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Geologic Map of the Basin Mountain Quadrangle, La Plata County, Colorado

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COLORADO GEOLOGICAL SURVEY

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 01-4, *Geological Map of the Basin Mountain Quadrangle, La Plata County, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located in southwestern Colorado, immediately southwest of the town of Durango. Robert M. Kirkham, staff geologist at the Colorado Geological Survey, and Alexis K. Navarre, consultant, completed the field work on this project in the summer of 2000.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program which is authorized by the National Geologic Mapping Act of 1997, Agreement No. 00HQAG0119, and the Colorado Geological Survey (CGS) using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

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Mary Gillam, consultant, and Steve Condon, USGS, reviewed this map and book. Paul Oldaker reviewed the section on Moving Mountain. Their comments and suggestions were of great value and improved the publication; however, the authors are solely responsible for the content of the published report.

We appreciate the cooperation of the many landowners, including the Southern Ute Tribe, who granted permission to map on their property. Several landowners and land managers also contributed valuable information and ideas that aided our investigation. Dennis Lee was especially helpful, as it was his advice that caused us to look for scoria and find heretofore unreported evidence of nearby volcanic eruptive centers.

We thank Chris Carroll, Dick Baughman, David Gonzales, Mary Gillam, Jim Cappa, Vince Matthews, and Francisco Gutierrez for their discussions, data, help with logistics, and/or field trips. Kirk Johnson identified fossils for us. Bill Walsh provided copies of the U.S. Bureau of Reclamation maps and reports on their investigation of the proposed Ridges Basin reservoir, and arranged for access onto the Bureau's property. Digital information on petroleum wells was researched by Laura Wray and Matt Morgan. Paul Oldaker and Mary Gillam contributed newspaper and magazine articles and published scientific papers on Moving Mountain. Gary Gianney and Spencer Lucas shared information about the mosasaur found in the quadrangle while our investigation was underway. Alan Andrews, La Plata County, created very helpful land ownership maps for us.

Photogrammetric models were set by James Messerich on a Kern PG-2 plotter at the USGS laboratory in Denver. Jane Ciener served as the technical editor for this map. Cheryl Brchan produced the digital map and Larry Scott was responsible for formatting the book.

INTRODUCTION

The Basin Mountain 7.5-minute quadrangle is located in La Plata County in southwestern Colorado, immediately southwest of the town of Durango (Figure 1). It is in the east-central part of the Colorado Plateau physiographic province (Fenneman, 1931). The Animas River, a major south-flowing river that drains much of the southwestern San Juan Mountains, runs along the eastern margin of the quadrangle. Ridges Basin, Basin Mountain, and Bridge Timber Mountain are prominent landforms within the quadrangle. A dam site associated with the proposed U.S. Bureau of Reclamation's Animas-La Plata project is at the downstream end of Ridges Basin. Bridge Timber Mountain, on the western edge of the quadrangle, lies along the drainage divide between the Animas and La Plata Rivers. Elevations within the map area range from about 6,140 to 8,366 ft above sea level.

Geologic mapping of the Basin Mountain quadrangle was conducted by the Colorado Geological Survey (CGS) as part of the Colorado Department of Natural Resources Severance Tax Operational Fund. Geologic maps produced by the CGS are useful for many purposes, including land-use planning, geotechnical engineering, geologic-hazards assessment, analysis and mitigation of environmental problems, and mineral-resource and ground-water exploration and development. The maps describe the geology of the quadrangle at a scale useful to many customers. They serve as good starting points for more detailed studies and are also valuable for regional and broad-scale studies.

Research, field work, and map preparation and digitization were completed during a one-year period. Mr. Kirkham worked on this project for about four months during the project year, and Ms. Navarre, field assistant, spent about two months on the project. About eight weeks of field investigations were conducted by the authors during the summer of 2000. During this period many, but not all, of the outcrops and landforms in the map area were inspected. Interpretation of aerial photography and previously published geologic investigations were used to delineate unit contacts in areas not visited by the authors. Black and white 1:40,000-scale photographs were

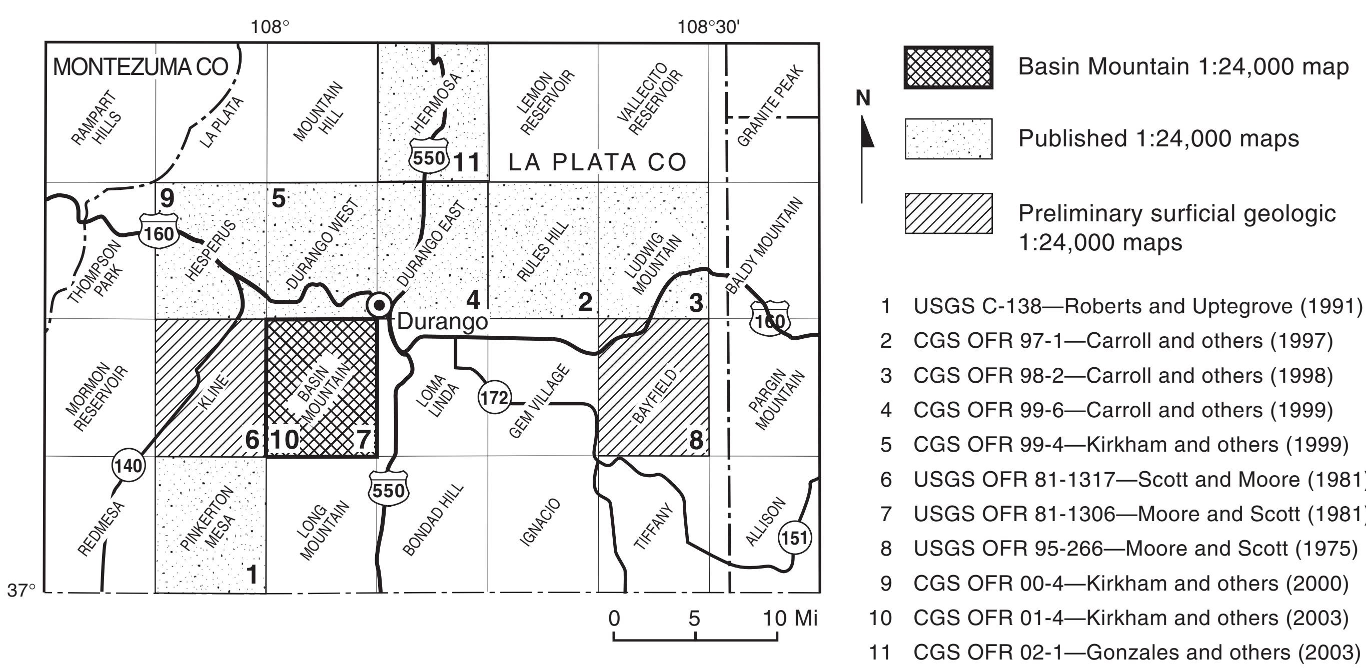

Figure 1. Status of 1:24,000-scale geologic mapping of 7.5-minute quadrangles near Durango, Colorado.

available for the entire quadrangle. Various portions of the map area were covered by color photography ranging in scale from 1:16,000 to 1:24,000. Information collected in the field was inked onto aerial photographs and transferred to a mylar base map using a Kern PG-2 plotter.

Several prior geologic maps greatly aided our mapping effort. Maps by Barnes and others (1954) at a scale of 1:62,500 and Zapp (1949) at a scale of 1:31,680, were especially helpful for the bedrock geology. Detailed mapping in the Basin Creek area by Condon (1997; scale 1:6,000) and coalbed mapping by Carroll (1999; scale 1:24,000) and Streufert (scale 1:16,000, in Wray, 2000) aided our mapping of areas underlain by the Fruitland Formation. Surficial geologic mapping at a scale of 1:24,000 by Moore and Scott (1981), surficial geologic and hazards maps at a scale of 1:24,000 by Miller (1976), terrace mapping by Gillam (1998) at a scale of 1:50,000, and regional mapping by Condon (1990; scale 1:100,000) and Steven and others (1974, scale 1:250,000) were also very useful. Previous 1:24,000-scale mapping of adjacent quadrangles by the CGS (Kirkham and others, 1999, 2000; Carroll and others, 1999) and USGS (Roberts and Uptegrove, 1991) provided a strong basis for the mapping of Basin Mountain quadrangle.

Detailed geologic studies by the U.S. Bureau of Reclamation for the proposed Animas-La Plata project (U.S. Bureau of Reclamation, 1992a, 1992b; Piety and Vetter, 1992) and investigations related to the U.S. Department of Energy's Durango Uranium Mill Tailings Remedial Action Project (Colorado Geological Survey, 1981; Jacobs-Weston Team, 1985a, 1985b) contained valuable information. Subsurface data from the numerous gas and oil wells in the map area were used to construct the cross section. These data were obtained from the Colorado Oil and Gas Conservation Commission and Petroleum Information/Dwights LLC (2000).

Figure 1 shows the current status of geologic mapping of 7.5-minute quadrangles in the Durango area. The Rules Hill, Ludwig Mountain, Durango East, Durango West, and Hesperus quadrangles were mapped and published by the CGS during previous projects (Carroll and others, 1997, 1998, 1999; Kirkham and others, 1999, 2000).

GEOLOGIC SETTING

STRUCTURE

Figure 2 depicts the regional structural setting of the Basin Mountain quadrangle. The map area is bisected by the northeast-trending Hogback monocline, a major, down-to-the-southeast, Laramide-age structure that borders the northern and northwestern sides of the San Juan basin. Basin Mountain is a prominent landform associated with the Hogback monocline, and Bridge Timber Mountain, which is capped by late Tertiary fluvial deposits, lies astride the monocline. Rocks that crop out along the Hogback monocline dip south and southeast as much as 34° in the quadrangle. A subtle flexure in the axis of the monocline between Bridge Timber Mountain and Basin Mountain coincides with West Gap and East Gap. Barnes and others (1954) described this flexure as a shallow syncline. Southwest of West Gap, rocks generally strike about N30°E, whereas northeast of East Gap they have an average strike of about N70°E for a short distance before returning to a N30°E that continues northeastward beyond the quadrangle boundary.

The Four Corners platform is northwest of the Hogback monocline. This broad, northeast-trending structural bench extends from northwestern

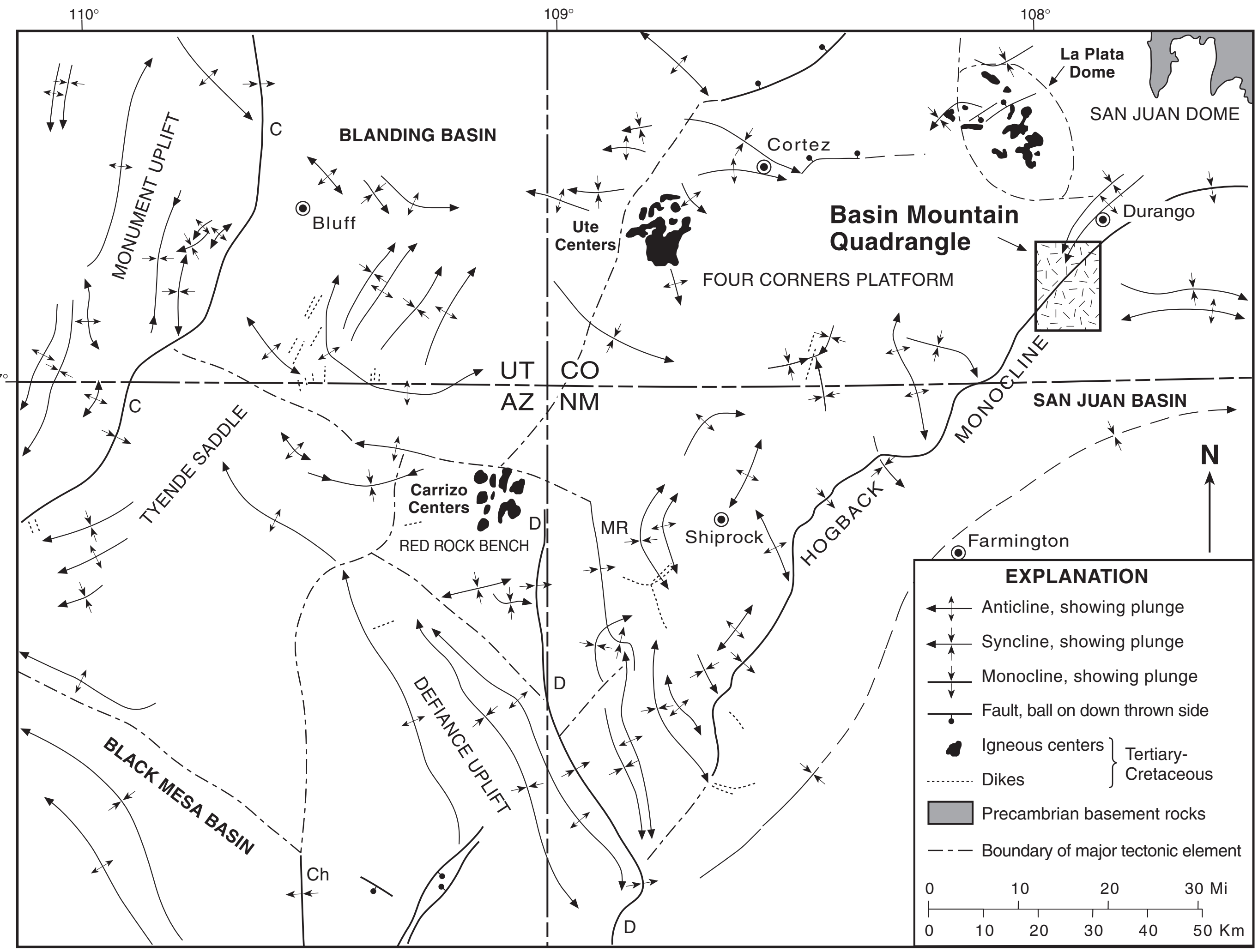

Figure 2. Generalized tectonic map of the Four Corners area. Modified from Woodward and others (1997). C = Comb monocline, Ch = Chinle monocline, D = Defiance monocline, and MR = Mitten Rock monocline.

New Mexico into southwestern Colorado and is underlain by relatively flat-lying sedimentary rocks (Haynes and others, 1972; Woodward and others, 1997). The northwestern one-third of the quadrangle is on the Four Corners platform, where rocks generally dip less than 10° south, southeast, or southwest.

Two small northeast-trending folds, the Durango anticline and Perins Peak syncline (Zapp, 1949), are superimposed on the Four Corners platform. These folds, which cross the northwestern corner of the quadrangle, are best developed in Durango West quadrangle (Kirkham and others, 1999). Unfortunately, much of the northwestern corner of the Basin Mountain quadrangle is covered by a veneer of surficial deposits, and the underlying Lewis Shale does not form good outcrops. Even in artificial exposures, good bedding-plane surfaces on which to measure attitudes are often difficult to locate in the Lewis. Because of these factors, the location and character of the Durango anticline and Perins Peak syncline in the map area are not well constrained. Available structural data suggest that these folds are dying out within the map area.

The San Juan basin is southeast of the Hogback monocline. Approximately the southeastern two-thirds of the Basin Mountain quadrangle is underlain by this large, Laramide-age structural basin. Within the quadrangle this limb of the San Juan basin is a southeast-dipping homocline. Immediately adjacent to the Hogback monocline, dips are about 5 to 15° southeastward, but dips flatten to 5° or less a mile or two from the monocline. Local changes in strike and dip directions in outcrops within the San Juan basin may reflect minor, unrecognized structures.

A few small high-angle normal faults were mapped in the quadrangle. Faults with the greatest displacement, the Bodo and Smelter Mountain faults near the northeast corner of the quadrangle, cut obliquely across the structural flexure between the Durango anticline and upper limb of the Hogback monocline. These northeast-trending, down-to-the-southeast faults are best exposed to the north in the Durango West quadrangle (Kirkham and others, 1999), where they have vertical displacements of about 100 ft or less. The Bodo fault, referred to as fault 1 by Jacobs-Weston Team (1985b) and as the Durango pumping plant fault by Piety and Vetter (1992), is well exposed in a road cut on County Road 211 immediately north of the Basin Mountain quadrangle. Here the Cliff House Sandstone is faulted against the Menefee Formation, and a prominent dike is associated with the fault plane. The dike rock is highly weathered, brightly colored with oxidized iron, and is soft and easily eroded. A coal bed in the footwall of the fault was dragged downward along the fault plane, and it was metamorphosed to coke by heat related to the dike. The general alignment of the Bodo fault can be traced northeastward by following the baked host rock along the dike. The baked sedimentary rocks are more resistant to erosion than the weathered dike and, consequently, form small ridges on one or both sides of the dike. The Bodo fault is also very evident where it crosses the arroyo south of County Road 211. A prominent white sandstone in the Menefee Formation on the downthrown side of the fault abruptly terminates against the fault in the arroyo bottom. To the south, the fault trace is less well defined but is thought to follow a tributary arroyo for at least one-quarter mile. As in the Durango quadrangle, a weathered dike is associated with the Bodo fault. Discontinuous outcrops of the dike and clasts of dike material are found in float south of the mapped end of the fault, suggesting the fault may extend southward from its mapped terminus.

Trenching studies of the Bodo fault by Jacobs-Weston Team (1985b) near where it crosses the Animas River on the Durango West quadrangle demonstrated that the last fault movement predated deposition of late Pleistocene terrace alluvium (Qt_1). The fault and related dike are well exposed in the stream bank on the southwest side of the river and west of the US Highway 160/550 bridge, adjacent to the unfaulted terrace.

The Smelter Mountain fault is best exposed near an inactive coal mine along County Road 211 in Basin Mountain quadrangle; here the Cliff House Sandstone is downdropped against the Menefee Formation. To the south it follows an arroyo and is not exposed. Zapp (1949), Colorado Geological Survey (1981), and Jacobs-Weston Team (1985b) showed a southwest-trending branch fault splaying off the main trace of the Smelter Mountain fault just north of the county road. This interpretation was probably based on the numerous blocks of Cliff House Sandstone exposed in a road cut. The blocks are stratigraphically below an outcrop of Menefee Formation that is in the arroyo west of the splay, which suggests the presence of a fault. These large blocks could be mistaken for in-place bedrock, but they are part of a previously unmapped landslide. The blocks are oriented in many different directions and are floating in a matrix of jumbled landslide debris. We found no evidence of the splay fault. The Smelter Mountain fault is well exposed on the east end of Smelter Mountain in the Durango West quadrangle, where it has several tens of feet of vertical displacement. Late Pleistocene deposits conceal the Smelter Mountain fault immediately north of this good exposure (Jacobs-Weston Team, 1985b; Piety and Vetter, 1992).

Zapp (1949) mapped a relatively long, down-to-the-northwest fault that originated in Ridges Basin in the SW1/4 of sec. 1, T. 34 N., R. 10 W. and extended northeastward to near the power station in the SW1/4 of sec. 31, T. 34.5 N., R. 9 W. This fault was called the Ridges Basin fault by Jacobs-Weston Team (1985b) and Piety and Vetter (1992), but its existence is questionable. Thin beds of Cliff House Sandstone appear juxtaposed against the Lewis Shale in the hills southwest of the power station at the northeast end of Ridges Basin. Our mapping supports the non-tectonic origin of these features that was proposed by Jacobs-Weston Team (1985b). The thin beds of Cliff House Sandstone are both overlain and underlain by shale beds typical of the Lewis. These sandstone beds are interpreted as tongues of Cliff House Sandstone within the basal Lewis Shale (unit Kcht on the geologic map). A similar tongue of Cliff House Sandstone crops out to the northeast, and intertonguing of the strata deposited by the Western Interior Seaway is common throughout the region. Another possible exposure of the Ridges Basin fault is in the bedrock hills in the northeast part of Ridges Basin in the SW/ of sec. 1, T. 34 N., R. 10 W. Outcrops here are inadequate to confidently conclude whether the strata are faulted or are intertongued, so we honor the previously published interpretations and include this end of the fault on our map.

Moore and Scott (1981) showed an inferred west-northwest-striking fault in the southwestern end of Ridges Basin. Piety and Vetter (1992) described this feature, along with four others in or near Ridges Basin, as lineaments. They concluded it was unlikely that any of the lineaments, including the inferred fault of Moore and Scott, were of tectonic origin, a conclusion supported by our mapping.

A small displacement, N56°W-trending normal fault, herein called the Black Ridge fault, is exposed in a roadcut near the southern edge of the quadrangle. The fault plane dips 74° to the northeast, and slickenlines on the plane plunge about 74° to the southeast. Beds of the San Jose Formation are offset about 5 ft in a down-to-the-northeast sense. Fault displacement may increase with depth, because there apparently is greater offset of the underlying "c" sandstone interval to the south in the Long Mountain quadrangle. This suggests syndeposition activity on the fault. In other words, Black Ridge fault is a Laramide growth fault that was active during the Early Eocene. A northeast-striking, down-to-the-northwest fault abuts the Black Ridge fault in Long Mountain quadrangle immediately south of the map area.

