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Geologic Map of the Frisco Quadrangle, Summit County, Colorado

By Karl S. Kellogg, Paul J. Bartos, and Cindy L. Williams

Pamphlet to accompany
MISCELLANEOUS FIELD STUDIES MAP MF-2340

2002

U.S. Department of the Interior
U.S. Geological Survey

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DESCRIPTION OF MAP UNITS

af **Artificial fill (recent)**—Compacted and uncompacted rock fragments and finer material underlying roadbed and embankments along and adjacent to Interstate 70. Also includes material comprising Dillon Dam

dt **Dredge tailings (recent)**—Unconsolidated, clast-supported deposits containing mostly well-rounded to subrounded, cobble- to boulder-size clasts derived from dredging of alluvium for gold along the Blue and Swan Rivers; similar dredge tailings along Gold Run Gulch are too small to show on map. Dredge tailings were mapped from 1974 air photos; most tailings have now been redistributed and leveled for commercial development

Qal **Alluvium (Holocene)**—Unconsolidated clast-supported deposits containing silt- to boulder-size, moderately sorted to well-sorted clasts in modern floodplains; includes overbank deposits. Clasts are as long as 1 m in Blue River channel; clasts are larger in some side-stream channels. Larger clasts are moderately rounded to well rounded. Includes some wetland deposits in and adjacent to beaver ponds along Ryan Gulch. Maximum thickness unknown, but greater than 10 m in Blue River channel

Qw **Wetland deposits (Holocene)**—Dark-brown to black, organic-rich sediment underlying wetland areas, commonly containing standing water and dense willow stands. Maximum thickness estimated to be about 15 m

Qav **Avalanche deposits (Holocene)**—Unsorted, unstratified hummocky deposits at the distal ends of avalanche-prone hillside in Sec. 16, T. 5 S., R. 77 W. Contains clasts as long as about 1 m and abundant logs and wood fragments. Maximum thickness about 10 m

Qry **Active rock-glacier deposits (Holocene)**—Hummocky, lobate deposits of mostly angular boulders having frontal slope at angle of repose. Deposits are ice cored and moving; boulders are not covered with lichen. One small deposit in Secs. 16 and 21, T. 6 S., R. 78 W grades downslope into inactive rock-glacier deposit (unit Qr). Maximum thickness about 30 m

Qr **Inactive 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; boulders on frontal slope partly covered by lichens. In places, grades into and includes some talus (unit Qt). In cirques on east side of Tenmile Range. Maximum thickness about 25 m

Qtr **Travertine (Holocene)**—Brown to reddish-brown vuggy travertine in two roughly flat-cone-shaped deposits, each about 15 m in diameter, in S ½ Sec. 21, T. 5 S., R. 77 W., near Snake River inlet. Springs feeding travertine not currently active, but unweathered nature of deposits suggests (late?) Holocene age. Deposits less than about 5 m thick

Qf **Fan deposits (Holocene and upper Pleistocene)**—Moderately well sorted sand- to boulder-size gravel in fan-shaped deposits from side streams of Blue River Valley, Tenmile Creek, and below gully in northeastern corner of quadrangle. Deposits both matrix and clast supported, suggesting range in water content during transport. Clasts mostly subangular to subrounded and as long as about 2 m; most are considerably smaller. Include minor stream alluvium and debris-flow deposits. As much as about 15 m thick

Qt **Talus (Holocene and upper Pleistocene)**—Angular and subangular cobbles and boulders on steep mountain sides and below cliffs. Boulders generally are as large as 2 m, although in places are as large as 10 m. Sandy matrix rarely exposed as surface. Talus mapped extensively on both sides of crest of Tenmile Range and commonly grades into felsenmeer (fields of frost-shattered bedrock boulders, which are mapped as underlying bedrock unit) near crest of range. As much as 20 m thick

Qc **Colluvium (Holocene and upper Pleistocene)—**Unconsolidated to slightly indurated, mostly massive, dark-brown to light-gray-brown deposits that mantle gently to moderately sloping surfaces; rock clasts and fine-grained material are mixed by downslope movement. Contains angular pebbles to cobbles derived from weathering of bedrock. Locally overlain by loess, which is very fine grained eolian sand, silt, and minor clay that displays poorly to moderately developed soil profile in upper part. Includes minor alluvium in small channels and sheetwash on steeper hillsides. Commonly underlies areas covered by open meadows, sagebrush, and (or) aspen groves. Smaller colluvial areas unmapped, particularly where unit is thin and discontinuous. Correlates with colluvium and loess, undivided, of Dillon quadrangle (Kellogg, 2000). Maximum thickness probably less than 15 m

Qac **Alluvium and colluvium, undivided (Holocene and upper Pleistocene)**—Alluvium composed of unconsolidated silt- to boulder-size, moderately sorted to well-sorted sediment in narrow channels that are too small to map separately. Alluvium is flanked by colluvial deposits composed mostly of angular cobbles and smaller fragments derived from weathered bedrock transported by downslope movement. Colluvium may contain loess and have a moderate soil profile. Includes some wetland deposits and beaver ponds in northwestern part of quadrangle and along Miners Creek. 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. Surface of deposits commonly hummocky, and relatively steep breakaway zone generally identifiable. Large landslide deposit in Secs. 22, 23, 26, and 27, T. 5 S., R. 77 W is large earth flow. Larger landslide deposits greater than 50 m thick

Qls(Kb) **Large landslide deposit composed entirely of Benton Shale—**One block in sections 22 and 27 in the large landslide earth flow in Secs. 22, 23, 26, and 27, T. 5 S., R. 77 W., is composed entirely of Benton Shale

