TABLE 1.--GEOLOGIC CHARACTERISTICS OF BEDROCK UNITS

[Footnotes and references are listed on sheet 3]

Geologic characteristics	Castle Rock Conglomerate (Lee, 1902)	Dawson Arkose, upper part (Richardson, 1912)					Denver Formation, upper tongue (Cross, 1888)	
		Interbedded sandstone and claystone facies (Tdso), with individual beds having the characteristics listed below						
	Conglomerate Ter	Arkosic sandstone facies Tda	Conglomerate facies Tdc	Sandstone facies Tds	Claystone facies Tdo	Variegated (multicolored) claystone facies Tdv	Sandstone facies Tdes	Claystone facies Tdec
Thickness (maximum observed in quadrangle)[1]	40 ft (12 m)	75 ft (23 m) in individual beds; 250 ft (75 m) in zones where internal bedding is not distinguished.	65 ft (20 m)	20 ft (6 m) in individual beds; 175 ft (53 m) in zones.	50 ft (15 m)	50 ft (15 m)	15 ft (5 m) in individual beds.	40 ft (12 m) in individual beds.
Color[2]	Very light gray to light grayish yellow.	Very light gray, light yellowish gray, and reddish brown to brownish red.	Very light gray to light yellowish gray.	Olive brown to medium reddish brown.	Olive gray, olive brown, and dusky yellow; some medium to dark gray.	Various shades of pastel yellow, brown, green, red, and gray.	Medium grayish brown to yellowish brown.	Medium gray to light yellowish brown.
Texture Grain size (Pettijohn, 1957, p. 19)	Pebbles, cobbles, and boulders in medium sand matrix.	Very fine to very coarse sand; locally pebbly. Rare occurrences of clay balls of boulder size.	Fine sand matrix, containing pebbles, cobbles, and boulders as large as 4 ft (1.2 m) in maximum dimension.	Very fine to fine sand; some clay and silt.	Mostly clay and silt; local concretions of cobble size; some very fine sand.	Mostly clay and silt; some very fine to fine sand.	Clay, silt, and very fine to fine sand; locally pebbly, rarely conglomeratic.	Mostly clay and silt; some fine sand.
Sorting[3]	Poorly to moderately well sorted.	Moderately sorted; locally poor and chaotic.	Poorly sorted, chaotic deposition.	Well sorted.	Poorly sorted; discontinuous, chaotic layers.	Poorly sorted.	Poorly sorted.	Generally poorly sorted. Some individual beds well sorted.
Grain shape (ibid., fig. 25)	Mostly subspheroidal; some tabular.	Equant quartz grains; tabular mica and feldspar grains.	Equant and oblate; some subspheroidal.	Equant quartz, tabular mica.	Platy clay, equant silt, tabular mica.	Equant grain aggregates, platy grains.	Equant quartz, tabular mica, bladed volcanic glass, minor constituents.	Tabular and platy clay, equant quartz.
Grain roundness (ibid., fig. 28)	Subangular to well rounded.	Subangular to subrounded.	Subrounded to well rounded.	Subangular to rounded.	Clay-particle aggregates subrounded to well rounded.	Clay-particle aggregates poorly to well rounded.	Moderately well rounded.	Clay-particle aggregates poorly rounded, tabular, blocky.
Grain surface	Smooth to pitted, dependent on grain lithology.	Most are smooth to slightly pitted.	Generally smooth. Some fragments are pitted where unstable mineral grains have been removed.	Generally smooth.	Particle surface unknown--particles are too small to ascertain surfaces by normal investigation.	Particle surface unknown.	Quartz grains commonly pitted; other grains mostly smooth.	Clay surfaces unknown.
Composition, in order of abundance	Fragments of igneous, sedimentary, and metamorphic rocks in clayey quartz-sandstone matrix.	Quartz, feldspar, mica, minor accessory minerals; clay and some iron-oxide and silica cement.	Quartz, feldspar, mica, and clay in matrix; granite, orthoquartzite, gneiss, schist, arkose, sandstone, and quartz fragments.	Quartz, mica, clay, feldspar, minor accessory minerals; clay and iron-oxide cements.	Clay containing quartz silt and sand; common mica, some feldspar; clay and iron-oxide cements.	Clays: kaolinitic, illitic, mixed-layer, montmorillonitic. Quartz; some mica.	Quartz, mica, feldspar, andesite, rhyolite pebbles, volcanic glasses; minor chlorite, fluorite, and topaz; montmorillonitic and mixed-layer clays.	Montmorillonitic and mixed-layer clay, quartz, mica.
