Geologic Map of the Western Part of the Salmon 30 x 60 Minute Quadrangle, Idaho and Montana

Mapped and Compiled by
Russell F. Burmester, Reed S. Lewis, Kurt L. Othberg,
Loudon R. Stanford, Jeffrey D. Lonn, and Mark D. McFadden

Idaho Geological Survey
Third Floor, Morrill Hall
University of Idaho
Moscow, Idaho 83844-3014

Geologic Map 52
2016

Cover photo: View looking north along the Beaverhead Mountains, east-northeast of Salmon. Center Mountain (on right) consists of quartzite of the Swauger Formation. The west strand of the Beaverhead Divide fault is in the saddle on the west flank of the mountain.

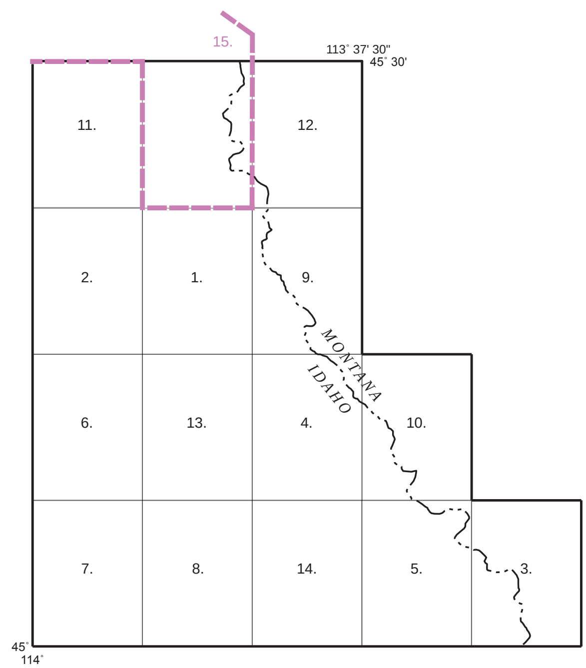
Geologic Map of the Western Part of the Salmon 30 x 60 Minute Quadrangle, Idaho and Montana

Mapped and Compiled by
Russell F. Burmester, Reed S. Lewis, Kurt L. Othberg,
Loudon R. Stanford, Jeffrey D. Lonn, and Mark D. McFaddan

INTRODUCTION

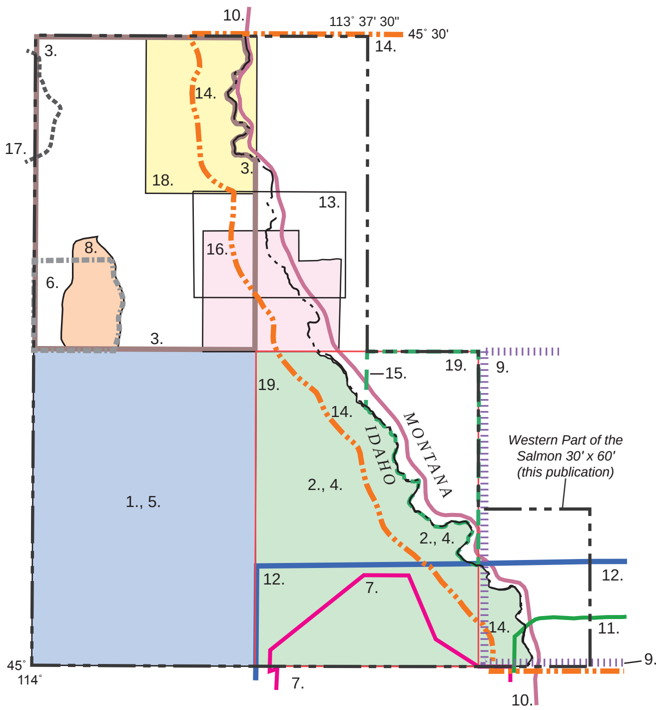
This geologic map of the western part of the Salmon quadrangle shows rock units exposed at the surface or underlying a thin surficial cover of soil or colluvium. Thicker surficial, alluvial, glacial, and landslide deposits are shown where they form mappable units. Geologic concepts and units for this map evolved while mapping in the Beaverhead Mountains along the Idaho-Montana border during a 1:24,000-scale collaborative project started in 2007 by the Idaho Geological Survey and the Montana Bureau of Mines and Geology. Geology depicted here is a compilation of 14 published 1:24,000-scale geologic maps that resulted from that collaborative effort (Fig. 1), plus part of a 1:40,000-scale map, with some changes, especially to older maps, made for consistency across this map. Evolution of our understanding of the regional geology has resulted in a transition from lithologic unit names (e.g., fine-grained quartzite) to lithostratigraphic names (e.g., Gunsight Formation) and, in places, new structural and stratigraphic interpretations that depart from our previous mapping. Some attitudes, faults, and folds from mapping by earlier workers supplement the structural data collected by the authors. Figure 2 shows the area covered by each of these secondary sources.

The oldest rocks in the area are metasedimentary rocks of Mesoproterozoic age that form the mountains in the west and east but also underlie the Salmon River valley.



1. Burmester, R.F. and others (2011)
2. Burmester, R.F. and others (2012)
3. Lewis, R.S. and others (2009a)
4. Lewis, R.S. and others (2009b)
5. Lewis, R.S. and others (2011)
6. Lewis, R.S. and others (2012)
7. Lewis, R.S. and others (2013a)
8. Lewis, R.S. and others (2014)
9. Lonn, J.D. and others (2008)
10. Lonn, J.D. and others (2009)
11. Lonn, J.D. and others (2013b)
12. Lonn, J.D. and others (2013c)
13. Othberg, K.L. and others (2010)
14. Othberg, K.L. and others (2011)
15. Stewart, E.D. and others (2014)

Figure 1. *Primary sources of geologic mapping.*



1. Anderson, A.L. (1956)
2. Anderson, A.L. (1957)
3. Anderson, A.L. (1959)
4. Anderson, A.L. (unpublished mapping in the Baker quadrangle, circa 1960)
5. Anderson, A.L. (unpublished mapping in the Salmon quadrangle, circa 1960)
6. Biddle, J.H. (1985)
7. Blankenau, J.J. (1999)
8. Brown, D.C. (1973)
9. Coppinger, Walter (1974)
10. Evans, K.V., and Green, G.N. (2003)
11. Hansen, P.M. (1983)
12. Janecke, S.U., Blankenau, J.J., VanDenburg, C.J., and Van Gosen, B.S. (2001)
13. Kilroy, K.C. (1981)
14. Lonn, J.D. and others (in press)
15. Lopez, D.A., O'Neill, J.M., and Ruppel, E.T. (2006)
16. MacKenzie, W.O. (1949)
17. Noranda, unpubished mapping (1982)
18. Steel, T.D. (2013)
19. Tucker, D.R. (1975)

Figure 2. *Secondary sources of geologic mapping.*

These were intruded locally in the Mesoproterozoic by granitic and mafic magmas and were extensively folded and faulted during multiple events. Cretaceous intrusive rocks are present in the northern part of the Beaverhead Mountains. Tertiary volcanic and sedimentary rocks of the Challis Volcanic Group and related intrusive rocks are widespread, but extensively eroded. The Salmon and Lemhi valleys that host Tertiary deposits are lowlands due to Tertiary extensional faulting. Those Tertiary deposits, which vary from coarse conglomerate to shale, record a wide range of depositional environments as the basin was forming. Subsequent erosion has removed much of the basin's sedimentary section. Lack of thick Quaternary alluvial fills in the Salmon and Lemhi valleys indicates that the Salmon basin detachment along the west side of the northern Beaverhead Mountains is inactive. The thin Quaternary deposits document erosion by glacial, alluvial, and mass-movement processes primarily during times of Pleistocene glacial climate.

DESCRIPTION OF MAP UNITS

Intrusive rock classification follows International Union of Geological Sciences nomenclature using normalized values of modal quartz (Q), alkali feldspar (A) and plagioclase (P) on a ternary diagram (Streckeisen, 1976). Mineral modifiers for igneous rocks appear in order of increasing abundance. Grain size classification of unconsolidated and consolidated sediment uses the Wentworth scale (Lane, 1947). Bedding thicknesses and lamination type are after McKee and Weir (1953), and Winston (1986). Grain sizes and bedding thicknesses are given in abbreviation of metric units (e.g., dm=decimeter). Unit thicknesses, distances, and elevations are in both metric and English units. Latitude and longitude are collected in North American Datum 1927 (NAD27). Stratigraphic units are described from bottom to top where possible, with multiple lithologies within them appearing in order of decreasing abundance. Soil descriptions are from Hipple and others (2006). Interpretations of kinematic indicators follow Simpson and Schmid (1983) for ductile fabrics, and Petit (1987) and Doblas (1998) for brittle fabrics.

