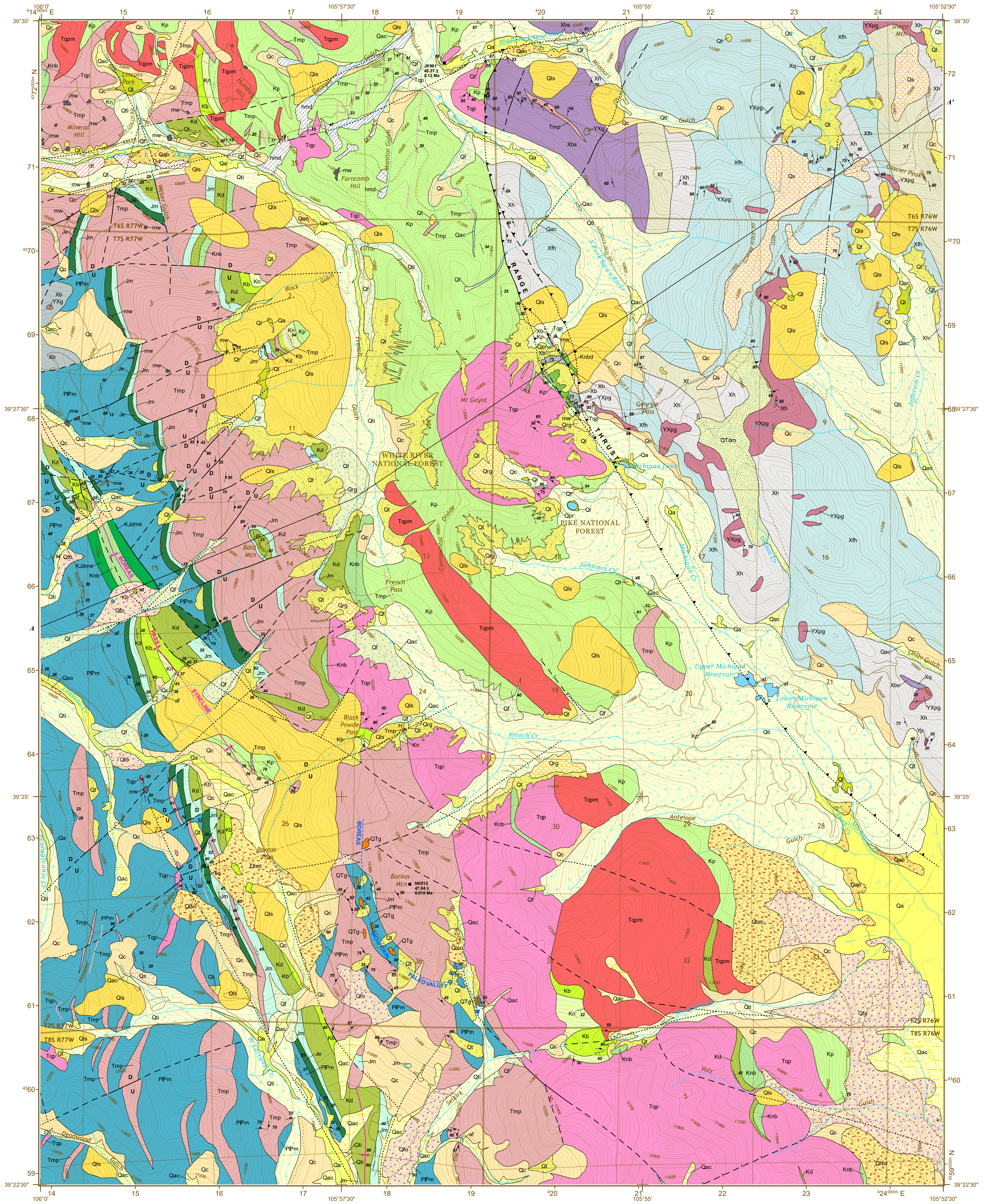
COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

GEOLOGIC MAP OF THE BOREAS PASS QUADRANGLE
PARK AND SUMMIT COUNTIES, COLORADO
OPEN-FILE REPORT 17-06
PLATE 1 OF 2



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

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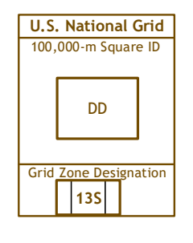
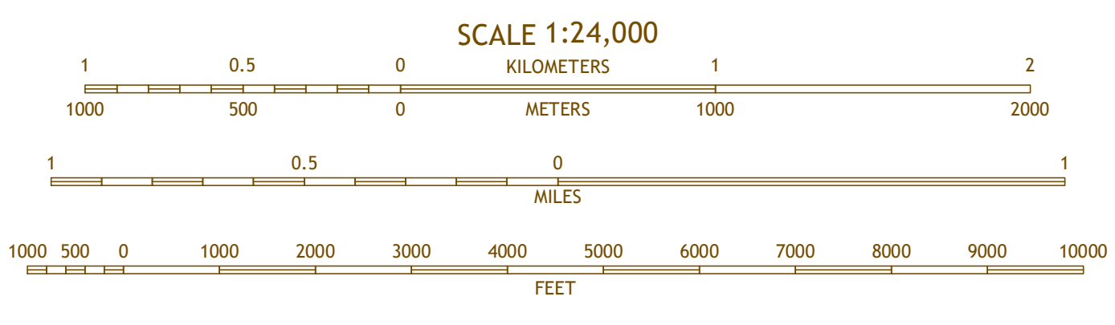
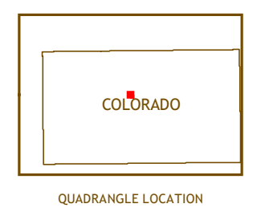
Contours..National Elevation Dataset, 2002
Roads..U.S. Census Bureau, 2015-2016
Roads within US Forest Service Lands.......FSTopo Data with limited Forest Service Updates, 2012-2016
Names...GNIS, 2016
Hydrography...................................National Hydrography Dataset, 2013
Boundaries.....................................Mulitple Sources; see metadata file, 1972-2016
Public Land Survey System...................BLM, 2011
Wetlands..FWS National Wetlands Inventory, 1977-2014

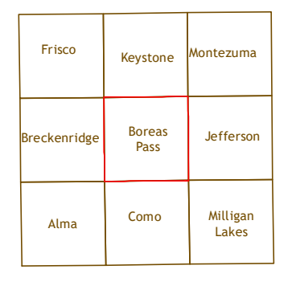




CONTOUR INTERVAL 40 FEET



QUADRANGLE LOCATION



ADJOINING QUADRANGLES

Geology mapped in 2016
GIS and cartography by Pangaea Geospatial

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Cooperative Geologic Mapping Program under STATEMAP agreement G16AC00189.

