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Milner Quadrangle Geologic Map, Routt County, Colorado

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FOREWORD

The purpose of Colorado Geological Survey's (CGS) *Milner Quadrangle Geologic Map,Routt County, Colorado* is to describe the geology, mineral and ground-water resource potential, and geologic hazards of this 7.5-minute quadrangle located west of Steamboat Springs in northwestern Colorado. CGS staff geologist David C. Noe, consulting geologist Alan J. Busacca, and field assistant Michael J. Zawaski completed the field work on this project during the spring of 2008. The geologic map plates and the Authors' Notes report were created using field maps, structural measurements, photographs, and field notes generated by all three investigators.

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and CGS. USGS funding comes from the STATEMAP component of the National Cooperative Geologic Mapping Program, award number 08HQAG0094, authorized by the National Geologic Mapping Act of 1997, reauthorized in 2009. CGS matching funding comes from the Colorado Department of Natural Resources Severance Tax Operational Funds, from severance taxes paid on the production of natural gas, oil, coal, and metals in Colorado.

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INTRODUCTION

The Milner 7.5-minute quadrangle is located in Routt County, Colorado, along the valley of the Yampa River (**Figure 1**). The unincorporated community of Milner lies along U.S. Highway 40 in the north-eastern part. Steamboat Springs, the county seat of Routt County, lies 10 miles to the east.

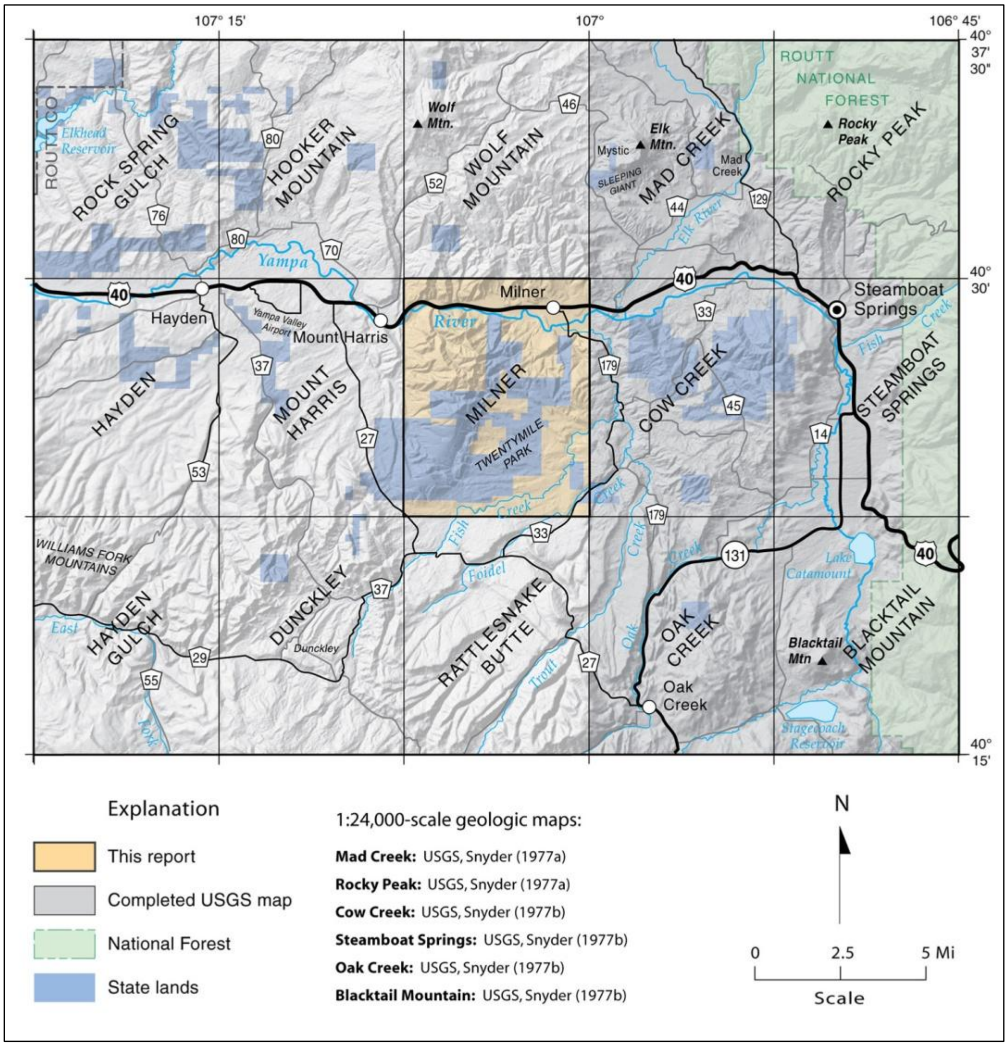

Figure 1. Index map of the Milner quadrangle.
The map shows federal- and state-owned land parcels and the status of 1:24,000-scale geologic mapping.

Figure 2 shows the major physiographic and structural features of the quadrangle. The Yampa River flows from east to west across the northern part of the quadrangle. It cuts across the Tow Creek anticline between the town of Milner and the town site of Bear River. US-40 and the Union Pacific railroad conveniently follow this river corridor. The highest elevation in the quadrangle is the Chavez survey triangulation station (8,106 ft) atop the Tow Creek anticline. The lowest elevation (6,420 ft) occurs where the Yampa River exits along the western border.

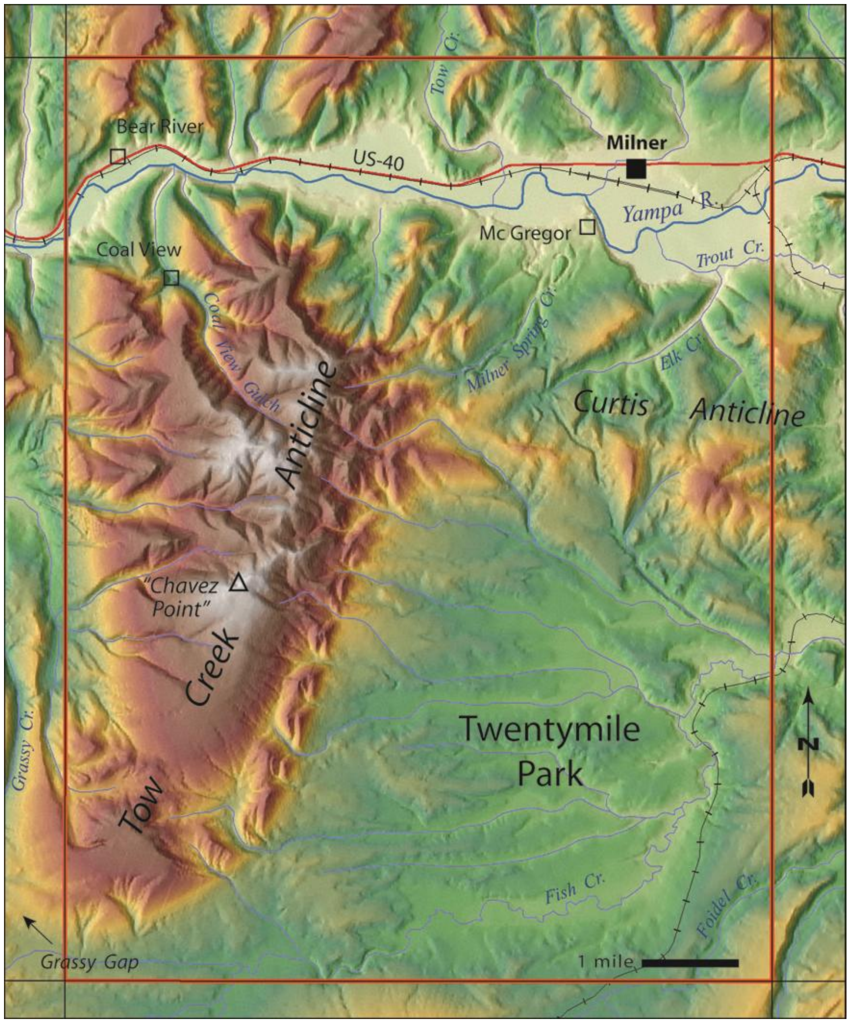

Figure 2. Shaded-relief index map of the Milner quadrangle.
The map shows major physiographic and structural features mentioned in the report. Open squares mark the locations of former coal-mining camps.

PREVIOUS MAPPING STUDIES

The earliest regional geological map of the region was published by Hayden (1877) (scale 1:253,440); a portion of that map is shown on the **Back Cover**. The study area is included in a regional geologic map of the Craig 1x2-degree sheet (Tweto, 1976) (1:250,000). Bass and others (1955) produced a geologic map and report on the region's coal resources (1:62,500). Madole (1989) mapped the surficial geology of the area (1:100,000). **Figure 1** shows the status of 7.5-minute (1:24,000-scale) quadrangle geologic mapping in the area. Snyder mapped six quadrangles 1:24,000, which were published as open-file maps (Snyder, 1977a, b) (1:48,000) and later republished in full color (Snyder, 1980a, b) (1:48,000).

Geologic mapping of the Milner quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP program. STATEMAP is a component of the National Cooperative Geologic Mapping Act, administered by the U.S. Geological Survey (USGS). The purpose of the CGS

STATEMAP program is to produce 1:24,000 scale geologic maps with a focus on surficial units, bedrock units, and structural features. The maps can be used for a variety of applications including land-use planning, geologic-hazard assessments, geotechnical-engineering, mineral-resource development, and ground-water resource development. This is the first geologic map done by CGS in the area. (For the current status of CGS STATEMAP projects, see http://geosurvey.state.co.us/mapping/Pages/24,000-ScaleMappingProgram.aspx.)

MAPPING METHODOLOGY

The Milner quadrangle geologic map is shown on **Plate 1**. The geologic interpretations are based on (1) CGS field investigations conducted from June to September 2008; (2) published and unpublished geologic maps and reports; (3) interpretation of remote-sensing images. The image data include 1:20,000-scale, black-and-white aerial photography taken in 1969 by the Agricultural Stabilization and Conservation Service (ASCS); 1-m resolution digital orthophotos taken in 2005 and 2006 by the National Agricultural Imagery Program (NAIP); a 10-m resolution digital elevation model (DEM); and the Google™ Earth on-screen map image viewer.

Bedrock geology and surficial deposits were mapped in the field on aerial photographs. Locations of key data points were recorded with a portable GPS receiver. ***All GIS locations reported herein and in the GIS database are in Universal Transverse Mercator (UTM), North American Datum 1983, Zone 13N projected coordinates, with units in meters. UTMX is the easting value; UTMY is the northing value***. Bedrock structure measurements including bedding and fracture orientations were taken using a Brunton compass. In certain cases, we augmented our data with strike-and-dip readings from Crawford and others (1920), Bass and others (1955), and ACZ, Inc. (1982). Mapping from the aerial photos was digitized into ESRI ArcMap. Line work was digitized on a flat-screen computer monitor using the digital topographic map, DEM, and NAIP orthophotos to correctly locate the geologic features. We used MicroDEM 12.0 to project dipping unit-contact surfaces across covered terrain and ERDAS IMAGINE 2010 to create the 3-D map in **Plate 2**.

DESCRIPTION OF MAP UNITS

This section contains descriptions of surficial and bedrock units from the geologic map. The surficial units are organized by the dominant process of deposition and by age, and listed from youngest to oldest in terms of latest depositional activity. The bedrock units are organized by increasing age. The geologic time divisions and nomenclature used in this report are shown in **Appendix A**. Sediment-clast sizes are based on the modified Wentworth grain-size scale (Wentworth, 1922; Ingram, 1989). Grain sizes are listed in the order of their relative abundance. Color names are taken from Munsell rock- and soil-color charts (Geological Society of America, 1991; GretagMacbeth, 2000). Stages of calcic soil development are described using the classification system of Machette (1985). Length and distance measurements are given in terms of inches, feet ("ft"), and miles.

SURFICIAL DEPOSITS

The surficial deposits in the Milner quadrangle are Quaternary (Holocene and Pleistocene) in age. The deposits shown on the map are generally more than 5 ft thick but may be thinner locally. Certain contacts between surficial units may be gradational, and mapped units locally may include deposits of other types. None of these deposits have been age-dated. Relative age assignments (early, middle, late) are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, and the degree of dissection, slope degradation, and soil development.

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene)** – Gravel, sand, silt, clay, and rock or concrete debris emplaced to construct highways, railroads, dams, and other human-made structures.

dr **Disturbed and reclaimed land (latest Holocene)** – Disturbed land includes areas such as surface coal mines, gravel pits, well-drilling pads, sanitary landfills, and other large excavations. Coal, aggregate, or waste overburden material are stockpiled at some sites. Reclaimed overburden material varies locally and may consist of gravel, sand, silt, clay, or rock debris. Fill properties vary as well; it may be engineered (controlled compaction) or completely uncontrolled. We mapped extensive areas of **dr** associated with former surface coal mines (as in **Figure 3**).

Figure 3. Disturbed and reclaimed land (**dr**) at the northern end of the former Seneca II coal mine. Here, following strip mining, overburden material was dumped into the mined-out area as uncontrolled fill, forming a hummocky dip slope. [UTMX: 318796, UTMY: 4479519]

ALLUVIAL DEPOSITS

Gravel, sand, silt, and clay deposited in major stream channels and flood plains, and as alluvial fans and sheet wash along valley sides, in tributary drainages, and on pediment surfaces. Terrace alluvium and age-related tributary stream deposits were formed mostly during periods of effective wetter climate, periglacial frost weathering, or outwash flooding that coincided with Pleistocene glaciations.

Alluvial Deposits of the Yampa River

Yampa River alluvium consists of sediments transported and deposited by flowing water. Alluvium deposited from confined-channel flow is the principal sediment underlying the modern flood plain and in five elevated, older alluvial-terrace deposits that represent former river courses. Grain sizes range from silt, sand, and some granule gravel in overbank deposits to pebbles, cobbles, and some boulders in basal channel deposits. The clasts are sub-rounded to well rounded. Average clast size in channel deposits is in the cobble-size range, about 5 to 8 inches. The largest observed boulders are up to than 3 ft in long dimension. Precambrian lithologies from the Park Range dominate the gravel and larger size fractions. The clasts are hard and resistant to weathering. About 60% are intrusive igneous rocks (porphyritic granite and quartz monzonite to tonalite); 30% are meta-igneous rocks (banded to finely speckled and foliated gneiss); 5% are Tertiary volcanic rocks (basalt and perhaps andesite); and 5% are fragments of Cretaceous sedimentary rocks.

Qay_1 **Alluvium one of the Yampa River (Holocene to late Pleistocene)** – Sand, silt, and gravel in the late Pleistocene to modern flood plain of the Yampa River. This is the most extensive deposit of the Yampa River in the quadrangle and extends basically from bedrock valley wall to bedrock valley wall. The modern flood plain consists of dozens of abandoned oxbow meander channels and overbank plains. The river channel apparently has been actively migrating throughout much of the Holocene. The unit includes thick, sandy gravel deposits of probably glacial-outwash origin that underlie the flood plain (**Figure 4**). Madole (1989) interprets most of the deposit to be of latest Pleistocene age (10 to 30 ka), with Holocene reworking of the uppermost part. Thickness may be more than 60 ft in places although it is poorly exposed.

Figure 4. Yampa River alluvial deposit (**Qay_1**) from the Holocene to late Pleistocene flood plain. Excavated exposure of Yampa River cobble gravel and gravelly sand lenses in the 25-ft high wall of the Camilletti Gravel Pit. Except for the uppermost part, which is reworked by the river during the Holocene, these are mostly late Pleistocene glacial-outwash deposits. The dark streaks contain granules of coal that are in the foresets and swales of trough cross beds. [UTMX: 329034, UTMY: 4482212]

Qay_2 **Alluvium two of the Yampa River (late Pleistocene) –** Sand, silt, and gravel in poorly preserved terrace remnants 6 to 10 ft above the modern floodplain. Thickness of this unit is not known. Most of this unit was reworked and removed by the Yampa River as it incised to the basal level of deposit **Qay_1**. The town of Milner is located on a large, remnant terrace of **Qay_2**.

