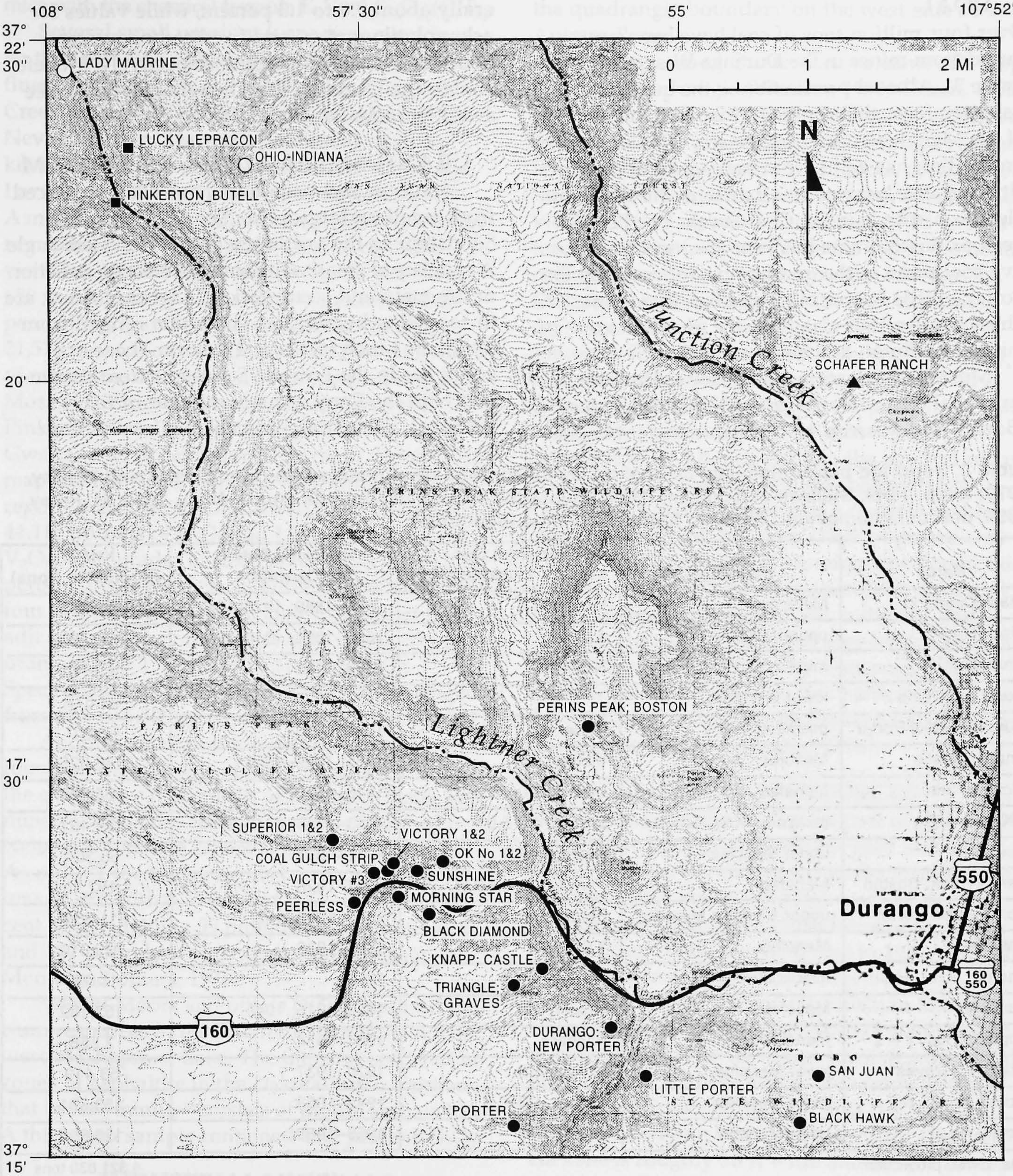


Figure 8. Map showing known mine locations on Durango West quadrangle. Locations are based on Boreck and Murray (1979), Sullivan and Jochim (1984), Nelson-Moore (1978), Eckel (1949), Zapp (1949), and Neubert and others (1992), and on field work conducted during this investigation. Solid circle = coal mine; solid square = uranium/ vanadium mine; solid triangle = thorium mine; open circle = precious metal mine or prospect. Some mines have been known by more than one name.

COAL

Over four million tons of coal have been produced from mines in the Durango West quadrangle (table 3). All coal production in the quadrangle has been from the upper, middle, and lower parts of the Menefee Formation. Nearly all historic coal production has come from underground mines, although the last operating mine in the quadrangle was a strip mine in Coal Gulch. The Perins Peak or Boston mine has been the most productive coal mine in the quadrangle, followed by the Porter/ Little Porter mine and San Juan mine. These three mines also have the greatest extent of mining (Sullivan and Jochim, 1984).

Menefee Formation coal is low-sulfur bituminous coal that averages about 13,800 BTUs/pound (Boreck and Murray, 1979). Sulfur content is generally about 0.9 to 1.3 percent, while values for ash, volatile matter, and fixed carbon average about 5, 38, and 55 percent, respectively. Menefee coal in the Durango West quadrangle has a free swelling index around 5.0 to 7.0.

URANIUM, VANADIUM, & THORIUM

Uranium and vanadium have been produced from small underground mines in the Entrada Sandstone in the northwest part of the quadrangle. A number of small adits and pits near the junction of the main and south forks of Lightner Creek are in roscoelite-bearing ore zones that ranged from less than 1 inch to about 4 ft thick. These ore zones are in the Entrada Sandstone near its contact with the Pony Express member of the Wanakah Formation. Roscoelite is a vanadium

Table 3. Reported production data for coal mines in Durango West quadrangle (from Boreck and Murray, 1979; Zapp, 1949; Sullivan and Jochim, 1984; Colorado Division of Minerals and Geology, 1998; M. Poley, 1999, oral communication). Refer to figure 8 for mine locations.

Name	Formation	Reported Bed Name & Thickness (ft)	Reported Dates of Operation	Known Production (tons)
Black Diamond	Menefee	Victory; 5.0	1885–1889; 1925–1942	61,122
Black Hawk	upper Menefee	4.0	1894–1896; 1918–1919	31,097
Champion[1]	middle Menefee	3.4–4.0	1888–1926	143,440[1]
Coal Gulch strip	lower Menefee		1977–1986	21,879
Durango; New Porter	middle Menefee	Porter #3; 2.7	1924–1943	67,961
Knapp; Castle	Menefee	Victory; 5.5	1885; 1929–1953	186,825
Morning Star	Menefee	Victory; 5.0	1916–1970	153,958
OK no.1 & 2	middle & lower Menefee	Victory; 4.0-5.0	1913–1947; 1948–1949	170,461
Peerless	upper Menefee	Peerless; 5.0	1913–1961	66,303
Perins Peak; Boston	Menefee	Porter-Ute; 1.5-7.8	1901–1926	1,192,105
Porter; Little Porter	upper & middle Menefee	Peacock no.1; 3.0	1886–1908; 1925	911,064[2]
San Juan	Menefee	3.5-4.8	1885–1930	739,310
Shore[3]	middle Menefee	4.0	1893	11,000
Sunshine	Menefee	Victory; 6.0	1893–1915; 1949	152,182
Superior nos. 1 & 2	Menefee	Peerless	1931–1934	2,658
Triangle; Graves[4]	lower Menefee	Victory; 5.3	1920–1937	53,419
Victory nos. 1 & 2	lower Menefee	Victory; 4.0–8.5	1943–1958	233,391
Victory no. 3	lower Menefee	Victory; 7.0	1956–1969	123,655
Total known production:				4,321,830 tons

[1] Exact location unknown; reportedly in section 31, T. 35 N., R. 9 W. and section 31, T. 34 ½ N., R. 9 W. (Sullivan and Jochim, 1984); not plotted on figure 8. Part of reported production is from Basin Mountain quadrangle.

