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COLORADO SCHOOL OF MINES
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GEOLOGIC MAP OF THE IGNACIO QUADRANGLE, LA PLATA COUNTY, COLORADO
OPEN-FILE REPORT 23-02
PLATE 1 OF 2
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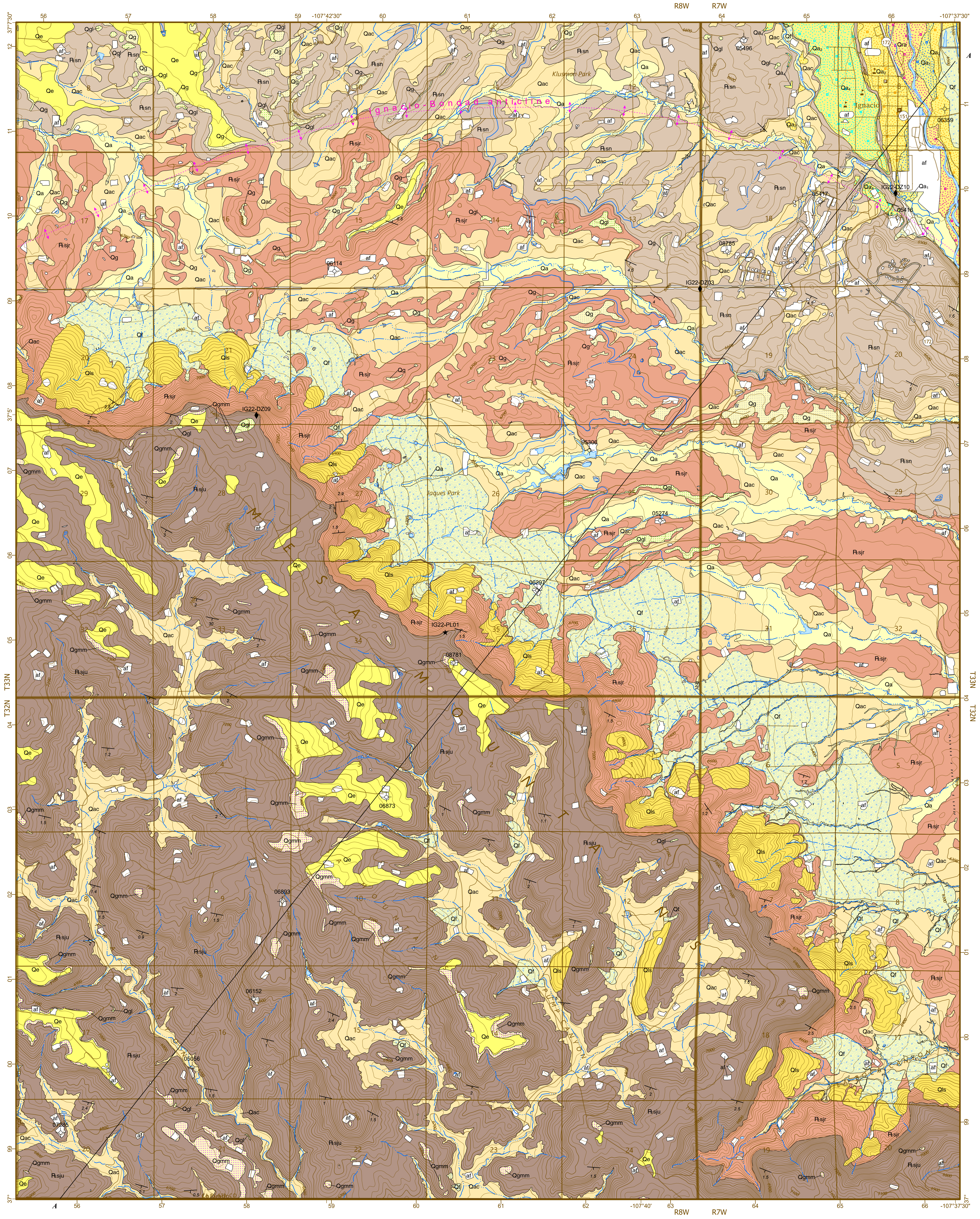

Coordinate System: NAD 1983 UTM Zone 13N
Projection: Transverse Mercator
Datum: North American 1983

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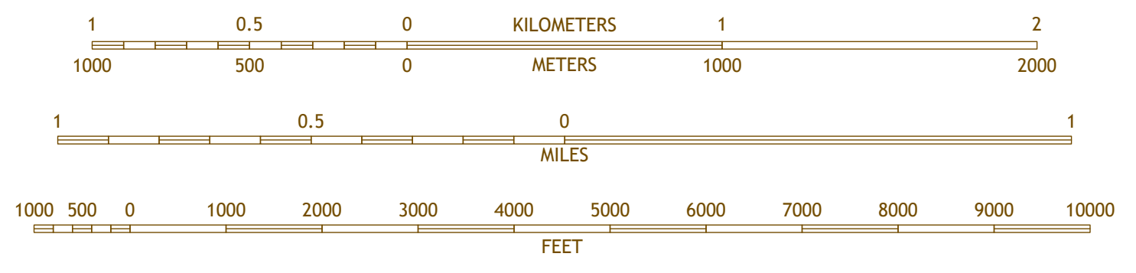
Roads...U.S. Census Bureau, 2016-2016
Names...GNIS, 1978-2021
Hydrography...................National Hydrography Dataset, 2000-2021
Contours...............................National Elevation Dataset, 2001
Boundaries..............Multiple sources; see metadata file, 2019-2021
Public Land Survey System................................BLM, 2019-2021

SCALE 1:24,000



Geology mapped in 2022
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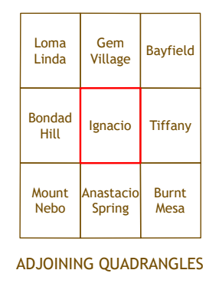

ADJOINING QUADRANGLES

QUADRANGLE LOCATION

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GEOLOGIC MAP OF THE IGNACIO QUADRANGLE, LA PLATA COUNTY, COLORADO

By Nathan T. Rogers and Mary L. Gillam
2024

DESCRIPTION OF MAP UNITS

Further discussion can be found in the accompanying Plate 2.

