COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

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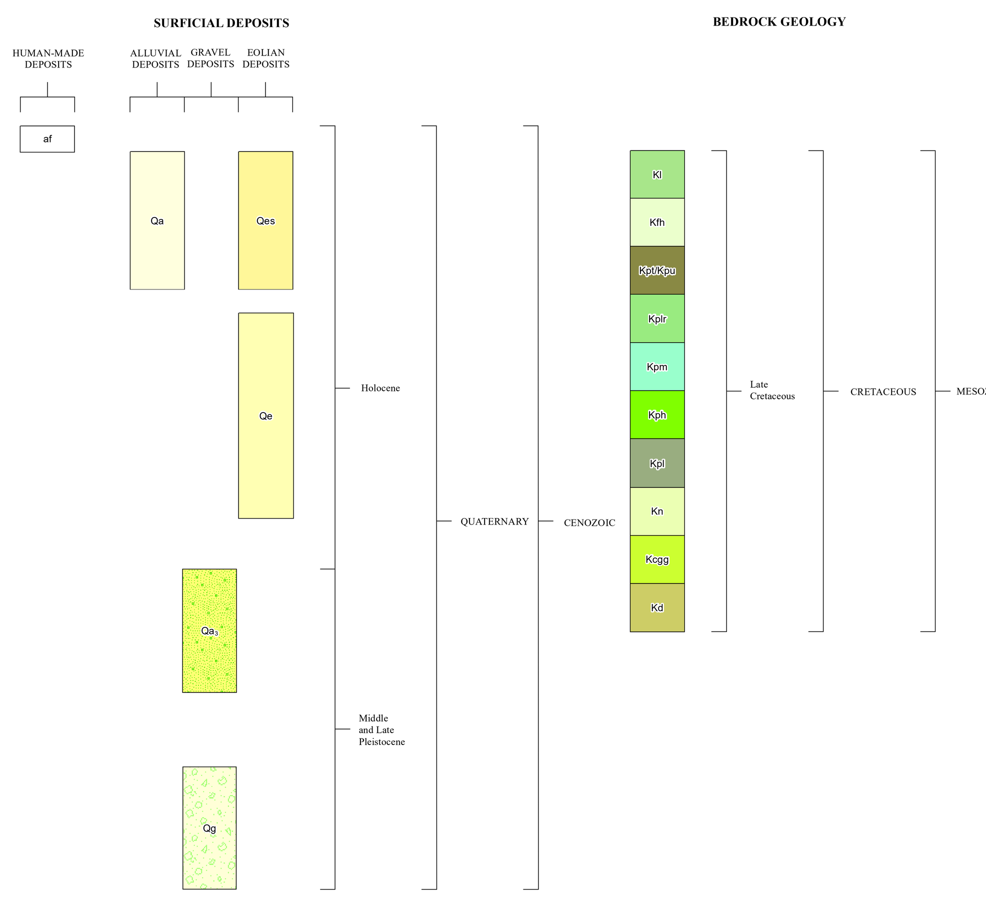
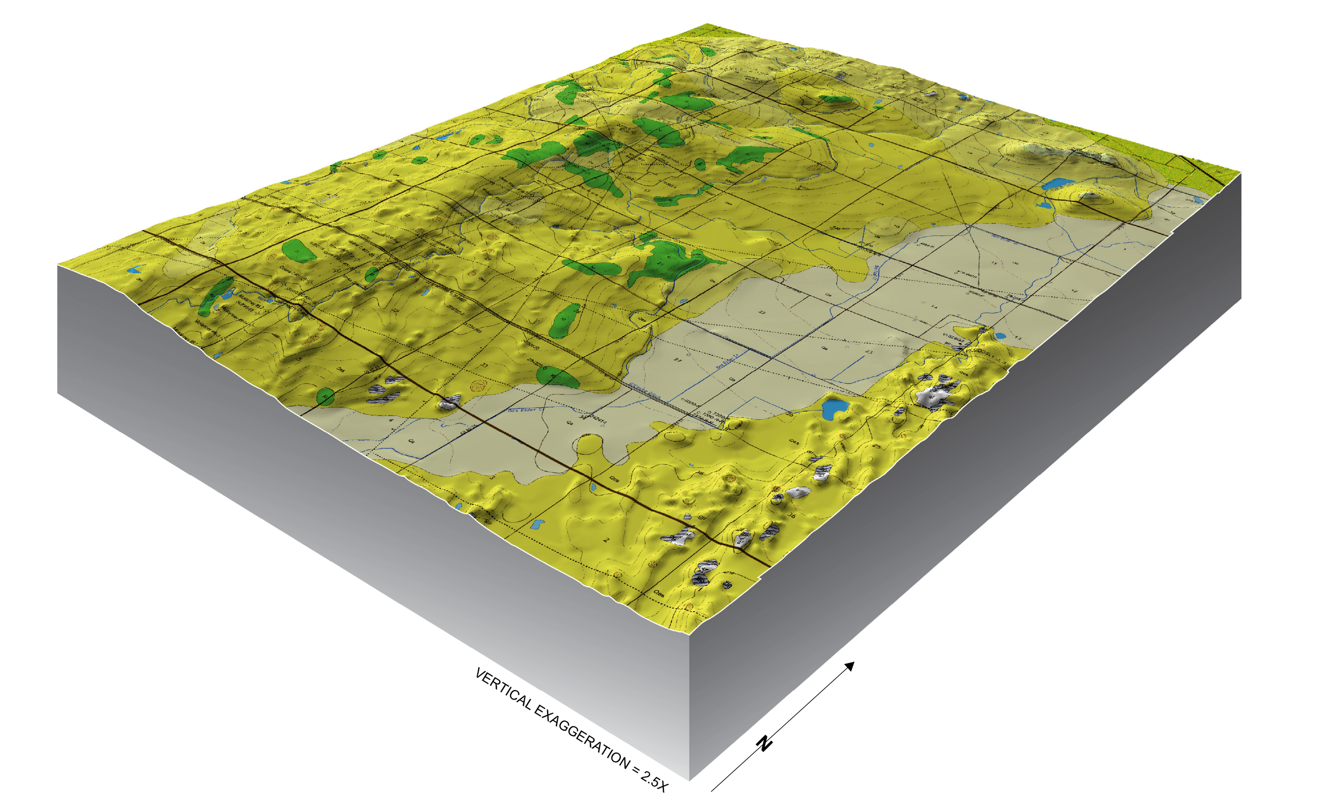
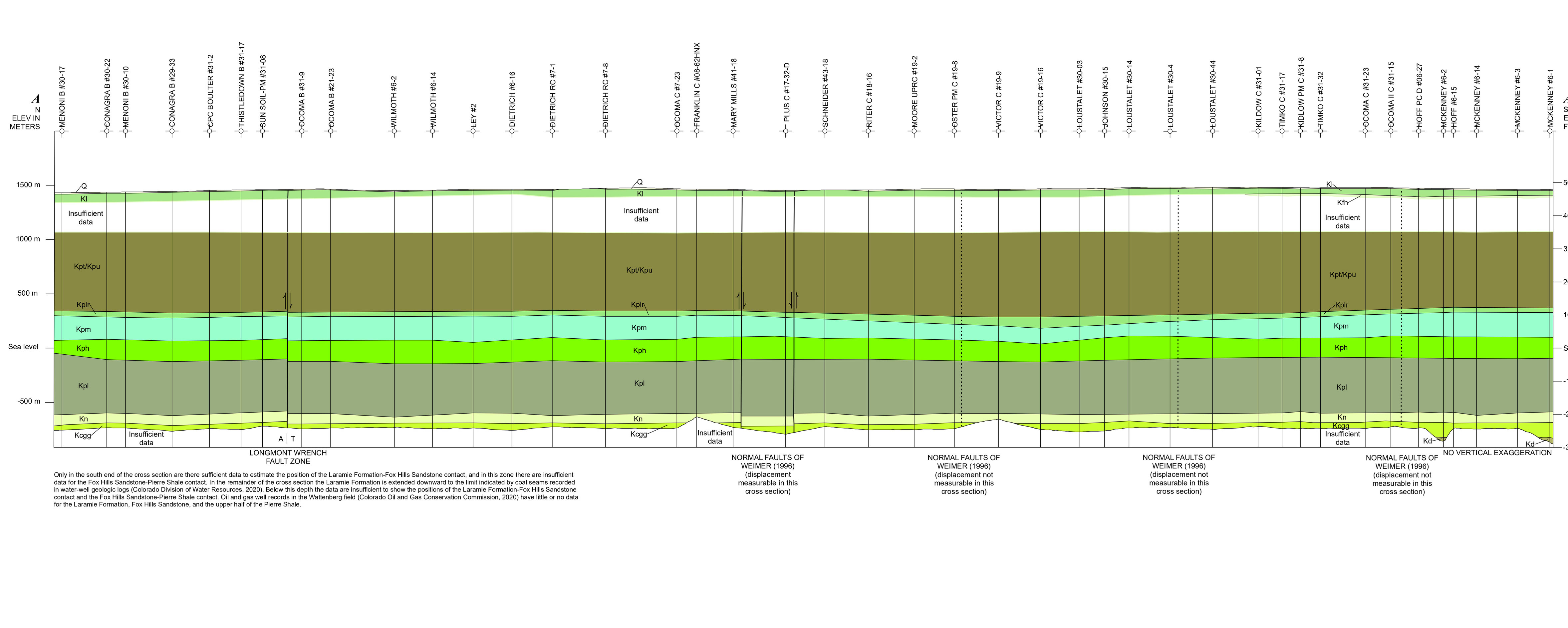
CORRELATION OF MAP UNITS