Qg **Terrace gravel (Holocene to middle Pleistocene)—**Moderately sorted, moderately rounded to well-rounded sand and gravel adjacent to modern floodplain of Blue, Snake, and Swan Rivers; one deposit also mapped along lower Salt Lick Gulch. Clasts as large as 1 m composed predominantly of Proterozoic gneiss. In Blue River Valley, clasts subordinately composed of Dakota Sandstone, Maroon Formation, and Tertiary intrusive rocks. Deposits are as much as about 20 m above present Blue River, but well-defined terrace morphology not developed. Highest gravels may be as old as Bull Lake (middle Pleistocene). Thickness as much as about 15 m

Qop **Pinedale outwash deposits (upper Pleistocene)**—Unconsolidated clast-supported alluvial deposits consisting of sand- to boulder-size clasts; cobbles and boulders (as long as 2 m) are moderately to well rounded. Deposited during retreat of Pinedale glaciers. Includes some Holocene overbank deposits near Tenmile Creek. Underlies downtown area of Frisco. Thickness as great as about 15 m

Qtp **Till of Pinedale glaciation (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 profile generally is thin with little clay development, and boulders are generally unweathered. Locally contains minor outwash and colluvial deposits. Age of Pinedale-age deposits in type area in Wyoming is 23-16 ka (Chadwick and others, 1997). Thickness as great as 135 m

Qtb **Till of Bull Lake glaciation (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 Precambrian gneiss and granitic rocks. In many localities west of Blue River, Bull Lake Till contains as much as about 10 percent clasts of Dakota Sandstone. Boulders of Proterozoic gneiss and plutonic rock slightly to moderately weathered. Soil profile is moderately to well developed; commonly, an uppermost black organic-rich zone several centimeters thick (A horizon) overlies a pale-colored elutriation zone (E horizon) in which clay and iron have been leached. E horizon, in turn, overlies an orange-brown zone (B horizon) of clay and iron accumulation. B horizon overlies unweathered till (C horizon). Thickness may exceed 100 m

Qgo **Older outwash gravel (middle or lower Pleistocene)**—Light-yellowish-brown, unconsolidated, moderately rounded to well-rounded, poorly stratified to almost massive, mostly matrix-supported 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. Overlain by well-developed soil profile. Mapped in Dillon quadrangle (Kellogg, 2000) as high as 100 m above present Blue River. Interpreted as "Older outwash and pediment gravels" of Pleistocene age (Tweto, 1973), although no pediment surface is apparent. Probably is predominantly outwash of either Bull Lake or pre-Bull Lake age. Present as one small exposure along northern border of quadrangle adjacent to Dillon Reservoir in Sec. 7, T. 5 S., R. 77 W. Much more widely exposed in adjacent Dillon quadrangle, where this unit underlies town of Dillon and surrounding areas (Kellogg, 2000). Greater than 30 m thick in places

QTd **Diamicton (middle Pleistocene to Pliocene?)**—Unsorted, unstratified rock debris containing poorly to moderately rounded clasts that range in size from clay to boulders; poorly exposed west of Blue River. Forms smooth slopes containing weathered clasts and well-developed soil profile, commonly topographically below Bull Lake moraines. Origin uncertain; may be Bull Lake or older till, older landslide deposits, debris-flow deposits, or bouldery gravel corelative with bouldery gravels of Mesa Cortina and Gold Run

QTgm **Bouldery gravel of Mesa Cortina ("Buffalo placers") (middle Pleistocene to Pliocene?)**—Poorly sorted, poorly stratified to massive, subrounded to well-rounded, poorly consolidated, light-tan to grayish-orange bouldery deposits underlying much of the terracelike surface (Mesa Cortina) in northwestern part of quadrangle. Deposits are deeply weathered, matrix supported, and contains clasts of Precambrian gneiss and granite, Dakota Sandstone, Maroon Formation, and rare Tertiary porphyritic rocks similar to the quartz monzonite porphyry mapped in the quadrangle. Boulders of Dakota and Maroon are as large as 5 m across, although most are less than 2 m across; Precambrian boulders are as long as 8 m and generally strongly weathered. Matrix is weathered (clay-rich) grussy sand. Deposits poorly exposed on sloping, dissected surface as high as 330 m above Blue River, where they resemble old till deposits. Enormous size of some clasts and their distance from source suggests that deposits may be result of large debris and hyperconcentrated flow deposits. Clast compositions suggest source is either upper Blue River Valley, south of quadrangle, or upper Ten Mile Creek. Enormous size of some clasts, the deeply weathered character of the deposits, and their distance from source suggest that deposits may be derived from pre-Bull Lake glacial deposits. The deposits, also known as the Buffalo Placers, was first mined for gold by hydraulic methods in the 1870's and 1880's; 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 fluvial Dry Union Formation of the Arkansas River valley near Leadville (Tweto, 1961) seems unlikely. Probably correlates with gold-bearing gravel of Gold Run (QTgg). Age unknown, but alteration and morphology of deposits suggest they may be as old as Pliocene. Total thickness unknown, but may be more than 100 m

QTgg **Bouldery gravel of Gold Run (middle or lower Pleistocene to Pliocene)**—Poorly sorted, poorly stratified to massive, poorly consolidated, subrounded to well-rounded, light-tan to grayish-orange bouldery deposits underlying extensive area adjacent to Gold Run Gulch in southeastern part of quadrangle. Also mapped in terrace-shaped deposits as high as 165 m above present Blue River. Deposits are deeply weathered, matrix-supported, and contains clasts predominantly of Precambrian gneiss, Dakota Sandstone (unit Kd), and quartz monzonite porphyry (unit Tqp). Boulders are less than 2 m across; Precambrian boulders are strongly weathered. Matrix is weathered (clay-rich) grussy sand. Large size of some clasts, their distance from source, and degree of weathering suggests that deposits may be pre-Bull Lake glacial outwash and (or) debris-flow deposits. Mapped as older terrace gravels by Ransome (1911) and Dry Union Formation of Pliocene and Miocene age by Tweto (1973) but, as with gravel of Mesa Cortina (unit QTgm), correlation with the well-stratified, well-indurated Dry Union Formation of the Arkansas River valley near Leadville (Tweto, 1961) seems unlikely. The deposits were extensively mined for gold by hydraulic methods starting in 1860 (Parker, 1974) and worked well into the twentieth century. Total thickness unknown, but probably locally more than 50 m