Qay_3 **Alluvium three of the Yampa River (middle Pleistocene) –** Sand, silt, and gravel in terrace remnants with undulating upper surfaces 60 to 90 ft above the modern floodplain. This is the most extensive alluvial terrace in the quadrangle. Remnants are found along the north and south sides of the river valley. Maximum clast size is up to 3 ft long. Thickness of this unit is 20 to 40 ft over a sub-planar, basal erosion surface cut on Cretaceous-age bedrock in the few locations where it is exposed.

Qay_4 **Alluvium four of the Yampa River (middle Pleistocene) –** Sand, silt, and gravel in isolated, deeply eroded terrace remnants with rolling upper surfaces 125 to 150 ft above the modern floodplain. Thickness of this unit is unknown as its base is not exposed, but probably does not exceed 20 to 40 ft based on extent of deposits and relationship with bedrock outcrops.

Qay_5 **Alluvium five of the Yampa River (middle Pleistocene) –** Sand, silt, and gravel represented by a few isolated, deeply eroded terrace remnants with rolling upper surfaces 200 to 240 ft above the modern floodplain. Thickness of this unit is up to 80 ft based on quarry pit exposures. The average size of the dominantly Precambrian gravels is about 8 inches and maximum size is about 3 ft. A few volcanic cobbles were observed in these exposures. This alluvial terrace is at approximately the same height above modern stream level as the 60-m (197-ft) terrace along the nearby Elk River. There, Madole (1989; 1991) found a 9-ft thick deposit of reworked Lava Creek B volcanic ash (640 ka) within the alluvium. We infer that **Qay_5** may be the same age.

Qay_6 **Alluvium six of the Yampa River (early Pleistocene) –** Sand, silt, and gravel represented by a single isolated, deeply eroded terrace remnant about 280 ft above the modern floodplain. Thickness of this unit is about 50 ft based on extent of deposits and relationship with bedrock outcrops. Gravels and coarser clasts are dominantly Precambrian-age granitics and quartzite from an apparent source on the main stem of the ancestral Yampa River in the Park Range. Few to no volcanic rocks or other lithologies were observed.

Alluvial Deposits of Tributary-Stream Areas

Alluvium of the tributary-stream areas consists of gravel, sand, silt, and clay transported and deposited by perennial and ephemeral streams throughout the Milner quadrangle. The main perennial stream is Fish Creek, which flows through the southwestern to east-central part of the quadrangle. It joins Trout Creek, which flows in turn into the Yampa River in the northeastern part of the quadrangle. Alluvium deposited from confined-channel flow is the principal sediment underlying flood plains and elevated and dissected bodies of older alluvium of these tributary streams. Sediments range in size from silt, sand, and some granule gravel in overbank deposits to pebbles and some cobbles in basal channel deposits of some tributaries. These units are equivalent to Yampa River units **Qay_1** and **Qay_2**.

Qa_{1a} **Alluvium one(a) of tributary streams (late to middle Holocene) –** Silt, clay, sand, and minor gravel in modern, active flood plain of tributary streams. The flood plain surface is generally flat, with sharp slope breaks at the valley sides. The larger tributary streams typically have low gradients and are highly meandering. Locally derived sandstone clasts are found in variable amounts in stream deposits throughout the quadrangle. The Fish Creek drainage contains pebbles and cobbles of vesicular basalt, granitics, and quartzite derived from its head in the Flat Tops. Soil formed on **Qa_{1a}** has a poorly developed A-C profile. This unit may be more than 20 ft thick in places although it is poorly exposed.

Qa_{1b} **Alluvium one(b) of tributary streams (early Holocene to late Pleistocene) –** Silt, clay, sand, and gravel of a moderately well-preserved low terrace 5-8 ft above the modern floodplain along Fish Creek and minor tributaries. The lithologies are the same as for **Qa_{1a}**. Soil formed on **Qa_{1b}** has a slightly developed A-Bw (cambic)-Bk (calcic) profile. This unit is not well exposed. It appears to consist of a single, basal channel gravel overlain by overbank deposits, about 10 to 12 ft thick.

Qa_2 **Alluvium two of tributary streams (late Pleistocene) –** Silt, clay, sand, and gravel of a poorly-preserved, intermediate terrace 10-15 ft above the modern floodplain along Fish Creek and minor tributaries. The lithologies are the same as for **Qa_{1a}**. Soil formed on **Qa_{1c}** has a strongly developed A-Bt (argillic)-Bk (calcic) profile about 5 ft thick. This unit poorly exposed. Its thickness may be 3 to 15 ft over a sub-planar basal erosion surface cut on the Lewis Shale.

Qac **Alluvium and colluvium, undifferentiated (late Holocene to late Pleistocene) –** Silt, clay, sand, and variable amounts of gravel in the bottoms of valleys of tributary streams. The streams are age indeterminate but generally grade to **Qa_1**. Locally derived **Qac** alluvium takes its character from surrounding bedrock types. It is clay-rich in basins underlain by shale and sand-rich in basins underlain by sandstone. The valley bottoms typically are gently rounded. This is a result of down-slope encroachment of colluvium and slope-wash deposits at the valley sides (**Figure 5**). Many of the streams do not have a well-defined channel. Thickness is poorly known but is generally less than 10 ft.

Older Gravel Deposits of Twentymile Park

Units **Qg_3** through **Qg_7** form a series of elevated and dissected bodies of older alluvium of tributary streams. Many of them are not obviously associated with the modern course of Fish Creek. From younger to older, the remnants generally become more highly dissected and stand at higher elevations. These units are generally equivalent to Yampa River units **Qay_3** to **Qay_6**. The mapping and correlation of individual bodies is challenging due to poor preservation.

Individual remnant bodies of these units cap east-west trending, ‘finger’ mesas. They occupy interfluves between small modern streams and lose elevation eastward across Twentymile Park. Their upper surfaces range from 100 ft to more than 2,000 ft wide and up to 1.5 miles long. Where exposed, individual remnant bodies generally consist of one or more basal channel sets up to 6 ft thick each, with clasts of cobble to boulder size, overlain by up to 20 ft of gray-brown mud. The basal gravels are generally deposited on sub-planar erosion surfaces cut into Lewis Shale. Thickness of these units is difficult to determine but ranges from about 10 ft to 60 ft.

Figure 5. Alluvium and colluvium (**Qac**) in a small, tributary stream in northern Twentymile Park. Note the gently rounded valley bottom and indistinct sides. [UTMX: 326676, UTMY: 4478446]

These deposits are distinguished by (1) relatively large clast sizes, containing occasional boulders up to 4 ft long; (2) the presence in some cases of muddy, chaotic matrix fabric; and (3) caps of silty clay derived locally from the Lewis Shale. We interpret that glacial outwash floods or debris flows were responsible for transporting and mixing muddy to bouldery sediments. The timing of these events is likely related to Pleistocene glacial cycles. We also infer that the finger-like deposits originally occupied paleo valleys flanked by Lewis Shale. After abandonment, the basal gravels were covered with mud-rich sediments that were eroded from the surrounding shale hills. Eventually, the surrounding landscape eroded away. The former valley was abandoned and newer, lower-elevation valleys were eroded, leaving an inverted topography of narrow mesas.

There are two distinct gravel compositions (**Figure 6**). In the northern half of Twentymile Park, the gravel consists exclusively of angular to sub-rounded sandstone blocks and chips. The source is in the eroded sandstone terrain of the Tow Creek anticline. Gravel in the southern half of Twentymile Park consists of sub-rounded to well-rounded, intrusive and extrusive igneous rocks and metamorphic rocks. The nearest source of these resistant clasts is the Dunckley Flat Tops, 10 to 15 miles to the southwest at the headwaters of Fish Creek. We interpret that the clasts were eroded there from Tertiary-age Browns Park Formation conglomerates and basalt flows. Large glacial-outwash and debris-flow events, possibly involving landsliding failure of the Mancos-Shale slopes of the Dunckley Flat Tops, carried the sediments down the paleo Fish Creek valley system.

Qg_3 **Gravel three of Twentymile Park (middle Pleistocene) –** Bodies of gravel three have their upper surfaces about 45 to 65 ft above local stream base. Surface relief is less than 4 ft. Basalt makes up about 80% of clasts, with diameters up to 2 ft. Three bodies of Qg_3 on the western side of Twentymile Park have fan-like geometries (**Figure 6**). The fans were sourced by local streams issuing from the flank of Tow Creek anticline. Unit thickness is 10 to 30 ft.

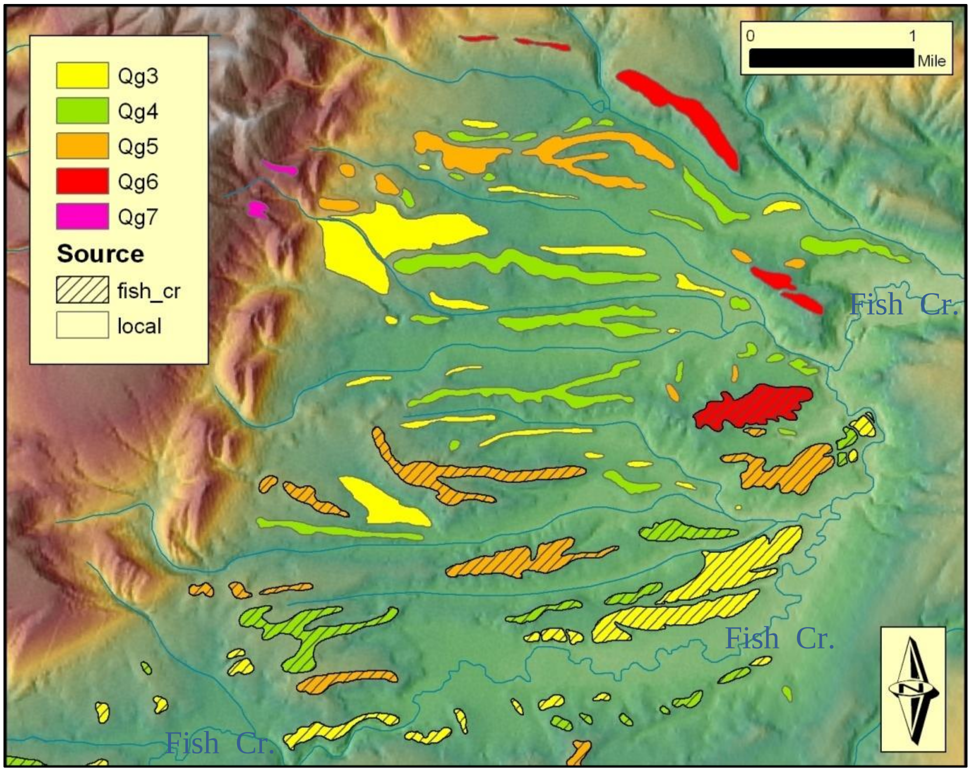

Figure 6. Map of Twentymile Park showing distribution and sources of older gravel deposits. Gravel bodies in the northern part were sourced locally, while those in the southern part are remnants of paleo valleys and are remnant outwash plains of Fish Creek.

Qg_4 **Gravel four of Twentymile Park (middle Pleistocene) –** Bodies of gravel four have their upper surfaces about 70 to 125 ft above local stream base. Surface relief is up to about 8 ft. Side slopes below remnants have noticeable mantles of colluvium derived from the unit. At one exposure, the maximum clast size is about 3 ft. Composition is about 80% basalt with lesser percentages of granitics, sandstone, and quartzite. The unit contains a few, rounded, light-brown limestone clasts derived locally from the Lewis Shale. It is up to 25 ft thick.

Qg_5 **Gravel five of Twentymile Park (middle Pleistocene)** – Bodies of gravel five have their upper surfaces about 140 to 185 ft above local stream base. Surface relief is about 20 ft. Colluvium derived from the unit mantles slopes below some interfluves even where the unit is completely removed by erosion. At one prominent gully head cut exposure, the basal coarse clasts are composed of about 40% quartzite, 30% basalt, and 30% all other lithologies, including several types of granitics. Maximum clast size for basalt is 3 ft and about 1 ft for other lithologies. We interpret that this deposit is correlative with Yampa River terrace Qay_5 and Madole's (1991) 640-ka Elk River terraces. The unit is up to 30 ft thick.

Qg_6 **Gravel six of Twentymile Park (early Pleistocene) –** Bodies of gravel six have their upper surfaces about 180 to 260 ft above local stream base. Surface relief is up to 50 ft. Colluvium derived from the unit thickly mantles even slopes below some interfluves where the original gravel body is completely removed by erosion. Coarse clasts up to 2 ft in diameter include basalts, quartzite, and other lithologies. In the east-central part of the quadrangle, the unit consists of three inset deposits totaling 50 to 60 ft thick.

Qg_7 **Gravel seven of Twentymile Park (early Pleistocene to late Pliocene) –** Only two small remnants of this unit were recognized. They are about 320 to 360 ft above a small stream emerging from the flank of the Tow Creek anticline east of “Chavez Point,” in the central part of the quadrangle. The deposits are mostly vegetated, but contain angular, chaotically arranged sandstone blocks up to 5 ft long. The unit is about 10 to 15 ft thick.

Qg **Surficial gravel lag deposits (Pleistocene) –** Several red “bulls’-eyes” mark the locations of relict gravel deposits on the flanking divides of a Mancos-Shale floored valley in the north-eastern part of the quadrangle, between Elk and Fish Creeks. The gravel bodies are too small in extent (10s of ft) and too thin (<3 ft) to show as polygons. These appear to be in-place deposits. They consist of igneous and metamorphic cobbles and pebbles, with a few boulders up to 1.5 ft long.

ALLUVIAL FAN DEPOSITS

Qf **Alluvial fan deposits (late to middle Holocene) –** Poorly sorted sand, silt, gravel, and occasional coarser fragments as large as boulder size. These deposits form at the mouths of ephemeral stream valleys where the streams lose confinement. They also occur on side slopes beneath actively eroding outcrops of sandstone and shale. The sediments are deposited by flood, debris, and sheet flow processes. On steeper slopes, colluvial and rock fall processes may contribute sediments. The fan-shaped geomorphic form of these deposits is especially distinctive in areas eroding from sandstone bedrock. The unit is 5 to as much as 50 ft thick.

Qfo **Older alluvial fan deposits (early Holocene to late Pleistocene) –** Composition and mode of deposition is the same as for **Qf**. Older fans are mapped north of the Yampa River and in the north-central part of Twentymile Park. Those fans are inactive. They were incised and bypassed by younger fans or tributary streams. Unit thickness is 5 to 40 ft.

Qdf **Debris flow deposits (Holocene) –** Sinuous and elongate bodies of extremely poorly sorted mud, sand, silt, gravel, and boulders. They are deposited primarily during intense thunder storms or times of heavy snow-melt runoff. Debris flows involve mixtures of sediment and lesser amounts of water and air that move as a mass; the fluidity varies depending on the proportions of debris and water present. They bridge the continuum between alluvial and mass wasting deposits. Individual debris flow lobes may resemble fans or earth flows. Unit thickness is 5 to 10 ft.

MASS WASTING DEPOSITS

Qls **Landslide deposits (Holocene to early(?) Pleistocene) –** Non-sorted, heterogeneous mixtures of surficial materials and fragmented rock debris in a wide range of sizes. The matrix and rock types, compositions, and sizes of fragments present reflect the properties of the local source area. The unit includes material deposited in the lower part of the slide area or the zone of accumulation. We map the landslide head scarps as separate features. Many landslides in the Milner quadrangle occur as dip-slope failures. These may occur in response to the incision and deepening of an adjacent stream, which removes support at the base of the slope. Dip-slope failures include block-glide landslides, where large, irregular blocks of bedrock and surficial debris slide down a basal failure plane (**Figure 7a**). The failure plane is typically a weak layer such as a shale unit. Earth flow landslides occur in relatively fine-grained and homogeneous slope materials. They are recognized in areas underlain by the Lewis and Mancos Shales (**Figure 7b**). The deposits range from 5 to more than 200 ft thick.

Qc **Colluvial deposits (Holocene)** – Deposits found generally at the base of slopes that were transported by a combination of gravity and water. Deposits consist mainly of silty sediment, sand, and fine gravel. In many cases, they contain locally derived cobbles, boulders, or blocks of more resistant gravels or sandstone lithologies. Deposits typically are massive and very poorly to extremely poorly sorted. Thickness is poorly known but estimated to be 2 to 100 ft thick.