Lithification attributes of fresh rock Type of cement	Iron oxide, clay, locally calcium carbonate, rarely silica.	Mostly kaolinitic clay; locally iron oxide; rarely silica; very rarely opaline silica.	Mostly kaolinitic and mixed-layer clay; some secondary silica.	Mostly kaolinitic clay, some montmorillonitic clay; local iron-oxide cement.	Mostly mixed-layer clays, some montmorillonitic clay, local iron-oxide cement.	Clay cement; see composition.	Commonly iron oxide and clay; calcium carbonate; rarely silica.	Clay; some iron oxide; rarely calcium carbonate.
Degree of cementation	Fair to poor; zones of iron-oxide or silica cementation are good.	Fair to poor; very good in beds cemented by iron oxide or silica.	Poor to fair.	Fair to poor; good in beds cemented with iron oxide.	Poor; fair in beds cemented with iron oxide.	Poor.	Variable; beds cemented with silica or iron oxide are well cemented; poor in beds cemented with clay.	Poorly cemented throughout.
Compaction	Moderately well compacted.	Well compacted.	Moderately well compacted.	Well compacted.	Well compacted.	Moderately well compacted.	Moderately well compacted.	Well compacted while unweathered.
Hardness	Moderately hard to very hard, dependent on type of cement and degree of weathering.	Moderately soft; iron-oxide- and silica-cemented beds very hard.	Moderately soft.	Generally soft to medium hard.	Mostly very soft. Clay-ironstone concretionary layers very hard.	Moderately hard when dry; very plastic when wet.	Soft to very hard, varying with type of cement.	Soft to very soft, varying with content of silt and sand.
Friability	Moderately friable; large fragments may be picked from matrix.	Mostly very friable; commonly may be crumbled in the fingers.	Very friable; may be picked apart or crumbled in the fingers.	Very friable when dry; commonly plastic when wet.	Very friable and crumbly when dry; very plastic when wet.	Slightly friable and crumbly when dry; very plastic when wet.	Moderately to very friable; siliceous beds are not friable.	Very friable.
Concretions	Unknown.	Football-shaped concretions of fine-grained sandstone; pillow-shaped clay concretions as large as 4 ft (1.2 m).	Unknown.	Scattered subspheroidal claystone concretions.	Clay-ironstone concretionary layers common; some sandstone concretions.	Unknown.	Clay-ironstone concretions rare.	Common subspheroidal clay-ironstone concretions.
Fossil content	Very sparse; early Oligocene titanothere parts have been found in nearby areas.	Petrified wood very common.	Unknown.	Plant debris rare.	Plant debris common on bedding surfaces and throughout layers.	Unknown.	Unknown in this area; early Paleocene fossil mammals and reptiles found in the littleton quadrangle to the west.	Vertebrate remains rare; plant remains scattered throughout.
Significant variations	Contains some beds of coarse to very coarse boulder conglomerate; locally contains extremely large boulders.	Local beds of claystone and ironstone.	Interbeds of fine- to coarse-grained arkosic sandstone.	Local interbeds of arkosic sandstone and of claystone.	Local interbeds of sandstone.	Color and clay type change laterally and vertically.	Unknown.	Variations in color, and in silt and sand content.
Bedding Quality and regularity	Poorly and irregularly bedded; imbricate layering of large fragments common; locally chaotic.	Moderately well bedded. Single beds persistent; interbeds present locally.	Chaotically bedded in irregular units of variable thickness.	Well bedded; individual beds easily distinguishable. Local beds of claystone or pebble conglomerate.	Commonly very poorly bedded. Individual beds distinguishable only where enclosed by other lithologies. Beds are irregular, commonly lenticular in large deposits.	Moderately well bedded, fairly regular; some beds lenticular, but most persist laterally. Beds are of variable thickness.	Well bedded. Single beds persistent; interbeds present locally.	Mostly obscurely bedded, poorly and irregularly bedded.