QTls **Older landslide deposits (middle Pleistocene to Pliocene)**—Mostly angular fragments of Proterozoic rock in grussy matrix that is partially altered to clay. Locally contains relatively unfractured gneiss blocks as long as about 30 m, suggesting at least some movement was by downslope creep. All topographic evidence of breakaway zone and original hummocky landslide morphology eroded, although deposits may include small reactivated areas. Very extensive; underlies extensive area on west side of Williams Fork Mountains (Kellogg, 2000), just north of Frisco quadrangle, obscuring most of the trace of the Williams Range thrust. Exposed in northeast corner of quadrangle. Interpreted to include earth slides, earth flows, rock slides, and debris slides, using criteria of Cruden and Varnes (1996). Where weathering is deep and clast size small, deposits are covered by thick conifer and aspen forests. May be locally thicker than 100 m

Tqp **Quartz monzonite porphyry (Eocene)**—Light-gray, conspicuously porphyritic, massive, quartz-plagioclase-orthoclase-biotite-hornblende quartz monzonite. Orthoclase phenocrysts are 2 mm to 4 cm long (Lovering, 1934, reports phenocrysts as long as 8 cm) and comprise as much as 20 percent of the rock. Partially resorbed and embayed quartz phenocrysts are 2 mm to 1.5 cm long and comprise 2-10 percent of the rock. Abundant white, chalky plagioclase phenocrysts are as long as 1 cm. Euhedral biotite comprises 1-3 percent of the rock and is much more abundant than sparse hornblende. The groundmass is fine grained (< 0.5 mm). Weathers to buff or light brown, with flaggy to blocky fracture. It did not prove practical to differentiate two different phases of the quartz monzonite porphyry based on variations in quartz and orthoclase phenocryst abundances (Ransome,1911). Quartz monzonite porphyry at the north end of the main intrusive body underlying Swan Mountain yielded a potassium-argon age on biotite of 44.1±1.6 Ma (Marvin and others, 1989) and a rubidium-strontium whole-rock age of about 44 Ma (Simmons and Hedge, 1978). Igneous rock classification is according to Streckeisen (1976)

Tmp **Hornblende-biotite monzonite porphyry (Eocene)—**Dark-grey with 5 percent plagioclase phenocrysts 1-3 mm long, 5 percent orthoclase phenocrysts 1-3 mm long, 3 percent hornblende as subhedral blades 1-6 mm long, 3 percent biotite as pseudohexagonal phenocrysts 1-2 mm wide in an aphanitic groundmass. Occurs as thin dikes and one small stock in the southeastern corner of the quadrangle. A large mass of hornblende-biotite monzonite porphyry intrudes just south of the quadrangle. The monzonite porphyry is intruded by quartz-monzonite porphyry (Tqp), although both phases are considered close in age (Ransome, 1911; Lovering, 1934). Igneous rock classification is according to Streckeisen (1976)

Pierre Shale (Upper Cretaceous)

Kpm **Shale and sandstone member**—Black and gray fissile shale, black and grayish-brown claystone, and subordinate, thin, commonly shaly, very fine grained brown sandstone. Conformable above Kremmling Sandstone Member. Top not exposed, but member is greater than about 500 m thick in quadrangle

Kps **Kremmling Sandstone Member—**Very fine grained to medium-grained, light-brown, well-indurated, ledge-forming, feldspathic graywacke that contains about 50 percent quartz, 30 percent feldspar, and about 15 percent green, black, and brown lithic grains. Beds are 5-25 cm thick, flaggy- to blocky-weathering, and locally contain dark-grayish-brown interbedded shale. May correlate with 30-m-thick shaly sandstone bed encountered 225 m above base of formation in Harold D. Roberts Tunnel (Wahlstrom and Hornback, 1962; the west portal of tunnel is in northeast corner of quadrangle), although 225 m appears uncharacteristically thin for the lower shale member. Correlated (W.A. Cobban, oral commun., 1999) with type section of Kremmling Sandstone Member, located about 37 km north of quadrangle (Izett and others, 1971); there, the member is about 575 m above base of formation. Member is about 20 m thick in map area

Kpl **Lower shale member**—Dark-gray, brownish-gray, and black marine shale and mudstone. Lowest 10-20 m is calcareous, and calcite veins are common near basal contact. Bedding indistinct in fresh outcrops; breaks with conchoidal fracture. In weathered outcrops, bedding fissility is visible. Conformable, gradational lower contact with underlying Niobrara Formation; mapped above uppermost horizon of light-gray weathering, platy, calcareous fragments, typical of upper Niobrara Formation. Thickness in quadrangle about 400 m, which compares to thickness of about 440 m in Blue River Valley north of quadrangle (Holt, 1961)

