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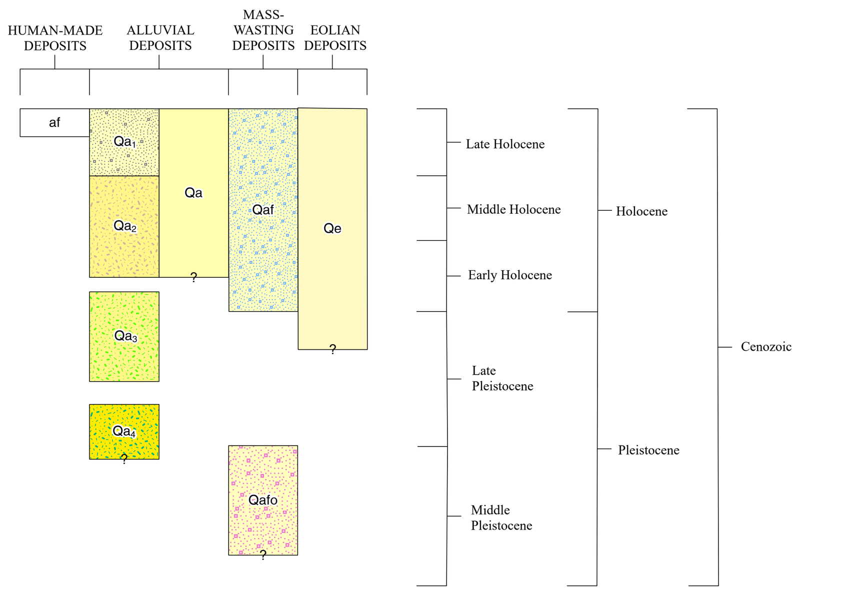
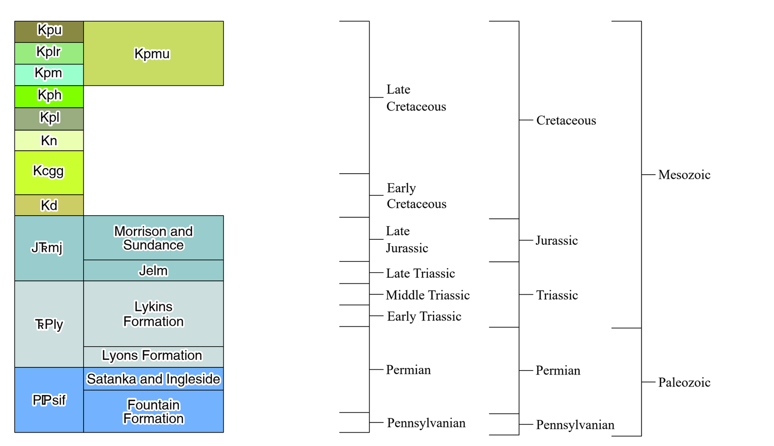
CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS



BEDROCK GEOLOGY



3D OBLIQUE

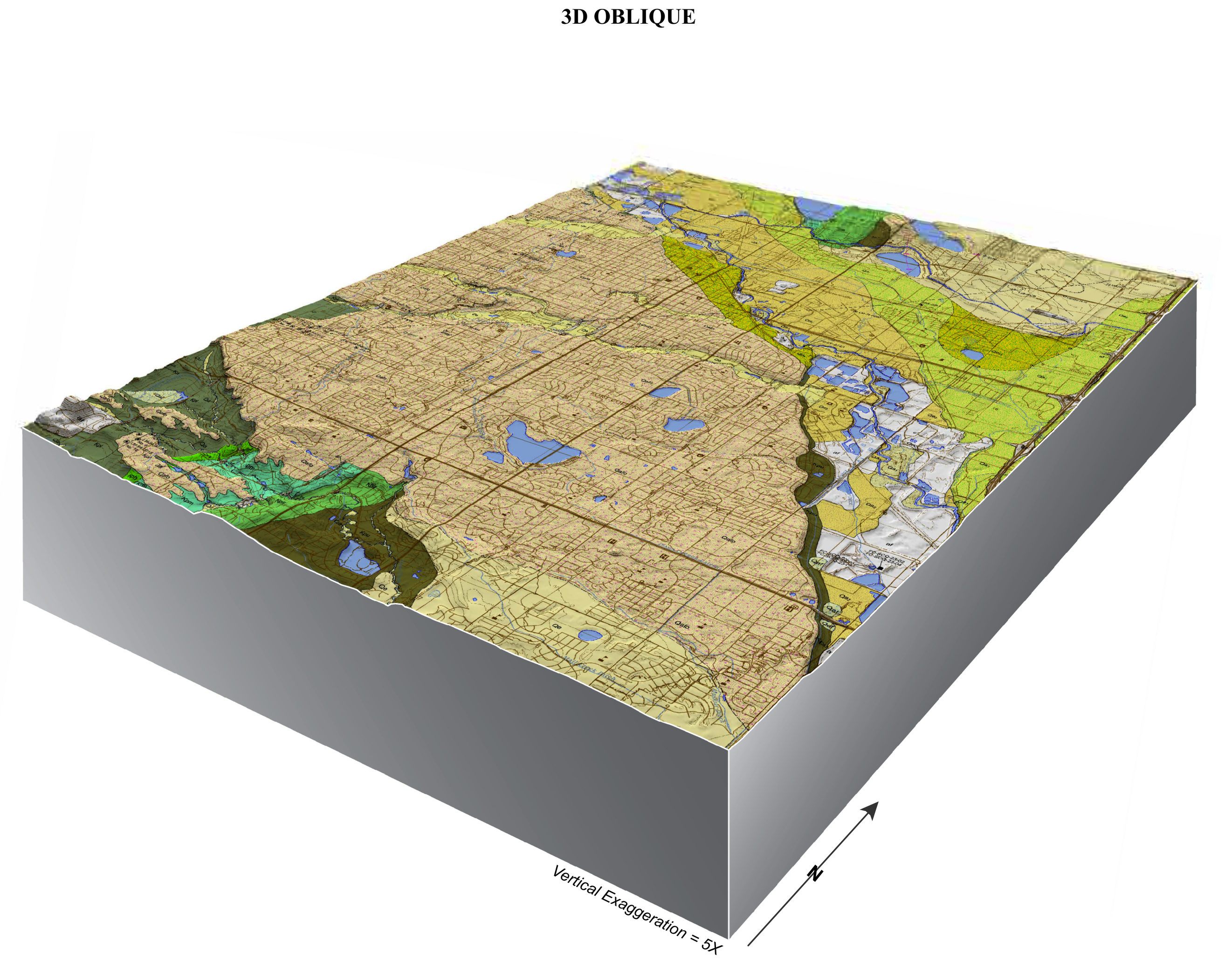


Table 1. OSL analyses of Quaternary deposits in the Fort Collins quadrangle. Analyses by Steve Forman, Baylor University.

Sample ID	Lab ID	Latitude	Longitude	Depth (m)	Sample Description	Aliquots [a]	Equivalent Dose (De) (Gy)[b]	Over dispersion (%)[c]	U (ppm)[d]	Th (ppm)[d]	K_2O (%)[d]	H_2O (%)	Cosmic dose rate (mGray/yr)[e]	Dose Rate (mGray/yr)	SAR-OSL age (yr)[f]
FC-KF-23-01	5882	40.577	-105.0472	2.0	Reddish-brown, carbonate-rich, silt to coarse sand	16/16	256.04 ± 16.67	24 ± 5	3.97 ± 0.01	11.65 ± 0.01	2.35 ± 0.01	15 ± 2	0.223 ± 0.022	3.33 ± 0.07	76,820 ± 5,210
FC-SCQ-23-01	5889	40.5344	-105.0042	0.8	Brown/gray planar and cross-bedded sand with minor manganese accumulation	32/32	41.66 ± 1.58	21 ± 3	7.96 ± 0.01	5.50 ± 0.01	2.79 ± 0.01	10 ± 2	0.254 ± 0.025	4.30 ± 0.09	9,665 ± 415
FC-SCQ-23-02	5890	40.5344	-105.0042	0.6	Tan/brown, non-calcareous, silt to medium sand	38/38	29.61 ± 0.79	16 ± 2	5.65 ± 0.01	21.50 ± .0.01	2.65 ± 0.01	10 ± 2	0.274 ± 0.027	4.84 ± 0.10	6,100 ± 210
FC-SCQ-23-03	5891	40.5345	-105.0043	1.9	Pebble-gravel lens with minor manganese accumulation	34/35	18.37 ± 0.87	27 ± 4	1.52 ± 0.01	5.0 ± 0.01	4.17 ± 0.01	10 ± 2	0.222 ± 0.022	3.60 ± 0.15	5,085 ± 325
FC-SCQ-23-04	5892	40.5345	-105.0043	4.3	Coarse sand lens with minor manganese accumulation	34/44	53.24 ± 2.43	26 ± 3	1.72 ± 0.01	8.37 ± 0.01	4.10 ± 0.01	20 ± 3	0.174 ± 0.017	3.32 ± 0.13	16,025 ± 975