GEOLOGIC MAP OF THE BOREAS PASS QUADRANGLE, PARK AND SUMMIT COUNTIES, COLORADO

By John W. Keller, Karen J. Houck, Erinn P. Johnson, Noah H. Keller, Matthew L. Morgan, Daniel P. Miggins, and George F. Klemmick
2017

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (uppermost Holocene)** — Earth materials emplaced to construct the historic Boreas Pass rail line and the existing road, and small dams along Michigan Creek. Estimated thickness is 3-40 ft (1-12 m).

dt **Dredge tailings (uppermost Holocene)** — Coarse, dominantly rounded and subrounded gravel derived from historic dredging operations in the early- to mid-1900s along French Gulch (Parker, 1974). Cobble-size clasts are dominant in most surface exposures. Gravel is loose, unconsolidated, and prone to slumping. Estimated thickness is 3-25 ft (1-8 m). Unit is a potential source of high-quality construction aggregate and decorative stone.

hmd **Hydraulic mine disturbance (uppermost Holocene)** — Areas of disturbed soil, colluvium, and the uppermost fractured bedrock caused by hydraulic mining for gold from the late 1800s to the early 1900s in the northwestern part of the quadrangle.

mw **Mine waste (uppermost Holocene)** — Waste rock from historic mines and mineral exploration workings. Typically consists of pebbles and cobbles of hydrothermally altered and iron-stained rocks in a sparse matrix of finer-grained sediment derived from the weathering and disaggregation of softer rock. Unit is unconsolidated and is prone to rilling and mass wasting. Estimated thickness is 3-30 ft (1-9 m).

ALLUVIAL DEPOSITS

Qa **Stream-channel, floodplain, and low-terrace alluvium (Holocene and Upper Pleistocene)** — Clast-supported, unconsolidated, moderately to well-rounded pebble, cobble, and locally bouldery gravel in a silty sand matrix. Deposits are locally interbedded with, and commonly overlain by, overbank deposits consisting of sandy silt and silty sand. Locally overlain by 1-3 ft (0.3-1 m) of organic-rich sediment, which may include peat. Includes low-terrace alluvium that rests a maximum of 10 ft (3 m) above modern stream levels. Estimated thickness is 3-20 ft (1-6 m). Unit is a potential source of high-quality construction aggregate, and may locally contain pockets of placer gold. Unit Qa is prone to flooding during sustained, heavy rain events and during periods of snowpack melt.

Qao **Old terrace alluvium and outwash gravel (Upper to Middle Pleistocene)** — Clast-supported, unconsolidated to poorly consolidated, moderately to well-rounded cobble, pebble, and locally boulder gravel in a silty sand matrix underlying small terraces up to 30 ft above modern stream levels. Clasts are more weathered and soil horizons are more developed than in younger terrace alluvium. Estimated thickness is 3-25 ft (1-8 m). Unit is a source of high-quality construction aggregate, and may locally contain pockets of placer gold.

QTg **Fluvial gravel of the Boreas Mountain paleovalley (lower Pleistocene to Upper Tertiary?)** — Small, isolated remnants of coarse, fluvial gravel exposed in several subtle topographic saddles and shoulders high on the western slopes of Boreas Mountain, and in one outcrop in upper Selkirk Gulch that may be down-dropped by faulting. Deposits partly define a feature herein named the Boreas Mountain paleovalley, which is aligned N-S to NW-SE along the western and southern sides of Boreas Mountain, near the contact between monzonite porphyry and Maroon Formation. Deposits are dominantly clast supported and consist of moderately to strongly weathered, subrounded to well-rounded pebble, cobble, and sparse small boulder gravel in a moderately lithified matrix of light greenish-gray, medium- to coarse-grained, subrounded to subangular sand. Clasts include several types of Tertiary and Cretaceous (?) intrusive rocks, Dakota Sandstone, Maroon Formation sandstone and conglomerate, hornfels, and Proterozoic metamorphic and igneous rocks. Some Tertiary and Cretaceous (?) igneous clasts are derived from distal sources, while others closely resemble Eocene porphyritic intrusive rocks mapped on and adjacent to this quadrangle. Sparse measurements of bedding attitudes in thin, discontinuous sand layers indicate the possibility of 5-10 degrees of post-deposition, down-to-the-east tilting that potentially is related to late Cenozoic extension or regional differential uplift. Estimated present thickness of these eroded remnants is 3-20 ft (1-6 m). Due to limited extent and poor access, unit QTg is not considered a significant source of construction aggregate. A composite sample of sand and gravel from several locations was panned to determine if placer gold was present; no gold was found.

LACUSTRINE DEPOSITS

Ql **Lacustrine deposits (Holocene to Middle? Pleistocene)** — Unconsolidated silt, sand, clay, pebbles, and organic material deposited in small lakes and ponds in some glaciated valleys and cirque basins. The deposit in Lincoln Park in the northwestern part of the quadrangle was formed due to damming of the south-flowing Rich Gulch drainage by till and ice from the French Gulch glacier during the Pleistocene. Estimated thickness is generally 3-10 ft (1-3 m), but possibly as thick as 20 ft (6 m) in Lincoln Park.

MASS-WASTING DEPOSITS

Qc **Colluvium deposits (Holocene and Upper Pleistocene)** — Poorly sorted, dominantly matrix-supported, unconsolidated, nonstratified to coarsely stratified silt, sand, clay, and rock fragments on mainly moderate slopes and along the margins of valleys. Clasts are angular to subangular and range in size from pebbles to boulders. Material mobilized, transported, and deposited primarily by gravity, but commonly assisted by sheetwash and freeze-thaw processes. In places, unit Qc may include old landslide deposits that have been extensively modified by erosion. Estimated thickness is 3-25 ft (1-8 m). May be a source of low-quality construction aggregate and fill material. Unit is locally subject to future slope movements and rockfall events.