Qt **Talus deposits (Holocene) –** Deposits of cobble to boulder size, in the form of broken and shattered rock blocks, found generally at the base of steep slopes underlain by sandstone. There is often a matrix of mixed sand, mud, and sandstone fragments. The sediment is transported and deposited primarily by raveling and rock fall, slope failure, and sheet wash processes. Unit thickness is 5 to 50 ft.

BEDROCK UNITS

Sedimentary bedrock formations of Upper Cretaceous age are found throughout the Milner quadrangle. Tertiary intrusive igneous bedrock is found in one small area. The Cretaceous bedrock units are shown within a regional stratigraphic geologic context in **Appendix B**.

TERTIARY INTRUSIVE ROCKS

Tli **Latite-trachite intrusive dike (Miocene?) –** Two closely-spaced dikes are exposed in a railroad cut east of the town of Milner (**Figure 8a**), and are mapped as a single feature. Each dike is about 12 to 15 ft wide. A distance of 20 ft separates them. They are oriented north-to-south and are parallel. The western body dips 85^{o} to the west; the eastern dike dips from 68^{o} to 74^{o} to the east. A third, poorly exposed dike is located about 300 ft to the east, along the alluvial-terrace riser slope. It is oriented southwest-to-northeast. The top of each dike is eroded away coincident with the strath of the Qay_3 Yampa River terrace. The host rock is highly weathered sandstone of the lower Iles Formation. The dikes are composed of latite-trachite. The rock is medium grayish purple, weathering reddish purple. It has a finely textured, potash-feldspar ground mass and contains abundant, medium-grained biotite and clear-to-amber quartz and cloudy white feldspar phenocrysts (**Figure 8b**).

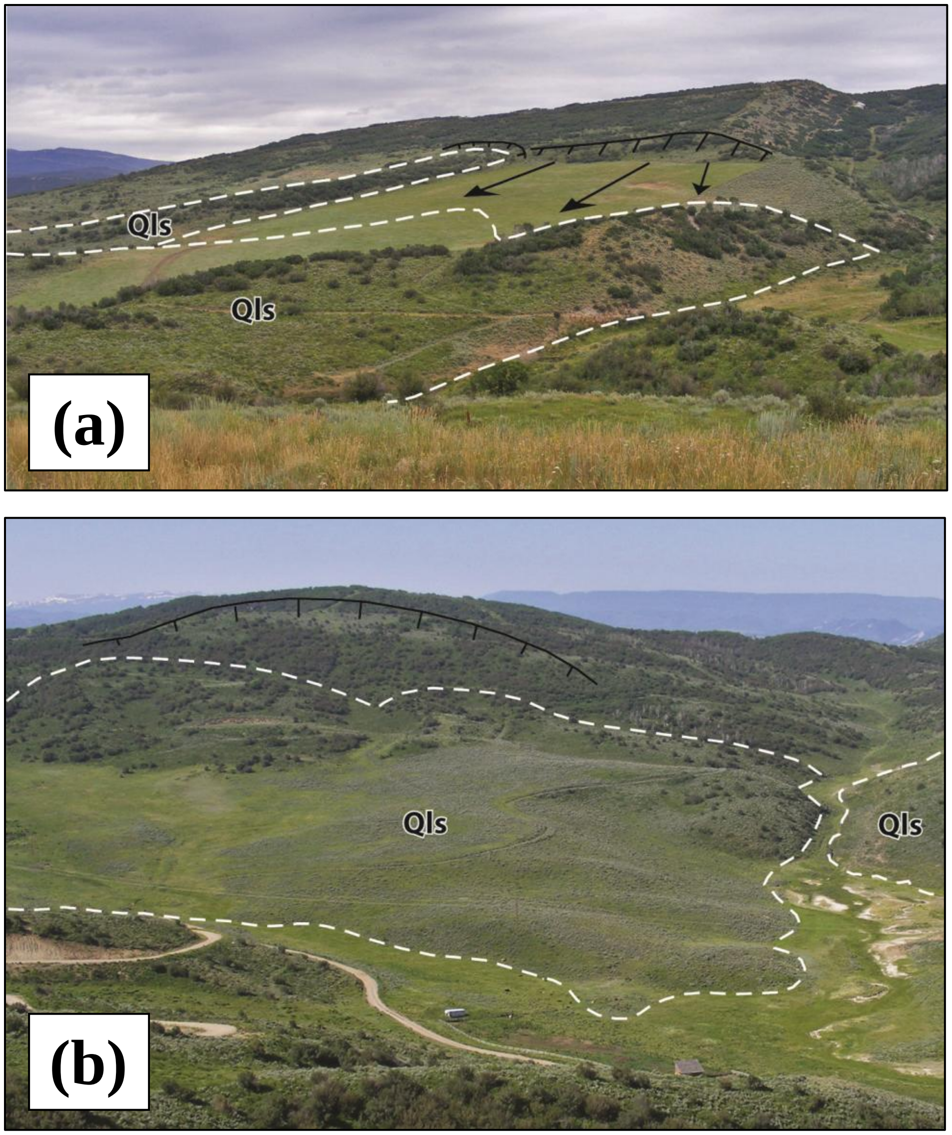

Figure 7. Examples of different types of landslide deposits (**Qls**) in the Milner quadrangle.
(a) Block-glide landslides on the lower Williams Fork Formation dip slope. The closest landslide body is separated from its head scarp (black line with tics) by a planar evacuated zone (arrows) floored by the slide plane. Part of the slope surface is modified by agriculture. [UTMX: 319227, UTMY: 4481319]
(b) Earth-flow landslide (Qls) spreading across Mancos Shale. The hummocky surface and presence of numerous, coalesced lobes indicates periods of recurring movement. [UTMX: 330058, UTMY: 4481018]

CRETACEOUS SEDIMENTARY ROCKS

Cretaceous formations outcropping in the Milner quadrangle include the Lewis Shale, Williams Fork and Iles Formations, and Mancos Shale (**Figure 9**). The Williams Fork and Iles units comprise the Mesaverde Group in northwestern Colorado. They form three wedges of clastic, marginal-marine to continental sediments that prograded eastward into the Cretaceous Western Interior Seaway (**Appendix B**). The

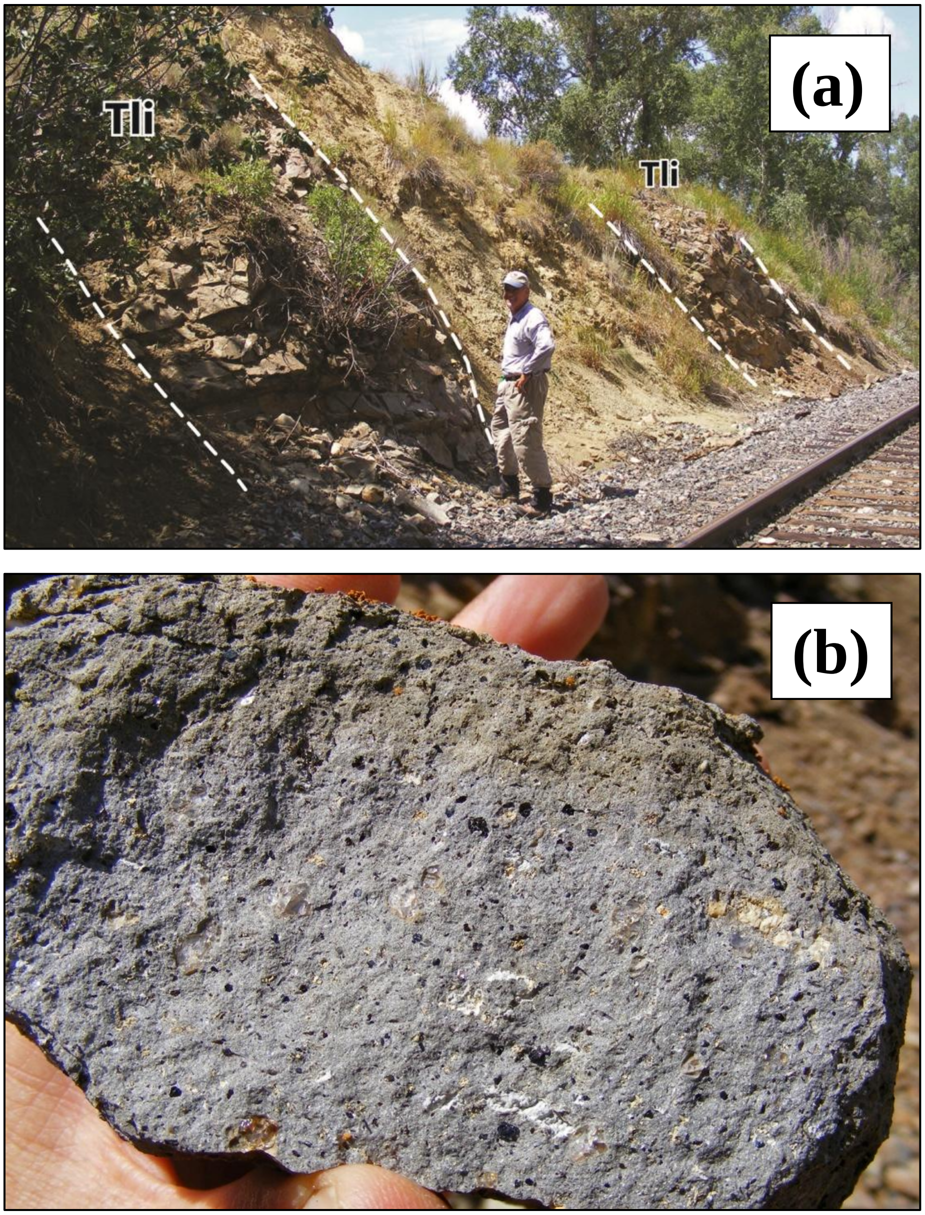

Figure 8. Latite-trachite dike (Tli) exposed in railroad cut, 0.5 miles to the southeast of Milner.
(a) Two near-vertical dikes exposed in south face of cut. [UTMX: 329641, UTMY: 4482827]
(b) Hand sample showing biotite, quartz, and feldspar crystals in a fine, grayish-purple ground mass.

wedges contain three zones of coal-bearing strata: the lower, middle, and upper coal groups. They are bounded by and intertongue to the east with marine Lewis and Mancos Shales.

We map several persistent sandstone bodies within the Williams Fork and Iles Formations and the Mancos Shale. They include the Twentymile (Williams Fork), Trout Creek and Tow Creek (Iles), and Loyd and Wise Gulch (Mancos Shale) sandstone members. In addition, we map transgressive tongues of the Lewis and Mancos Shales that occur within the Iles and Williams Fork Formations.

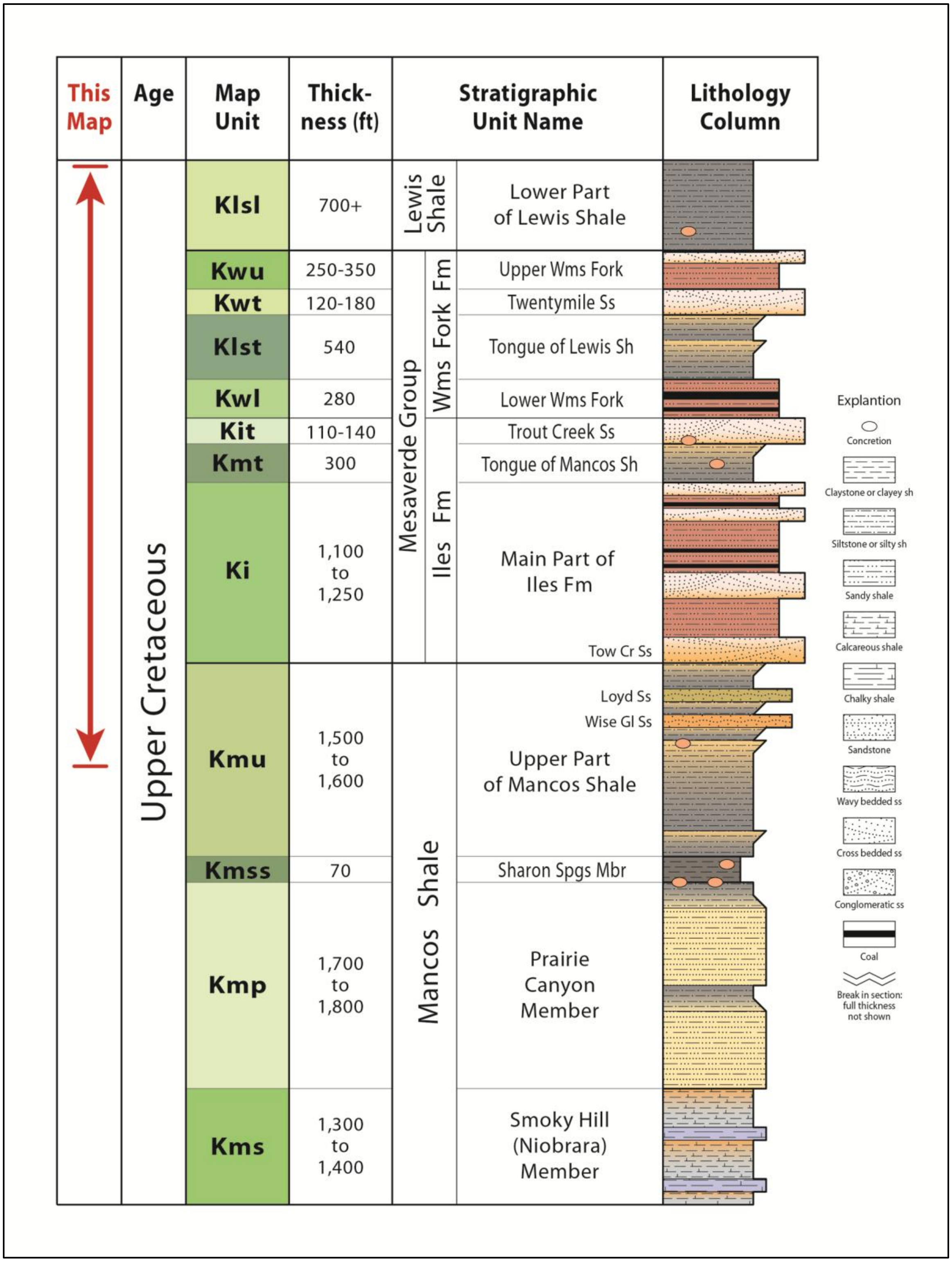

Figure 9. Generalized stratigraphic column of Cretaceous bedrock units for the Milner quadrangle. Red arrow denotes bedrock units exposed in outcrops in the quadrangle. **Appendix B** shows how this column relates to the Upper Cretaceous and Tertiary geologic framework of northwestern Colorado.

These bedrock units are well described in the geologic literature. For nomenclature history and regional stratigraphic and depositional-systems studies of units within the Mesaverde Group, see Bass and others (1955), Masters (1965; 1967), Izett and others (1971), Bader and others (1983), and Johnson and others (2000). In addition, for the sandstone units at the Mesaverde/Mancos interface and within the upper part of the Mancos Shale, see Konishi (1959), Dyni and Cullins (1965), Gill and Hail (1975), Boyles and others (1981), Boyles (1983), Kiteley (1983), Kiteley and Field (1983), Crabaugh (2001), Hampson and others (2008), and Gomez-Veroiza and Steel (2010).

CGS STATEMAP geologic mapping includes the collection and cataloging of fossils. We collected marine invertebrate fossils of Late Cretaceous age from several locations in the quadrangle. The fossils are potentially useful as paleo-environmental or biostratigraphic-age indicators. **Appendix C** contains a listing of fossils found in and near to the quadrangle by CGS and previous authors.

Lewis Shale (Upper Cretaceous)

Klsl **Lewis Shale, lower part of main body –** The lower part of the main body of Lewis Shale is present within Twentymile Park. The shale supports extensive grasslands. In rare exposures, it consists of slightly sandy, non-calcareous, shaley to bioturbated, marine mudstone. The shale is medium gray when fresh and weathers to pale to moderate yellowish brown (**Figure 10a**). It contains yellowish-orange to light brown limestone concretions. Residual soil on the shale consists of a thin, weak A horizon, a well-developed Bw horizon several feet thick, and a thin, stage I-II Bk-Ck horizon at the soil and weathered bedrock interface (**Figure 10b**). The unit is commonly fractured in the shallow subsurface. Using sub-surface data from Robson and Stewart (1990), its maximum thickness is about 700 ft.

