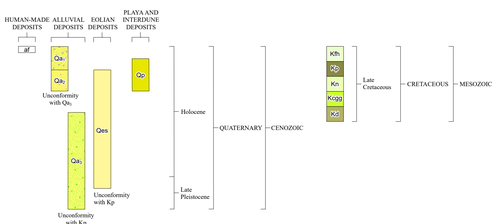
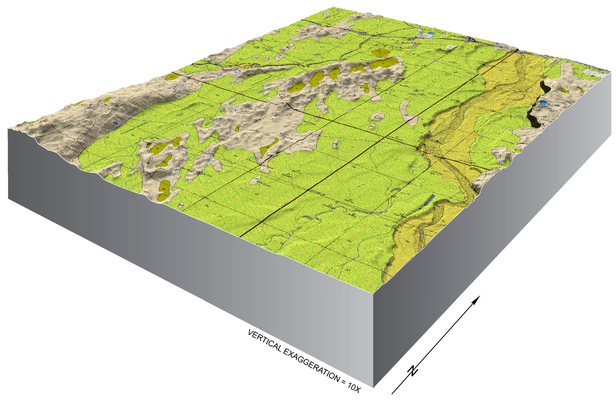
COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

DOI: https://doi.org/10.58783/cgs.of2306.zluy3701

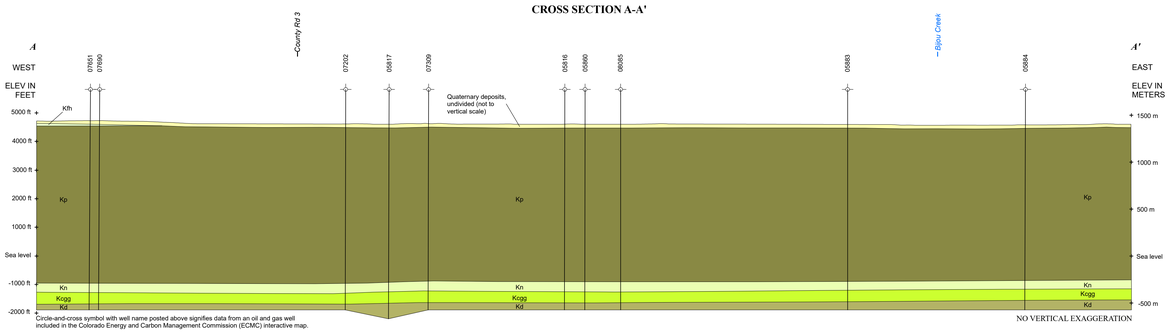
CORRELATION OF MAP UNITS



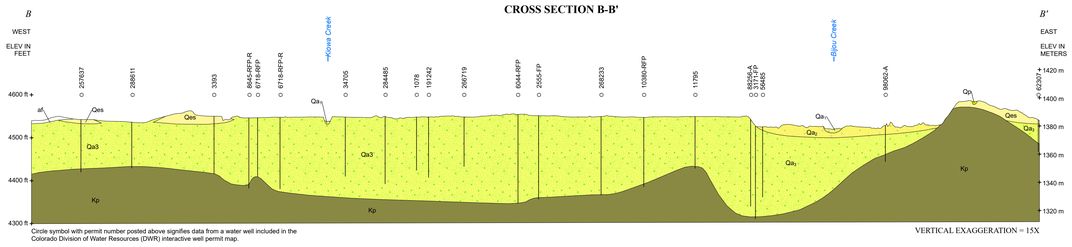
3-D OBLIQUE



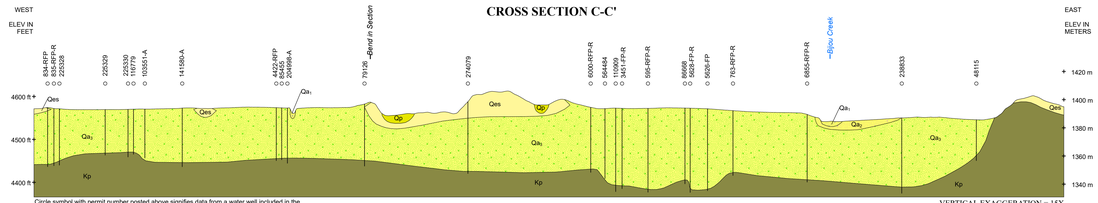
CROSS SECTION A-A'



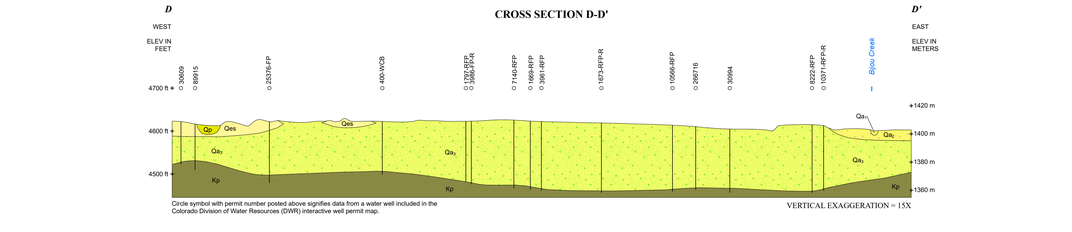
CROSS SECTION B-B'