[a] Aliquots measured, used to define De population by Central or Minimum age models (Galbraith and Roberts, 2012)
[b] Equivalent dose calculated on a pure quartz fraction with ultra-small aliquots with 20-80 grains/aliquot and analyzed under blue-light excitation (470 ± 20 nm) by Single Aliquot Regeneration protocols (SAR; Murray and Wintle, 2003; Wintle and Murray, 2006). Equivalent dose (De) was calculated by the Central Age or Minimum Age model when overdispersion values are < 20% (at two sigma) and >20% (at two sigma) and assuming a normal data distribution (Galbraith and Roberts, 2012; Liang and Forman, 2019).
[c] Overdispersion values reflects precision beyond instrumental errors; values of ≤ 20% (at 1 sigma limit) indicate low dispersion in equivalent dose values and defines a unimodal distribution. Values > 20% are associated with mixed equivalent dose signature reflecting multiple grain populations or partial solar resetting.
[d] U, Th, Rb and K content analyzed by inductively coupled plasma-mass spectrometry by ALS Laboratories, Reno, NV.
[e] Includes a cosmic dose rate calculated from parameters in Prescott and Hutton (1994) and includes soft components (Liang and Forman, 2019).
[f] Systematic and random errors calculated in a quadrature at one standard deviation by the Luminescence Dating and Age Calculator (LDAC) at: https://www.baylor.edu/geosciences/index.php?id=962356 (Liang and Forman, 2019) Datum year is AD 2010.

SUMMARY OF GEOLOGIC HISTORY

The Fort Collins quadrangle spans three physiographic settings: the northern Colorado Piedmont section of the Great Plains, the northern margin of the Colorado Front Range, and the western edge of the Denver Basin. The city of Fort Collins is mostly within the quadrangle boundaries, as is part of the city of Loveland. The Denver Basin is an asymmetric basin formed during the Laramide Orogeny and is bounded on the west by the Rocky Mountains. The Laramide Orogeny started near the end of the Cretaceous period, contemporaneous with the final transgressions and regressions of the Western Interior Seaway. The final transgressive and regressive sequences are recorded by the sediments comprising the members of the Pierre Shale (unit Kp), Fox Hills Sandstone, and Laramie Formation; the latter two are not mapped in the quadrangle but are present in the Severance quadrangle to the east of the mapped area (Marr and others, 2025). Bedrock in the Fort Collins quadrangle includes the lower (unit Kpl), Hygiene Sandstone (unit Kph), middle (unit Kpm), Larimer, Richard, and Rocky Ridge (unit Kplr), and upper (unit Kpu) members of the Pierre Shale, as well as the upper part of the Niobrara Formation (unit Kn), which is present only along the western border.

Bedrock units west of the quadrangle are moderately dipping and resistant units form hogbacks like those elsewhere along the Colorado Front Range. Unit Kn forms low-lying hogbacks close to the western border of the quadrangle and dips at about 25 degrees to the east. Dips decrease quickly to the east. In the southern part of the mapped area, units Kph, Kplr, and Kpu dip approximately 12 to 16 degrees east and strike north-northeast. In the middle and northern parts of the mapped area, units Kplr and Kpu dip approximately 9 to 10 degrees and strike more consistently north.