Williams Fork Formation of the Mesaverde Group (Upper Cretaceous)

Kwu **Williams Fork Formation, upper part –** This unit contains interbeds of sandstone, siltstone, coal, and carbonaceous shale . It represents the uppermost of the three Mesaverde clastic wedges. Most of the sandstone beds are grayish to yellowish orange, very fine to fine grained, lenticular, and contain trough cross beds and ripples. An exception is the Fish Creek Sandstone at the top of the unit, which is whitish to very pale orange and contains low-angle to planar cross beds. The coal beds comprise the upper coal group of the Yampa coal field. Thickness is 250 to 350 ft.

Kwt **Twentymile Sandstone Member –** The Twentymile Sandstone forms a series of distinctive, whitish sandstone hogbacks that are often subsidiary to hogbacks of the overlying upper part of the Williams Fork Formation (**Figure 11**). The sandstone coarsens upward from very fine to fine grained. The unit consists of one to three, thick sandstone bodies that are sometimes separated by thin shale stringers. It has a gradational (often covered) contact with the underlying marine shale and a sharp contact with overlying upper Williams Fork strata. According to Siepman (1985, 1986) and Benda (2000), the Twentymile Sandstone was deposited in deltaic, strand plain, and barrier island settings.

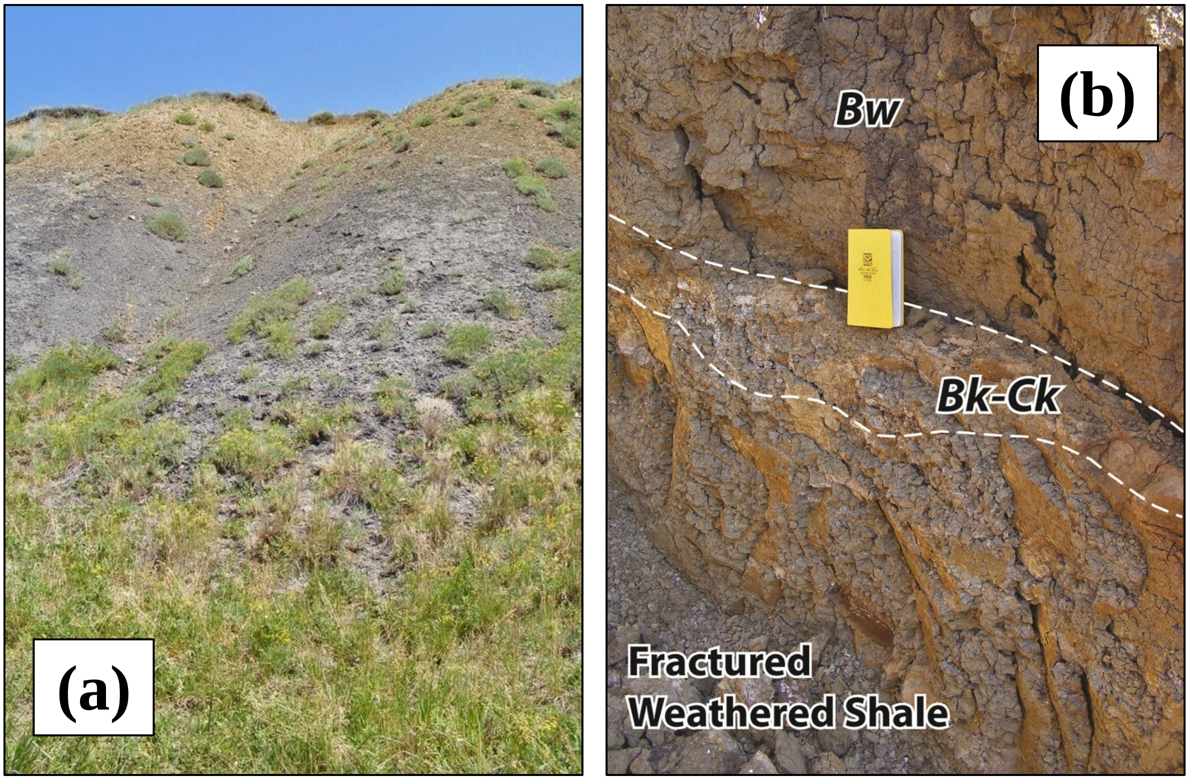

Figure 10. Lower part of the Lewis Shale (**Klsl**) in outcrop and trench exposures.
(a) Outcrop of Lewis Shale along Fish Creek. A color change upward from gray to yellowish brown commonly occurs where the shale is overlain by Quaternary gravel-terrace deposits. [UTMX: 326180, UTMY: 4472640]
(b) Lewis Shale exposed in a utility trench in Twentymile Park. The exposure consists of weathered and fractured shale bedrock overlain by a residual clay soil. [UTMX: 326343, UTMY: 4471580]

From our mapping field work in the Milner quadrangle, we note that each of the sandstone bodies shows a general, full to partial progression of sandstone lithofacies from base to top: (1) individual to amalgamated, hummocky to swaley cross-beds; (2) an extensively bioturbated interval; (3) low-angle, trough cross-beds; and (4) low-angle, planar beds. The shale stringers appear to mark the beginning of a similar progression in the next-highest sand body. The basal, hummocky sandstone beds, rarely exposed in outcrop, are often light brown in color. Most of the beds in the overlying, amalgamated sandstone bodies are whitish to very pale orange. The uppermost part of the unit forms a flat surface covered with carbonaceous shale. In places, the upper contact is sometimes eroded away by channel sandstone from the upper Williams Fork unit. The Twentymile Sandstone is 120 to 180 ft thick in the Milner quadrangle.

Klst **Tongue of Lewis Shale** – This tongue of the Lewis Shale represents a westward incursion of the Western Interior Seaway (**Appendix B**). The unit forms a distinctive band of gentle, grass-covered or forested slopes. In rare exposures, it contains silty, shaley to bioturbated, marine mudstone that looks similar to the main body of Lewis Shale. It is about 540 ft in a coal-exploration core on the nose of Tow Creek anticline, and probably thickens eastward.

Figure 11. Twentymile Sandstone Member of the Williams Fork Formation (**Kwt**).
Upper part of the unit exposed in a hogback along the eastern flank of Tow Creek anticline. The lower cliff face has trough cross-bedding and is partially bioturbated. The cliff face contains well-developed, low-angle planar bedding. Thinner, lenticular sandstone beds make up the overlying, upper Williams Fork (**Kwu**) hogback at right. [UTMX: 323394, UTMY: 4476334]

We mapped a horizon of thin hummocky cross-bedded sandstone beds within the tongue of Lewis Shale in the southwestern part of the quadrangle. Its thickness is about 10 to 15 ft. This sandstone horizon appears to be an offshore equivalent to the **Sub-Twentymile Sandstone**, which thickens and becomes a readily recognizable stratigraphic unit toward the west (see **Appendix B**). In the southwestern part of the Milner quadrangle, we mapped the horizon as a dashed line (labeled as **Kwst**).

Kwl **Williams Fork Formation, lower part –** This unit contains interbeds of sandstone, siltstone, coal, and carbonaceous shale. It represents the middle of the three Mesaverde clastic wedges. It is similar to the upper part of the Williams Fork Formation in terms of composition and lithofacies. The coal beds comprise the middle coal group, which is the major producing interval of the Yampa coal field (see **Mineral Resources** section). We observed the Yampa Bed (Brownfield and Johnson, 2008), a 1-ft thick tonstein (volcanic ash) deposit, near the base of the unit in a coal-exploration core. We did not see the ash bed in outcrop. The lower Williams Fork outcrop belt is covered in many places by disturbed and reclaimed land from coal mining. Where exposed in hogback-capping bluffs, the unit contains lenticular, cross-bedded sandstone bodies and reddish clinker from burnt coal (**Figure 12**). The unit is 280 ft thick in a coal-exploration core on the southern nose of Tow Creek anticline. It thickens toward the northwest.

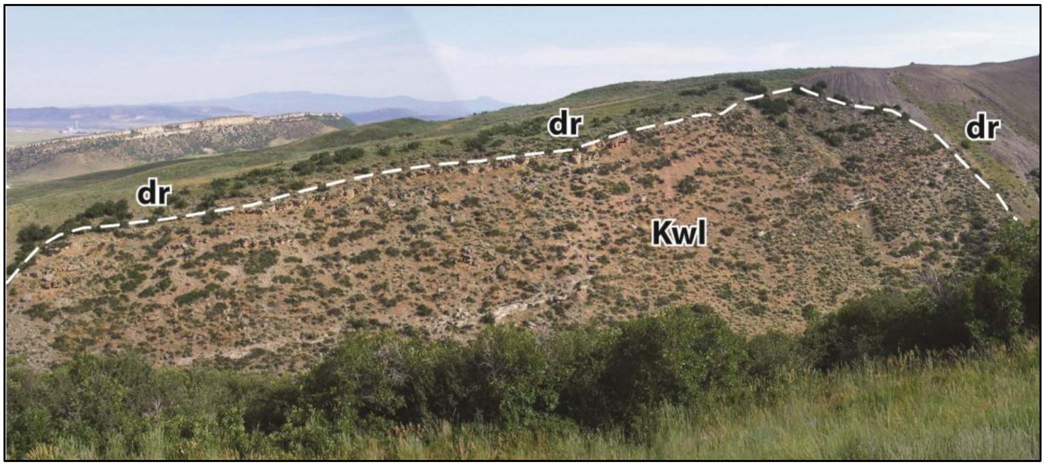

Figure 12. Lower part of the Williams Fork Formation (**Kwl**).
This outcrop is exposed in a hogback along the western side of the Tow Creek anticline. It consists mostly of shale and a few discontinuous, lenticular sandstone bodies. The reddish material is clinker formed by coal-outcrop fires. Here, the unit is covered by reclaimed and end-dumped spoil materials (map unit **dr**) from the Seneca II coal mine. [UTMX: 320723, UTMY: 4477410]

Iles Formation of the Mesaverde Group (Upper Cretaceous)

Kit **Trout Creek Sandstone Member –** The Trout Creek Sandstone forms a series of whitish cliffs below hogbacks of the overlying lower Williams Fork Formation (**Figure 13a**). The sandstone coarsens upward from very fine to fine grained. The unit consists of one to three, thick sandstone bodies separated by thin shale stringers. It has a gradational to sharp (often covered) contact with the underlying marine shale and a sharp contact with overlying lower Williams Fork strata. The unit is similar to the previously described Twentymile Sandstone in terms of color, lithofacies, and thickness. In rare outcrop exposures, we found that the lowermost, hummocky cross-bedded interval of the Trout Creek Sandstone appears to be very thin or missing (**Figure 13b**). We collected *Exiteloceras jenney*, *Didymoceras cheyennense*, and associated fossils from above and below the lower contact of the sandstone (**Appendix C**). Siepman (1985, 1986) interpreted the Trout Creek Sandstone as being deposited in deltaic, strand plain, and barrier island settings. The unit is 110 to 140 ft thick in the Milner quadrangle.

Kmt **Tongue of Mancos Shale** – This tongue of the Mancos Shale represents a westward incursion of the Western Interior Seaway. The unit forms a distinctive band of gentle, grass-covered or forested slopes. In rare exposures, it consists of silty to sandy, bioturbated to shaly mudstone that looks similar to the main body of Mancos Shale. The unit is about 300 ft thick beneath Tow Creek anticline. It probably thickens eastward across the quadrangle.

Ki **Iles Formation –** The main body of the Iles Formation contains interbeds of sandstone, siltstone, carbonaceous and marine shale, and coal. It represents the lowermost of the three Mesaverde clastic wedges. The coal beds comprise the lower coal group of the Yampa coal field. The best exposures of this unit are seen in road cuts along US-40, in the western and eastern limbs of

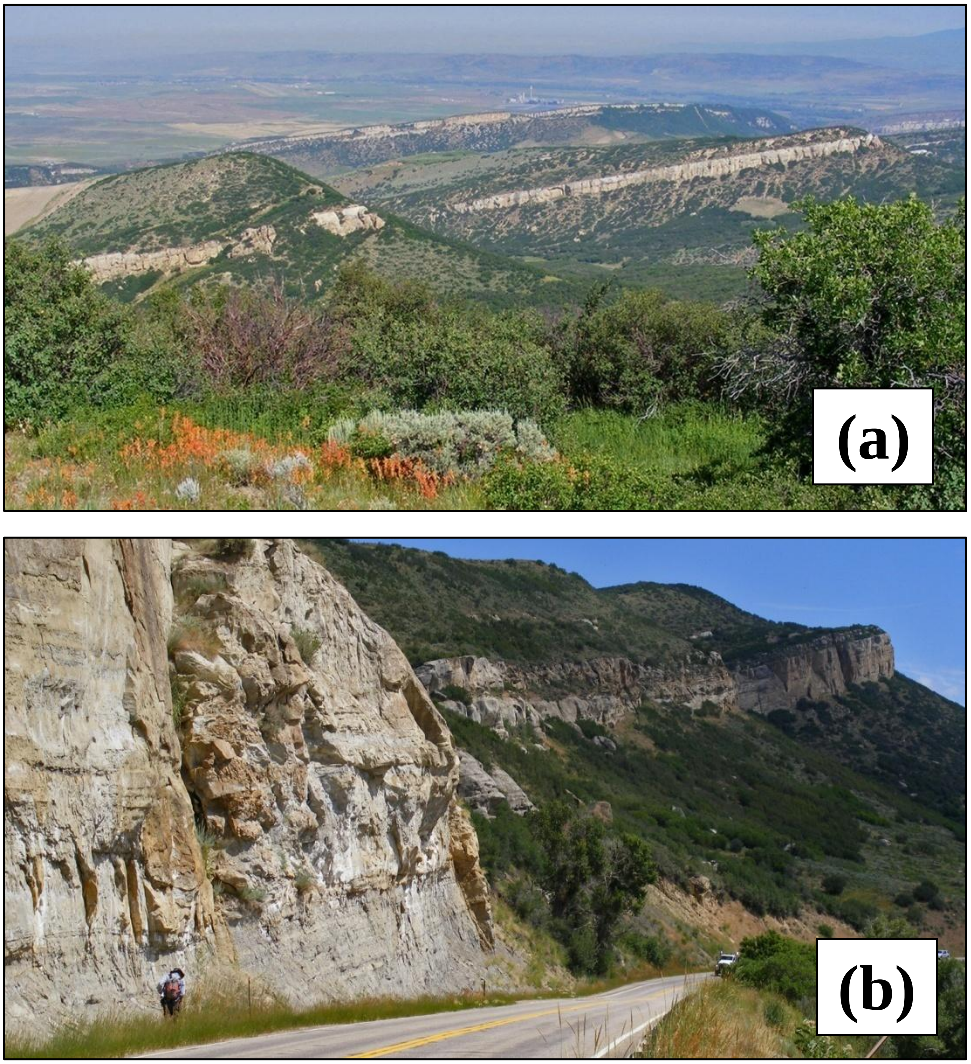

Figure 13. Trout Creek Sandstone Member of the Iles Formation (**Kit**).
(a) Extensive, white cliffs of Trout Creek Sandstone (in middleground), seen in adjacent, hogback ridges along the western side of the Tow Creek anticline. The Twentymile Sandstone forms a second line of cliffs in the center background. [UTMX: 322350, UTMY: 4477474]
(b) Base of the Trout Creek Sandstone (just above geologist's head) along US-40. Here, amalgamated and bioturbated, hummocky to swaley cross-bedded sandstone sits directly on grayish, sandy shale of the Mancos Shale tongue. [UTMX: 319997, UTMY: 4483502]

Tow Creek anticline (**Figure 14**). The sandstone bodies are very fine to fine grained. They are light brown to whitish to very pale orange. From our mapping field work, we noted three main sand-body geometries and lithofacies types: (1) lenticular sandstone bodies with cross-bedded to rippled beds; (2) thin, sheet-like sandstone bodies with rippled or foreset bedding; and (3) thick, tabular, laterally continuous sandstone bodies with basal hummocky beds overlain by bioturbated intervals, low-angle trough cross-beds, and capped by low-angle planar beds. Crabaugh (2001) defined 16 separate regressive-transgressive couplets within the Iles clastic