CROSS SECTION C-C'



CROSS SECTION D-D'



GEOLOGIC HISTORY AND STRUCTURE

The Wiggins quadrangle lies in the northeast part of the Colorado Piedmont, a widespread erosional feature below the foothills of the Front Range. Topographic relief in the piedmont is relatively low. The quadrangle has only 82 m of elevation difference between its lowest elevation (1,372 m, where Bijou Creek crosses the quadrangle's north boundary) and highest elevation (1,454 m, in the quadrangle's southwest corner). Approximately three-quarters of the quadrangle consists of wide, generally north-to-south-trending valleys containing alluvial sand, silt, and clay at the ground surface and some alluvial gravel at depth. Approximately one-quarter consists of intervening uplands covered with eolian sand, with pond and sheetwash deposits in some of the flat depressions in the dune fields (see geologic map, Plate 1). Eolian sand uplands are bedrock-cored on the east and southwest parts of the quadrangle but not in the center. A thin band of weathered bedrock (Pierre Shale Upper Transition Member) is exposed on the east valley wall of Bijou Creek in the northeast portion of the quadrangle. The relatively few natural exposures of the alluvial and eolian sediments occur in valley walls and cut banks of streams. Bedrock topography beneath alluvial valleys is generally aligned with valley surface topography, except in the center of the quadrangle, where the eolian sand upland has no bedrock core and is underlain by Middle Holocene to Late Pleistocene alluvium.

The Wiggins quadrangle is near the northeast extent of the Denver Basin, as indicated by a regional map of the basin and by a structure contour map on the top of the Fox Hills Sandstone (Dechesne and others, 2011). This formation is the youngest bedrock unit present in the quadrangle but has no surface exposure. Also from the structure contour map, the Fox Hills Sandstone in the vicinity of the Wiggins quadrangle dips to the west at ~0.2 degrees. Cross section A-A' indicates that the bedrock units beneath the Wiggins quadrangle are nearly flat-lying.

All the bedrock units shown in cross section A-A' are Cretaceous members, formations, or groups formed from sediments deposited in the Western Interior Seaway, which at its maximum extent reached from the Arctic Ocean to the Gulf of Mexico and divided the North American continent. From Middle Jurassic into Late Cretaceous time the seaway occupied the Western Interior Foreland Basin east of the Cordilleran Orogenic Belt. The basin and orogenic belt were formed as North America drifted westward away from Europe and as the Pacific (Panthalassan) oceanic crust was subducted beneath the North American Plate (Slattery and others, 2013). The Laramide orogeny during Late Cretaceous and Paleogene time, along with a drop in eustatic sea level, caused the Western Interior Seaway to retreat from the interior of North America. The Late Cretaceous Fox Hills Sandstone is the youngest of the seaway's marine deposits and is present (beneath Quaternary deposits) along the west boundary of the Wiggins quadrangle. This formation represents near-shore and beach environments on the western margin of the retreating seaway. The Upper Transition Member of the Pierre Shale underlies the Fox Hills Sandstone and represents the near-shore environment of the seaway. Because the Cretaceous strata dip gently westward, it is the Pierre Shale that underlies the Quaternary sediments in almost the entire quadrangle. The Dakota Group is the oldest geologic unit encountered by oil and gas drilling in the Wiggins quadrangle (cross section A-A', Plate 2). The Cretaceous marine deposits in cross section A-A' overlie a subsided package of Mesozoic and Paleozoic formations, and these in turn overlie Precambrian cratonic crystalline basement. For a description of geologic units older than the Dakota Group, and not appearing in the cross section, see Braddock and others (1988).

The present-day landscape of the Colorado Piedmont between the Rocky Mountain Front Range and the High Plains Escarpment results chiefly from the downcutting and geomorphic evolution of the South Platte River and Arkansas River drainage basins mainly during late Neogene and Quaternary time, and was accelerated during Pleistocene glacial epochs. These processes began with removal of Paleogene and Neogene rocks and sediments that once covered Upper Cretaceous strata in these basins (Madole, 1991). The predominant Quaternary deposits in the piedmont, including those in the Wiggins quadrangle and surrounding area, are fluvial sediments of the South Platte River and its major tributaries, and eolian sediments (dune sand and loess) deflated from alluvium in the stream valleys and from upwind bedrock exposures (Madole, 1991; 2016). (Note that loess is not separately mapped in the Wiggins quadrangle, but that unit Qp could partly originate from loess deposition.) There are three active drainages and two inactive paleovalleys in the quadrangle.