Thickness, and shape or character of bedding surfaces	Very thickly and unevenly bedded. Rolling uneven surfaces; unit commonly pinches and swells abruptly. Scour-and-fill channel structures common.	Thickly bedded to massive; individual beds generally 2-4 ft (0.6-1.2 m). Crossbedded, with tangential foresets; locally rippleмarked; irregular surfaces; channel fills common.	Individual beds as thick as 12 ft (3.6 m), crossbedded in steep-angle sets in lenticular beds. Wedge-shaped sets common.	Single beds as thick as 8 ft (2.4 m); thick to massive. Commonly crossbedded; as commonly even rhythmic bedding.	Single beds as thick as 25 ft (7.5 m). Some low-angle smoothly curving tangential foreset crossbedding. Bedding commonly obscured by fracturing or weathering.	As much as 20 ft (6 m) in single beds. Bedding surfaces uneven and rolling; no obvious internal bedding structures.	Thick to very thick bedded, commonly 4-6 ft (1.2-1.8 m) in cross-bedded, irregular, and wavy-surfaced sets.	Thin individual beds, very thick sets of beds. Sets commonly 4-8 ft (1.2-2.4 m) thick; surfaces are irregular and wavy.
Prevalent orientation	Gentle dip northeastward; most channel-fill structures trend N. 5°-40° E.	Crossbedding dips mostly northeastward. Beds generally horizontal. Channel-fill structures trend mostly N. 5°-40° E.	Unit is generally horizontal; individual sets dip mostly northeastward.	Unit is generally horizontal. Internal structures may dip gently northeastward.	Unit is horizontal; some internal structures dip steeply northeastward.	Generally horizontal. Local gentle dip northeastward and eastward.	Very gentle dip, less than 2°, northeastward.	Very gentle dip, less than 2° northeastward.
Fracturing (joints are the only type of fracturing known in bedrock in the quadrangle. No faults were seen during fieldwork or photointerpretation) Pattern	Rectangular, planar; irregular X-shaped shear joints common on outcrops.	Rectangular in two major sets; planar.	Rectangular, planar.	Rectangular, commonly slightly curved. One major set, one minor set.	Rectangular and irregular, some polygonal. One major set, many minor sets.	Rectangular in both curved and planar sets.	Rectangular and planar, some X-shaped intersections.	Rectangular; planar and curved; incipient joints throughout.
Development	Well developed, but poorly preserved on vertical weathered outcrops; well preserved on horizontal stripped surfaces.	Well developed; best preserved in well-cemented individual beds.	Well developed but poorly preserved on weathered surfaces.	Moderately well developed; weathering rapidly obscures joints.	Very well developed; weathering along joints tends to reduce rocks to rubble very rapidly.	Well developed; incipient joints throughout.	Moderately well developed.	Moderately well developed, best preserved on weathered surfaces. Closely spaced jointing develops soon after exposure.
Prominence and distribution	Conspicuous on fresh exposures and persistent throughout beds, but difficult to observe. Shear fractures in beds commonly terminate upward from base within about 2 ft (0.6 m).	Major and conspicuous where preservation is good. Prevalent and persistent throughout individual beds.	Moderately conspicuous; best seen in fresh exposures on sides of ridges.	Generally inconspicuous except in beds cemented by iron oxide or in fresh exposures, but common throughout the unit.	Generally very conspicuous and very abundant throughout the unit on all outcrops.	Conspicuous and prevalent throughout unit.	Prominent; lined with limonite or clay. Prevalent throughout some individual beds.	Subdued in unweathered or fresh exposure, very prominent otherwise. Commonly lined with limonite. Prevalent throughout unit.
Extent	Wide extent.	Wide ranging, especially in highland areas.	Probably throughout unit.	Throughout unit.	Throughout unit.	Throughout unit.	Throughout unit.	Major joints extend throughout unit. Minor joints develop shallowly.
Abundance	Major joints common; shear joints locally abundant.	Highly fractured.	Common; highly fractured.	Moderately abundant.	Very abundant; highly fractured with incipient joints.	Very common; highly fractured.	Common in all exposures.	Very abundant.