[2] Part of reported production is from Basin Mountain quadrangle.

[3] Exact location unknown; reportedly in section 31, T. 35 N., R. 9 W.

[4] Also called Castle mine by Zapp (1949)

mica with the chemical formula $K_2V_4Al_2Si_6O_{20}(OH)_4$.

Several small uranium/vanadium workings on the west side of Lightner Creek near the confluence of the main and south forks of Lightner Creek are collectively known as the Good Hope-Nevada Group. The most prominent mine is known as the Pinkerton-Butell mine (Violet and Laverne Gwaltney, 1998, oral communication). A moderately large, yellow, steel loadout structure remained at this mine at the time of our field visit. The Good Hope-Nevada Group produced 650 tons of ore by 1971 with ore grades of 1.66 percent V_2O_5 and 0.07percent U_3O_8, yielding 21,578 pounds of vanadium oxide and 956 pounds of uranium oxide (Nelson-Moore and others, 1978). Most of this production was likely from the Pinkerton-Butell mine (Violet and Laverne Gwaltney, 1998, oral communication). Keith (1945) mapped the Good Hope-Nevada Group and reported 25,580 tons of inferred ore containing 44,119 pounds of U_3O_8 and 1,315,457 pounds of V_2O_5, with grades of 0.086 percent U_3O_8 and 2.57 percent V_2O_5. Neubert and others (1992) collected four samples from the ore zone exposed at the adit portals. They contained from 20 to 420 ppm uranium and 136 to 4,560 ppm vanadium. Spectrometer readings near the adit portals ranged from 500 to 5,500 cps (Neubert and others, 1992).

Another small uranium-vanadium mine was found on the east side of Lightner Creek just above the confluence of the forks of Lightner Creek. This mine could be the Lucky Lepracon described by Nelson-Moore and others (1978) as unlocatable. As of 1971 the Lucky Lepracon reported mining 8 tons of ore with 0.24 percent U_3O_8 and 1.17 percent V_2O_5, yielding 39 pounds of uranium oxide and 187 pounds of vanadium oxide (Nelson-Moore and others, 1978).

Nelson-Moore and others (1978) reported thorium resources at the Schafer Ranch mine northwest of Chapman Lake. The thorium occurred in zones of asphaltite in the Dakota-Burro Canyon that bears "minute" crystals of thorite and anatase. A thirty-ton sample contained 1.52 percent ThO_2.

INDUSTRIAL MINERALS

Dimension stone has been quarried from the massive member of Point Lookout Sandstone at two small workings in the first canyon north of the quadrangle boundary on the west side of the Animas River.

Two deposits of Quaternary volcanic ash crop out in the quadrangle (Woolsey, 1906; Gillam, 1998). One is along the quadrangle boundary northeast of Chapman Lake; a second is on the ridge between Dry Gulch and Junction Creek, south of the junction of Falls Creek Road and Junction Creek Road. Woolsey (1906) reported a thickness of 25 to 50 ft for the ash northeast of Chapman Lake. It extends eastward across the map boundary and into Durango East quadrangle. 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). In Durango East quadrangle just east of the map boundary we encountered what appeared to be a bench cut into the ash bed many years ago. The volcanic ash bed between Dry Gulch and Junction Creek has a maximum thickness of about 15 ft. Woolsey (1906) reported that the Lavaline Company of Durango developed this deposit with a surface excavation 10 ft deep and 20 ft in diameter. A depression in the ash bed where it crosses the ridgeline may be this excavation. The ash was apparently transported down the ridge in chutes, loaded into carts, and hauled into Durango, where it was packaged and sold as an abrasive cleaner (Woolsey, 1906).

METALLIC RESOURCES

Several claims in the northwest part of the quadrangle have been prospected for gold and silver. The Lady Maurine claims are on the west side of Junction Creek about 0.9 miles north of the confluence of the main and south forks of Lightner Creek. Eckel (1949) reported that in 1937 the Lady Maurine claims were held by A.S. Butell of Durango, perhaps the same gentleman later associated with the Good Hope-Nevada claims or one of his relatives. The workings consisted of a small open cut and shallow adit driven into a breccia zone in the Cutler Formation near the contact with the overlying Dolores Formation. The breccia zone is roughly 50 ft wide and strikes about east-west (Eckel, 1949). The northern part of the breccia zone is well brecciated, bleached, and slightly silicified. Eckel (1949) reported small specks and blebs of pyrite, tetrahedrite, and galena throughout the breccia, especially along and near the northern edge of the breccia zone. A thin seam of pyrite and galena occurred along the southern margin. Eckel (1949) quoted Mr. Butell as stating that a sample from the entire width of the breccia zone yielded 0.25 ounces per ton of gold, 3.5 ounces per ton of silver, and 4 percent copper. Neubert and others (1992) collected eight samples from this site; three samples from the breccia zone contained 611, 470, and 120ppb gold. A sample from a nearby limestone-pebble conglomerate in the Cutler Formation contained 1.06 percent copper.

About 700 ft south of the Lady Maurine claims and on the same side of Junction Creek an adit is driven about 80 ft into a narrow breccia zone in the Dolores Formation. Eckel (1949) reported that the adit was dug in 1894 and produced only minor amounts of ore. Veinlets of quartz and calcite occur in the breccia zone. Eckel (1949) stated that the vein is cut off by a fault 75 ft into the adit. We did not enter this adit, so the fault could not be verified and is not shown on our geologic map.

The Ohio-Indiana prospect is in the Morrison Formation on the east side of Deep Creek, just below the Colorado Trail near the contact with the Junction Creek Sandstone. Eckel (1949) reported that the workings consist of a 200-ft-deep adit and a small open-cut which were first opened in 1937. A brief reconnaissance of this area during our study failed to locate these workings, but they likely are near the cabin shown on the topographic base map. The Morrison Formation in this area is generally highly fractured and several strong fracture zones were encountered in the last 50 ft of the adit (Eckel, 1949). He reported small ore zones within the fracture zones and along small bedding-plane slips that were locally rich in gold.

PETROLEUM RESOURCES

Information on petroleum resources in Durango West quadrangle is based largely upon three sources. Copies of historical reports and newspaper articles on oil seeps and old oil test wells were provided by Paul Oldaker (1999, written communication), who also shared his interpretations of many of the records. Data on two recently drilled oil test wells are from the unpublished file records of the Colorado Oil and Gas Conservation Commission and a CD-ROM published by Petroleum Information/Dwights LLC (1998).