The three active drainages are Bijou Creek, Antelope Creek, Kiowa Creek; each of these is situated in a paleovalley. The inactive paleovalleys are informally named the County Road 3 paleovalley and the Empire Reservoir paleovalley (see geologic map, Plate 1). The two larger active drainages, Kiowa Creek and Bijou Creek, drain north of the Palmer Divide, a high upland divide separating the drainage basins of the South Platte River to the north and Arkansas River to the south. The elevation of the Palmer Divide ranges between 1,829 and 2,404 m. The headwaters of both creeks are in northernmost El Paso County, ~140 km southsouthwest of the town of Wiggins. Kiowa Creek flows north out of the Wiggins quadrangle to join the South Platte River at ~10 km north of the town of Wiggins. Bijou Creek flows north out of the Wiggins quadrangle for ~3 km, then turns east to join the South Platte River at ~17 km east of Wiggins. Antelope Creek flows north-northeast from the Hoyt quadrangle into the Wiggins quadrangle and joins Bijou Creek at ~6 km north of the Wiggins quadrangle south boundary.

The Antelope Creek valley floor grades into the west terrace of the Bijou Creek valley. Lidar imagery suggests that the terraces bounding the Antelope Creek valley (at the south quadrangle boundary) are the maximum aggradation surface (Late Pleistocene to Middle Holocene) of a former, wider Bijou Creek valley. The Antelope Creek valley lacks unit Qa_2 but contains a deposit of unit Qa_3 too narrow to be mapped.

The County Road 3 paleovalley is a prominent topographic feature on the west side of the Wiggins quadrangle and extends south into the Hoyt quadrangle. Morgan County Road 3 runs north to south through the valley and the valley width is ~1.5 km. Formerly, the valley probably was part of the west side of the Bijou Creek valley. The County Road 3 drainage presently contains an unnamed intermittent stream that flows north only to between County Roads L and M and does not join Kiowa Creek. Lidar imagery interpretation indicates the County Road 3 valley floor has a few large mid-channel bars similar to those of the unit Qa_3 east terrace in the Bijou Creek valley.

The Empire Reservoir paleovalley formerly was a north-trending tributary to the South Platte River and may have been on the west side of a much wider combined Kiowa Creek and Bijou Creek paleovalley. The Empire Reservoir paleovalley is ~1 km wide and originates in the northwest corner of the Wiggins quadrangle and northeast corner of the Omar quadrangle (adjacent to the west of the Wiggins quadrangle). From the area (in the Wiggins quadrangle) between the Burlington Northern rail line and U.S. Interstate Highway I-76, the paleovalley trends north along the east side of Empire Reservoir (in the Masters quadrangle, to the north) and joins the South Platte River valley at ~6 km north of the Wiggins quadrangle northwest corner.

During the Late Pleistocene glacial epoch both Bijou Creek and Kiowa Creek likely were braided stream systems occupying the entire widths of their respective modern valleys. The east ends of cross sections B-B', C-C', and D-D' show the Bijou Creek valley as bounded to the east by bedrock upland of the Pierre Shale Upper Transitional Member, covered by eolian sand. The north-southtrending upland in the southwest corner of the Wiggins quadrangle has no recorded water wells and thus is not included in cross section D-D'. It does, however, appear to be a sand-covered bedrock upland bounding the County Road 3 drainage on the west and continuing south into the Hoyt quadrangle. To the south, in the topographic map of the Hoyt quadrangle, the County Road 3 drainage is not distinguishable, and the Bijou Creek valley is confined by bedrock upland on the west and east. The low relief of the bedrock surface on the west side of cross section D-D' indicates that the County Road 3 drainage was not a distinct feature during the Late Pleistocene, but during that time was the western side of a larger Bijou Creek valley. It is probable that the County Road 3 drainage was blocked off from the Bijou Creek valley by Holocene accumulation of the eolian sand, creating the low upland hills that presently separate the two drainages.

The Bijou Creek and Kiowa Creek drainages presently have markedly separate channels flowing to the South Platte River, their junctions being respectively east and north of the Wiggins quadrangle, but lidar imagery interpretation and water well data suggest that their paleovalleys converged in the east-central part of the quadrangle. The convergence appears to be near where County Road 2 crosses modern Kiowa Creek. South and upstream from there the Kiowa Creek paleovalley is separated from the Bijou Creek paleovalley by the extensive sand-covered bedrock upland in the southwest corner of the quadrangle. North of the convergence, a low-relief bedrock surface, shown in cross sections B-B' and C-C', indicates a continuous bedrock valley floor underlying the modern courses of both creeks. Probably during Late Pleistocene through Middle Holocene time, the extensive eolian sand upland lying south of the town of Wiggins (cross section C-C') was deposited in the area of paleovalley convergence and now separates the two modern valleys. This upland has no bedrock core, and its eolian sand overlies alluvium of unit Qa_2. Upstream and north along the trend of the combined paleovalleys, the topographic map of the Orchard quadrangle (adjacent to the north of the Wiggins quadrangle) shows a broad, fan-like surface extending from the Wiggins quadrangle north boundary to the south bluff of the South Platte River valley. The geologic map of the Orchard quadrangle (Berry and others, 2015a) shows Broadway sidestream deposits (unit Qbs, equivalent to unit Qa_3 in the Wiggins quadrangle) to be exposed all along the south bluff of the South Platte River valley. This deposit appears to be continuous with unit Qa_3 sediments deposited in the combined paleovalleys of Kiowa Creek and Bijou Creek in the Wiggins quadrangle. The modern drainages of Bijou Creek, Kiowa Creek, and the Empire Reservoir paleovalley all are incised in the above fan-like surface. Kiowa Creek and the Empire Reservoir drainage head north along the trend of the combined paleovalleys, but the Bijou Creek incision has been diverted about 90 degrees to the east, possibly by avulsion during the Holocene. Bjorklund and Brown (1957) state that at present the South Platte River is flowing at grade, a condition in which erosion and deposition are approximately equal, but that its tributaries, including Bijou Creek, are still actively eroding because they are not yet adjusted to the river.