A small shear zone in the Pictured Cliffs Sandstone east of Ridges Basin (south edge of sec. 6, T. 34 N., R. 9 W.) was described by U.S. Bureau of Reclamation (1992b) and Piety and Vetter (1992). They report that the southwest-dipping, normal shear zone has about 4 to 9 ft of displacement. The fault trace shown on our geologic map is from U.S. Bureau of Reclamation (1992b).

At least two small faults are exposed in baked and oxidized beds in the Fruitland Formation in the scarp of the recent landslide on "Moving Mountain". These faults are probably collapse features related to subsidence induced by burning of an underlying coal bed.

Several small displacement and/or short faults occur in the quadrangle but cannot be shown at a scale of 1:24,000. A special symbol marks the location of these small structures on the geologic map. The structures are visible only in artificial cuts or limited natural outcrops, and cannot be traced beyond the limits of the exposure.

Two unmapped normal faults, first reported by the Colorado Geological Survey (1981), cut the

Cliff House Sandstone in the cut slope for a power station in the SW⁄ of sec. 31, T. 34.5 N., R. 9 W. These faults trend about N10–15°E, are down-dropped to the southeast along fault planes that dip around 50 to 60° southeast and have vertical displacements of 4 ft or less.

A swarm of small, unmapped faults cuts the McDermott Member of the Animas in a small area on the north side of Indian Creek between Pine and Cottonwood Canyons. One of the more prominent faults here strikes N52°E and dips 82° to the southeast. This high-angle reverse fault has about 10 inches of diplacement, and beds in the hanging wall are folded by drag along the fault.

A small unmapped fault in the Fruitland Formation was reported by the U.S. Bureau of Reclamation (1992b), Piety and Vetter (1992), and Condon (1997) in the lower end of Ridges Basin in the first roadcut downstream of the Pictured Cliffs Sandstone. This subtle feature strikes roughly parallel to the roadcut and dips southwest. Condon (1997) described two other small displacement faults in this vicinity: one in the next roadcut downstream, and a second about 1,400 ft to the north. The one in the roadcut has about 1 or 2 ft of throw to the northwest. The fault to the north offsets a Fruitland sandstone bed as much as 10 ft in a high-angle reverse fashion, strikes about N30°W, and is down to the southwest (Condon, 1997).

Prominent topographic lineaments are associated with East Gap and West Gap at the west end of Basin Mountain and with Forty-Four Canyon on the west side of Bridge Timber Mountain. Although faults may be associated with these features, no strong evidence of faulting was noted at the ground surface during this investigation.

STRATIGRAPHY, LARAMIDE OROGENESIS AND LATE CENOZOIC VOLCANISM

Rocks ranging in age from the Upper Cretaceous Menefee Formation to the Lower Eocene San Jose Formation crop out in Basin Mountain quadrangle. Older rocks exposed in the map area were deposited in or adjacent to the Cretaceous Western Interior Seaway. Evidence of the Late Cretaceous to Eocene Laramide orogeny is preserved in the younger rocks exposed in the quadrangle. On the basis of changes in paleoslope direction and presence of volcanic detritus, Klute (1986) suggested that Laramide orogenesis began during deposition of the upper shale member of the Kirtland Formation. Conglomerate and conglomeratic sandstone containing well-rounded clasts of quartz, quartzite, and chert locally occur at the top of the upper shale member of the Kirtland Shale. These beds are similar to ones in adjacent areas that Zapp (1949) also included in the top of the upper Kirtland, but that Barnes and others (1954) placed in the basal McDermott. The well-rounded siliceous pebbles were probably eroded from an early Laramide uplift.

Coarse (up to boulder-sized) clasts of igneous rock in the conglomerates and sedimentary breccias of the McDermott Member indicate that igneous rocks were exposed to erosion in nearby Laramide uplifts. Most clasts are generally altered and/or weathered, making identification of the rock fragments difficult. Many previous investigators (for example Reeside, 1924; Baltz, 1953; Barnes and others, 1954; Fassett, 1985; Sikkink, 1987) described the clasts as volcanic, and most interpreted the La Plata Mountains as the source area. However, no volcanic rocks have been found in the La Plata Mountains, only intrusive dikes, sills, and stocks (Eckel, 1949; Kirkham and others, 2000; D. Gonzales, 2001, oral communication). The interior portions of some boulders in the McDermott are composed of relatively fresh, coarse-grained intrusive rock that are megascopically similar to intrusive rocks exposed in the La Plata Mountains (D. Gonzales, 2001, oral communication). Detailed studies of clasts contained in the McDermott to rocks exposed in the La Plata Mountains, including petrographic studies and geochemical correlation, could potentially establish the provenance of the McDermott.

A brightly colored and mottled sequence of shale and siltstone at the top of the McDermott Member of the Animas Formation was interpreted as a palesol by Sikkink (1987), but it might also be related to diagenetic alteration. These brightly colored and mottled strata crop out intermittently along the Hogback monocline, starting on the north side of McCullogh Canyon and extending beyond the eastern margin of the quadrangle. Between McCullogh and Pine canyons these strata are fairly continuous, but between Pine Creek and the Animas River this interval alternately thins and thickens. The brightly colored and mottled strata pinch out in the eastern end of the prominent exposure along the west bank of the Animas River about one-half mile east of the quadrangle boundary but may re-occur east of the river (Sikkink, 1987). If the brightly colored and mottled strata are a paleosol, then a period of non-deposition and weathering of exposed sediments occurred after deposition of the McDermott Member and prior to deposition of the overlying upper member of the Animas Formation. Alternatively, if the brightly colored strata are related to diagenesis, then the alteration may have been localized along the contact between the McDermott and upper members of the Animas.

The contact between the McDermott Member and upper member of the Animas was interpreted as an angular unconformity by Reeside (1924), but Zapp (1949), Baltz (1953), and Barnes and others (1954) described it as conformable. If the brightly colored and mottled interval at the top of the McDermott is a paleosol, then the contact is probably an angular unconformity. If this interval is related to diagenesis, then the contact is likely conformable, and the apparent erosional pinchout of the brightly colored and mottled strata is the margin of the alteration front. In the excellent exposures along the west bank of the Animas River about one-half mile east of the quadrangle, beds in the McDermott Member appear to dip more steeply than those in the overlying upper member of the Animas (Reeside, 1924). Baltz (1953) attributed this apparent angularity to “an optical illusion due to rapid steepening of dip” as the rocks approach the Hogback Monocline. If there is an unconformity between the McDermott and upper member of the Animas, then these apparent dip differences indicate that in the west bank of the Animas River it is an angular unconformity.

The basal part of the upper member of the Animas Formation is coarse volcaniclastic conglomerate, conglomeratic sandstone, and sandstone that was probably eroded from volcanic highlands formerly present in the San Juan Mountains. Locally, a thin sequence of brightly colored, oxidized fine-grained sediments separates the basal conglomeratic beds of the upper member of the Animas from the McDermott Member. These strata include beds that resemble reworked McDermott paleosol. Alternatively, these brightly colored beds in the basal part of the upper member may be related to diagenetic alteration.

The Laramide-age volcanoes contributed major quantities of volcanic detritus to the Animas and Nacimiento Formations. This package of rocks is essentially a thick fining-upward sequence of sediments that may reflect diminishing tectonic uplift or gradual erosional removal of a volcanic edifice in the source area. The Nacimiento and upper Animas are considered lateral facies in some studies (for example Smith and Lucas, 1991; Smith, 1992). We noted evidence of possible intertonguing of these strata in Basin Mountain quadrangle, but near the monocline there appears to be an angular unconformity between rocks mapped as Nacimiento and the upper Animas, similar to relationships described by Baltz (1953).

A major pulse of orogenic uplift affected the monocline during and perhaps shortly before deposition of the Lower Eocene San Jose Formation, as evidenced by the overstepping or overlapping relationships between the San Jose and older rocks. For example, in the upper end of Sawmill Canyon, beds in the upper part of the San Jose Formation dip about 6°, whereas the underlying McDermott Member dips more than 30°. Strata comprising the basal San Jose, Nacimiento, upper and McDermott members of the Animas, and upper and Farmington Sandstone members of the Kirtland Formation were removed from this area by syn-orogenic erosion prior to deposition of the upper San Jose. To the west in the Kline quadrangle, rocks as old as the lower shale member of the Kirtland were eroded prior to deposition of the San Jose (Barnes and others, 1954). These relationships document major uplift on the monocline either during or before the Early Eocene. The overstepping and onlapping relationships of younger San Jose strata over older San Jose beds and the dips up to 6° in upper San Jose strata indicate continued uplift of the monocline during the Early Eocene.

Angular clasts of relatively unabraded dacitic scoria and rounded clasts of quartz, quartzite, chert, diorite and monzonite porphyry, and granite were found in a thin, lag deposit overlying the upper member of the Animas Formation near the mouth of Indian Creek in the NW⁄ of sec. 24, T. 34 N., R. 10 W. Original flow structure is well preserved on the fragile clasts of scoria, suggesting the clasts were transported only a very short distance. The scoria clasts were probably eroded from a volcano located within the quadrangle somewhere between Indian Creek and Basin Mountain. The little-abraded and unweathered character of the scoria clasts suggest the eruptive center was active during the late Cenozoic. The whole-rock geochemistry of the scoria is reported in Table 1. This analysis indicates the volcanic scoria is a dacite, based on the classification system of Le Bas and others (1986).

Table 1. Whole-rock XRF geochemical analyses of a dacitic clast from a lag deposit north of the mouth of Indian Creek. [See map for location. Analysis by ALS Chemex, Sparks, Nevada. Values given in weight percent.]

Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_20	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	Total
13.69	5.92	<0.01	5.08	2.37	0.90	0.09	0.87	0.08	64.97	0.68	4.41	99.06

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Since the intended users of this map include geotechnical engineers, engineering geologists, and land-use planners who are interested in unconsolidated surficial materials and active surficial processes, the map includes a large number of surficial stratigraphic units. Most of the surficial deposits in the quadrangle are not well exposed. Therefore, the attributes of these units, such as thickness, texture, stratification, and composition, are described from observations made at only a few locations and from geomorphic characteristics. The surficial stratigraphic units are generally classified by genesis or, if genesis is unknown, by the type of material of which they are composed. Informal names are given for some surficial units based on landforms or geographic features associated with them.

Surficial units shown on the map are generally more than about 5 ft thick. In some instances, particularly for fluvial gravels and loess, the deposits may be much thinner than 5 ft. Areas mapped as colluvium may include small outcrops of bedrock that are not shown. Fractional map units (for example Qlo/Qss) indicate that a thin mantle material, in this case loess, overlies another deposit. The minimum width of surficial deposits shown on the map is about 75 to 100 ft, which is due to the scale of the map. Artificial fill of limited areal extent and residuum were not mapped. Contacts between many surficial units may be gradational and therefore should be considered as approximate boundaries. The topographic base map was published in 1968 and the primary aerial photographs used during the investigation were flown in 1973. Consequently, cultural features and deposits that post-date the base map and photographs may not be depicted on the map.

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

Divisions of the Pleistocene used herein correspond to those of Richmond and Fullerton (1986). Characteristics such as the degree of erosional modification of original surface morphology, height above modern stream levels, and relative degree of weathering and soil development were used to estimate the relative ages for many of the surficial deposits. The ages of the fluvial terrace deposits in the quadrangle largely correspond to those assigned by Gillam (1998).

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)—**Consists of fill and waste rock placed during construction of dams, roads, landfills, and home sites. This unit is composed mostly of unsorted silt, sand, and rock fragments but may include construction materials. Maximum thickness is about 30 ft. Artificial fill may compact when loaded, if not adequately compacted. Old landfills are susceptible to severe settlement and can generate explosive biogenic methane.

mw — **Coal mine waste (latest Holocene)—**Includes rock debris and coal refuse in mine dumps at inactive coal mines. Maximum thickness is about 20 ft. Coal mine waste may compact or ignite.

umtra — **Bodo Canyon uranium mill tailings (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 Tailings Remedial Action Project and placed in the Bodo Canyon disposal site. Material is protected by a cap of clay and riprap to minimize radon emissions and erosion. Maxiumum thickness is estimated at about 40 ft. According to signs posted around the disposal site, the materials pose a low-level radiation hazard.

ALLUVIAL DEPOSITS

Gravel, sand, silt, and clay deposited by flowing water in stream channels and flood plains or as hillslope runoff or sheet flow along the Animas River and its tributaries. Terrace alluvium along the Animas River is chiefly glacial outwash that was probably deposited during late-glacial and early-interglacial stages. Deposits resulting from sheet flow are called sheetwash. Alluvial deposits locally include colluvium or loess too small to be mapped at a scale of 1:24,000. The approximate terrace heights are the elevation differences measured between the adjacent modern stream valley and either the top of the original alluvial depositional surface near the river-side edge of the terrace or the top of the preserved deposit, if eroded.

Qa

Stream channel, flood-plain, and low terrace deposits (Holocene)—Includes modern stream-channel deposits of the Animas River, adjacent flood-plain deposits, and low-terrace alluvium that is up to 8 ft above modern stream level. These deposits are mostly poorly sorted and clast supported. They consist of unconsolidated pebble, cobble, and locally boulder gravel in a sandy or silty matrix that is locally interbedded with or overlain by sandy silt and silty sand. Clasts are round to subangular. Deposits contain clasts with diverse lithologies such as sandstone, quartzite, limestone, granite, monzonite porphyry, diorite porphyry, gneiss, ash-flow tuff, amphibolite, and schist, reflecting the wide variety of bedrock that crops out within the Animas River drainage basin. Maximum thickness is estimated at 25 ft. Low-lying areas are subject to flooding. Unit is a source of sand and gravel.

Qsw

Sheetwash (Holocene and late Pleistocene)—Includes materials that are transported chiefly by sheet flow and deposited in valleys of ephemeral and intermittent streams, on gentle hillslopes, or in topographic depressions. These deposits are locally derived from weathered bedrock and surficial materials. Sheetwash typically consists of pebbly silty sand, sandy or clayey silt, and sandy silty clay. Locally it grades to and interfingers with colluvium (Qc) on steeper hillslopes. In many areas the contacts between sheetwash and colluvium cannot be defined, so the deposits are lumped into a single, undivided unit (Qcs). In closed depressions sheetwash may grade to lacustrine or slack-water deposits. The maximum thickness is about 20 ft, but commonly the deposits are much thinner. Areas mapped as sheetwash are subject to future sheet-flow deposition. Unit may be prone to hydrocompaction, settling, and piping where fine-grained and low in density.

Qt_1

Terrace alluvium one (late Pleistocene)—Chiefly stream alluvium that underlies several fill, fill-cut, or strath terrace surfaces along or near the Animas River. Terrace heights range from about 25 to 65 ft above the river, and they converge slightly with the river in a downstream direction. The unit is mostly 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, and they are composed of the varied bedrock lithologies that crop out within the Animas River drainage basin, mostly sandstone, quartzite, limestone, granite, monzonite porphyry, diorite porphyry, gneiss, ash-flow tuff, amphibolite, schist, and conglomerate. Clasts are generally unweathered or only slightly weathered. Soils developed on unit Qt_1 have weakly to moderately developed textural B horizons.

Terraces related to terrace alluvium one are correlated with terrace group TG7 of Gillam (1998), which is graded to the Animas City moraines in the Durango East quadrangle (Carroll and others, 1999). These moraines, which formed roughly from 12 to 35 ka (Richmond, 1986; Carroll and others, 1999), 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 10 to 30 ft in fill and fill-cut terraces. Unit is locally only a few feet thick in strath terraces and may be over 30 ft thick in buried channels. 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 fill and fill-cut terraces that generally range from about 80 to 120 ft above the Animas River. These terrace surfaces converge slightly with the river in a downstream direction. Large remnants of terrace alluvium two occur in the southeast corner of the quadrangle and at the mouths of Indian Creek and Sawmill Canyon, where the alluvium is in part overlain by younger fan deposits (Qfy) and loess (Qlo). Smaller remnants are broadly distributed along much of the Animas River valley. The very small remnant of sandy cobble and pebble gravel found a short distance north of the mouth of Goat Canyon was mapped as terrace alluvium two, but it may have been reworked from a higher and older terrace prior to deposition of other Qt_2 terrace material in the quadrangle. It lies about 170 ft above the river, which is higher than the other Qt_2 terraces in the map area or in adjacent Loma Linda quadrangle (Gillam, 1998), and it is lower in the landscape than are the Qt_3 terraces.

Deposits of terrace alluvium two are texturally and lithologically similar to terrace alluvium one deposits (Qt_1). Clasts within terrace alluvium two are slightly weathered, and soils formed on the surface of the unit commonly have a moderately well-developed textural B horizon. Two terrace scarps or risers separate different terrace surfaces underlain by terrace alluvium two between Indian Creek and Goat Canyon.

Terrace alluvium two correlates with deposits underlying terrace group TG6 of Gillam (1998), which is graded to the Spring Creek moraines on the Durango East quadrangle (Carroll and others, 1999). These moraines probably correlate with Bull Lake, Eowisconsinan, 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, but commonly it is much thinner. The unit is a potential source of sand and gravel.

Qt_3 **Terrace alluvium three (middle Pleistocene)—** Chiefly stream alluvium that underlies at least two fill or fill-cut terrace surfaces at heights of about 240 to 430 ft above the Animas River in two areas of the quadrangle. A large remnant of terrace alluvium three crops out along the eastern edge of the map area between Basin Creek and the Animas River, and two small remnants are in the northeast corner of the quadrangle. Erosional incision has significantly altered the original depositional surface of the two small remnants in the northeast part of the map area. Terraces associated with unit Qt_3 converge with the Animas River in a downstream direction more rapidly than do younger terraces (Gillam, 1998). Terrace alluvium three deposits generally have textural and lithological characteristics that are similar to those of terrace alluvium one **(Qt_1)**, but clasts are moderately weathered. Deposits between Basin Creek and the Animas River are overlain by a locally thick mantle of loess.

Terrace alluvium three correlates with deposits that underlie terrace group TG5 of Gillam (1998), which grades or projects to the Durango moraines in the Durango East quadrangle (Carroll and others, 1999). Gillam (1998) reported that the inner (younger) Durango moraines formed during the coldest part of oxygen-isotope stage 8 at about 250 to 275 ka, whereas the outer Durango moraines were deposited during stage 10 approximately 345 to 360 ka. Deposits in the northeast part of the quadrangle vary from only a few feet thick to perhaps as much as 25 ft. Between Basin Creek and the Animas River, the unit is about 40 to 45 ft thick. Since Gillam (1998) reported a maximum thickness of about 150 ft for terrace alluvium three in the adjacent Loma Linda quadrangle, it is possible that the unit is locally thicker than 45 ft in Basin Mountain quadrangle. Terrace alluvium three is a source of sand and gravel.

Qt_4 **Terrace alluvium four (middle Pleistocene)—** Includes three remnants of chiefly stream alluvium that underlie terraces along the Animas River between Sawmill Canyon and Goat Canyon at a height of about 440 ft above the river. The larger remnant physically grades to and thus is age-equivalent to a mesa-capping deposit of the sediments of Sawmill Canyon **(Qsc)**. Differences in clast lithology were used to discern the approximate gradational boundary between these two units, both of which are mantled by several feet of loess **(Qlo)**.

Deposits of terrace alluvium four texturally and lithologically resemble those of terrace alluvium one **(Qt_1)**, but they locally have a weakly to moderately well-developed carbonate soil. Gravel clasts are moderately weathered. In the reach of the Animas River between Durango and La Posta, the terraces associated with terrace alluvium four converge with the river in a downstream direction more rapidly than do younger terraces (Gillam, 1998). Farther downstream, there is a section of the river valley where terraces slightly diverge, followed by another reach with converging terraces.

Terrace alluvium four is correlated with terrace group TG4 of Gillam (1998), which projects above the Durango moraines. Unit Qt_4 relates to the lower terraces of Gillam's group TG4, which were thought to be deposited near the end of oxygen isotope stage 14 about 520 ka (M. Gillam, 2001, written communication). Maximum thickness of terrace alluvium four deposits in this quadrangle may locally exceed 80 ft. In the adjacent Loma Linda quadrangle the maximum thickness is about 200 ft (Gillam, 1998). The unit is a potential source of sand and/or gravel.