Kn **Niobrara Formation (Upper Cretaceous)—**Consists of two members that were not mapped separately. Upper Smoky Hill Shale Member consists of gray, light-gray and platy-weathering, calcareous shale and shaly limestone that generally becomes more shaly upward; thickness in quadrangle about 138 m (Robinson and others, 1974). Lower Fort Hays Limestone Member is blocky, gray, light-gray weathering, relatively resistant micritic limestone in beds 5-15 cm thick that commonly contain encrusted inoceramid bivalves (large oysters); 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 shows pinch-and-swell structures and contains thin, dark-gray, siliceous siltstone interbeds; interpreted to correlate with Juana Lopez Member of the Carlile Shale of Berman and others (1980). The uppermost limestone overlies about 5 m of dark-gray, fetid limestone and dark-brown to gray calcareous, rusty siltstone and shale that, in turn, overlies about 3 m of resistant brownish-gray, fine-grained, rusty, arkosic sandstone that is bioturbated at base and locally contains chert pebbles; interpreted to correlate with Codell Sandstone Member of Carlile Shale of Berman and others (1980). The Codell unconformably overlies mostly dark-brown to black, fissile, rusty shale. Calcareous beds characteristic of the Greenhorn Limestone near Denver (Scott, 1972) are not apparent in the area; sequence below Codell is more characteristic of lower Mancos Shale as described west of area (for example, Merewether and Cobban, 1986). About the lower 25 m, which is equivalent to Mowry Shale of Wyoming (W.A. Cobban, oral commun., 1998) consists 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. The term "Benton Shale" is well established to designate the black-shale-dominated sequence between the Dakota Sandstone and the Niobrara Formation; although correlated with several other units elsewhere in Colorado, the name is retained in the Frisco quadrangle. 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 shaly member, and a lower quartzite member. The upper quartzite member is 6-20 m thick and contains light-gray, commonly cross-bedded quartzite in beds 10-30 cm thick, with thin, black, commonly carbonaceous shale interbeds. In most places, the base of the upper member is a massive, 2-10 meter thick, resistant quartzite bed. Joint surfaces contain red, orange, and yellow limonite encrustations. The middle shaly 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 shaly member is highly variable: 6-28 m thick. The lower quartzite member consists of thick (as much as 12 m), massive, medium-grained, grayish-white, equigranular quartzite with thin, dark-gray shale interbeds; quartzite is very rusty on joint surfaces. Chert-pebble beds, characteristic of the lower Dakota elsewhere, were not observed in the lower member, which is unconformable above the Morrison Formation. Thickness of lower member is 20-26 m. Throughout the Dakota Sandstone, the quartzite beds are somewhat lenticular, undergoing lateral changes in thickness over short distances. The total thickness of the Dakota Group in the Breckenridge area, just south of the quadrangle, is 52-69 m (Lovering, 1934). Total thickness of the Dakota Group in the Harold D. Roberts Tunnel is reported to be 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 (rusty layers parallel to joint surfaces) and limonitic spots. One prominent 2-4-m-thick gray limestone bed is about 5-10 m from base of formation. The Morrison Formation conformably overlies the Entrada Sandstone. Thickness of formation in the Blue River Valley about 55-79 m (Holt, 1961); in the spillway shaft of Dillon Dam, the formation is about 70 m thick (Wahlstrom and Hornback, 1963)

Je **Entrada Sandstone (Middle Jurassic)**—Light-gray to pale-yellowish-gray, well-sorted, fine- to medium-grained, commonly cross-bedded, carbonate-cemented, quartzose sandstone. Grains are frosted, reflecting eolian deposition. Small, brown limonitic spots are common in hand specimen. Locally ledge forming. The unit unconformably overlies Triassic red beds. Thickness is highly variable; at Dillon Dam, it is about 50 m thick (Wahlstrom and Hornback, 1963), although only 3 km to the east, at a locality now under water, it is only about 11 m thick (Holt, 1961)

ȒPcm **Chinle (Upper Triassic) and Maroon Formations (Lower Permian to Middle Pennsylvanian), undivided**—Rocks correlated with the Upper Triassic Chinle Formation consist of dark-red, pale-pink, and greenish-gray, locally mottled silty shale, siltstone, and fine-grained silty sandstone, with platy fracture. Just southwest of Boreas Pass, about 10 km southeast of quadrangle, a 46-m-thick red shale and sandstone sequence underlying the Entrada Sandstone is correlated with sections of Chinle Formation measured throughout western Colorado and eastern Utah (Poole and Stewart, 1964). The Boreas Pass section includes the basal Gartra Member of the Chinle Formation (a sandstone unit), although the Gartra has not been recognized in the Frisco quadrangle. The best partial section is exposed in the center of Sec. 1, T. 6 S., R. 78 W. At Dillon Dam, the Chinle is about 61 m thick; these rocks were previously named the Lykins Formation (Wahlstrom and Hornback, 1963), a name more appropriate for a Triassic and Permian redbed sequence on the east flank of the Front Range (for example, Broin, 1956). The Chinle unconformably overlies a sequence of red to orange-red, medium- to coarse-grained, micaceous, poorly sorted, locally conglomeratic, arkosic sandstone that locally contains interbeds of red sandy siltstone. Sand grains are angular to sub-angular. This sequence is correlated with the Maroon Formation of Early Permian to Middle Pennsylvanian age, although it cannot be ruled out that these beds, at least in part, correlate with the Lower Triassic and Permian State Bridge Formation, which is similar in composition to the Maroon Formation. The State Bridge, however, typically contains rounded sand grains and thin beds of laminated sandstone and siltstone that are absent in the Maroon Formation (Freeman, 1971). The Maroon Formation rests disconformably on Proterozoic basement rocks and is poorly exposed in the quadrangle. The Maroon is estimated to be about 180 m thick along cross section D-D', but thickens considerably to the south; near Boreas Pass, the combined Chinle and Maroon Formations are more than 1,200 m thick (Taranik, 1974) where the Chinle is only about 40-50 m of that combined thickness

Proterozoic rocks

[Grain sizes for both plutonic and metamorphic rocks folows Compton (1962): *fine-grained*, less than 1 mm; *medium-grained*, 1-5 mm; and *coarse-grained*, greater than 5 mm]