The topographic base in the geologic map (Plate 1) indicates that the fill-terrace elevations of the Kiowa Creek valley floor and the western valley floor of Bijou Creek are comparable, with a difference in elevation of less than 2 m. In both valleys, in areas covered by the youngest alluvium of unit Qa_3, lidar imagery interpretation indicates that there are a few large mid-channel bars oriented parallel to the direction of paleoflow during the time when the youngest sediments of the unit Qa_3 fill terrace were deposited. The bars are about ~800 to 1,200 m long, ~70 to 90 m wide, and as high as 2 m.

The Kiowa Creek and Bijou Creek valleys have been differentially incised in the Holocene. This is supported by the following observations made from the lidar imagery: 1) in the Kiowa Creek valley, unit Qa_3 is only a little incised, whereas in the Bijou Creek valley the deposit is markedly incised; 2) in the Kiowa Creek valley there are no fill-cut terraces within unit Qa_3, whereas there are many such terraces in the Bijou Creek valley; 3) in the Kiowa Creek valley, unit Qa_2 terraces are few and narrow (~200-m wide), whereas in the Bijou Creek valley they are multiple and wide (up to 1,200 m); and 4) in the Kiowa Creek valley the incision occupied by unit Qa_3 is narrow (15 m or less), whereas in the Bijou Creek valley the incision is much wider (up to 260 m).

Several terrace elevation profiles were plotted across the Bijou Creek and Kiowa Creek valleys, using elevation data from the Wiggins quadrangle lidar digital elevation model (DEM). Lidar DEM modeling clearly identifies the fill terraces of Bijou Creek and Kiowa Creeks. These highest terraces are assumed to be the maximum elevations of Late Pleistocene to Middle Holocene aggradation of unit Qa_2, associated with Pinedale glaciation in the Rocky Mountains and extending into post-Pinedale time. The fill terrace of the Bijou Creek valley bounds three lower levels of fill-cut terraces, indicating periods of incision and lateral erosion during post-Pinedale time. The terraces occur on both sides of the valley, only one set is paired (i.e., same elevation on opposite valley sides), and exposed incision depths (heights of terrace risers) are 0.6–2.1 m on the west side of the valley, where areas of two or three stepped terraces occur. In the Kiowa Creek valley there are no fill-cut terraces in unit Qa_3. In the Bijou Creek valley the elevation difference between the fill terraces of units Qa_3 and Qa_2 is 5.2–6.7 m, and the difference between the fill terraces of units Qa_2 and the top of Qa_1 deposits is 1.8–2.7 m. In the Kiowa Creek valley (where only one deposit of unit Qa_2 is mapped), the elevation difference between fill terraces of units Qa_3 and Qa_2 is 3.0 m, and the difference between the fill terrace of units Qa_2 and the top of Qa_1 deposits is 1.5 m. Therefore, it appears that post-Pinedale incision in the Kiowa Creek valley was much less developed than in the Bijou Creek valley.

The optically stimulated luminescence (OSL) age of the near-surface part of unit Qa_3 alluvium (top of Kiowa Creek valley fill) is ~9.8 ky. In a unit Qa_3 fill-cut terrace within the Bijou Creek valley the OSL age is ~6.1 ky (sample WS025OSL). (For sample locations see the geologic map in Plate 1; for OSL ages with error ranges see Table 2.) The Orchard and Weldona quadrangles are adjacent to the Wiggins quadrangle on the north and northeast, respectively. Berry and others' (2015a, 2015b) unit Qbs in these two quadrangles is continuous with unit Qa_3 in the Wiggins quadrangle. The above two CGS ages for unit Qa_3 are Early and Middle Holocene, respectively. Ages for unit Qbs in the Orchard and Weldona quadrangles are Late Pleistocene to Early Holocene: ~15.2 ky (OSL), ~14.6 ky (OSL), ~14.5 ky (radiocarbon), ~12.4 ky (OSL), ~12.0 ky (OSL), and ~9.4 ky (OSL) (Berry and others, 2015a, 2015b).