Spacing	6-10 ft (1.8-3 m).	4-6 ft (1.2-1.8 m).	Generally 2-6 ft (0.6-1.8 m).	2-6 ft (0.6-1.8 m).	1/2-4 in (0.13-10 cm).	As close as 1/8 in (0.3 cm); generally 1-2 in (3-9 cm).	2-4 ft (0.6-1.2 m) most common; rarely less than 2 ft (0.6 m).	Mostly less than 2 ft (0.6 m); incipient joints less than 1/2 in (1.3 cm).
Orientation (strike and dip)	N. 5°-25° W., 75°-90° NE.; N. 45°-65° E., 70°-90° NW.	N. 10°-17° W., 75°-90° NE.; N. 70°-90° E., 70°-90° NW.	Trend north-northwest to northwest. Not measured due to deep weathering.	Major set: N. 10°-15° W., 60°-90° NE.; minor set: N. 40°-70° E., 35°-80° NW.	Major set: N. 10°-20° W., dip not determined; minor sets trend in all directions.	Major sets trend north-northwest; minor sets trend in all directions.	N. 15° W., 90°-50° NE.; N. 10°-25° E., 70°-40° NW.	Major sets trend northeasterly and north-northwesterly. Directions not measured.
Weathering Susceptibility	Moderately susceptible.	Moderately to highly susceptible.	Highly susceptible.	Moderately to highly susceptible.	Extremely susceptible.	Very susceptible.	Moderately susceptible.	Extremely susceptible.
Degree	Deeply weathered in coarsest grained deposits; moderately weathered in medium-grained deposits.	Clay-cemented deposits commonly are deeply weathered. Deposits cemented by iron oxide or silica are slightly weathered.	Deeply weathered and noncohesive in clay-cemented deposits; slightly weathered in iron-oxide-cemented deposits.	Moderately to deeply weathered. Tends to slake on exposure.	Deeply weathered in all exposures; weathers rapidly and slakes severely when freshly exposed.	Deeply weathered throughout; slakes and falls apart rapidly when freshly exposed.	Moderately weathered along joints, bedding planes, and flat-lying surfaces.	Deeply weathered on all exposures.
Depth	As deep as 5 ft (1.5 m).	Commonly deeper than 5 ft (1.5 m); rarely deeper than 10 ft (3 m).	Commonly deeper than 10 ft (3 m).	Commonly deeper than 10 ft (3 m); locally deeper than 20 ft (6 m).	Commonly deeper than 25 ft (7.5 m).	Commonly deeper than 15 ft (4.5 m).	Commonly 1-2 ft (0.3-0.6 m) below surfaces; as much as 3 ft (1 m) along joints.	known as deep as 20 ft (6 m), probably greater locally.
Internal controls	Fragment size, type of cement, jointing, extent of exposure.	Bedding configuration, type of cement, jointing, extent of exposure.	Type of cement, plant roots, fragment size, jointing.	Bedding configuration, type of cement, type of overburden.	Jointing, type of cement, plant roots.	Jointing, shrink-swell capability, organic debris, plant roots.	Jointing, bedding, type of cement.	Jointing, strong shrink-swell capability of clays; no clay mineralogy.
Type	Mechanical disintegration.	Mostly mechanical disintegration, following chemical weathering of feldspars to clay.	Mechanical disaggregation.	Mechanical disaggregation; minor shrinkage upon drying after saturation.	Shrinkage cracking when drying, and disaggregation.	Mechanical and chemical: removal of large grains by erosion, and clay alteration.	Mostly mechanical disintegration, some chemical.	Principally mechanical disintegration, owing to the expansive clays.
Weathering products Color	Very light yellowish gray to white.	Light yellowish gray, light reddish tan, grayish orange pink.	Dark brown, dark reddish brown, medium yellowish brown.	Color generally lighter than in unweathered rocks.	Generally much lighter than unweathered rocks; commonly very light gray to light grayish brown.	Generally very light gray; commonly light shades of tan and green.	Generally yellowish brown to reddish brown, usually darker than fresh rock.	Dark to very light gray and light grayish brown.
Character of the weathered surface	Loose sandy boulder gravel.	Loose sandy pebbly gravel; noncohesive surficial deposit.	Loose sandy boulder gravel and noncohesive sand.	Noncohesive fine sand, covering smooth rounded bluffs and slopes.	Smooth slopes covered with disaggregated clay blocks.	Rubbly "popcorn" surface composed of blocky clay fragments with slight cohesion.	Small rectangular loose blocks of sandstone; loose noncohesive sand; rounded smooth bluffs and slopes.	Small rectangular blocks of claystone; "popcorn" surface. Tabular clay-particle agglomerates with little cohesion.