ARTIFICIAL DEPOSITS

m—Man-made ground (Holocene)—Artificial fills composed of excavated, transported, and emplaced construction materials typically derived locally. Includes levees, reservoir dams, and berms and small dams for artificial ponds and lakes.

p—Placered ground (Holocene)—Includes gold placer tailings of Bohannon Creek valley and dredge tailings northeast of East Fork confluence with Bohannon

Figure 3. *Placer tailings along Kirtley Creek; view to southwest. Google Earth, Image NASA, Image USDA Farm Service Agency, Image© 2016 DigitalGlobe.*

Creek. Tailings from hydraulic mining southwest of that confluence form "alluvial" fans deposited into the flood plain of Bohannon Creek. Also includes tailings mostly from dredging of terrace gravel in valleys of Kirtley and Hughes creeks (Fig. 3).

ALLUVIAL DEPOSITS

Stream drainage in the Salmon basin is dominated by high-mountain runoff that drains into the valleys of the Lemhi River and the Salmon River. The Salmon River, part of the Columbia River system, moves all water northward then west out of the Salmon valley. Prior to the Pleistocene, the continental divide, now along the crest of the Beaverhead Mountains, was farther west. Evidence in this quadrangle indicates that drainage of the area in the Oligocene was southeast across the Beaverhead divide into the ancestral Missouri River system (see *Tkg* below). Later, Salmon valley drainage was captured by the ancestral Salmon River and the basin was deeply incised. We found no evidence for thick Quaternary alluvial valley fills in the Salmon and Lemhi valleys. In fact, available exposures and water-well logs show that terrace gravel deposits and mainstream alluvium are thin coverings on stream-cut surfaces (see Figure 5).

Qam—Main-stream alluvium (Holocene)—Well-rounded, moderately sorted and stratified pebble to boulder sandy gravel of the Salmon and Lemhi rivers. Gravel clasts are mostly quartzite, siltite, granite, and volcanic rocks. Includes flood-plain areas of sand, silt, and clay. Deposits are 1-12 m (3-40 ft) thick. Soils not developed to weakly developed.

Qas—Side-stream alluvium (Holocene and Late Pleistocene)—Subangular to rounded, moderately sorted and stratified pebble to boulder sandy gravel. Gravel clasts primarily quartzite, siltite, and volcanic rocks. Includes minor colluvium, fan deposits, and pebbly to cobbly sandy silt in local lower energy drainages. Deposits are 1-18 m (3-60 ft) thick. Soils not developed to weakly developed.

Qaf—Alluvial-fan and debris-flow deposits (Holocene and Late Pleistocene)—Angular to subrounded, poorly sorted, matrix-supported pebble to boulder gravel in a sand, silt, and clay matrix (Fig. 4). Commonly grades into, interfingers with, and caps side-stream alluvium (*Qas*). Thickness of deposits varies greatly, ranging from 1 to 24 m (3 to 80 ft). Soils weakly to moderately developed.

Qafo—Older alluvial-fan deposits (Pleistocene)—Angular to subrounded, poorly sorted, matrix-supported pebble to boulder gravel in a matrix of sand, silt, and clay. Some deposits clast-supported. Locally caps and interfingers with terrace gravel. Thickness of deposits varies greatly, ranging from 1 to 15 m (3 to 50 ft). Soils moderately to well developed.

Figure 4. *Photo of a typical debris flow deposited on an alluvial fan (Qaf). Flow was generated by intense runoff from a summer storm rainfall event southeast of Bobcat Gulch in 2011.*

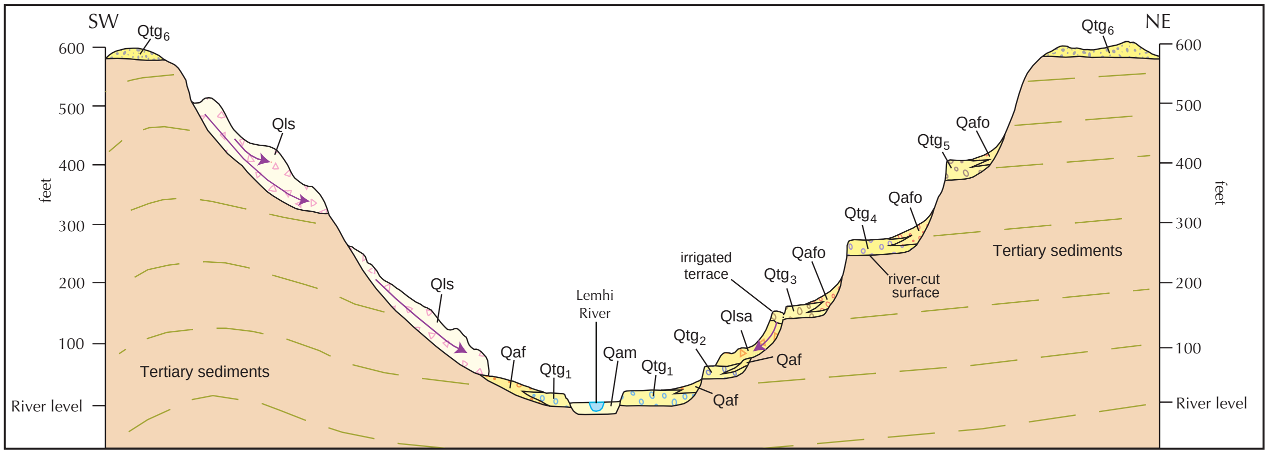


Figure 5. *Schematic cross-section across the Lemhi River Valley showing relative position and stratigraphic relationships of gravel terrace deposits, landslide deposits, and alluvial fan deposits. Not to scale.*

GRAVEL TERRACE DEPOSITS

Gravel deposits of Pleistocene alluvial terraces are moderately sorted and clast-supported sandy gravel. Clasts are subrounded to rounded pebbles, cobbles, and boulders. Clast lithologies are quartzite, siltite, and volcanic rocks from the adjacent mountains. Terrace deposits form relatively thin (9 m; 30 ft) caps over stream-cut bedrock surfaces. Six levels of terraces and terrace remnants are preserved that range from 3 m (10 ft) to more than 180 m (600 ft) above present-day streams. Terrace gravels commonly are capped by, and interfinger with, alluvial-fan deposits (*Qaf* and *Qafo*), which are included in the terrace unit locally (Fig. 5). The terrace sequence records long-term episodic incision of the Salmon basin, which was probably driven by glacial climate fluctuations during the Pleistocene.

Qtg_1—Gravel of first terrace (Holocene and Late Pleistocene)—Forms terrace 3-9 m (10-30 ft) above modern streams. Soils weakly developed.

Qtg_2—Gravel of second terrace (Late Pleistocene)—Forms terrace 9-24 m (30-80 ft) above modern streams (Fig. 6). Soils moderately developed.

Figure 6. *Grass-covered second terrace above Salmon River (Qtg_2) about 18 km (11 mi) north of Salmon. Gravel was deposited on a bedrock stream-cut surface and the upper part of the terrace has been eroded near the river.*

Figure 7. *Gravel pit roughly 1.6 km (1 mi) east of the confluence Lemhi and Salmon rivers that exposes approximately 5 m (15 ft) of gravel of 5th terrace (Qtg_5) with a well-developed indurated soil duripan (composed of light-colored precipitates of silica and carbonate). Base of gravel is near floor of pit.*

Qtg_3—Gravel of third terrace (Late? to Middle? Pleistocene)—Forms terrace 18-49 m (60-180 ft) above modern streams. Soils well developed.

Qtg_4—Gravel of fourth terrace (Middle? Pleistocene)—Forms terrace 61-110 m (200-360 ft) above modern streams. Soils well developed.

Qtg_5—Gravel of fifth terrace (Early? Pleistocene)—Forms terrace 91-146 m (300-480 ft) above the modern streams (Fig. 7). Soils of original terrace surface mostly eroded away.

Qtg_6—Gravel of sixth terrace (Early? Pleistocene)—Forms terrace remnants 150-210 m (500-700 ft) above modern streams. Soils of original terrace surface eroded away (Fig. 8).

GLACIAL DEPOSITS

Glacial deposits in the quadrangle are associated with the glaciation of the Beaverhead Mountains, Salmon River Mountains, and northern Lemhi Mountains. Moraine locations and ice sculpting indicate that both valley glaciers and small ice caps were active. Valley glaciers were most extensive along the east side of the Beaverhead Mountains where moraines form a coalescing front that extends far into the Big Hole Valley in Montana. On the Salmon valley side, glaciers advanced mostly within their valleys. Moraine positions indicate that ice was as low as 1800 m (6000 ft) on the western side of the Beaverhead Mountains and 2000 m (6500 ft) in the Big Hole Valley. Glacial deposits were not previously subdivided within the area but glacial units on this map probably correlate with units mapped by Scott (1982) in the Lemhi Range to the south. Primarily based on their position and morphology, the most prominent moraines formed during the last local

Figure 8. *Road cut exposes stream channel gravel of the highest terrace (Qtg_6) and river-cut surface on light-colored Tertiary sediments about 2 km (1.3 mi) northeast of the confluence Lemhi and Salmon rivers.*

Figure 9. *Little Ice Age(?) moraines, inactive rock glacier deposits, and pro-talus ramparts on the Montana side of the Continental Divide at the heads of Little Lake and Big Swamp creeks;view south-southwest. Google Earth, Image NASA, Image USDA Farm Service Agency, Image© 2016 DigitalGlobe.*

glacial maximum, regionally known as the Pinedale Glaciation, which occurred 20-13 ka. Remnants of older glacial deposits probably formed during early Pinedale, Bull Lake, or older glaciations. Evidence for younger glacial advance and periglacial activity related to the Little Ice Age is found in cirques and northeast-facing protected areas above 2,500 m (8,200 ft).