Minor faulting could account for the slightly steeper dips and the slightly more northeast-trending strike of the units in the southern part of the mapped area. A minor, apparently strike-slip or oblique-slip fault mapped by Braddock and others (1989) may project from the southern part of the Horsetooth Reservoir quadrangle into the Fort Collins quadrangle and could account for the difference in dips between the northern and southern parts of the mapped area. Owing to the weak nature of the lower member of the Pierre Shale, the fault likely attenuates quickly, and, with no opportunities to collect structural data in the area of the fault in the Fort Collins quadrangle because of the poor exposure, the fault is not mapped. In the northern part of the mapped area, Weimer (1996) mapped an anticline and dome, the southern end of which projects into the Fort Collins quadrangle. There are well logs north of the quadrangle that show bedrock dipping shallowly to the east and a marked increase in dip around the area of Weimer's anticline and dome. Workman and others (2018) mapped this structure as a Laramide-aged syncline and anticline pair and that is reflected in cross-section C-C'. The few oil and gas wells in the mapped area are only located near the very southern extent of the structures. There is little control on the precise location and geometry of any structures underlying the quadrangle.

Much of the quadrangle's bedrock is mantled by surficial sediments deposited repeatedly during the Pleistocene and Holocene. The oldest Quaternary sediments in the mapped area, unit Qafo, were deposited by alluvial-fan processes over broad areas in the western and central portions of the quadrangle. Unit Qafo in the mapped area is correlative with Qafo in the southern adjacent Loveland quadrangle based on morphology and depositional processes. These deposits are mapped as Slocum Alluvium by Colton (1978), Kellogg and others (2008), Cole and Braddock (2009), and Workman and others (2018). Defining a specific age for Middle Pleistocene and older deposits is difficult near the foothills as streams likely undergo repeated cycles of deposition, erosion, and avulsion before an alluvial surface is abandoned (Rihimaki and others, 2006). A sample collected from unit Qafo in the Loveland quadrangle and analyzed by infrared stimulated luminescence techniques yielded age estimates of 166.2 ± 21.8 ka (Lindsey, 2024). The age estimate from this sample indicates parts of unit Qafo could be correlative with the Louviers Alluvium (Bull Lake glaciation) of Colton (1978), Kellogg and others (2008), Cole and Braddock (2009), and Workman and others (2018).

Kellogg and others (2008) place the Bull Lake glaciation (marine oxygen isotope stage (MIS) 6) and the associated Louviers Alluvium around 170-120 ka. Madole (1991) considers the Bull Lake glaciation to be 200 to 130 ka. The Louviers Alluvium also includes MIS 5-aged sediment, 70-130 ka (Lisiecki and Raymo, 2005; Workman and others, 2018). Kellogg and others (2008) give tentative, relative ages of 390-320 ka and 300-220 ka to the Slocum Alluvium in the Denver area. More geochronology and mapping are necessary to fully constrain the ages of these deposits.

Unit Qafo underlies fan surfaces at several levels in the landscape, indicating ancestral drainages likely experienced several distinct periods of deposition and erosion, with younger deposits underlying lower surfaces in the landscape. Since the depositional surfaces were abandoned, periodic downcutting has formed minor, ephemeral channels that dissect fan surfaces and flow into the Cache la Poudre River (hereafter referred to as the Poudre River). These ephemeral streams have and continue to deposit alluvial sediments, mapped as Qa, in and near the bases of their channels.

There are four alluvial units younger than unit Qafo in the mapped area. On cross-section B-B', possibly three distinct terraces underlain by unit Qa_4 are mapped on the northeast side of the Poudre River. Unit Qa_3 forms an inset strath terrace relative to unit Qa_4. In the Fort Collins quadrangle, and similar to other areas near the foothills of the northern Colorado Piedmont, unit Qa_2 subsequently incised Qa_3 to create a nested fill terrace, leaving remnants of Qa_3 preserved as an unpaired, higher terrace adjacent to the modern Poudre River. Unit Qa_1 is currently incising into unit Qa_2, leaving low-lying terraces that are underlain by unit Qa_2, adjacent to the river.