A brief description of an oil seep near Durango was contained in the February 19, 1881 issue of *The Durango Record*. The article first discusses the "Oil Creek well", the discovery well for the Florence oil field near Canon City, and then states "In this connection we wish to call the attention of the public to the indications of coal oil, almost within the confines of Durango. Across the Animas, opposite the upper part of town, is a small gulch, making in from the northwest, striking the river valley about three hundred feet north of the gulch which forms the northern boundary of the mesa opposite town. The waters flowing through this little gulch carry more or less crude or coal oil...". This gulch is shown on the base map as flowing southward along the east section line of the SE¼ of section 19, T. 35 N., R. 9 W., and then turning southeastward for a short distance before flowing into the Animas River in the NW¼ NW¼ of section 29.

According to historical research by Paul Oldaker (1999, written communication) the first oil well drilled in the Durango West quadrangle was the Durango no. 1 well. It was spudded in the morning of April 24, 1902 *(The Durango Semi-Weekly Herald, April 24, 1902)*, making it perhaps the second oldest oil well in the entire Durango region. An earlier well may have been drilled sometime in the early 1890's (Paul Oldaker, 1999, written communication). The Durango no. 1 well was probably drilled on the west side of the Animas River in the general vicinity of an old footbridge across the Animas River. This footbridge is likely the one visible in an 1888 photograph by J.A. Boston (available from Eye Level Photographics, telephone 970-247-4446). This location is in close proximity to and perhaps at the oil seep reported in the February 19, 1881 issue of *The Durango Herald*.

The Durango no. 1 well encountered "a strong flow of gas" at a depth of 700 ft. The gas apparently ignited, which threatened the rig for a while, but fortunately the fire was extinguished before serious damage occurred. Drilling continued, and a small flow of oil was found at 750 ft. Both the gas and oil were likely found in the Dakota Sandstone. The last reported depth for the well was about 1,100 ft. After the loss of tools in the hole, it was abandoned and a second hole started. The second well also was abandoned; it apparently was not drilled much deeper than 200 ft.

Mr. Oldaker's research also yielded information on the Leidecker no. 2 well, which was drilled along Lightner Creek about two miles west of Durango, probably near the mouth of Wildcat Canyon (*Bayfield Blade*, June 6 and July 25, 1924; *The Durango Weekly Democrat*, September 5, 1924). This well was drilled to a depth of at least 1,400 ft and encountered shows of gas and oil, perhaps from the Dakota Sandstone.

The Colorado Oil and Gas Conservation Commission has data in its files on two other petroleum exploration wells drilled in Durango West quadrangle. In 1956 the Pinion Oil and Uranium Company drilled the Johnson no. 1 well in the center of the NE¼ NW¼ of section 32, T. 35 N., R. 9 W. The Colorado Oil and Gas Conservation Commission records have more than one location for this well. Elliot Riggs (1999, oral communication) has records that indicate the well

REFERENCES CITED

Anderson, O.J., and Lucas, S.G., 1997a, Lake T'oo'dichi' and the Brushy Basin member of the Morrison Formation, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 2.

_______1997b, The Jurassic Morrison Formation in the Four Corners Region, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 139–156.

Anderson, O.J., Lucas, S.G., Semken, S.C., Chenoweth, W.L., and Black, B.A., 1997, Third-day road log from Durango, Colorado to Aztec, Farmington and Shiprock, New Mexico, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 35–53.

Atwood, W.W., and Mather, K.F., 1932, Physiography and Quaternary geology of the San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 166, 171 p.

Aubrey, W.A., 1991, Geologic framework of Cretaceous and Tertiary rocks in the Southern Ute Indian Reservation and adjacent areas in the northern San Juan Basin, southwestern Colorado: U.S. Geological Survey Professional Paper 1505–B, p. B1–B24.

Baars, D.L., and Ellingson, J.A., 1984, Geology of the western San Juan Mountains, *in* Brew, D. C., ed., Field trip guidebook of the 37th annual meeting of the Rocky Mountain section of the Geological Society of America, Fort Lewis College, Durango, Colo., p. 1–45.

Barnes, Harley, Baltz, E.H., Jr., and Hayes, P.T., 1954, Geology and fuel resources of the Red Mesa area, La Plata and Montezuma Counties, Colorado: U.S. Geological Survey Oil and Gas Investigations Map OM 149.

Blair, R.W., 1977, Surficial geologic map and geologic hazards map of Durango East quadrangle: unpublished Colorado State Legislature House Bill 1041 maps prepared for La Plata County.

Blodgett, R.H., 1984, Nonmarine depositional environments and paleosol development in the upper Triassic Dolores Formation, southwestern Colorado, *in* Brew, D. C., ed., Field trip guidebook of the 37th annual meeting of the Rocky Mountain section of the Geological Society of America, Fort Lewis College, Durango, Colo., p. 46–49.

Boreck, D.L., and Murray, D.K., 1979, Colorado coal reserve depletion data and coal mine summaries: Colorado Geological Survey Open-File Report 79–1.

Campbell, J.A., 1976, Depositional environments of the Cutler Formation, northern San Juan and southern Grand Counties, Utah [abs.]: Geological Society of America, Abstracts with Programs, v. 9, no. 6, p. 713.

_____1979, Lower Permian depositional system northern Uncompahgre Basin, *in* Baars, D.L., ed., Permianland: Four Corners Geological Society Guidebook, 9th Field Conference, p. 13–21.

_____1980, Lower Permian depositional systems and Wolfcampian paleogeography, Uncompahgre Basin, eastern Utah and southwestern Colorado, *in* Fouch, T.D., and Magathan, E.R., eds., Paleozoic paleogeography of west-central United States: Rocky Mountain Section Society of Economic Paleontologists and Mineralogists Symposium 1, Denver, Colo., p. 327–340.

Carroll, C.J., Gillam, M.L., Ruf, J.C., Loseke, T.D., and Kirkham, R.M., 1999, Geologic map of the Durango East quadrangle, La Plata County, Colorado: Colorado Geological Survey Open-File Report 99-6, scale 1:24,000.

Carroll, C.J., Kirkham, R.M., and Wracher, Andrew, 1997, Geologic map of the Rules Hill Quadrangle, La Plata County, Colorado: Colorado Geological Survey Open-File Report 97-1, scale 1:24,000.

Carroll, C.J., Kirkham, R.M., and Wilson, S.C., 1998, Geologic map of the Ludwig Mountain Quadrangle, La Plata County, Colorado: Colorado Geological Survey Open-File Report 98-2, scale 1:24,000.

Chadwick, O., Hall, R., Conel, J., Phillips, F., Zreda, M., and Gosse, J., 1994, Glacial deposits and river terraces in Wind River Basin, *in* Chadwick, O., Hall, R., Kelly, G., Amundson, R., Gosse, J., Phillips, F., and Jaworowski, C., Quaternary geology of the Wind River Basin, Wyoming: Friends of the Pleistocene, Rocky Mountain Cell, Field trip guidebook, p. 11–31.

Chapin, C.E., and Cather S.M., 1983, Eocene tectonics and sedimentation in the Colorado Plateau: Rocky Mountain area, *in* Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists, 1983 symposium, p. 33–56.

Chenoweth, W.L., 1997, The Durango uranium-vanadium mill, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 35–36.

Colorado Division of Minerals and Geology, 1998, Coal mine production statistics: Denver, Colo., unpublished records on coal mine production in La Plata County from 1977 to 1997.