YXu **Early Proterozoic rocks, undivided**—Shown on cross sections only

YXdi **Diorite (Middle and Lower Proterozoic)**—Dark-gray, medium- to coarse-grained, equigranular, hypidiomorphic to xenomorphic, massive hornblende-plagioclase diorite. Contains 40-50 percent plagioclase (approximately An_{40}), 30-45 percent hornblende, 5 percent biotite (strongly chloritized), 5 percent quartz, 3-4 percent opaque minerals, trace apatite, and 0-2 percent secondary epidote. Forms relatively small, irregular intrusive masses in southwestern part of quadrangle. Age unknown; may be part of the Early Proterozoic (1,660-1,790 Ma) Routt Plutonic Suite or the Middle Proterozoic (1,400-1,450 Ma) Berthoud Plutonic Suite (Tweto, 1987; Reed and others, 1987)

YXp **Pegmatite (Middle and Lower Proterozoic)**—Very coarse grained microcline-plagioclase-quartz-muscovite rock in pods and dikes as wide as about 25 m; mostly much smaller. Locally grades into quartz veins or aplitic granite. Most and possibly all pegmatites are related to late stages of the Early Proterozic Routt Plutonic Suite (Tweto, 1987), although it cannot be ruled out that some pegmatites of the Middle Proterozoic Berthoud Plutonic Suite (Tweto, 1987) also exist in the Frisco quadrangle

Lower Proterozoic rocks

Routt Plutonic Suite—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 1,660-1,790 Ma (Reed and others, 1987)

Xgg **Granitic gneiss**—Gray to light-gray, medium- to coarse-grained, hypidiomorphic to xenomorphic, massive to strongly foliated equigranular microcline-plagioclase-quartz-biotite monzogranite to granodiorite. Contains 35-50 percent oligoclase, 25-30 percent undulatory quartz, 15-25 percent microcline, 5-15 percent biotite, 1-2 percent opaque minerals, 0-1 percent muscovite, 0-trace garnet, trace zircon, and trace apatite. Retrograde greenschist metamorphism has altered some biotite to chlorite and oligoclase to sericite and epidote. Rock locally sheared parallel to foliation; thin shear planes commonly biotite rich, forming black streaks on outcrop surfaces. Unit intimately interlayered with amphibolite and hornblende-plagioclase gneiss unit (Xhpg), which it intrudes, but is not interlayered with migmatitic biotite gneiss (Xmg) or biotite gneiss (Xbg). Called “granulite” by Bergendahl (1963), a name used to reflect the quartzofeldspathic nature of the rock and not a metamorphic facies. Bergendahl interpreted the unit to be the stratigraphically lowest unit in a metasedimentary sequence, an interpretation that was not supported by the present study

Xgd **Granodiorite**—Gray, medium-grained, equigranular, massive granodiorite or quartz diorite. Contains about 25 percent biotite, 15 percent quartz, and 60 percent white feldspar (mostly plagioclase). One poorly exposed outcrop mapped in NE ¼ Sec. 23, T. 6 S., R. 78 W.

Xmg **Migmatite**—Consists of gray, well-foliated, inequigranular to equigranular, medium-grained, hypidiomorphic to xenomorphic biotite gneiss alternating with varying amounts (commonly as much as 70 percent of rock) of very light gray to white granitic layers ranging from a fraction of a centimeter to about 10 centimeters thick. Rock contains 10-60 percent oligoclase, 0-30 percent microcline, 0-20 percent quartz, 0-50 percent brown biotite (commonly chloritized), 0-30 percent fibrous sillimanite, 0-5 percent phlogopite, 0-3 percent muscovite, and traces of opaque minerals, garnet, zircon, and apatite. Layers show much pinch and swell and in most places are strongly folded. Leucocratic layers due both to injection (igneous origin) and in-situ diffusion; the latter commonly have biotite-rich selvages adjacent to layer

Xhpg **Amphibolite and hornblende-plagioclase gneiss—**Dark-gray to black, fine- to medium-grained, hypidiomorphic, well-foliated rock containing about 15-70 percent green (in thin section) hornblende, 0-5 percent brown biotite (commonly chloritic), 15-60 percent plagioclase, 0-10 percent quartz, 1-2 percent opaque minerals, and traces of apatite and garnet. Commonly contains numerous diffuse, white, plagioclase-rich, felsic segregations that form a spotted pattern (relict phenocrysts?)

Xbg **Biotite gneiss**—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, 0-10 percent sillimanite, 0-5 percent hornblende, 1-2 percent opaque minerals, and a trace zircon. Typically contains 5-20 percent leucocratic layers, so distinction with migmatite (unit Xmg) somewhat arbitrary

Xum **Ultramafic rock—**Black, medium-grained hypidiomorphic equigranular rock contains 40 percent light-green (in thin section) hornblende, 30 percent augite, 20 percent olivine (partly altered to iddingsite and opaque minerals), 10 percent opaque minerals, 5 percent secondary calcite, and trace apatite. One elongate pod mapped in NE ¼ Sec. 11, T. 6 S., R. 78 W.

Geologic History

The geologic history of the Frisco quadrangle spans more than 1.7 billion years. The oldest rocks underlie the crest of the Tenmile Range and include biotite-sillimanite schist and gneiss, amphibolite, and quartzite. These rocks represent sandstones, shales, and volcanic rocks that were deeply buried, metamorphosed, and intruded by granitic rocks that are part of the 1,667-1,750 Ma Routt Plutonic Suite (Tweto, 1987), which is widespread throughout the central Rocky Mountains. The oldest exposed sedimentary rocks in the quadrangle are the brick-red locally conglomeratic sandstones of the Pennsylvanian and Permian Maroon Formation. Uplift of the “ancestral Front Range” (e.g., Sonnenberg and Bolyard, 1997) stripped pre-Pennsylvanian rocks from the Front Range region, including the Frisco quadrangle area, and detritus shed from the uplift and deposited on the flanks of the uplift contributed to the Maroon Formation. By the time that the rocks of the Upper Jurassic Morrison Formation were deposited by slow-moving rivers on broad flood plains and mud flats and in freshwater lakes, the ancestral Front Range was completely eroded.