Tbt

Bridgetimber Gravel (Pliocene or Upper Miocene)— Unit includes weakly lithified-gravel deposits beneath Bridge Timber Mountain on the drainage divide between the Animas and La Plata Rivers on the western edge of the map. The unit also includes one small outlier of gravel immediately north of Bridge Timber Mountain and another farther north that is on the ridgetop west of West Gap. The northernmost remnant is lower in the landscape than are the other deposits, so it may consist of reworked Bridgetimber gravel. These deposits occur about 2,100 ft above the Animas River and about 1,100 ft above the La Plata River. The Bridgetimber Gravel was deposited in a late Tertiary paleovalley.

The deposits are generally poorly exposed. They appear to consist mostly of interbedded sandy gravel, gravelly sand, and silty sand deposited in a fluvial environment. Gravel clasts are chiefly round and subround cobbles, pebbles, and boulders composed of sandstone and diorite porphyry, with lesser amounts of monzonite porphyry, syenite porphyry, conglomerate, limestone, siltstone, and lamprophyre. These clasts indicate a source in the La Plata Mountains. Many clasts in the upper part of the unit are strongly weathered.

The Bridgetimber Gravel was originally named by Atwood and Mather (1932) and included various high-level gravel deposits derived from the La Plata, Animas, and Florida river drainages. Richmond (1965) restricted the unit to include only material deposited by an ancestral La Plata River. Atwood and Mather (1932) and Richmond (1965) indicated that these high-level gravel deposits also extensively crop out along parts of Basin Mountain and along most of Black Ridge, but these deposits were not recognized during this investigation or by Barnes and others (1954), Steven and others (1974), Condon (1990), or Gillam (1998). Isolated remnants of gravelly material are preserved in a few locations on Black Ridge, but these deposits are interpreted as being reworked from the Bridgetimber Gravel and are much younger in age; therefore they are included with the unit called sediments of Sawmill Canyon **(Qsc)**.

A Pliocene age was assigned to the Bridgetimber Gravel by Atwood and Mather (1932), Richmond (1965), Moore and Scott (1981), and Condon (1990), whereas Barnes and others (1954) described it as Pliocene or Pleistocene, Steven and others (1974) showed it as Quaternary, and Gillam (1998) stated it was Miocene or Pliocene. An approximate age of the Bridgetimber Gravel can be estimated using incision rates based on the heights of the closest outcrops of the Lava Creek B ash above the rivers and assuming those rates were constant throughout the latter part of the Cenozoic.

Recent $^{40}Ar/^{39}Ar$ dating by M. Lanphere (2001, written communication) indicates the Lava Creek B ash is 640±2 ka. Scott and Moore (1981) and Izett and Wilcox (1982) reported the Lava Creek B ash at heights of about 110 ft above the La Plata River in the east-central part of Kline quadrangle, which yields an average incision rate of 0.17 ft per thousand years during the past 640 ka. This suggests the Bridgetimber Gravel, at a height of about 1,100 ft above the La Plata River, is approximately 6.5 Ma. In the northwest part of Loma Linda quadrangle the Lava Creek B ash is about 510 ft above the Animas River (Izett and Wilcox, 1982; Gillam, 1998), resulting in an average incision rate of 0.80 ft per thousand years since the ash was deposited. On the basis of this incision rate, the Bridgetimber Gravel, at 2,100 ft above the Animas River, is about 2.6 Ma. Since both of the ash outcrops occur upstream of the outcrop of the Bridgetimber Gravel and the terraces along both rivers are converging in these reaches, these calculated ages based on incision rates likely represent minimum ages for the unit. These incision rates suggest the Bridgetimber Gravel is probably late Miocene or Pliocene in age.

Since the base of the Bridgetimber Gravel is not exposed, its thickness is poorly constrained. The gravel thickness probably exceeds 100 ft beneath most of the mountain and may locally exceed 150 ft, based on the road cut along the access road that leads to gas wells on top of Bridge Timber Mountain and on the slope break at the base of the mountain, which may coincide with the base of the unit. The Bridgetimber Gravel is a potential source of sand, but due to strong weathering of clasts, it may not be a suitable source of gravel.

COLLUVIAL DEPOSITS

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

Qlsr

Recent landslide deposits (latest Holocene) — Includes several recently active landslides with documented evidence of historical movement or fresh morphological features suggestive of movement during the past several decades. Other recently active landslides besides the ones identified may exist in the quadrangle. For example, some of the large landslide complexes in unit Qls may have experienced recent movement in part, but detailed examination of these large landslides was beyond the scope of this investigation. Recent landslide deposits are heterogeneous and consist of unsorted, unstratified rock debris, clay, silt, sand, and sometimes rounded river gravel. Texture and lithology of these rock fragments depend upon the source area.

The largest and best known recent landslide in the map area is "Moving Mountain", also referred to as "Democrat Mountain" or "Hoover Slide" in some newspaper articles, in reference to political campaign promises by the democrats to "start things moving if they were elected" (Durango News, Dec. 30, 1932). The upper part of the landslide is in the northeast part of the quadrangle in sec. 5, T. 34 N., R. 9 W.; the lower part of the landslide is in Loma Linda quadrangle. Because this landslide occurs within the Fruitland Formation and apparently involves explosions of coal-bed methane, a topic of considerable current interest, it is discussed in detail. The following description is largely based upon newspaper and magazine articles and on a paper published in the Journal of Geology (Vanderwilt, 1934) that were provided to the authors by P. Oldaker and M. Gillam.

The first reported landslide activity on Moving Mountain occurred in the spring of 1918 (Durango Herald-Democrat, Dec. 23, 1932), when a small part of the hillslope slid. The landslide was very active during the winter of 1932 to 1933. Numerous newspaper articles about the landslide appeared in local papers (for example Durango Herald-Democrat, Dec. 22, 24, 27, 29, and 30, 1932, Jan. 3 and 9, 1933; Durango News, Dec. 23, 1932), and it eventually gained international recognition (Durango Herald-Democrat, March 14, 1933). The articles described reports of numerous "rumblings" and even "explosions"during initial phases of movement in the winter of 1932-1933. The Dec. 22 article suggested the explosions were due to ignition of "gasses coming from the huge coal deposits". This article also mentioned that some residents believed a mysterious explosion that occurred during the prior summer may have marked the beginning of landslide activity (Durango Herald-Democrat, June 9, 1932).

The Durango News on Dec. 23, 1932 suggested "great heat is emanating from the mountain", because of the "disappearance of snow from the mountain". This article also reported that gases, including ignitable gas, issued from an old coal mine located on the mountain, a claim supported by Vanderwilt (1934). This mine may be the one shown by Zapp (1949) between two landslide deposits on and below Moving Mountain. Problems related to gases may have led to the closure of the coal mine (Durango Herald-Democrat, Dec. 30, 1932). Thick beds of clinker exposed in the headwall of the landslide indicate signicant burning occurred here at sometime in the past. An article in the Durango Herald-

Democrat (Dec. 30. 1932) described evidence of burned rock at the time of the major slide movement, but Vanderwilt (1934) attributed the oxided rock described in the article to near surface weathering of iron contained in the rocks.

Vanderwilt (1934), felt many of the newspaper articles were contradictory and exaggerated. He attributed the reported explosions to "the rupture of the larger slabs of the sandstone." Several newspaper articles described reports of "sulfurous" gas associated with the landslide, which are of interest because methane and hydrogen sulfide gas currently bubbles to the surface from beneath the Animas River and from the west bank of the river below the slide.

Initial landsliding on Moving Mountain in 1932 reportedly first involved a northward-moving block of Fruitland Formation that separated from the mountain along a large fracture or head scarp (Vanderwilt, 1934). Rockfall and debris avalanches shed from this block spilled over the north-facing ridge capped by the Pictured Cliffs Sandstone, "pushing many tons of rock over the edge of the hogback to form the talus slopes below" (Vanderwilt, 1934). An article in the Durango Herald-Democrat on Dec. 29, 1932 by F. D. Allen stated "The talus forming slides on the northern face of moving mountain are merely the result of material which is 'spilling' over the edge of the inclined face." This talus or spill-over material is clearly visible in a photograph in the Jan. 9, 1933 issue of the Durango Herald-Democrat. It is shown on our geologic map as recent landslide deposits **(Qlsr)**. P. Oldaker (written communication, 2001) suspects that part of the material on the north-facing slope may have been blown off the mountain during one of the explosions reported during initial phases of activity.

After the northward-moving block broke free, it began to slide eastward, obliquely across the dip slope formed by the top of the underlying Pictured Cliffs Sandstone, "and the fall of talus material (down the north-facing slope) virtually ceased" (Vanderwilt, 1934). Subsequent smaller rockfall and/or debris avalanches down the north-facing the slope are documented in the Jan. 9 issue of the Durango Herald-Democrat article which described a man who "miraculously escaped death or serious injury, as he came tumbling down the north face of Carbon Mountain.... with big boulders and tons of earth moving all around him." Witnesses stated that "Conway, who was standing on the north edge of the mountain, lost his footing when the ground crumbled beneath him, and slipped over the ledge and onto the incline where the avalanches have been running for several weeks. After rolling for about a hundred feet, Conway succeeded in getting onto his feet and ran most of the remainder of the distance down the slope with the slide roaring around him."

When the main slide mass moved eastward, it used the top of the Pictured Cliffs Sandstone as a basal slip plane. An interesting observation of Professor Needham (Durango Herald-Democrat, Dec. 27, 1932) was that the slide mass was relatively dry, in contrast to the typical water-saturated landslides in the region. Many newspaper accounts reported concern that the slide could block the river. However, Vanderwilt (1934) stated that the toe of the slide was 1,000 ft from the river and that it was unlikely that the landslide would reach the river. Much of the area between the river and the toe of the historic landslide described by Vanderwilt (1934), which is on the adjacent Loma Linda 7.5-minute quadrangle, is now disturbed by human activities, but it appears to be a debris-flow fan. Water-saturated surficial deposits, possibly fan deposits, are now present along the west bank of the river below the slide, and gas issues from these materials.

Minor reactivation of part of the landslide was reported in the 1940s, 1950s, and 1980s (P. Oldaker, written communication, 2001; R. Blair, oral communication, 1998). The toe of the original landslide was reactivated sometime prior to August 1, 1973, as the reactivated part of the landslide is visible in aerial photography by the U.S. Forest Service (project no. 08067; photograph 773–116). The reactivation was probably triggered by erosion of a channel through the original landslide toe by a tributary drainage. When this channel was cut, one or more debris flows carried material from the channel and deposited it on a fan between the original landslide and the Animas River on Loma Linda quadrangle. A smaller landslide formed within the tribtary drainage sometime after August 1, 1973 and prior to July 3, 1992, as this younger landslide is not visible in the 1973 U.S. Forest Service aerial photography, but is apparent in aerial photography flown for the U.S. Bureau of Land Management in 1992 (project CO-92-BC; photograph 2-13-15).

Another relatively large, recent landslide is in the southwestern part of the quadrangle on a northwest-facing slope on the west side of Black Ridge. This event post-dates aerial photography flown by the U.S. Forest Service on July 31, 1973. The recent translational landslide on Black Ridge largely involved reactivation of a pre-existing landslide deposit, but it also included in-place bedrock of the San Jose Formation upslope from the head scarp of the prior landslide.

Small recent landslides with relatively fresh landforms suggestive of movement during the past several decades were noted in other parts of the quadrangle. One on the north side of Basin Mountain about one mile east of East Gap formed on a steep north-facing slope in surficial deposits overlying Lewis Shale. It probably moved rapidly downslope as a thin-skinned debris avalanche. A small recent landslide on the north-facing slope north of Basin Mountain is in the center of sec. 5U, T. 34 N., R. 10 W. It developed in residuum overlying the Lewis Shale. Several small recent slides are in the upper end of La Posta Canyon. Most of these recent landslide deposits resulted from debris avalanches involving pre-existing landslide deposits that overlie the San Jose Formation on steep unvegetated slopes. A number of very small recent slope failures which involve deposits too small to show at a scale of 1:24,000 are depicted on the map by an arrow symbol and are generically referred to as soil slips.

Maximum thickness of the recent landslide deposits on Moving Mountain may be around 100 ft, on the basis of the newpaper accounts and Vanderwilt (1934). Elsewhere they are probably at most 30 ft thick and commonly are much thinner. These deposits are prone to renewed or continued landsliding and may be susceptible to settlement when loaded. They also indicate the setting in which future slope failures will likely occur. Shallow groundwater may be present within areas mapped as recent landslide deposits.

Qc

Colluvium (Holocene and late Pleistocene) — Unit ranges from unsorted, clast-supported gravel consisting of pebble-sized to boulder-sized rock fragments in a sandy or silty matrix, to matrix-supported gravelly sand or clayey silt. Colluvium is locally derived from weathered bedrock and surficial deposits and is transported a short distance downslope. As used herein, colluvium follows most aspects of the definition of Hilgard (1892), which allows colluvium to include a minor amount of sheetwash. Other processes, particularly debris flows, may be active at different times on the same hillslopes on which colluvium is the dominant material. As a result, many deposits mapped as colluvium likely include materials of varied genesis. The unit may also include talus, landslide deposits, sheetwash, and debris-flow deposits that are areally too small or too indistinct on aerial photographs to be mapped separately.

Colluvium is usually coarser grained in upper reaches and finer grained in distal areas. However, deposits derived from thick shale beds tend to be clayey and matrix supported throughout. Colluvial deposits are generally unsorted or poorly sorted with weak or no stratification. Most rock clasts in colluvium are angular to subangular, but colluvium derived from fluvial gravels will contain rounded clasts. Clast lithology is variable, as it depends on type of material exposed in the source area. Maximum thickness is estimated at about 30 ft, but the unit commonly is much thinner. Areas mapped as colluvium are susceptible to future colluvial deposition and locally subject to sheetwash, rockfall, small debris flows, mudflows, and landslides. Fine-grained, low-density colluvium may be prone to collapse upon wetting or loading.

Qls

Landslide deposits (Holocene and Pleistocene)— Heterogeneous deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Unit includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes. In a few areas, in particular the higher elevations on the eastern and southern sides of Bridge Timber Mountain and on the northern side of Basin Mountain, the unit may include deposits formed by solifluction or frost creep.

Landslide deposits are widely distributed across the quadrangle. Large landslide complexes are present on the east side of Bridge Timber Mountain. Most slope failures in this area are in the San Jose Formation, but slip planes also occur in rocks as old as the Kirtland Formation. The late Tertiary gravels that underlie Bridge Timber Mountain also are disrupted by the landslides, so the landslide deposits in this area are rich in rounded pebbles, cobbles, and boulders derived from the Bridgetimber Gravel. This led one previous investigator to mistakenly identify these landslide deposits as fluvial deposits (Richmond, 1965). Some landslide deposits on the east side of Bridge Timber Mountain have been reworked and redeposited as alluvium, debris-flow deposits, and sheetwash in a unit called the sediments of Sawmill Canyon **(Qsc)**.

Landslide deposits on the north side of Basin Mountain involve the Lewis Shale and surficial deposits derived from it. The overlying Pictured Cliffs Sandstone has been incorporated into many of the slides, creating deposits with abundant blocks and clasts of sandstone. Some of these landslides contain toreva blocks of sandstone. Smaller and more widely dispersed landslides are associated with many of the other formations, including the San Jose, Nacimiento, Animas, Kirtland, Lewis and Cliff House. Maximum thickness of landslide deposits may exceed 100 ft. Landslide deposits may be subject to future movement. Large blocks of rock locally found in these deposits may hinder excavation. Landslide deposits may be prone to settlement when loaded, and shallow groundwater may occur within them.

Qco

Older colluvium (Pleistocene)— Unit occurs on dissected hillslopes, ridgelines, and drainage divides as erosional remnants of formerly more extensive deposits that were transported primarily by gravity. Deposits near Black Ridge, in the upper reaches of La Posta Canyon, on the north side of Basin Mountain, and on the east side of Ridges Basin may be erosional remnants of older landslides. These remnants, however, no longer possess geomorphic features indicative of landslides, and therefore are mapped as older colluvium. Texture, bedding, and clast lithology resemble those of colluvium **(Qc)** and landslide deposits. The abundance of angular blocks and clasts of sandstone and the scarcity of rounded cobbles and pebbles of intrusive rocks distinguish older colluvium from the sediments of Sawmill Canyon **(Qsc)**. Older colluvium also tends to occur on steeper slopes. Maximum thickness probably is about 40 ft, but the deposits are commonly much thinner. Areas mapped as older colluvium generally are not subject to significant future colluviation, except where below steep, eroding hillslopes. Unit may be subject to collapse, piping, and settlement where fine grained and low in density.

ALLUVIAL AND COLLUVIAL DEPOSITS

Silt, sand, gravel, and clay deposited in alluvial and colluvial environments in fans, stream channels, flood plains, and adjacent hillslopes. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheetwash processes prevail on fans and on or adjacent to hillslopes.

Qfy

Younger fan deposits (Holocene)— Includes hyperconcentrated flow, debris-flow, alluvial, and sheetwash deposits in fans and tributary drainages. Locally the unit may include earthflows or landslides too small to map separately at a scale of 1:24,000. Younger fan deposits consist of crudely stratified deposits that range from very poorly sorted, clast-supported, pebble-sized, cobble-sized, and boulder-sized rock fragments in a clayey silt or sand matrix to matrix-supported, gravelly, clayey silt. Unit is frequently bouldery, particularly near the heads of some fans. Deposits tend to be finer grained in the distal ends of fans, where sheetwash and mudflow processes may be more common. Clasts range from angular to subround. Maximum thickness is estimated at about 30 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 is a potential minor 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 subordinate amounts of colluvium and sheetwash along valley sides.

Locally includes debris-flow deposits or small subdued hills underlain by bedrock. The alluvial and colluvial deposits are mapped as a single unit because they (1) are interbedded, (2) are gradational and have boundaries that are difficult to discern, or (3) occur side by side but are too small to show as individual polygons at the map scale. The alluvial component of the unit is poorly to well sorted and ranges from stratified fine sand to sandy gravel , whereas the colluvial component consists of poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt. Clast lithologies reflect the rocks within the provenance area.

A sample of charcoal was collected from this unit near the base of a 25-ft-high arroyo bank along Basin Creek in sec. 1U, T. 34 N., R. 10 W. The sample yielded a conventional radiocarbon age of 8,160±60 years BP (Beta Analytic sample no. 149934). The exposure consisted of interbedded silt, sand, gravelly sand, and pebbly sand, most of which was eroded from the McDermott Member in the hills northeast of the creek. The charcoal was a burned branch contained within a bed of gravelly medium-grained sand located about 20 ft from the top of the exposure and about 5 ft above the floor of the arroyo.

Unit Qac is commonly 5 to 15 ft thick and has a maximum thickness estimated at about 35 ft. Stream channels, adjacent flood plains, and low terraces may flood. Valley sides are prone to colluvial processes, sheetwash, rockfall, and small debris flows. Unit may be subject to settlement or collapse where low in density or to piping where fine grained and exposed in deep arroyo walls. These deposits are a potential source of sand and gravel.

Qcs **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene?)—** Unit is 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 gradational and difficult to discern. Refer to unit descriptions for colluvium **(Qc)** and sheetwash deposits **(Qsw)** for genetic, textural, and lithologic characteristics, and for engineering properties and geologic hazards. Thickness is typically 5 to 20 ft.

Qaco **Older alluvium and colluvium, undivided (Holocene and/or late Pleistocene)—** Unit includes scattered remnants of mixed alluvium and colluvium that cap hilltops in an area about one-half mile north of the mouth of Basin Creek. Deposits of older alluvium and colluvium also fill a basin floor on the north side of La Posta Canyon about one mile above its mouth. Physical characteristics of this unit are similar to those of alluvium and colluvium, undivided **(Qac)**. Thickness ranges between 3 to 20 ft. Unit may be a potential source of sand and gravel.

Qss **Sediments of Sheep Springs Gulch (late or middle Pleistocene)—** Unit includes gravel deposits that cap several broad benches, narrow ridges, and hilltops in the northwestern part of the quadrangle. Kirkham and others (1999) informally named the unit based on outcrops in Durango West quadrangle. The unit is poorly exposed, but appears to be chiefly of fluvial origin with subordinate amounts of sheetwash and debris-flow deposits. The sediments of Sheep Spring Gulch range 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 fragments of diorite porphyry and monzonite porphyry with lesser amounts of sandstone and siltstone that were originally eroded from the La Plata Mountains. These deposits grade westward (uphill) into landslide deposits that have formed on the southeastern margin of the prominent gravel-capped mesa on the eastern side of the La Plata River (Scott and Moore, 1981; Kirkham and others, 2000).