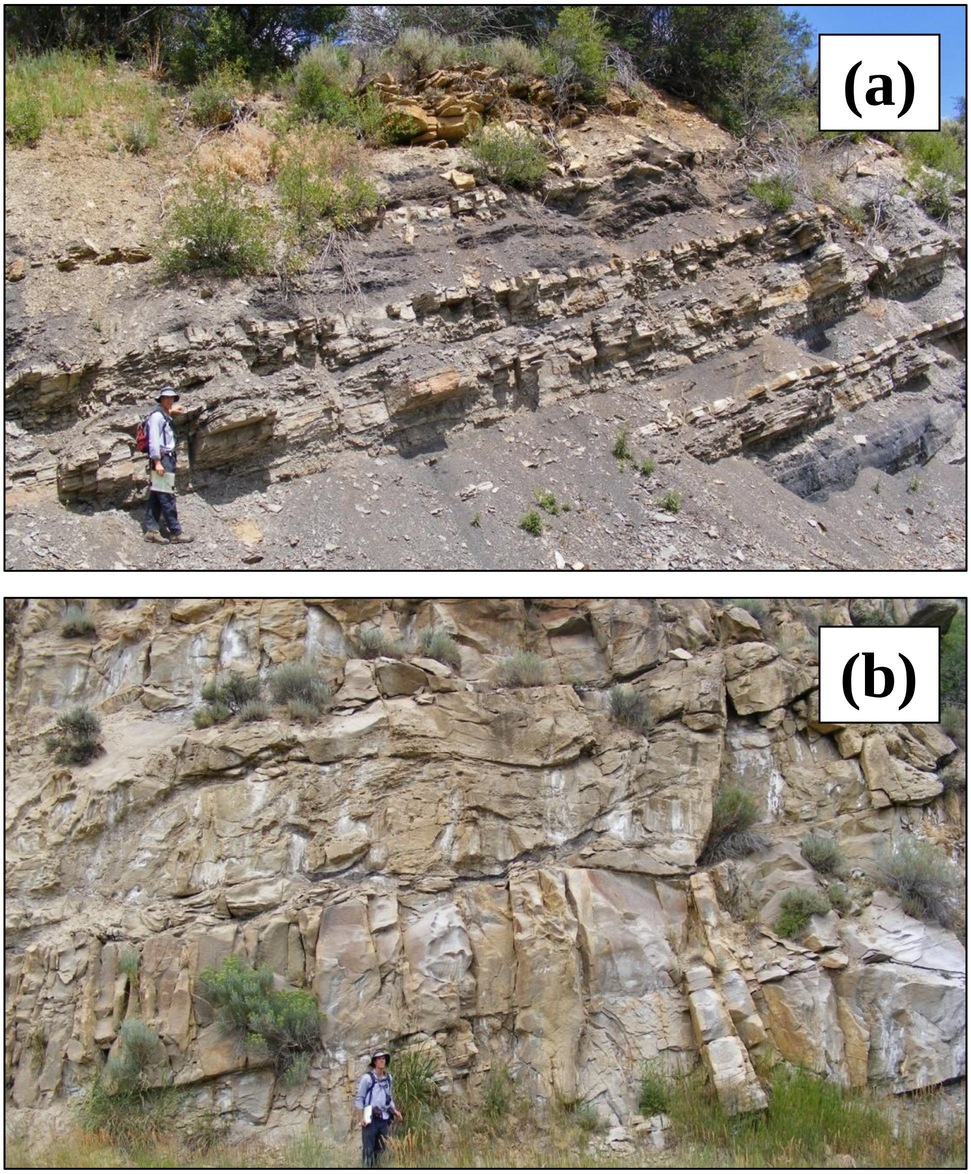

Figure 14. Main body of Iles Formation (**Ki**) exposed along US-40 near the Bear River town site.
(a) Interbedded coal, carbonaceous shale, and sheet-like sandstone beds in the lower coal group. A yellowish-brown, lenticular, rippled sandstone body caps the hill. [UTMX: 320425, UTMY: 4483689]
(b) Channel-like bodies of amalgamated, stacked, lenticular, cross-bedded sandstone. [UTMX: 320925, UTMY: 4484042]

wedge to the southwest of Milner quadrangle. Gomez-Veroiza and Steel (2010) found that the seaward part of the wedge (which includes the present-day Milner quadrangle) is dominated by regressive, deltaic-shoreface and coastal-plain facies. The transgressive tracts contain near-shore marine, tidal, estuarine, and coal-swamp facies, and extend nearly 100 miles to the northwest into the Wyoming thrust-belt foreland. The main body of the Iles Formation is about 1,100 to 1,250 ft thick in the Milner quadrangle.

The basal unit of the Iles Formation in the Milner quadrangle is the **Tow Creek Sandstone Member**, a 100- to 125-ft thick sandstone interval with lithofacies of type 3, above. This unit forms the distinctive rim rock along the western side of the Tow Creek valley (**Figure 15**). It is also present in the Curtis anticline, in the northeastern part of the quadrangle. The Tow Creek Sandstone is typically light brown in color. Its basal contact is gradational with the underlying Mancos Shale. The unit is similar to the previously described Twentymile and Trout Creek Sandstone units in terms of lithofacies, and thickness. Kiteley (1983) and Kiteley and Field (1984) interpreted the Tow Creek Sandstone as a fluvial-dominated deltaic deposit comprised of channel-mouth bar and delta-front sheet sandstones facies. It is mapped as a dashed line (labeled as **Kito**).

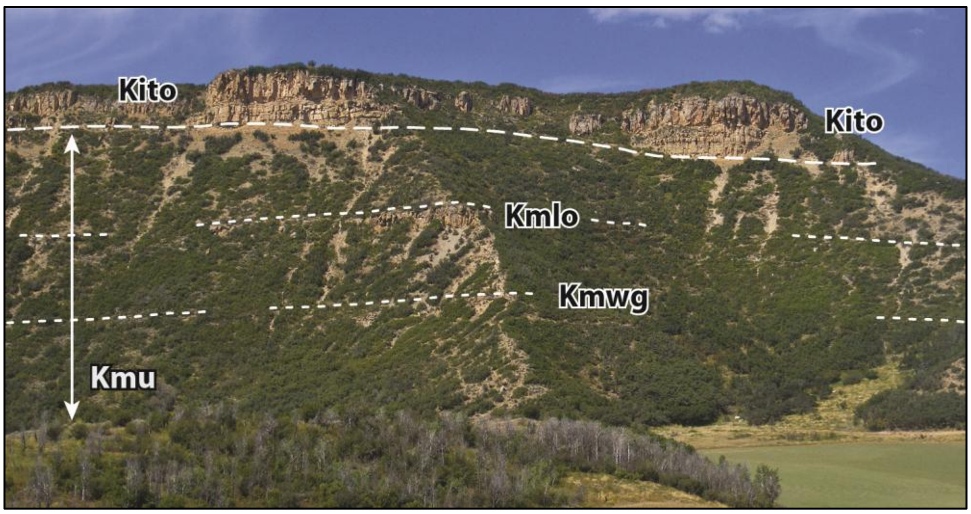

Figure 15. Tow Creek Sandstone Member (**Kito**) of the Iles Formation.
Rim-rock cliffs of Tow Creek Sandstone at its type section along the western side of Tow Creek. Also shown are two tabular sandstone bodies encased within the upper part of the Mancos Shale (**Kmu**): the Loyd (**Kmlo**) and Wise Gulch (**Kmwg**) Members. [UTMX: 325517, UTMY: 4485090]

Mancos Shale (Upper Cretaceous)

Kmu **Mancos Shale, upper part of main body** — The upper part of the main body of Mancos Shale is present in the core of the Tow Creek and Curtis anticlines and near the mouth of Trout Creek. It forms steep, covered slopes and broad valleys. The shale consists primarily of olive-gray to pale yellowish-brown, non-calcareous, silty to sandy, shaley to bioturbated, marine mudstone. It contains some dark yellowish-orange to light brown concretions. The uppermost 800 ft of the unit is exposed in the quadrangle (see **Appendix B**). In comparison, its entire thickness is 1,500 to 1,600 ft in nearby oil-and-gas well logs.

Two intervals containing tabular, laterally extensive sandstone bodies are found within the upper Mancos Shale unit (**Figure 15**) and are mapped as dashed lines. The highest, the **Loyd**

Sandstone Member (**Kmlo**), is about 200 ft beneath the base of the Iles Formation. It is light olive-brown, bioturbated, contains trough cross-beds, and is 30 to 40 ft thick. The USGS (in Dyni and Cullins, 1965) collected a *Baculites perplexus* specimen from the Loyd Sandstone, to the east of Tow Creek. The lowest, the **Wise Gulch Sandstone Member** (**Kmwg**), is about 400 ft beneath the base of the Iles Formation. It is thin-bedded, rippled, shows some pinching and swelling, and occupies at least two closely spaced horizons. The sandstone bodies are 20 to 30 ft thick. Kiteley and Field (1984) interpret the Loyd Sandstone to be a slowly transgressed, deltaic deposit. Hampson and others (2008) interpret the Wise Gulch Sandstone to be a nearshore shelf- bar complex within an estuarine river-delta system.

Older Mancos Shale Members Shown on Geologic Cross Sections A-A’ and B-B' Only

Cross Section A-A’ crosses the core of the Tow Creek anticline and northern flank of the Curtis anticline. **Cross Section B-B’** crosses the southern nose of the Tow Creek anticline and the north-central part of Twentymile Park. The section lines are shown on **Plate 1**. The cross sections are shown on **Plate 2**. The cross sections show the subsurface stratigraphy and structure the Upper Cretaceous strata. Additional members of the Mancos Shale are included as subsurface units on the geologic cross sections, and are described below. They do not crop out within the Milner quadrangle but occur in outcrops to the south. Reported thickness values are estimated from oil and gas well logs in the area.

Kmss **Sharon Springs Member** — This thin, black, bentonitic shale is shown as a line rather than an interval. The unit serves as a regional subsurface marker separating the upper part of the Mancos Shale from the underlying Prairie Canyon Member. Thickness: 70 ft.

Kmp **Prairie Canyon Member** — This sandy shale interval is the offshore equivalent of the Blackhawk and Star Point Formations in central Utah (Cole and others, 1997). Thickness: 1,700 to 1,800 ft.

Kms **Smoky Hill and Fort Hays (Niobrara) Members, undifferentiated** — This section of calcareous shale and marly limestone is a favored oil-and-gas exploration target in the region. Thickness: 1,300 to 1,400 ft.

Kml **Mancos Shale, lower part of main body** — This interval contains black shale and minor sandstone. It includes the upper Carlile, Frontier and Mowry Members. Thickness: 700 ft.

OLDER SEDIMENTARY AND BASEMENT ROCKS

Approximately 2,500 ft of older sedimentary formations underlie the Mancos Shale in the vicinity of the Milner quadrangle (RMAG Research Committee, 1977). Only the uppermost part of this interval is shown on the geologic cross sections as an undivided unit, "Older sedimentary rocks." It includes, from youngest to oldest, the Dakota and Lakota/Cedar Mountain Formations (Cretaceous); Morrison, Curtis, and Entrada Formations (Jurassic); Chinle, Shinarump, and Moenkopi Formations (Triassic); State Bridge/ Park City/Phosphoria Formations (Permian); Weber, Maroon, Morgan, Minturn, Belden, and Molas

Formations (Pennsylvanian) (Tremain Ambrose, 1998; New Mexico Bureau of Mines and Mineral Resources, 1993). Tremain Ambrose (1998) shows the Mississippian to Cambrian section as missing, unconformably, at the top of the Precambrian basement rocks at Tow Creek oil field.

As inferred from the statewide map of Sims and others (2001), the Precambrian basement rock in the vicinity of the quadrangle consists of felsic and hornblende gneiss (Paleoproterozoic). In contrast, a driller's log from Tow Creek oil field lists the basement rock as "granite" (Saterdal, 1955).

STRUCTURAL GEOLOGY

The Milner quadrangle lies within the southeastern part of the Wyoming basin physiographic province (Fenneman and Johnson, 1946). It lies at the southeastern margin of the Sand Wash geologic basin. The Sand Wash basin is bordered by Precambrian basement-cored uplifts to the east (Park Range) and to the south (White River Plateau). The southeastern margin of the basin contains a series of ridges and valleys that mark the locations of tightly folded anticlines and synclines. The basin formed during the Laramide orogeny, in Late Cretaceous to Eocene time (Tweto, 1977; Finn and Johnson, 2005). Later, during the Miocene Epoch, rifting, block faulting, and basaltic volcanism related to crustal extension occurred in central Colorado (Tweto, 1977).

Major structural elements of the Milner quadrangle include compressional folds and faults that are associated with the Laramide orogeny (late Cretaceous to Paleocene) and extensional faults associated with Neogene-age orogenic episodes (Miocene to Pliocene) (Tweto, 1976). The primary Laramide folds include the Tow Creek and Curtis anticlines and the Twentymile Park syncline and basin (**Figure 16**).

The Tow Creek anticline is asymmetrical, with a gentle western limb (10° to 15° dip angles in outcrop strata) and a steep eastern limb (26° to 45°). Crawford and others (1920) correctly speculated that the fold was a favorable target for oil and gas exploration. Our **Cross Section A-A’** (**Plate 2**) crosses the Tow Creek oil field where erosion has exposed Mancos Shale at the core of the fold. **Cross Section B-B’** crosses the more subdued, southern nose of the anticline at the Grassy Creek oil field. Livesey (1985) studied an east-to-west seismic line along the same alignment as section B-B’. He concluded that the structure is formed by a basement-cored thrust fault with at least one mile of lateral movement at depth. He shows the eastern edge of Tow Creek anticline as having about 1,000 ft of offset at the ground surface. Our geologic mapping did not reveal any offset in strata along the eastern side, however. An alternate explanation is that the anticline is a forced fold in sedimentary rocks over a tilted crystalline rock block.

The Curtis anticline is subtle, east-west feature that plunges westward and terminates at the Twentymile syncline. The anticline has a broad, gently dipping crest and is surrounded by a relatively narrow zone (1/4 to 1/2 mile wide) of strata with dip angles of 17° to 28°.

The Twentymile Park syncline separates the Tow Creek and Curtis anticlines. It runs in a north-south direction and plunges into Twentymile Park. Twentymile Park is an enclosed basin where four different synclinal folds intersect. **Cross Section A-A’** crosses the Twentymile Park syncline where it separates the Tow Creek and Curtis anticlines. **Cross Section B-B’** crosses the Twentymile Park basin.

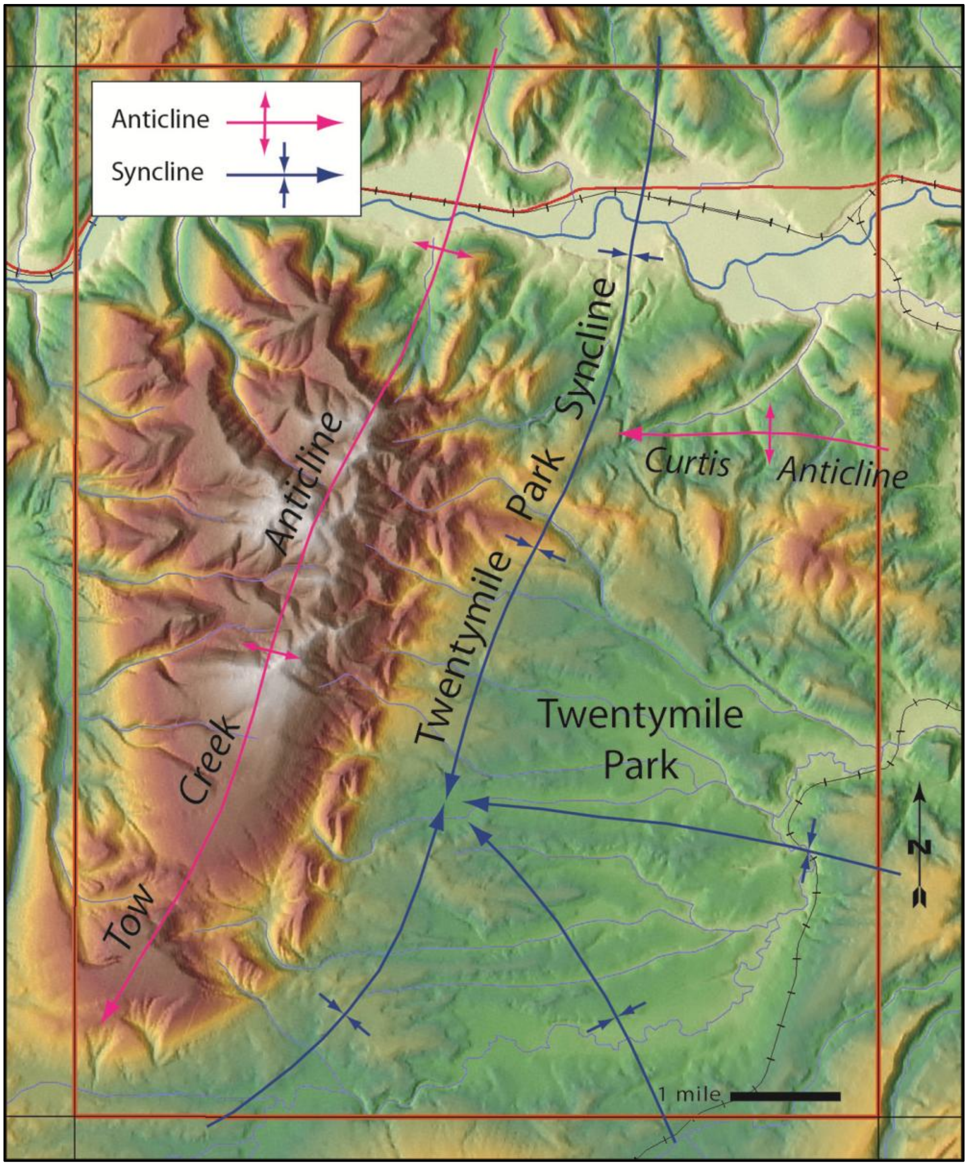

Figure 16. Shaded relief map showing anticlines and synclines in the Milner quadrangle.