The thickest sequence of sedimentary rocks in the Frisco quadrangle is Cretaceous in age and includes almost 1,000 m of chiefly black to gray-brown shale and brown sandstone of the Upper Cretaceous Pierre Shale. All the Upper Cretaceous formation 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 old landslide deposits in the northwestern corner of the quadrangle. Following the Laramide Orogeny, Eocene, mostly porphyritic rocks intruded the region. Numerous sills crop out in the Frisco quadrangle and a large laccolith-like body of quartz monzonite porphyry, dated at 44 Ma (Simmons and Hedge, 1978; Marvin and others, 1989), underlies Swan Mountain.

The Blue River valley is controlled by west-northwest-striking normal faults and marks the northernmost extent of the Rio Grande rift, The rift is comprised of a series of north-striking grabens that extend 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, the lower slopes of which are exposed in the northwestern part of the quadrangle north of Interstate 70. Unlike other portions 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 valley. 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 hydraulically, mostly in the 1860s and 1870s).

Although the Blue River valley in the Frisco quadrangle is not glacially carved (glaciers in the Blue River valley reached the outskirts of Breckenridge, a couple of km north of the quadrangle boundary), large glaciers of at least two major glacial periods (Pinedale, Bull Lake, and possibly pre-Bull Lake) flowed out of valleys in the Gore and Tenmile Ranges to the west. In addition, glaciers of the Bull Lake glaciation in the Snake and Swan River valleys barely reached the Frisco quadrangle. Westerly winds caused accumulation of snow on the east side of the Tenmile Range, resulting in glacers that formed cirques on the east side of the range. Although the glaciers are gone, mostly inactive rock glaciers are common in cirques on the east side of the Tenmile Range.

Colluvium, a mixture of rock fragments and smaller debris from small landslides and soil-creep and sheet-wash deposits, mantles many of the meadows and aspen-covered hillsides in the quadrangle. Alluvium, composed of well-rounded, clast-supported gravels that contain clasts as long as about 2 m, forms terraces (deposited most prominently during past glacial periods) and the floodplain of the Blue River.

Geologic Hazards

Potential geologic hazards in the Frisco quadrangle can be placed in seven categories: 1) landslides, 2) floods, 3) abandoned mined lands and placer deposits, 4) seismicity, 5) expansive soil, 6) elevated radon, and 7) avalanches.

Landslides

Landslide deposits are extensive in the Frisco 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-Holocene) landslide deposits are extensive and consist of Proterozoic rocks above the Williams Range thrust. Younger (undifferentiated late Pleistocene and Holocene) deposits commonly form in a number of poorly consolidated units, particularly glacial till of Pinedale age and Bull Lake age (units Qtp and Qtb), bouldery gravels of Mesa Cortina (unit QTgm), and diamicton (unit QTd). The Pierre Shale (units Kpm, Kps, and Kpl), commonly unstable elsewhere in the Blue River valley (e.g., Kellogg, 2000), does not host many slides, probably due to low-grade metamorphism (formation of hornfels) caused by Tertiary intrusive activity. Most landslides in the quadrangle are now considered inactive, although one large landslide deposit just north of Interstate 70, in Secs. 22, 23, 26, and 27, T. 5 S., R. 78 W., has hummocky topography and well-formed scarps in the crown region and zone of deflation (terminology of Cruden and Varnes, 1997) and may be undergoing very slow creep.

Conditions that contribute to sliding in this area include: 1) oversteepening of slopes by processes such as fluvial erosion of toe slopes, man-made 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 development, 4) high water content (by intense or prolonged rainfall, or rapid snow melt), 5) contrast in stiffness of materials (dense, stiff material over plastic material), and 6) shrink-and-swell processes (Cruden and Varnes, 1996).

Floods

Intense summer rainstorms or rapid melting of deep snowpack during unusually warm spring thaws may cause localized flooding and debris-flow activity. Roads and structures built on the present floodplain (unit Qal) of Tenmile Creek and the Blue River may be susceptible to floods during periods of high runoff. Debris from steep tributary channels may damage structures and roads during intense summer rainstorms.

Abandoned mines and placer deposits

Collapse of abandoned mine portals and stopes, many of which may be covered by thin surficial material or incompetent bedrock, pose a potential hazard, particularly in the southeast corner of the quadrangle where mining activity was high in the latter part of the nineteenth century. Mine water also tends to be acidic, due to oxidation of sulfide minerals (mostly pyrite), and commonly contains toxic levels of heavy elements such as zinc, cadmium, lead, and arsenic. Soil contaminated by acidic mine drainage may be corrosive to metal and concrete and pose a hazard to building foundations. Reclamation of matrix-poor placer gravel by covering with topsoil may cause piping problems, particularly where clasts are large and well sorted and soil cover is thin. Piping is a process whereby incompetent overlying material washes into underlying voids, producing cylindrical cavities or holes.

Seismicity

The Frisco quadrangle lies near the northern terminous of the Rio Grande rift, an active zone of crustal extension and elevated heat flow, although no faults in the Blue River Valley are known to be currently active. The timing of youngest movement along normal faults in the valley, including the Blue River frontal fault, is somewhat controversial. Although Tweto and others (1970) believed that the prominent scarp that defines the Blue River frontal fault indicated Holocene movement, a subsequent study suggested that movement on the frontal fault was probably no younger than Pliocene (West, 1978). Low (less than about 2 m), subtle fault scarps west of Interstate 70 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 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 considered highly unlikely in the next few hundred years.