In the Basin Mountain quadrangle, the original depositional surfaces of most of the remnants of unit Qss are poorly preserved, and the base of the unit is rarely exposed. The poorly preserved depositional surfaces occur at fairly accordant positions in the landscape, suggesting deposition in a pediment or fan apron downslope from the landslide complex. To the north, in the Durango West quadrangle, remnants of this unit occur at higher positions in the landscape and are probably older than the sediments in Basin Mountain quadrangle (Kirkham and others, 1999). The sediments of Sheep Springs Gulch may be as much as 40 ft thick but typically are thinner. The unit is a potential source of sand and gravel.

Qsc

Sediments of Sawmill Canyon (late and/or middle Pleistocene)— This unit is similar in genesis to the sediments of Sheep Springs Gulch (Qss), but is associated with a different landslide complex. These gravelly deposits cap several broad benches and fan-like surfaces, narrow ridges, and isolated hilltops on the east and south sides of Bridge Timber Mountain in the south-central and southwest parts of the quadrangle. On the eastern side of the mountain, these sediments can be traced to the landslide complex at the base of the mountain in many areas, whereas in other areas, especially on the south and southeast sides of Bridge Timber Mountain, they occur as isolated remnants on hilltops and ridges and cannot be related to any obvious upslope source area. The sediments of Sawmill Canyon, especially those deposits on the south and southeast sides of the mountain, occur at various positions in the landscape and probably were deposited at different times during the late and/ or middle Pleistocene.

The unit is well exposed in the steep hillslopes in La Posta and Goat Canyons but is poorly exposed elsewhere. Basal contacts are rarely observed except in the steep hillslopes of the two canyons. On the basis of available exposures, the unit appears to be primarily of fluvial origin with subordinate amounts of debris-flow deposits and sheetwash. The sediments of Sawmill Canyon range from poorly sorted, stratified, clast-supported, silty, clayey, and sandy, cobble and pebble gravel to poorly sorted, unstratified, matrix-supported sandy to clayey gravel and gravelly clayey silt. Clasts are chiefly rounded to subangular fragments of commonly very weathered diorite porphyry and monzonite porphyry, with lesser amounts of sandstone and siltstone. Most clasts in the unit have been reworked at least twice. The clasts were originally deposited in the fluvial Bridgetimber Gravel, then incorporated into the landslide complex that borders the mountain. They were subsequently eroded from the landslides and redeposited as the sediments of Sawmill Canyon. The unit is as much as 80 ft thick but more typically is 10 to 20 ft thick. It is a potential source of sand and gravel.

EOLIAN DEPOSITS

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

Qlo

Loess (late and late middle? Pleistocene)— Reddish-brown to light-brown sandy silt and silty, very fine sand deposited by wind. Deposits may be slightly clayey. In many areas the contacts are approximately located, because the deposits lack distinctive geomorphic expression and sometimes are very thin. Loess is commonly unstratified, friable, and plastic or slightly plastic when wet. Unit commonly overlies the sediments of Sawmill Canyon (Qsc), locally overlies outwash terraces along the Animas River, and occurs as scattered small remnants over the Cliff House Sandstone in the northwest part of the quadrangle. Small unmapped deposits of loess may be found in many parts of the map area. Thickness is as much as about 20 ft but commonly is only a few feet to several feet thick. Low-density loess may be prone to settlement when loaded, to hydrocompaction when wetted, or to piping where exposed adjacent to steep hillslopes or deep arroyos.

SEDIMENTARY BEDROCK

Tsj

San Jose Formation (Lower Eocene)—Mostly red, gray, brown, and dark-greenish-brown shale, mudstone, and sandy shale interbedded with light-gray, grayish-yellow, red-brown, and brown fine-grained to conglomeratic sandstone. Lower and upper parts of the unit are mostly shale and mudstone. A prominent thin interval of indurated sandstone beds is in the middle part of the formation and serves as a fairly good stratigraphic marker. The base of the cliff-forming sandstone beds was mapped as the “c” contact by Barnes and others (1954), a practice we have followed on our map. This cliff-forming sandstone interval consists of several beds of sandstone; as many as four stacked beds were observed in some locations. The individual beds within the “c” sandstone interval partially overlap and progressively climb in the stratigraphic section towards the Laramide-age paleovalley that is cut through the Hogback monocline at Bridge Timber Mountain. Conglomeratic clasts in the “c” sandstone beds include granule- and small pebble-sized fragments of rounded quartz, chert, jasper, sandstone, andesite(?), and diorite.

The lower shale-rich interval of the San Jose Formation thins rapidly to the north and northwest. Although exposures are poor, this basal shaly interval may be absent within the Bridgetimber paleovalley. The “c”sandstone interval and upper shaly part of the formation apparently were deposited within the Bridgetimber paleovalley. Tuff beds were described in the San Jose Formation by several previous investigators (for example, Baltz, 1953; Barnes and others, 1954; Aubrey, 1991).

Simpson (1948) was the first to call Eocene rocks in the San Juan basin the San Jose Formation. Previously, these strata were referred to as the Wasatch. Baltz (1953, 1967), Barnes and others (1954), Smith (1988), and Smith and Lucas (1991) divide the San Jose into four or five members in the southern part of the San Juan basin. No members are defined in the map area, but work by Smith (1988, 1992) immediately south of the quadrangle suggests that the Lower Eocene rocks in the map area may correlate with the Regina Member.

The contact between the San Jose Formation and underlying Nacimiento Formation is poorly constrained in most of Basin Mountain quadrangle. In and near the Bridgetimber paleovalley, the San Jose was deposited on an angular unconformity that is cut on progressively older rocks folded by the Hogback monocline. The Nacimiento, Animas, and even most of the Kirtland are cut out beneath the unconformity. In this area, dips in the San Jose Formation are flatter than in the underlying formations. In the southern part of the quadrangle, south of the monocline, no difference in the dips of the San Jose and underlying rocks are discernable. There may be a disconformity between the formations, but Barnes and others (1954) and Stone and others (1983) described the contact between the San Jose and Nacimiento Formations as conformable in areas south of the Bridgetimber paleovalley to beyond the Colorado-New Mexico state line. Further south in New Mexico, Baltz (1967) and Lucas and others (1981) demonstrated that the contact is an unconformity. In the southern part of the quadrangle, we arbitrarily placed the San Jose-Nacimiento contact at the base of a fairly prominent and continous sandstone bed that appears to correspond to contact "b" of Barnes and others (1954). The San Jose Formation was deposited in a fluvial environment (Smith, 1988). Maximum preserved thickness in the quadrangle is about 1,000 ft. The formation is prone to landsliding in the higher parts of the quadrangle near Bridge Timber Mountain.

Tn

Nacimiento Formation (Paleocene)— Gray, red, brown, and green shale and mudstone interbedded with tan, yellowish- to greenish-gray fine-grained sandstone. Although the Nacimiento Formation is well studied in the New Mexico part of the San Juan basin, it is poorly understood in the vicinity of Basin Mountain quadrangle. In geologic maps by Barnes and others (1954), Steven and others (1974), and Condon (1990), the Nacimiento crops out beneath much of the south-central part of the quadrangle, but Fassett (1985), and cross sections by Smith (1988, 1992) and Smith and Lucas (1991), suggest the San Jose Formation overlies the Animas Formation in Basin Mountain quadrangle and that the Animas and Nacimiento Formations are laterally equivalent. Because of this discrepancy, and because detailed stratigraphic study of these rocks was beyond the scope of this investigation, we chose to map the San Jose and Nacimiento as distinct formations and to use the contact between them that was defined by Barnes and others (1954) and Baltz (1966). It is possible that rocks mapped in this report as Nacimiento Formation may actually be part of the San Jose Formation.

The Nacimiento Formation, as mapped in this investigation, conformably overlies the Animas Formation in the quadrangle except in and east of the Bridgetimber paleovalley, where the Nacimiento overlies an angular unconformity cut on the Animas Formation. The apparent discordancy of dips in the two formations across the angular unconformity is observable in sec. 22, T. 34 N., R. 10 W. (Barnes and others, 1954), where dips in the Nacimiento are about 2° to 4° and dips in the Animas vary from 8° to 22°. In the remainder of the quadrangle the contact between the Nacimiento and Animas Formations is gradational.

The Nacimiento Formation contains Puercan and Torrejonian fossils in New Mexico, indicating a Paleocene age (Baltz, 1967). It was deposited in an alluvial environment. Thickness of the Nacimiento Formation is poorly constrained in the quadrangle; Barnes and others (1954) suggested a maximum thickness of about 350 ft for the Nacimiento Formation in this area.

Tsn

San Jose and Nacimiento Formations, undivided (Eocene and Paleocene)— Mapped between Goat and Sawmill Canyons where limited exposures prevent recognition of the contact between the formations

Animas Formation (Paleocene and Upper Cretaceous)— Unit includes two members, the upper member and underlying McDermott Member. These rocks were originally named the Animas River beds by Cross (Emmons, Cross, and Eldridge, 1896) for exposures along the Animas River valley and later called the Animas Formation in stratigraphic sections by J.H. Gardner (in Lee, 1912; Lee and Knowlton, 1917). Reeside (1924) subsequently subdivided these strata into two formations, the Animas and McDermott Formations. Barnes and others (1954) believed the two formations were genetically similar and gradational, and that only color differentiated them. They assigned member status to the two formations and described them as a locally present McDermott Member and an upper member. Where the McDermott was absent, the upper member comprised the entire formation (Barnes and others, 1954). Our investigation suggests the two members have different source areas and that an angular unconformity may separate them. A locally present, brightly colored interval of rocks at the top of the McDermott may be a paleosol (Sikkink, 1989) that was partially removed by erosion as the angular unconformity was cut. Alternatively, these strata may be brightly colored due to diagenetic alteration, in which case the thinning of the interval would relate to variation in thickness of the altered zone.

Ta

Upper member (Paleocene)— Olive-brown, light-brown, gray-green, and light-reddish-brown shale, sandstone, conglomerate, and minor lithic tuff, tuffaceous sandstone and thin coal and carbonaceous shale. The upper member of the Animas Formation constitutes a generally fining-upward sequence; the basal part of the unit is mostly conglomerate, conglomeratic sandstone, and sandstone, whereas the upper part of the unit is chiefly shale and sandstone, with subordinate amounts of conglomerate and sparse carbonaceous and coaly shale and very thin coal beds. Locally the base of the upper member contains a thin interval of strata that include beds typical of the upper member and beds that appear to be reworked material from the brightly colored rocks at the top of the underlying McDermott Member. Fine-grained material in the upper Animas is predominantly reworked and weathered volcanic detritus, with arkosic sandstones and conglomerates present in the top of the member. Conglomerate clasts are predominantly of volcanic origin. Siliceous rocks, chiefly quartz, quartzite, chert, granite, and weathered intrusive rocks that may be diorite porphry comprise a minor component of the conglomeratic clasts; non-volcanic clasts are more common in the upper part of the formation. Subrounded clasts of coal were noted in conglomeratic beds in the Animas that crop out on the ridgeline between the Animas River and Basin Creek in the SW⁄ NE⁄ of sec. 13, T. 34 N., R. 10 W. This suggests an older coal-bearing formation was exposed at the land surface in a nearby upland, as the Animas was being deposited. The continental deposits in the upper member of the Animas were deposited in fluvial and alluvial-fan environments (Fassett, 1985; Smith and others, 1985). Laramide volcanoes in the San Juan Mountains are commonly postulated as the source of the volcanic material in the upper member (for example, Fassett, 1985; Aubrey, 1991).

The upper member of the Animas Formation contains Paleocene plant fossils (Knowlton, 1924), and imprints of logs are common. Late Paleocene Tiffany vertebrate fauna were reported in the upper member by Granger (1917) and Simpson (1935a, b, c), which is younger than the age of the Nacimiento as dated in New Mexico. Perhaps this apparent age discrepancy relates to deposition of the Nacimiento Formation in New Mexico prior to deposition of the upper Aminas in Colorado. Newman (1987) described early Paleocene (Puercan) palynomorphs from upper Animas strata about 100 ft above the McDermott. These data support a Paleocene age for the upper member of the Animas Formation, although no age control is available for the basal 100 ft of the member, which potentially could be Upper Cretaceous. Reeside (1924) reported a thickness of 1,110 ft for the upper member of the

Animas Formation based on a measured section along the Animas River immediately east of the quadrangle.

Kam

McDermott Member (Upper Cretaceous) — Mostly purplish-red to red-brown, poorly sorted sedimentary breccia, conglomerate, sandstone, conglomeratic sandstone, shale, and siltstone in a generally fining-upward sequence. The basal part of the unit, which commonly crops out in bold hogbacks, is coarser grained and dominantly matrix-supported sedimentary breccia, clast-supported conglomerate, and conglomeratic sandstone that grades upward into shale, siltstone, sandstone, and conglomeratic sandstone. Sedimentary breccia, which most previous workers described as volcaniclastic conglomerate or lahar (Reeside, 1924; Barnes and others, 1954; Sikkink, 1987), comprises much of the basal McDermott bed in most of the quadrangle. One bed in the basal part of the member between Indian Creek and McCullough Canyon contains euhdral plagioclase crystals and lacks sedimentary matrix, suggestive that the unit is an igneous flow or sill. Tables 2 and 3 describe the whole-rock chemistry of a sample collected from this bed.

Most clasts in the conglomerates and conglomeratic sandstones are round to subangular pebbles and cobbles, whereas clasts in the sedimentary breccia are chiefly angular to subangular and are as much as about 6 ft in diameter. The clasts are chiefly fine- to medium-grained, frequently porphyritic igneous rocks, with subordinate amounts of quartz, quartzite, and chert. The clasts are generally weathered or altered, making positive identification of the clast lithology difficult. The interior portions of some large boulders are relatively fresh, and are intrusive rocks that are megascopically similar to rocks exposed in the La Plata Mountains (D. Gonzales, 2001, oral communication). Geochemical analyses for two of the fresh samples collected from the interior of large boulders are presented in Tables 4 and 5. The two sampled clasts are quartz monzodiorite or quartz monzogabbro, based on the IUGS classification system. These geochemical data are included because they may be useful to future studies of the McDermott clasts. Detailed comparisons of the McDermott clasts with intrusive rocks exposed in the La Plata Mountains, including both petrographic studies and geochemical correlation, could potentially establish the provenance of the McDermott.

In several parts of the quadrangle beds of light-brown to greenish-brown, matrix-supported sedimentary breccia occur in the basal part of the predominantly purplish McDermott Member. Following the approach of Zapp (1949) and Carroll and others (1997), these beds were initially interpreted as tongues of Animas-like sediments within the basal McDermott Member. However, the color changes are at least locally a result of chemical alteration.

An interval of brightly colored, purple, red, and pink, chiefly mottled shale and siltstone that is locally present at the top of the McDermott Member was interpreted as a paleosol by Sikkink (1987). Alternatively, the brightly colored strata could be evidence of diagenetic alteration along the contact between the McDermott and upper members of the Animas. The mottled or speckled appearance of the rocks results from the abundant blebs and worms of a light-colored, tan to white mineral surrounded by the red and purple iron-oxide-rich matrix. Sikkink (1987) described the light-colored minerals as kaolinite and chalcedony. Petrographic examination of this material suggests it may be a zeolite mineral (J. Cappa, 2001, oral commun.). Small root structures, small burrows, and traces of organic materials are suggestive of a paleosol origin (Sikkink, 1987). The brightly colored and mottled strata locally contain abundant small, irregular, intersecting planes with prominent slickenlines, possible evidence of near-surface shrink-swell behavior of soil (M. Gillam, 2001, oral communication). If these strata are a paleosol, then a period of non-deposition and weathering of exposed sediments occurred after deposition of the McDermott Member and prior to deposition of the upper member of the Animas Formation.

The brightly colored and mottled strata are only locally present. They crop out intermittently along the Hogback monocline in Basin Mountain quadrangle,

Table 2. Whole-rock XRF geochemical analysis of a possible igneous flow or sill in the basal part of the McDermott Member of the Animas Formation. Analysis by ALS Chemex, Sparks, Nevada. Values given in weight percent.

Sample No.	Al_2O_3	Bao	CaO	Cr_2O_3	Fe_2O_3	K_20	MgO	MnO	Na_2O	P_2O_5	SiO_2	SrO	TiO_2	LOI	Total
BM 89	17.1	0.11	8.39	<0.01	8.27	1.48	2.67	0.59	5.15	0.33	49.08	0.08	0.95	5.36	99.56

Table 3. Whole-rock ICP-MS geochemical analysis of a possible igneous flow or sill in the basal part of the McDermott Member of the Animas Formation. Analysis by ALS Chemex, Sparks, Nevada. Values given in weight parts per million.

Sample No.	Ba	Ce	Cs	Co	Cu	Dy	Er	Eu	Gd	Ga	Hf	Ho	La	Pb	Lu	Nd	Ni	Nb
BM 89	662	32.0	0.8	11.5	15	2.8	1.5	1.2	3.5	12	<1	0.5	16	<5	0.2	20.5	<5	7

Sample No.	Pr	Rb	Sm	Ag	Sr	Ta	Tb	Tl	Th	Tm	Sn	W	U	V	Yb	Y	Zn	Zr
BM 89	4.9	13.2	4.1	<1	509	<0.5	0.5	<0.5	1	0.2	<1	<1	1.5	150	1.4	14.5	35	65.5

Table 4. Whole-rock XRF geochemical analyses of relatively fresh clasts in the McDermott Member of the Animas Formation. Analysis by ALS Chemex, Sparks, Nevada. Values given in weight percent.

Sample No.	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_20	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	Total
BM 49	17.47	1.19	0.05	3.82	2.65	1.23	0.12	7.17	0.20	63.16	0.53	1.57	99.16
BM 88	18.13	5.07	0.04	5.45	2.58	0.24	0.26	4.38	0.41	58.58	0.81	3.05	99.00

Table 5. Whole-rock ICP-MS geochemical analyses of relatively fresh clasts in the McDermott Member of the Animas Formation. Analysis by ALS Chemex, Sparks, Nevada. Values given in parts per million.

Sample No.	Ba	Ce	Cs	Co	Cu	Dy	Er	Eu	Gd	Ga	Hf	Ho	La	Pb	Lu	Nd	Ni	Nb
BM 49	1900	81.0	3.0	6.0	5	3.9	2.2	1.7	5.5	20	4	0.8	38.0	<5	0.3	35.0	<5	16
BM 88	4340	71.0	0.9	5.5	30	4.2	2.3	1.9	5.7	26	5	0.8	35.5	<5	0.4	29.5	5	15

Sample #	Pr	Rb	Sm	Ag	Sr	Ta	Tb	Tl	Th	Tm	Sn	W	U	V	Yb	Y	Zn	Zr
BM 49	9.1	30.8	6.1	<1	829	1.0	0.8	<0.5	6	0.3	1	<1	2.5	50	2.2	21.5	70	176.5
BM 88	7.7	47.0	5.9	<1	939	1.0	0.8	<0.5	7	0.3	1	<1	3.5	110	2.3	21.5	80	189.0

starting on the north side of McCullogh Canyon and extending beyond the eastern margin of the quadrangle. Between McCullogh Canyon and Pine Canyon the interval is fairly continuous, whereas between Pine Creek and the Animas River it appears to be very lenticular, and alternately thins and thickens. In a good exposure on the west bank of the Animas River about one-half mile east of the quadrangle boundary, the brightly colored and mottled strata thin eastward and completely pinch out.

Reeside (1924) described the contact between the McDermott and upper members of the Animas Formation as an angular unconformity, but Zapp (1949), Baltz (1953), and Barnes and others (1954) considered it to be conformable. The contact relationship will not be known until the origin of the brightly colored and mottled strata at the top of the McDermott is determined. If these strata are a paleosol, then the contact is probably an angular unconformity. If the brightly colored interval is related to diagenesis, then the contact is probably conformable.

The McDermott Member of the Animas was deposited in fluvial and debris-flow environments, perhaps in an apron around the source area (Fassett, 1985). Reeside (1924) described indeterminate dinosaur bones, fragments of turtle bone, and plant fossils probably of Late Cretaceous age in the McDermott Member. Fragments of dinosaur bones observed during this investigation in float overlying the top of the McDermott Member between Basin Creek and Pine Canyon supports a Late Cretaceous age. Pollen collected from strata about 10 ft above the base of the McDermott Member is early Maastrichtian and is similar to pollen from the upper Kirtland (Newman, 1987). The McDermott Member conformably overlies the Kirtland Formation. Sikkink (1987) reported a thickness of about 350 ft for the McDermott Member in a measured section along Indian Creek. Other measured sections from east of the quadrangle indicate a thickness of 256 to about 290 ft (Reeside, 1924; Sikkink, 1987).