The geologic descriptions and mapped contacts in this report are based on field observations in accessible areas. However mechanical leveling of irrigated agricultural fields obscured some geologic features. For land without access, contacts are based on observations from other accessible areas, publicly available aerial imagery, lidar digital elevation data, and hillshade models. Particle-size classes for sandy to clayey sediments are based on the Udden-Wentworth scale (Carpenter and Keene, 2023, p. 161), except for USDA soil textural terms that are used for the near-surface parts of certain Quaternary units (Pannell and others, 1988; Carpenter and Keene, 2023, p. 461). Descriptive phrases for textural mixtures are based on the Folk classification (Folk, 1974). Color names and Munsell codes were obtained for dry sediments with the aid of Munsell and Globe soil color books (Munsell Color, 1975; Visual Color Systems, 2012) or from soil-series data (Pannell and others, 1988). Descriptions of soil calcium carbonate ($CaCO_3$) stage morphology are after Machette (1985). Divisions of geologic time follow Cohen and others (2023) and the U. S. Geological Survey (2018).

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (Uppermost Holocene)** — Unit includes fill material placed during the construction of well pads, road embankments, water catchments, dams, buildings, and residences. Fill consists of locally derived materials and (or) externally sourced materials such as waste rock, demolition concrete, gravel, and topsoil. These materials are usually unsorted and may be as much as 12 m (40 ft) thick. Some fills are loose while others are placed to engineering recommendations. Overlying structures may settle if fill is loose or inadequately compacted. Some areas of artificial fill in the town of Ignacio may be subject to infrequent flooding along the Los Pinos River (Colorado Water Conservation Board, 2024).

ALLUVIAL AND COLLUVIAL DEPOSITS

These unconsolidated sedimentary deposits consist of clay, silt, sand, and clasts ranging in size from very fine pebbles (granules) to rare boulders up to 1 m (3 ft) in diameter. Alluvium was deposited in low-lying areas along the Los Pinos River and smaller tributary streams, on floodplains, and on debris-fan units or alluvial fans. Sediment size and bedding vary with factors including flow velocity and sediment source. Distinctive glaciofluvial, sandy gravel composed of well-rounded, pebble- to boulder-sized, igneous and metamorphic rocks from the San Juan Mountains underlies terraces of the Los Pinos River (see provenance in descriptions below). Some of these clasts have been reworked into younger deposits of alluvium and colluvium. Bedrock strata yield mostly clay and silt, but also sand and rock fragments from pebble- to boulder-size. Finer-grained deposits accumulated along ephemeral tributary streams as well as during overbank flow on the floodplain of the Los Pinos River. Observed thicknesses of alluvium range from very thin (less than 30 cm or 1 ft) to approximately 9 m (30 ft). Colluvium was deposited on slopes or at the base of slopes mainly by gravity-influenced processes such as creep, sheetwash, and rockfall that mobilized materials from higher on the slopes. Most colluvial deposits are relatively small and vary in thickness so colluvium was mapped mainly along with adjacent alluvium in a combined unit Qac. Most young deposits are on or near valley floors, but older deposits cap benches, hills, or uplands as topography is inverted because later erosion and stream incision has lowered the adjacent ground surface of the watershed.

Qa — **Alluvium (Holocene and Upper Pleistocene?)** — Light brownish-gray (10YR 6/2), grayish-brown (10YR 5/2), and reddish-gray (5YR 5/2) sediment composed of stratified, moderately sorted, unconsolidated sand, silt, clay and rarely up to 10% pebbles. Upper 1.5 m (5 ft) of unit typically classified as silty clay loam and sandy clay (Pannell and others, 1988). Unit is composed almost entirely of sediment eroded locally from nearby bedrock units and deposited in stream channels and on floodplains of tributaries of the Los Pinos River and, near the northwestern corner of the quadrangle, to the Florida River. Deposits accumulated on slopes as much as 5° to 7°. Thickness varies; three water-well logs document thicknesses of 3.0 to 3.7 m (10 to 12 ft) (Sebol and others, 2023; Colorado Division of Water Resources, 2024) but locally thickness may be as much as 6 m (20 ft). Incised channels vary in depth below adjacent alluvium or fan (unit Qf) surfaces from <0.3 m (<1 ft) in some higher-elevation parts of the deposits to as much as 5.2 m (17 ft) locally along larger streams. Holocene and Upper Pleistocene(?) age is estimated based on the unit's height above and proximity to modern drainages (Johnstone and others, 2023). Surface disturbance resulting from agricultural practices is common. Low-lying areas are locally prone to periodic flooding and possibly over-bank sediment deposition. Unit is not a suitable source of sand and gravel. Clayey deposits have high shrink-swell potential (Pannell and others, 1988) and may be susceptible to hydrocompaction (White and Greenman, 2008).