Numerous, high-angle faults having southeast-to-northwest orientation cross Milner quadrangle. In rare exposures, they cut cleanly through the Cretaceous sedimentary strata. Associated large-scale folding is absent. Many of the mapped faults were originally recognized in coal mines (Bass and others, 1955). Tyler and Tremain (1994) and Gillett (2009) describe the faults as Miocene to Pliocene in age. They are part of a fault system that extends between the Colorado Rift in north-central Colorado and the Unita Mountains in far northwestern Colorado. The faults have a normal sense of movement with indications of left-lateral, strike-slip movement (Tyler and Tremain, 1994; Gillett, 2009). This is in accordance with the left-oblique, extensional tectonic regime that existed in the region during rifting (Chapin and Cather, 1994).

Most of the Tertiary normal faults mapped within the quadrangle have offsets of less than 100 ft. Bass and others (1955) mapped one fault with an offset of up to 500 ft that crosses the northwestern corner. Robson and Stewart (1990) mapped a 1,400-ft drop in the structural elevation of the Trout Creek Sandstone along the margin between Twentymile Park and the Curtis anticline. They map a single fault within the fold limb that drops the surface to the southwest. North of the Yampa River valley, along the western flank of the Tow Creek anticline, the normal faults produce a horst-and-graben pattern that offsets sandstone bodies in the lower Iles Formation and upper Mancos Shale. These same faults may cut and modify the Laramide-age anticlinal fold in the Tow Creek oil field a mile to the southeast (**Cross Sections A-A'** and **B-B'**, **Plate 2**).

Geologists at Foidel Creek coal mine, using seismic surveys, recognized a zone of numerous, sub-parallel faults along that trend (R. Thompson, Twentymile Coal Company, personal communication, 1996). We show this zone as a number of inferred faults in our map. However, at the ground surface, we could not discern individual faults that cross the shale-floored grasslands of Twentymile Park. The subsurface layout of Foidel Creek coal mine explicitly avoids long-wall mining near the faults that cross Twentymile Park (see *Mineral Resources* section). Mr. Thompson reports that he directly observed and measured fault planes and offsets in haulage tunnels that pierce the faults. He notes that some of the faults display scissor-like movements, with differences in offsets and/or reversal of direction of normal-fault movement from one location to another.

A series of NE-SW oriented shear zones were observed by geologist R. Thompson (Twentymile Coal Company, personal communication, 2011), within the Foidel Creek coal mine. The largest is 3,000 ft wide and underlies the Foidel Creek valley. Two smaller shear zones cross Twentymile Park. Within the Wadge coal bed, the zones contain vertical slickenside surfaces with horizontal grooves and striations, giving a corrugated appearance. The surfaces do not continue into the roof and floor of the coal seam. The roof contact of the coal contains bedding-plane slickensides. Mr. Thompson interprets the features as being related to the Precambrian Soda Creek-Fish Creek ductile shear zone (Snyder, 1980a; Sims and others, 2001), which is exposed in crystalline rocks in the Park Range, to the east of Steamboat Springs. He suggests that they may record minor movement along the deeper Precambrian shears.

Gillette (2009) conducted surface and subsurface analyses of faults, fractures, and coal cleats at Tow Creek anticline, Twentymile Park, and other northwestern Colorado locations. He gives evidence for multiple phases of rock deformation. They include the following structural elements: (1) small thrust faults (σ_1 = N57°E) near Craig, showing Laramide compression; (2) normal faults (avg. strike = N60°W); minor right- and left-lateral strike-slip faults (N60°W and N10°W), and joints and coal cleats (N40°W), all formed in response to regional extension during Middle to Late Miocene time; and (3) joints (N70°W) that conform to regional present-day stresses.

MINERAL RESOURCES

The Milner quadrangle has hosted an active coal-mining area for over a century. It contains the largest underground coal mine in Colorado. One of the earliest oil and gas fields in Colorado was discovered here, as well. Sand and gravel resources are locally found in abundance. The following paragraphs summarize historical and current production activities for those mineral resources.

Coal. The Milner quadrangle is at the eastern end of the Yampa coal field. Coal-bearing, Upper Cretaceous strata of the Iles and Williams Fork Formations were studied in detail over nearly 100 years. Reports and maps that consider coal resources in the Milner area include those by Fenneman and Gale, (1906); Campbell (1923), Bass and others (1955); Dames and Moore (1979); and Johnson and others (2000). There are three productive coal zones or groups, the upper, middle, and lower (**Table 1**). The middle coal group, and particularly the Wadge bed, is the dominant producing interval.

Table 1. Coal zones of the Yampa coal field, Mesaverde Group, Milner quadrangle.

Formation	Coal Zones	Coal Beds	Primary Coal Mines
Upper Williams Fork (**Kwu**)	Upper coal group	Fish Creek	
Lower Williams Fork (**Kwl**)	Middle coal group	Lennox, Wadge, Wolf Creek	Foidel Creek, Seneca II, Osage, McGregor
Iles (**Ki**)	Lower coal group	3, 2, 1	Bear River, Pinnacle, Meadows #1
Coal zone and bed terminology from Bass and others (1955)			

The extent of historic coal mining in the quadrangle, along with the names of the prominent mines, is shown in **Figure 17**. The landscape around the northern part of the quadrangle is peppered with adits and small tailings piles from the earliest underground mines (black dots). Extensive underground mines were developed in some locations. They included the Bear River (lower coal group) and the McGregor, Osage, and Harris mines (middle coal group). By the 1970s, mining had moved to the ground surface, exploiting shallow coal seams on the flanks of Tow Creek anticline and Twentymile syncline. Prominent strip mines included the Pinnacle and Meadows #1 (lower coal group), McGregor, Osage-Black Dan Strip, Energy #2, and Seneca II (middle coal group). These mines are no longer active.

The final chapter of coal-mine development began in 1987, when the underground Foidel Creek coal mine (also known as the Twentymile coal mine) was converted to a high-production, state-of-the-art longwall mining operation. Using longwall panels that are 1,000 ft wide and more than 2 miles long, the mined area now extends northward beneath the Twentymile Park basin (**Figure 17**, above). It is now the largest producing mine in the region. The mine produces high-Btu, low-sulphur, bituminous, steam and stoker coal from the Wadge bed at depths of up to 1,750 ft. It holds the world production record for annual output from an underground coal mine (8.7 million tons in 2005). This remarkable mine is in its final phases of operation. The panel- layout design and ultimate footprint of the Foidel Creek coal mine was heavily influenced by the subsurface geology of the Twentymile Park basin. The limiting factors include proximity to individual faults and fault zones and to the shallow-dip limbs of fold axes.

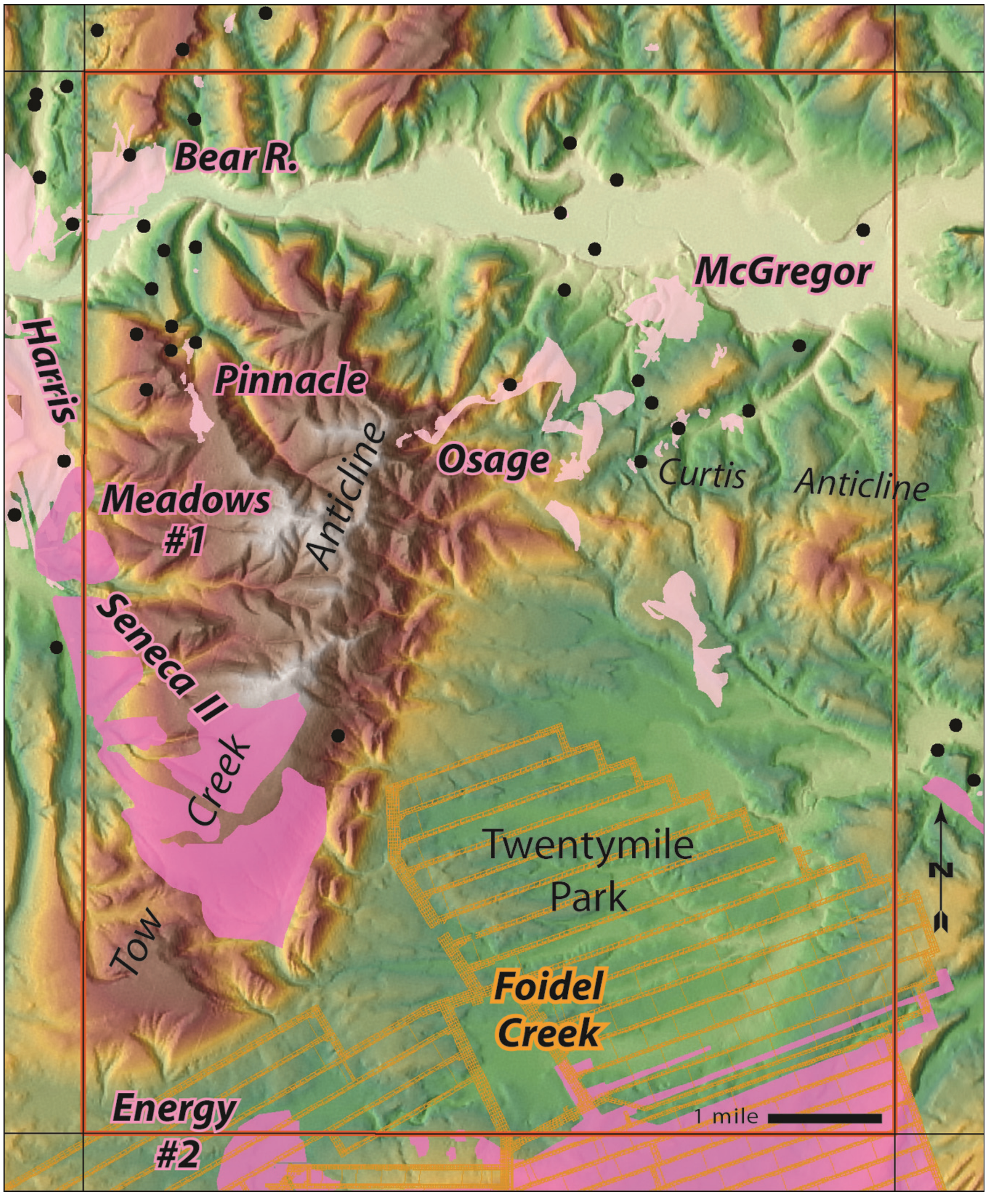

Figure 17. Shaded relief map showing surface and underground coal mines in the Milner quadrangle. Black dots are historic (1864 to 2002) coal mines (Carroll and Bauer, 2002). Colored polygons show the extent of underground (light pink) and surface-strip (dark pink) coal mining (Keller and others, 2002). Orange lines denote haulways around longwall panels in the Foidel Creek underground coal mine (Twentymile Coal Company, unpublished digital data, used with permission).

To date, coal mining from the Milner quadrangle has been extensive, and has exploited the most favorable underground and above-ground coal fairways. This section was compiled using a number of online references including Colorado State Board of Land Commissioners (2009), Peabody Energy (2010), RitchieWiki (2010), Union Pacific Railroad (2010), as well as personal communications from R. Thompson, senior geologist, Foidel Creek mine (2008, 2010, 2011).

Oil and gas. Three oil fields, Tow Creek, Grassy Creek, and Bear River, are located in the northwestern and western part of Milner quadrangle (**Figure 18**). The fields occupy the crest and flanks of the Tow Creek anticline. Several small oil fields occur along the same trend to the north of the quadrangle. The fields produced from folded and fractured, Niobrara-Formation-equivalent rocks in the lower Mancos Shale.

Tow Creek oil field is the oldest and best studied of the fields (Frey, 1954; Dahm and others, 1955; Saterdal, 1955; Ogle, 1961; Cummings and Pott, 1962). It was discovered in 1924 and was among the first fields established in this part of northwestern Colorado. Open-hole cable tools were used to drill and develop much of the field. Later, Colorado's first rotary well was drilled in the field. Subsurface maps by those authors show and anticline with 500 ft of surface closure and two to three northwest-to-southeast trending normal faults intersecting the main reservoir. The faults have up to 200 ft of vertical displacement and appear to compartmentalize the field.

The Niobrara interval at Tow Creek field consists of brittle, calcareous shale interbedded with plastic clay shales. Relatively plastic and less-calcareous Mancos Shale (Prairie Canyon Member) forms the cap rock. According to Saterdal, the later extension of the field focused on the trend of highest fracturing instead of the structural axis. Cummings and Potts postulated a regional, southwest-to-northeast zone of weakness or tectonic shear zone between Wilson Creek and Tow Creek fields. Vincelette and Foster (1992) found that the Laramide-age fractures in the region were plugged and filled by vein calcite. In contrast, the fractures formed by Tertiary extensional tectonics were calcite-lined but open. Natural fracturing was enhanced within the most brittle (calcareous) parts of the Niobrara section. They concluded that post-Laramide faulting and fracturing are the key considerations for finding future oil reserves in northwestern Colorado's Niobrara play. A similar conclusion was reached by Gillett (2009).

Grassy Creek oil field was discovered in 1959 (Ogle, 1961). Other wells were added until 1990, resulting in nine oil-producing wells. Certain wells were active at the time of our field work in 2008. The wells in the Bear Creek oil field were drilled between 1975 and 1986, resulting in nine oil-producing wells. Oil was discovered in 1985 in a single well on the northwestern flank of the Curtis anticline. Other tests in that area were unsuccessful to date. Just east of the quadrangle, the Curtis oil field produces from the Niobrara along the Curtis anticline crest.

Early petroleum-prospecting studies in the region focused on structural traps such as the Tow Creek anticline (e.g., Crawford and others, 1920; Coffin and others, 1924). Later studies integrated regional subsurface and surface stratigraphy, outcrop-facies relationships, and source and reservoir rock characterization (for example, Kiteley, 1983; Kiteley and Field, 1984; Siepman, 1985, 1986; Roehler, 1990; Benda, 2000; U.S. Geological Survey Southwestern Wyoming Province Assessment Team, 2005; Gomez-Veroiza and Steel, 2010). Besides the rejuvenated Niobrara play, historical drilling targets in the region include the Dakota Sandstone, Salt Wash Member of the Morrison Formation, Entrada Sandstone, Shinarump Conglomerate, and Weber Formation (Dahm and others, 1955; Tremain Ambrose, 1998).

Construction aggregates (gravel, sand, and crushed rock). Sand and gravel are produced from one active pit in the Milner quadrangle. The Camilletti Milner Pit #2 (shown in **Figure 3**) produces around 40,000 tons per year (Guilinger and Keller, 2004) from the flood plain of the Yampa River (unit **Qay_1**).