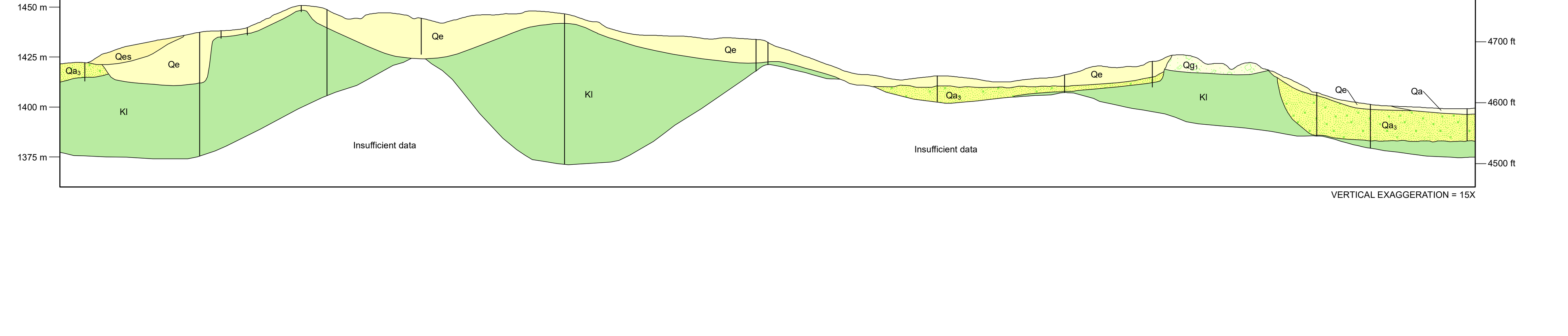
3-D OBLIQUE



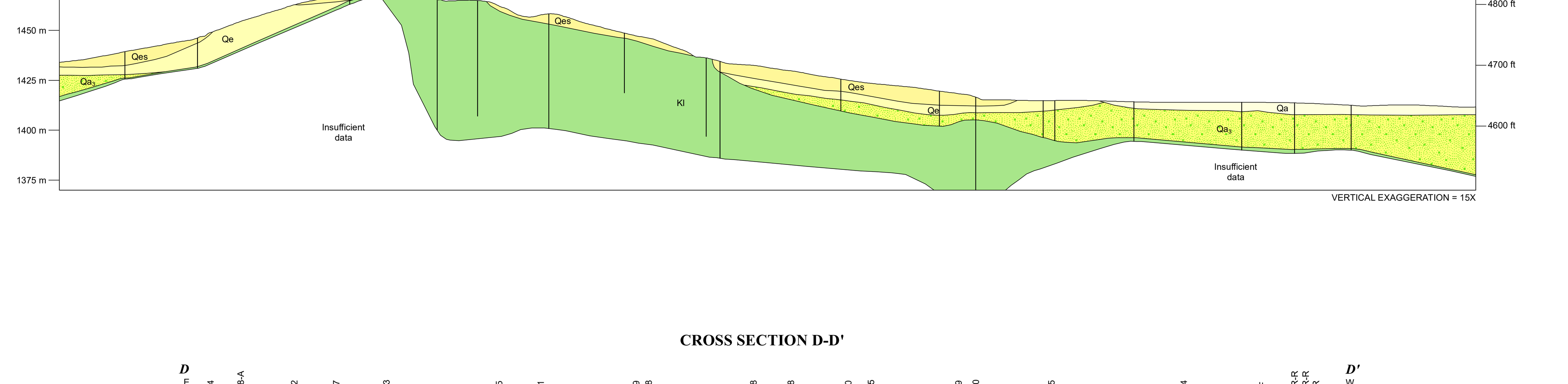


Only in the south end of the cross section are there sufficient data to estimate the position of the Laramie Formation-Fox Hills Sandstone contact, and in this zone there are insufficient data for the Fox Hills Sandstone-Pierre Shale contact. In the remainder of the cross section the Laramie Formation is extended downward to the limit indicated by coal seams recorded in water-well geologic logs (Colorado Division of Water Resources, 2020). Below this depth the data are insufficient to show the positions of the Laramie Formation-Fox Hills Sandstone contact and the Fox Hills Sandstone-Pierre Shale contact. Oil and gas well records in the Wattenberg field (Colorado Oil and Gas Conservation Commission, 2020) have little or no data for the Laramie Formation, Fox Hills Sandstone, and the upper half of the Pierre Shale.