Qgty—Young glacial and periglacial deposits (Holocene?)—Poorly sorted angular to subangular boulder gravel and till. Includes pro-talus ramparts, inactive rock glaciers, and moraines of the Little Ice Age and older(?) deposits in cirques and east- and northeast-facing protected areas above 2,500 m (8,200 ft). Lichens common on all but youngest (highest and most protected) deposits. MacKenzie (1949) classified the larger deposits as rock glaciers, but well-developed lateral moraines of some deposits indicate a glacial component to their origin. Today, deposits appear inactive; debris-covered ice is found only in protected areas above youngest ramparts or moraines at or above 2,800 m (9,300 ft) (Fig. 9). Thickness as much as 25 m (80 ft). Soils undeveloped.

Qalc—Fine-grained alluvial and lacustrine deposits (Holocene to Pleistocene)—Silt, sand, and minor gravel deposited in glacially scoured closed depressions, typically behind end moraines. Deposits are 1-12 m (3-40 ft) thick. Soils undeveloped.

Qgt—Till deposits of last local glacial maximum (Late Pleistocene)—Poorly sorted sandy to clayey boulder till. Clasts subangular to subrounded (Fig. 10). Forms end moraines and stagnation moraines in the Big Hole Valley (Fig. 11). Late Pinedale Glaciation equivalent. Till thickness 20-120 m (65-400 ft). Soils weakly developed.

Figure 10. *Typical sandy boulder till found in a lateral moraine of the last local glacial maximum (Qgt) in the Big Lake Creek drainage. Large quartzite boulder at center right is about 0.7 m (28 in) across.*

Qgo—Outwash gravels of last local glacial maximum (Late Pleistocene)—Subrounded to rounded, well-sorted sandy cobble to boulder gravel. Primarily Pinedale equivalent; traceable to terminal moraine deposits of *Qgt*. Outwash thickness 2-9 m (6-30 ft). Soils weakly developed.

Qgto—Till deposits older than the last local glacial maximum (Late? to Middle? Pleistocene)—Poorly sorted cobble and boulder till. Mostly subangular to subrounded clasts. Till thickness 1-15 m (3-50 ft). Soils moderately well developed.

Qgoo—Outwash gravels older than last local glacial maximum (Late? to Middle? Pleistocene)—Subrounded to rounded, well-sorted sandy cobble to boulder gravel. Traceable to old moraine deposits (*Qgto*). Early Pinedale or older. Shows evidence of relict meltwater channels. Probably overlies stream-cut surface on bedrock. Thickness 3-12 m (10-40 ft). Soils moderately well developed.

QTcg—Colluvial and glacial deposits (Early? Pleistocene to Pliocene?)—Pebble, cobble, and boulder gravel that caps highest foothill ridges and overlies erosion surface on Tertiary sediments. Primarily colluvium with large, lag surface boulders; original deposits probably include till, pediment gravel, and creep and lag deposits derived from Tertiary conglomerate (*Tkg*). Deposits are 12-24 m (40-80 ft) thick. Soils of original surface eroded away.

MASS-MOVEMENT DEPOSITS

Mass-movement deposits in the quadrangle include deep-seated rotational landslides or slumps, thinner translational slides, debris flows of widely varying volume and extent, and periglacial colluvium that moved more actively by solifluction during times of Pleistocene glacial climates. Other colluvium, including talus, was not separately mapped but included in the rock units on which it lies. Mass-movement deposits are common in the Salmon basin. Most are relict from the Pleistocene when moisture more effectively saturated the soil and rock masses sufficiently to cause common landsliding. This is evidence of a strikingly different climate from that of the Holocene. Most active

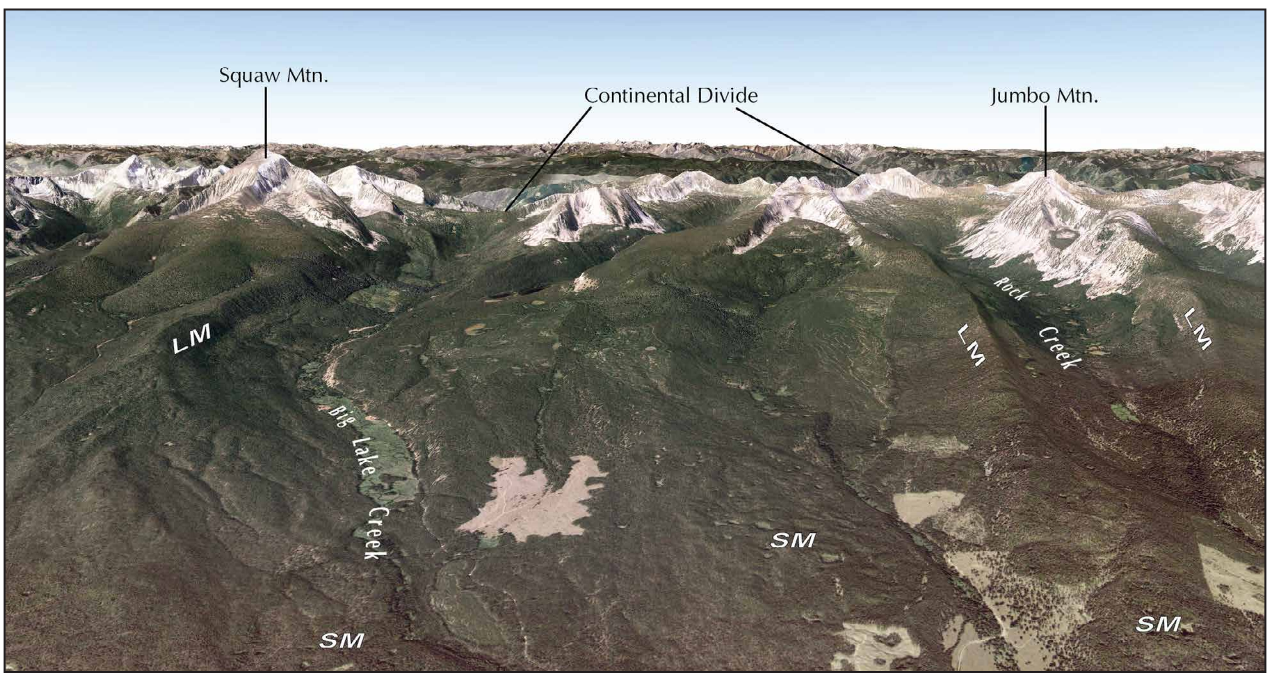


Figure 11. *View of the till deposits on the eastern flank of the Beaverhead Mountains, looking west-southwest at the Continental Divide. Lateral moraines (LM) of the last local glacial maximum (Qgt) are visible in both drainages as are stagnation moraines (SM) near glacial terminus (bottom of image). Google Earth, Image NASA, Image USDA Farm Service Agency, Image© 2016 DigitalGlobe.*

landslides, i.e., ones that show historic activity, are associated with artificially altered local stream drainage and increased localized groundwater.

Qlsa—Deposits of active landslides (late Holocene)—Unstratified, poorly sorted silty clay and gravelly silty clay. Deposited by slumps, slides, and debris flows from slope failures primarily in Tertiary sediments (Fig. 12). Typically related to and formed after development of water ditches and irrigation. Deposits as thick as 4 m (13 ft).

Qls—Landslide deposits (Holocene to Pleistocene)—Unstratified, poorly sorted silty clay, gravelly silty clay, and boulders. Deposited by slumps, slides, slide blocks, earth flows, debris flows, debris avalanches, and rockfalls. Landslides are common in areas of Tertiary sediments. Large, complex landslide masses occur in Challis volcanics (Fig. 13). Deposits as thick as 35 m (120 ft).

Figure 12. *Active landslide and headwall scarp near Sevenmile Creek south of Salmon.*

Qms—Mass-movement deposits (Holocene to Pleistocene)—Angular to subangular poorly sorted silty and clayey gravel. Includes solifluction deposits, colluvium, and some alluvial-fan gravel. Deposits are thin.