Expansive soil

Expansive soils are a potential problem for building foundations and for roads. The problems are particularly serious in sedimentary geologic units that have a high content of montmorillonitic clay, which are have the capacity to hold large quantities of adsorbed water. During subsequent dry periods, the clays release water and the soil contracts. The deeply weathered bouldery gravels of Mesa Cortina (QTgm) and the diamicton 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, personal commun., 2000).

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 Frisco quadrangle, the Pierre Shale is apparently more indurated and sandier than east of the Front Range (W.A. Cobban, personal commun., 2000), and bentonitic horizons tend to be well lithified, probably due to low-grade thermal metamorphism by Tertiary intrusive activity. 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 cutoff 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 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 U.S. Environmental Protection Agency, 1993).

Avalanches

Snow avalanches may occur anywhere where 1) slopes are steeper than about 25° (90 percent of avalanches are on slopes between 30°-45°), 2) snow accumulates to a sufficient depth, 3) a weak layer (or layers) develops at depth, and 4) a trigger exists to initiate the snowslide (Colorado Avalanche Information Center, 2000). The prevailing winds in the region are westerlies and most slides start on the lee (downwind) or eastern side of ridges where snow accumulates, such as on the east side of the Tenmile Range. Large avalanches may cross a valley and move hundreds of meters up the opposite valley slopes. Triggers might be a skier, animal, or a sonic boom, but most avalanches are caused simply by the weight of accumulated snow; the avalanche occurs when shear stress exceeds shear strength along a weak layer of snow. Avalanche tracks are commonly devoid of large trees; broken logs and tree limbs litter the paths of recurrent avalanches. One avalanche-debris deposit (Qav), composed of unsorted and unstratified rock and wood fragments, is mapped in Sec. 16, T. 5 S., R. 78 W. Debris flows and rock fall may contribute to the surficial material.

ECONOMIC GEOLOGY

Mining was concentrated in the southeastern portion of the Frisco quadrangle, in the northern part of the Breckenridge mining district (Ransome, 1911; Lovering, 1934). Limited mining activity also began in the northern end of the Tenmile Range just before the close of the nineteenth century, where production of gold, silver, lead, and copper was from mixed-sulfide veins cutting the Proterozoic rocks (Bergendahl, 1963); mining in this region had ceased by 1940 .

The dominant operation in the quadrangle was placer dredging, focused in the Swan and Blue River drainages, with lesser activity (both dredging and hydraulic mining) in Gold Run Gulch and near Mesa Cortina. More than $15.5 million worth of gold (at historical prices of $17.50 to $35 per ounce) was recovered from these placers (Parker, 1974), of which approximately $750,000 of gold was produced from the Gold Run Gulch placer. This latter placer was known in the early days of the district as the "Pound Diggings" because workers were said not to labor in areas that averaged less than a pound of gold per day (Ransome, 1911). Placer dredging in the quadrangle lasted for one hundred years (from 1859 to 1959), with most production occurring from 1906-1924 (Parker, 1974).

Hard-rock mining of gold commenced in the southeastern corner of the quadrangle in 1884 and was concentrated in three small areas (the names refer to clusters of mines referred to in Ransome [1911]): Jessie, located in the south-central portion of section 20; Jumbo, located in the northwestern portion of section 29; and Galena Gulch, located in the central portion of section 21 (all in T. 6 S., R. 77 W.) An estimated $800,000 to $1.5 million worth of gold at prevailing prices was produced from Jessie prior to 1909 (Ransome, 1911) with minimal gold produced thereafter (based on comparing the size of workings in photographs in Ransome (1911) with the size of workings remaining today). Production figures from Jumbo are not known with certainty, but were estimated by Ransome (1911) to exceed $300,000. However, the size of the Jumbo stopes suggests production comparable to that of Jessie. The workings at Galena Gulch did not generate much production, although a 29 ¼ ounce nugget was reported from the mouth of Galena Gulch (Ransome, 1911). All told, hard-rock gold production from the area is estimated at 90,000 to 170,000 ounces.

The southeastern portion of the Frisco quadrangle, south of the Swan River and east of the Blue River, was explored by Asarco, Incorporated, a major mining company, in 1989-1990 under the supervision of one of the authors (PJB, assisted by CLW). Descriptions of mine geology, alteration, and geochemistry are derived from this work. Thirteen angled reverse-circulation drill holes, ranging in depth from 245 to 365 feet, were drilled at Jessie while nine angled reverse-circulation drill holes, ranging in depth from 225 to 455 feet, were drilled at Jumbo. Local interesting intercepts were encountered, but these were perceived to be too erratic to be mined in bulk and too low grade to be selectively mined underground.

The geology of Jessie consists of pervasively sericitized quartz monzonite porphyry intruded into Pierre Shale. Radial dikes and peripheral sills surround the porphyry. Drilling of the Jessie intrusion indicates that it is an asymmetric laccolith whose lower contact is dipping approximately 35° to the southeast. The root of the laccolith is believed to be on its eastern margin, as drilling in this area failed to intersect a bottom contact despite drill depths of more than 350 feet. Most mineral production occurred in the shallow arm of the laccolith that has a thickness of 200-250 feet.

Major faults were not observed in the Jessie area, although there are some small shears characterized by fault gouge and (or) breccia, exposed in “glory holes” (large open pits). These shears typically had displacements on the order of inches to several feet where relations could be observed.

The quartz monzonite porphyry at Jessie contains a stockwork of gold-bearing, iron oxide-quartz veinlets, typically ⅛ to ¼ inch wide. Large veins (generally greater than about one inch wide and continuing laterally for tens or hundreds of meters) are lacking, but the concentration of subparallel veinlets permitted mining on a bulk basis (Ransome, 1910). Individual veinlets have limited extent along strike (generally less than 10 m) and contain quartz as druse or crystals parallel to the plane of the veinlet, commonly overgrowing the original igneous quartz phenocrysts. Accompanying quartz in veinlets in the oxide zone are, in decreasing order of relative abundance, massive goethite, earthy yellow limonite, red hematite, jarosite, sericite, and, rarely, visible native gold. Veinlets are dominated by iron oxides (typically in abundance ratios of 14:1 with respect to quartz). The iron oxides appeared to have been derived from pyrite. As indicated by drilling, oxidation typically extends to 40 to 80 feet below the surface. Dump sampling suggests that oxidation increased the gold content by a factor of approximately two over sulfide ore.