Qac — **Alluvium and colluvium, undivided (Holocene and Upper Pleistocene?)** — Undifferentiated alluvium and colluvium consisting of light brownish-gray (10YR 6/2), grayish-brown (10YR 5/2), brown (7.5YR 5/2; 5/3), light brown (7.5YR 6/3), and reddish-gray (5YR 5/2) sediment composed of unconsolidated sand, silt, clay and rarely up to 10% matrix-support pebbles and cobbles. Upper 1.5 m (5 ft) of unit typically classified as silt loam, silty clay loam, clay loam, sandy clay, and clay (Pannell and others, 1988). Deposits on the Mesa Mountains are sandier than those in the lowlands and contain pebble- and cobble-sized fragments of San Jose Formation sandstone as well as reworked clasts from unit Qgmm. Unit was mapped mainly based on its topographic expression on lower hillsides and valley floors where individual deposits cannot be differentiated. These deposits accumulated as stream-channel, floodplain, fan, sheetwash, debris flows, and sediment transported by gravitational process such as creep. The uppermost deposits locally contain very weakly-developed soils with Bw and minor Bk horizons (Pannell and others, 1988), while deeper deposits may contain buried A horizons. Thicknesses as much as 6 m (20 ft) are common in water wells (Sebol and others, 2023; Colorado Division of Water Resources, 2024) but thickness locally exceeds 8.2 m (27 ft). Depths of incised channels range from <0.3 m (<1 ft) in higher-elevation parts of the deposits to locally as much as 3.7 m (12 ft) in the lowlands and 8.2 m (27 ft) in the Mesa Mountains. The unit's age is estimated from its proximity to and height above modern drainages and its position in the landscape. Surface disturbance resulting from agricultural practices is common. Low-lying areas are locally prone to periodic flooding and possible sediment deposition. Unit is not a suitable source of sand and gravel. Clayey deposits may have high shrink-swell potential (Pannell and others, 1988) and may be susceptible to hydrocompaction (White and Greenman, 2008).

Alluvium of the Los Pinos River — River alluvium is present in modern stream channel (Qra) and in terrace deposits, the latter numbered from youngest (Qa_1) to oldest (Qa_4) based on the terminology of Gonzales and others (2008). Alluvium is commonly brown, dark gray, gray or yellowish-brown. It consists mainly of poorly sorted, clast-supported, weakly stratified, subrounded to well-rounded large pebble- to cobble-dominated gravel with subordinate amounts of finer pebbles and rare boulders up to 1 m (3 ft) in diameter in a matrix composed of sand, silt, or silty clay. The gravel may locally contain lenses of moderately to poorly sorted sand and silt that vary from brown to light olive-brown and gray. Beneath terrace surfaces, these units contain mostly hard metamorphic and igneous clasts of San Juan Mountains provenance and are resistant to erosion. The most common clasts are various quartzites. Distinctive and diagnostic to the Los Pinos drainage basin are prominent cobbles and boulders composed of silicic Vallecito metaconglomerate. Other clast types, in very roughly decreasing abundance, are porphyritic rhyolite, andesite, granite, granodiorite, gabbro, amphibolite, felsic gneiss, schist, limestone, siltstone, sandstone, greenstone, and vein quartz (Scott and Moore, 2007; Gonzales and others, 2008). Included in these units are overlying mantles of unmapped fine-grained deposits such as alluvial overbank flood deposits, loess, and local fan alluvium. Terrace gravel alluvium commonly occurs in treads that overlie relatively flat, river-cut bedrock surfaces (straths) and is often overlain by younger loess. Gravelly alluvium has been mined for sand and gravel in nearby quadrangles but not in the Ignacio quadrangle because of buildings, roads, infrastructure facilities, and riparian parklands within or near the town of Ignacio that is located in the northeast corner of the map area.

Qra — **Alluvium of the Los Pinos River (Holocene)** — Unit includes the modern stream channel, floodplain, and low terrace deposits of the Los Pinos River that are generally less than 1.5 m (5 ft) above the modern river channel. Bar-and-swale topography occurs locally on the unit's surface. Clasts may be derived mainly from the reworking of older river alluvium, but may also be transported as bedload from farther upstream in the San Juan Mountains. Correlative units in the Bayfield quadrangle are unit Qal (Moore and Scott, 1995) and units Qa and Qsa (Gonzales and others, 2008). Several water well logs record thicknesses of about 4.3 to 6.7 m (14 to 22 ft) (Sebol and others, 2023; Colorado Division of Water Resources, 2024). Unit Qra is hydrologically connected to the river (Sebol and others, 2023) and is within zone A or AE of the 1% (100-year) regulatory floodplain (FEMA, 2024a,b; Colorado Water Conservation Board, 2024).

Qa_1 — **Alluvium one (Holocene and Upper Pleistocene?)** — Unit forms the first well-defined terrace above the Los Pinos River. Unit Qa_1 is distinguished from lower unit Qra by a smoother tread surface and slightly higher elevation above the modern river channel, as much as 3.7 m (12.1 ft). Thin, up to 1.5 m (5 ft) of discontinuous mantles of unmapped Holocene alluvial and floodplain deposits are locally included. This unit underlies areas around the Tribal Fairgrounds and the Post Office in Ignacio. Correlative units on the Bayfield quadrangle are Qtg1 (Moore and Scott, 1995) and Qt1 (Gonzales and others, 2008). Unit Qa_1 may be hydrologically connected to the river during stream flood flows (Sebol and others, 2023) and most of its surface may be within zone AE of the 1% (100-year) regulatory floodplain (FEMA, 2024a,b; Colorado Water Conservation Board, 2024). The unit's estimated age (Johnstone and others, 2023) is based on its low height above the modern channel.