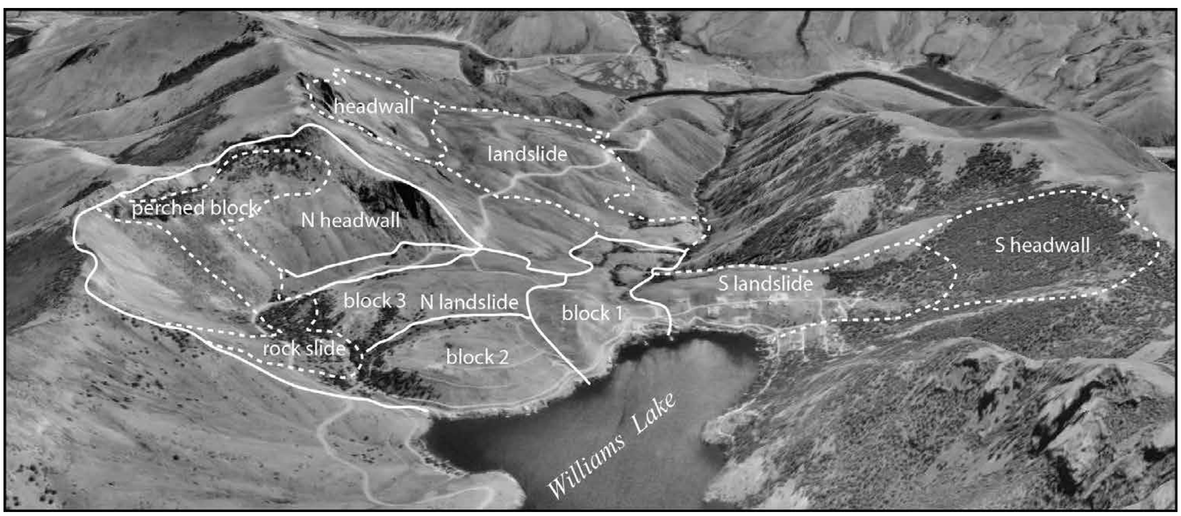


Figure 13. *Oblique view to east of Williams Lake landslide dam, annotated to outline landslides, landslide blocks, and headwalls (modified from Lewis and others, 2013b). Salmon River is in upper part of photo.*

TERTIARY SEDIMENTARY DEPOSITS, BLOODY DICK CREEK

Ts—Sedimentary rocks and sediment (Oligocene to Eocene)—Light yellowish brown siltstone to claystone in exposure along Dutch Creek, and pebble-rich sediment north of Dutch Creek. Dutch Creek exposure probably is basin fill in the hanging wall of the Dutch Creek fault, east of Bloody Dick Creek.

TERTIARY SEDIMENTARY DEPOSITS AND VOLCANIC ROCKS OF THE SALMON BASIN

Janecke and Blankenau (2003) interpreted the Salmon basin as one of several supradetachment basins that formed in east-central Idaho and western Montana between 46 and 31 Ma (late middle Eocene to early Oligocene). Blankenau (1999) studied the structure and stratigraphy in the southern portion of the Salmon basin. Previously, sedimentary rocks of the Salmon basin were described, subdivided, and mapped by Anderson (1957) and Tucker (1975). Harrison (1985), in studying sedimentology of the Tertiary sediments that fill the Salmon basin, identified a series of gradational facies and informal lithostratigraphic units that are adopted here in modified form. The units are conformable and were deposited in alluvial-fan, braided-stream, mixed-channel, flood-plain, and lake environments as the basin was being downfaulted. Deposits of fluvial single-channel streams are rare, but debris flows and braided-channel deposits are common, suggesting that most of the deposition occurred on alluvial fans. Each unit comprises a suite of dominant lithologies, but interfingering of the lithostratigraphic units renders contacts gradational and difficult to trace. Volcanic ash and bentonite are important constituents in the finer-grained facies, but thin ash beds also occur in coarser units. Conglomerate and breccia predominate in the proximal facies, especially adjacent to the Salmon basin detachment fault, but diminish in thickness and extent basinward, and are rare in the nearshore lake facies. Most conglomerates represent debris flows, and some probably had long run-outs into flood-plain and near-shore lake environments. Geomorphic expression of lithology was used to map the gradational contacts. Most units are semi-consolidated; cementation is restricted to thin beds of sandstone and conglomerate, which are not laterally extensive. As a result, outcrops are rare, with many slopes covered by thin sheet wash and colluvium. Conglomerate beds weather to a gravelly soil mantle. Most common structures in the basin-fill sediments are broad folds. Dips in the units are generally basinward, and steepest near the detachment fault at the base of the Beaverhead Mountains. Contacts with the underlying Challis Volcanic Group are unconformable. No major angular unconformities within the basin-fill sediments were seen. Rather, the sedimentary facies represent

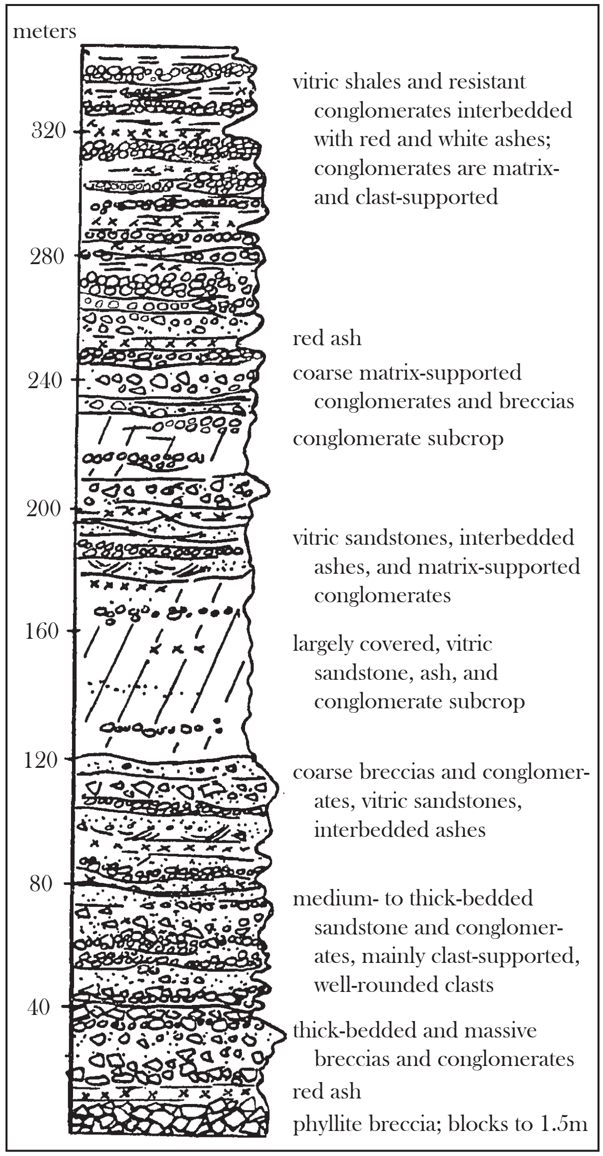


Figure 14. *Descriptive column for conglomerate of Kriley Gulch (Kriley Gulch formation of Harrison, 1985). From Harrison (1985) Figure 9.*

Figure 15. *View looking northeast, north of Carmen. Prominent cliffs are conglomerate of Kriley Gulch (Tkg).*

depositional environments that persisted over time. When basin filling ceased is not known, but early incision of the valley is recorded by Early(?) Pleistocene stream-cut surfaces averaging about 180 m (600 ft) above the present streams. Age is constrained by the older Challis Volcanic Group and overlying Quaternary units. Well-preserved plant remains studied by Axelrod (1998) are representative of the Oligocene Haynes Creek Flora. A thin tuff interbedded with lake sediments was dated at 31 Ma (Axelrod, 1998).

Tkg—Conglomerate of Kriley Gulch (Oligocene to Eocene)—Matrix-supported conglomerate, clast-supported conglomerate, and matrix-poor breccia. Includes interbeds of ash, vitric siltstone, and sandstone (Fig. 14). Proportion of fine-grained beds increases basinward where the unit interfingers with finer grained units. Colors are gray, white, and red. Silica and hematite cement are common. Lag cobbles and boulders as large as 3 meters in diameter cover surfaces of weathered and eroded beds. Unit predominantly composed of debris-flow deposits. Forms steep slopes with coarse gravelly soils and resistant ridges (Fig. 15) commonly capped with lag pebbles and cobbles, and rare boulders. Boulders and cobbles of Mesoproterozoic quartzite and siltite predominate (Fig. 16). Clasts of Challis volcanics are common near Challis Volcanic Group rocks and higher in the section. Depositional environments include proximal fan and fan head to mid fan, proximal braided stream, and a through-flowing river channel. These environments suggest a high-relief landscape that experienced episodes of high-energy discharge.