Qt **Talus deposits (Holocene and Upper Pleistocene)** — Angular and subangular, non-consolidated rock debris ranging in size from cobbles to boulders as large as 8 ft (2.4 m), deposited on and at the base of steep slopes. Talus is derived from cliffs primarily by rockfalls, rockslides, and snow avalanches. Includes both active talus deposits and older, stabilized talus with vegetation. Estimated thickness is 3-75 ft (1-23 m). Areas of scree (rock rubble) are also common in the map area on steep slopes that are not subjacent to cliffs or steep outcrops from which rocks could fall. These deposits were not usually mapped as Qt because they are typically less than 5 ft (1.5 m) thick and are the product of frost-wedging of bedrock rather than mass wasting and are properly referred to as block slopes or felsenmeer. Unit is subject to future rockfall events and may be prone to localized debris flows.

Qls **Landslide deposits (Holocene and Upper Pleistocene)** — Non-sorted, nonstratified, heterogeneous mixtures of surficial deposits and fragmented bedrock in a wide range of clast sizes. The matrix and the lithologies and sizes of rock fragments in landslides vary according to the type of parent material involved. May contain intact blocks of bedrock more than 50 ft (15 m) long. All areas underlain by Benton Shale (Kb) and Niobrara Fm (Kn) are very susceptible to landsliding. Steep to moderate slopes underlain by the Morrison Formation (Jm), Pierre Shale (Kp), and Maroon Formation (PIPm) are also susceptible to landslides. Fault zones in steep terrain in any bedrock are susceptible to landslides. In places above timberline, landslides may include material that was affected by solifluction and frost creep. Unit Qls may include areas of exposed bedrock on basal slip planes and in headscarps. Estimated thickness ranges from 3-200 ft (1-60 m).

Qlso **Old landslide deposits (Upper to Middle Pleistocene)** — Similar in composition and form to unit Qls, but more subdued by erosion. Geomorphic features that are common in more recent landslides, such as lobate topography and exposed headscarps, are often unrecognizable. Old landslides are also more dissected by erosional gullies than are recent landslides. Some areas mapped as colluvium (Qc) may be partly composed of older landslide debris. Estimated thickness ranges from 3-150 ft (1-45 m).

ALLUVIAL AND MASS-WASTING DEPOSITS

Qac **Alluvium and colluvium, undivided (Holocene and Upper Pleistocene)** — Unconsolidated gravel, sand, and silt in debris fans, stream channels, floodplains, and lower reaches of adjacent hillslopes. Consists of poorly to moderately sorted, interbedded alluvium and unsorted, matrix-supported, pebbly, cobbly, and locally bouldery colluvium. Includes stream-channel, low-terrace, and floodplain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and colluvium deposits on lower slopes adjacent to the drainages. May also include sheetwash deposits. May be a source of low- to medium-quality construction aggregate and fill material. Estimated thickness is 3-25 ft (1-8 m).

Qf **Debris-fan deposits (Holocene and Upper Pleistocene)** — Poorly sorted, unconsolidated, clast- and matrix-supported, sandy to silty gravel in fan-shaped, lobate, and nearly linear deposits within and at the mouths of steep drainages. Clasts are usually angular to subangular and range from pebbles to large boulders, depending on source area bedrock. Boulders the size of small houses are present in fans derived from erosion of Proterozoic biotite-sillimanite gneiss (Xbs) on the very steep slopes north of the Middle Fork of the Swan River near the northwestern quadrangle boundary. Unit Qf is primarily deposited by debris flows and runoff from intense rain events and rapid snowmelt, processes that are ongoing and potentially hazardous to human-made structures. Locally includes significant debris deposited by snow avalanches. May be a source of construction aggregate and fill material. Estimated thickness is 3-80 ft (1-25 m).

Qfo **Old fan deposits (Pleistocene)** — Similar to unit Qf but dissected by post-depositional erosion, and may be partly covered by younger alluvial, colluvial, or glacial deposits. May be a source of construction aggregate and fill material. May be subject to future debris-flow events. Estimated thickness 3-80 ft (1-25 m).

PERIGLACIAL DEPOSITS

Qpr **Protalus rampart deposits (Holocene and Upper Pleistocene)** — Unsorted, nonstratified, unconsolidated, angular, cobble- to boulder-size rock debris (talus) that form slope-parallel, arcuate ridges at the downslope edge of areas that have historically been the sites of long-lasting snow or ice fields. Rock debris is derived from cliffs or very steep, rocky slopes directly above the snow or ice fields. Estimated thickness is 3-50 ft (1-15 m).

Qs **Solifluction deposits (Holocene and Upper Pleistocene)** — Unconsolidated, nonstratified, angular to subrounded pebbles, cobbles, and boulders in a sandy and silty matrix on gentle to moderate slopes mainly above treeline. Locally contains areas of cobble- to boulder-size clasts free of matrix material (small blockfields, or felsenmeer). Deposition is the result of slow, down-slope flowage of water-saturated surficial deposits by frost creep and melt-water transport. Unit is characterized by slightly hummocky and lobate ground patterns. Estimated thickness 3-15 ft (1-5 m). May be subject to future rockfall events.

Qrg **Rock glacier deposits (Holocene and Upper Pleistocene)** — Hummocky, lobate to tongue-shaped deposits having a surface veneer of mostly angular boulders and cobbles devoid of matrix material. The bouldery and cobbly veneer is inferred to cover a thicker mass of rock rubble with interstitial silty and sandy matrix. The rock rubble and matrix below the surface may be frozen (permafrost) or ice-cemented and may overlie an ice core. The frontal slopes of rock glaciers are at or near the angle of repose. Includes lobate rock glaciers along valley sides, and tongue-shaped rock glaciers in cirque basins. Includes both active and inactive rock glaciers. Unit may be prone to slow, downslope movement and collapse from melting ice. Estimated thickness is 10-100 ft (3-30 m).