CROSS SECTION B-B'



CROSS SECTION C-C'



CROSS SECTION D-D'

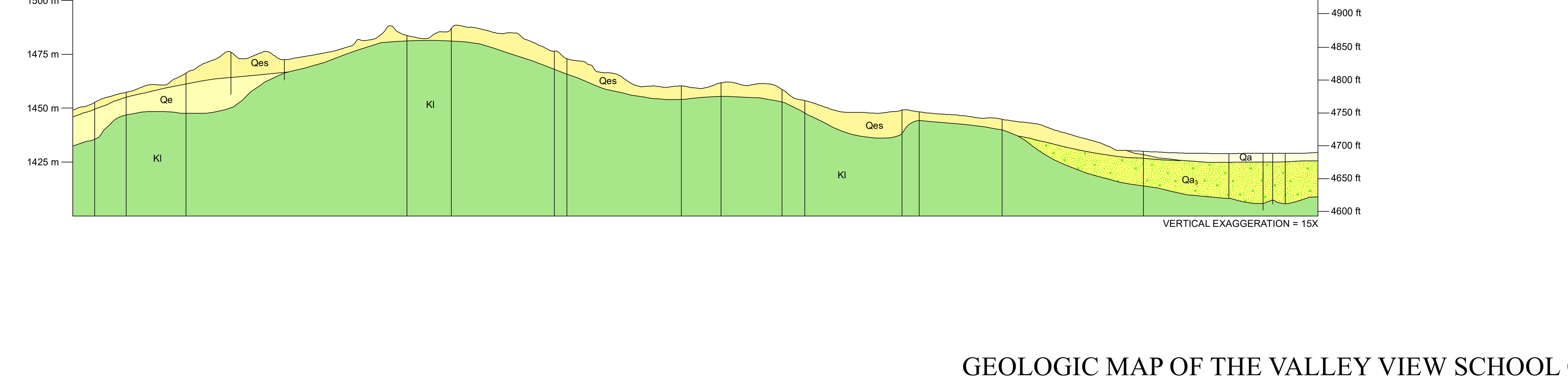


Table 1. Detailed Characteristics of Quaternary Units in the Valley View School Quadrangle

Map Unit	Grain Size Distribution	Bedding	Sorting	Roundness	Color (per Munsell Color, 1991)	Sand Composition	Gravel Composition	Cohesion	Secondary Carbonate	Soils (from Crabb, 1980)
Qa	Silty clay or clayey silt with 5-35% fine to medium sand and some larger sand (40% of samples); very fine (vfL) to medium sand (mU) with minor fines and minor coarse to very coarse sand (40%); fine (fL) to very coarse sand (vcU) with minor fines (20%)	0.3 to 0.7 m	Poorly to moderately sorted	Subrounded to rounded	Olive-brown, dark olive-brown, grayish-brown of Munsell hue 2.5Y; brown, dark brown, dark grayish-brown, and very dark grayish-brown of hue 10YR	Quartz 75-80%, feldspar 15-20% , opaques 5%, trace mica	[No gravel content]	Moderately to very cohesive	Effereveseence absent to weak in most samples; carbonate nodules and filaments in only a few samples	Columbo clay loam, Dacono clay loam, Nunn clay loam, Haverson loam, Otero fine sandy loam, Otero sandy loam, Nunn loamy sand, Vona sandy loam, Valent sand
Qg_1	Matrix-supported sandy gravel with matrix (75%) of very fine (vfL) to very coarse (vcU) sand, and clasts from granules to 7 cm; medium (mU) to very coarse (vcU) sand with minor very fine and fine sand, and 5% clasts from granules to 2.5 cm; gravelly sand or sandy gravel with matrix (50%) mostly of fine (fL) to medium (mU) sand, and minor very fine and coarse sand, gravel is 75% granules and small pebbles, with some clasts up to 11 cm; medium (mL) to coarse (cL) sand with 5% gravel from granules to small pebbles	0.5 to 0.6 m	Poorly sorted	Sand subangular to subrounded, granules angular to subangular, pebbles and cobbles subrounded to rounded	Pinkish-gray of hue 5YR; pale yellow of Munsell hue 5Y; white, pinkish-gray, pale brown, and brown of hue 10YR	Quartz 60%, feldspar 35% feld, opaques 5%, no mica	Granitics, quartz, quartzite (including bluish-gray quartzite of Coal Creek Canyon), gneiss, sandstone, chert, fine-grained metamorphics	Sandy layers weakly cohesive; carbonate-cemented sandy gravel, hard and resistant	Sand has no visible carbonate and weak effervescence, sandy gravel locally carbonate-cemented (stage II to III), and cobbles have prominent carbonate rinds up to 5 mm thick	Cascajo Series
Qes	Very fine (vfL) to coarse (cU) or very coarse (vcU) sand (25% of samples), fine (fL) to medium (mU) sand with minor coarse to very coarse sand (25% of samples), and fine (fL) to coarse (cU) sand with minor very coarse sand (50% of samples); fines content absent to very small; trace to very small content of mostly granitic or quartz granules to pebbles (mostly less than 1 cm) in ~50% of samples, and rare pebbles 2 to 4 cm in a few samples	Several millimeters to several centimeters	Poorly sorted in 25% of samples, poorly to moderately sorted in 30%, moderately sorted in 30%, moderately to well sorted in 15%	Subangular to subrounded in 30% of samples, subrounded in 10%, subrounded to rounded in 50%, subrounded to well rounded in 10%	Olive-brown and dark grayish-brown of Munsell hue 2.5Y; brown, dark brown, grayish brown, dark grayish-brown, very pale brown, pale brown, pale yellowish-brown , dark yellowish-brown of hue 10YR	Quartz 70-80%, feldspar 15-20% , opaques 5%, trace mica in a few samples	Granitics and quartz	Very weakly cohesive to weakly cohesive	No visible carbonate, no effervescence	Olney fine sandy loam, Otero sandy loam, Vona sandy loam, Olney loamy sand, Vona loamy sand, Valent sand
Qe	Silty sandy clay or clayey sandy silt with 25-35% sand; very fine (vfU) to coarse (cL) sand with minor very coarse sand and rare pebbles; fine (fL) to medium (mU) sand with minor coarse (cL) to very coarse (vcL) sand and some fines; fines fraction 22% and 30% in two samples	[In Valley View School quadrangle, not well enough exposed to detect possible bedding; deposit is massive in other Colorado Piedmont quadrangles mapped by CGS (e.g., Keller and Morgan, 2021)]	Poorly to moderately sorted	Subangular to subrounded, subrounded to well rounded	Brown, dark brown, dark grayish brown, and dark yellowish-brown of Munsell hue 10YR	Quartz 75-85%, feldspar 10-20% , opaques 5%, no mica	[Granules and pebbles rare]	Weakly to moderately cohesive	No visible carbonate, no effervescence	Thedalund loam, Olney fine sandy loam, Perry fine sandy loam, Vona sandy loam, Vona loamy sand