Kk

Kirtland Formation, undivided (Upper Cretaceous)—Consists of three members, a lower member, Farmington Sandstone Member, and upper member. Undivided formation is shown on cross section only. The unit was originally named the Kirtland Shale by Bauer (1916) for "predominantly clayey" strata that conformably overlie the Fruitland Formation. Lindsay and others (1981) renamed the unit the Kirtland Formation because sandstone and siltstone are the dominant lithologies. The lower and upper members are chiefly shale and form two parallel valleys or swales on either side of the hills underlain by the sandstone-rich Farmington Sandstone Member. Contacts between the members are gradational. They are mapped largely from the landforms associated with the lenticular, erosion-resistant sandstone beds in the Farmington Member, because the upper and lower shale members rarely crop out.

Hunt and Lucas (1992) proposed new names for the lower shale member (a basal Bisti member and overlying Hunter Wash member) and for the upper shale member (De-na-zin member and Naashoibito member), but this nomenclature was not adopted for this study because these strata are seldom exposed. The Kirtland Formation conformably overlies the Fruitland Formation. It was deposited in alluvial environments on the landward side of the Fruitland coastal plain (Fassett and Hinds, 1971; Aubrey, 1991; Carroll and others, 1999). Guide palynomorphs from the Farmington Sandstone Member and upper shale member are early Maastrictian (Newman, 1987). Hunt and Lucas (1992) suggested that their four lower members in the Kirtland Formation are Edmontonian (early Maastrictian), and their uppermost member in the Kirtland, the Naashoibito, is of Lancian (late Maastrictian) age. Thickness of the formation ranges from about 900 to 1,250 ft in the quadrangle.

Kku

Upper member—Olive-gray to medium-gray shale and siltstone interbedded with yellowish-gray to white sandstone. Sandstone beds are fine to medium grained, locally conglomeratic, and cross-bedded. A thick, prominent, white, cliff-forming sandstone commonly crops out at the top of the member. In Indian Creek these strata include conglomerate and conglomeratic sandstone containing well-rounded siliceous clasts. Zapp (1949) included these conglomerate beds in the Upper Kirtland, whereas Barnes and others (1954) placed them in the McDermott Member of the Animas. In two locations on either side of Pine Canyon, lag gravel and float consisting of well-rounded clasts of quartzite, quartz, and chert were found near the McDermott-Kirtland contact. These clasts may be eroded from a conglomeratic bed in the top of the upper shale member of the Kirtland. Feldspar, mafic minerals, and volcanic detritus in the upper shale member indicate a northern source area, and southwest-oriented paleocurrent directions support this interpretation (Klute, 1986). The upper member varies from about 100 to 200 ft thick. It may contain shale beds prone to shrink-swell problems.

Kkf

Farmington Sandstone Member—Yellowish-gray, tan, and light-orange, fine- to medium-grained sandstone and olive-gray to medium-gray shale. Sandstone beds are fine to medium grained with subround to round grains, crossbedded, well sorted, and non-calcerous. The Farmington Sandstone Member averages about 650 ft thick. It may cause rockfall hazards where exposed in steep cliffs, and may be difficult to excavate.

Kkl

Lower member—Olive-gray to greenish-gray shale, siltstone, and sandy shale with thin interbedded lenses of light-gray to greenish-gray fine-grained sandstone. Contact with the underlying Fruitland Formation is conformable and has been placed at various stratigraphic positions by different workers. According to Hunt and Lucas (1992), Bauer (1916) and Reeside (1924) originally placed the contact at the top of a sandstone that was above the last persistent coal bed. Hunt and Lucas now include this sandstone bed in the Bisti member of the Kirtland Formation. Most investigations conducted during the past several decades defined the contact as the top of the highest coal, an arbitrary contact that rises or falls depending on the continuity of the upper coal seams. In subsurface work the coal bed must be thick enough to be characterized on geophysical logs, so thin coals in the upper Fruitland might not be recognized. Hunt and Lucas (1992) recommended placing the contact at the base of a sequence of brown-capped sandstones, but these strata were not consistently recognized in Basin Mountain quadrangle, largely due to poor exposures. For this investigation, the Kirtland-Fruitland contact is placed at the base of the first green shale above the highest persistent Fruitland coal bed. Thickness of the lower member of the Kirtland ranges from about 150 to 300 ft. This member includes shale beds that may have shrink-swell potential.

Kf

Fruitland Formation (Upper Cretaceous)—Light-gray, light-brown, and olive-green very fine- to medium-grained sandstone interbedded with light-brown to dark-gray claystone and mudstone and brown, gray, and black carbonaceous shale and bituminous coal that contains tonsteins. Locally includes burnt rock and clinker resulting from burning of coal beds within the formation. Sandstone beds and coal beds are thicker in the lower part of the formation, whereas claystone, shale, and mudstone comprise much of the upper part of the formation. Holmes (1877) originally named these strata the Laramie Formation. Bauer (1916) renamed these rocks the Fruitland Formation. They have been studied extensively throughout the San Juan basin (for example, Reeside, 1924; Fassett and Hinds, 1971; Hunt and Lucas, 1992).

Most beds in the Fruitland are discontinuous; coal beds are the most continuous and some can be traced for miles (Barnes and others, 1954; Carroll, 1999; Streufert, in Wray, 2000). Fruitland coal beds have well-developed cleat. Carroll (1999) mapped the Fruitland coal beds south of the Ute Line in detail, and Streufert (in Wray, 2000) mapped them in detail north of the Ute Line. The basal coal in the Fruitland Formation is generally the thickest and most continuous coal bed in the formation, but the character of the basal coal bed changes near the tip of the tongues in the Pictured Cliffs Sandstone. Coal beds that are higher in the formation, especially those in the second coal interval above the main body of the Pictured Cliffs Sandstone, can locally be thick. The highest coal beds with the Fruitland tend to be carbonaceous.

The Fruitland Formation intertongues with the underlying Pictured Cliffs Sandstone in two small areas: north of Basin Creek (Condon, 1997; Streufert, 2000) and north of Bridge Timber Mountain. The thin tongue north of Basin Creek extends northward for about one-half mile but is not present on the south side of Basin Creek. A measured section by Streufert (2000) indicated this Fruitland tongue is a total of 6 ft thick and includes, in ascending order, a basal shale bed that is 4 ft thick, a 1-ft-thick carbonaceous shale bed, and a coal bed 1 ft thick. The coal bed within the Fruitland tongue pinches out about one-quarter mile north of Basin Creek, and farther north the tongue is as much as 50 ft thick but is composed only of sandstone and shale (Condon, 1997). The Fruitland tongue eventually dies out or becomes indistinguishable from the Pictured Cliffs near the center of the Sfi of sec. 6, T. 34 N., R. 9 W.

A second minor intertonguing of the Fruitland and Pictured Cliffs is on the ridgeline extending north from Bridge Timber Mountain. The tongue of Pictured Cliffs Sandstone caps a small hill on the west side of the ridgeline. The Fruitland Formation and an unknown thickness of the Pictured Cliffs tongue are eroded from the hill; the preserved remnant of Pictured Cliffs tongue is 10 to 15 ft thick. The underlying Fruitland tongue is very poorly exposed, but appears to be about 5 or 6 ft thick and includes a bed of coal.

The lower part of the Fruitland Formation was deposited in non-marine, brackish water lagoonal and swampy coastal-plain environments that grades upward into well-drained coastal-plain environments (Condon, 1990). A Late Cretaceous age is widely accepted for the Fruitland Formation. Hunt and Lucas (1992) suggested a Judithian (late Campanian) age for the Fruitland, based on evidence from marine invertebrates, mammals, dinosaurs, and pollen. The formation usually averages about 400 ft thick, but ranges from 320 ft to over 600 ft thick in some gas wells (Petroleum Information/ Dwights LLC, 2000) and measured sections (Zapp, 1949; Condon, 1997; Streufert, in Wray, 2000). The thickest Fruitland coal beds are usually in the basal part of the formation, and they tend to be thickest adjacent to tongues or buildups of Pictured Cliffs Sandstone. Minor historic mining of Fruitland coals in the quadrangle is evidenced by the small adits and mine dumps scattered across the quadrangle, for which there is no recorded production. The Fruitland is the primary production horizon for San Juan basin coalbed methane. Many producing gas wells in the quadrangle are completed in the Fruitland. Methane and associated gases may seep from outcrops of Fruitland strata. A possible gas seep is in sec. 16, T. 34 N., R. 10 W. (C. Carroll, 2001, written communication), and gas seeps from Fruitland coals in many other parts of the northern San Juan basin. Ground water pumped from the Fruitland Formation may contain methane. Areas overlying coal mines in the Fruitland may be prone to subsidence. Burning coal beds can be hazardous.

Kpc

Pictured Cliffs Sandstone (Upper Cretaceous)—Light-gray to white, tan or grayish-orange, fine-to medium-grained sandstone and medium- to dark-gray shale. The sand grains are mostly quartz, with minor amounts of potassium feldspar, plagioclase feldspar, and coal fragments. Coal fragments are more abundant near the top of the formation. Calcite, clay, and silica are the primary cementing materials.

The formation typically consists of two parts, an upper and lower part. The upper part is composed of one or more thick, massive sandstone beds that are interbedded with thin beds of shale. The upper part of the formation intertongues with the overlying Fruitland Formation. The tips of the Pictured Cliffs tongues in the top of the formation are generally oriented southwestward or landward from the northwest-trending shoreline. Abrupt rises in the top of the formation, commonly referred to as "buildups", were noted in several locations. The top of the Pictured Cliffs is about 30 to 40 ft higher on the northwest side of a southeast-facing buildup in the NE⁄ NE⁄ of sec. 13, T. 34 N., R. 11 W. In another prominent buildup in the SW⁄ NW⁄ of sec. 9U, T. 34 N., R. 10 W., the top of the Pictured Cliffs rises 10 to 12 ft on the west side of an east-facing buildup. The lower part of the formation, which is transitional and intertonguing with the underlying Lewis Shale, contains thin alternating beds of shale and sandstone; the shale is similar to beds in the Lewis and the sandstone is similar to beds in the upper part of the Pictured Cliffs. The shale interbeds thicken and compose more of the formation towards the base of the unit. An unusually thick tongue of sandstone occurs in the lower part of the Pictured Cliffs in West Gap.

Locally the sandstone beds contain sparse to abundant pellet-lined *Ophiomorpha* burrows that are characteristic of sediments deposited in shallow-marine environments (Fassett and Hinds, 1971). Iron cementation causes *Ophiomorpha* burrows to be locally well preserved on the prominent sandstone surface exposed at the top of the Pictured Cliffs on Basin Mountain. The iron cementation locally forms a hard caprock at the top of the formation. In addition to forming prominent dip-slope pavements, the thick sandstones in the upper part of the Pictured Cliffs Sandstone crop out in bold cliffs between Basin Creek and Moving Mountain. Elsewhere they generally form rounded ledges. Sandstone beds in some outcrops of the Pictured Cliffs locally have a honeycombed appearance, with large grottos and rounded overhanging sides.

The Pictured Cliffs Sandstone was named by Holmes (1877) for outcrops along the San Juan River west of Fruitland, New Mexico that contain numerous native American petroglyphs. The formation is conformable and intertonguing with both overlying and underlying formations. The contact with the underlying Lewis Shale is placed where shale comprises over half of the strata. It was deposited in a shallow, prograding marine, shoreface environment associated with the final regression of the Cretaceous Western Interior Seaway (Fassett and Hines, 1971; Condon, 1990; Aubrey, 1991). Buildups of the Pictured Cliffs Sandstone occurred during periods of shoreline stability, and tongues of sandstone formed during periods of minor shoreline transgression. Thickness is generally between 225 to 250 ft but changes abruptly due to buildups and tongues. The Pictured Cliffs Sandstone may pose rockfall hazards where exposed in cliffs. It is a reservoir for natural gas in the San Juan basin.

Kpct

Tongue of Pictured Cliffs Sandstone— Light-gray to white, tan or grayish-orange sandstone intertongued with the basal Fruitland Formation. Mapped in two areas in the quadrangle: north of Basin Creek and north of Bridge Timber Mountain. *Ophiomorpha* burrows were not observed in either tongue. In the area north of Basin Creek, the map unit includes a thin underlying tongue of Fruitland Formation, which is denoted on the map by the special symbol. Refer to the unit descriptions for the Fruitland Formation and Pictured Cliffs Sandstone for additional descriptions of the Pictured Cliffs tongue.

Kl

Lewis Shale (Upper Cretaceous)—Dark-gray, fissile shale containing thin sandstone beds at the top of the formation and gray, rusty-weathering concretionary limestone in the lower part. Altered volcanic ash beds within the Lewis Shale, most notably the Huerfanito Bentonite Bed (dated at 75.76 Ma by Fassett and Steiner, 1997), are used as time-stratigraphic markers throughout the San Juan basin (Fassett and Hinds, 1971; Fassett and Steiner, 1997). Although the Lewis underlies much of the quadrangle north of Basin Mountain and Carbon Mountain, it rarely crops out except in artificial excavations or stream banks. The unit weathers easily and is generally covered by surficial deposits, mostly residuum, colluvium, landslide deposits, and alluvium.

A large mosasaur was discovered in a calcareous iron-stained bed in the middle part of the Lewis Shale during the fall of 2000 (G. Gianney and S. Lucas, 2001, written communications). The specimen was found by a contractor who was excavating a foundation for a new residence in Trappers Crossing subdivision in the NW/ of sec. 7U, T. 34 N., R. 10 W. The fossil-bearing block of rock was set aside, and the Fort Lewis College geology department was later notified of its existence. The specimen was collected and transported to the New Mexico Museum of Natural History for preparation and study.

The Lewis Shale conformably overlies the Cliff House Sandstone in a gradational contact or intertonguing relationship. A subtle slope break commonly coincides with the Lewis-Cliff House contact. The Lewis Shale was deposited in a low-energy, off-shore, marine environment (Fassett and Hinds, 1971). Formation thickness ranges from about 1,600 to 1,850 ft in the quadrangle. It is a minor reservoir for natural gas in the San Juan basin. The Lewis Shale is prone to landsliding, especially along the northern flank of Basin Mountain. The Lewis Shale is susceptible to shrink-swell problems where it contains expansive clays.

Kmv

Mesaverde Group (Upper Cretaceous)— Consists of three formations, which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone. Only the Cliff House Sandstone, the upper part of the Menefee Formation, and a mappable tongue of the Cliff House crop out in Basin Mountain quadrangle. The undivided Mesaverde Group is shown only on cross section.

Kch

Cliff House Sandstone—Interbedded sequence of thin beds of weakly to moderately indurated, calcareous sandstone and easily eroded light-gray mudstone, siltstone, and silty shale. Sandstone beds contain locally abundant small-diameter *Ophiomorpha* burrows. The sandstone beds weather to yellow brown or light-red brown, forming a rusty-colored outcrop or residuum that sharply contrasts with the drab colors of the underlying Menefee Formation, with the dull-gray colors of the overlying Lewis Shale, and with surficial deposits derived from them. The Cliff House Sandstone caps many of the broad, rounded ridges and hills in the north-central part of the quadrangle in the vicinity of Ridges Basin and Wildcat Canyon.

Individual sandstone beds within the Cliff House Sandstone thicken west of the quadrangle. Barnes and others (1954) described sandstone beds up to 14 ft thick on Weber Mountain south of the town of Mancos. In Mesa Verde National Park sandstone beds in the Cliff House may exceed 100 ft in thickness (Wanek, 1959). To the east of Basin Mountain quadrangle, shale and siltstone beds within the Cliff House thicken and sandstone beds thin (Carroll and others, 1999). The Cliff House Sandstone is usually poorly exposed in the quadrangle except in artificial cuts and stream banks.

The contact with the underlying Menefee Formation is locally disconformable (Barnes and others, 1954; Condon, 1990). There commonly is a subtle but consistent slope break at the Menefee-Cliff House contact. To the west on Barker Dome, Barnes and others (1954) described local intertonguing of the Cliff House Sandstone and Menefee Formation. Kirkham and others (2000) described similar intertonguing relationships in Hesperus quadrangle. Conclusive evidence of intertonguing of the Menefee and Cliff House was not found in Basin Mountain quadrangle.

The Cliff House Sandstone is a transgressive, shallow marine unit rapidly deposited on the upper shoreface zone of a barrier-island beach front (Siemers and King, 1974). Thickness in the quadrangle averages about 350 to 400 ft and may locally exceed 440 ft. East of Basin Mountain quadrangle the formation thins. Shale beds in the Cliff House Sandstone may have moderate to high swell potential. The formation is an important natural gas reservoir in the San Juan basin.

Kcht

Tongue of Cliff House Sandstone—Thin beds of moderately hard, yellowish-orange to white, very fine- to fine-grained sandstone intertongued with the basal part of the Lewis Shale. Mapped only in the northeast part of the quadrangle. Remnants of the Cliff House tongue in the northeast part of Ridges Basin southwest of the power substation were previously interpreted as part of the main Cliff House strata that were in fault contact with the Lewis along the Ridges Basin fault (Zapp, 1949; Colorado Geological Survey, 1981; Moore and Scott, 1981; Condon, 1990). Jacobs-Weston Team (1985b) was the first to suggest these sandstone bodies were in-place tongues of Cliff House, not faulted strata. Our mapping supports the non-tectonic origin, because beds of Lewis Shale are present both below and above these sandstone tongues.

As originally mapped by Zapp (1949), the Ridges Basin fault continued southwestward into the low bedrock hills near the center of Ridges Basin, where Cliff House strata appear to be in fault contact with the Lewis. We did not locate conclusive field evidence that this body of sandstone was another Cliff House tongue and therefore chose to follow the majority of the literature and map the feature as a fault. A shallow drill hole or trench would probably yield definitive evidence on the origin of this feature.

Kmf

Menefee Formation—Interbedded gray, brown, and black carbonaceous shale and siltstone, light-gray, brown, and orange-brown, locally lenticular, crossbedded sandstone, and coal. Only the upper part of the formation crops out in the quadrangle. The Menefee Formation locally includes burnt rock and clinker resulting from burning of coal beds within the formation. Sandstone beds are commonly well cemented, contain ripple marks, and sometimes have abundant organic debris that is coalified. Coal was mined from the Menefee in Wildcat Canyon.

The Menefee Formation was deposited in a coastal-plain environment (Aubrey, 1991). Thickness ranges from about 225 to 300 ft. Thin coal beds are present within the Menefee Formation in Wildcat Canyon near the "Porter mines" (Taff, 1907; Zapp, 1949); "bed no.1" near the top of the Menefee is 2.3 ft thick, "bed no. 2" includes 4.6 ft of coal with a 0.8-ft-thick bony interval that is about 85 ft below the top of the formation, and "bed no. 3", a 5-ft-thick coal interval with 1.1 ft of partings, is about 120 ft below the top of the formation. Boreck and Murray (1979) described a single mine with historic production in Basin Mountain quadrangle, the Peacock-Porter mine in Wildcat Canyon. They reported the 5.5-ft-thick Peacock or Porter no. 3 bed was worked by this mine. A lithologic log in the collections of the Denver Earth Resources Library for the Ernst et al. Durango no. 1 well, drilled in 1947 and 1948 in the center of the SE⁄NW⁄of sec. 8, T. 34 N., R. 10 W., described a 15-ft-thick Menefee coal bed at a depth of 360 to 375 ft, a 12-ft-thick coal at 428 to 440 ft, and a 10-ft-thick coal at 545 to 555 ft. Zapp (1949) reported thicknesses of 12 ft for the upper coal and 9 ft for the lower coal in this well.

Subsidence of the land surface may occur above underground mines where coal was extracted from the Menefee and Fruitland Formations. Burning coal beds and seepage of methane or hydrogen sulfide from coal outcrops can be hazardous. Thick sandstone beds in the formation may cause local rockfall hazards.

Kpl **Point Lookout Sandstone (Upper Cretaceous)—**Shown only on cross section.

Km **Mancos Shale (Upper Cretaceous)—**Shown only on cross section.

FRACTURE DATA

Fracture data are potentially valuable in the evaluation of migration paths for fluids and gas, such as ground water, coalbed methane, and hydrogen sulfide. A primary purpose of the fracture investigation involved collection of fracture-orientation data that could be useful to regional fracture analyses. Our investigation built upon that of Condon (1997), who described many of the overall characteristics of the fractures in the vicinity of Basin Creek, and supplements fracture data reported by Kirkham and others (1999) and Carroll and others (1999).

Data on 1,860 fractures were collected at forty sites (fracture stations) in sedimentary rocks in the quadrangle. Locations of the fracture stations are shown in Figure 3, and rose diagrams for each fracture station are in Figure 4. Most fracture stations are sited along or near the Hogback monocline because this area contains many fracture-rich outcrops. In Figure 4, the footer for each rose diagram begins with the fracture station number and is followed by the formation symbol and, where applicable, the coal bed interval. The number of fractures measured at the fracture station completes the footer. Each wedge in the rose diagram has a class interval of 10°. The length of each wedge represents the percentage of fractures with that particular orientation.