Qa_2 — **Alluvium two (Upper Pleistocene)** — Unit forms the next-higher terrace above the Los Pinos River and includes unmapped deposits of sheetwash and colluvium in hillside wedges at the foot of the slope that rise upslope toward the terrace surface underlain by unit Qa_4 in the map area. Unit Qa_2's height above the modern river channel is about 4.3 to 5.8 m (14 to 19 ft) but is difficult to determine accurately because much of the town of Ignacio is built on unit Qa_2 and terrace scarps are obscured or obliterated. Correlative units on the Bayfield quadrangle are Qtg1 (Moore and Scott, 1995), later called Qt2 (Gonzales and others, 2008). Outcrops and one water well log indicate thicknesses from 2.0 to 3.7 m (6.5 to 12 ft) (Sebol and others, 2023; Colorado Division of Water Resources, 2024), but the unit may be thicker locally. A few alluvial terraces along Rock Creek, in the northeast part of the quadrangle, are also mapped as unit Qa_2. The age of this unit (Richmond, 1965; Johnstone and others, 2023) is estimated from its height above the river, which is roughly comparable to the height of unit Qa_3 along the Florida River where an optically stimulated luminescence age estimate of 27,090 ± 1715 yrs was obtained (Lindsey and Gillam, in prep.). A higher alluvium along the Los Pinos River, intermediate between Qa_2 and Qa_4, was likely removed by fluvial erosion and was not identified in the Ignacio quadrangle. However, this unit Qa_3 farther north in the nearby Bayfield quadrangle, is as much as 15 m (50 ft) above the Los Pinos River (Gonzales and others, 2008).

Qa_4 — **Alluvium four (Upper Pleistocene)** — Unit forms the highest terrace alluvium along the Los Pinos River in the Ignacio quadrangle, although higher terraces deposits are locally present farther upstream (Moore and Scott, 1995; Gonzales and others 2008; Rogers, in prep.), as well as east and downstream from the Ignacio quadrangle (Barnes, 1953; Condon, 1990). Unit Qa_4 forms the relatively flat to gently sloping mesa west of the town of Ignacio where the elementary and middle schools are located, as well as another mesa south of town where the cemetery is located. Gravel in this unit is lithologically and texturally similar to that of units Qa_1 and Qa_2, but the bottoms of cobbles in unit Qa_4 have calcium carbonate rinds 0.5 mm to 1.0 mm thick that effervesce when treated with dilute hydrochloric acid. The deposits locally contain up to 1 meter (3.3 ft) thick Bt and Bk (carbonate Stage II) soil horizons (Pannell and others, 1988) that are very poorly exposed. Included in unit Qa_4 are overlying, poorly exposed, fine-grained deposits that are typically reddish brown (5YR 5/4) to yellowish red (5YR 5/6). These deposits of varying thickness consist of unconsolidated silt, clay, and sand that are generally classified as loam or silty clay loam in the upper 1.5 m (5 ft) of the deposits (Pannell and others, 1988). Most of the fine-grained deposits are probably loess, but locally reworked as sheetwash or low-gradient alluvial fan deposits. The highest levels of the gravelly deposits that underlie the fine-grained deposits are approximately 25.9 to 29.0 m (85 to 95 ft) above the modern river channel. However, a break in slope along the east edge of this terrace remnant suggests that the top of the alluvial gravel is roughly 22.9 to 24.4 m (75 to 80 ft) above the modern channel. Five water well logs record thicknesses of 0.6 to 6.7 m (2 to 22 ft) for the fine-grained deposits and 2.4 to 7.6 m (8 to 25 ft) for the underlying gravel, with total thickness about 6.7 to 9.1 m (22 to 30 ft) (Sebol and others, 2023; Colorado Division of Water Resources, 2024). The gravel-bedrock contact is as much as 21 m (70 ft) above the modern Pinos River channel. The correlative unit on the Bayfield quadrangle is the upper level of unit Qtg2 (Moore and Scott, 1995), later called unit Qt4 (Gonzales and others, 2008). The age of unit Qa_4 in the Ignacio quadrangle, and of its correlatives along the Pine River, was previously estimated as Middle Pleistocene (Richmond, 1965; Johnstone and others, 2023). However, an optically stimulated luminescence age, 34,085 ± 1,605 years before present (Plate 2, Table 3), was obtained from a correlative deposit of the Los Pinos River downstream in the adjacent Tiffany quadrangle, revising the unit's age to Upper Pleistocene. The dated sample was collected from a gravel quarry in the southeast quarter-quarter of sec. 16 T. 32 N., R. 7 W. This sample is located off this map area approximately 1.6 km (1 mile) east of the southeastern corner of the Ignacio quadrangle. Unit Qa_4 along the Pine River could correlate either to unit Qa_3 along the Animas and Florida rivers on the Loma Linda quadrangle (Lindsey and Gillam, in prep.), or it could be intermediate in age between units Qa_3 and Qa_4 on that quadrangle. Unit Qa_4 may be a gravel resource if the fine-grained overburden is removed, but most of the unit is within or adjacent to the city limits of Ignacio.