Compton, R.R., 1966, Analyses of Pliocene-Pleistocene deformation and stresses in northern Santa Lucia Range, California: Geological Society of America Bulletin, v. 77, p. 1361–1380.

Condon, S.M., 1990, Geologic and structure contour map of the Southern Ute Indian Reservation and adjacent areas, southwest Colorado and northwest New Mexico: U.S. Geological Survey Miscellaneous Investigation Series Map I–1958, scale 1:100,000.

_____1997a, Fracture studies on the Upper Cretaceous Pitctured Cliffs Sandstone and Fruitland Formation, Northern San Juan Basin, La Plata County, Colorado, *in* Close, J.C., and Casey, T.A., eds., Natural fracture systems in the southern Rockies: Four Corners Geological Society Symposium Guidebook, Durango, Colo., 1997, p. 85–96.

_____1997b, Geologic mapping and fracture studies of the Upper Cretaceous Pictured Cliffs Sandstone and Fruitland Formation in selected parts of La Plata County, Colorado, *in* Fassett, J.E., Condon, S.C., Huffman, A.C., and Taylor, D.J., Geology and structure of the Pine River, Florida River, Carbon Junction, and Basin Creek gas seeps, La Plata County, Colorado: U.S. Geological Survey Open-File Report 97-59, 126 p.

Devine, P.E., 1980, Depositional patterns in the Point Lookout Sandstone, northwest San Juan Basin, New Mexico: University of Texas at Austin, Master's thesis, 238 p.

Eckel, E.B., 1949, Geology and ore deposits of the La Plata district, Colorado, with sections by Williams, J.S., Galbraith, F.W., and others: U.S. Geological Survey Professional Paper 219, 179 p.

Erslev, Eric, 1997, Multi-directional Laramide compression in the Durango area—Why?, *in* Close, J.C., and Casey, T.A., eds., Natural fracture systems in the southern Rockies: Four Corners Geological Society Symposium Guidebook, Durango, Colo., 1997, p. 1–5.

Fassett, J.E., 1977, Geology of the Point Lookout, Cliff House, and Picture Cliffs Sandstone of the San Juan Basin, New Mexico and Colorado, *in* Fassett, J.E., and James, H.L., eds., San Juan Basin III, Guidebook of northwestern New Mexico: New Mexico Geological Society 28th Field Conference, p. 193–197.

Fassett, J.E., and Hinds, J.S., 1971, Geology and fuel resources of the Fruitland Formation and Kirtland Shale of the San Juan Basin, New Mexico and Colorado: U.S. Geological Survey Professional Paper 676, 76 p.

Fassett, J.E., and Steiner, M.B., 1997, Precise age of C33N–C32R magnetic-polarity reversal, San Juan Basin, New Mexico and Colorado, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 229–232.

Gansecki, C.A., Mahood, G.A., and McWilliams, M., 1998, New ages for the climactic eruptions at Yellowstone; Single-crystal $^{40}Ar/^{39}Ar$ dating identifies contamination: Geology, v. 26, no. 4, p. 343–346.

Gillam, M.L., 1998, Late Cenozoic geology and soils of the lower Animas River valley, Colorado and New Mexico: Boulder, Colo., University of Colorado, Ph.D. dissertation, 477 p.

Gillam, M.L., Blair, R.W., and Johnson M.D., 1985, Geomorphology and Quaternary geology of the Animas River valley, Colorado and New Mexico: Friends of the Pleistocene, Rocky Mountain Cell, Field Trip Guidebook, 80 p.

Gillam, M.L., Moore, D.W., and Scott, G.R., 1984, Quaternary deposits and soils in the Durango area, southwestern Colorado, *in* Brew, D.C., ed., Geological Society of America, Rocky Mountain Section, 37th annual meeting, Field Trip Guidebook, Fort Lewis College, Durango, Colo., p. 149–182.

Gregson, J.D., and Erslev, E.A., 1996, Heterogenous Laramide deformation in the Uinta Mountains, Colorado and Utah: Geological Society of America, Abstracts with Programs, v. 28, p. 447.

Haynes, D.D., Vogel, J.D., and Wyant, D.G., 1972, Geology, structure, and uranium deposits of the Cortez quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-629, scale 1:250,000.

Huffman, A.C., Jr., and Condon, S.M., 1993, Stratigraphy, structure, and paleogeography of Pennsylvanian and Permian rocks, San Juan Basin and adjacent areas, Utah, Colorado, Arizona, and New Mexico: U.S. Geological Survey Bulletin 1808-0, p. 01–044.

Izett, G.A., and Wilcox, R.E., 1982, map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek ash beds (Pearlette family ash beds) of Pliocene and Pleistocene age in the western United States and southern Canada: U.S. Geological Survey Miscellaneous Investigations Map I-1325, scale 1:4,000,000.

Jacobs-Weston Team, 1985a, Geomorphic evaluation, Durango tailings site: unpublished report by Sergent, Hauskins & Beckwith Geotechnical Engineers, Inc, a part of the Jacobs-Weston Team, for the U.S. Department of Energy for the Uranium Mill Tailings Remedial Action Program for the Durango uranium mill tailings site, 49 p.

______ 1985b, Geomorphic evaluation, Bodo Canyon alternative site for disposal of Durango uranium mill tailings: unpublished report by Sergent, Hauskins & Beckwith Geotechnical Engineers, Inc., a part of the Jacobs-Weston Team, for the U.S. Department of Energy for the Uranium Mill Tailings Remedial Action Program for the Durango uranium mill tailings site, 37 p.

______1985c, Supplemental seismic and geomorphic evaluation, Bodo Canyon Area E alternative site area, Durango, Colorado, Uranium Mill Tailings Remedial Action Project: unpublished report by Sergent, Hauskins & Beckwith Geotechnical Engineers, Inc, a part of the Jacobs-Weston Team, for the U.S. Department of Energy for the Uranium Mill Tailings Remedial Action Program for the Durango uranium mill tailings site, 34 p.

Johnson, M.D., And Gillam, M.L., 1995, Composition and construction of late Pleistocene end moraines, Durango, Colorado: Geological Society of America Bulletin, v. 107, no. 10, p. 1241–1253.

Keith, S.B., 1945, Lightner Creek District, San Juan Basin area, Colorado: Union Mines Development Corporation, Raw Materials Observation RMO 453, 16 p.

Kilgore, L.W., 1955, Geology of the Durango area, La Plata County, Colorado, *in* Geology of parts of Paradox, Black Mesa, and San Juan basins: Four Corners Geological Society, Field Conference Guidebook, p. 118–124, 1 plate, scale approximately 1:33,700.

Lamb, G.M., 1973, The lower Mancos Shale in the northern San Juan Basin, *in* Fassett, J.E., ed., Cretaceous and Tertiary rocks of the southern Colorado Plateau: Four Corners Geological Society Memoir, p. 72–77.

Leckie, R.M, Kirkland, J.I., and Elder, W.P., 1997, Stratigraphic framework and correlation of a principal reference section of the Mancos Shale (Upper Cretaceous), Mesa Verde, Colorado, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 163–216.

Lucas, S.G., and Anderson, O.J., 1997a, Lower Cretaceous stratigraphy on the Colorado Plateau, *in* Anderson, O.J., Kues, B.S, and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 6–7.

_______ 1997b, The Jurassic San Rafael Group, Four Corners region, *in* Anderson, O.J., Kues, B.S.,and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 115–132.