The fracture data are for joints only; no evidence of minor faulting or shear fractures was observed at the fracture stations. All measured joint sets are generally perpendicular to bedding; steep dips apparently do not affect their orientation. Two prominent joint sets occurred at most fracture stations. Age relationships between the joint sets were evaluated based on cross-cutting relationships. The oldest joints, or J1 set, were the first to propagate. They are commonly, but not always, more abundant and longer than the younger joints, or J2 set, which abut against the older joints. Succesively younger joints are referred to as J3, J4, etc., but these younger joints are rare in Basin Mountain quadrangle and have not been included in the analysis. Joints in coal beds are called cleats. The older and more continous fractures in coal are known as face cleats and are equivalent to J1 joints. The younger cleats that terminate against the face cleats are referred to as butt cleats; they are comparable to J2 joints.

At many fracture stations in sandstone, the cross-cutting relationships are clear, but at others the age relationships are not consistent. Relationships between face and butt cleats in coal beds are generally consistent, and the cleats are sharp and well defined at most stations. In a few coal beds, the cleats are somewhat curvilinear and difficult to measure. Most joints are open and many are weathered. In general, the fractures in thinner and more indurated sandstone beds were better preserved and more linear, and cross-cutting relationships are more consistent. Some joints in sandstone beds, particularly those in the Pictured Cliffs, have prominent iron-oxide bands or halos associated with them. In a few areas where joints are irregular, the weathering of these iron-oxide-cemented bands and associated fractures creates a turtleback-type of pavement surface on the Pictured Cliffs dip slopes.

J1 joints are typically about 1 to 10 ft in length, but occasionally exceed 100 ft in length. Spacing between J1 joints ranges from about 3 in. to10 ft, whereas face cleats in coal are only about⁄to 5 inches apart. J2 joints are generally shorter than J1 joints, with most being about 1 to 8 ft long. J2 joint spacing varies from about 0.5 to 15 ft. Butt cleats in coal beds are commonly⁄to 3 in. apart. A few joints and cleats are mineralized with calcite, and more are coated with iron oxides.

Measurements were recorded in several formations: one in the tongue of Pictured Cliffs Sandstone (Kpct); ten in the Pictured Cliffs Sandstone (Kpc); sixteen in the Fruitland Formation (Kf), four in the Farmington Sandstone Member of the Kirtland Formation (Kkf); five in the McDermott Member of the Animas Formation (Kam); three in the upper member of the Animas (Ta); and one in the San Jose Formation (Tsj). Of the sixteen fracture stations in the Fruitland Formation, one was in a sandstone bed and fifteen in coal beds, including nine in the C1 (lowest coal interval), two in the

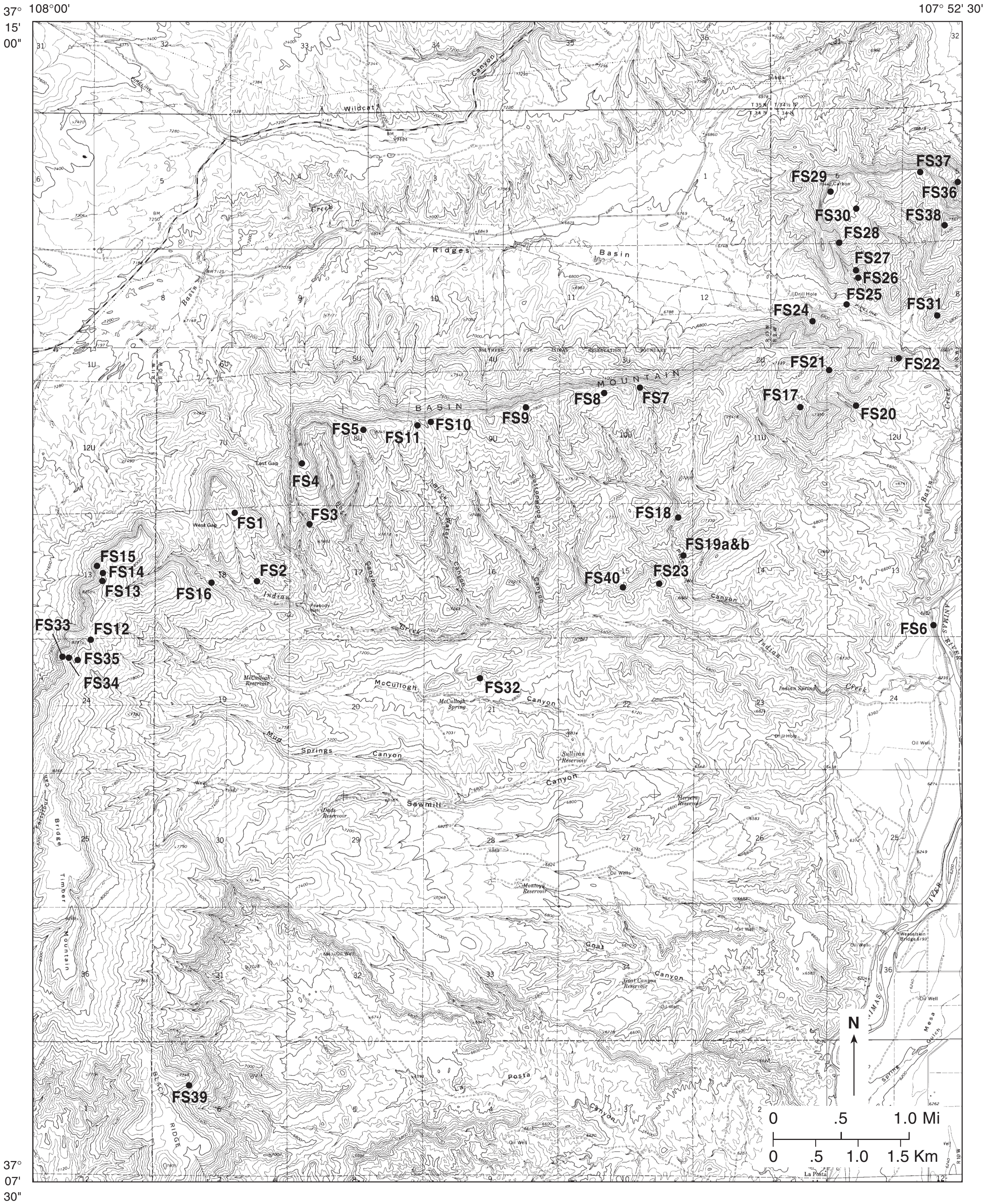

Figure 3. Map showing locations of fracture stations where joint data was collected.

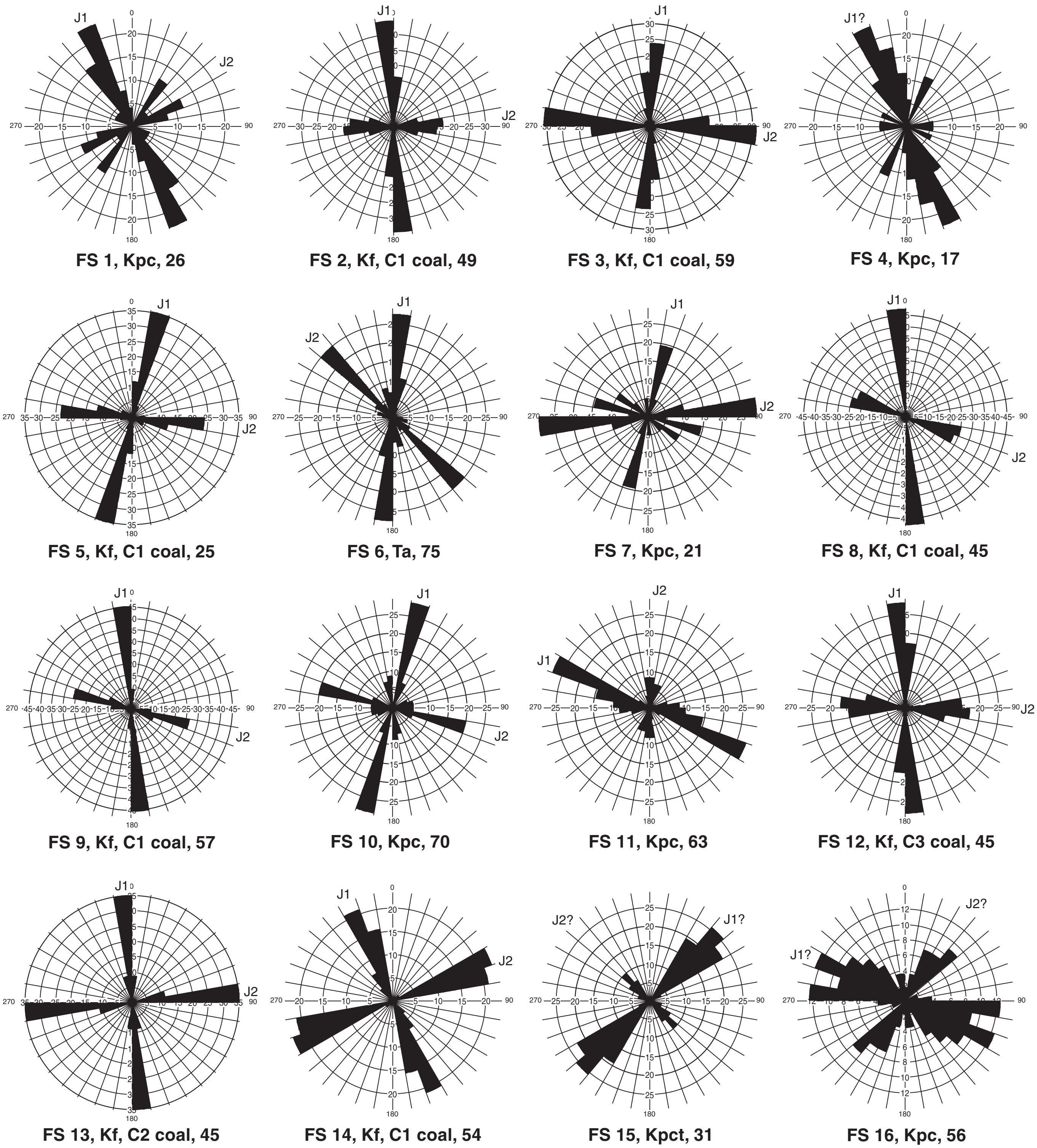

Figure 4. Rose diagrams for fracture stations FS1 to FS40. The footer for each rose diagram indicates the fracture station number, formation (and coal zone, where applicable), and number of measurements. J1 (includes face cleat in coal beds) and J2 (includes butt cleat in coal beds) orientations are labeled. Queries that follow a joint-set designation indicate cross-cutting relationships of fractures are somewhat ambiguous. Where queries only are shown, the relationships are very ambiguous.

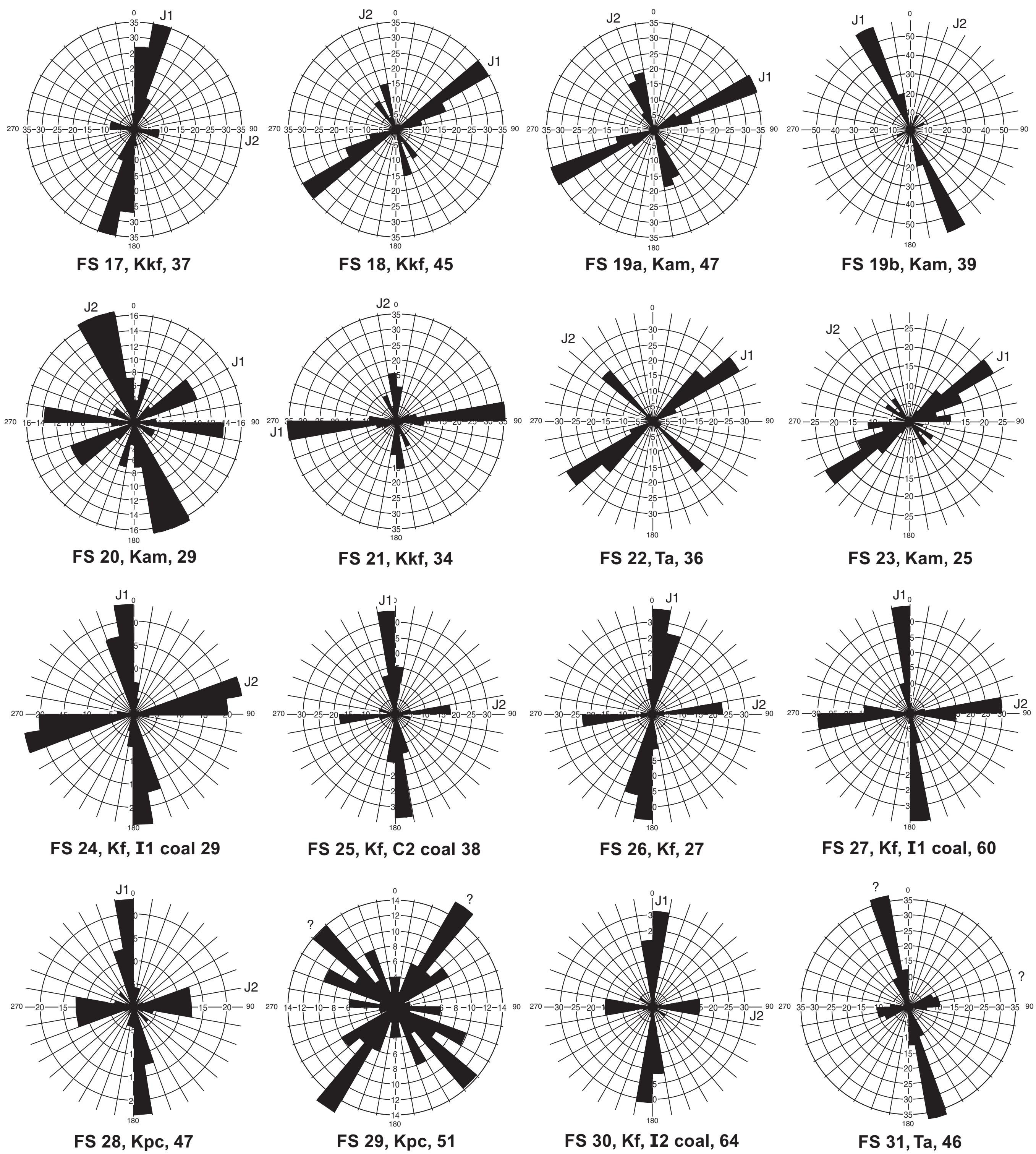

Figure 4. Rose diagrams for fracture stations FS1 to FS40 (continued).

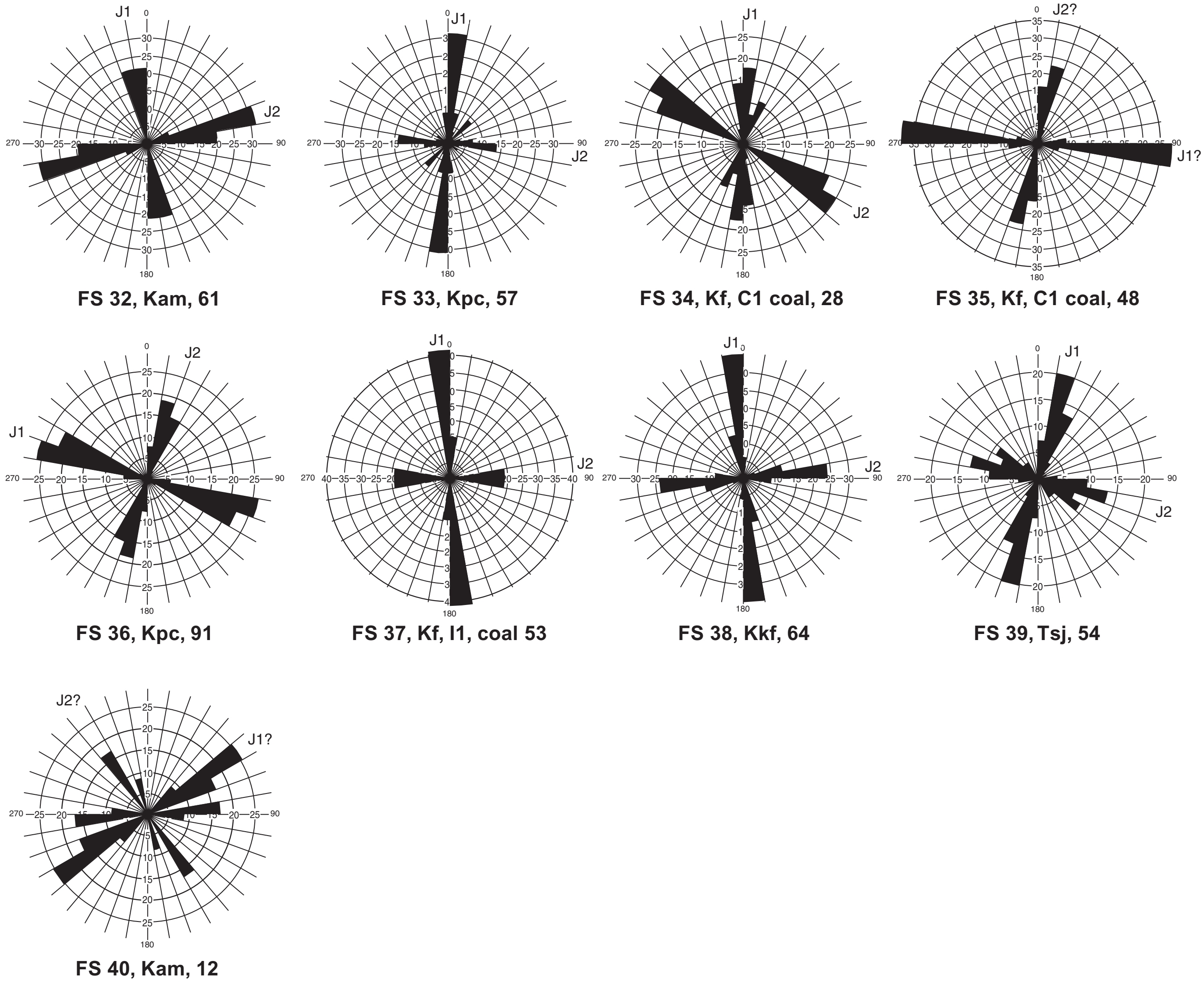

Figure 4. Rose diagrams for fracture stations FS1 to FS40 (continued).

C2 coal interval, and one in the C3 coal interval of Carroll (1999), and one in the I1 interval and two in the I2 interval of Wray (2000).

Rose diagrams for the eleven fracture stations in the Pictured Cliffs Sandstone and tongue of Pictured Cliffs are shown in Figure 5. Orientations of J1 and J2 fractures in the Pictured Cliffs vary widely, with no apparent systematic pattern. J1 fractures range from about N60°E to N70°W. J2 fractures are commonly perpendicular to J1 fractures except at a few stations where the acute angle between the two joint sets is 65° to 70°. Condon (1997) reported more consistent orientations at his fracture stations in the Pictured Cliffs near Basin Creek. His J1 joints average N28°W, and the J2 joints average N59°E.