Figure 16. *Close-up view of quartzite cobbles under silt beds within Tkg in the Kenney Creek drainage.*

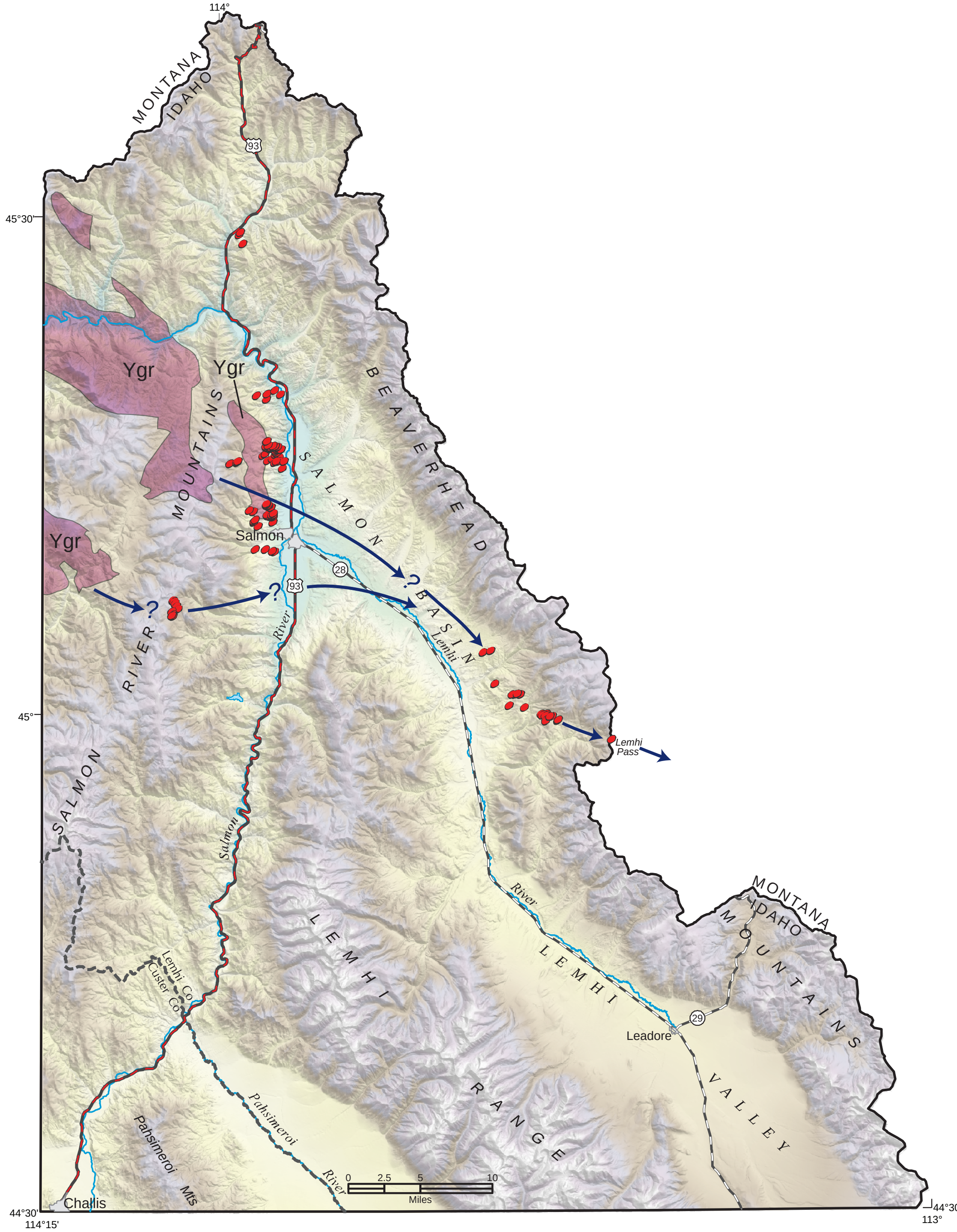


Figure 17. *Shaded relief map of the area around Salmon showing distribution of known locations of rounded megacrystic granite (Ygr) boulders (red blobs). These likely mark ancestral stream flow from a high-relief landscape northwest of Salmon southeastward into Montana. Blue arrows show inferred transport paths. Age of this river system is uncertain, but appears to be both Challis (Eocene) and post-Challis (Oligocene?).*

Figure 18. *Large boulder of megacrystic granite (Ygr unit) near Lemhi Pass fault. May mark a river channel that flowed southeastward into Montana from a high-relief landscape northwest of Salmon.*

Distinctive boulders of Mesoproterozoic granite are found north of the city of Salmon in conglomerate adjacent to exposures of *Ygr,* but also 40 km (25 mi) to the southeast and in the Lemhi Pass area (Figs. 17, 18; Blankenau, 1999, Lewis and others, 2011). Blankenau (1999) and Janecke and others (2000) included these boulders low in the Challis stratigraphy and postulated that they were evidence for an Eocene paleoriver that flowed across the Beaverhead Mountains at Lemhi Pass before the Salmon basin formed. In addition, we include these distinctive granitic boulders stratigraphically high in the conglomerate of Kriley Gulch and suggest that the drainage was through-flowing also in the Oligocene.

Tcc—Sandstone of Carmen Creek (Oligocene to Eocene)—Trough cross-stratified sandstone beds that vary from well-sorted quartz arenites to vitric and lithic wackes. Common interbeds of massive and trough cross-stratified conglomerate; conglomerate beds similar to those in the conglomerate of Kriley Gulch. Less commonly includes interbedded volcanic ash beds and vitric siltstones with abundant plant remains (Fig. 19). Contains rare Mesoproterozoic granite pebbles 1.5 km (1 mile) southwest of Salmon. Resistant beds cemented with silica and hematite. Buff colored in outcrop (Fig. 20). Depositional environment primarily distal gravelly streams, but facies exhibit a continuum from distal gravelly braided streams to flood-basin swamps and ponds. Forms low-relief hills and valleys.

Twc—Siltstone of Wimpey Creek (Oligocene to Eocene)—Vitric siltstone, bentonite, mudstone, and carbonaceous shale with minor interbeds of

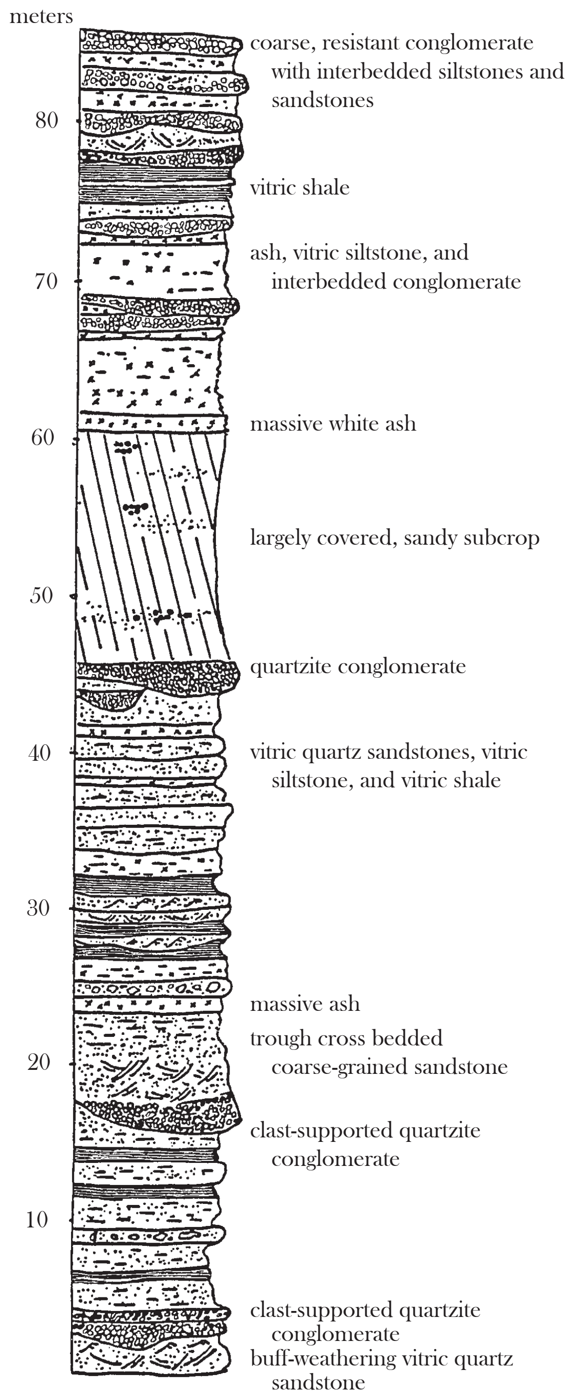


Figure 19. *Descriptive column for sandstone of Carmen Creek (Carmen Creek formation of Harrison, 1985). From Harrison (1985) Figure 13.*

Figure 20. *Exposure of sandstone of Carmen Creek at the west edge of the city of Salmon in landslide headwall above displaced landslide deposits. View is northeast along axis of anticline in folded beds of fine sand, silt, and ash.*

conglomerate and sandstone (Fig. 21). In the center of the basin, unit lacks conglomerate and sandstone. Colors range from white to greenish gray and pinkish brown. Locally stained and cemented with iron and manganese (Fig. 22). Poorly consolidated vitric siltstone, bentonite, and carbonaceous to lignitic shale characterize the fine-grained facies (formerly mapped as the Mulkey Creek formation; Harrison, 1985). Bed thickness varies from a few millimeters to a few meters. Depositional environments include proximal mixed-load streams, sandy mixed-load streams, flood-basin swamps and ponds, and lake bottoms. Includes portions of Blankenau's (1999) shale facies of the sedimentary rocks of Tendoy. Where fine-grained facies predominate, forms gently sloping, low-relief, 'badland' topography. Prone to erosion and landsliding.