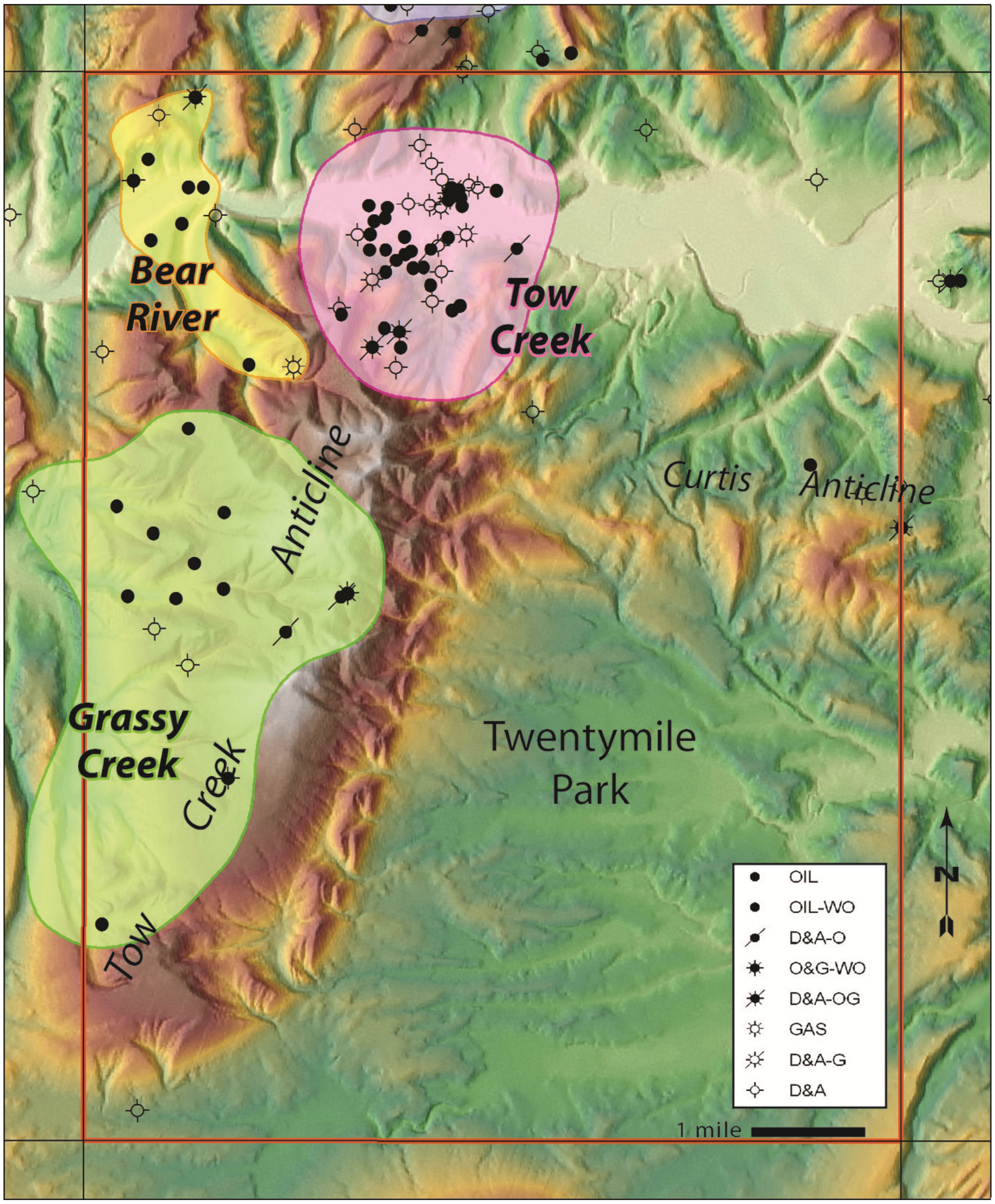

Figure 18. Shaded relief map showing oil and gas fields and well locations in the Milner quadrangle. Well data from Colorado Oil and Gas Conservation Commission (2007). Field boundaries from Wray and others (2005).

At least seven other sand and gravel pits were once active within the quadrangle (Schwochow, 1981; Keller and others, 2002). Those pits have ceased operation. Production came primary from the **Qay₁** alluvium. A few small pits are located in low alluvial terraces (**Qay₃**, **Qay₄**, and **Qay₅**) to the north and east of Milner town site. We are unsure whether crushed rock was produced from these various operations. Several of the alluvial deposits contain relatively hard cobbles that could be used to make crushed-rock aggregate.

Potential exists for the development of additional, high-quality sand and gravel operations in the Yampa River flood plain (unit **Qay_1**). Other map units that contain potential extractable sand and gravel deposits include alluvial terraces of the Yampa River (**Qay_2**, **Qay_3**, **Qay_4**, and **Qay_5**), and in the southern portion of Twentymile Park (**Qg_3**, **Qg_4**, **Qg_5**, **Qg_6**) (**Figure 10**; shown as Fish Creek source). Those other deposits are relatively thin (except for **Qg_6**), limited in extent, and may be relatively dry in terms of ground water. However, they may serve as local sources of borrow material.

GROUND-WATER RESOURCES

The primary sources of ground water for domestic use within the Milner quadrangle are Quaternary alluvium or Cretaceous sandstone beds. We examined GIS data from the State Water Engineer's office (Colorado Division of Water Resources, unpublished data) to find the location, depth, and pump rate of ground-water wells in the quadrangle. The data show that most of the ground-water wells are located in populated areas along the Yampa River corridor. Water wells producing from Yampa River alluvium (primarily map units **Qay_1** and **Qay_2**) are clustered in the town of Milner and at ranches located within the flood plain. Those well are typically less than 50 ft deep and produce up to 60 gpm.

Bedrock aquifers are tapped for ground water in rural subdivisions, one located along Trout Creek, and another in the hills that flank Butcherknife and Little Butcherknife Gulches. A few wells produce from bedrock at ranches along the edge of the Yampa River valley and along the flanks of the major folds. Those wells are typically 150 to 500 ft deep. Production varies from less than 5 gpm to 60 gpm. The bedrock aquifers may include the Twentymile Sandstone (**Kwt**); Trout Creek sandstone (**Kit**); unnamed sandstone beds in the Williams Fork and Iles Formations; the Tow Creek Sandstone (**Kito**); and the Loyd, Wise Gulch, and Marapos Sandstones in the Mancos Shale.

Robson and Stewart (1990) identify the Twentymile and Trout Creek Sandstones as major regional aquifers in the Sand Wash Basin region. In addition, they found that sandstone and coal beds in the lower part of the Williams Fork Formation (unit **Kwl**; coincident with the middle coal group) constitute a significant aquifer of local extent. They report the average hydraulic conductivity of the local aquifer as being 20 times greater than that of the regional aquifers. Its mean transmissivity is 20 ft^2/day, superior to that of the Twentymile (4 ft^2/day) and Trout Creek (0.6 ft^2/day) aquifers. They attribute the greater water-yield potential of the local aquifer to the presence of fractured coal seams.

GEOLOGIC HAZARDS

We recognize several potential geologic hazards in the Milner quadrangle area. The hazards arise when naturally occurring geologic processes affect constructed facilities such as buildings and roads. Human activities may greatly increase the rate of process activity, thus increasing the level of hazard. Geologic hazards are detrimental to individual property owners and owners of public and private facilities.

Landslides (unit **Qls**) are common in many parts of the quadrangle. Rotational failures occur in the Mancos and Lewis Shales, while translational failures occur along dipping sandstone and shale interbeds in the Mesaverde Group. Many of the landslides are older features with movements dating to the late Pleistocene ice ages. Landslides are metastable features, meaning that modifications to the hill slope, loading, or ground-water levels and pore pressures could reinitiate landslide movements. New landslides can be triggered by such activities as excavation of roads, pipelines, or borrow material.

Stream flooding hazards and associated high water tables exist within the modern flood plains of the Yampa River (unit $\mathbf{Qay_1}$) and the valleys of tributary streams (units $\mathbf{Qa_{1a}}$ and **Qac**). Spring flooding in many extensive areas of the flood plain appears to be the result of rising ground water in addition to overbank stream flooding. In addition to annual snow melt, flooding along the through-flowing main streams and tributary streams may be initiated by occasional large rain fall events. Residences and critical facilities in those areas should be avoided.

Debris flow (also known as **mud flow**) hazards occur in hilly areas along confined stream reaches (unit **Qc** and some $\mathbf{Qa_{1a}}$) and in alluvial fans where the confined reaches terminate and valleys broaden (unit **Qf**). These flows are produced by large rain fall events, and are sometimes generated by failures of saturated landslides. Debris flows are dense, heterogeneous mixtures of mud, rock fragments, and plant materials (Varnes, 1978). They can form at any point along a drainage including on the sides of valleys. They may cause deep erosion in some areas and dump thick deposits in other areas (both on the order of several feet). The moving flows present life-and-limb safety hazards, and they can cause damage to roads and buildings. Much of the hilly terrain In the Milner quadrangle has the potential to generate debris flows. The construction of buildings in those areas should be avoided if possible.

Rock fall hazards occur locally within many parts of the quadrangle. Rock falls are prevalent at the toes of slopes that are capped with sandstone rim rock and along highway cuts that expose sandstone cliffs. The size of the falling blocks is a function of bedding thickness, fracture spacing, and exposure of the slope to ground-water seepage and freeze-thaw processes. Large precipitation events may trigger rock falls, as well. We observed several boulder-sized, angular blocks of sandstone up to 10 ft in diameter at the edge of agricultural fields below the Tow Creek Sandstone. US-40 has several rock-fall-prone segments where the road cuts through the Tow Creek anticline. Rock fall is a minor hazard at the toes of slopes beneath elevated, alluvial-terrace deposits, where loose cobbles and small boulders may roll down the hill. Rock-fall mitigation may involve expensive devices and ongoing maintenance and evaluation. The best mitigation is to avoid rock-fall slopes and roll-out zones.

Expansive soil and bedrock hazards occur in clay-rich materials. These materials are relatively dry under natural climate conditions. Upon wetting, water is drawn into crystal matrices and the clay particles swell to accommodate the added water molecules (Noe, 2007). The resultant ground heaving may cause damage to buildings, roads, and underground utilities and pipelines. Upon drying, the clay particles lose water and shrink. This shrink-swell behavior may continue over numerous wetting and drying cycles. Potentially expansive soil and bedrock is found in the main bodies of Lewis and Mancos Shales (units **Klsl** and **Kmu**), in tongues of marine shale and continental-shale beds in the Mesaverde Group (units **Kwu**, **Klst**, **Kwl**, **Kmt**, and **Ki**), and in clay-rich surficial units derived from those shales (upper parts of all alluvial deposits and all alluvial-fan and mass-wasting deposits). The hazard and ground-heave movements may be significantly reduced if proper geotechnical engineering studies and designs are employed at potentially affected construction sites.

Collapsible soil hazards occur in silt-rich sediments that are relatively quickly deposited and have high internal porosity (White and Greenman, 2008). Such deposits include tributary-stream alluvium, alluvial fans, and debris flows (units **Qac**, **Qf**, **Qfo**, and **Qdf**). Collapsible soil occurs in eolian deposits that sometimes overlie alluvial terraces. Unlike many areas of western Colorado, the Milner quadrangle does not contain extensive deposits of this type. Nonetheless, ground-collapse hazards may be reduced if proper geotechnical engineering studies and designs are employed at potentially affected sites.

Seismicity and earthquake hazards are difficult to evaluate for Milner quadrangle. We did not see evidence of younger faulting or offsets of Quaternary-age deposits while mapping. One historical earthquake is shown within the quadrangle in the CGS Colorado earthquake map server (Kirkham and others, 2004). The 1895 Yampa Valley earthquake was felt from south of Steamboat Springs to Hayden. Hadsell (1968) rated this event at intensity V. The epicenter is located at the divide between Butcherknife and Little Butcherknife Gulches near the northern quadrangle boundary. Other notable earthquakes in the region include an intensity VI event in 1955, near today's Stagecoach Reservoir, and a magnitude 4.4 event in 1971, near the town of Clark. In March 2011, a magnitude 2.8 event was recorded in the southwestern corner of the Milner quadrangle. It was beneath the southern nose of Tow Creek anticline at 1 km depth.

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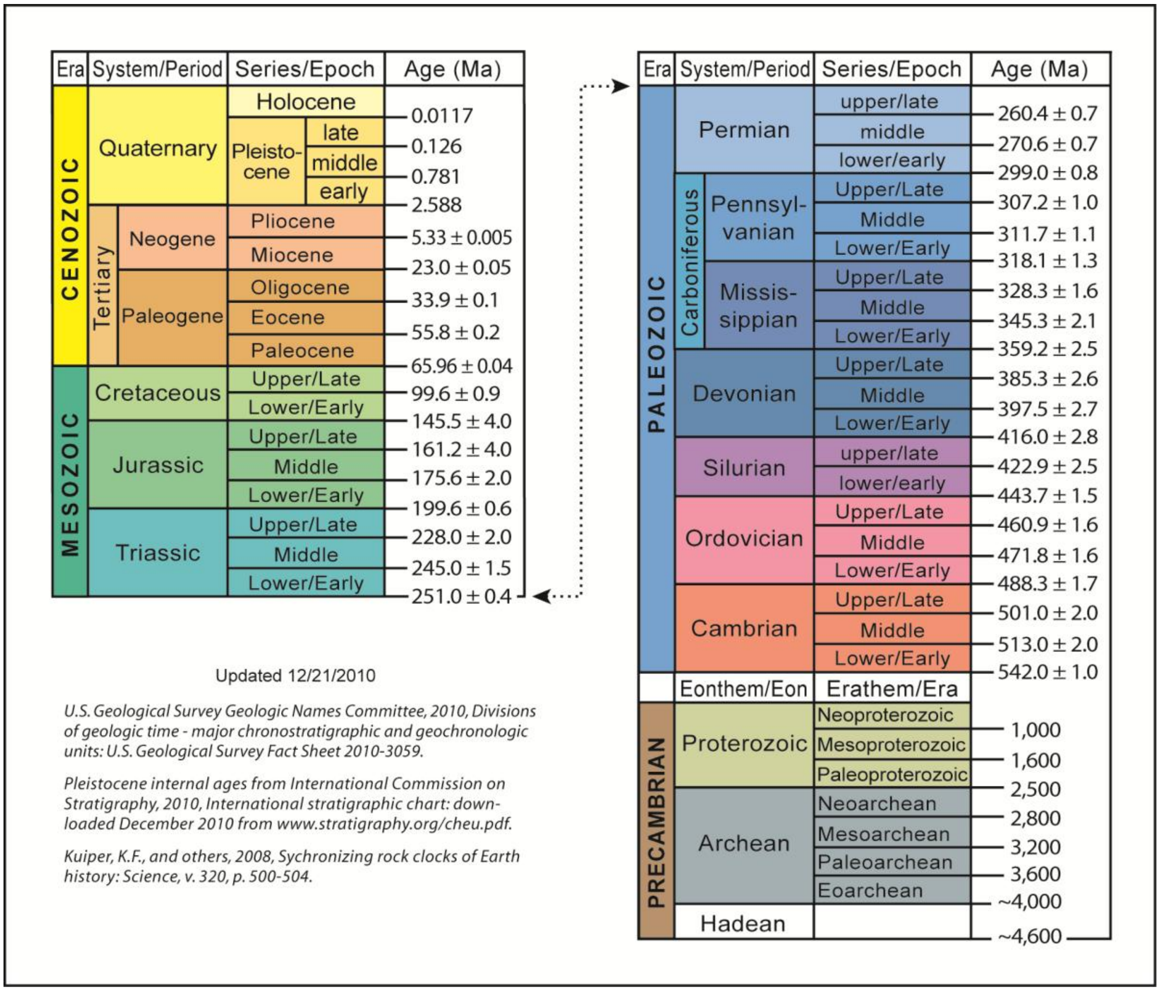
APPENDIX A

Appendix A. Geologic time chart adopted by the Colorado Geological Survey



APPENDIX B

Appendix B. Stratigraphic chart of Upper Cretaceous and Tertiary formations in northwestern Colorado

The schematic stratigraphic chart inserted at the end of this document was compiled by CGS as part of a regional study of the geology of the Williams Fork Mountains and surrounding areas in northwestern Colorado. It contains the basic geologic framework from the seminal, coal-stratigraphic studies of Hancock (1925) and Bass and others (1955), and regional mapping by Tweto (1976). The chart is augmented with information from stratigraphic studies by Boyles and others (1981), Boyles (1983), Kiteley (1983), Brownfield and others (1999), Johnson and others (2000), and Hampson and others (2008).