Lucas, S.G., Anderson, O.J., Leckie, R.M., Wright-Dunbar, Robyn, and Semken, S.C., 1997a, Second-day road log, from Cortez to Mesa Verde National Park, Mancos, and Durango, *in* Anderson, O.J., Kues, B.S.,and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 19–33.

Lucas, S.G., Heckert, A.B., Estep, J.W., and Anderson, O.J., 1997b, Stratigraphy of the Upper Triassic Chinle Group, Four Corners region, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 81–107.

Miller, A.E., 1977, Surficial geologic map and geologic hazards map of Durango West quadrangle: unpublished Colorado State Legislature House Bill 1041 maps prepared for La Plata County.

Moore, D.W., and Gillam, M.L., 1984, Road log-Quaternary deposits and soils in the Durango area, southwestern Colorado, *in* Brew, D.C., ed., Geological Society of America, Rocky Mountain Section, 37th annual meeting, Field Trip Guidebook, Fort Lewis College, Durango, Colo., p. 183–209.

Moore, D.W., and Scott, G.R., 1981, Generalized surficial geologic map of the Basin Mountain quadrangle, Colorado: U.S. Geological Survey Open-File Report 81-1306.

_____1995, Generalized surficial geologic map of the Bayfield quadrangle, La Plata County, Colorado: U.S. Geological Survey Open-File Report 95-266, scale 1:24,000.

Nelson-Moore, J.L., Collins, D.B., and Hornbaker, A.L., 1978, Radioactive mineral occurrences of Colorado: Colorado Geological Survey Bulletin 40, 1,054 p.

Neubert, J.T., Ellis, C.E., Hannigan, B.J., Jeske, R.E., Martin, C.M., Thompson, J.R., Tuftin, S.E., Wood, R.H., II, and Zelten, J.E., 1992, Mineral appraisal of San Juan National Forest, Colorado: U.S. Bureau of Mines Mineral Land Assessment 2-92, 311 p.

O'Sullivan, R.B., 1970, The upper part of the Upper Triassic Chinle Formation and related rocks, southeastern Utah and adjacent areas: U.S. Geological Survey Bulletin 644-E, p. E1–E22.

_____1997, The Jurassic section along McElmo Canyon in southwestern Colorado, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 109–114.

Pemberton, S.G., MacEachern, J.A., and Frey, R.W., 1992, Trace fossil facies models; Environmental and allostratigraphic significance, *in* Walker, R.G., and James, N.P., eds., Facies models: Response to sea level change: Geological Association of Canada Publications, p. 47–72.

Peterson, J.A., 1972, Jurassic system, *in* Mallory, W.W., ed., Geologic atlas of the Rocky Mountain Region: Denver, Colo., Rocky Mountain Association of Geologists, p. 177–189.

Petit, J.R., 1987, Criteria for the sense of movement on fault surfaces in brittle rocks: Journal of Structural Geology, v. 9, p. 597–608.

Petroleum Information/Dwights LLC, 1998, petroROM, Rocky Mountain/west coast-Alaska well data, 3rd quarter, 1998: Denver, Colo., Petroleum Information/Dwights LLC, CD-ROM.

Piety, L. A., and Vetter, U.R., 1992, Seismotectonic evaluation for Ridges Basin damsite, Animas-La Plata Project, southwestern Colorado: U.S. Bureau of Reclamation Seismotectonic Report 92-2, 54 p.

Reeside, J.B., Jr., 1924, Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico: U.S. Geological Survey Professional Paper 134, p. 1–70.

Richmond, G.M., 1965, Quaternary stratigraphy of the Durango area, San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 525-C, p. C137–C143.

_______ 1986, Stratigraphy and correlation of glacial deposits of the Rocky Mountains, the Colorado Plateau and the ranges of the Great Basin, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.S., eds., Quaternary glaciations in the northern hemisphere: Quaternary Science Reviews, v. 5, p. 99–127.

Richmond, G.M., and Fullerton, D.S., 1986, Introduction to Quaternary glaciations in the United States of America, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.S., eds., Quaternary glaciations in the northern hemisphere: Quaternary Sciences Reviews, v. 5, p. 99–127.

Ruf, J.C., in preparation, Fracture analysis of the northern San Juan Basin using both shear fractures and joints: Fort Collins, Colo., Colorado State University, M.S. thesis.

Siemers, C.T., and King, N.R., 1974, Macroinvertebrate paleoecology of a transgressive marine sandstone, Cliff House Sandstone (Upper Cretaceous), Chaco Canyon, northwestern New Mexico, *in* Siemers, C.T., ed., Ghost Ranch, central-northern New Mexico: New Mexico Geological Society Guidebook, 25th Field Conference, p. 267–278.

Steven, T.A., Lipman, P.W., Hail, W.J., Jr., Barker, Fred, and Luedke, R.G., 1974, Geologic map of the Durango area, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–764, scale 1:250,000.

Sturchio, N.C, Pierce, K.L., Murrel, M.T., and Sorey, M.L., 1994, Uranium-series ages of travertines and timing of the last glaciation in the northern Yellowstone area, Wyoming-Montana: Quaternary Research, v. 41, no.3, p. 265–277.

Stewart, Steve, 1989, Geology of the Durango, Colorado area: Durango, Colo., Fort Lewis College, unpublished map prepared for senior thesis.

Sullivan, K.A., and Jochim, C.L., 1984, Inactive coal mine data and subsidence information, Durango and Pagosa Springs Coal Fields: Colorado Geological Survey, unpublished subsidence information maps.

Taff, J.A., 1907, The Durango coal district, Colorado: U.S. Geological Survey Bulletin 316, p. 321–337.

Turner, C.E., and Fishmann, N.S., 1991, Jurassic Lake T'oo'dichi': a large, saline lake, Morrison Formation, eastern Colorado Plateau: Geological Society of America Bulletin, v. 103, p. 538–558.

Verbeek, E.R., and Grout, M.A., 1997, The post-Laramide joint network of the Colorado Plateau, *in* Close, J.C., and Casey, T.A., eds., Natural fracture systems in the southern Rockies: Four Corners Geological Society, Symposium Guidebook, Durango, Colo., 1997, p. 7–21.

Wanek, A.A., 1959, Geology and fuel resources of the Mesa Verde area, Montezuma and La Plata Counties, Colorado: U. S. Geological Survey Bulletin 1072–M, p. 667–721.

Whitehead, III, N.H., 1997, Fractures at the surface, San Juan Basin, New Mexico and Colorado, *in* Hoak, T.E., Klawitter, A.L., Blomquist, P.K., eds., Fractured reservoirs; characterization and modeling: Rocky Mountain Association of Geologists, p. 27–42.

Woodward, L.A., Anderson, O.J., and Lucas, S.G., 1997, Tectonics of the Four Corners region of the Colorado Plateau, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., eds., Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society 48th Field Conference, p. 57–64.

Woolsey, L.H., 1906, Volcanic ash near Durango, Colorado: U.S. Geological Survey Bulletin 285, p. 476–479.

Wright, R., 1986, Cycle stratigraphy as a paleogeographic tool-Point Lookout Sandstone, southeastern San Juan Basin, New Mexico: Geological Society of America Bulletin, V. 96, p. 661–673.