Fifteen fracture stations record joint orientations in Fruitland coal beds and one in a Fruitland sandstone (Figure 6). Fracture data for the Fruitland Formation are fairly consistent. Most face cleats and J1 joints trend between N10°W and N10°E. All face cleats and J1 joints, except those at fracture station 35, are oriented between N20°W and N20°E. Cross-cutting fracture relationships at fracture station 35, which is in the basal coal interval, are somewhat ambiguous. J2 joints are

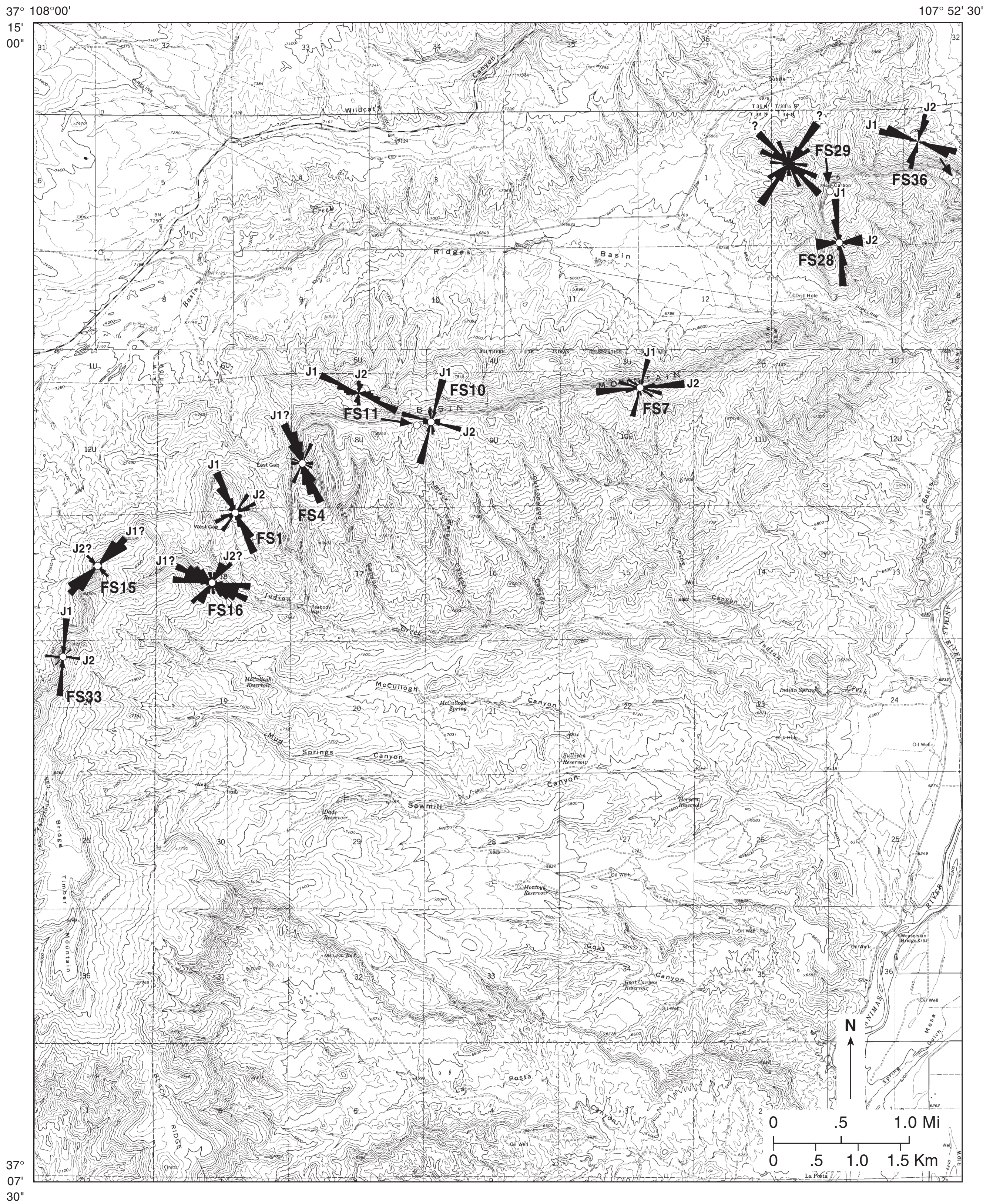

Figure 5. Map showing rose diagrams for fracture stations in the Pictured Cliffs Sandstone and Pictured Cliffs tongue. Open circles indicate location of fracture stations. J1 and J2 orientations are labeled. Queries indicate cross-cutting relationships are ambiguous.

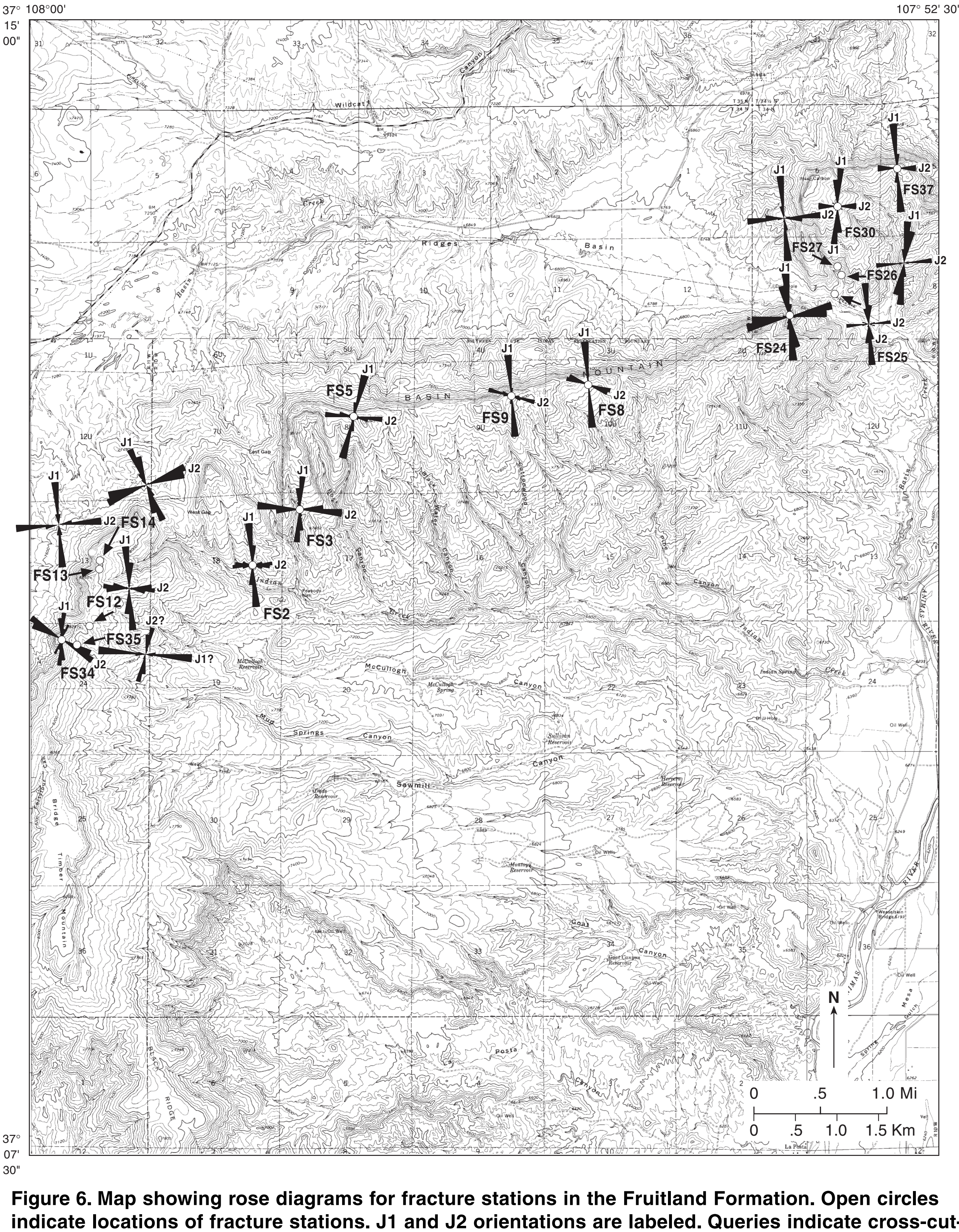

Figure 6. Map showing rose diagrams for fracture stations in the Fruitland Formation. Open circles indicate locations of fracture stations. J1 and J2 orientations are labeled. Queries indicate cross-cutting relationships are ambiguous.

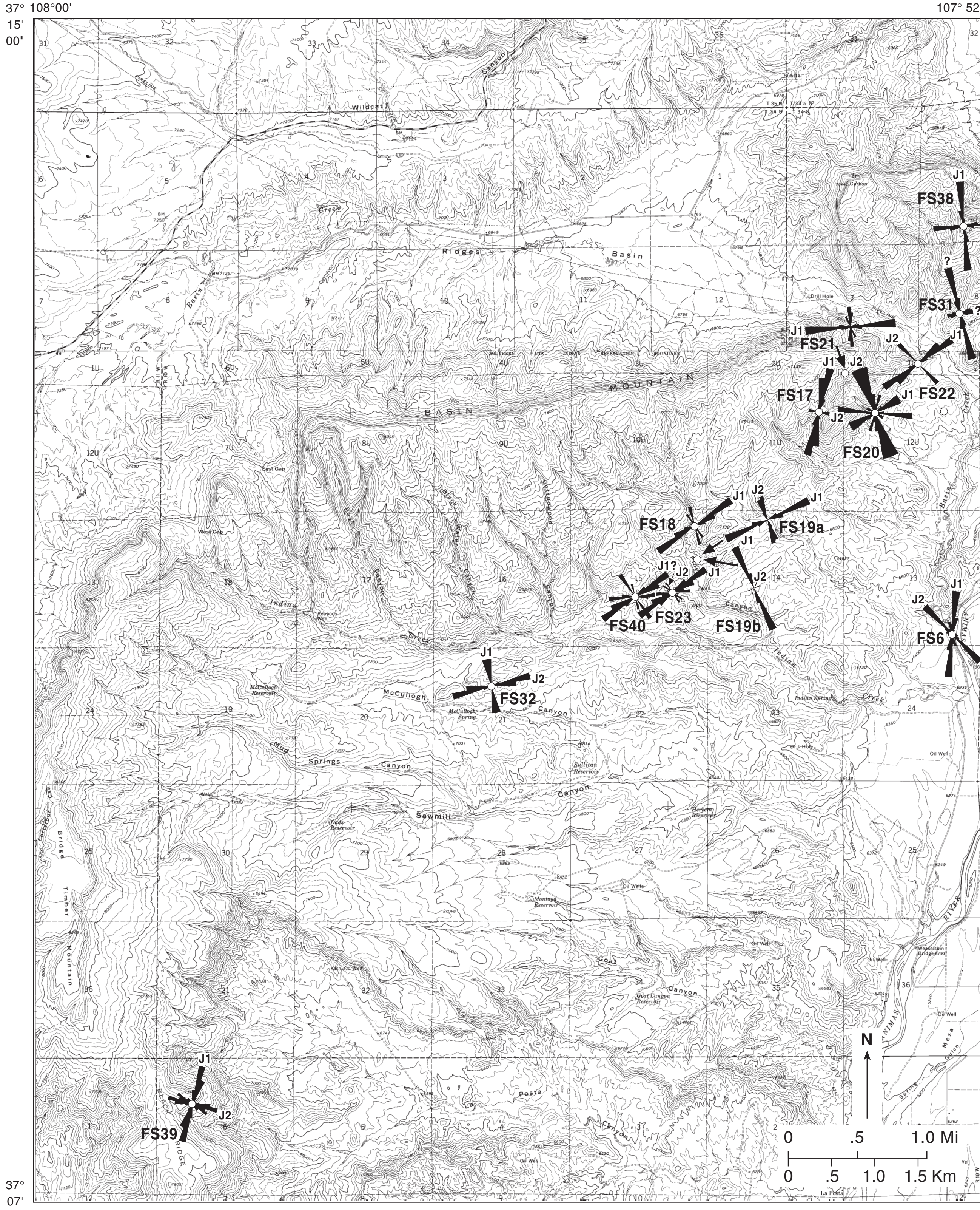

Figure 7. Map showing rose diagrams for fracture stations in the Farmington Sandstone Member of the Kirtland Formation, McDermott and upper members of the Animas formation, and San Jose Formation. Open circles indicate locations of fracture stations. J1 and J2 orientations are labeled. Queries indicate cross-cutting relationships are ambiguous.

perpendicular to J1 fractures at over half the stations. Where not perpendicular, the acute angle between the fracture sets ranges from 55° to 80°; most are 65° to 80°.

Figure 7 depicts the rose diagrams for fracture stations in the Farmington Sandstone Member of the Kirtland Formation, McDermott and upper members of the Animas Formation, and San Jose Formation. J1 and J2 cross-cutting relationships are generally evident and unambiguous at individual fracture stations, but their orientations vary widely between fracture stations, even within a single formation. Fractures in two beds in the same outcrop of the McDermott Member were measured at fracture station 19. The lower bed (FS19a) is a conglomeratic mudstone with an average J1 orientation of N65°E. Fracture station 19b is in mudstone bed about 20 ft stratigraphically higher than FS19b. Its average J1 orientation is N23°W, nearly at a right angle to the the J1 trend for the underlying bed.

MINERAL AND ENERGY RESOURCES

Historic mineral and energy production in the Basin Mountain quadrangle includes gas, coal, sand, and gravel. Locations of known sand and gravel pits, petroleum wells, coal adits observed in the field and a single named coal mine are shown on the geologic map. Surficial deposits that contain potential sand and gravel resources include units Qa, Qt_1, Qt_2, Qt_3, Qt_4, and Tbt.

COAL

The Porter mine (Taff, 1907; Zapp, 1949, Sullivan and Jochim, 1984), which was called the Peacock-Porter mine by Boreck and Murray (1979), is the only known mine in the quadrangle with recorded production. Located at the north-central edge of the quadrangle on the northwest side of Wildcat Canyon, this mine worked at least one coal bed in the Menefee Formation. Sullivan and Jochim (1984) indicated there were three adits into this mine and that the mine worked multiple beds. Evidence of only one collapsed adit was found during our investigation.

According to Boreck and Murray (1979), the Peacock-Porter mine worked the “Peacock” bed in the “Porter, C coal zone”, which they thought could be the same bed as the Porter no.3 bed. This stratigraphic information is confusing, as it contradicts Figure 6 of Boreck and Murray, a generalized columnar section of coal-bearing rocks in the Menefee Formation in the Durango coal field. In this figure, the Peacock seam is in the Peacock coal zone at the top of the formation, and the Porter no. 3 bed is in the Porter no. 3 coal zone about mid-way in the formation. There is no mention of a “Porter, C coal zone” in their columnar section. On the basis of available information, we believe the historic coal production of 3,052,800 tons for the Porter or Peacock-Porter mine reported by Boreck and Murray (1979) probably included production from more than a single coal bed. Part of this reported production is from the Durango West quadrangle. Zapp (1949) described an analysis of the Porter bed no. 3: on an as-received basis, the coal contained 13,910 Btu/pound and was 2.7% moisture, 36.1% volatile matter, 54.5% fixed carbon, and 6.7% ash.

Two other coal adits were noted in the Menefee Formation on the southeast side of Wildcat Canyon, opposite of the Porter or Peacock-Porter mine. A small dump below one of the adits suggests the adit extends into the hill for some distance, but there is no known recorded production for it. Another coal adit with small dump in the Menefee Formation, for which there is no known name or production statistics, is in the northeast corner of the quadrangle in the upthrown side of the Smelter Mountain fault. A few small adits driven into coal beds in the Fruitland Formation are present north and south of Basin Creek, but no historical records are known for these workings.

PETROLEUM RESOURCES

Upper Cretaceous rocks underlying Basin Mountain quadrangle have produced major quantities of natural gas. The wells in the quadrangle are part of the huge Ignacio Blanco gas field, which has cumulative gas production of 1,675,259,292 MCF (1000 cubic ft) and 113,878 barrels of oil (Colorado Oil and Gas Conservation Commission, 1998).

According to digital records (Petroleum Information/Dwights LLC, 2000; Colorado Oil and Gas Conservation Commission, 2001), there are 155 well permits issued for wells in Basin Mountain quadrangle. They include 77 producing gas wells, 22 shut-in gas wells, three injection wells, 13 drilled and abandoned wells, nine plugged and abandoned wells, 23 abandoned locations, one tested and abandoned well, and seven permitted wells pending action. Records from one additional well, the Ernst et al. Durango no. 1 well in the center of the SE⁄ NW⁄ of sec. 8, T. 34 N., R. 10 W., are in the Denver Earth Resources Library. Zapp (1949) also described this well. All of the wells, but none of the abandoned locations, are shown on the geologic map.

Most natural gas produced in Basin Mountain quadrangle is coalbed methane from the Fruitland Formation. The second most productive horizon includes sandstone beds in the Mesaverde Group, especially the Point Lookout Sandstone. The Dakota Sandstone is the oldest formation penetrated by the gas and oil wells in the quadrangle.

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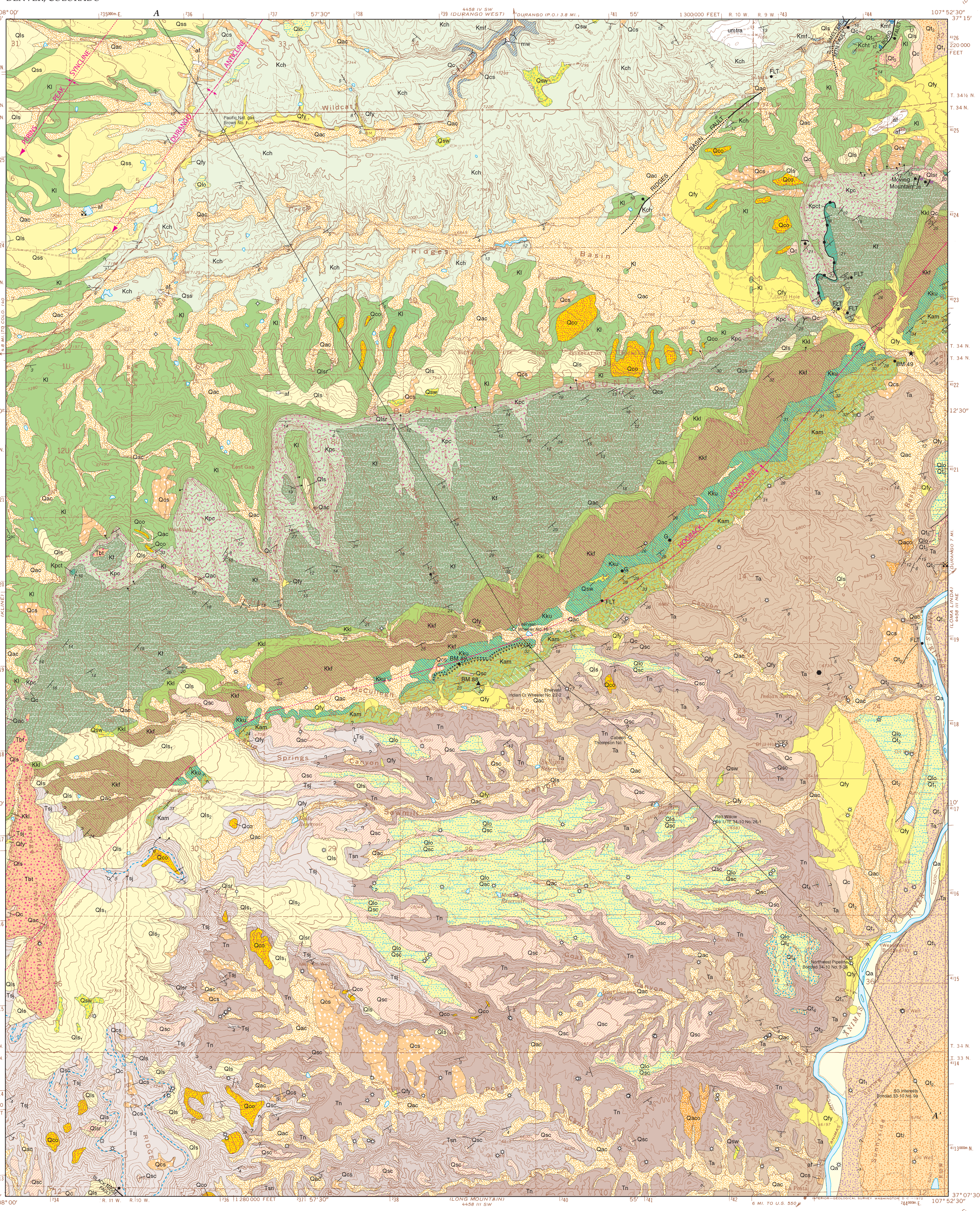
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINERALS AND GEOLOGY
DENVER, COLORADO

OPEN FILE MAP 01-4
GEOLOGIC MAP OF THE BASIN MOUNTAIN
QUADRANGLE, LA PLATA COUNTY, COLORADO
Booklet accompanies map

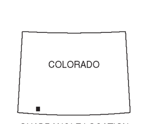


Base from U.S. Geological Survey, 1963
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

UTM GRID AND 1968 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1: 24,000

1 MILE; 7000 FEET; 1 KILOMETER



QUADRANGLE LOCATION

Geology mapped in 2000
Digital cartography by Cheryl Brchan

CONDENSED DESCRIPTION OF MAP UNITS

Expanded descriptions can be found in accompanying booklet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)**—Fill and waste rock placed during construction of dams, roads, landfills, and resi-dences

mw — **Coal mine waste (latest Holocene)**—Rock fragments and coal refuse placed in dump piles at inactive coal mines

umtra — **Bodo Canyon uranium mill tailings disposal site (latest Holocene)**—Low-level radioactive materials were re-moved 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 chan-nels, 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 (Holocene and late Pleistocene)**—Pebbly, silty sand, sandy or clayey silt, and sandy, silty clay in valleys of ephemeral and intermittent streams and in basins

Qt_1 — **Terrace alluvium one (late Pleistocene)**—Chiefly stream allu-vium that underlies several terrace surfaces along the Animas River. Mostly poorly sorted, clast-sup-ported, locally bouldery, pebble and cobble gravel in a silty or sandy matrix. Terrace surfaces range from about 25–65 ft above the river

Qt_2 — **Terrace alluvium two (late? and late middle Pleistocene)**—Mostly stream alluvium that underlies at least three terrace surfaces along the Animas River. Deposits are similar to terrace alluvium one (Qt_1). Terrace surfaces range from about 80 to 120 ft above the river. Includes a deposit of cobble and pebble gravel north of Goat Canyon that may have been reworked from an older terrace deposit prior to deposition of terrace alluvium two, as it is 170 ft above the river

Qt_3 — **Terrace alluvium three (middle Pleistocene)**—Chiefly stream alluvium similar to terrace alluvium one (Qt_1) that underlies several terrace surfaces along the Animas River at heights of about 240–430 ft above the river.