Tsc—Quartz arenite of Salmon City (Oligocene to Eocene)—Fine- to coarse-grained, moderately- to well-sorted vitric quartz arenite interbedded with vitric siltstone, shale, and minor conglomerate (Fig. 23). Outcrops generally buff colored (Fig. 24). Locally cemented beds of sandstone form low ridges. Massive sandstone forms broad resistant hills. Bed thicknesses range from 50 cm to 3 m (1.6 to 10 ft). Depositional environments predominantly distal sandy stream and distal shallow braided streams. Includes portions of Blankenau's (1999) Tertiary sandstone and the middle conglomerate of the sedimentary rocks of Tendoy.

Twcb—Intercalated basalt (Oligocene or Eocene)—Thin flow or sill of basalt or andesite, either interbedded with siltstone and shale or intruded into the sedimentary rocks along bedding.

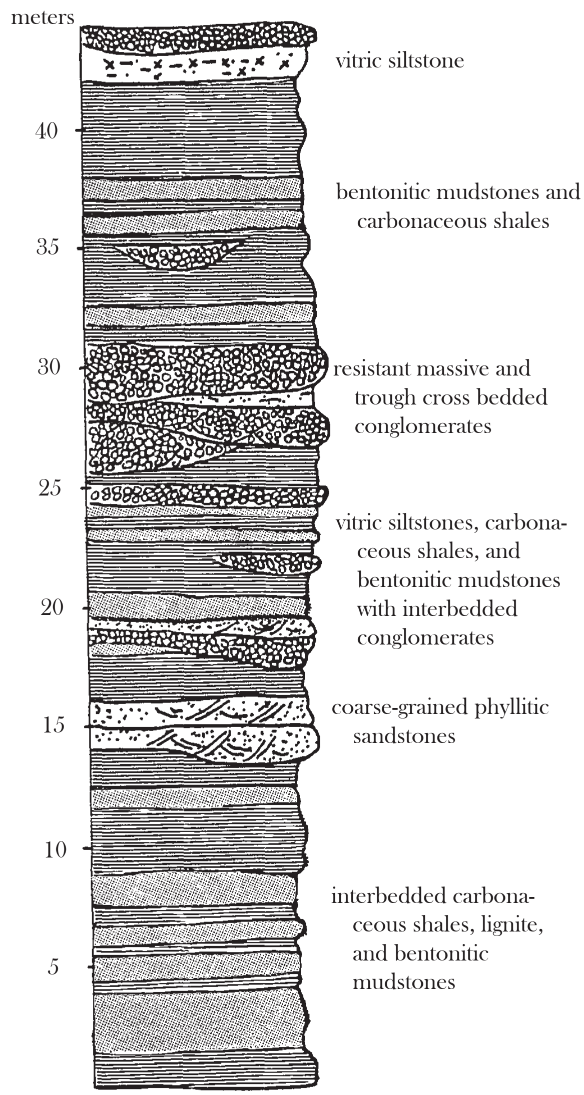


Figure 21. *Descriptive column for siltstone of Wimpey Creek (Wimpey Creek formation of Harrison, 1985). From Harrison (1985) Figure 16.*

Tccg—Clay-rich conglomerate (Oligocene or Eocene)—Deeply weathered conglomerate with clasts of dark-gray quartzite (probably unit *Yg*) and latite (unit *Tlm*). Volcanic clasts are observed only in recently cut or eroded banks or landslide scarps and do not show on the surface where unit is decomposed. Soils formed from unit are unusually clay rich and dark-brown in color. Highly susceptible to mass wasting.

Figure 22. *Ashy, muddy sediments of the siltstone of Wimpey Creek located along a gully adjacent to Lemhi River valley approximated 6.4 km (4 mi) southeast of Baker.*

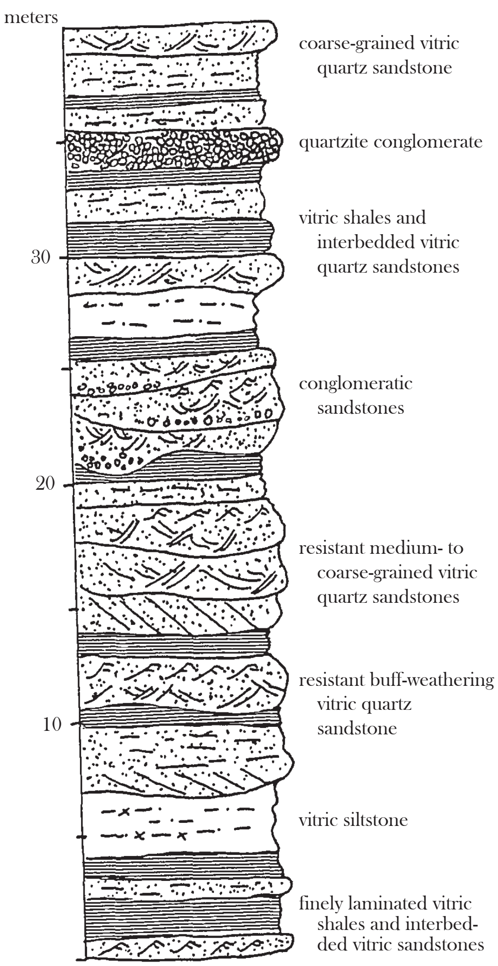


Figure 23. *Descriptive column for quartz arenite of Salmon City (Salmon City formation of Harrison, 1985). From Harrison (1985) Figure 12.*

Figure 24. *Sandstone, ashy shale, and conglomerate of the quartz arenite of Salmon City approximately 0.8 km (0.5 mi) northeast of Salmon.*

CHALLIS VOLCANIC GROUP

Rocks of the Challis Volcanic Group in the Salmon area are northeast of the main Challis volcanic field that erupted in the Eocene (about 51-44 Ma). Remnants of these lava flows, tuffs, and subordinate sediments, which are widespread in east-central Idaho, were mapped and described by D.H. McIntyre, E.B. Ekren, and R.F. Hardyman in the Challis 1° x 2° quadrangle to the southwest (Fisher and others, 1992). A stratigraphic section has also been established in and adjacent to the southeast corner of the map in the Lemhi Pass area (Blankenau, 1999). As noted below, most or all of the Challis Volcanic Group units in the Salmon area were erupted between 50 and 46 Ma.

Tcv—Challis Volcanic Group, undivided (Eocene)—Varied volcanic rocks in the north part of map where sparse distribution and poor preservation inhibit correlation with more continuous sections to the south. A resistant knob west of Carmen Creek is suspected to be mafic to intermediate volcanic rock. Includes porphyritic hornblende-biotite dacite with phenocrysts of plagioclase, quartz, biotite, and hornblende. Rocks exposed along Little Fourth of July Creek have a very fine grained to glassy groundmass and weather easily to a brown soil. These are interpreted as dacite lava flows, but may be shallow intrusive rocks and thus equivalent to *Tdr*. Exposures near the northern map boundary include some rhyolite (*Tct?*), but most are probably dacite or andesite.

Figure 25. *East-dipping tuffaceous rocks of Ttss at Sevenmile Creek south of Salmon.*

Tbo—Olivine basalt (Eocene)—Basalt or basaltic andesite flow(?) or large dike(?) south of Chipps Creek southwest of Salmon. Contains conspicuous 1-2 mm glomerocrysts of olivine. Plagioclase present as sparse 0.5-1 mm phenocrysts and as trachytic texture in groundmass. Lacks continuity with other Challis units; if a flow, the stratigraphic position is uncertain. May correlate with a relatively young olivine basalt unit (Tob) mapped by Tysdal and Moye (1996) east of the Salmon River 32 km (20 mi) south of Salmon.