Note: Unit Qa_3 is not included in this table because the unit is not exposed in the quadrangle.

Table 2: Optically stimulated luminescence (OSL) ages (Baylor University, Waco, Texas, March 23 and October 14, 2021)

Sample Number	Laboratory Number	Map Unit	UTM Easting[1]	UTM Northing[1]	Depth Below Ground Surface (bgs) (m)	Date Collected	Material Dated	Aliquots[2]	Grain Size ([mu symbol]m)	Equivalent Dose (D_e) (Gy)[3]	Over-dispersion (%)[4]	U (ppm)[5]	Th (ppm)[5]	K_2O (%)[5]	H_2O (%)	Cosmic Dose Rate (mGray/yr)[6]	Dose Rate (mGray/yr)	Central/Minimum Model SAR age (yr)[7]
V017COSL1	5036	Qg1	540180	4468190	1.1	9-Dec-20	Qg1	12/16	250-355	>280	NA	1.76+/-0.01	7.35+/-0.01	3.81+/-0.01	15+/-5	0.187+/-0.019	3.51+/-0.17	>80,000
V017COSL2	5037	Qg1	540180	4468190	2.0	9-Dec-20	Qg1	8/18	250-355	>300	NA	1.77+/-0.01	8.83+/-0.01	3.68+/-0.01	15+/-5	0.136+/-0.014	3.30+/-0.16	>90,000
New thermal transfer OSL analysis of sample V017COSL2	5037TT	Qg1	540180	4468190	2.0	9-Dec-20	Qg1	20/20	250-355	1179.20+/-53.22	17+/-3	1.77+/-0.01	8.83+/-0.01	3.68+/-0.01	15+/-5	3.68+/-0.01	3.3	341,080+/-22840
V132DOSL1	BG5010	Qa	541721	4461774	2.1	21-Oct-20	Qa	36-40	100-150	15.36 +/- 0.70	16 +/- 2	2.92 +/- 0.01	18.30 +/- 0.01	2.96 +/- 0.01	10+/-2	0.22 +/- 0.02	4.21 +/- 0.09	3640 +/- 180
V132DOSL2	BG5011	Qa	541721	4461774	0.4	21-Oct-20	Qa	38/40	100-150	3.30 +/- 0.16	20 +/- 2	2.89 +/- 0.01	8.87 +/- 0.01	3.31 +/- 0.01	10+/-2	0.30 +/- 0.03	3.96 +/- 0.09	825 +/- 45
V132DOSL3	BG5012	Qes	541721	4461774	1.9	21-Oct-20	Top of Qes right below overlying Qa	36/40	100-150	12.06 +/- 1.08	30 +/- 4	1.95 +/- 0.01	5.85 +/- 0.01	3.72 +/- 0.01	10+/-2	0.22 +/- 0.02	3.80 +/- 0.08	3165 +/- 290

[1] UTM zone 13, 1983 North American Datum (NAD 83).

[2] Aliquots measured, used to define De population by Central or Minimum age models (Galbraith and Roberts, 2012)

[3] 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 (SAR) protocols (Murray and Wintle, 2003; Wintle and Murray, 2006). Equivalent dose (De) was calculated by the Central or Minimal age models (Galbraith and Roberts, 2012).

[4] Overdispersion values reflects precision beyond instrumental errors; values of ≤ 20% (at 1 sigma limit) indicate low dispersion in equivalent dose values and define a unimodal distribution. Values > 20% are associated with mixed equivalent dose signature reflecting multiple grain populations or partial solar resetting.

[5] U, Th, Rb and K content analyzed by inductively-coupled plasma-mass spectrometry by ALS Laboratories, Reno, NV; and includes dose contribution from Rb.

[6] Includes also a cosmic dose rate calculated from parameters in Prescott and Hutton (1994) and includes soft components (Peng and Forman, 2019).

[7] 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 (Peng and Forman, 2019). Datum year is AD 2010.

Table 3: Grain size analyses for Valley View School quadrangle

Field Sample Number and Map Location	Laboratory Number	Map Unit	UTM Easting[1]	UTM Northing[1]	Depth Below Ground Surface (m)	Date Collected	Material Analyzed	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
V030GS	25191336	Qe	539163	4466558	0.8	27-Aug-20	fine to medium sand with trace coarse sand to granules, some fines	0.4	77.7	14.4	7.5
V035GS	25191336	Qe	536544	4465719	0.4	28-Aug-20	fine to medium sand with significant fines	0.0	69.8	17.5	12.7
V132BGS	25191336	Qes	541691	4461946	0.8	4-Sep-20	fU to mU w minor cs and vcs	0.0	94.4	2.6	3.0

[1]UTM zone 13, 1983 North American Datum (NAD83).

GEOLOGIC HISTORY AND STRUCTURE

The Valley View School quadrangle lies in the northern part of the Colorado Piedmont where much of the topographic relief is relatively low (98 m difference between lowest and highest points in the quadrangle). The quadrangle has no natural exposures of bedrock and only a few natural exposures of surficial units. The area is covered mostly by Quaternary deposits, and bedrock residuum is present near the ground surface in areas in the upland on the west side of the quadrangle. Fresh bedrock is exposed only in a gravel pit in the northeast corner of the quadrangle. North-northwest- to south-southeast-oriented duneforms are prominent in the southern part of the quadrangle and are due to the prevalence of eolian sand at the ground surface. The present-day landscape of the Colorado Piedmont results from the downcutting and geomorphic evolution of the South Platte River and Arkansas River drainage basins mainly during late Neogene and Quaternary time. This began with removal of Paleogene and Neogene rocks and sediments that once covered Upper Cretaceous strata in the basins (Madole, 1991). The predominant Quaternary deposits in the piedmont, including those in the Valley View School quadrangle and surrounding area, are fluvial sediments of the South Platte River and its tributaries, and eolian sediments deflated from alluvium in these stream valleys and from upwind bedrock exposures in the piedmont (Madole, 1991; 2016). Most of the eastern two-thirds of the Valley View School quadrangle is drained by Box Elder Creek, a north-flowing minor tributary of the South Platte River. The quadrangle's west side is drained by Beebe Draw, another north-flowing minor tributary of the South Platte River, and a small area in the north is drained directly by the river. The Box Elder Creek valley has a maximum width of ~3 km within the quadrangle and joins the South Platte River valley at the boundary between the Valley View School and Hardin quadrangles.