Kellogg and others (2008) give an age range of 12–30 ky for Broadway Alluvium (unit Qa_3 equivalent) in the northern Colorado Piedmont and correlate it with Pinedale glaciation in the Rocky Mountains. Unit Qa_3 (Pinedale equivalent) ages are approximately 11–18 ky (Madole, 2016; Keller and others, 2017; Palkovic and others, 2018; Keller and Marr, 2023b; Lindsey and Palkovic, 2020). In the northern Colorado Piedmont there is, however, a group of CGS ages for unit Qa_3 that do not correlate either with Pinedale glaciation or with CGS unit Qa_4 (Louviers Alluvium; Scott, 1960), which has an age of 120–170 ky and is associated with the older Bull Lake glaciation (Kellogg and others, 2008). These intermediate ages are approximately 40–87 ky (Keller and others, 2019; Keller and Morgan, 2020; Lindsey and Palkovic, 2020; Palkovic, 2020). An explanation for this group of ages intermediate between those of the Pinedale and Bull Lake glaciations has not yet been advanced and is a possible subject for further investigation.

The two CGS Wiggins quadrangle ages for unit Qa_3 (~9.8 ky and ~6.1 ky) are Early to Middle Holocene and are notably younger than the above Late Pleistocene ages for unit Qa_3 and Berry and others' (2015a, 2015b) unit Qbs. These two ages probably represent the maximum aggradation of unit Qa_3 in the Kiowa Creek and Bijou Creek valleys, during a period lasting for some time after Pinedale glaciation. Up through Middle Holocene time the aggradation rates of unit Qa_3 in Kiowa Creek and Bijou Creek apparently were similar because the present valley floors are at approximately the same elevation. During the Early Holocene these two north-flowing drainages possibly received sediment from erosion of eolian sand fields. During the Middle Holocene, after aggradation had ceased, incision apparently affected the Kiowa Creek valley much less than the Bijou Creek valley. Stream flow in both creeks likely was considerably reduced during post-Pinedale incision, but stream flow in Kiowa Creek, relative to that of Bijou Creek, apparently decreased from what it had been during maximum aggradation. If the relative flows of both creeks had remained the same or similar after aggradation ceased (even while the flows in both streams were reduced), incision and channel development of the Kiowa Creek valley would be similar to the Bijou Creek valley. A hypothesis for inferred Middle Holocene diminution of Kiowa Creek flow relative to Bijou Creek flow is a possible subject for further investigation.

About 1 km south of the town of Wiggins there is a south-trending series of five unconnected deposits of unit Qp enclosed by eolian sand unit Qes, between the Kiowa Creek and Bijou Creek valleys (see geologic map, Plate 1). The top elevations of these deposits are several meters lower than the Kiowa Creek and Bijou Creek valley floors. It is presumed that unit Qp was deposited in interdune depressions in the dune field. Based on this presumption, cross sections C-C' and D-D' depict the base of unit Qes as also being lower in elevation than the present valley floors. Water well logs supporting the depiction of unit Qa_3 in the three Quaternary cross sections indicate that alluvial sediments (including gravel layers) underlie the dune field. Therefore, it is probable that the dune field was initially deposited on a topographically lower, Late Pleistocene unit Qa_3 valley-fill surface. Thus, during the initial deposition of eolian sand, the interdune depressions were higher than the contemporary valley floors. As the creek valleys aggraded to their maximum elevations during the Middle Holocene, their valley fills became high enough to allow their groundwater to infiltrate the lower deposits of unit Qes. During times of high water table, such as during flood events, heavy precipitation events, and (or) seasonal fluctuations, groundwater from the valley fill may have infiltrated into the low interdune areas and formed temporary ponds in which pond and sheetwash sediments (unit Qp) were deposited during the Middle Holocene. Note that unit Qp at sample location WS137BC14 (geologic map, Plate 1) has a radiocarbon age of ~6.1 ky, which is younger than the OSL age of ~12.8 ky for unit Qes at sample location WS111OSL (Table 2). Deflation of fines from Kiowa Creek valley alluvium and perhaps more distant sources, entrapment of fine eolian particles during times of open water, sheetwash from the surrounding sand dunes, and minor winnowing of fines from the dunes may have been sources for the sand and fines in the interdune unit Qp sediments.

The County Road 3 paleovalley is a prominent topographic feature on the west side of the Wiggins quadrangle and extends south into the Hoyt quadrangle. Morgan County Road 3 runs north to south through the valley and the valley width is ~1.5 km. Formerly, the valley probably was part of the west side of the Bijou Creek valley. The County Road 3 drainage presently contains an unnamed intermittent stream that flows north only to between County Roads L and M and does not join Kiowa Creek. Lidar imagery interpretation indicates the County Road 3 valley floor has a few large mid-channel bars similar to those of the unit Qa_3 east terrace in the Bijou Creek valley.