GLACIAL DEPOSITS

Qti **Glacial till, undivided (lower Holocene to Middle Pleistocene)** — Heterogeneous deposits of poorly sorted, nonstratified to poorly stratified, unconsolidated to poorly consolidated, mostly matrix-supported cobble, pebble, and boulders in a silty-sand or sandy-silt matrix deposited by ice in ground, lateral, and end moraines. May locally include lenses of clast-supported gravel transported by meltwater adjacent to ice. Weathering of clasts and soil development is highly variable, and local variations may be due to the age difference between Late Pleistocene Pinedale deposits and Middle Pleistocene Bull Lake deposits. May be a source of low- to medium-quality construction aggregate and fill. Estimated thickness is 3-100 ft (1-30 m).

DIAMICTON DEPOSITS

QTdm **Diamicton (lower Pleistocene to upper Tertiary?)** — Diamicton is mapped in a single, 1.5-mile-long (2.4 km) deposit of undetermined origin on and south of the Continental Divide east of Georgia Pass. The diamicton consists of unsorted, nonstratified to poorly stratified, unconsolidated to poorly consolidated, subangular to subrounded pebbles, cobbles, and boulder gravel in a matrix of silty sand and pebbly, granular sand. The deposit is dominantly matrix supported but may be locally clast supported. Most boulders are less than 5 ft (1.5 m) long, though some on the western side of the deposit are as long as 12 ft (4 m). Clasts are moderately to strongly weathered and many are broken, and consist of Proterozoic metamorphic and igneous rocks. The deposit forms part of the headwalls of two east- and southeast-facing glacial cirques and was exposed and partly eroded by glaciation; the deposit therefore predates at least the most recent major Pleistocene glaciations. Estimated maximum thickness is 120 ft (37 m).

Q **Surficial deposits, undivided (Holocene and Pleistocene)** — Shown only on cross section

BEDROCK GEOLOGY

TERTIARY INTRUSIVE ROCKS

Tqpm **Quartz monzonite porphyry - megacrystic variety (Eocene)** — Occurs primarily as sills and possible laccoliths of varying thickness. Gray to light bluish-gray quartz monzonite porphyry containing 3-15% prominent, often large phenocrysts (megacrysts) of orthoclase 0.5-8 cm long, and 3-15% rounded and nearly equant phenocrysts of quartz 3-10 mm in diameter. Weathers light brown and orange-brown. The megacrysts are set in a porphyritic matrix with up to 15% phenocrysts of subhedral to anhedral plagioclase 2-10 mm long and 1-3% biotite phenocrysts 1-3 mm long, and sparse hornblende and magnetite in a gray to bluish-gray aphanitic matrix consisting almost entirely of quartz and orthoclase. Minor constituents are apatite, titanite, zircon, allanite, and small quantities of secondary calcite, chlorite, and pyrite (Ransome, 1911). Quartz phenocrysts are often partially resorbed. Megacrysts are variable in size and abundance, and are not always immediately apparent, but the unit is nonetheless typically distinguishable from non-megacrystic quartz monzonite porphyry (Tqp) due to the darker and finer-grained matrix, and darker brown and orange-brown weathering color of the megacrystic unit. Ransome (1911) described in detail the Tertiary igneous rocks of the Breckenridge region, and called what we map as unit Tqpm "quartz monzonite porphyry (silicic type)". Field relations on the adjoining Breckenridge quadrangle (Wallace and others, 2002) and elsewhere suggest that megacrystic quartz monzonite crosscuts quartz monzonite porphyry without megacrysts (Tqp). A similar megacrystic quartz monzonite from the adjoining Frisco quadrangle was dated at 44.1 ± 1.6 Ma by the K-Ar method (Marvin and others, 1989). Unit Tqpm is potentially a source of medium- to high-quality crushed-rock aggregate; however, in many places it is altered and too soft for many applications.

Tqp **Quartz monzonite porphyry (Eocene)** — Occurs mainly as sills and possible laccoliths intruded into sedimentary rocks, and to a lesser extent as dikes, especially where intruded into Proterozoic rocks. Light gray to very light gray on freshly exposed surfaces, light yellowish-gray, tan, and light yellowish-brown on weathered surfaces, porphyritic to nearly equigranular, fine- to medium-grained quartz monzonite and granodiorite. Unit Tqp is composed primarily of plagioclase, orthoclase, quartz, biotite, sparse hornblende, and magnetite. Plagioclase phenocrysts (1-5 mm) comprise 20-30% of the rock, and rounded, equant quartz phenocrysts (1-3 mm) comprise 5-10%. Euhedral biotite (0.5-2 mm) forms 3-10% of the rock and is much more abundant than hornblende. The matrix consists mainly of anhedral orthoclase and quartz. Minor constituents include titanite, apatite, and secondary chlorite and epidote (Ransome, 1911). A few small xenoliths of Proterozoic gneiss were found within a large mass of unit Tqp southeast of Bald Mountain, nowhere near Proterozoic outcrops. Cross-cutting field relationships indicate that unit Tqp is younger than monzonite and diorite porphyry (unit Tmp). Ransome (1911) called what we map as unit Tqp "quartz monzonite porphyry (intermediate type)" for samples collected on Mount Guyot. Geochemical analysis of a sample from the adjoining Como quadrangle (Widmann and others, 2005) indicates that unit Tqp is locally granodioritic in composition. Biotite in sample JK961, from an outcrop of unit Tqp north of Mount Guyot near the Swan River, yielded an $^{40}Ar/^{39}Ar$ plateau age of **45.27 ± 0.12 Ma.** Unit Tqm is potentially a source of medium- to high-quality crushed-rock aggregate; however, in many places it is altered and too soft for many applications.