The Valley View School quadrangle is in the central part of the Greeley Arch, a structural saddle separating the Denver Basin to the south from the Cheyenne Basin to the north (Dechesne and others, 2011). Cross section A-A' indicates that bedrock strata in the quadrangle are essentially flat-lying. The Laramie Formation is the uppermost and youngest bedrock unit in the quadrangle. It is a coal-bearing formation composed of sediments deposited in a low coastal-plain environment along the western margin of the Western Interior Seaway during the Late Cretaceous (100-66 Ma). The formation is the bedrock immediately underlying the Quaternary surficial deposits. This is indicated by coal seams recorded in the bedrock portions of water-well driller's logs within the quadrangle (Colorado Division of Water Resources, 2020). The coal seams are in the lowest 60 to 90 m of the formation. In the north part of the Denver Basin, the Fox Hills Sandstone lies beneath the Laramie Formation and overlies the Pierre Shale. In the Valley View School quadrangle this relationship is indicated by the Laramie Formation-Fox Hills Sandstone contact depicted at the south end of cross section A-A'. In the remainder of the cross section, however, no oil and gas well data were available to extend this contact northward. Also, data for the Fox Hills Sandstone-Pierre Shale contact were not available, and therefore, the thickness of the Fox Hills Sandstone could not be shown in the cross section. Sediments of the Fox Hills Formation were deposited in near-shore and beach environments as the Western Interior Seaway retreated to the east (Dechesne and others, 2011). The Upper Transition Member of the Pierre Shale underlies the Fox Hills Sandstone. Sediments of this member were deposited in deeper marine environments of the seaway. Oil and gas wells in the Valley View School quadrangle have penetrated underlying Cretaceous rocks down into those of the Dakota Group (cross section A-A').

The Longmont wrench fault zone trends west-southwest to east-northeast across the northern part of the Valley View School quadrangle, as seen in a structure map of central Denver Basin fault zones in Weimer (1996), and also in the geologic map of the present report (Plate 1). Cross section A-A' shows the fault zone to have ~23 m of vertical displacement, downthrown to the south; this sense of displacement accords with Weimer (1996). Right-lateral movement along this oblique-slip fault zone occurred during Cretaceous time and was intermittent from 110 to 65 Ma (Weimer, 1996), an interval that includes the beginning of the Laramide orogeny. Cross section A-A' also intersects five high-angle normal faults presented in Weimer (1996). All five faults are shown on the cross section, but in cross section A-A' vertical displacement could be measured only at two, based on the available oil and gas well data.

During Pliocene time in the Colorado Piedmont, major streams incised rocks and sediments of Neogene and Paleogene age as well as Upper Cretaceous sedimentary rocks; no rocks or sediments of Paleogene or Neogene age likely remain in the Valley View School quadrangle. The incision presumably resulted in the development of the South Platte River and its major and minor tributaries. (Some of these tributaries, however, especially minor ones, may have formed later during the Quaternary.) The stream network within and near the Valley View School quadrangle includes the junction in the Greeley quadrangle of the South Platte River and its major tributary the Cache la Poudre River. Buried paleovalleys, at present the sites of minor streams, are tributaries to the Cache la Poudre River valley in the Greeley quadrangle and to the South Platte River valley in the Kersey, Barnesville, and Valley View School quadrangles.

The Quaternary history of the Valley View School quadrangle and environs begins with deposition of Early and Middle Pleistocene stream and alluvial-fan gravels, termed "old alluvium" by Lindsey and others (2005). These deposits include the Nussbaum Alluvium, spanning the Pliocene and Early Pleistocene(?), and (from older to younger) the Rocky Flats, Verdos, and Slocum alluviums. From Early to Middle Pleistocene time there were periods of incision as well as periods of alluvial deposition, and, probably, eolian deposition. The incision and lateral cutting of surrounding, fine-grained, less-resistant alluvial deposits and bedrock left isolated remnants of the older, more resistant "old alluviums" at higher elevations. Lindsey and others (2005) recognize occurrences of dissected alluvial fans and terrace gravels of Middle Pleistocene age extending as far as 5 km east of Fort Lupton (~35 km southwest of the Valley View School quadrangle). These deposits include the Rocky Flats and Verdos alluviums. The Rocky Flats Alluvium is not mapped in the Greeley or Valley View School quadrangles, and ranges in estimated age from ~400 ky to 2 My (Middle to Early Pleistocene; Riihimaki and others, 2006). Verdos Alluvium is mapped in the Greeley quadrangle by Colton (1976) and by Keller and Morgan (2020) and is termed unit Qg2 in Colorado Geological Survey (CGS) publications. Its estimated age ranges from between 410 and 475 ky to ~631 ky (see unit Qg2 section in Description of Map Units section, Greeley quadrangle, in Keller and Morgan, 2020). As summarized in Berry and others (2019), the maximum age for the Verdos Alluvium is constrained by the underlying Lava Creek B ash, erupted from the Yellowstone Plateau volcanic field at ~631 ka (Matthews and others, 2015, cited in Berry and others, 2019). The ash is present in Verdos Alluvium at sites along the South Platte River northeast of Fort Morgan; although at many sites the ash is likely to be reworked. The ash is present within and at the top of Verdos Alluvium as well as at the base. The age assignments of these Early and Middle Pleistocene Colorado Piedmont alluvial deposits are based chiefly upon the following: height above present stream level near the east side of the Front Range hogback belt; tentative correlation with marine oxygen isotope stages; and assumption of a nonlinear rate of stream incision since the deposition of the Lava Creek B tephra at ~631 ka. The above age estimate of the Verdos Alluvium is based chiefly on its stratigraphic relationship with Lava Creek B tephra but also on soil carbonate morphology in the greater Denver area (Kellogg and others, 2008); there are also younger age estimates for this alluvium. The only mapped unit of "old alluvium" in the Valley View School quadrangle is unit Qg1 (also called Slocum Alluvium), the age of which in the quadrangle is ~341 ky (Table 2). Unit Qg1 deposits occupy inverted topography in the northeast corner of the quadrangle. Unit Qg1 probably correlates with the intermediate alluvium (unit Qai) in the Masters quadrangle, thought to correlate with Slocum Alluvium (Berry and others, 2015a).