Shape or size of weathered fragments	Medium sand to rounded rectilinear boulders.	Fine sand to coarse gravel; local pebbles and cobbles.	Well-rounded pebbles and cobbles as large as 4 in (0.1 m), and fine to medium loose sand.	Rounded to angular sandstone boulders and noncohesive sand grains.	Small crumbly blocks of clay; locally "popcorn" surface occurs; puffy ground in areas of expansive clays.	Rounded to blocky very fine to fine equant noncohesive aggregates of clay.	Angular to subrounded blocks of sandstone; loose sand.	Incipient breakdown to loose clay and silt with many angular pebble-sized blocks of clay.
Physical changes	Loses hardness and cohesion.	Loses hardness and cohesion.	Loss of hardness and cohesion.	Loses hardness and cohesion; fine grains removed by water and wind.	Loses hardness and cohesion, disaggregates to very small incipiently blocky pieces.	Loses hardness; shrinkage cracks appear; blocks disaggregate.	Loss of hardness and cohesion; andesite pebbles disintegrate.	Loss of hardness and cohesion, destruction of bedding.
Chemical/mineralogical changes	Unknown.	Feldspar changes to clay; micas slowly decompose.	Oxidation of iron.	Oxidation of iron, decomposition of micas.	Local Na-K ion exchange suspected; slow decomposition of mica; iron oxidation.	Local Na-K ion exchange suspected; iron-ion valence changes in oxidation and reduction.	Oxidation of iron and organic constituents.	Probable Na-K ion exchange; adsorption of water by clays; oxidation of iron.
Soil-zone development	Thin stony gravelly sandy residual soil, calcareous, very porous; commonly less than 1 ft (0.3 m) deep.	Generally very thin stony and gravelly residual soil, very porous; depth commonly less than 1 ft (0.3 m).	Generally very thin sandy rocky residual soil, poorly developed. Fine grains mostly removed by wind. Depth 1-3 ft (0.3-1 m).	Sandy silty clayey calcareous residual soil, moderately porous; depth commonly 1-2 ft (0.3-0.6 m).	Clayey calcareous silty slightly sandy residual soil, locally stony; depth 2-4 ft (0.6-1.2 m). Strongly developed Cca zone.	Clayey silty noncalcareous gummy residual soil; locally sandy; depth as much as 10 ft (3 m); Cca zone poorly developed.	Loose thin stony sandy clayey silty calcareous acidic residual soil. Mostly 1-2 ft (0.3-0.6 m) deep.	Heavy dense gummy silty clay, calcareous, slightly sandy. Commonly as deep as 10 ft (3 m).
Interpreted origin of deposits	Alluvial fans and stream deposits, flowing southwest to northeast.	Alluvial fans, stream deposits, and flood-plain deposits, flowing from granite highland (to southwest) toward northeast.	Alluvial fan deposits.	Coalescing stream-channel deposits; local flood-plain deposits of silt and clay.	Flood-plain and swamp deposits in meandering-stream environment.	Flood-plain and swamp deposits in meandering-stream environment.	Alluvial fans, colluvium; some landslide deposits; coalescing stream deposits.	Alluvium, colluvium; local landslide deposits.
Mode of occurrence Geographic distribution	Only in southern part of map area; highest unit in geologic section.	Occurs throughout southern half of map area in very thick zones and single beds.	Single deposit in highland area, south part of map area.	Cyclic deposits in southeast three-quarters of map area.	Cyclic deposits in southeast three-quarters of map area.	Mostly in southern part of map area, south of County Line Road.	In northern part of map area.	Single beds interbedded with Dawson beds in southern part of the map area; widespread in northern part.
Major landforms	Caprock of high mesas; bluffs, cliffs, and other abrupt slopes.	In lowland: low flat-topped gently sloping ridges; in highland: steeply sloping hills and sheer bluffs.	Caprock of highland mesa near south-central part.	Low flat to gently rolling hills and low-angle foreland slopes.	Low flat to gently rolling hills and low-angle foreland slopes.	Low-angle slopes between more erosion-resistant units.	Low hills and gently sloping ridges; low rounded bluffs.	Steep slopes where protected from erosion by overlying resistant units; low rills and valley slopes.