The Empire Reservoir paleovalley formerly was a north-trending tributary to the South Platte River and may have been on the west side of a much wider combined Kiowa Creek and Bijou Creek paleovalley. The Empire Reservoir paleovalley is ~1 km wide and originates in the northwest corner of the Wiggins quadrangle and northeast corner of the Omar quadrangle (adjacent to the west of the Wiggins quadrangle). From the area (in the Wiggins quadrangle) between the Burlington Northern rail line and U.S. Interstate Highway I-76, the paleovalley trends north along the east side of Empire Reservoir (in the Masters quadrangle, to the north) and joins the South Platte River valley at ~6 km north of the Wiggins quadrangle northwest corner.

During the Late Pleistocene glacial epoch both Bijou Creek and Kiowa Creek likely were braided stream systems occupying the entire widths of their respective modern valleys. The east ends of cross sections B-B', C-C', and D-D' show the Bijou Creek valley as bounded to the east by bedrock upland of the Pierre Shale Upper Transitional Member, covered by eolian sand. The north-southtrending upland in the southwest corner of the Wiggins quadrangle has no recorded water wells and thus is not included in cross section D-D'. It does, however, appear to be a sand-covered bedrock upland bounding the County Road 3 drainage on the west and continuing south into the Hoyt quadrangle. To the south, in the topographic map of the Hoyt quadrangle, the County Road 3 drainage is not distinguishable, and the Bijou Creek valley is confined by bedrock upland on the west and east. The low relief of the bedrock surface on the west side of cross section D-D' indicates that the County Road 3 drainage was not a distinct feature during the Late Pleistocene, but during that time was the western side of a larger Bijou Creek valley. It is probable that the County Road 3 drainage was blocked off from the Bijou Creek valley by Holocene accumulation of the eolian sand, creating the low upland hills that presently separate the two drainages.

The Bijou Creek and Kiowa Creek drainages presently have markedly separate channels flowing to the South Platte River, their junctions being respectively east and north of the Wiggins quadrangle, but lidar imagery interpretation and water well data suggest that their paleovalleys converged in the east-central part of the quadrangle. The convergence appears to be near where County Road 2 crosses modern Kiowa Creek. South and upstream from there the Kiowa Creek paleovalley is separated from the Bijou Creek paleovalley by the extensive sand-covered bedrock upland in the southwest corner of the quadrangle. North of the convergence, a low-relief bedrock surface, shown in cross sections B-B' and C-C', indicates a continuous bedrock valley floor underlying the modern courses of both creeks. Probably during Late Pleistocene through Middle Holocene time, the extensive eolian sand upland lying south of the town of Wiggins (cross section C-C') was deposited in the area of paleovalley convergence and now separates the two modern valleys. This upland has no bedrock core, and its eolian sand overlies alluvium of unit Qa_2. Upstream and north along the trend of the combined paleovalleys, the topographic map of the Orchard quadrangle (adjacent to the north of the Wiggins quadrangle) shows a broad, fan-like surface extending from the Wiggins quadrangle north boundary to the south bluff of the South Platte River valley. The geologic map of the Orchard quadrangle (Berry and others, 2015a) shows Broadway sidestream deposits (unit Qbs, equivalent to unit Qa_3 in the Wiggins quadrangle) to be exposed all along the south bluff of the South Platte River valley. This deposit appears to be continuous with unit Qa_3 sediments deposited in the combined paleovalleys of Kiowa Creek and Bijou Creek in the Wiggins quadrangle. The modern drainages of Bijou Creek, Kiowa Creek, and the Empire Reservoir paleovalley all are incised in the above fan-like surface. Kiowa Creek and the Empire Reservoir drainage head north along the trend of the combined paleovalleys, but the Bijou Creek incision has been diverted about 90 degrees to the east, possibly by avulsion during the Holocene. Bjorklund and Brown (1957) state that at present the South Platte River is flowing at grade, a condition in which erosion and deposition are approximately equal, but that its tributaries, including Bijou Creek, are still actively eroding because they are not yet adjusted to the river.

The topographic base in the geologic map (Plate 1) indicates that the fill-terrace elevations of the Kiowa Creek valley floor and the western valley floor of Bijou Creek are comparable, with a difference in elevation of less than 2 m. In both valleys, in areas covered by the youngest alluvium of unit Qa_3, lidar imagery interpretation indicates that there are a few large mid-channel bars oriented parallel to the direction of paleoflow during the time when the youngest sediments of the unit Qa_3 fill terrace were deposited. The bars are about ~800 to 1,200 m long, ~70 to 90 m wide, and as high as 2 m.

The Kiowa Creek and Bijou Creek valleys have been differentially incised in the Holocene. This is supported by the following observations made from the lidar imagery: 1) in the Kiowa Creek valley, unit Qa_3 is only a little incised, whereas in the Bijou Creek valley the deposit is markedly incised; 2) in the Kiowa Creek valley there are no fill-cut terraces within unit Qa_3, whereas there are many such terraces in the Bijou Creek valley; 3) in the Kiowa Creek valley, unit Qa_2 terraces are few and narrow (~200-m wide), whereas in the Bijou Creek valley they are multiple and wide (up to 1,200 m); and 4) in the Kiowa Creek valley the incision occupied by unit Qa_3 is narrow (15 m or less), whereas in the Bijou Creek valley the incision is much wider (up to 260 m).