These relationships are identified in cross-section B-B'. The single Qa_4 deposit mapped on the southwestern side of the Poudre River is likely paired with the youngest (lowest) Qa_4 deposit on the northeastern side, owing to similar basal elevations. Interpretations and correlations of these deposits have a high degree of uncertainty because they are buried by eolian deposits (unit Qe) and owing to the proximity to the Box Elder Creek and the Poudre River confluence. The top of the middle terrace, underlain by Qa_4 terrace on the north side of the Poudre River (on the east side of cross-section B-B'), is approximately 20 m above the modern Poudre River. Kellogg and others (2008) report that the top of the correlative Louviers Alluvium is around 20 m. Additionally, Kellogg and others (2008) speculate that the Louviers Alluvium (unit Qa_4) underlies unit Qe in the quadrangle. The alluvium underlying the highest terrace furthest east on cross-section B-B' is interpreted as unit Qa_4 owing to how closely inset the lower (younger) terraces are. Typically, the next oldest alluvial unit in the sequence, unit Qa_5, exists on a strath with bedrock well-exposed from subsequent erosion. Interpretations from DWR well logs indicate that, while the unit does exist on a strath, subsequent erosion and aggradation did not fully expose the bedrock at this location before the next youngest terrace was abandoned.

A cutbank in NW ¼, sec. 18, T. 7 N., R. 68 W., exposes approximately 3 m of unit Qa_4 and the underlying Pierre Shale. At this exposure, an optically stimulated luminescence (OSL) sample, FC-KF-23-01, was collected approximately 2 m below ground surface (bgs). It yielded a SAR-OSL age estimate of 76,820 ± 5,210 yrs. This age is correlative with later MIS 5, possibly MIS 4 (Lisiecki and Raymo, 2005). Deposits of this age do not commonly form the upper parts of terraces along the Front Range and in the northern Piedmont. Colorado Geological Survey work has confirmed that Qa_4-aged (MIS 2) sediments typically bury MIS 4, MIS 5, and locally MIS 6 (Bull Lake) deposits. Sampling and OSL dating in the Kersey quadrangle (Lindsey and Palkovic, 2022) and Gowanda quadrangle (Keller and others, 2019) indicate a series of deposits spanning the time between the end of the Bull Lake glaciation (approximately 130 ka; Madole, 1991) and the beginning of the Pinedale glaciation (approximately 30 ka (Nelson and others, 1979) or possibly earlier (Madole and others, 2010)). Some of the intermediate dates, ranging from 42 to 87 ka, indicate that some deposits may be correlative with MIS 3, 4, and 5 (Lisiecki and Raymo, 2005). Kellogg and others (2008) mapped MIS 5-aged and MIS 6-aged deposits as the Louviers Alluvium, which is correlative with unit Qa_4.

Unit Qa_3 is exposed in places adjacent to the Poudre River and its major tributaries, as well as in quarries underlying unit Qa_2. Exposed terraces range from 3 to 8 m above the modern Poudre River channel. In the Fort Collins quadrangle, four samples were collected from an exposure in Strang Quarry in the NW ¼, sec. 33, T. 7 N., R. 68 W., and analyzed by OSL techniques. The older two samples, FC-SCQ-23-01 and FC-SCQ-23-04, yielded age estimates of SAR-OSL 9,665 ± 415 yrs and SAR-OSL 16,025 ± 975 yrs, respectively. Sample FC-SCQ-23-04 is correlative with the Pinedale Glaciation, which ended by 12 ka (Madole and Shroba, 1979). An additional, more recent study suggests that complete deglaciation occurred by 14 ka in the Arkansas River valley (Schweinsberg and others, 2020). Sample FC-SCQ-23-01 may be correlative with a period of glacial outwash deposition that occurred as glaciers retreated. Prior studies indicate that Pinedale outwash deposition likely ended around 10 ka (Holliday, 1987; Kellogg and others, 2008).