Wright-Dunbar, R., Zech, R.S., Crandall, G.A., Katzman, Danny, 1992, Strandplain and deltaic depositional models for the Point Lookout Sandstone, San Juan Basin and Four Corners Platform, New Mexico and Colorado, *in* Lucas, S.G., Kues, B.S., Williamson, T.E., and Hunt, A.P., eds., San Juan Basin IV: New Mexico Geological Society Forty-third Annual Field Conference September 30-October 3, 1992, p. 199–206.

Zapp, A.D., 1949, Geology and coal resources of the Durango area, La Plata and Montezuma Counties, Colorado: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 109, scale 1:31,680.

Zech, R.S., 1982, Paleoshorelines in the Upper Cretaceous Point Lookout Sandstone, southern San Juan Basin, New Mexico: U.S. Geological Survey Open-File Report 82-135, 23 p.

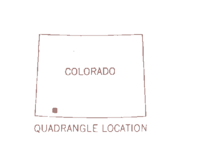
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN FILE MAP 99-4
GEOLOGIC MAP OF THE DURANGO WEST
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

SCALE 1:24,000



QUADRANGLE LOCATION

CONDENSED DESCRIPTION OF MAP UNITS

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

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

lf — **Landfill (latest Holocene)**—Household, agricultural, and commercial refuse placed by humans in a landfill west of Durango

mw — **Mine waste (latest Holocene)**—Rock debris and coal refuse placed in dump piles near underground coal mines

rm — **Reclaimed mine or mill waste (latest Holocene)**—Various types of rock debris and soil that have been reclaimed at three mining and milling sites

umtra — **Bodo Canyon uranium mill tailings disposal site (latest Holocene)**—Low-level radioactive materials removed from the Durango mill site and raffinate ponds as part of the Durango Uranium Mill Tailing Remedial Action Project and placed in the Bodo Canyon disposal site

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

Qa — **Stream-channel, flood-plain, and low terrace deposits (Holocene)**—Poorly sorted, clast-supported, unconsolidated silty, sandy, and occasionally bouldery pebble and cobble gravel in a sandy or silty matrix

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly, silty sand, sandy or clayey silt, and sandy, silty clay in valleys of ephemeral and intermittent streams, on gentle hillslopes below landslides or alluvial fans, or in basinal areas

Qt_1 — **Terrace alluvium one (late Pleistocene)**—Chiefly stream alluvium that underlies several terraces from about 20–100 ft above the Animas River, and at least one terrace from 5–13 ft above Junction Creek and roughly 30 ft above Lightner Creek. Includes a fan-like deposit along Junction Creek that extends up a dry tributary toward Chapman Lake. Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a silty or sandy matrix. May include fine-grained overbank or overlying sheetwash deposits

Qt_2 — **Terrace alluvium two (late? and late middle Pleistocene)**—Mostly stream alluvium that underlies several terraces from 110–180 ft above the Animas River and at least two terraces from 60–120 ft above Lightner Creek. Deposits are similar to terrace alluvium one (Qt_1)

Qt_3 — **Terrace alluvium three (middle Pleistocene)**—Chiefly stream alluvium similar to terrace alluvium one (Qt_1) that underlies at least two terraces along Junction Creek and Lightner Creeks and one terrace along the Animas River. Terrace heights along Junction Creek are 250–450 ft, which are comparable to heights of 290–450 ft along the Animas River at and near Durango. Along Lightner Creek terraces are only 140–240 ft high

Qt_4 — **Terrace alluvium four (middle Pleistocene)**—Mostly stream alluvium similar to terrace alluvium one (Qt_1) that underlies terraces along Junction and Lightner Creeks. Terrace heights along Lightner Creek about 320–380 ft and 400–480 ft along Junction Creek. Includes two terraces in vicinity of Lightner and Deep Creeks; an upper (Qt_{4u}) and lower (Qt_{4l}) terrace

Qt_5 — **Terrace alluvium five (early middle or early Pleistocene?)**—Two small, thin, isolated remnants of probable fluvial gravel on the southeast end of the Barnroof Point cuesta about 590 to 690 ft above the valley floor of Lightner Creek. Deposit appears to be similar to terrace alluvium one (Qt_1)

Qgh — **High-level gravel (middle and early Pleistocene)**—Includes four remnants of high-level gravel deposits on the saddle in Perins Peak and on the drainage divide between Lightner Creek and Coal Gulch. Appears to be chiefly fluvial, clast-supported, cobble and pebble gravel in a sandy or silty matrix. Although all four remnants of high-level gravel occur at altitudes of 8,000 to 8,300 ft, they range from about 930 to 1,550 ft above Lightner Creek

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

Qlsr — **Recent landslide deposits (latest Holocene)**—Includes four recently active landslides with fresh morphological features. A heterogeneous deposit consisting of unsorted, unstratified rock debris, clay, silt, and sand. Soil slips (see explanation of map symbols) are a type of recent landslide, but are too small to be shown as a map unit at a scale of 1:24,000

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/Burro Canyon Formation, Morrison Formation, or Junction Creek Sandstone, and transported downslope primarily by gravity during rockfalls, rockslides, or rock topples

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. Deposits are 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. Numeric modifiers denote nested landslides with apparent age differences. Deposits labeled Qls_1 are younger than deposits labeled Qls_2

Qpl — **Deposits of the Perins Peak landslide complex (Holocene to early middle Pleistocene)**—Landslide deposits and colluvium that are found around Perins Peak. Deposits formed during the destruction of the sandstone-capped mesa by mass-wasting. Unit is unsorted, unstratified, and matrix-supported and consists of angular to subangular clasts of sandstone in a matrix of oxidized, yellow-brown silt and clay. Apparently began to form at least by early middle Pleistocene time and has been locally reactivated as landslides and colluvium as recently as late Holocene

Qco — **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes and generally is not subject to significant future colluviation

Qlso — **Older landslide deposits (Pleistocene)**—Landslide deposits moderately to deeply dissected by erosion that lack distinctive landslide geomorphology. Similar in texture to recent landslide deposits (Qlsr)

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

Qfy — **Younger fan deposits (Holocene)**—Sediments deposited by hyperconcentrated flow, debris flow, alluviation, and sheetwash. Range from poorly sorted, clast-supported, pebble, cobble, and boulder gravel in a clayey silt or sand matrix to matrix-supported, gravelly, clayey silt. Frequently bouldery, particularly near the heads of fans which are rich in large sandstone blocks. Deposits tend to be finer grained in the distal ends of some fans

Qac — **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Stream-channel, low-terrace, and flood-plain deposits along tributary valley floors. May be interfingered with colluvium and sheetwash along valley sides. Ranges from poorly to well sorted, stratified, pebbly sand and sandy gravel interbedded with sand 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)**—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 locate

Qcso — **Older colluvium and sheetwash deposits, undivided (Pleistocene)**—Deposits texturally and depositionally similar to colluvium and sheetwash (Qcs) that are on a ridge about 200–400 ft above the adjacent stream valley

Qss — **Sediments of Sheep Springs Gulch (middle Pleistocene)**—Poorly sorted, stratified, clast-supported, silty, clayey, and sandy, cobble and pebble gravel to poorly sorted, unstratified, matrix-supported, gravelly clayey silt that cap several broad benches and narrow ridges in the southwestern part of quadrangle. Chiefly fluvial, but includes deposits of sheetwash, colluvial, and debris-flow origin that were eroded from landslides formed by mass wasting of Lewis Shale and overlying gravel deposits