Tmp **Monzonite and diorite porphyry (Eocene)** — Occurs mainly as sills and possible laccoliths intruded into sedimentary rocks, and to a lesser extent, as dikes, especially where intruded into Proterozoic rocks. Bald Mountain and Boreas Mountain are mostly composed of unit Tmp, which is medium to dark gray and greenish-gray on fresh surfaces, light to medium brown, tan, and brownish-gray on weathered surfaces. The porphyritic nature of Tmp is usually inconspicuous due to the small size and abundance of phenocrysts. Phenocrysts are 5-10 % plagioclase 1-5 mm long, 3-7 % narrow hornblende laths 2-12 mm long, and 2-5 % biotite 1-3 mm across. The slender hornblende phenocrysts are the most prominent and distinguishing feature of unit Tmp. Quartz phenocrysts are absent or extremely sparse. Phenocrysts are set in a fine-grained, nearly aphanitic, holocrystalline matrix dominated by plagioclase, orthoclase, and quartz, but also including biotite, augite, hypersthene, hornblende, magnetite, apatite, allanite, and zircon. Ransome (1911) referred to our unit Tmp as "monzonite porphyry (calcic type)" and found that it ranges in composition from monzonite to diorite. The greenish hue common on freshly broken surfaces is due to alteration of biotite and hornblende, which produces chlorite, epidote, and calcite. Clots and ellipsoid blebs of non-resistant, biotite-rich material 1-5 cm long locally make up 1-3 % of the rock mass, and form pock-marked surfaces on some weathered outcrops. The origin of these clots is not known. Hornblende in sample NK012, from an outcrop of unit Tmp near the summit of Boreas Mountain, yielded an $^{40}Ar/^{39}Ar$ weighted mean age of **47.84 ± 0.18 Ma.** Tmp is potentially a source of medium- to high-quality crushed-rock aggregate; however, in many places it is altered and too soft for many applications.

MESOZOIC AND PALEOZOIC SEDIMENTARY ROCKS

Kp **Pierre Shale (Upper Cretaceous)** — Generally very poorly exposed because it is easily eroded and usually concealed by surficial debris. Dominantly medium to very dark gray and dark brownish-gray, moderately fissile shale with thin interbeds of grayish-brown, fine-grained calcareous silty sandstone and shaly siltstone. Basal part of the unit is calcareous. Most of the exposures in the map area correlate with the thick, shale-dominant lower part of the formation as described on the adjoining Frisco, Keystone, and Como quadrangles (Kellogg and others, 2002; Widmann and others, 2002 and 2005). However, in the north-central part of the map area adjacent to the Williams Range thrust, between the northern quadrangle boundary and Mount Guyot, light- to medium-brown and brownish-gray, fine-grained silty sandstone, shaly siltstone, and shale of the middle part of the unit are present. These sandy units are thinly bedded, flaggy to blocky weathering, and well indurated. Contact metamorphism, particularly in the area around Mount Guyot, produced extremely hard and compact dark-gray to black hornfels that weathers dark reddish-brown and produces angular, cobble-sized talus with sharp edges. Hornfelsed Pierre Shale forms spectacular protalus rampart deposits. Total stratigraphic thickness in the map area is indeterminate due to complex faulting, numerous igneous intrusions, and surficial cover. Based on estimates in adjacent quadrangles, thickness is likely to be 1000 to over 2000 ft (244- 610 m). Highly prone to landslides in the map area, except where strongly affected by contact metamorphism. Prone to swelling soils and heaving bedrock where bentonitic clay is present.

Kn **Niobrara Formation (Upper Cretaceous)** — Poorly exposed in the map area. Includes the upper Smoky Hill Shale Member and the lower Fort Hays Limestone Member (not mapped separately). The Smoky Hill Shale Member consists of light to medium gray, platy- to chippy-weathering, calcareous shale and shaly limestone. It weathers to a characteristic light yellowish-gray to very light-gray color. The Smoky Hills Shale Member is estimated to be 300-450 ft (91-137 m) thick where better exposed in adjoining areas. The Fort Hays Limestone Member is gray to light gray, blocky, relatively resistant, micritic limestone beds a few inches to a few feet thick, with interbeds of less resistant calcareous shale that weathers light yellowish-gray. Kellogg and others (2002) reported inoceramid bivalves in the Fort Hays Member in the adjacent Frisco quadrangle. The Fort Hays Limestone Member is 20-33 ft (6-10 m) thick where better exposed on adjacent quadrangles. It conformably overlies the Benton Shale. The Niobrara Formation, along with the underlying Benton Shale, was preferentially intruded by numerous Tertiary igneous bodies in the map area, and it is often deformed by faults and folds. Thus, the actual stratigraphic thickness in the map area is indeterminate. Unit Kn is extremely prone to landslides in the map area, which often initiate along slip planes in the underlying Benton Shale.

Kb **Benton Shale (Upper Cretaceous)** — Very poorly exposed in the map area. Chiefly dark-gray, black, and dark grayish-brown, non-resistant, wavy-bedded, fissile, carbonaceous shale interbedded with dark grayish-brown to medium-gray, rusty-weathering, calcareous siltstone and silty sandstone, dark-gray to dark brownish-gray, thin-bedded, fetid, crystalline limestone in beds 1-5 ft (0.3-1.5 m) thick near the top of the formation, and 1-3 in (2-8 cm) beds of fine-grained gray quartzite near the base of the formation. Shale in unit Kb is usually darker and softer than Pierre Shale, is commonly wavy bedded and calcareous, and locally contains thin veinlets of gypsum. Kellogg and others (2002) reported fish scales in some of the shale. Conformably overlies the Dakota Sandstone. Benton Shale was preferentially intruded by Tertiary igneous bodies in the map area, and it is often strongly deformed by faults and folds. Thus, the actual stratigraphic thickness in the map area is indeterminate. Based on estimates in adjacent quadrangles (Kellogg and others, 2002; Widmann and others, 2002 and 2005), unit Kb in the map area is probably 250-360 ft (76-110 m) thick where not disturbed by faults, folds, or intrusions. Extremely prone to landslides in the map area due to the abundance of soft, clay-rich, carbonaceous shale beds. Also prone to swelling soils and heaving bedrock.

Knb **Niobrara Formation and Benton Shale, undivided (Upper Cretaceous)** — Mapped in strongly structurally deformed areas, areas obscured by surficial deposits, and in areas with difficult access where the formations were interpreted visually from a distance and with satellite imagery. Unit Knb is susceptible to landslides and prone to swelling soils where bentonitic clay is present.