Within the Valley View School quadrangle, Quaternary alluvial map units were deposited by the South Platte River, and its minor tributary Box Elder Creek, or were deposited as older alluvial fans. From oldest to youngest they are units Qg1 (gravel deposit one, also called Slocum Alluvium), Qa_3 (alluvium three, also called Broadway Alluvium), and Qa (alluvium, undivided). The positions of these units in the landscape and relative to each other are shown in cross sections B-B', C-C', and D-D'. As mentioned earlier, unit Qg1 is an alluvial deposit much older than units Qa and Qa_3, but because of the alignment of its erosional remnants along the south side of the South Platte River valley, it may, like unit Qa_3, have been deposited by an ancestral South Platte River. Along the river unit Qa_3 was incised and then partially filled with Qa_2 alluvium. Unit Qa_2 then was partially incised, with the incision then partially filled by deposition of unit Qa_1, as presented in the Greeley quadrangle geologic map (Keller and Morgan, 2020). In the Box Elder Creek valley unit Qa_3 was not incised but was simply covered by unit Qa (which is probably coeval with unit Qa_2 of the South Platte River valley). The unit Qa floodplain is incised by a narrow channel, but the channel does not contain mappable bodies of unit Qa_1 (alluvium one - modern alluvium). The Box Elder Creek valley (and similar, buried north- or south-trending tributary valleys in the Greeley, Kersey, and La Salle quadrangles) lacks a terrace analogous to the terrace that developed from the incision of unit Qa_3 in the South Platte River valley. During the Late Holocene incision of unit Qa_3 in the South Platte River valley, it is probable that river discharge originated mainly from streams that head in the Front Range. Tributary valleys, whose catchment areas were in the piedmont, apparently did not have comparable discharge sufficient to cause comparable incision. This based on the absence of Qa_3 terraces in these tributary valleys.

In the Valley View School quadrangle, unit Qa_3 is not exposed and thus was not sampled for optically stimulated luminescence (OSL) dating. Optically stimulated luminescence age estimates for unit Qa_3 in other Colorado Piedmont quadrangles mapped by the CGS are as follows: ~12 ky, ~12 ky, ~13 ky, and ~13 ky in the Longmont quadrangle (Madole, 2016); ~11 ky in the Berthoud quadrangle (Keller and others, 2017); ~13 ky in the Milliken quadrangle (Palkovic and others, 2018); ~49 ky and ~70 ky in the Greeley quadrangle (Keller and Morgan, 2020); ~42.3 ky, ~54.5 ky, and >56 ky in the Gowanda quadrangle (Keller and others, 2019); and ~28 ky and ~40 ky in the Bracewell quadrangle (Palkovic and Morgan, 2020). Unit Qa_3 ages in the Longmont, Berthoud, Johnstown, and Milliken quadrangles are at the younger end of the age range for Broadway Alluvium (12 to 30 ky; see Kellogg and others, 2008) for alluvial deposits in the Colorado Piedmont near Golden and Morrison. This 12-30 ky age range correlates with the time of Pinedale glaciation in the Rocky Mountains. The unit Qa_3 ages in the Greeley, Gowanda, Bracewell, and Kersey quadrangles, however, are markedly older (with a single exception - ~28 ky in Bracewell). They partially fall within Early Wisconsin time, during which interval Kellogg and others (2008) present that there are no known deposits in the Colorado Piedmont near Golden and Morrison. The deposits are too young to be Louviers Alluvium (designated as Qa_4 in CGS publications), the age of which is ~120 to ~170 ky (Kellogg and others, 2008), and which is associated with Bull Lake glaciation. Unit Qa_4 forms remnants along valley walls, as well as underlying unit Qa_3 along the valleys of the South Platte River and major tributaries (Lindsay and others, 2005). At present, the apparently pre-Pinedale age and post-Bull Lake age alluviums of the Greeley, Gowanda, Bracewell, and Kersey quadrangles continue to be designated as unit Qa_3 although their ages are not yet explained. A more detailed discussion of this older set of OSL ages is in the unit Qa_3 section of the Description of Map Units for the Greeley quadrangle (Keller and Morgan, 2021).

In Late Pleistocene time, following the deposition of unit Qa_4 (Louviers Alluvium), an episode of stream incision removed most of unit Qa_4 from the South Platte River valley and its major tributaries. The incision was followed by a Late Pleistocene aggradational period (coeval with Pinedale glaciation) during which unit Qa_3 accumulated in the valleys of the South Platte River and Box Elder Creek (in the Valley View School quadrangle). Unit Qa_3 sediments extended west beyond the present west valley wall of Box Elder Creek. In the South Platte River valley, a second episode of Late Pleistocene incision occurred, possibly extending into the Early Holocene. This second episode removed some of the uppermost part of the unit Qa_3 valley fill but left deposits of unit Qa_3 beneath the surfaces of fill-cut terraces. The Kersey terrace, portions of which are in the northwest and northeast corners of the Valley View School quadrangle, is an example of such a unit Qa_3 terrace. The second episode of incision apparently did not affect unit Qa_3 in the Box Elder Creek Valley because no terraces were cut there. Following the latter incision episode, unit Qa_2 aggraded in the South Platte River valley during Late Holocene time, and unit Qa aggraded in the Box Elder Creek valley. In the South Platte River valley, a third incision episode, in Late Holocene time, created terraces of unit Qa_2 and a valley floor underlain by modern alluvial unit Qa_1. These features are mapped along the river in the adjacent La Salle, Greeley, and Kersey quadrangles (Palkovic and others, 2019; Keller and Morgan, 2020; Lindsey and others, 2020). In the Box Elder Creek valley the third incision cut a narrow channel in the unit Qa valley floor, and the channel now is occupied by unit Qa_1 (too small to show at map scale).

Eolian sediment (unit Qe) in the Valley View School quadrangle is not sufficiently exposed to identify sites for sampling for radiocarbon age determinations. Unit Qe was deposited during Early and Middle Holocene time, based upon the radiocarbon age of ~9 ky for unit Qe in the Greeley quadrangle (Keller and Morgan, 2020), ~9 ky for unit Qe in the Johnstown quadrangle (Palkovic and Morgan, 2017), ~4 ky and ~5 yr for unit Qel (equivalent to unit Qe) in the Frederick quadrangle (Keller and others, 2018), and ~5 ky in the Gowanda quadrangle (Keller and others, 2019). The ages at ~9 ky fall within an early Holocene episode of eastern Colorado loess deposition that spanned ca. 11 to 9 ka (Muhs and others 1999). Unit Qe lacks sufficient silt to be termed loess or sandy loess, but it may be coeval at least in part with the loess deposition and may have derived its high sand content from unit Qa_3 alluvium exposed along the South Platte River.