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by ice or adjacent to ice in meltwaters

Qmd — **Durango moraine (middle Pleistocene)**—Consists of a single eroded remnant of end moraine or perhaps lateral moraine along the east edge of the quadrangle at the southern tip of Animas City Mountain. A heterogeneous, poorly sorted, matrix-supported unit consisting of cobbles, pebbles, and boulders in a sandy, silty, or clayey matrix

EOLIAN DEPOSITS—Sediments deposited by wind

Qlo — **Loess (late and late middle? Pleistocene)**—Slightly clayey, sandy silt and silty, very fine to fine sand deposited by wind and preserved on level to gently sloping surfaces. Typically is unstratified, friable, and plastic or slightly plastic when wet

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

Qva — **Volcanic ash (middle Pleistocene)**—White to light-gray, bedded, volcanic ash correlated with the 602 ka Lava Creek B ash. Found at two locations, one along the eastern quadrangle boundary northeast of Chapman Lake and a second on the southwest side of Junction Creek southwest of Chapman Lake. Locally includes pebble and cobble gravel that locally underlies the ash but is too thin to map separately

BEDROCK

TKi — **Diorite porphyry and monzonite porphyry sills and dikes (Upper Cretaceous or Paleocene)**—Medium-brown to medium-gray igneous sills and dikes in the northwest and southeast parts of quadrangle. Generally moderately to highly weathered or altered. Petrographically both dikes and sills appear to be diorite porphyry or monzonite porphyry, although degree of weathering inhibits identification of some minerals. Sills are slightly enriched in silica, potassium, and sodium relative to the dikes. Whole-rock chemical analyses indicate the sills and dikes are subalkaline to alkaline and have high loss on ignition. On basis of silica content and petrographic analysis, they are probably diorite porphyry and monzonite porphyry. In southeast part of quadrangle dikes occur within or very near the Bodo Fault zone; these loca-tions are identified by the symbol "d" next to the fault

Kl — **Lewis Shale (Upper Cretaceous)**—Dark-gray, fissile shale containing thin sandstone beds at top and gray, rusty-weathering concretionary limestone in the lower part

Mesaverde Group (Upper Cretaceous)—Consists of three mappable formations in Durango West quadrangle, which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone

Kch — **Cliff House Sandstone**—Interbedded sequence of thin beds of moderately indurated, yellowish-orange to white, very fine- to medium-grained calcareous sandstone and softer light-gray mudstone, siltstone, and silty shale

Kmf — **Menefee Formation**—Interbedded light-gray, brown, and orange-brown sandstone, gray, brown, and black carbonaceous shale, and coal. Locally includes burnt rock and clinker resulting from burning of coal beds within the formation

Kplu — **Point Lookout Sandstone, undivided**—Shown only on cross section. Consists of two lithostratigraphic units, a lower part and a massive part

Kplm — **Massive part of Point Lookout Sandstone**—Thick beds of light-gray to yellowish-gray or brown, quartzose sandstone, with very minor interbeds of dark-gray shale. Sandstone is fine to medium grained, cross laminated, well sorted, and cemented with calcite

Kpl — **Lower part of Point Lookout Sandstone**—Sequence of interbedded thin sandstone, siltstone, and shale beds that are gradational to the Mancos Shale. Basal contact arbitrarily placed at the base of the lowest 1-ft-thick sandstone bed or where the strata contain more than 50 percent shale in a 6-ft-thick interval

Km — **Mancos Shale (Upper Cretaceous)**—Dark-gray to black shale and silty shale, dark-gray to blue-gray argillaceous limestone, and calcarenite. Includes numerous thin beds of bentonite, especially in the lower part of the formation, and thin, sometimes argillaceous sandstone beds in the upper part immediately below contact with lower member of the Point Lookout Sandstone

Kdb — **Dakota Sandstone (Upper Cretaceous) and Burro Canyon Formation (Lower Cretaceous), undivided**—Dakota Sandstone composed of white, light- to medium-gray, and yellowish-brown conglomeratic sandstone, fine- to coarse-grained sandstone, and conglomerate interbedded with dark- to medium-gray siltstone, carbonaceous shale, and thin coal beds. Burro Canyon Formation consists of sandstone, chert-pebble conglomerate and grayish-green, non-carbonaceous claystone

Jm — **Morrison Formation (Upper Jurassic**—Consists of an upper Brushy Basin Member and a lower Salt Wash Member not mapped individually. Brushy Basin Member is predominantly greenish-gray, occasionally reddish-brown, bentonitic mudstone and claystone containing thin beds of very fine-grained sandstone and rare conglomeratic sandstone. Salt Wash Member is mainly locally silicified, light-gray to white, fine- to medium-grained, lenticular sandstone interbedded with thin beds of greenish-gray mudstone

Jjc — **Junction Creek Sandstone (Middle Jurassic)**—Light-gray to tan, highly crossbedded to massive, fine-grained sandstone. Correlative with the Bluff Sandstone in the Four Corners region and southeastern Utah

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. Upper member is correlative with the Summerville Formation in the Four Corners region. Pony Express Limestone member correlates with the Todilto Limestone in New Mexico

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

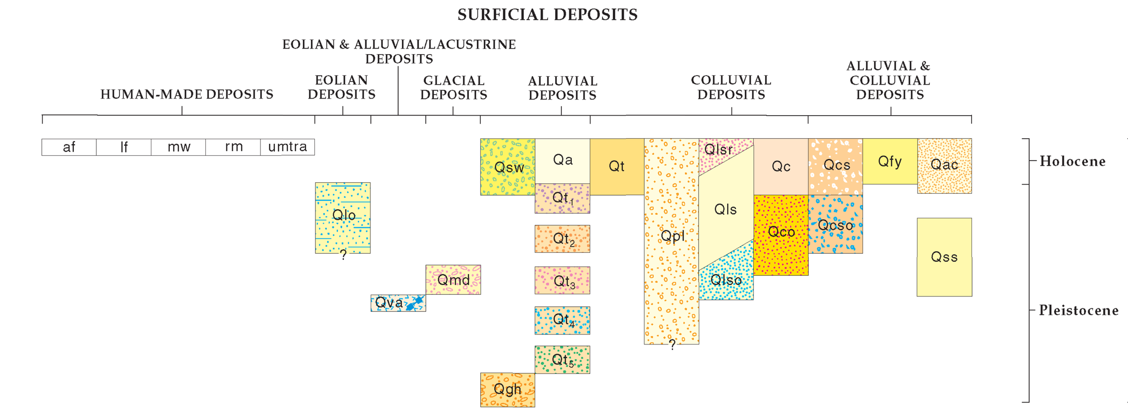
Jje — **Junction Creek Sandstone, Wanakah Formation, and Entrada Sandstone, undivided (Middle Jurassic)**—Mapped in north-central part of quadrangle where poor exposures limit recognition of contacts

ℜd — **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 containing rare thin limestone beds. Limestone-pebble conglomerate beds contain rare crocodilian teeth and bone fragments. Correlative with the Chinle Group in adjacent areas