Tct—Challis tuff, undivided (Eocene)—Mixed unit of predominantly rhyolitic composition in northern part of map. Most or all of unit is welded tuff, but wide compositional range is suggestive of several extrusive events. Tuff from ridge northwest of Bobcat Gulch contains flattened pumice, quartzite lithics, and quartz well in excess of sanidine phenocrysts. Exposures along and north of Kriley Creek include stratigraphically lowest biotite-plagioclase vitrophyre and hornblende-bearing dacite(?) and stratigraphically higher (eastward) rhyolite tuff with abundant dark quartzite clasts and quartz, sanidine, and biotite phenocrysts. Highway exposure west of the mouth of Kriley Creek is a lithic-rich biotite-sanidine-plagioclase-quartz tuff. This exposure, and the exposure of sanidine(?)-quartz tuff with sparse quartzite lithics on the opposite side of the river 1 km to the west, are unusual in that they occupy low elevations. Either they filled a paleovalley, or they have been downdropped on unrecognized faults. The largest mass of tuff immediately southeast of Wagonhammer Creek contains abundant lithic clasts of medium-gray, fine-grained quartzite along with abundant crystals of dark-gray and light-gray quartz, less abundant plagioclase, and sparse altered mafic minerals. Crystal-lithic tuff is also present north of Wagonhammer Creek, but there the lithic clasts are dark gray to black. Tuff with black quartzite lithics also is present near the mouth of Little Fourth of July Creek. This part of the section is likely correlative with *Tqt* to the southeast of Salmon, which characteristically contains black quartzite lithic fragments. Stratigraphically above the tuff with black quartzite lithics is a crystal tuff containing feldspar, biotite, quartz, and possibly hornblende.

Ttss—Tuff, sandstone, and siltstone, undivided (Eocene)—Volcanic and sedimentary rocks south of Salmon (Fig. 25). Overlies the quartz-rich tuff (*Tqrt*) in Henry Creek drainage, the biotite-plagioclase tuff (*Tbpt*) north and northeast of there, and locally *Tlm* where the other two units are missing. Includes pink welded tuff both north and south of Henry Creek with euhedral chatoyant sanidine and smoky quartz in a fine to glassy groundmass. Locally prospected for uranium (see Mineralization section below). The pink welded tuff is correlated with upper quartz-sanidine tuff (*Tqs_2*)

and Tqs_2 of Blankenau (1999) in the Baker and Lemhi Pass areas to the southeast. Production by multiple eruptive events documented by several basal zones rich in lithic fragments in exposures along Sevenmile Creek.

Tcty—Younger Challis tuff and sandstone, undivided (Eocene)—Volcanic and sedimentary rocks overlying the mafic lava flows (*Tlm*) in the southern part of the map. Includes tuff of Curtis Ranch (*Ttcr*) and overlying quartz-sanidine welded tuff (Tqs_2) along Withington Creek west of the Lemhi River, Tqs_2 resting directly(?) on *Tlm* on the north side of Haynes Creek, and lapilli-crystal-lithic tuff and interbedded sandstone higher(?) in the section east and west of Kadletz Creek. The lapilli-crystal-lithic tuff contains potassium feldspar and quartz phenocrysts, and dark-gray fine-grained quartzite clasts similar to those found in *Tqt.* Alternative explanation is that the Kadletz Creek area contains a remnant high with rocks that predate the mafic lavas rather than overlie them (*Tqt* rather than *Tcty*). Interlayered sandstone in the Kadletz Creek area contains subangular clasts of quartz, potassium feldspar, and plagioclase. North of Withington Creek contains units recognized by Blankenau (1999). These are mapped separately in the eastern part of the Baker quadrangle as a lower tuff with plagioclase, quartz, sanidine, and biotite phenocrysts (tuff of Curtis Ranch; *Ttcr*) overlain by a tuff with quartz and chatoyant sanidine phenocrysts (younger quartz-sanidine welded tuff; Tqs_2). West of the Salmon River fault, the stratigraphy is uncertain because of poor exposure, hydrothermal alteration, and brecciation. Most tuffs there contain plagioclase, quartz, and biotite phenocrysts, but some are quartz-poor. In the Salmon quadrangle includes poorly welded lapilli tuff with 9-12 percent sanidine and 5-8 percent quartz phenocrysts 1-2 mm across. Also locally aphyric. At least part likely correlates with the younger quartz-sanidine tuff (Tqs_2) mapped by Blankenau (1999), Lewis and others (2011), and Othberg and others (2011) northwest of Lemhi Pass.

Tqs_2—Younger quartz-sanidine welded tuff (Eocene)—White to pale-green or gray-green welded tuff exposed east of Lemhi River in southern part of map. Contains euhedral chatoyant sanidine and smoky quartz in a fine ash groundmass. Degree of welding varies. Equivalent to Tqs_2 unit of Blankenau (1999), who obtained a $^{40}Ar/^{39}Ar$ age of 45.95 ± 0.12 Ma from a sample collected along Agency Creek just south of the map. A slightly older $^{40}Ar/^{39}Ar$ age of 46.13 ± 0.19 Ma from the Sharkey Hot Spring area was also reported by Blankenau (1999).

Ttcr—Tuff of Curtis Ranch (Eocene)—White to greenish-white tuff exposed east of Lemhi River in southern part of map. Contains abundant biotite and

Figure 26. *Resistant ridge of Tqrt northeast of Williams Lake.*

Figure 27. *Vitrophyre of Tbpt on ridge north of Williams Creek about 1.8 km (1.1 mi) from the west edge of the map. Layering dips east; hammer head is about 20 cm long.*

lesser amounts of smoky quartz, plagioclase, and angular volcanic and quartzite lithics. Pumice is abundant to rare and typically concentrated at the top of the unit. Sandstone present locally at base. Typically poorly welded, but densely welded in places. Equivalent to Tcr unit of Blankenau (1999) who obtained a $^{40}Ar/^{39}Ar$ age of 47.58 ± 0.14 Ma from a sample collected along Warm Spring Creek northeast of Sharkey Hot Spring.

Tqrt—Quartz-rich tuff (Eocene)—Pink tuff south of Salmon that contains conspicuous quartz phenocrysts, most but not all of which are smoky. Also contains sanidine, plagioclase, and biotite phenocrysts. Well exposed in cliffs north and northeast of Williams Lake (Fig. 26), where the lowest part of the unit is densely welded and contains flattened pumice (fiame).

Tbpt—Biotite-plagioclase tuff (Eocene)—Pink tuff south of Salmon that contains plagioclase and biotite, and minor hornblende and quartz phenocrysts. Characterized by extensive vapor-phase alteration resulting in devitrification, formation of spherulites, and formation of drusy quartz as vug fillings. Contains minor vitrophyre (Fig. 27). Sample collected near the mouth of Henry Creek (lat 45.0506° N, long 113.9207° W) was dated by U-Pb zircon methods, resulting in an age of 48.27 ± 0.15 Ma (Fig. 28a; Jesse Mosolf, written commun., 2016). Locally prospected for uranium (see Mineralization and Hydrothermal Alteration section below).

Tvcm—Mafic volcaniclastic rocks (Eocene)—Green, quartz-poor volcaniclastic rocks locally present above the mafic lava flows (*Tlm*) south of Salmon.

Trt—Rhyolite tuff (Eocene)—White rhyolite tuff with small phenocrysts of sanidine and quartz exposed south of Salmon. Well bedded and possibly water lain. Stratigraphic position uncertain, but may be at the same level as the mafic lava flows (*Tlm*) or perhaps the hornblende dacite (*Thd*). Northwest part of exposure is massive vitrophyre with quartz, biotite, and feldspar phenocrysts.