From Late Pleistocene to Late Holocene time, eolian sand (unit Qes) was deposited over much of the northeastern plains of Colorado and nearly as far west as Boulder (Madole and others, 2005). The Late Pleistocene eolian sand deposits were more extensive than those of the Middle Holocene and Late Holocene (Madole and others, 2005). Unit Qes presently occupies approximately half the surface of the Valley View School quadrangle, and it is not known whether its coverage was at one time more extensive. Unit Qes occupies most of the quadrangle's higher ground, mostly overlying older eolian sediment (unit Qe) or Laramie Formation bedrock (cross sections B-B', C-C', and D-D').

Eolian sediment (unit Qe) in the Valley View School quadrangle is not sufficiently exposed to identify sites for sampling for radiocarbon age determinations. Unit Qe was deposited during Early and Middle Holocene time, based upon the radiocarbon age of ~9 ky for unit Qe in the Greeley quadrangle (Keller and Morgan, 2020), ~9 ky for unit Qe in the Johnstown quadrangle (Palkovic and Morgan, 2017), ~4 ky and ~5 yr for unit Qel (equivalent to unit Qe) in the Frederick quadrangle (Keller and others, 2018), and ~5 ky in the Gowanda quadrangle (Keller and others, 2019). The ages at ~9 ky fall within an early Holocene episode of eastern Colorado loess deposition that spanned ca. 11 to 9 ka (Muhs and others 1999). Unit Qe lacks sufficient silt to be termed loess or sandy loess, but it may be coeval at least in part with the loess deposition and may have derived its high sand content from unit Qa_3 alluvium exposed along the South Platte River.

From Late Pleistocene to Late Holocene time, eolian sand (unit Qes) was deposited over much of the northeastern plains of Colorado and nearly as far west as Boulder (Madole and others, 2005). The Late Pleistocene eolian sand deposits were more extensive than those of the Middle Holocene and Late Holocene (Madole and others, 2005). Unit Qes presently occupies approximately half the surface of the Valley View School quadrangle, and it is not known whether its coverage was at one time more extensive. Unit Qes occupies most of the quadrangle's higher ground, mostly overlying older eolian sediment (unit Qe) or Laramie Formation bedrock (cross sections B-B', C-C', and D-D').

Eolian sand originated mainly from sediment in stream channels and flood plains. In northeastern and east-central Colorado the sediment was transported by northwest prevailing winds (Madole and others, 2005). In the Valley View School quadrangle, the South Platte River valley and Cache la Poudre River valley, north and northwest of the quadrangle, may have contributed some sediment to unit Qes. Aleinikoff and Muhs (2010) demonstrated that the Laramie Formation north of the City of Greeley was the major source for eolian sand in an area they named the Greeley dune field, east of the city and partly within the Kersey and Barnesville quadrangles. Because of its exposure within the Valley View School quadrangle, it is possible that the Laramie Formation sandstone locally contributed sediment to bodies of unit Qes. OSL sample V132DOSL3 (see geologic map, Plate 1) was collected in a sand pit at Box Elder Creek, at the top of a unit Qes exposure where the deposit is overlain by unit Qa. The sample yielded an age of 3,165 +/- 290 yr. The radiocarbon age of unit Qes in the City of Greeley is 850 yr (Keller and Morgan, 2020). Both the above ages are in accord with Madole's Late Holocene age group for eolian sand (0 to 4 ky), of three eolian sand age groups presented in Madole and others (2005). Other recently reported dates for unit Qes in the nearby Colorado Piedmont quadrangles are ~3 ky and ~8 ky in the Frederick quadrangle (Keller and others, 2018) and ~3 ky in the Gowanda quadrangle (Keller and others, 2019). The locations of the samples collected for these ages are ~30 km southwest of Greeley.

MINERAL RESOURCES, GROUNDWATER RESOURCES, AND GEOLOGIC HAZARDS

Within the Valley View School quadrangle there are seven inactive construction permits and one active permit for sites excavating borrow material for construction (Colorado Division of Reclamation and Mine Safety [DRMS] AUGER interactive map, 2021). All the sites are in the northwest quarter of the quadrangle, and only two are large enough to be discerned on the lidar image and plotted on the geologic map. Most pits were excavated in the eolian sand of unit Qes. Elsewhere in the quadrangle, and notably in the area east of Box Elder Creek, there are 23 sand borrow pits in unit Qes and one gravel pit in unit Qg_1. All are plotted on the geologic map and several pits (all inactive) were visited for the present mapping project. The gravel pit is the site of OSL samples V017COSL1 and V017COSL2. None of these 24 sites are posted on the DRMS AUGER interactive map as having either active or inactive permits. There are no active or inactive aggregate workings in the small areas of unit Qa_3 terrace within the quadrangle. These areas are mapped by Schwochow and others (1974) as older stream terrace deposits containing fine aggregates of coarse gravelly sands to fine sands. In the Greeley quadrangle, diagonally adjacent to the northwest of the Valley View School quadrangle, aggregate is produced from unit Qa_3 in the South Platte River valley. For the years 2020 and 2021 the annual aggregate production in Weld County was ~14.7 million and 15.2 million metric tons, respectively (Weld County Assessor's Office, oral commun., 2021).

The Valley View School quadrangle lies in the northern part of the Wattenberg field, an active and prolific oil and gas producing area located mostly in Weld and Adams counties. Oil and gas infrastructure is present throughout the quadrangle. As of 2021 the Wattenberg field was the fourth-largest oil field and ninth-largest natural gas field in the U.S. (U.S. Energy Information Administration, 2021). As of summer 2020, the Valley View School quadrangle was still an active area for oil and gas production. Production in the Wattenberg field is principally from the Niobrara Formation but also from the Middle Member of the Pierre Shale, the Colorado Group, and the Dakota Group. In 2020, the field produced ~137 million barrels of oil and ~1.1 trillion MCF (thousand cubic ft) of natural gas (Colorado Oil and Gas Conservation Commission, 2021).