Several terrace elevation profiles were plotted across the Bijou Creek and Kiowa Creek valleys, using elevation data from the Wiggins quadrangle lidar digital elevation model (DEM). Lidar DEM modeling clearly identifies the fill terraces of Bijou Creek and Kiowa Creeks. These highest terraces are assumed to be the maximum elevations of Late Pleistocene to Middle Holocene aggradation of unit Qa_2, associated with Pinedale glaciation in the Rocky Mountains and extending into post-Pinedale time. The fill terrace of the Bijou Creek valley bounds three lower levels of fill-cut terraces, indicating periods of incision and lateral erosion during post-Pinedale time. The terraces occur on both sides of the valley, only one set is paired (i.e., same elevation on opposite valley sides), and exposed incision depths (heights of terrace risers) are 0.6–2.1 m on the west side of the valley, where areas of two or three stepped terraces occur. In the Kiowa Creek valley there are no fill-cut terraces in unit Qa_3. In the Bijou Creek valley the elevation difference between the fill terraces of units Qa_3 and Qa_2 is 5.2–6.7 m, and the difference between the fill terraces of units Qa_2 and the top of Qa_1 deposits is 1.8–2.7 m. In the Kiowa Creek valley (where only one deposit of unit Qa_2 is mapped), the elevation difference between fill terraces of units Qa_3 and Qa_2 is 3.0 m, and the difference between the fill terrace of units Qa_2 and the top of Qa_1 deposits is 1.5 m. Therefore, it appears that post-Pinedale incision in the Kiowa Creek valley was much less developed than in the Bijou Creek valley.

The optically stimulated luminescence (OSL) age of the near-surface part of unit Qa_3 alluvium (top of Kiowa Creek valley fill) is ~9.8 ky. In a unit Qa_3 fill-cut terrace within the Bijou Creek valley the OSL age is ~6.1 ky (sample WS025OSL). (For sample locations see the geologic map in Plate 1; for OSL ages with error ranges see Table 2.) The Orchard and Weldona quadrangles are adjacent to the Wiggins quadrangle on the north and northeast, respectively. Berry and others' (2015a, 2015b) unit Qbs in these two quadrangles is continuous with unit Qa_3 in the Wiggins quadrangle. The above two CGS ages for unit Qa_3 are Early and Middle Holocene, respectively. Ages for unit Qbs in the Orchard and Weldona quadrangles are Late Pleistocene to Early Holocene: ~15.2 ky (OSL), ~14.6 ky (OSL), ~14.5 ky (radiocarbon), ~12.4 ky (OSL), ~12.0 ky (OSL), and ~9.4 ky (OSL) (Berry and others, 2015a, 2015b).

Kellogg and others (2008) give an age range of 12–30 ky for Broadway Alluvium (unit Qa_3 equivalent) in the northern Colorado Piedmont and correlate it with Pinedale glaciation in the Rocky Mountains. Unit Qa_3 (Pinedale equivalent) ages are approximately 11–18 ky (Madole, 2016; Keller and others, 2017; Palkovic and others, 2018; Keller and Marr, 2023b; Lindsey and Palkovic, 2020). In the northern Colorado Piedmont there is, however, a group of CGS ages for unit Qa_3 that do not correlate either with Pinedale glaciation or with CGS unit Qa_4 (Louviers Alluvium; Scott, 1960), which has an age of 120–170 ky and is associated with the older Bull Lake glaciation (Kellogg and others, 2008). These intermediate ages are approximately 40–87 ky (Keller and others, 2019; Keller and Morgan, 2020; Lindsey and Palkovic, 2020; Palkovic, 2020). An explanation for this group of ages intermediate between those of the Pinedale and Bull Lake glaciations has not yet been advanced and is a possible subject for further investigation.

The two CGS Wiggins quadrangle ages for unit Qa_3 (~9.8 ky and ~6.1 ky) are Early to Middle Holocene and are notably younger than the above Late Pleistocene ages for unit Qa_3 and Berry and others' (2015a, 2015b) unit Qbs. These two ages probably represent the maximum aggradation of unit Qa_3 in the Kiowa Creek and Bijou Creek valleys, during a period lasting for some time after Pinedale glaciation. Up through Middle Holocene time the aggradation rates of unit Qa_3 in Kiowa Creek and Bijou Creek apparently were similar because the present valley floors are at approximately the same elevation. During the Early Holocene these two north-flowing drainages possibly received sediment from erosion of eolian sand fields. During the Middle Holocene, after aggradation had ceased, incision apparently affected the Kiowa Creek valley much less than the Bijou Creek valley. Stream flow in both creeks likely was considerably reduced during post-Pinedale incision, but stream flow in Kiowa Creek, relative to that of Bijou Creek, apparently decreased from what it had been during maximum aggradation. If the relative flows of both creeks had remained the same or similar after aggradation ceased (even while the flows in both streams were reduced), incision and channel development of the Kiowa Creek valley would be similar to the Bijou Creek valley. A hypothesis for inferred Middle Holocene diminution of Kiowa Creek flow relative to Bijou Creek flow is a possible subject for further investigation.