Dominant gradational agent	Sheetwash and rockfall.	Sheetwash; streamflow; local rockfalls.	Sheetwash, downslope creep, local rockfalls.	Sheetwash and streamflow.	Sheetwash and streamflow; local landslides.	Sheetwash and streamflow; local landslides.	Mostly streamflow.	Streamflow, sheetwash, landslides.
Stability of natural slopes	Stable in all known slopes, except where undermined by erosion.	Stable in all known slopes, except where undermined by erosion or quarrying.	Unstable due to weak, easily eroded cement and tendency to weather to noncohesive pieces.	Stable in all known slopes.	Inherently unstable in slopes steeper than about 1:1; highly unstable when saturated.	Moderately stable in all known slopes; inherently unstable when saturated.	Stable in all known slopes, except where undermined by erosion.	Unstable on slopes steeper than 1:1; inherently unstable when saturated. Colluvium on claystone is unstable on any slope.
General comments	Moderately permeable, moderate internal drainage. Furnishes large blocks of rock to colluvium on slopes below mesas. Disaggregates slowly after exposure. Water-trapping pothole "tanks" common on exposed bedding surfaces. Calcareous. Laminar particles, firm cementation, and encrustations limit use as concrete aggregate. Locally used for decorative stone. Trafficable under all conditions. Ponderosa pines flourish on unit.	Moderately to highly permeable; springs commonly issue from bedding surfaces and from contacts with claystone or fine-grained sandstone interbeds. Thick zones on map are characterized by mostly arkosic pebbly sandstone with minor interbeds and lenses of claystone and fine-grained sandstone. Arkose is easy to moderately difficult to excavate, easy to crush, and commonly is used to surface secondary roads. High water table on north-facing slopes. Noncalcareous. Feldspar and petrified-wood content limit use as concrete aggregate. Easily trafficable when dry. Ponderosa pines and yucca plants flourish on unit.	Highly permeable, high internal drainage. Sheds loose rocks onto colluvium on slopes below outcrops. Local high iron-oxide content may cause corrosive ground water. Component rocks probably useful for crushed stone, decorative stone, building stone, or mortar sand. Noncalcareous. Disintegrates slowly after exposure. Trafficable by common wheeled vehicles under all conditions. Ponderosa pines flourish on unit.	Moderately permeable, low internal drainage. Weathered sandstone becomes very soft and muddy when saturated. When wet, trafficability is very difficult to common wheeled vehicles; easily trafficable when dry. Widespread aquifer. Slightly calcareous. Easily excavated, but iron content may limit use as mortar sand. Very tough and resistant to pick blows on weathered outcrops.	Low permeability, low internal drainage. Very plastic when wet. Locally contains clay with critical swelling-pressure potential. Springs issue from upper surfaces where unit is overlain by sandstone or conglomerate. Slakes rapidly on exposure. Slightly calcareous. Local aquiclude. Locally quarried for refractory clay. When wet, trafficability very difficult to common wheeled vehicles.	Low permeability, low internal drainage. Very plastic when wet. Local aquiclude. Locally contains clay with critical swelling-pressure potential. Slakes rapidly on exposure. Possible use as refractory or ceramic clay. Deposits commonly contain internal slickensided surfaces, indicating inherent instability. When wet, trafficability very difficult to common wheeled vehicles.	Moderately to highly permeable, moderate internal drainage. Commonly contains springs. Contains high percentage of volcanic rock fragments. Very calcareous, locally very heavily stained by iron oxide. Disaggregates rapidly on exposure. Locally contains expansive clay. Trafficability good to moderately difficult to common wheeled vehicles under all but most severe conditions. Local aquifer, but heavy iron-oxide content probably precludes culinary use. Not known to be commercially usable for construction materials.	Slightly permeable, low internal drainage. Extremely plastic when wet. Clays derived from unit commonly have very high swelling-pressure potential. Landslides are very common on slopes underlain by unit. Local aquiclude. Moderately to slightly calcareous. When wet, untrafficable to common wheeled vehicles.

GEOLOGIC MAP AND ENGINEERING DATA FOR THE HIGHLANDS RANCH QUADRANGLE, ARAPAHOE AND DOUGLAS COUNTIES, COLORADO

By

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