A historic coal-producing area within the Valley View School quadrangle is situated on the Greeley Arch between the Denver Basin and Cheyenne Basin. This historic area is outside the coal fields identified in Roberts (2005) but is included in one of coal-mine map compilations of Turney and Murray-Williams (1983, Plate 12). Their map has nine historic underground mines, all in the southwest quarter of the quadrangle. The mines were worked in coal seams of the lower 60 to 90 m of the Laramie Formation. Mine operations mostly spanned the period between 1931 and 1945, seam thicknesses ranged from 0.8 to 1.4 m, seam depths ranged from 24 to 40 m, and total production was ~100,000 metric tons (Turney and Murray-Williams, 1983). Existing Laramie Formation coal resources in the Valley View School quadrangle probably have little economic potential. In contrast, coal mining in the Boulder-Weld coal field, adjacent to and south of the Greeley Arch, had more than 160 historic mines that operated in seams more numerous and thicker than seams in the Valley View School quadrangle. The Boulder-Weld coal field ceased production in 1979 (Spencer, 1986). Surface subsidence caused by underground coal mining in the Laramie Formation is a well-documented geologic hazard in the north part of the Denver Basin (Myers and others, 1975). The historic mines in the southwest quarter of the Valley View School quadrangle are in agricultural land. Therefore, surface subsidence due to historic coal mining is not now expected to be an important potential geologic hazard within the quadrangle but could be a hazard if development should encroach on this agricultural land.

Alluvium three (unit Qa_3) and the Laramie-Fox Hills aquifer are the important aquifers in the Valley View School quadrangle, and over 300 water-well permits have been issued in this area. Unit Qa_3 consists of interbedded layers of sand, gravel, and clay. In the Colorado Piedmont, the alluvium is found along the valleys of the South Platte River and its major tributaries, as well as in minor tributary paleovalleys (buried valleys) to these streams (e.g., Box Elder Creek valley). The basal part of the Laramie Formation contains two relatively thick sandstone units; these sandstones and the underlying Fox Hills Sandstone constitute the Laramie-Fox Hills aquifer. The aquifer underlies much of the Denver Basin and extends north on to the Greeley Arch, including the area of the Valley View School quadrangle. The aquifer is as much as 107 m thick although its water-yielding thickness is seldom greater than 61 m, and it is generally under artesian conditions (Topper and others, 2003). It underlies the Quaternary deposits of the quadrangle and appears to be of less local importance than the shallow aquifer of unit Qa_3. Water wells are relatively densely spaced in unit Qa_3 in the Box Elder Creek valley and in unit Qa_3 in the small areas of the South Platte River valley impinging on the quadrangle (Colorado Division of Water Resources [DWR] Well Permit Research Viewer, 2020). Water wells are sparser in the uplands, where more wells terminate in the Laramie Formation than in unit Qes and unit Qa_3. In the 58 water-well driller's logs used to assemble cross sections B-B', C-C', and D-D', water wells in the Box Elder Creek valley range from 16 to 31 m deep. Laramie Formation wells in upland areas range from 25 to 134 m deep and are deeper in the south part of the quadrangle, where the topography rises toward the south. Wells in upland bodies of unit Qes and unit Qa_3 range from 4 to 18 m deep.

During the catastrophic September 2013 regional flood events along the Colorado Front Range, there were some fatalities, large-scale damage to property and infrastructure, and some adverse environmental effects. Flood waters of the South Platte River covered much of the area mapped as alluvium one (unit Qa_1) and alluvium two (unit Qa_2) in the southeast corner of the Greeley quadrangle (Keller and Morgan, 2020), diagonally adjacent on the northwest to the Valley View School quadrangle. Along the south side of the South Platte River valley the floodwaters did not overtop the Qa_3 terrace (Kersey terrace) and thus did not extend as far south as Colorado State Highway 34 and the community of Kersey, both of which are along the northern boundary of the Valley View School quadrangle (Town of Kersey Clerk, oral commun., 2021). During the 2013 flood, Box Elder Creek locally ran bank-full but did not inundate its valley (local residents P. Sater and G. Booth, oral commun., 2021). Currently the portion of Box Elder Creek valley lying within the quadrangle is designated as a 100-yr flood plain, and the two areas of unit Qa_3 terrace within the quadrangle are not designated as flood hazard zones (Weld County Property Portal, 2021).

Eolian sediment (unit Qe) and eolian sand (unit Qes) locally may be susceptible to collapse when under load and wet or saturated, owing to hydrocompaction. Soil engineers refer to these deposits as collapsible soils. The fine-grained fractions (silt and especially clay) of these deposits give them relatively high compressive strength and shear strength under dry conditions. When wet or saturated and under load, however, the fine-grained particles in these deposits can be displaced into a denser configuration such that the void space between particles is reduced. Compaction and associated decrease in volume can cause settlement at and near the ground surface, potentially resulting in damage to any overlying structures and (or) infrastructure (White and Greenman, 2008).

During June 2014 in the Greeley quadrangle (adjacent on the northwest to the Valley View School quadrangle), there was an apparent wastewater injection-induced earthquake of moment-magnitude (Mw) 3.2 and Modified Mercalli intensity IV, great enough to be felt throughout the Front Range (Yeck and others, 2016). The epicenter for the earthquake was in a historically aseismic part of Colorado, ~4 km northeast of the east end of the City of Greeley and Weld County Municipal airport, and ~2.5 km northeast of a high-rate oilfield injection well. The well was being used for wastewater disposal into the Pennsylvanian-Permian Fountain Formation overlying the Precambrian crystalline basement rocks. The monthly rate of oilfield wastewater injection in Weld County had increased significantly over the period of 2010 to 2014. Suspecting that the nearby injection well had caused the earthquake, the Colorado Oil and Gas Conservation Commission temporarily halted injection activity, and the University of Colorado, with support from other agencies, rapidly installed a local seismic monitoring network. The bottom of the well was cemented to prevent hydraulic communication between the injection zone and the basement rocks, and injection then was resumed at a lower rate. During the following 16 months (through about October 2015) there were no earthquakes greater than Mw 1.5 associated with the injection well (Yeck and others, 2016). During the period from October 2015 through February 2020 there were 21 earthquakes in the Greeley quadrangle. Half of the earthquakes ranged from local Richter magnitude (Ml) 1 to 1.9 and half ranged from 2.1 to 3 Ml (U.S. Geological Survey Online Earthquake Catalog, February 2020, cited in Keller and Morgan, 2020). (Local Richter magnitude and moment-magnitude are nearly equivalent for small earthquakes.) The local seismicity is believed to be induced by continuing injection-well operations, although the cause of these earthquakes is still a subject of debate. The center of the Valley View School quadrangle lies ~20 km southeast of the June 2014 earthquake epicenter in the Greeley quadrangle. For the period from the beginning of June 2014 through the end of March 2021 there was no recorded seismic activity in the Valley View School quadrangle (U.S. Geological Survey Online Earthquake Catalog, March 2021).

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GEOLOGIC MAP OF THE VALLEY VIEW SCHOOL QUADRANGLE, WELD COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D OBLIQUE, GEOLOGIC HISTORY, GROUNDWATER, AND MINERAL RESOURCES AND CROSS SECTIONS

By Stephen M. Keller and Alexander E. Marr
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