The chart shows (a) marine sands deposited within the Mancos Shale in the Cretaceous Western Interior Seaway; (b) the progradation of three regressive wedges of continental sediments (Iles and Williams Fork Formations of the Mesaverde Group) into the seaway, with minor marine transgressions; (c) a major transgression and deposition of marine Lewis Shale; (d) final regression and closure of the seaway, and deposition of Fox Hills Sandstone and Lance Formation; (e) deposition of coarse Tertiary deposits during the Laramide and later orogenic episodes; and (f) emplacement of Miocene igneous rocks in underground dikes and sills and as surface volcanic flows.

Explanation:

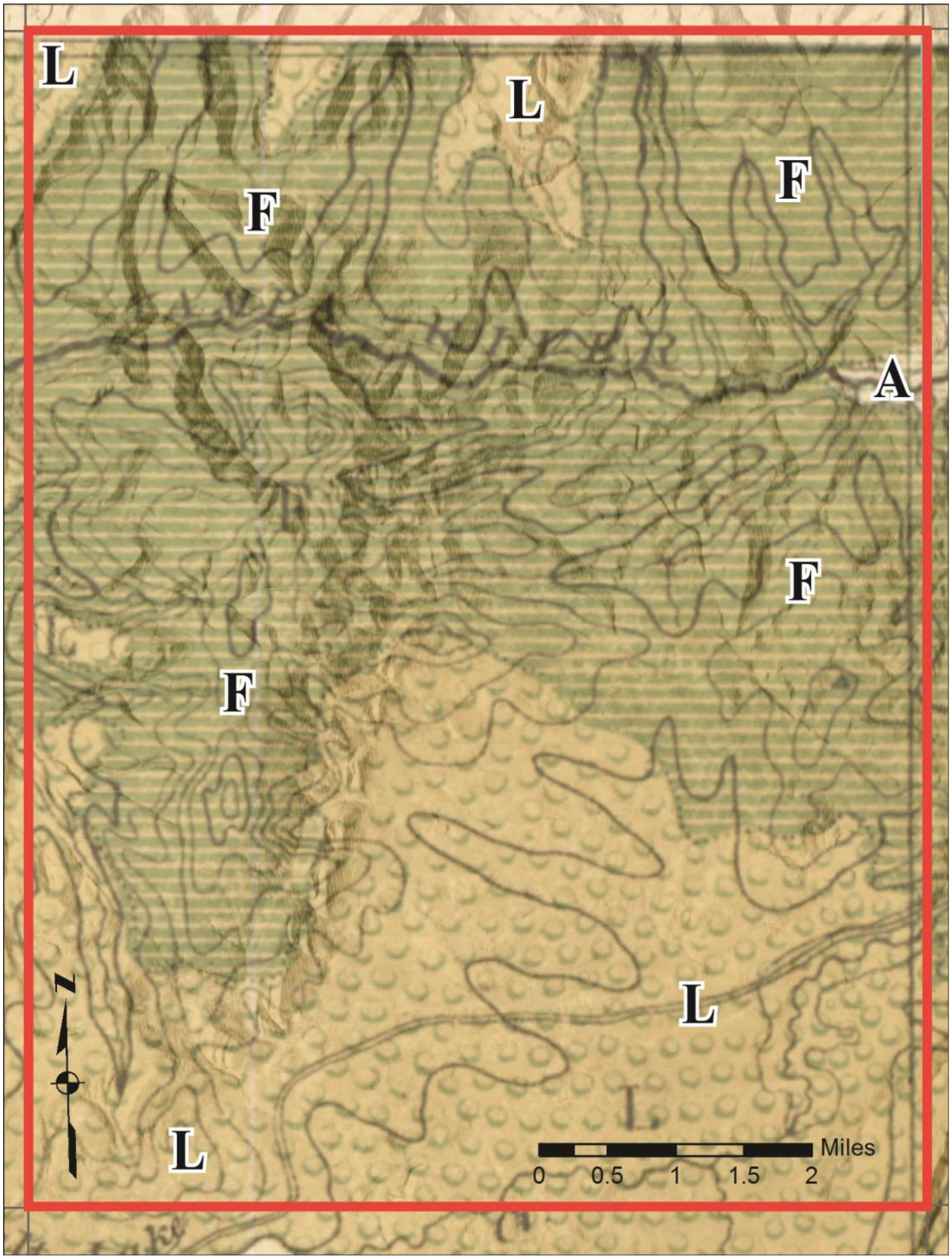
	Section of bedrock units mapped in the Milner quadrangle
Kit	Unit abbreviation used for geologic mapping
	Volcanic flows (Tertiary)
	Continental deposits, synorogenic, coarse (Tertiary)
	Continental deposits, sandstone-shale-coal (Upper Cretaceous and Tertiary)
	Shoreline and marine sandstones (Upper Cretaceous)
	Marine shales (Upper Cretaceous)

APPENDIX C

Appendix C. Fossils collected from the Milner quadrangle and vicinity

The table inserted at the end of this document contains a listing of marine invertebrate fossils collected within or near to the Milner quadrangle by the CGS mapping crew during the 2008 field season. The fossils were donated to the U.S. Geological Survey (USGS) for their Cretaceous Western Interior Seaway (CWIS) collection. USGS collection numbers (beginning with a "D" for Denver collection) were assigned and are shown on the Milner quadrangle map. Dr. William Cobban, USGS, provided identification of the fossils species and catalogued the specimens into the CWIS collection. In addition, where possible, we add fossils collected in the immediate area (within the quadrangle or within 1 mile of the quadrangle) by other investigators and authors. Those additions are the result of a technical-literature search.

The table includes ages and guide-fossil zones from Cobban and others (2006). All of the specimens are Late Cretaceous in age.

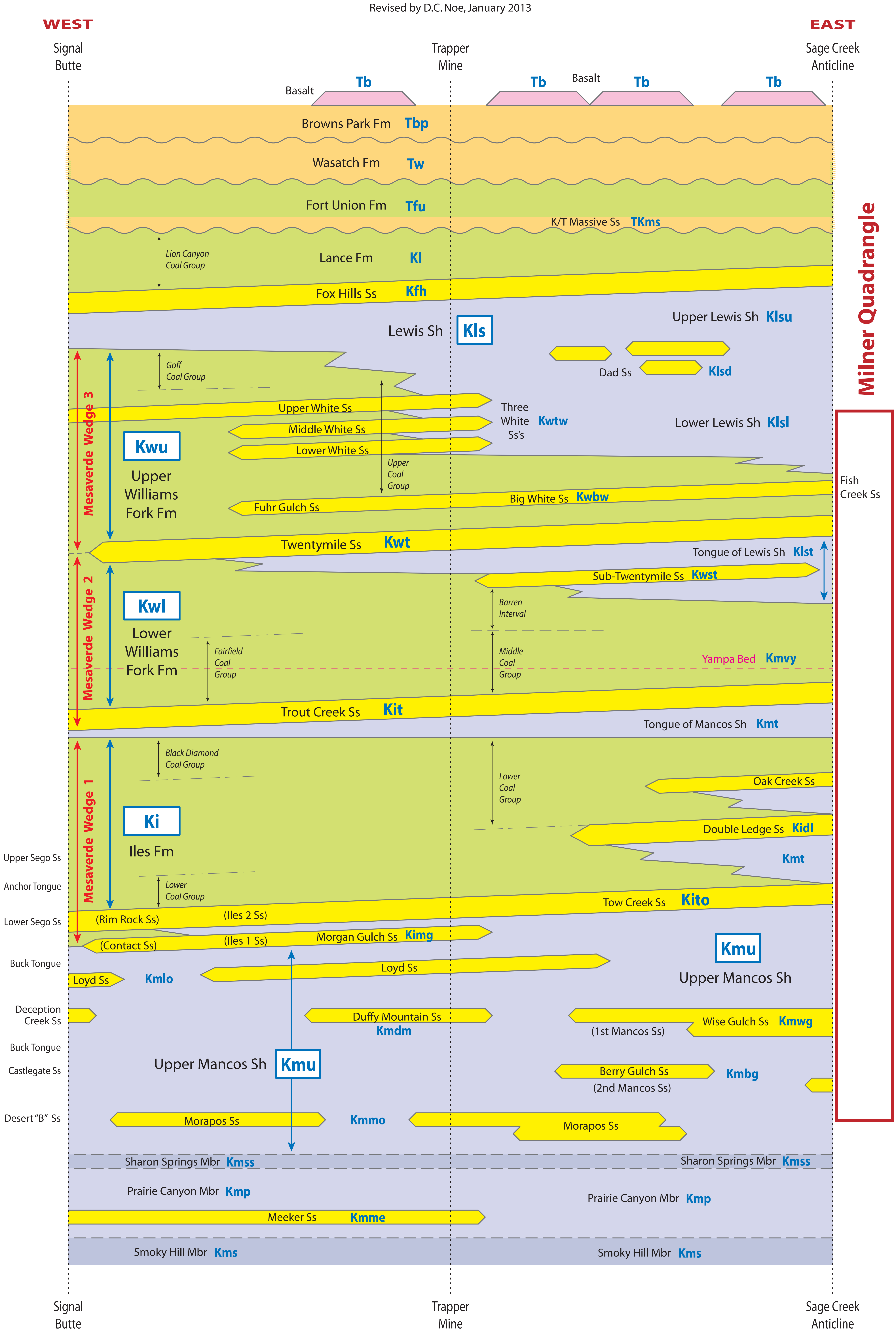


The first geologic map of the Milner area, published by F.V. Hayden (1877) at a scale of 1:235,440. Fieldwork for the map was conducted during the 1874 Geological and Geographical Survey of the Territories (a precursor to the U.S. Geological Survey) under Professor Hayden. A portion of the map is shown, with a red box around the Milner quadrangle. The map is overlain onto a digital elevation model (DEM) to show the topography. The map units are as follows:

A = Alluvium (Quaternary)
L = Laramie (Post-Cretaceous)
F = Fox Hills-Fort Pierre (Cretaceous)

Upper Cretaceous and Tertiary Stratigraphy, Northwestern Colorado

Compiled by D.C. Noe, P.E. Barkmann, and C.J. Carroll
Colorado Geological Survey, May 2010
Revised by D.C. Noe, January 2013



Sources: Hancock (1925); Bass and others (1955); Konishi (1959); Dyni and Cullins (1965); Masters (1965); Izett and others (1971); Gill and Hail (1975); Bader and others (1983); Boyles and others (1981); Boyles (1983); Kitely (1983); Kiteley and Field (1984); Johnson and others (2000); Crabaugh (2001); Hampson and others (2008); and Brownfield and others (2009)

Appendix C. Fossils Collected From the Milner Quadrangle and Vicinity

CGS Locality Number	USGS Locality Number	Fossils Collected and Identified	Ammonite or Mollusc Guide Fossil Zone	Age	Formation or Mancos Shale Member	Quadrangle	County	State	Land Survey Location	UTM83-X	UTM83-Y	Collected by	Date
MIL-7	D14834	small bivalves; fish scale	*Baculites grandis* or later	Lower Maastrichtian	Lower Lewis Sh	Milner	Routt	CO	s nw 21-5N, 86W	326344	4471580	David C. Noe	07/15/08
MIL-8	D14835	*Hoploscaphites sp.;* corbulid bivalve; small gastropod	*Baculites grandis* or later	Lower Maastrichtian	Lower Lewis Sh	Milner	Routt	CO	c w sw 16-5N-86W	326186	4472628	D.C. Noe and M.J. Zawaski	07/15/08
---	D2181	*Baculites grandis*	*Baculites grandis*	Lower Maastrichtian	Lower Lewis Sh	Rattlesnake Butte	Routt	CO	sw 23-5N-87W	319880	4471339	A.D. Zapp and W.A. Cobban	pre-1983
MIL-68	(no #)	pelecypod	*Baculites reesidei* or later	Upper Campanian	Twentymile Ss	Milner	Routt	CO	c sw sw 34-6N-86W	327932	4477251	D.C. Noe and M.J. Zawaski	08/05/08
---	3413	*???*	*???*	Upper Campanian	Lower Wms Fork Fm?	Milner	Routt	CO	ne sw ne 16-6N-86W	327358	4483227	T.W. Stanton	1905
MIL-51	D14838	brackish-water oysters	(can't tell)	Upper Campanian	Lower Wms Fork Fm	Milner	Routt	CO	nw se sw 23-6N-87W	320121	4480997	D.C. Noe and M.J. Zawaski	07/24/08
MIL-41	D14840	*"Inoceramus" cf. tenuilineatus*	*Didymoceras cheyennense; Exiteloceras jenneyi*	Upper Campanian	Trout Cr. Ss	Mt. Harris	Routt	CO	nw ne se 15-6N-87W	319626	4482794	D.C. Noe and M.J. Zawaski	07/23/08
---	D8104	*Didymoceras cheyennense; Exiteloceras jenneyi*	*Didymoceras cheyennense; Exiteloceras jenneyi*	Upper Campanian	Trout Cr. Ss	Milner	Routt	CO	nw ne sw 6-6N-87W	320280	4479676	J.R. Gill and T.R. McHargue	pre-1983
MIL-43	D14836	*"Inoceramus" scotti*	*Didymoceras cheyennense; Exiteloceras jenneyi*	Upper Campanian	Trout Cr. Ss	Milner	Routt	CO	sw nw nw 14-6N-87W	320000	4483506	D.C. Noe and M.J. Zawaski	07/23/08
---	3414	*???*	*???*	Upper Campanian	Trout Creek Ss?	Milner	Routt	CO	sw nw sw 15-6N-86W	328040	4482481	T.W. Stanton	1905
---	3415	*???*	*???*	Upper Campanian	Trout Creek Ss?	Milner	Routt	CO	sw nw nw 29-6N-86W	324586	4480029	T.W. Stanton	1905
---	3447	*???*	*???*	Upper Campanian	Trout Creek Ss?	Milner	Routt	CO	nw nw nw 14-6N-87W	319894	4483611	H.S. Gale	1905
---	D8103	*Didymoceras cheyennense; Exiteloceras jenneyi*	*Didymoceras cheyennense; Exiteloceras jenneyi*	Upper Campanian	Mancos tongue	Milner	Routt	CO	nw ne sw 6-6N-87W	320350	4479702	J.R. Gill and T.R. McHargue	pre-1983
MIL-49	D14837	*Cataceramus? cf. subcompressus*	*Exiteloceras jenneyi?*	Upper Campanian	Mancos tongue	Milner	Routt	CO	se se se 23-6N-87W	321277	4480559	D.C. Noe and M.J. Zawaski	07/24/08
---	3411	*???*	*???*	Middle to Upper Campanian	Iles Fm?	Cow Creek	Routt	CO	n nw we 1-5N-86W	331868	4476947	T.W. Stanton	1905
MIL-76	D14839	*Placenticeras sp.*	*Baculites perplexus (B. gilberti)*	Middle Campanian	Loyd SS	Milner	Routt	CO	sw nw ne 17-6N-86W	325582	4483404	D.C. Noe and M.J. Zawaski	08/07/08
---	D4011	*Baculites perplexus; Inoceramus aff. I pertenuis*	*Baculites perplexus (B. gilberti)*	Middle Campanian	Loyd SS	Milner	Routt	CO	c 8-6N-86W	325645	4484525	W.A. Cobban?	pre-1963
---	3412	*???*	*???*	Middle Campanian	Upper Mancos Sh?	Cow Creek	Routt	CO	nw nw se 25-6N-86W	331825	4479325	T.W. Stanton	1905
---	3425	*???*	*???*	Middle Campanian	Upper Mancos Sh?	Milner	Routt	CO	c nw ne 14-6N-86W	330418	4483312	N.M. Tenaeman	1905

Includes collection sites in and within one mile of the Milner quadrangle. Sources of information for fossils collected previous to this study include Dyni and Cullins (1965), Bader and others (1983), and unpublished USGS databases for Denver and Washington D.C. collections.

All GIS locations are reported using Universal Transverse Mercator (UTM), North American Datum 1983, Zone 13N projected coordinates, with units in meters. UTM83-X is the easting value; UTM83-Y is the northing value.

Collections from early 1900s not shown on geologic map; their exact locations could not be verified.