The younger two samples collected from the Strang Quarry, FC-SCQ-23-02 and FC-SCQ-23-03, yielded age estimates of SAR-OSL 6,100 ± 210 yrs and SAR-OSL 5,085 ± 325 yrs, respectively, and both post-date the Pinedale glaciation. These samples and their respective deposits are interpreted as correlative with unit Qa_2. However, sample FC-SCQ-23-01 (unit Qa_3) is higher in stratigraphic order (0.8 m bgs) than FC-SCQ-23-03 (unit Qa_2, 1.9 m bgs). There are two possible explanations for this: 1. Unit Qa_2 and unit Qa_3 comprise nested terrace deposits and the quarry exposure shows a complex relationship of channel cut and fills throughout the depositional history of these units. While FC-SCQ-23-01 may be higher stratigraphically, these samples were not taken in direct vertical succession and are slightly offset laterally. It is possible that a lower portion of a younger channel cut and fill comprised of unit Qa_2 was sampled at site FC-SCQ-23-03, yielding an age estimate of 5,085 ± 325 yrs that appears lower in the stratigraphic sequence than the age estimate from FC-SCQ-23-01, which is 9,665 ± 415 yrs; or, 2. The age estimate is incorrect. Sample FC-SCQ-03 has the highest overdispersion of the OSL samples collected at the Strang Quarry site: 27 ± 4%. Higher overdispersion values (>20%) may indicate multiple age populations owing to partial bleaching of the quartz grains or from sediment mixing (Steve Forman, written commun., 2025). Sample FC-SCQ-23-01 has an overdispersion of 21 ± 3. Option 2 seems most likely because sample FC-SCQ-03 was collected very close to an erosional contact between lower gravelly alluvium generally considered to be unit Qa_3 and upper, finer-grained alluvium considered to be Qa_2.

Unit Qa_1 underlies the modern Poudre River and some very low-lying (1 to 2 m-high) terraces adjacent to the channel in the river's floodplain. Much of the lower river valley has been modified and quarried for gravel. Eolian sediment (unit Qe) has been deposited and reworked periodically by later eolian processes and (or) fluvial transport, through the Holocene and possibly during the Late Pleistocene. Subtle dune crests in the northeastern part of the mapped area indicate a northwest to southeast wind direction. These deposits, given the presence of dune features, likely have a higher concentration of sand than other eolian deposits in the quadrangle.

SUMMARY OF RESOURCES

The quadrangle lies outside of any major oil and gas and groundwater producing areas. The Wattenberg Field, a world-class oil and gas-producing area, lies east and southeast of the mapped area (Weimer, 1996). The major bedrock aquifer-bearing units are also located outside the mapped area, to the east; however, local, perched groundwater may be present in Quaternary units that overlie clayey and shaley members of the Pierre Shale. The clays in the bedrock unit function as natural barriers to downward groundwater movement.

The Poudre River channel is heavily modified by human activity and quarrying of the stream's gravelly alluvium is extensive. Quarrying operations typically target the gravelly alluvium of unit Qa_2. Reclaimed quarries span the length of the channel in the mapped area and now serve as fishing ponds and wildlife habitat. The quarried aggregate is used in road base and construction operations in the region.

Units Qafo and Qa_2 may be local sources of gravel or sand aggregate; however, unit Qa_2 is often treated as overburden in quarrying operations and removed to access the underlying gravel. Additionally, the gravel of unit Qafo may not be extensive enough or clean enough to be economically viable. Schwochow and others (1974) list parts of unit Qafo as an A2 deposit and Qa_2 as an F1 deposit. A2 deposits are alluvial-fan deposits that are "gently sloping, fan-shaped deposits of gravel, sand, silt, and clay produced by a stream that issued or issues from a narrow valley or point source onto an open plain or valley. Includes erosional remnants of fan deposits." and there may be gravel with significant silt, clay, and rock with calcium carbonate. F1 deposits are floodplain deposits that may have clean gravel aggregate sources. Units Qa, Qaf, Qe, and Qa_1 are not likely sources of sand or gravel aggregate because they are not typically well-sorted and are too limited in extent to serve as commercially viable resources.

SUMMARY OF GEOLOGIC HAZARDS

Expansive and collapsible soils:

The shaley, clayey, and muddy Cretaceous bedrock in the mapped area can contain naturally occurring, high-swell clays. These clays pose a hazard when they are not properly mitigated. Mitigation typically includes over-excavation of the deposit. If these soils are not properly treated, when structures with conventional foundations are built and soils are wetted, the clays will absorb the water and expand. The soil expansion exerts compressional forces that may cause damage to the structure. Additionally, when the clays dry after being wetted, they contract and decrease in volume (referred to as shrink-swell), and structures are not designed to accommodate these volume changes over time.

Some Quaternary deposits, such as units Qa and Qe, are fine-grained and loosely consolidated, owing to an excess of interstitial space in the deposit. These deposits are referred to as collapsible soils. If loosely consolidated sediments are wetted and compressed, the interstitial space is reduced irregularly through the deposit. Infrastructure built on collapsible soils may be subject to irregular settlement if these soils are not properly treated and compacted prior to construction.