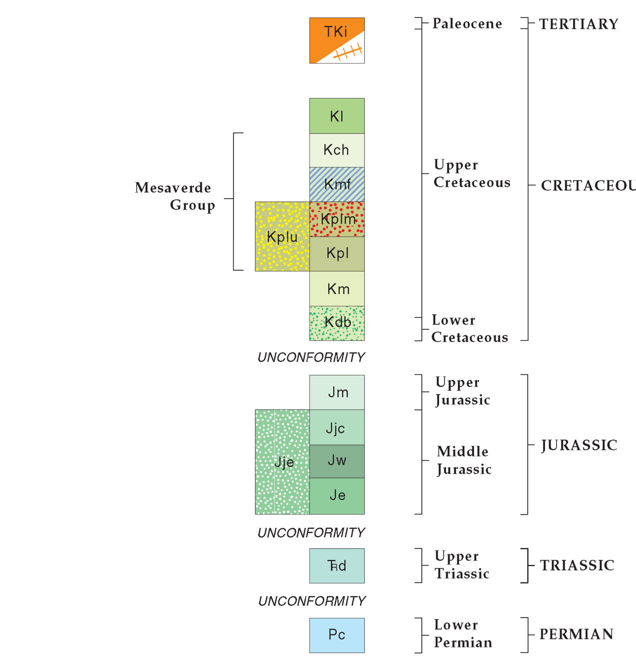
Pc — **Cutler Formation (Lower Permian)**—Medium- to dark-reddish-brown, medium-gray, and medium- to dark-brown sandstone, arkosic sandstone, and arkosic conglomerate and reddish-brown to purplish-brown shale and siltstone containing occasional limestone-pebble conglomerate and rare, thin limestone beds

CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS



BEDROCK



MAP SYMBOLS

Contact—Dashed where approximately located; queried where uncertain

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

Late Cretaceous or Paleocene monzonite porphyry or diorite porphyry dike (unit TKi)—Symbol is placed next to a fault trace where one or more dikes are within or very near the mapped fault; refer to the section on "Description of Map Units" for information on these rocks; dikes in southeastern part of quadrangle generally are very weathered, highly oxidized, and easily eroded; they were sufficiently hot upon emplacement to moderately bake adjacent sedimentary wall rock; baked sedimentary rock is more resistant to erosion and frequently forms two, narrow, parallel ridges that flank the easily eroded dikes and extend out from the hillslope several inches further than the dikes; maximum thickness about 6 ft

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

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

Syncline—Showing axial trace; dashed where approximately located; dotted where concealed

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

Headscarp of landslide

Soil slip—Small, thin recent landslides on steep hillslopes; most appear to be small debris avalanches involving colluvium or residuum; common on slopes underlain by colluvium, Mancos Shale, lower part of the Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone; base of arrow placed at head of slip; tip of arrow extends to end of runout zone visible on aerial photographs

Toreva block—Large, relatively intact block of bedrock within a large landslide

Linear valley in Mancos Shale—Probably a sackung feature related to lateral spreading of the bedrock ridge or an incipient landslide scarp developed in Mancos Shale

Terrace scarp or riser—Dashed where approximately located

Adit—Marks portal of coal, uranium, vanadium, thorium, gold, or silver tunnel; may represent more than one adit where they are in close proximity

Adit driven into breccia zone

Sand or gravel pit

Dimension stone quarry

Small open pit in volcanic ash bed

Caymon Colo. Fed. #1 TD 9781 ft — **Plugged and abandoned petroleum test well**—Operator, well name, and total depth given; location not confirmed by field inspection

DW 112 — **Geochemical sample location and sample number**

A———A′ **Alignment of cross section**

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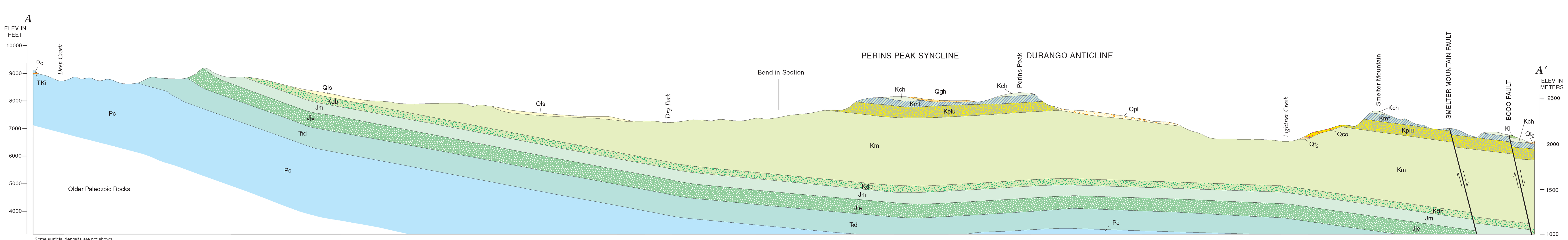
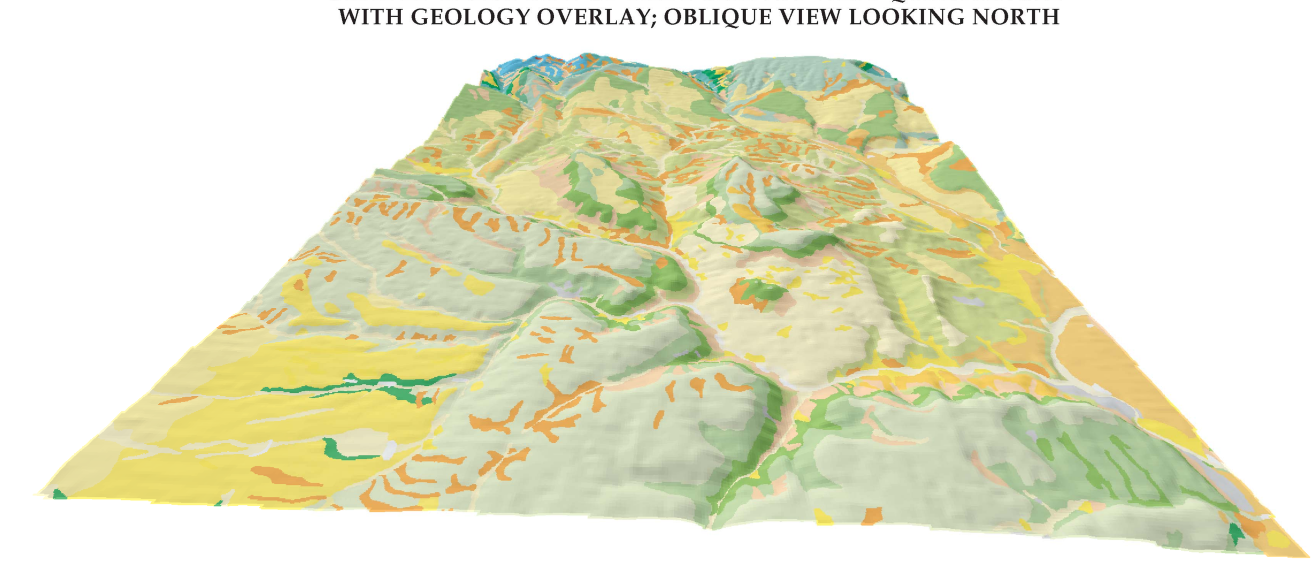


SHADED RELIEF MAP OF THE DURANGO WEST QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTH



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

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

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