Kd **Dakota Sandstone (Lower Cretaceous)** — Mostly poorly exposed in the map area due to cover by surficial deposits. Consists chiefly of light- to medium-gray, white, and light yellowish-brown, fine- to medium-grained, well-sorted, resistant quartzite and well-indurated quartz sandstone. Medium- to thick-bedded and crossbedding is common. Weathers light gray to white, and is rusty orange-brown or dark red where stained with limonite or hematite. Locally forms ledges and small cliffs. Thin beds of black shale are present in the middle part of the formation. Thin beds and lenses of conglomerate occur at and near the base. Conglomerate clasts are typically composed of well-rounded granule- to pebble-sized quartz and chert. Quartzite and sandstone beds typically erode into angular to subangular, cobble- to small boulder-size fragments. The Dakota Sandstone is 174 ft (53 m) thick at Rocky Point, 1.3 mi (2.6 km) west of the quadrangle boundary (Lovering, 1934). The Dakota rests unconformably on the Morrison Formation. It is also commonly in contact with Eocene intrusions, which preferentially intruded the underlying Morrison Formation and the overlying Benton Shale. Just west of Georgia Pass, the Dakota Sandstone is only 20 ft (6 m) thick and is in stratigraphic contact with Proterozoic crystalline rocks (Lovering, 1934). At that location, the Dakota is interpreted to be part of an overturned and steeply dipping fault-bounded slab within the Williams Range thrust fault zone. The Dakota is a potential source of crushed rock aggregate, riprap, and decorative stone. It is locally prone to landslides with basal slip planes in shales in the underlying Morrison Formation.

Knbd **Niobrara Formation(?), Benton Shale(?), and Dakota Sandstone, undivided (Upper Cretaceous and Lower Cretaceous)** — Mapped only in a small area between Mount Guyot and Georgia Pass in the Williams Range thrust fault zone. These formations in this area are complexly deformed by both the fault zone and by the intrusion of the Mount Guyot igneous body. Dakota Sandstone at this location is only about 20 ft (6 m) thick and rests stratigraphically on Proterozoic crystalline rocks, with overturned bedding dipping 70-75° east-northeast. Limestone and shale, interpreted to be part of the Niobrara Formation or upper Benton Shale, is locally contact metamorphosed to skarn and hornfels. A mine adit located on the south-facing slope of the cirque basin due west of Georgia Pass, and several prospect pits northwest of the mine, explored magnetite- and sulfide-bearing skarn beds that are oriented subparallel to a strand of the Williams Range thrust, and dip 70-80° east-northeast (overturned). These overturned sedimentary formations and Proterozoic rocks are interpreted to be part of a fault-bounded slab within the Williams Range thrust fault zone. We interpret the very steep easterly dips of the formations, as well as the Williams Range thrust fault zone, in this area are partly due to the forceful intrusion of the adjacent Mount Guyot pluton during Eocene time.

Jm **Morrison Formation (Upper Jurassic)** — The Morrison Formation is generally poorly exposed in the map area due to cover by surficial deposits. Mapped largely on the basis of float. Consists chiefly of non-micaceous, non-fissile claystone and mudstone, with lesser siltstone, sandstone, limestone, and shale. Claystone, mudstone, and shale are variably colored, locally calcareous, and are thin- to thick-bedded. Colors include various shades of gray, olive-green, bluish-green, dark red, and purplish-brown. May be orange and yellow-brown due to limonite stain, especially near intrusive contacts and faults where affected by contact metamorphism or hydrothermal alteration. A 10-20 ft (3-6 m) thick zone containing one or more resistant beds or lenses of micritic limestone generally 1-4 ft (0.3-1.2 m) thick (rarely up to 10 ft (3 m) thick) is characteristic of the lower part of the formation. This zone is 15-50 ft (5-15 m) above the contact with the Entrada Sandstone (unit Je). Limestone beds are interbedded with calcareous shale or mudstone. Limestone is typically medium to dark gray or dark brownish to purplish-gray on fresh surfaces, and weathers light gray and light grayish-brown. The lower part of the middle of the formation contains one or more light yellow to white, medium-grained, crossbedded, silty sandstone beds up to 15 ft (5 m) thick (Lovering, 1934; Kellogg and others, 2002). Thin beds of fine-grained, quartz-rich sandstone are interbedded with mudstone and claystone near the top of the formation. Tertiary intrusives have preferentially intruded the Morrison along upper and lower contacts, and also within the formation. At some places, such as on Bald Mountain, thick sills have separated the Morrison Formation into three parts. Argillaceous rocks are locally contact-metamorphosed to hornfels near intrusives, and limestone beds are locally altered to calc-silicate skarn minerals including garnet, epidote, and magnetite (Lovering, 1934). The total thickness in the map area was not determined due to poor exposure, intrusion of igneous masses, and structural complexity. Based on contact relations, and on measurements in nearby quadrangles, the thickness of the Morrison is estimated to range from 180-300 ft (55-91 m). It is prone to landslides, and some claystone units may be prone to swelling.

Je **Entrada Sandstone (Middle Jurassic)** — Light-gray to pale yellowish-gray, well-sorted, fine- to medium-grained, crossbedded, massive-weathering, calcite- and dolomite-cemented, non-micaceous, quartzose sandstone. Sand grains are subrounded or rounded and are frosted, indicating eolian deposition. Commonly ledge-forming, being more resistant than overlying Morrison and underlying Maroon formations. Outcrops are often brown due to manganese oxide staining. Small brown spots are common in this sandstone and they probably result from weathering of iron- and/or manganese-rich carbonate cement (Wallace and others, 2002). Narrow, sometimes regularly spaced carbonate and/or quartz veinlets are common. Beds with a distinctive nodular weathering pattern are present locally, with nodules being 0.25-1 in (6-25 mm) in diameter. The Entrada is softer, less fractured, more homogeneous, and it tends to erode into larger and less angular blocks than most Dakota Sandstone. Contacts are usually obscured due to surficial cover. The Entrada is regionally highly variable in thickness. Thickness estimates are complicated by igneous intrusions. We estimate thickness varies from 20-180 ft (6-55 m). We assign this sandstone unit to the Entrada Sandstone, as did Kellogg and others (2002) on the Frisco quadrangle. Similar sandstone found south and southeast of the quadrangle was named the Permian Garo Sandstone by De Voto (1965), nomenclature that was used by Widmann and others (2005) and Kirkham and others (2006). Our assignment to the Entrada is supported by Poole and Stewart (1964), who identified Chinle Formation beneath the Entrada on a hill about ½ mile (0.8 km) southwest of Boreas Pass.

KJdme **Dakota Sandstone, Morrison Formation, and Entrada Sandstone, undivided (Lower Cretaceous, Upper Jurassic, and Middle Jurassic)** — Mapped in structurally complex areas and in areas obscured by surficial deposits.

TRc **Chinle Formation (Upper Triassic)** — Mapped only on a hill about ½ mile (0.8 km) southwest of Boreas Pass as a thin unit between the Entrada Sandstone and Maroon Formation. Elsewhere in the map area it is either not present, is not exposed due to surficial cover, or is not distinguishable from the Maroon Formation. The Chinle Formation may be difficult to recognize due to lithological similarities with the Maroon (both are red-bed sequences). Where identified, the Chinle consists of non-micaceous, calcareous, thin-bedded, fine-grained, moderately cemented silty sandstone and siltstone with a platy weathering habit. Some sandstone has distinctive, semi-bright reddish-orange to grayish-orange color. Locally mottled red and gray. The orange color and lack of visible mica helps distinguish the Chinle from the generally dark-red and reddish-brown micaceous rocks that typify the Maroon, and from the light-gray, massive sandstone of the Entrada. Poole and Stewart (1964) measured a 150 ft (46 m) section of Chinle Formation on the hill about ½ mile (0.8 km) southwest of Boreas Pass. We only identified 10-20 ft (3-6 m) of orange- to pink-hued, non-micaceous sandstone and siltstone. The Chinle unconformably overlies the Maroon on the adjacent Frisco quadrangle (Kellogg and others, 2002), and is about 200 ft (61 m) thick at Dillon Dam. The Chinle Formation was not identified on adjacent quadrangles south and southwest of Boreas Pass (Widmann and others, 2005; Kirkham and others, 2006).

PIPm **Maroon Formation (Lower Permian to Upper Pennsylvanian)** — Chiefly red, reddish-gray, reddish-brown, and orange-gray, fine-grained micaceous sandstone; thinly laminated and commonly calcareous siltstone and mudstone; light-gray to pinkish-gray, pebble- to cobble-conglomerate; and a few discontinuous beds of light-gray to reddish-gray limestone generally less than 1 ft (0.3 m) thick. Sandstone beds are arkosic, micaceous, locally conglomeratic, and are tabular and trough cross-stratified (Widmann and others, 2004, 2005). Siltstone and mudstone beds are highly micaceous, and are darker in color than the coarse-grained strata. Sandstone beds consist primarily of grains of quartz, feldspar, biotite altered to hematite, and muscovite. Much of the siltstone is arkosic. Shale beds are rare. Most of the non-resistant beds are clayey siltstone and fine- and very fine-grained argillaceous sandstone (Wallace and others, 2002). Some calcareous siltstone and mudstone beds contain abundant nodules and/or pebbles of gray to reddish-gray limestone. Conglomerate contains well-rounded to subangular pebble-size clasts in a matrix of arkosic sand. Locally, cobble-size clasts are common. Clast lithologies include Proterozoic igneous and metamorphic rocks, quartzite, vein quartz, limestone, sandstone, and chert. Near intrusive contacts, the Maroon is often bleached light gray, light brown, or yellowish-brown. Thickness of the Maroon within the quadrangle is highly variable. In the southern map area, the base of unit is not exposed; however, the exposed section is estimated to be over 3000 ft (914 m) thick. True thickness is indeterminate due to Tertiary intrusions and structural complexity. In the southern part of the Breckenridge quadrangle, the total thickness is estimated to be over 3900 ft (1189 m) where it was deposited on older Paleozoic strata (Wallace and others, 2002). In the northwestern map area, the Maroon rests nonconformably on Proterozoic gneiss and is estimated to be less than 600 ft (183 m) thick. In the northeastern map area, it may have been removed by erosion prior to deposition of the Dakota Sandstone. The Maroon Formation is prone to landslides due to the abundance of mudstones and siltstones.

MESOPROTEROZOIC AND PALEOPROTEROZOIC INTRUSIVE ROCKS

Yp **Pegmatite (Mesoproterozoic)** — Includes a single body in the east-central map area. May also be present elsewhere as isolated masses too small to map separately. White, light gray, and pink, extremely coarse-grained, non-foliated, irregularly shaped to podiform body consisting chiefly of light-gray to clear quartz, white plagioclase, microcline, muscovite books to 6 in wide, and graphic granite. The mapped pegmatite may occupy the nose of an antiform in the enclosing hornblende-plagioclase gneiss (unit Xh). Mesoproterozoic age is assigned based on lack of foliation and lack of biotite, both of which characterize the more widespread pegmatitic granite (unit YXpg). Similar pegmatites elsewhere in central Colorado have been mined for rare-earth elements, feldspar, mica, and quartz.

YXpg **Pegmatitic granite (Mesoproterozoic or Paleoproterozoic)** — Light pinkish-gray, light-gray, and white irregularly shaped intrusions of variable length and thickness. Commonly limonite-stained to a light orange-brown color on weathered and fractured outcrops. Composed mainly of quartz, plagioclase, microcline, and biotite with accessory magnetite and hornblende. Locally contains muscovite and red-brown garnet. Textures are variable over short distances and include medium- to very-coarse-grained granite, pegmatite, and aplite. This unit is not as coarse grained as unit Yp, and is commonly weakly foliated near contacts and where finer grained. Only larger bodies are mapped separately from the enclosing Paleoproterozoic metamorphic rocks. Often forms small, irregular dikes and veins too small to map separately. In some areas, it appears to have preferentially intruded along hinges of folds in metamorphic rocks. Dikes and veins occur both concordantly and discordantly to metamorphic foliation in enclosing gneiss.

YXg **Granite or granodiorite (Mesoproterozoic or Paleoproterozoic)** — Includes two small, poorly exposed intrusions in the northern and northwestern map area. Light pinkish-gray, medium- to coarse-grained, equigranular granite or granodiorite. Non-foliated to weakly foliated. Composed chiefly of quartz, plagioclase, microcline, and biotite.

PALEOPROTEROZOIC METAMORPHIC ROCKS

Xb **Biotite gneiss (Paleoproterozoic)** — Hard, medium- to dark-gray, fine- to medium-grained, well-foliated gneiss consisting chiefly of quartz (30-50%), plagioclase (20-30%), and biotite (10-15%). Microcline, muscovite, hornblende, and sillimanite occur as accessory minerals in variable proportions (Kellogg and others, 2002). Mapped only in a small area near the Boreas Pass Road along the western margin of the quadrangle, and as part of a faulted slab within the Williams Range thrust fault zone near Georgia Pass. In the Front Range, biotite gneiss has been interpreted to be derived from the metamorphism of sandy shale or graywacke (Sheridan and Marsh, 1976). Biotite gneiss is a potential source of high-quality crushed rock aggregate and riprap. It is prone to landslides on steep slopes in glaciated areas, and where it is cut by faults.

Xbs **Biotite-sillimanite gneiss and schist (Paleoproterozoic)** — Medium- to dark-gray, medium-grained, well-foliated gneiss and lesser schist consisting mainly of quartz, plagioclase, biotite, sillimanite, and locally, red-brown garnet. Microcline, muscovite, tourmaline, and cordierite are accessory constituents. Sillimanite occurs as cloudy white to light-gray rods and bundles or flattened elongate pods locally up to about 2 in (5 cm) long (Widmann and others, 2002) that parallel foliation. Foliation is commonly wavy, and locally kink-banded. The masses of sillimanite are slightly more resistant to weathering than the surrounding rock and form bumpy surfaces in outcrops. The abundance of sillimanite suggests that this rock was derived from the metamorphism of an alumina-rich mudstone or shale (Sheridan and Marsh, 1976). Locally grades into migmatite (not mapped separately) where leucosomes comprise 20% or more of the rock mass. Unit Xbs is moderately hard and resistant unit and weathers into massive, subrounded, bouldery outcrops. It is a potential source of riprap and crushed rock aggregate.

Xf **Felsic gneiss (Paleoproterozoic)** — Light-gray, light-tan, and white, medium- to coarse-grained, weakly foliated to well-foliated quartzofeldspathic gneiss. Composed chiefly of microcline, plagioclase, and quartz. Locally, especially where massive or weakly foliated, felsic gneiss contains magnetite up to 0.3 in (0.75 cm) in diameter. Where foliation is more prominent, felsic gneiss contains thin, discontinuous, biotite-rich layers and has little or no magnetite (Widmann and others, 2002). Small amounts of hornblende and garnet may be present locally. Commonly contains layers of hornblende-plagioclase gneiss (unit Xh) that are too thin to map separately. Felsic gneiss is a potential source of high-quality riprap and crushed rock aggregate. It is prone to landslides on steep slopes in glaciated areas.

Xfh **Interlayered felsic and hornblende gneiss (Paleoproterozoic)** — Interlayered dark-gray and light-gray, well-foliated felsic gneiss (unit Xf) and hornblende-plagioclase gneiss and amphibolite (unit Xh) in roughly equal proportions. Also mapped where surficial cover and lack of field data have made separately delineating the constituent units problematic. Individual layers range from a few inches to tens of feet thick. Locally contains sparse layers and lenses of calc-silicate rock (Ruleman and others, 2011). Locally may grade into migmatite (not mapped separately) where leucosomes comprise 20% or more of the rock mass. Unit Xfh is a potential source of high-quality crushed rock aggregate and riprap. It is prone to landslides on steep slopes in glaciated areas.

Xh **Hornblende-plagioclase gneiss and amphibolite (Paleoproterozoic)** — Medium- to dark-gray, black, and dark-green, fine- to medium-grained gneiss consisting of hornblende and plagioclase with lesser quartz, biotite, and pyroxene. Garnet is locally present as an accessory mineral. Local green coloration due to the presence of chlorite and/or epidote as alteration minerals. Weakly to moderately foliated. May be massive with a distinct salt-and-pepper appearance, or faintly layered due to the uneven segregation of light and dark minerals. Amphibolite occurs as massive to weakly foliated, medium- to coarse-grained layers and lenses, usually less than 2 ft (0.6 m) thick, containing 50-90% hornblende. Unit Xh commonly includes layers of felsic gneiss (unit Xf) that are too thin to map separately. Locally grades into migmatite (not mapped separately) where leucosomes comprise 20% or more of the rock mass. Lovering (1935) suggested that hornblende-plagioclase gneiss is derived from the metamorphism of igneous rock intermediate between gabbro and diorite in composition. Unit Xh is a potential source of high-quality crushed rock aggregate and riprap. It is prone to landslides on steep slopes in glaciated areas.

Xq **Quartzite (Paleoproterozoic)** — Includes two small outcrops of medium- to dark-gray, fine- to medium-grained, recrystallized quartzite found in the eastern and northeastern map area. Occurs as thin, discontinuous layers and lenses within Paleoproterozoic gneiss. Very hard, dense, and resistant to erosion. Faint foliation, defined by thin biotite-bearing bands, may reflect relict bedding. Protoliths may be quartzose sandstone, quartz veins, or both. Unit Xq is a potential source of high-quality crushed rock aggregate and riprap, but the quantity of material available on this quadrangle is small.

YX **Metamorphic and igneous rocks, undifferentiated (Mesoproterozoic and Paleoproterozoic)** — Shown only on cross section.

MAP SYMBOLS

Contact — Approximately located

U 19 D **Fault** — Dashed where approximately located, dotted where concealed; U = upthrown side, D = downthrown side; tick mark shows dip of fault plane

Thrust fault — Dashed where approximately location, dotted where concealed; sawteeth on upper plate

Syncline — Identity and existence certain, dashed where approximately located, dotted where concealed

Boreas Mountain paleovalley — Approximately located, arrow shows inferred flow direction. See Geologic History (Plate 2) for explanation.

56 **Strike and dip of inclined bedding** — Showing direction and angle of dip

32 **Estimated strike and dip of inclined bedding** — Showing direction and angle of dip

12 **Strike and dip of overturned bedding** — Showing direction and angle of dip

8 **Strike and dip of fractures and joints** — Showing direction and angle of dip

37 **Attitude of metamorphic foliation** — Showing direction and angle of dip

■ NK012 47.84 ± 0.18 Ma **Numerical age date location** — Showing sample number and approximate age

A A' **Alignment of cross section**

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