Qt_4 — **Terrace alluvium four (middle Pleistocene)**—Mostly stream alluvium similar to terrace alluvium one (Qt_1) under terraces along the Animas River west and southwest of Weaselskin bridge. Terrace surfaces are about 440 ft above the river

Tbt — **Bridgetimber Gravel (Pliocene or Upper Miocene)**—Sandy cobble and pebble gravel, gravelly sand, and silty sand. Underlies Bridge Timber Mountain

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 several recently active landslides with fresh morph-ological features or other evidence of historical move-ment. Heterogeneous deposits consisting of unsorted, unstratified rock fragments, 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

Qc — **Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble-sized to boulder-sized rock fragments 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. Relative ages of nested or adjacent landslides are in-dicated by subscripts. Deposits labeled Qls_1 are younger than and frequently derived at least in part from deposits labeled Qls_2

Qco — **Older colluvium (Pleistocene)**—Texturally similar to col-luvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. May include older landslide deposits where original landform surfaces are modified by erosion

ALLUVIAL AND COLLUVIAL DEPOSITS—Sediments of both alluvial and colluvial origin in fans, stream channels, flood plains, and adjacent hillslopes

Qfy — **Younger fan deposits (Holocene)**—Sediments deposited by hyperconcentrated flow, debris flow, alluviation, and sheetwash in fans and tributary drainages. Range from extremely poorly sorted, clast-supported, pebble-, cobble-, and boulder-sized rock fragments and re-worked stream gravels in a clayey silt or sand matrix to matrix-supported, gravelly, clayey silt. May be bouldery, particularly in the upper reaches of some fans. 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, flood-plain, debris-flow, and hillslope deposits along tributary valley floors. 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. Unit is mapped where contacts between the various types of deposits are gradational, or where the deposits exist side by side but are too small to depict individually

Qcs — **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene?)**—Composed of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Unit is mapped where contacts between the two types of deposits are very gradational and difficult to locate

Qaco — **Older alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Includes scattered remnants north of the mouth of Basin Creek and a single deposit in La Posta Canyon. Deposits are similar to alluvium and colluvium, undivided (Qac), but cap low hills and surfaces 10–30 ft above adjacent drainages

Qss — **Sediments of Sheep Springs Gulch (late or middle Pleis-tocene)**—Range from poorly sorted, stratified, clast-supported, silty, clayey, and sandy cobble and pebble gravel to poorly sorted, unstratified, matrix-supported gravelly silt and clay. Unit caps several broad ridges and hilltops in the northwest corner of the quadrangle. It consists of reworked landslide material deposited chiefly in fluvial and debris-flow environments

Qsc — **Sediments of Sawmill Canyon (late and/or middle Pleistocene)**—Similar in origin and texture to Sediments of Sheep Springs Gulch, but derived by reworking of landslides on the east and south sides of Bridge Timber Mountain

EOLIAN DEPOSITS—Sediments deposited by wind

Qlo — **Loess (late and middle? Pleistocene)**—Slightly clayey, silty very fine sand and sandy silt deposited by wind and preserved on level to gently sloping surfaces

SEDIMENTARY BEDROCK

Tsj — **San Jose Formation (Lower Eocene)**—Red, gray, and brown mudstone, shale, and sandy shale interbedded with light-gray, grayish-yellow, and brown fine-grained to conglomeratic sandstone. Includes a prom-inent cliff-forming sequence of sandstone beds de-noted by a special symbol

Tn — **Nacimiento Formation (Paleocene)**—Gray, red, brown, and green shale and mudstone interbedded with tan, yellowish- to greenish-gray fine-grained sandstone

Tsn — **San Jose and Nacimiento Formations, undivided (Eocene and Paleocene)**—Mapped where limited exposures prevent recognition of the contact between the formations

Animas Formation (Paleocene and Upper Cretaceous)—Includes two members, the upper member and underlying McDermott Member

Ta — **Upper member (Paleocene)**—Olive-brown, light-brown, gray-green, and light-reddish-brown shale, sand-stone, conglomerate, and minor lithic tuff, tuf-faceous sandstone and thin coal and carbonaceous shale. Basal part of unit commonly is coarser grained and locally includes strata that appear to contain reworked rocks from the underlying McDermott Member (Kam). Conglomerate clasts are chiefly of volcanic origin. Siliceous clasts are more abundant in upper part of member

Kam — **McDermott Member (Upper Cretaceous)**—Mostly pur-plish-red to red-brown, poorly sorted sedimentary breccia, conglomerate, sandstone, conglomeratic sandstone, shale, and siltstone. Locally includes a possible igneous flow or sill. Conglomerate clasts are commonly very weathered and include in-trusive, volcanic, and siliceous lithologies. Interior parts of boulders that are relatively fresh are composed of intrusive rock. Basal part of unit is coarser grained and predominantly conglomerate, sedimentary breccia, and conglomeratic sandstone that generally fines upward to shale, siltstone, and sandstone. A brightly colored mottled shale and siltstone is locally present at the top of the member

Kk — **Kirtland Formation, undivided (Upper Cretaceous)**—Consists of three members, a lower member, Farm-ington Sandstone Member, and upper member. Undi-vided formation shown only on cross section

Kku — **Upper member**—Olive-gray to medium-gray shale and siltstone interbedded with yellowish-gray to white sandstone. Locally includes prominent, cliff-forming sandstone, conglomerate, and conglom-eratic sand-stone at top of member

Kkf — **Farmington Sandstone Member**—Yellowish-gray, tan, and light-orange, fine- to medium-grained sandstone and olive-gray to medium-gray shale

Kkl — **Lower member**—Olive-gray to greenish-gray shale, siltstone, and sandy shale with thin interbedded lenses of light-gray to greenish-gray, fine-grained sandstone

Kf — **Fruitland Formation (Upper Cretaceous)**—Light-gray, light-brown, and olive-green, very fine- to medium-grained sandstone interbedded with light-brown to dark-gray claystone and mudstone and brown, gray, and black carbonaceous shale and coal. Locally includes burnt rock and clinker resulting from burning of coal beds within the formation

Kpc — **Pictured Cliffs Sandstone (Upper Cretaceous)**—Light-gray to white, tan or grayish-orange, siliceous, fine-to medium- grained sandstone and medium- to dark-gray shale. Sandstone beds are thicker in the upper part. Shale beds thicker in lower part. Locally inter-tongues with overlying Fruitland Formation

Kpct — **Tongue of Pictured Cliffs Sandstone**—Light-gray to white, tan or grayish-orange sandstone intertongued with the basal Fruitland Formation. In northeast part of quadrangle, map unit includes a thin underlying tongue of Fruitland Formation

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. Basal part of formation intertongues with the Cliff House Sandstone

Kmv — **Mesaverde Group (Upper Cretaceous)**—Includes three formations, which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Look-out Sandstone. Only the Cliff House Sandstone and upper part of Menefee Formation crop out in the map area. Also includes a tongue of the Cliff House Sandstone that extends into the overlying Lewis Shale. Undivided unit shown only on cross section

Kch — **Cliff House Sandstone**—Interbedded sequence of thin beds of moderately hard, commonly silty, yellowish-orange to white, very fine- to medium-grained cal-careous sandstone and less indurated light-gray mudstone and silty shale. Commonly contains sparce, small-diameter *Ophiomorpha* burrows. Inter-tongues with overlying Lewis Shale and underlying Menefee Formation

Kcht — **Tongue of Cliff House Sandstone**—Thin beds of mod-erately hard, commonly silty, yellowish-orange to white, very fine- to medium-grained calcareous sandstone and less indurated light-gray mudstone and silty shale within the basal part of the Lewis Shale. Commonly contains sparce, small-diameter *Ophiomorpha* burrows. Shown only where outcrop is sufficiently large to be depicted at a scale of 1:24,000

Kmf — **Menefee Formation**—Interbedded light-gray, brown, and orange-brown sandstone, gray, brown, and black shale, carbonaceous shale, and coal

Kpl — **Point Lookout Sandstone**—Shown only on cross section

Km — **Mancos Shale (Upper Cretaceous)**—Shown only on cross section

MAP SYMBOLS

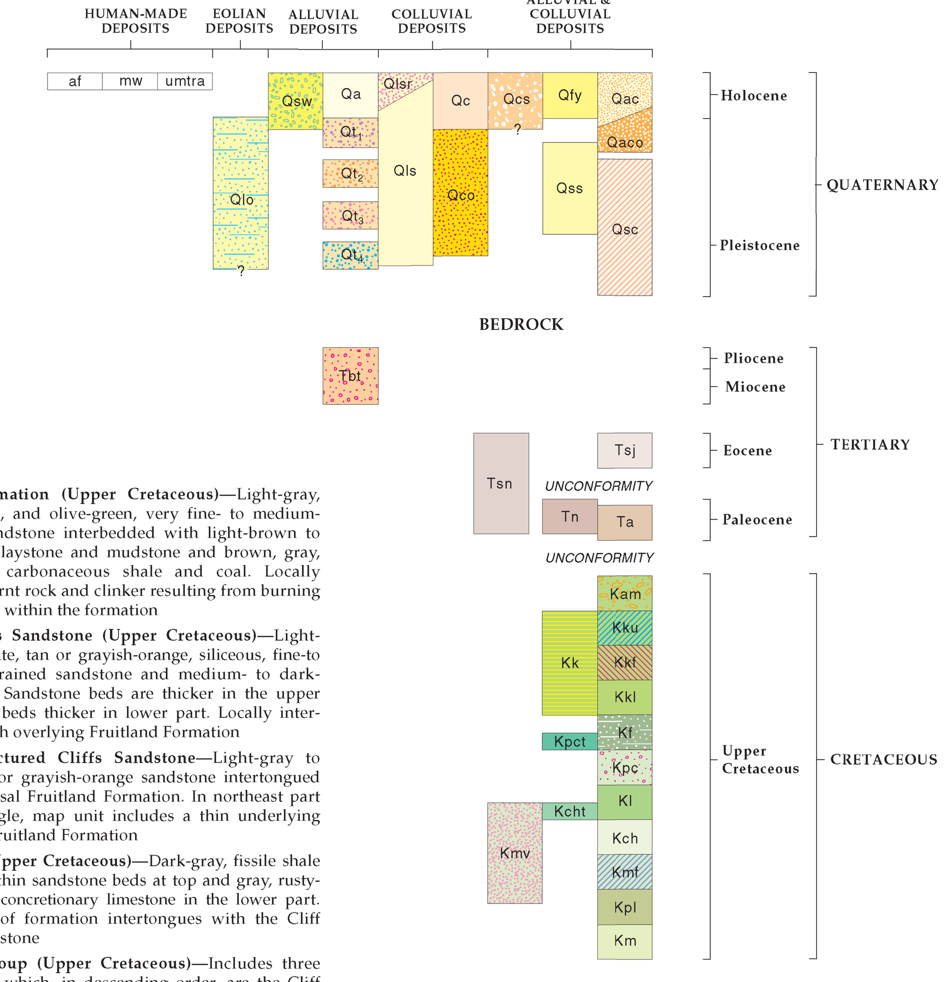
Contact—Dashed where approximately located; queried where uncertain; also used to indicate the base of a paleosol or diagenetically altered interval at the top of the McDermott Member of the Animas Form-ation

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

Possible paleosol or diagenetically altered interval at the top of the McDermott Member of the Animas Formation

Tongue of Fruitland Formation in Pictured Cliffs Sand-stone

CORRELATION OF MAP UNITS



Base of the "c" sandstone interval of Barnes and others (1954)—Interval consists of a sequence of indur-ated, commonly ledge-forming sandstone beds in the San Jose Formation that gradually rise in the stratigraphic section in a north-northwest dir-ection; queried where uncertain

Lag deposit—Contains angular clasts of dacite scoria and rounded gravel. Original flow structure formed on the surface of these fragile scoria clasts is well preserved, indicating the volcanic clasts were transported only a very short distance. The eruptive center for this material likely was in or just east of Basin Mountain quadrangle

G — **Lag gravel or float**—Consists of well-rounded siliceous pebbles of quartzite, quartz, and chert that overlie the upper shale member of the Kirtland Formation near the contact with the McDermott Member of the Animas Formation. Clasts are probably derived from a conglomeratic bed in the Kirtland

Conglomerate and sandstone at the top of the upper member of the Kirland Shale—Contains well-rounded pebbles of quartzite, quartz, and chert

Possible igneous flow or sill in basal McDermott Member

Approximate location of zone of discontinuous outcrops and float of igneous dike—Probably late Cretaceous or Paleocene monzonite porphyry or diorite porphyry

d — **Fault**—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; symbol "d" indicates a weathered igneous dike is within or very near the fault zone. Dike is probably late Cretaceous or Paleocene monzonite porphyry or diorite porphyry; maximum thickness about 1 ft

s — **Fault**—Collapse structure related to burning of under-lying coal beds

FLT — **Outcrop with small fault or faults exposed in artifi-cial cut or natural exposure**—Trace of fault be-yond exposure is unknown

Monocline—Showing approximate trace of the inflec-tion plane within the broad central limb of the structure; dashed where approximately located; dotted where concealed

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; arrow on end of axis indicates direction of plunge

9 — **Strike and dip of inclined beds**—Angle of dip shown in degrees (some attitudes on and immediately south of Basin Mountain are from Carroll, 1999)

Soil slip—Small, thin recent landslides on steep hill-slopes; most appear to be small debris avalanches involving colluvium, residuum, and sheetwash on slopes underlain by Mancos Shale, Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone; some areas mapped as soil slips may be rockfall paths. Length of arrow approximately equals the length of the slip path

Terrace scarp or riser

Coal-mine adit—Only coal-mine adits observed in the field are shown; may be open or collapsed shut; refer to the original mine maps held by the Colorado Division of Minerals and Geology, Sullivan and Joachim (1984), and Zapp (1949) for locations of other coal mine adits

Sand or gravel pit

Gas well—Operator, well name, and total depth given for wells used on cross section; source of infor-mation: Petroleum Information/Dwights LLC (2000); Colorado Oil and Gas Conservation Commission (2001); Zapp (1949); Carroll (1999). Refer to these sources for specific well information

- **Producing gas well**
- **Abandoned gas well**
- **Dry and abandoned gas well**
- **Temporarily abandoned**
- **Temporarily abandoned gas show**
- **Suspended well**
- **Service well, disposal, etc.**
- **Service well**
- **Water injection gas show**

s — **Gas seep in Blackwater Canyon reported by C. Carroll (2001, written communication)**

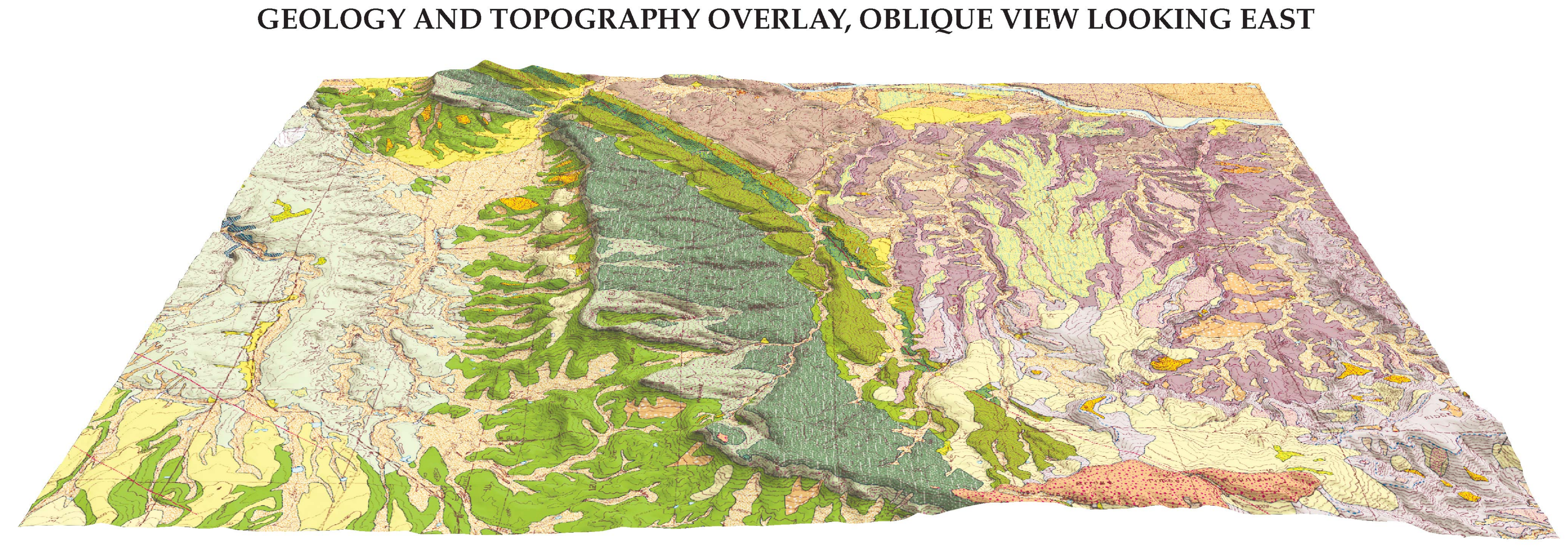
Location of sample dated using ^{14}C radiometric methods

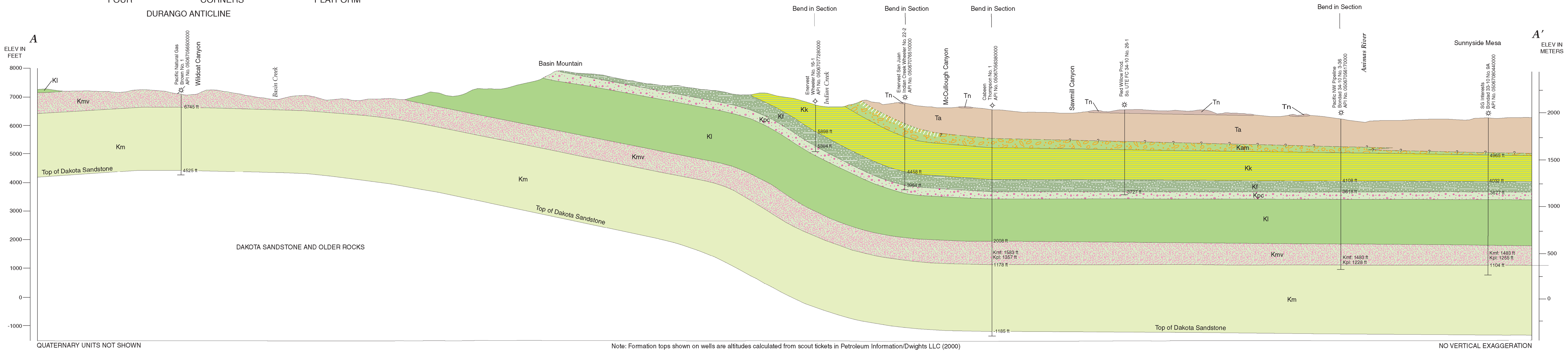
BM 49 — **Location and identification number of samples collec-ted from boulders in McDermott Member (see Tables 4 and 5 in booklet for geochemical analysis)**

BM 89 — **Location and identification number of sample collected from igneous flow or sill in McDermott Member (see Tables 2 and 3 in booklet for geo-chemical analysis)**

A———A′ — **Alignment of cross section**—Formation tops shown on wells are from Petroleum Information/ Dwights LLC (2000)

SHADED-RELIEF MAP OF THE BASIN MOUNTAIN QUADRANGLE WITH GEOLOGY AND TOPOGRAPHY OVERLAY, OBLIQUE VIEW LOOKING EAST





Note: Formation tops shown on wells are altitudes calculated from scout tickets in Petroleum Information/Dwights LLC (2000)

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GEOLOGIC MAP OF THE BASIN MOUNTAIN QUADRANGLE, LA PLATA COUNTY, COLORADO

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2003