Qgl — **Gravel lag (Holocene to Middle Pleistocene?)** — Locally thin, up to 1.5 m (5 ft) thick deposits consisting of lag cobbles in a fine-grained matrix. Clasts are typically matrix-supported, and consist mostly of hard, rounded, weathering-resistant rock types. Local sandstone and mudstone commonly comprise up to 5% of the clasts. These originally alluvial and (or) colluvial deposits have been reworked mainly from older, topographically higher gravelly deposits such as old river alluvium that is no longer preserved in the area, older gravels on the Mesa Mountains (unit Qgmm), and old gravels (unit Qg) north of the Mesa Mountains. Deposits commonly consist of a cobbly layer that contains rare boulders but typically lacks granules, pebbles, sand, and certain clast types that have either been disintegrated by weathering processes or have been selectively removed during transport while the original source deposits were being eroded and redeposited. The present matrix usually consists of loess, loess-like material, and (or) sediment derived from nearby bedrock. Deposits commonly occur on ridge tops and flanks or on slopes where they protect underlying bedrock from erosion. The unit's estimated Holocene to Middle(?) Pleistocene age is based on its relationship to old gravels (unit Qg), the presence of secondary calcium carbonate coatings up to 0.5 to 1.0 mm thick on the bottoms of some clasts, and the likelihood that some of the unit was reworked during Upper Pleistocene and Holocene time.

Qg — **Older gravel (Lower upper and Middle Pleistocene?)** — Cobble-rich gravel in a matrix composed of unconsolidated sand, silt, and clay. Clasts are mainly subangular to well-rounded, hard igneous and metamorphic rocks that resemble those in gravel lag (unit Qgl) and old gravel on Mesa Mountains (unit Qgmm), but unit Qg also includes very small amounts of locally sourced sedimentary rocks. The matrix consists of sediment derived from sedimentary rocks and probably loess-like sediment. These deposits cap low ridges that radiate out from the Mesa Mountains and are roughly parallel to the trends of adjacent streams with drainage basins limited to the flank of the Mesa Mountains. This pattern suggests that most of the gravel was initially eroded from sources on or near the mountain top by mass wasting and (or) alluvial-fan processes that also mobilized locally sourced materials. Alluvial-fan facets rise toward the mountain front but are no longer connected to the channel mouth or fan apex, which suggests subsequent erosion and southward retreat of the mountain front after deposition of the unit. In the unit, pebble-sized igneous and metamorphic clasts are less common than larger clasts of similar composition. Once deposited, the gravel armored the channel floors overlying relatively soft bedrock. Subsequent erosion and topographic inversion formed gravel-capped ridges between more recent lower-stream tributary deposits (units Qa and Qac). Unit Qg ranges in thickness from 0.6 to 2.0 m (2 to 6.5 ft). A lower Upper to Middle(?) Pleistocene age is inferred based on the height of unit Qg above adjacent drainages (as much as 45 m or 150 ft) and discontinuous carbonate coatings as much as 1 mm thick on the bottoms of some clasts. Some deposits near the northwestern corner of the quadrangle slope toward Middle Pleistocene terrace deposits of the Florida River in the adjacent Loma Linda quadrangle (Lindsey and Gillam, in prep.). The Upper Pleistocene age is based on the likelihood that some of deposits in unit Qg may have been reworked during Upper Pleistocene time by continued alluvial and (or) colluvial processes.

Qgmm — **Gravel on Mesa Mountains (Lower Pleistocene?)** — Rounded, typically clast-supported gravel with a matrix of reddish-gray-brown (5YR 5/2.5), reddish-brown (5YR 5/4) or light brown (7.5YR 6/3) sediment composed of unconsolidated sand, silt, and clay. Informally named unit (Richmond, 1965; Scott and Moore, 2007) consists of alluvium and colluvium that locally mantle the highest ridges and underlie stream terraces in the Mesa Mountains (e.g. Pantea, 1989; Gillam, 1998). Some gravel deposits are overlain by loess and thinner unmapped gravel deposits are common. Clasts are mostly cobbles and pebbles, but also include rare boulders up to 1 m (3 ft) in diameter. These clasts are composed mainly of igneous and metamorphic rocks of San Juan Mountains provenance, as well as smaller amounts of locally sourced sedimentary rocks. Except for the local rocks, clasts resemble rock types deposited by the Animas, Florida, and Los Pinos rivers. Unit Qgmm is poorly exposed except for one deposit in the Bondad Hill quadrangle (NE 1/4 sec. 35, T. 33 N., R. 9 W.), where it consists of clast-supported, stratified, gravelly alluvium as much as 4.9 m (16 ft) thick that contains lenses of silty clay (Pantea, 1989; Scott and Moore, 2007; McCalpin and Gillam, in prep.). Comparable thicknesses, fluvial-cut scarps, and paleochannels suggest that poorly exposed, southward-sloping deposits likely contain similar alluvium. One such deposit (SE ¼ sec. 17, T. 32 N., R. 8 W.), up to 4 m (13 ft) thick, has been mined for gravel while others range from 0.3 to 2.1 m (1 to 7 ft) thick, likely reworked into younger colluvium or alluvium. Near the southwest corner of the quadrangle (sec. 21, T. 32 N., R. 8 W.), reworked alluvium forms two terraces, 67 m (220 ft) and 91 m (300 ft) below the mined deposit, indicating at least three cycles of alluviation followed by stream incision. A lower inset deposit, 55 m (180 ft) above the canyon floor, aligns in height with Qg deposits in the northern part of the quadrangle. While the clasts originated from the San Juan Mountains, it is uncertain whether Qgmm represents ancient river alluvium or material reworked from older, eroded deposits. Cobbles of Vallecito Conglomerate, likely from the Los Pinos River, are found in the eastern Mesa Mountains, while clasts further west reflect Animas and Florida River sources. The varying heights of deposits suggest different ages, with many likely dating to the Lower Pleistocene, their elevations: ~275 m (900 ft) above the Los Pinos River and ~425 m (1,400 ft) above the Animas River. An earlier Upper Pliocene age proposal (Scott and Moore, 2007), was revised to Lower Pleistocene. Although one deposit was briefly mined, unit Qgmm is not economically viable for sand and gravel due to remoteness, weathered clasts, and a clayey matrix.