About 1 km south of the town of Wiggins there is a south-trending series of five unconnected deposits of unit Qp enclosed by eolian sand unit Qes, between the Kiowa Creek and Bijou Creek valleys (see geologic map, Plate 1). The top elevations of these deposits are several meters lower than the Kiowa Creek and Bijou Creek valley floors. It is presumed that unit Qp was deposited in interdune depressions in the dune field. Based on this presumption, cross sections C-C' and D-D' depict the base of unit Qes as also being lower in elevation than the present valley floors. Water well logs supporting the depiction of unit Qa_3 in the three Quaternary cross sections indicate that alluvial sediments (including gravel layers) underlie the dune field. Therefore, it is probable that the dune field was initially deposited on a topographically lower, Late Pleistocene unit Qa_3 valley-fill surface. Thus, during the initial deposition of eolian sand, the interdune depressions were higher than the contemporary valley floors. As the creek valleys aggraded to their maximum elevations during the Middle Holocene, their valley fills became high enough to allow their groundwater to infiltrate the lower deposits of unit Qes. During times of high water table, such as during flood events, heavy precipitation events, and (or) seasonal fluctuations, groundwater from the valley fill may have infiltrated into the low interdune areas and formed temporary ponds in which pond and sheetwash sediments (unit Qp) were deposited during the Middle Holocene. Note that unit Qp at sample location WS137BC14 (geologic map, Plate 1) has a radiocarbon age of ~6.1 ky, which is younger than the OSL age of ~12.8 ky for unit Qes at sample location WS111OSL (Table 2). Deflation of fines from Kiowa Creek valley alluvium and perhaps more distant sources, entrapment of fine eolian particles during times of open water, sheetwash from the surrounding sand dunes, and minor winnowing of fines from the dunes may have been sources for the sand and fines in the interdune unit Qp sediments.

Table 1a. Detailed Characteristics of Units Qa_1, Qa_2, Qes, and Qp in the Wiggins quadrangle

Map Unit	Grain Size Distribution	Bedding	Sorting	Roundness	Color (per Munsell Color, 1991)	Sand Composition	Gravel Composition	Secondary Carbonate
Qa_1	Sand is fine (fU) to coarse (cL), with rare cU; medium (mU) to coarse (cU), with minor medium (mL) sand and rare very coarse sand; rare gravel content is granules to pebbles up to 10 mm	Coarse interbeds 6–10 cm thick	Highly variable, ranging from well to very poorly sorted	Sand is angular to subangular with some subrounded; gravel is angular to subangular	Light gray (10YR), pinkish white (5YR) (both dry)	Quartz 85–90%, feldspar and others 5–14%, opaques from <1 to 5%, trace mica	Granitic	Absent
Qa_2	Most locations are sand with fines scarce or absent. Sand is: very fine (vfL) to fine (fU) with rare medium (mL) sand; fine (fL or fU) to medium (mL) sand or coarse (cL) sand with minor vfs; and rare cU to vcs. Rare gravel content of granules up to 3 mm. Some locations are sandy clayey silt or sandy silty clay, with 30–50% sand content consisting of very fine (vfL) sand to coarse (cU) sand, with rare very coarse (vcL) sand, or very fine sand and trace mica (very fine). A few locations are clay with rare grains of medium sand	Sand locations (Bijou Creek) have bedding at 1–3 cm with cross bedding, channel scouring, lenticular bedding, coarsening–upward sequences, and laminated clay interbeds. In one location (Kiowa Creek), interbeds of clay and sand range from ~6–30 cm thick. Within these larger beds, dark–gray clay interbeds are 6–7 cm thick, sometimes with lighter silty interbeds 2–3 cm thick. Clay layers locally are massive, or have laminations and/or fragments of very fine sand, 1–5 mm thick	Sand deposits and sand fraction of clay deposits both are well to poorly sorted	Sand deposits are angular to subangular, or subangular to subrounded. Sand fraction in clay is subangular to subrounded with some rounded, or rarely angular to subangular	Sand: light brownish gray, light gray (10YR); light olive brown, light yellowish brown (2.5 Y) (all dry). Sandy clayey silt/sandy silty clay: dark gray, dark grayish brown, light brownish gray, white (10YR) (all dry)	Sand deposits are quartz 85–95%, feldspar and others 4–10%, opaques from <1 to 5%, with occasional trace mica up to 3 mm. Sand fraction in clay contains trace mica	Not noted	In most locations, no secondary carbonate apparent. In one location (Kiowa Creek), sandy clayey silt/sandy silty clay with very fine sand has a few very small carbonate nodules having violent effervescence. Some