Mass-wasting, flooding, and erosion:

Though none are mapped in the quadrangle, due to the relatively low strength of the clayey members of the Pierre Shale, landslides can occur even on lower gradient slopes, especially where Quaternary deposits overlie bedrock. Several factors can contribute to landslide initiation in these geological conditions: 1. The clayey bedrock tends to be more easily erodible than the overlying Quaternary units, leading to undercut, over-steepened slopes; and, 2. Groundwater accumulating at the contact between Quaternary deposits and underlying clayey, less permeable bedrock can cause a reduction of internal friction of the units, leading to slope destabilization. These slopes can become easily destabilized by human activity that either cuts or erodes the toes of slopes without properly reinforcing or stabilizing the excavation.

Unit Qaf consists of alluvial-fan and debris-flow deposits and sediments deposited by floods. Alluvial-fan, debris-flow, and flood processes can carry large sediment loads and clasts large enough to impart considerable damage to infrastructure. In the quadrangle, areas underlain by unit Qaf are prone to flooding, sediment inundation, and erosion.

Much of the area underlain by units Qa_1 and Qa_2 is within the FEMA 1% annual chance of flooding (Zone AE), and some have a 0.2% annual chance floodway (URL link in references). Other areas that may be prone to seasonal flooding include those underlain by unit Qa. Flooding can pose hazards via extensive erosion or sediment inundation. Other areas that may be prone to erosion include areas underlain by easily eroded bedrock, like the shaley and clayey members of the Pierre Shale.

MAP PRODUCTION

Contacts are difficult to identify in the field given how extensive human development is in the Fort Collins area. Many contacts were mapped using 1-m resolution lidar-derived maps and 2- to 5-ft contours. The authors used well-log and boring-log data to estimate some unit contacts and develop cross-sections. Well and boring location accuracy is unknown but assumed to be relatively good. Wells and borings are projected to the cross-section lines. With limited surface exposure of Quaternary and bedrock units, the cross-sections are largely illustrative and may not be accurate, locally.

ACKNOWLEDGMENTS

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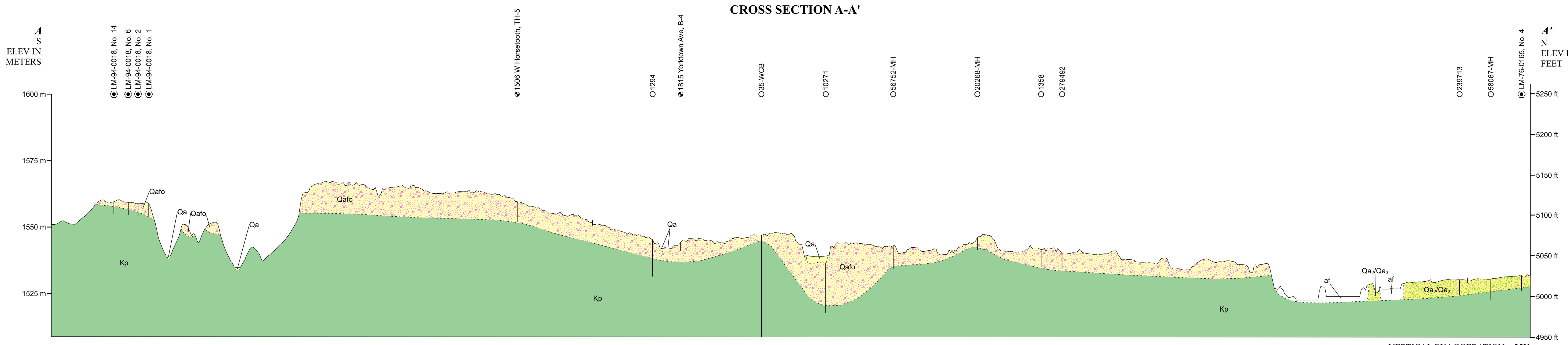
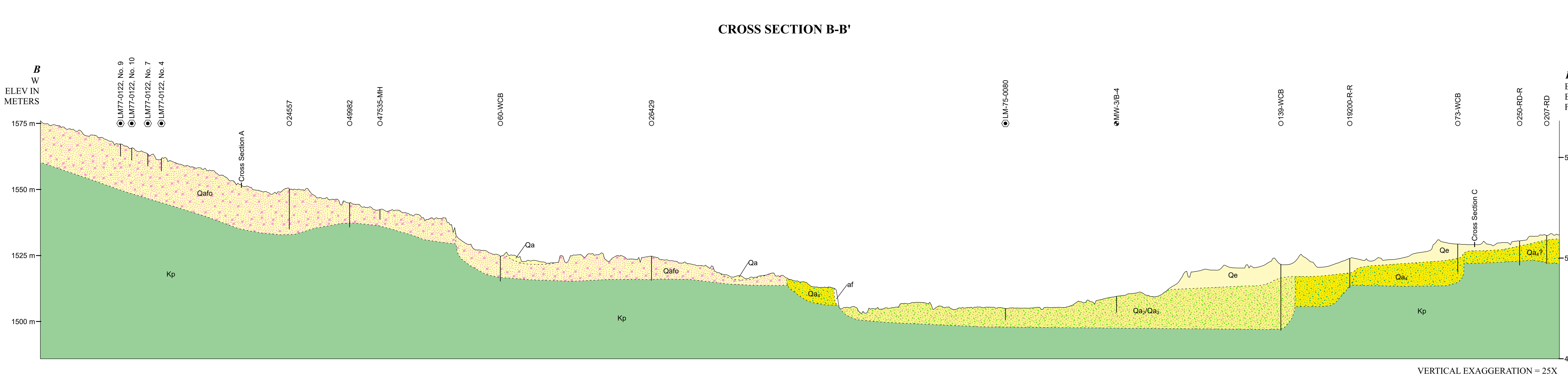
CROSS SECTION A-A'