EOLIAN DEPOSITS

Qe — **Loess (Holocene to Middle? Pleistocene)** — Reddish-brown (5YR 5/4) and yellowish-red (5YR 5/6) sediment that consists of unconsolidated silt, fine sand, and clay. Upper 1.5 m (5 ft) of unit typically classified as clay loam, silty clay loam, and loam (Pannell and others, 1988). Deposits up to 4.6 m (15 ft) thick were observed on relatively flat to gently sloping surfaces such as those formed on some deposits of old gravel (unit Qg) and older gravel on Mesa Mountains (unit Qgmm). Unit Qe locally includes unmapped deposits of sheetwash alluvium. Many deposits of unit Qe are too thin and (or) too discontinuously mantle other surficial units to be mapped individually. Loess deposits locally contain moderately to strongly developed Bt and Bk soil horizons (Pannell and others, 1988) that are poorly exposed. Elsewhere in the region, loess deposits thinner than about 2 m (6 ft) have been dated from approximately 50 to 2 ka in age, but basal parts of thicker deposits could be older (Reheis and others, 2017; Price and others, 1988). Along the Animas and Florida rivers, loess and reworked loess as much as 10.6 m (34.8 ft) thick, containing several buried paleosols, overlie alluvial terraces of probable Middle Pleistocene age (Gillam, 1998; Lindsey and Gillam, in prep.). An optically stimulated luminescence age estimate of 220,180 ± 17,520 yr was obtained from one deposit (Lindsey and Gillam, in prep.), suggesting that some basal loess in the Ignacio quadrangle may be as old as Middle Pleistocene. Unit locally has moderate shrink-swell potential (Pannell and others, 1988).

MUD FLOW, FAN, AND MASS-WASTING DEPOSITS

Qf — **Debris-fan deposits (Holocene and Upper Pleistocene)** — Unit consists of light brownish-gray (10YR 6/2), brown (7.5YR 5/4) and pinkish-gray (5YR 6/2) sediment composed of unconsolidated clay, silt, sand, and locally small amounts of pebbles and cobbles, and is weakly stratified. The upper 1.5 m (5 ft) of unit are typically classified as silty clay loam, clay loam, and clay (Pannell and others, 1988). Unit was deposited at the base of the Mesa Mountains front mainly in broad fan-shaped deposits that were identified from lidar-derived 1-meter elevation contours. Some proximal deposits contain matrix-supported, angular clasts composed of sandstone or reworked rounded igneous and metamorphic clasts. Varying colors and clast types reflect distinctive, localized sediment sources such as purplish brown mudstones of the San Jose Formation or brownish loess and gravelly deposits. Deposits of unit Qf accumulated as stacked mud flows initiated by concentrated runoff events from adjacent, steep slopes composed mainly of erodible shale and mudstone. Downslope, as slope gradients flatten, these deposits transition to form alluvium and colluvium (units Qa and Qac). Not all deposits of unit Qf have a fan-shaped geometry, especially the older ones that have been buried or reworked. Ten water well logs indicate thicknesses ranging from about 4.3 to 30.5 m (14 to 100 ft) (Sebol and others, 2023; Colorado Division of Water Resources, 2024). Depths of incised channels vary from <0.3 m (<1 ft) in some higher-elevation deposits in the proximal parts of the fans, to as much as 4.3 m (14 ft) locally along larger streams. Deposits of unit Qf may be prone to hydrocompaction settlement (White and Greenman, 2008) and piping. They may also have expansive clay and high shrink-swell potential (Pannell and others, 1988).

Qls — **Landslide deposits (Holocene to Middle? Pleistocene)** — Unit is composed of sheared and chaotically mixed masses of disturbed mudstone, shale, clay, silt, sand, and sandstone, produced by gravitational failure and downslope movement on relatively steep slopes. Unit locally contains transported bedrock blocks. Landslides have formed along roughly half of the length of the Mesa Mountains front, where sandstone of the upper part of the Ditch Canyon Member of the San Jose Formation (unit PEsju) at the mountain crest overlies shale-dominated, landslide-prone Regina Member (unit PEsjr). In addition, higher elevations and northern to northeastern aspects likely promote higher seasonal soil moisture along the mountain front. Sandstone blocks of the Ditch Canyon Member (upper part) contained within the landslide deposit indicate that most of these blocks originated either at the crest or as colluvial debris farther downslope. Landslide deposits have not been differentiated by age or by movement type as defined by Varnes (1978). Younger landslide deposits commonly have fresh morphologic features; typically, some of the youngest deposits have fresh scarps, ruptured ground surfaces, and disturbed and sloughed vegetation. Older landslide deposits are more eroded, have muted morphologic features, and their vegetative cover has regrown. Landslide deposits may be as much as 50 m (165 ft) thick. Along with the soft underlying bedrock, loose disturbed landslide deposits are sources for Quaternary mudflow deposits (unit Qf) as well as other deposits (units Qac and Qa). The abundance of landslides and landslide deposits along the northern slopes of the Mesa Mountains indicates this area has been prone to mass wasting, both historic and prehistoric. Many of the older landslides may have occurred during colder and wetter climatic conditions when glaciers were present in the San Juan Mountains. Site-specific geological hazard evaluation, slope-stability analyses, and appropriate engineering considerations are recommended prior to construction, road building, water works, and placement of heavy loads on landslide deposits and geologically unstable slopes. Unit Qls may be susceptible to instability and mass-movement processes.

SEDIMENTARY BEDROCK GEOLOGY

San Jose Formation (Upper Paleocene and Lower Eocene?) — The San Jose Formation consists of four members listed in ascending order: Cuba Mesa Member (coarse, locally conglomeratic, sandstone), lower part of the Ditch Canyon Member (sandstones and shales), Regina Member (variegated shale), and upper part of the Ditch Canyon Member (sandstone and shale). Sandstone in the San Jose Formation is arkosic compared to the older andesitic sandstone of the Animas Formation (Reeside, 1924). The weakly cemented San Jose Formation consist of fluvial sandstone and shale floodplain and channel deposits. Resistant sandstone beds are typically buff to rusty-yellow in color. Easily eroded shales are variegated white, purple, green, and red. In Colorado, the San Jose Formation contains the Tiffanian North American Land Mammal Ages (NALMA) zones Ti4 and Ti5 (Sloan, 1987). A recent palynological determination (see Table 2, Plate 2) suggests that the San Jose contains pollen zones (P5) of Nichols and Ott (1978) which corresponds to Tiffanian age (Upper Paleocene). This unit includes the following mapped members.

PEsju — **Ditch Canyon Member, upper part (Upper Paleocene and Lower Eocene?)** — The upper part of the Ditch Canyon Member is an informally named unit (Smith, 1992) that is the highest stratigraphic member of the San Jose Formation observed on the Ignacio quadrangle. The unit is a light-gray to buff-colored, medium- to fine-grained, cross-bedded sandstone. Distinctively cliff-forming sandstone beds thicker than 3 m (10 ft) overlie the erosion-prone underlying shales along the north rim of the Mesa Mountains. On the northernmost part of the Mesa Mountains, there are two distinct resistive sandstone ledges in the unit. Further south in La Boca Canyon, there are as many as five identifiable resistive sandstone ledges. In the mapped area, the basal contact of the Ditch Canyon Member (upper part) was mapped progressively lower in the section toward the south at the base of the lowest traceable sandstone overlying the main body of Regina Member shale. The thickness of the Ditch Canyon Member (upper part) thins northward from 100 m (330 ft) in La Boca Canyon (near southeast corner of map area) to 10 m (33 ft) along the northernmost rim of the Mesa Mountains. One detrital zircon sample was collected from the southeast quarter of sec. 21, T. 33 N., R. 8 W. (Plate 2, Table 1). Sample IG22-DZ09 was collected from a gray-tan sandstone outcrop and yielded a youngest age population of 75.3 ± 1.4 Ma (n = 5; Mean Square Weighted Deviate (MSWD) = 0.57; youngest single grain of 68.4 ± 5.5 Ma) indicating a recycling of zircons from Upper Cretaceous strata. A fossil pollen sample (IG22-PL01) from a hillside trench in the southwest quarter of sec. 35, T. 33 N., R. 8 W. was interpreted to be zone P5 of Tiffanian age (Plate 2, Table 2), but more study of paleontology and palynology is needed.

PEsjr — **Regina Member (Upper Paleocene)** — Unit is variegated shale and mudstone with light-gray, maroon red, white, lavender, and brown colors that give the unit a banded appearance where exposed in hill slopes of the Mesa Mountains. The unit forms colorful badlands where exposed. Sandstone beds are very rare. This shale unit interfingers with the contemporaneous and overlying Ditch Canyon Member (upper part) sandstones, as seen near La Boca Canyon. The total thickness of the Regina Member in the Ignacio quadrangle is 223 m (670 ft) but it thins to the south as a sandier facies of the Ditch Canyon Member is more prevalant. The basal contact of the Regina Member is identified at the top of the first occurrence of a regionally continuous sandstone, when present, in the underlying undivided lower San Jose and Nacimiento Formations. The upper contact of the Regina Member is the base of the lowest traceable sandstone overlying the main sequence of banded shale strata. Good exposures of the Regina Member on the northern slope of the Mesa Mountains are discontinuous due to the presence of landslide deposits.

PEsn — **San Jose and Nacimiento Formations, undivided (Upper Paleocene)** — Unit includes the undivided San Jose Formation Ditch Canyon Member (lower part), Cuba Mesa Member, and the uppermost portion of the underlying Nacimiento Formation, listed in order from top to bottom. These were mapped as an undifferentiated unit in the Ignacio quadrangle due to the difficulty in determining formation and member boundaries in outcrops. The lower part of the Ditch Canyon Member is an informally named unit (Smith, 1992) that is a sequence of buff-colored, arkosic, fluvial-channel sandstone benches interspersed with grayish to green slope-forming mudstones. The sandstone benches are similar in lithology and sedimentary character to that of the underlying Cuba Mesa Member, but lack the lenses of very coarse, conglomeratic facies that are diagnostic of the Cuba Mesa Member. No fossils have been observed or reported in the Ditch Canyon Member (lower part) (Smith, 1992). Further detailed paleontological investigation is needed. The Cuba Mesa Member is the basal unit of the San Jose Formation and consists of a sequence of buff to rusty-yellow, coarse-grained, sandstone that overlies gray shale sequences of the underlying Nacimiento Formation. The Cuba Mesa Member is typically 1.6 meters (5 ft) thick. Diagnostic of the Cuba Mesa Member sandstone interval is the unique coarseness of arkosic grains compared to sandstone strata in other members of the San Jose Formation. Although sand grain size ranges from fine to very coarse, there are local granule laminae less than 2.5 cm thick (1 inch) and lenses of coarse sand as much as 1.6 m (5 ft) thick (Barnes, 1953). Crossbedding occurs in laminated beds. The Cuba Mesa Member is recognized where it forms resistant cliffs in the adjacent Bondad Hill quadrangle (McCalpin and Gillam, in prep.). At the western boundary of the Ignacio quadrangle, the Cuba Mesa Member is not exposed. The Nacimiento Formation is a nonresistant greenish-gray shale with local beds more than 6 m (20 ft) thick composed of fine-grained, well-sorted sandstone. The Animas Formation mapped to the north in the Gem Village quadrangle (Rogers, in prep.) and Nacimiento Formation mapped in this area are coeval (Fassett and Hinds, 1971; Cather and others, 2019), gradational to each other, and locally interfinger. Nacimiento strata in the Ignacio quadrangle are included in this undifferentiated unit due to poor exposures where the unit is weathered or present in gently sloping areas that typically are locally mantled by Quaternary deposits. Two detrital zircon samples were collected from sandstone within the undivided Lower San Jose and Upper Nacimiento Formations (Plate 2, Table 1). Sample IG22-DZ03 was taken from the southeast quarter of sec. 24, T. 33 N., R. 8 W., from a roadcut through tan sandstone along La Plata County Road 318. This sample yielded a youngest-age population of 70.7 ± 1.7 Ma (n = 5; MSWD = 0.58) and a youngest single grain of 67.2 ± 3.5 Ma. Sample IG22-DZ10 is from the southeast quarter of sec. 17, T. 33 N., R. 7 W. from a tan sandstone along a Colorado Highway 172 roadcut. It yielded a youngest-age population of 71.6 ± 1.5 Ma (n = 5; MSWD = 0.27; youngest single grain of 68.6 ± 3 Ma). These two detrital zircon analyses indicate recycling of zircons from Upper Cretaceous strata.

PEn — **Nacimiento Formation (Paleocene)** — Unit is composed of greenish-gray shale and local beds composed of fine-grained, well-sorted sandstone. Shown in cross section only.

Kkl — **Kirtland Formation (Upper Cretaceous)** — Unit is composed of shale and sandstone deposited in a non-marine environment. Shown in cross section only.

Kf — **Fruitland Formation (Upper Cretaceous)** — The unit is composed of shale, discontinuous non-marine sandstone, and is a significant coal-bearing unit. Shown in cross section only.

Kpc — **Pictured Cliffs Sandstone (Upper Cretaceous)** — Unit is composed of primarily marine light-gray sandstone interbedded with dark-gray shale. Shown in cross section only.

Kl — **Lewis Shale (Upper Cretaceous)** — Unit is composed of dark-gray marine claystone and shale and contains the Huerfanito Bentonite bed, a significant regional marker bed in oil and gas geophysical logs. Shown in cross section only.

Mesaverde Group (Upper Cretaceous) — Stratigraphic group composed of the Cliff House Sandstone, Menefee Formation and Point Lookout Sandstone.

Kch — **Cliff House Sandstone (Upper Cretaceous)** — Marine unit composed of sandstone and minor shale. Shown in cross section only.

Kme — **Menefee Formation (Upper Cretaceous)** — Non-marine unit composed of fluvial sandstone, overbank shales, and coal beds. Shown in cross section only.

Kpl — **Point Lookout Sandstone (Upper Cretaceous)** — Marine unit composed of sandstone and minor shale. Shown in cross section only.

Km — **Mancos Shale (Upper Cretaceous)** — Marine unit composed of dark-gray shale. Shown in cross section only.

Kdb — **Dakota Formation and Burro Canyon Formation, undivided (Upper and Lower Cretaceous)** — This unit is composed of sandstone interbedded with siltstone and shale. The deposits are predominantely non-marine, however, the upper Dakota Formation sandstone beds are marine, showing evidence of near-shore influence. Shown in cross section only.

Jm — **Morrison Formation (Upper Jurassic)** — Non-marine unit composed of varicolored mudstone and sandstone. Shown in cross section only.

MAP SYMBOLS

— — – **Contact** — Existence certain, location approximate

Anticline — Ignacio-Bondad anticline (Anderson, 1995), existence certain, location concealed

⌖ **Oil and Gas Well** — Label is the American Petroleum Institute (API) Unique Well Identifier. Label does not include preceding State Code (05) and County Codes (067 for La Plata County). Oil and gas data is available at the Colorado Energy and Carbon Management Commission (ECMC) Colorado oil and gas information system (COGIS) map viewer.

★ **Pollen sample site** — See Table 2 on Plate 2

◆ **Detrital zircon sample site** — See Table 3 on Plate 2

A — A′ **Alignment of cross section**