Hypogene (unoxidized) sulfides exposed in deeper levels at Jessie include, in decreasing order of abundance, pyrite, sphalerite, and galena. Galena typically occurs only in or immediately adjacent to fractures. Ransome (1911) considered the presence of galena to be a particularly favorable indication of gold. Sphalerite, although present chiefly in veinlets, has a wider distribution away from fractures than galena and locally occurs disseminated throughout the rock. Samples having disseminated sphalerite but no veinlets contain as much as several 100 ppb Au but nothing of ore grade. Pyrite occurs both in the veinlets and widely disseminated throughout the quartz monzonite porphyry. Typically, samples containing pyrite in veinlets assay 2-15 ppm Au; samples containing disseminated pyrite, but lacking veinlets, assay much less (0.1-2 ppm Au).

The principal orientation of mineralized veinlets at Jessie is N30°-40°E, parallel to the long axis of the five main glory holes. However, the glory holes themself are aligned along an E-W line. Detailed mapping of veinlets within the glory holes at Jessie are aligned along two predominant orientations (N30°-40°E and E-W) and three minor orientations (N15°-20°E, N65°-75°E, N20°-25°W). Dips of the veinlets are typically steep (70°-90°), although shallow structures do occur.

The quartz monzonite porphyry at Jessie is pervasively altered to sericite throughout the mine areas and alteration and gold grades are directly correlated to veinlet density. Mineralization is essentially restricted to the porphyry. Pierre Shale is typically unaltered and unmineralized even where adjacent to stockwork veining in the intrusive. Strong sericitic alteration within the porphyry, characterized by coarse sericite replacing K-feldspar, quartz, sericite replacing the groundmass, and square vugs forming after pyrite, typically is found in rock containing greater than 10 volume-percent veinlets. Moderate sericitic alteration, characterized by partial replacement of K-feldspar by fine sericite and quartz, biotite replaced by sericite, and the groundmass replaced by sericite, quartz, and kaolinite, is typically found in rocks containing 2-10 percent veinlets. Weak sericitic alteration, characterized by partial replacement of K-feldspar by sericite, quartz, and kaolinite, with biotite replaced by sericite and iron-oxide minerals, and the groundmass partially altered to sericite, kaiolinte, and quartz, occurs in rocks with less than 2 percent veinlets. Propylitic alteration (characterized by K-feldspar that is as much as 5 percent altered to sercite, kaolinite, and quartz; biotite that is altered to chlorite and iron-oxide minerals; and groundmass that is as much as 20 percent altered to sericite, kaolinite and quartz) is found at the margin and fringe of the intrusion. The peripheral dikes and sills are typically unaltered.

The Jumbo area, like Jessie, consists of stockworks and disseminations in altered quartz monzonite porphyry. The rocks within the small stocks at Jumbo are very similar in appearance to the quartz monzonite porphyry at Jessie, except that they have fewer eye-shaped quartz phenocrysts (“quartz eyes”). Mineralization at Jumbo is likewise very similar to that at Jessie and consists of stockwork veinlets of pyrite-quartz (in some cases oxidized to iron-oxide minerals and quartz) and accompanying disseminated pyrite and sphalerite within a pervasively strongly sericitized quartz monzonite porphyry. The contact of the igneous intrusions and adjacent sedimentary rocks appeared particularly favorable for mineralization. Locally, a basal limestone within the Morrison Formation is also mineralized. Unlike Jessie, the Jumbo area did contain distinct 3.5-foot-wide, high-grade (1-8 oz/t Au) veins (Summit County Journal, 1927). Mining at Jumbo appears to have stopped once the limit of oxidation (and coarse, easily worked gold) was reached (Ransome, 1911).

The Galena Gulch mining area comprises a broad zone of shallow shafts, adits, and prospect pits. Production appears to have been limited compared to Jessie and Jumbo, although Ransome (1911) did report that some of the richest placer ground in the Breckenridge district occurred at the mouth of Galena Gulch, approximately 1¼ miles downstream from the concentration of old workings. The geology consists of a complex of quartz monzonite porphyry dikes and stacked sills intruding Pierre Shale. Three varieties of quartz monzonite are recognized at Galena Gulch: a fine-grained variety having as much as 4 percent biotite, a quartz monzonite porphyry having less than 2 percent K-feldspar megacrysts, and a quartz monzonite porphyry having greater than 5 percent K-feldspar megacrysts (Kurt C. Friehauf, 1989, Asarco unpublished report.). For mapping purposes, however, all of these rocks are lumped as quartz monzonite porphyry (Tqp). Alteration and mineralization typically occurs within the sills near contacts and consists of goethite after pyrite veinlets and, locally, breccia cemented by a matrix of anglesite after galena. The mineralization is erratic and localized and has isolated areas of high-grade samples, but has no broad zones of alteration and mineralization similar to that at Jessie and Jumbo.

ACKNOWLEDGMENTS

Kellogg was assisted in the field by A.M. Licamelli in 1997-98 during mapping for the quadrangle. Digital assistance was provided by S.A. Smith, R.G. Kuehn, and K.S. Morgan. Individual who assisted in Asarco’s exploration effort in the Frisco quadrangle include K.C. Friehauf and J.B. Turner. Permission to release data was generously granted by Asarco, Incorporated. Asarco is now a division of Grupo Mexico.

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