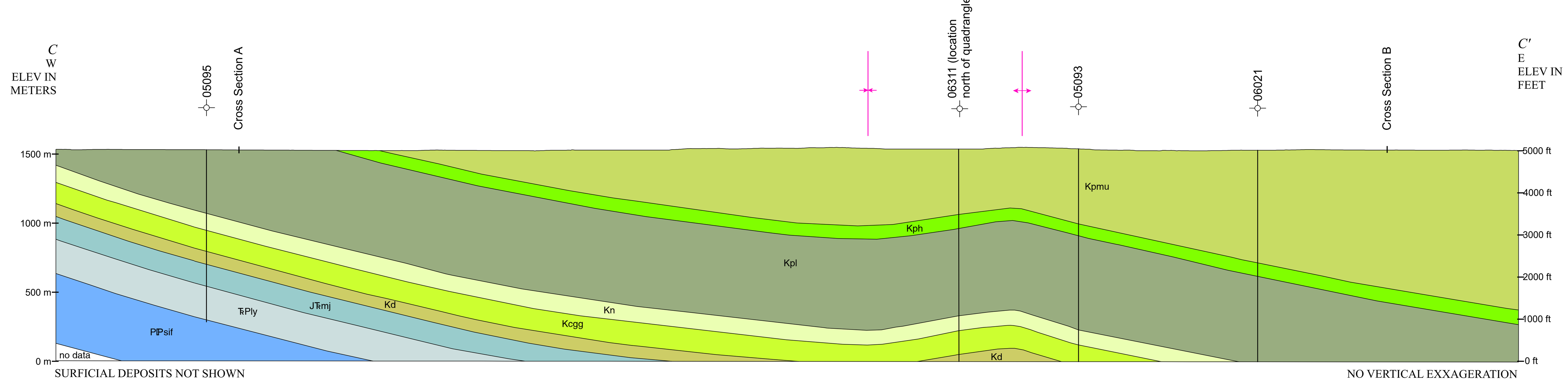
VERTICAL EXAGGERATION = 25X

CROSS SECTION B-B'



VERTICAL EXAGGERATION = 25X

CROSS SECTION C-C'



SURFICIAL DEPOSITS NOT SHOWN

NO VERTICAL EXXAGERATION

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GEOLOGIC MAP OF THE FORT COLLINS QUADRANGLE, LARIMER COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D OBLIQUE, GEOLOGIC HISTORY, RESOURCES, AND CROSS SECTIONS

By Kassandra O. Lindsey, Alexander E. Marr, and Emily A. Perman
2025

COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES