GEOLOGIC MAP OF THE DILLON QUADRANGLE, SUMMIT AND GRAND COUNTIES, COLORADO

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Pamphlet to accompany
Miscellaneous Field Studies Map MF-2390
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DESCRIPTION OF MAP UNITS

af **Artificial fill (recent)—**Compacted and uncompacted rock fragments and finer material derived from excavation for Interstate 70. Composes roadbed and embankments along and adjacent to the interstate

Qal **Alluvium (Holocene)**—Unconsolidated silt- to boulder-size, moderately sorted to well-sorted, stratified, clast-supported sediment in modern flood plains, including overbank deposits; larger clasts are moderately rounded to well rounded. Clasts are as long as about 2 m in channel of Straight Creek and 1 m in channel of Blue River. Includes swamp deposits in and adjacent to beaver ponds in North and South Willow Creek valleys. Maximum height of unit above Blue River about 3 m. Maximum thickness unknown, but suspected to be greater than 10 m

Qf **Fan deposits (Holocene and upper Pleistocene)—**Moderately well sorted sand- to boulder-size, stratified gravel in fan-shaped deposits; sand matrix. Deposits are both matrix and clast supported, suggesting varying ratio of water to sediment during transport. Clasts mostly subangular to subrounded and as long as about 2 m; most are considerably smaller. Deposited from side streams of Blue River, South Fork of the Williams Fork River, and Straight Creek. Include minor debris-flow and sheetwash deposits. Most distal deposits adjacent to Blue River are truncated, suggesting that these deposits probably are glacial-outwash deposits of the Pinedale glaciation. Fan deposits west of Blue River mapped by West (1978) as glacial outwash deposits of Pinedale age. Unit elsewhere overlies terrace gravel (unit Qg), so these deposits are probably Holocene in age. As much as about 15 m thick

Qt **Talus (Holocene and upper Pleistocene)—**Angular and subangular cobbles and boulders at base of steep valley walls or cliffs. Sandy matrix rarely exposed at surface. Boulders generally are as large as 2 m, although in places are as large as 10 m. As much as 20 m thick

Qcl **Colluvium and loess, undivided (Holocene and upper Pleistocene)**—Unconsolidated to slightly indurated, mostly massive, dark-brown to light-gray-brown deposits that mantle gently to moderately sloping surfaces; sediment types are mixed by downslope movement; locally stratified. Colluvium contains cobbles and pebbles derived from weathering of bedrock; loess is very fine grained sand, silt, and minor clay. Loess locally mantles colluvial deposits, although it is commonly intermixed by downslope movement. The unit commonly contains poorly to moderately developed soil profile in upper part and includes alluvium in small channels and sheetwash deposits on steeper hillsides. Commonly underlies areas covered by open meadows, sagebrush, and (or) sparse aspen. Unmapped in many areas, particularly where unit is thin and discontinuous. Maximum thickness probably less than 15 m

Qac **Alluvium and colluvium, undivided (Holocene and upper Pleistocene)**—Alluvium composed of unconsolidated silt- to boulder-size, poorly to moderately sorted sediment in narrow channels that are too small to map separately. Alluvium is flanked by colluvial deposits derived from weathering of bedrock and transported by downslope movement. The colluvial deposits are composed of mostly poorly sorted, angular clasts, typically as long as 1 m, in a fine-grained weathered matrix as fine as clay. Colluvium may contain mantle of loess and have a weakly to moderately developed soil profile. Generally less than 10 m thick

Qls **Younger landslide deposits (Holocene and upper Pleistocene)**—Range from chaotically arranged debris to almost intact slump blocks of bedrock. Interpreted to include earth slides, earth flows, rock slides, and debris slides, using criteria of Cruden and Varnes (1996). Surface of deposits commonly hummocky, and a relatively steep breakaway zone is identifiable in each deposit. Units in quadrangle most prone to sliding are older landslide deposits (unit QTls), diamicton (unit QTd), and Pierre Shale (unit Kp). Larger landslide deposits greater than 50 m thick

Qr **Rock-glacier deposits (Holocene and upper Pleistocene**)—Hummocky, lobate deposits of angular boulders and smaller clasts having a frontal slope near the angle of repose; locally active. In places, grade into and include some talus (unit Qt). Maximum thickness about 25 m

Qg **Terrace gravel (Holocene to middle Pleistocene)**—Moderately sorted sand and gravel adjacent to modern flood plain of Blue River and Straight Creek. Clasts as large as 1 m composed of Proterozoic gneiss and, in Blue River Valley, subordinately of Dakota Sandstone, Maroon(?) Formation, and Tertiary intrusive rocks. Clasts larger than about 1 cm are moderately rounded to well rounded. Includes deposits of lower terrace levels along Blue River that were part of active alluvial channel prior to completion of Dillon Dam, just south of quadrangle boundary, in 1962. Three terrace levels mapped by West (1978): a topographically lower Holocene terrace, an intermediate terrace of Pinedale age, and a high terrace of late Bull Lake age. The Pinedale terrace is about 10 m above river level; one colluvium-mantled Bull Lake terrace, about 45 m above river level, is preserved near center of Sec. 22, T. 4 S., R. 78 W. Thickness as great as about 15 m

Qop **Pinedale outwash gravel (upper Pleistocene)**—Unconsolidated clast-supported alluvial deposits consisting of sand- to boulder-size clasts as long as 2 m; cobbles and boulders are moderately to well rounded. Deposited during retreat of glaciers of Pinedale age. Mapped between North and South Willow Creeks (Sec. 3, T. 5 S., R. 78 W.) and adjacent to lower Willow Creek. Thickness unknown

Qtp **Pinedale Till (upper Pleistocene**)—Unsorted and unstratified bouldery till in moraines that have preserved original hummocky topography, commonly containing closed depressions and small ponds. Subrounded to subangular clasts composed entirely of Proterozoic gneiss and plutonic rocks. Soil is thin with little clay development and boulders are generally unweathered. Locally contains minor outwash and colluvial deposits; colluvium increases with elevation. Age of Pinedale deposits in type area in Wyoming is 23-16 ka (Chadwick and others, 1997). Thickness as great as 135 m

Qtb **Bull Lake Till (middle Pleistocene**)—Unsorted and unstratified bouldery till in moraines that have been dissected and rounded; hummocky topography rarely preserved. Subrounded to subangular clasts composed mostly of Proterozoic gneiss and granitic rocks; west of Blue River, Bull Lake Till contains as much as about 5 percent clasts of Dakota Sandstone. Boulders of Proterozoic gneiss and plutonic rock slightly to moderately weathered. Soil is moderately to well developed, commonly with an uppermost black organic-rich zone several centimeters thick (A horizon) over a pale-colored elutriation zone in which clay and iron have been leached (E horizon). E horizon, in turn, overlies an orange-brown zone of clay and iron accumulation (B horizon) which may be as thick as several meters. B horizon overlies unweathered to slightly oxidized till (C horizon). The A horizon may contain eolian silt (loess), and unit may locally be overlain by small areas of alluvium and colluvium. Age of Bull Lake glaciation in type area in Wyoming is 130-95 ka (Chadwick and others, 1997). Thickness may exceed 100 m

Qdf **Debris-flow deposits (upper to lower? Pleistocene)**—Poorly sorted, poorly stratified deposits containing clasts as large as about 2 m long that are composed entirely of Proterozoic crystalline rocks. Matrix not well exposed. Deposits dissected as deeply as about 25 m along Blue River; may correlate with or are older than Bull Lake glacial deposits (Qtb). As much as 30 m thick

Qgo **Older outwash gravel (middle or lower Pleistocene)—**Light-yellowish-brown unconsolidated, moderately rounded to well-rounded, almost massive, pebble- and cobble-size gravel consisting mostly of Proterozoic gneiss and granite; sandy and silty matrix contains much decomposed granite debris (grus) and clay; locally iron stained and Proterozoic clasts partially weathered. Clasts locally matrix supported, suggesting deposits may be, in part, result of hyperconcentrated flow. Overlain by well-developed soil, which includes eolian silt (loess). Mapped as high as 100 m above present Blue River. Mapped by Tweto (1973) as "Older outwash and pediment gravels" of Pleistocene age, although no pediment surface is apparent. Interpreted to be either Bull Lake (at lower elevations) or pre-Bull Lake (at higher elevations) in age. Underlies town of Dillon and surrounding areas. Greater than 20 m thick in places

QTd **Diamicton (middle Pleistocene to Pliocene?)—**Unsorted, angular to subrounded, unstratified, clay- to boulder-size clasts in a deeply weathered orange-brown (clay-rich) matrix. Clasts include about 20 percent Dakota Sandstone and 80 percent Proterozoic granitic rocks and gneiss. Overlain by dark-brown, well-developed soil. Deposit on west edge of quadrangle is interpreted as pre-Bull Lake till by Tweto (1973), but the similar clast composition and morphology at this locality as compared to bouldery gravels of Mesa Cortina (unit QTgm) suggest Tweto's "pre-Bull Lake till" may be an old debris-flow or gravel deposit. Elsewhere, diamicton may consist of till of Bull Lake or older age, older landslide deposits, or older debris-flow deposits. Total thickness unknown, but in places greater than about 80 m

QTgm **Bouldery gravel of Mesa Cortina ("Buffalo placers") (middle Pleistocene to Pliocene?)—** Poorly sorted, poorly stratified to massive, poorly consolidated, light-tan to grayish-orange bouldery deposits underlying much of the east-sloping, dissected surface (Mesa Cortina) near the southwestern corner of the quadrangle. Deposits are deeply weathered, matrix-supported, and contain clasts of Precambrian gneiss and granite, Dakota Sandstone, Maroon Formation, and rare Tertiary dacite porphyry. Boulders of Dakota and Maroon are as large as 5 m across, although most are less than 2 m across; Precambrian boulders are strongly weathered. Matrix is weathered, grus-rich clay, silt, sand, granules, and pebbles. Deposits, mapped as high as 330 m (1,000 ft) above Blue River, are poorly exposed, where they resemble an old till. Interpreted as debris-flow and hyperconcentrated-flow deposits. Clast compositions suggest source is upper Blue River near Breckenridge, more than 10 km south of quadrangle, or from Ten Mile Creek, about 5 km south of quadrangle. Enormous size of some clasts, the deeply weathered character of the deposits, and their distance from source suggests that deposits may be derived from pre-Bull Lake till. The deposit, also known as the Buffalo placers, was first mined for gold by hydraulic methods in the 1870s and 1880s; it was worked intermittently thereafter until 1934 (Parker, 1974). Mapped by Tweto (1973) as Dry Union Formation of Pliocene and Miocene age, but correlation with the well-stratified, well-indurated, mostly alluvial Dry Union Formation of the Arkansas River valley near Leadville (Tweto, 1961) seems unlikely. May correlate with similar auriferous terrace gravels along valley margins and tributaries of Blue River near Breckenridge, approximately 7-10 km south of quadrangle (Ransome, 1911; Kellogg, 2002). Total thickness unknown, but may be more than 100 m

QTls **Older landslide deposits (middle? Pleistocene to Pliocene?)—**Mostly angular fragments of Proterozoic rock in grus-rich matrix that is partially altered to clay. Locally contains relatively unfractured gneiss blocks as long as 30 m, suggesting at least some movement was by downslope creep. All topographic evidence of breakaway zone and original hummocky landslide morphology eroded; some valleys incised as much as 50 m into deposits, exposing underlying Cretaceous rocks. In Bushee Creek, underlying Pierre Shale deformed by landslide movement as much as 10 m below base of deposits. Very extensive in eastern part of quadrangle; underlies over half of west flank of Williams Fork Mountains, obscuring most of the trace of the Williams Range thrust. Where weathering is deep and clast size small, deposits are thickly forested by conifers and aspen. Interpreted to include earth slides, earth flows, rock slides, and debris slides, using criteria of Cruden and Varnes (1996). In places, deposits are remobilized by late Pleistocene and Holocene periglacial activity. Probably locally as thick as several hundred meters

Kp **Pierre Shale, undivided (Upper Cretaceous)**—Dark-gray, grayish-brown, and black fissile marine shale and mudstone in approximately lower 300 m; calcareous in lowest 10-20 m. Grades upward into a sequence of dark-gray and black silty shale and mostly thin, brown, clayey, commonly ripple-laminated, fine-grained to very fine grained sandstone. From top to bottom in quadrangle, divided into three informal members: shale and sandstone member, sandstone member, and lower shale member. Undivided Pierre Shale is mapped where exposures are too poor to determine stratigraphic position. Pierre Shale may have been as thick as about 2,600 m in region. Upper approximately 1,000 m removed by erosion (Izett and others, 1971)

Kpm **Shale and sandstone member**—Black and gray fissile shale, claystone, and subordinate, thin, clayey, very fine grained brown sandstone. Shale predominates. Poorly exposed in most places. Mapped where thin (typically 1-10 cm thick) sandstone beds conspicuously interbedded with shale. Top not exposed, but thickness greater than 500 m

Kps **Sandstone member**—Very fine grained to medium-grained, light-brown, well-indurated, ledgy, feldspathic graywacke that contains about 50 percent quartz, 30 percent feldspar, and about 15 percent green, black, and brown lithic grains. Beds generally are 5-50 cm thick, flaggy to blocky, and locally contain dark-grayish-brown interbedded shale. Sandstone predominates over shale. The member correlates with one of several ledgy, sand-rich sequences described about 30 km north of quadrangle, between 575-945 m above base of Pierre Shale (Izett and others, 1971); these sequences include the Hygiene Sandstone Member (a 30-m-thick blocky-weathering sequence about 915 m above base of formation), the Muddy Buttes Sandstone Member (about 635 m above base), and the Kremmling Sandstone Member (about 575 m above base). The sandstone member also tentatively correlated with 30-m-thick shaly sandstone bed encountered 225 m above base of formation in Harold D. Roberts Tunnel, one to two km south of quadrangle boundary (Wahlstrom and Hornback, 1962)

Kpl **Lower shale member**—Dark-gray, brownish-gray, and black marine shale and mudstone. Lowest 10-20 m is calcareous and calcite veining encountered at basal contact. Locally contains black limy concretions. Bedding indistinct in fresh outcrops; breaks with conchoidal fracture. In weathered outcrops, bedding fissility is visible. Lies comformably below Kremmling Sandstone Member of Izett and others (1971). Member about 575 m thick 30 km north of quadrangle (Izett and others, 1971), but sandstone sequence encountered 225 m above base of unit, less than 2 km south of quadrangle (Wahlstrom and Hornback, 1962), suggests that lower shale member thins to south. Conformable lower contact with underlying Niobrara Formation; mapped above point where weathered light-gray, platy, calcareous fragments, typical of upper Niobrara, no longer visible. About 300 m thick in quadrangle

Kn **Niobrara Formation (Upper Cretaceous)**—Consists of two parts: (1) an upper calcareous shale member (Smoky Hill Shale Member), consisting of gray, platy-weathering, calcareous shale and shaly limestone, becoming generally more shaly upward; weathers light gray; about one km south of quadrangle member is about 138 m thick (Robinson and others, 1974), and (2) a lower blocky, gray micritic limestone member (Fort Hays Limestone Member); beds 5-15 cm thick; commonly contains encrusted inoceramid bivalves; member about 6-10 m thick; weathers light gray; relatively resistant. Formation is conformable above Benton Shale

Kb **Benton Shale (Upper Cretaceous)**—Uppermost 1.5 m is a thin-bedded, black to dark-gray, fetid, resistant, crystalline limestone that has pinch-and-swell structures and contains thin, dark-gray, siliceous siltstone interbeds; interpreted to be equivalent to Juana Lopez Member of the Carlile Shale (Berman and others, 1980). The uppermost limestone overlies about 5 m of dark-gray fetid limestone and dark-brown to gray calcareous, brownish-red (“rusty”) siltstone and shale that, in turn, overlies about 3 m of resistant brownish-gray, fine-grained, rusty, arkosic sandstone, bioturbated at base, that locally contains chert pebbles (probably equivalent to Codell Sandstone Member of Carlile Shale; Berman and others, 1980). The Codell(?) Sandstone Member unconformably overlies mostly dark-brown to black, fissile, rusty shale. Calcareous beds characteristic of the Greenhorn Limestone near Denver (Scott, 1972) were not observed in the area; sequence below Codell(?) is more characteristic of lower Mancos Shale, as described west of area (for example, Merewether and Cobban, 1986). The lower approximately 25 m (equivalent to Mowry Shale of Wyoming) consist of wavy-bedded black shale containing fish scales and, in lowest 3 m, thin (less than 5 cm), fine-grained, gray quartzite beds; sequence is conformable above Dakota Group. Total thickness of unit about 95-110 m

Kd **Dakota Sandstone (Lower Cretaceous)**—Generally consists of three informal members: an upper quartzite member, a middle shale member, and a lower quartzite member. The upper quartzite member is 6-20 m thick and contains an upper sequence of light-gray, commonly cross-bedded, 10-30-cm-thick, quartzite beds, and thin, black, commonly carbonaceous shale interbeds. The basal 2-10 m of the upper member is a massive, resistant quartzite bed. Joint surfaces contain red, orange, and yellow iron oxide encrustations. The middle shale member consists of interbedded dark-gray to black, commonly carbonaceous shale and generally thin- to medium-bedded, medium-grained, equigranular, gray to light-gray quartzite; quartzite beds are as thick as about 2 m. The thickness of the middle shale member is highly variable: 6 to 28 m thick. The lower quartzite member consists of thick (as much as 12 m), massive, medium-grained, grayish-white, well-sorted quartzite with thin dark-gray shale interbeds; quartzite has very prominent iron-oxide coatings on joint surfaces. No chert-pebble beds, characteristic of the lower Dakota elsewhere, were observed in lower member, which is unconformable above Morrison Formation. Thickness of lower member is 20-26 m. The total thickness of the Dakota Sandstone in the Breckenridge area, about 10 km south of map area, is 52-69 m (Lovering, 1934). Total thickness of the Dakota in the Harold D. Roberts tunnel, about 1 km south of the Dillon quadrangle, is 66 m (Robinson and others, 1974)

Jm **Morrison Formation (Upper Jurassic)**—Mostly light-gray and light-greenish-gray, locally calcareous claystone; upper 4 m contains some maroon claystone. The lower half of the formation contains several light-yellow to white medium-grained sandstone beds as thick as about 5 m that commonly contain Liesegang rings (iron-oxide stained layers parallel to joint surfaces) and small (less than 3 mm), orange, limonitic spots. Approximately lower 20 m of formation not exposed in quadrangle. Thickness of formation in the Blue River Valley about 55-79 m (Holt, 1961)

JPu **Entrada Sandstone (Middle Jurassic), Chinle Formation (Upper Triassic), and Maroon Formation (Lower Permian to Middle Pennsylvanian), undivided**—Sequence does not crop out in Dillon quadrangle, although exposed just south in Frisco quadrangle (Kellogg, 2002); shown only in cross sections A-A' and B-B'. Includes the Middle Jurassic Entrada Sandstone (0-55 m thick just south of quadrangle; Holt, 1961) and underlying dark-red to pale-pink conglomerate, sandstone, and siltstone that are greater than 33 m thick in drill holes at Dillon Dam, just south of quadrangle (Wahlstrom and Hornback, 1963). This redbed sequence is correlated in the Frisco quadrangle with the Upper Triassic Chinle Formation and the Lower Permian to Middle Pennsylvanian Maroon Formation (Kellogg, 2002)

Proterozoic rocks

[Grain sizes for both plutonic and metamorphic rocks follow Compton (1962): *fine-grained*, <1 mm; *medium-grained*, 1-5 mm; and *coarse-grained*, >5 mm]

YXu **Middle? and Early Proterozoic rocks, undivided**—Shown only in cross sections

YXp **Pegmatite (Middle? and Early Proterozoic)—**Very coarse grained microcline-plagioclase-quartz-muscovite rock in pods and dikes as wide as about 25 m; mostly much thinner. Feldspar crystals locally longer than 20 cm. Locally grades into quartz veins or aplitic granite. Most pegmatite is associated with late stages of emplacement of rocks of the Early Proterozoic Routt Plutonic Suite, but some may be associated with the Middle Proterozoic Berthoud Plutonic Suite (Tweto, 1987), which is 1,380-1,420 Ma (W.R. Premo, oral commun., 1999)

YXpg **Pegmatite and granite complex (Middle? and Early Proterozoic)—**Approximately equal volumes of pegmatite and granitic rocks; pegmatite bodies are younger than granitic rocks, irregular in shape, and as much as 30 m wide; granitic rocks are in small, irregular-shaped stocks as much as several hundred meters across. Most rocks of this unit are Early Proterozoic, although some pegmatite may be Middle Proterozoic

YXggp **Granitic rocks, biotite gneiss, and pegmatite, undivided (Middle? and Early Proterozoic)**—Complex composed of approximately equal amounts of intrusive rocks and gneiss. Granite and pegmatite form irregular dikes and small intrusive bodies that contain rafts of gneiss as long as several tens of meters in which foliation is generally parallel from one raft to the next. Most rocks are Early Proterozoic, although some pegmatite may be Middle Proterozoic

Rocks of the Routt Plutonic Suite (Early Proterozoic)—Most rocks of the suite, defined by Tweto (1987), are granodiorite and quartz monzonite, but the suite also includes diorite, gabbro, and granite. Age of the suite is 1,700-1,790 Ma (W.R. Premo, oral commun., 1999), slightly older than the 1,667-1,750 Ma given by Tweto (1987)

Xgr **Granodiorite and quartz monzonite**—Gray to light-gray, medium- to coarse-grained, hypidiomorphic to xenomorphic, massive to slightly foliated equigranular microcline-plagioclase-quartz-biotite intrusive rock that exists as irregular-shaped stocks. Accessory minerals are zircon, opaque minerals, apatite, ± muscovite (locally as much as 5 percent), and ± epidote

Xdi **Diorite and quartz diorite**—Dark-gray, medium- to coarse-grained, inequigranular, hypidiomorphic to xenomorphic, massive to weakly foliated biotite-hornblende diorite and quartz diorite. Contains 40-50 percent plagioclase (approximately An_{40}), 5-30 percent hornblende, 5-40 percent biotite, 5-10 percent quartz, 0-10 percent potassium feldspar, 1-3 percent opaque minerals, trace apatite, and 0-2 percent secondary epidote. Forms relatively small, irregular intrusive masses tens to hundreds of meters wide

Xmg **Migmatite (Early Proterozoic)**—Gray, well-foliated biotite gneiss alternating with approximately equal amounts of very light gray to white granitic component in layers ranging from a few millimeters to about 10 centimeters thick. Layers commonly show pinch and swell and in most places are strongly folded. Igneous component interpreted to be injected rather than the product of local diffusion, and derived from granitic bodies. In most places, the gneiss component is biotite gneiss or biotite-muscovite gneiss

Xbg **Biotite gneiss (Early Proterozoic)**—Gray, medium-grained, hypidiomorphic to xenomorphic, well-foliated gneiss containing approximately 25-50 percent quartz, 20-30 percent plagioclase (approximately An_{30}), 0-30 percent microcline, 10-15 percent biotite, 0-15 percent muscovite, 0-5 percent sillimanite, 0-5 percent hornblende, 1-2 percent opaque minerals, and a trace zircon. Generally lacks conspicuous sillimanite and muscovite in hand sample, although these minerals are locally present. Typically contains 5-20 percent migmatitic layers

Xkbg **Microcline-biotite gneiss (Early Proterozoic)**—Gray and pinkish-gray medium-grained, well-foliated gneiss containing approximately 10-20 percent biotite and conspicuous pink microcline-rich layers as thick as 5 cm. Migmatitic; locally contains as much as 40 percent granitic migmatite layers. Mapped at one location along crest of Williams Fork Mountains

Xbmg **Biotite-muscovite gneiss and schist (Early Proterozoic)**—Gray, medium-grained, xenomorphic, well-foliated rock containing 30-60 percent quartz, 20-30 percent plagioclase, 0-10 percent microcline, 10-25 percent biotite, 10-40 percent muscovite, 0-5 percent sillimanite, 1-2 percent opaque minerals, and a trace zircon. Characterized by conspicuous muscovite on foliation planes. Locally contains as much as 40 percent migmatite layers

Xsg **Biotite-muscovite-sillimanite gneiss and schist (Early Proterozoic)**—Gray to light-gray, medium-grained, well-foliated, hypidiomorphic gneiss and schist that contains 25-50 percent quartz, about 20-30 percent plagioclase, 15-25 percent biotite, 5-10 percent muscovite, about 10 percent sillimanite (commonly in fibrous, elongate aggregates that produce light-colored masses as wide as about 1 cm), 1-2 percent opaque minerals, and a trace zircon. Locally migmatitic

Xam **Amphibolite (Early Proterozoic)**—Dark-gray to black, medium-grained, hypidiomorphic, well-foliated rock containing 50-70 percent green hornblende (in thin section), 0-5 percent brown biotite, 25-35 percent plagioclase, 0-10 percent quartz, 1-2 percent opaque minerals, and a trace apatite. Locally migmatitic and commonly contains numerous diffuse, white, plagioclase-rich, felsic segregations

Xqz **Quartzite (Early Proterozoic)**—Gray, medium- to coarse-grained, inequigranular, foliated rocks that contain about 70-90 percent quartz, 10-25 percent plagioclase, and as much as 5 percent epidote (after plagioclase?). Observed as layers as wide as several tens of meters at several localities

GEOLOGIC HISTORY

The geologic history of the Dillon quadrangle spans more than 1.7 billion years. The oldest rocks underlie the crest of the Williams Fork Mountains and the ridge east of South Fork Middle Fork River and include biotite-sillimanite schist and gneiss, amphibolite, and quartzite. These rocks represent sandstone, shale, and volcanic rocks that were deeply buried, metamorphosed, and intruded by granitic rocks that are part of the 1,700-1,790 Ma Routt Plutonic Suite (Tweto, 1987; new ages provided by W.R. Premo, oral commun., 1999), which is widespread throughout the central Rocky Mountains.

The oldest exposed sedimentary rocks in the quadrangle are the green-gray and maroon shale and sandstone of the Upper Jurassic Morrison Formation, deposited by slow-moving rivers on broad flood plains and mudflats, and in freshwater lakes, although sedimentary rocks as old as the sandstone and conglomerate of the Lower Permian to Middle Pennsylvanian Maroon Formation probably underlie the southern part of the quadrangle. Erosion of the "ancestral Front Range" uplift (for example, Sonnenberg and Bolyard, 1997) stripped pre-Pennsylvanian rocks from the Front Range region, including the Dillon quadrangle area. Detritus shed from the uplift and deposited on the flanks of the uplift comprise the rocks of the Maroon Formation.

The thickest sequence of sedimentary rocks in the Dillon quadrangle is Cretaceous in age and includes at least 500 m of chiefly black to gray-brown shale and brown sandstone of the Upper Cretaceous Pierre Shale. All the Upper Cretaceous formations in the quadrangle (Benton Shale, Niobrara Formation, and Pierre Shale) were deposited in an extensive seaway that covered the entire mid-continent region of North America.

The Laramide orogeny, between about 70-50 Ma, was a time of major uplift, compressive faulting, and mountain building in the southern Rocky Mountains (Tweto, 1975). The gently east-dipping Williams Range thrust, which marks the western structural boundary of the Colorado Front Range, formed at this time by the sliding of Proterozoic basement westward over Cretaceous rocks. The trace of the thrust is mostly buried beneath surficial deposits along the west side of the Williams Fork Mountains, although it is exposed in a roadcut along Interstate 70. Following the Laramide orogeny, Eocene granitic rocks, mostly porphyritic, intruded the region; some are exposed in the Frisco quadrangle, just south of the Dillon quadrangle (Kellogg, 2002). Abundant porphyritic-granite clasts are found in both terrace gravels and younger alluvium of the Blue River.

The Blue River valley is controlled by west-northwest-striking normal faults and marks the northernmost extent of the Rio Grande rift (Tweto, 1979; Kellogg, 1999). The rift comprises a series of generally north-striking grabens that extends southward through New Mexico and began forming shortly after 29 Ma (Tweto, 1979). Structurally, the Blue River valley is a half graben, dropped down along the Blue River frontal fault, a normal fault that lies along the base of the abrupt eastern front of the Gore Range, a few kilometers west of the quadrangle. Numerous west-northwest-striking, east-side-down normal faults, associated with formation of the Blue River half graben during late Tertiary crustal extension, are exposed in the quadrangle. The similar style of faulting suggests that the faults may curve downward and eastward into a detachment surface at depth (Kellogg, 1999). Unlike other parts of the Rio Grande Rift to the south, the Blue River half graben is not structurally deep and Tertiary basin-fill deposits are not as thick as elsewhere in the rift. An enigmatic bouldery diamicton (unit QTd on the map) and the bouldery gravel of Mesa Cortina (unit QTgm), both probably as old as Pliocene, partially filled the developing graben. The Mesa Cortina gravel is particularly interesting because of the enormous clast size (some clasts are at least 8 m long) and gold content (the gravels were locally mined by hydraulic methods, mostly in the 1860s and 1870s).

The crystalline rocks underlying the Williams Fork Mountains are extensively fractured and the entire mountain range has spread gravitationally, and may still be spreading (Varnes and others, 1989). Graben-like trenches and scarps (sackungen) are common near the crest of the mountains and are the result of this range-scale spreading, which caused oversteepening of the flanks and extensive landsliding, especially on the west side of the mountain range. A major period of landsliding, probably as young as late Pleistocene and as old as Pliocene, involved extensive downslope movement of crystalline rocks in the hanging wall of the Williams Range thrust (Kellogg, 2001). These older landslide deposits are deeply eroded, although widespread younger landslides, some probably still active, displace Cretaceous shale, glacial till, and gravel deposits. In addition, the younger landslides reactivated large areas in the older landslide deposits.

Although the Blue River valley in the Dillon quadrangle is not glacially carved, large glaciers of at least two major glacial periods (Pinedale, Bull Lake, and possibly pre-Bull Lake) flowed out of valleys in the Gore Range to the west. The South Fork Williams Fork River, however, does occupy a glacially carved valley. Westerly winds caused accumulation of snow on the east side of the Williams Fork Mountains, resulting in glaciers that formed prominent cirques on the east side of the range. Gravels deposited during glacial periods formed terraces adjacent to the Blue River. Although the glaciers are gone, mostly inactive rock glaciers are common in cirques on the east side of the Williams Fork Mountains.

Colluvium, a mixture of rock fragments and smaller debris, comprises small landslides and soil-creep and sheetwash deposits, and mantles many of the meadows and aspen-covered hillsides in the quadrangle. Alluvium, composed of well-rounded, clast-supported gravel, containing clasts as long as about 2 m, forms low terraces and the flood plain of the Blue River.

GEOLOGIC HAZARDS

Potential geologic hazards in the Dillon quadrangle can be placed in six categories: landslides, floods, seismic hazards, expansive soil, elevated radon, and avalanches.

Landslides:

Landslide deposits cover at least one-third of the Dillon quadrangle. These landslides are mostly earth flows and earth slides, as well as rock slides and debris slides (criteria of Cruden and Varnes, 1996). Older (pre-late Pleistocene) landslide deposits (unit QTls) are extensive and consist of Proterozoic rocks from the hanging wall of the Williams Range thrust. Younger (undifferentiated late Pleistocene and Holocene) landslide deposits commonly form in poorly consolidated units, particularly glacial till of Pinedale age and Bull Lake age (units Qtp and Qtb), bouldery gravels of Mesa Cortina (unit QTgm), diamicton (unit QTd), older landslide deposits (unit QTls), and Pierre Shale (units Kp, Kpl, Kps, and Kpm). Most of these landslides are now inactive, although there are several that may still be undergoing very slow movement. One of these "possibly active" landslides is just east of the Blue River, mostly in Sec. 23, T. 4 S., R. 78 W., and it is composed entirely of Pierre Shale. The surface of the slide is very hummocky and numerous scarps cut the crown area and zone of extension.

West of the Blue River and within 3 km north of North Fork of Willow Creek, there are two hummocky landslide deposits on gentle slopes that have displaced bouldery material (till and matrix-supported gravel) and Pierre Shale. The slides are transitional between earth flows and earth slides (terminology of Cruden and Varnes, 1996). They are likely to be Holocene in age based on their youthful morphology. However, field evidence is inconclusive as to whether either of these slides is currently active.

Conditions that contribute to sliding in the map area include: (1) oversteepening of slopes by such processes as fluvial erosion of toe slopes, human undercutting of slopes, and gravitational spreading of mountain flanks (Varnes and others, 1989), (2) bedding oriented parallel to slope, (3) deforestation by logging, fires, and (or) human activity, (4) high water content (by intense or prolonged rainfall, or rapid or protracted snow melt), (5) contrast in stiffness of materials (dense, stiff material over plastic material), and (6) shrink-and-swell processes (Cruden and Varnes, 1996).

Given the proper conditions, the Pierre Shale, Niobrara Formation, and Benton Shale are susceptible to landsliding. The Pierre Shale is particularly susceptible to shrink-and-swell processes east of the Front Range (Hart, 1974). However, in the Dillon quadrangle, the Pierre Shale appears to be sandier and more indurated, which may be the result of two factors: (1) it was deposited nearer to the margin (shoreline) of the Late Cretaceous seaway and (2) tectonism and possible regional heating produced very low-grade metamorphism and hardening (W.A. Cobban, oral commun., 2000). The consequence of these and other possible factors is that some steep (greater than 30 degrees) hillsides underlain by these Cretaceous shales remain in place and are undeformed by sliding.

Floods:

With the completion of Dillon Dam, just south of the Dillon quadrangle, in 1962, flow of the Blue River is now closely regulated and the potential for damaging floods downstream of the dam is unlikely. However, intense summer rainstorms or rapid melting of deep snowpack during unusually warm spring thaws may cause localized damage to roads and structures, either by flooding or debris flows. For example, prehistoric overbank flood deposits of Straight Creek currently underlie some roads and structures, indicating a continued possibility for flooding.

Seismicity:

The Dillon quadrangle is near the northern terminous of the Rio Grande rift, an active zone of crustal extension, although no faults in the Blue River Valley are known to be active. The timing of youngest movement along normal faults in the valley, including the Blue River frontal fault, is somewhat controversial. Tweto and others (1970) believed that the prominent scarp that defines the Blue River frontal fault, several kilometers west of the Dillon quadrangle, indicated Holocene movement. However, a subsequent study on the frontal fault suggested that movement was probably no younger than Pliocene (West, 1978). In the Frisco quadrangle (Kellogg, 2002), low (less than about 2 m), subtle fault scarps cut diamicton (QTd) of middle Pleistocene to Pliocene(?) age. The origin of the diamicton is enigmatic, but parts of it may be as young as the middle Pleistocene Bull Lake glaciation. However, the low scarps do not cut till of the late Pleistocene Pinedale glaciation. These relationships suggest ongoing seismicity into Pleistocene time, possibly as late as the middle Pleistocene.

Large historic earthquakes have occurred in the Front Range region. An earthquake of inferred magnitude 6.5 caused considerable damage in the northern Front Range in 1882 (Kirkham and Rodgers, 2000), and scattered earthquakes of smaller magnitude periodically shake the region. In all, the evidence suggests that damaging earthquakes in the Blue River valley, although possible, are highly unlikely.

Expansive soil:

Expansive soils are a potential problem for building foundations and for roads. The problems are particularly serious in sedimentary units that have high contents of montmorillonitic clays, which have the capacity to hold large quantities of adsorbed water. The deeply weathered bouldery gravels of Mesa Cortina (unit QTgm) and the diamicton east of the Blue River (unit QTd) both have a high clay content, and recurrent problems with expansive soil routinely require foundation stabilization with caissons as much as 9.7 m deep (L. Renfro, Summit County Building Inspector, oral commun., 2000). These problems are also present in the two large earth flow deposits (units Qls) within 4 km north of Willow Creek and west of Highway 9, which are derived, in part, from Bull Lake till and the diamicton unit.

East of the Front Range, the Pierre Shale is particularly susceptible to swelling, especially in bentonitic (altered volcanic ash) layers (Hart, 1974). However, in the Dillon quadrangle, the Pierre Shale is apparently more indurated and sandier than east of the Front Range and bentonitic horizons tend to be strongly lithified (W.A. Cobban, personal commun., 2000). Nonetheless, steps should be taken to stabilize structures built on Pierre Shale, especially where the unit is deeply weathered.

Elevated radon:

Most of Colorado has elevated radon values compared to other parts of the country. One in three homes in Colorado has values greater than 4 picocuries per liter (pCi/l), the maximum allowable value for household radon determined by the EPA; mitigating action is recommended for values higher than 4 pCi/l (EPA, 1993) because elevated radon in homes increases the risk for contracting lung cancer. Granite and felsic gneiss are relatively radiogenic compared to most other rocks, so surficial units, such as alluvium or till derived from felsic Proterozoic bedrock may be susceptible to elevated radon values (Otton and others, 1993). The hazard increases with increased permeability, so younger, less weathered units may have higher radon risk. Shale (particularly black shale, such as the lower shale member of the Pierre Shale), also has elevated radon values (Dubiel, 1993). Testing for radon is relatively easy and inexpensive and steps are available to mitigate the hazard (EPA, 1993).

Avalanches:

Snow avalanches may occur anywhere where (1) slopes are steeper than about 25^o (90 percent of avalanches are on slopes between 30^o-45^o), (2) snow accumulates to a sufficient depth, (3) weak layer(s) develop(s) at depth, and (4) a trigger initiates the snowslide (Colorado Avalanche Information Center, 2000). Most slides start on the lee (downwind) side of ridges where snow accumulates. Prevailing westerly winds cause cornices and snowpack to accumulate on the eastern sides of ridges, and most avalanches occur on this side. Triggers might be a skier, animal, or a sonic boom, but most avalanches are caused simply by the weight of accumulated snow, and avalanches occur when shear stress exceeds shear strength along a weak snow layer. Avalanche tracks are commonly devoid of large trees; where littered with broken logs and tree limbs, they mark paths of recurrent avalanches. Although not mapped in the Dillon quadrangle, debris cones and aprons, composed of unsorted and unstratified rock and wood fragments, commonly lie at the base of avalanche tracks. These debris deposits result from a combination of avalanche activity, as well as debris flows and rock falls. Large avalanches may cross a valley and move hundreds of meters up the opposite valley side.

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