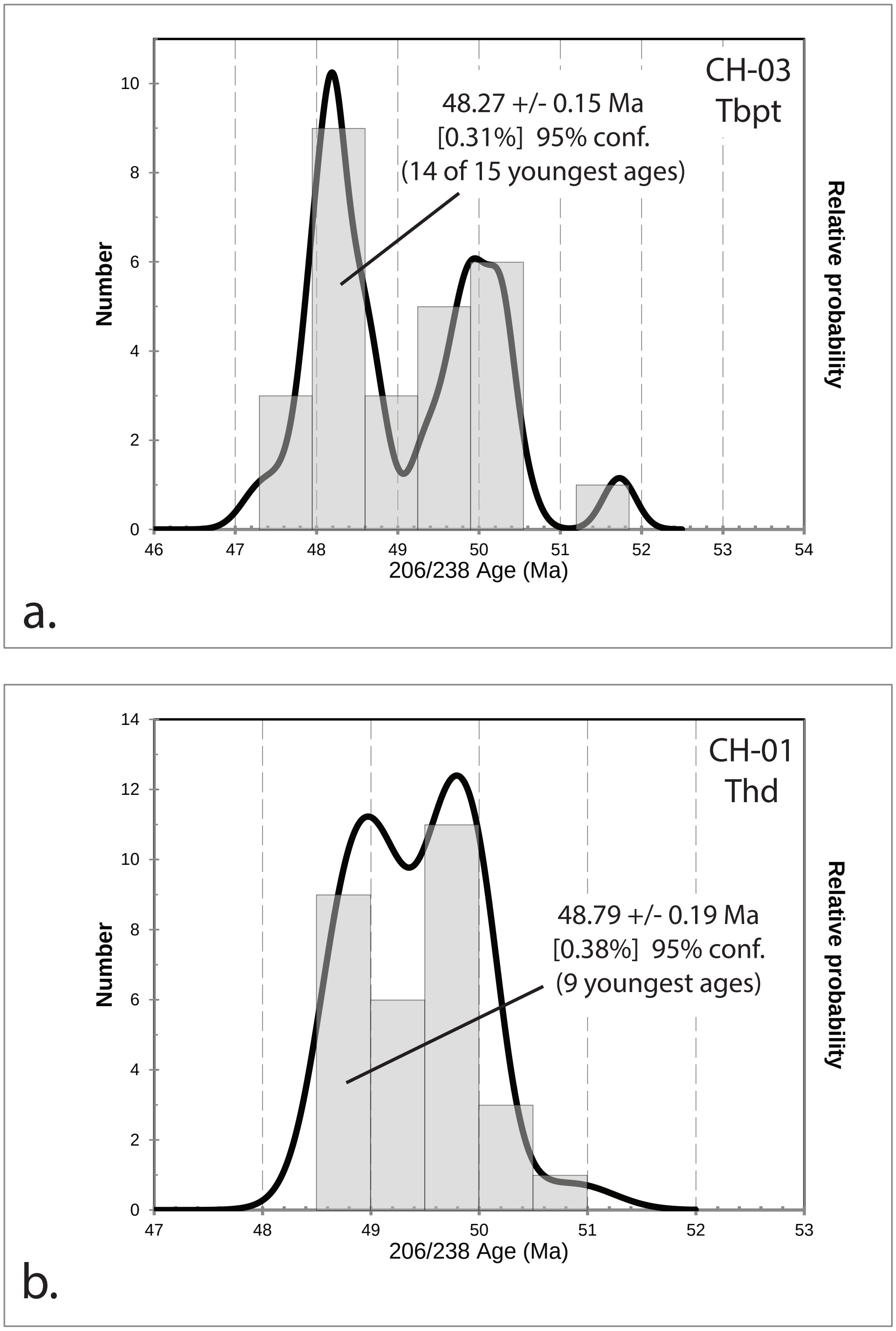


Figure 28. *Histogram and relative probability plots of U-Pb zircon age determinations. Analytical work was completed by Jesse Mosolf using facilities at University of California, Santa Barbara. Calculations and plots made using Isoplot 4.15 (Ludwig, 2012). (a) Sample of biotite-plagioclase tuff unit (Tbpt) collected near the mouth Henry Creek. Because of bimodal age distribution, only the young ages were used to determine the weighted mean (14 of 15 analyses). Older ages are likely from zircons inherited from older Challis intrusive material assimilated at depth. (b) Sample of hornblende dacite unit (Thd) collected northwest of Williams Lake. Although not as pronounced as in the Tbpt sample, a bimodal distribution is also apparent. Weighted mean was calculated based on the 9 youngest ages. If all but the oldest age are used (29 of 30 analyses), the weighted mean is 49.45 ± 0.18 Ma. The younger age is preferred.*

Figure 29. *Fragmental Tlm near south edge of map, east of Williams Lake. Red weathering and medium to dark brown color are typical.*

Tlm—Mafic lava flows (Eocene)—Black to dark-gray, dark green-gray or dark brown-black aphanitic to porphyritic lava flows; locally vesicular or fragmental (Fig. 29). Includes dark-brown shoshonite and medium-gray to light-brown latite. Shoshonite groundmass contains small plagioclase laths, olivine, and possibly pyroxene. Latite and andesite contain sparse 0.5-1 mm phenocrysts of clinopyroxene and altered olivine in a very fine groundmass that contains abundant plagioclase. Latite has plagioclase aligned in a trachytic texture, and high potassium content (> 9 percent K_2O; Lewis, 2016) in the Salmon quadrangle. A few 1 mm phenocrysts of plagioclase are present; similarly sparse olivine phenocrysts are largely altered to iddingsite. Locally contains xenocrystic quartz and plagioclase, particularly in the upper part of unit. Quartz is highly embayed and has reaction rims; plagioclase is not as embayed but is turbid and shows disequilibrium textures, especially in the Williams Lake quadrangle. A sample from a roadcut 2.1 km (1.3 mi) northeast of K Mountain (lat 45.0213°N, long 113.7420°W) contains rare xenocrystic clusters as much as 1 cm across of fine-grained olivine, and plagioclase xenocrysts as long as 6 mm. Interbedded with the flows are thin biotitic tuffs and volcaniclastic sandstones. Secondary chalcedony and calcite are common, especially in vesicular parts. Includes two isolated masses in upper Mulkey Creek in the Sal Mountain quadrangle that appear to be stratigraphically lower than the main exposures to the north (e.g., within *Tcto*). Although mineralogically similar to the main exposures, these two occurrences may be older unrelated mafic lavas or large feeder dikes. Forms brown cobbly colluvial slopes that typically armor less-resistant sedimentary units, and extensive talus north of Williams Lake. Includes Tl unit of Blankenau (1999). Also correlative with Tl unit of potassium-rich andesite, latite, and basalt lava in the Challis 1° x 2° quadrangle to the southwest (Fisher and others, 1992).

Tcto—Old ash-flow tuffs of Challis Volcanic Group (Eocene)—Multiple tuff units southeast of Salmon that are stratigraphically below *Tlm*. Most contain phenocrysts of plagioclase, quartz, and biotite in a welded groundmass. Lithic clasts of quartzite and volcanic rock present locally. Includes areas of *Thd* and *Tqt*.

Tgt—Green tuff (Eocene)—Green to light-green biotite tuff exposed east of Lemhi River in southern part of map. Contains abundant euhedral biotite, smoky quartz, minor subhedral sanidine, and pumice in a white to light-green ash-rich groundmass. Also contains chert-bearing siltstone. Equivalent to Tgt unit of Blankenau (1999).

Thd—Hornblende dacite (Eocene)—Purple to purple-gray, gray, or dark-brown dacite or andesite lava flows containing phenocrysts of euhedral hornblende and plagioclase along with minor amounts of biotite, quartz, and augite(?) in a finely crystalline groundmass. Near the top of the sequence are aphanitic layers like those of *Tlm*. Underlies *Tlm* in Sal Mountain and Williams Lake quadrangles. Includes tuff northeast of Sharkey Hot Spring containing abundant volcanic lithic clasts. Clasts there typically contain hornblende, but matrix apparently does not. Volcanic breccia, with clasts as large as 1 m across, is common in the Sal Mountain quadrangle. Interpreted there to be lava flows, but a pyroclastic origin is possible. Sample collected northwest of Williams Lake (lat 45.0170° N, long 113.9207° W) was dated by U-Pb zircon methods, resulting in an age of 49.45 ± 0.18 Ma (Fig. 28b; Jesse Mosolf, written commun., 2016). Opposite the mouth of Tenmile Creek in the Williams Lake quadrangle, includes vitrophyre that contains more quartz and biotite than the unit does elsewhere, and which may be a different unit (possibly tuff of Ellis Creek that is exposed southwest of the quadrangle; Fisher and others, 1992).

Tcg2—Younger conglomerate (Eocene)—Conglomerate interpreted to be interbedded with volcanic units at south edge of map. Characterized by quartzite cobbles and pebbles but lag deposits include distinctive granite boulders and cobbles likely derived from Ygr northwest of Salmon (Fig. 17). Mapped as granite clast conglomerate by Blankenau (1999).

Tqs_1—Older quartz-sanidine welded tuff (Eocene)—Tan-orange to light-pink welded tuff in southeast part of map near map boundary. Contains pumice fragments and euhedral to subhedral crystals of sanidine and smoky quartz in a fine crystalline groundmass (Tqs_1 of Blankenau, 1999). Quartzite lithics are present in minor amounts. Differs from Tqs_2 in that it typically is more densely welded and more tan to orange in color.

Tqt—Quartzite-bearing ash-flow tuff (Eocene)—White, white-gray, or pink-gray tuff in southeast part of map. Contains abundant angular dark-gray to black quartzite lithic fragments (Fig. 30) and less abundant quartz, plagioclase, and biotite phenocrysts. Quartz typically smoky. Ranges from poorly welded near Williams Lake to densely welded in Baker and Goldstone Mountain quadrangles. Depositional contact with *Yg* in the Williams Lake and Sal Mountain quadrangles. Overlain by tuffs of similar phenocryst mineralogy, but with fewer or no lithic clasts in the Sal Mountain quadrangle and by mafic volcanic breccia and vesicular lava (*Tlm*) near Williams Lake. Preserved only locally, probably as erosional remnants below *Tlm* north of Williams Creek. Correlated here with Tqt unit of Blankenau (1999). Sample of this unit collected along Withington Creek was dated by $^{40}Ar/^{39}Ar$ methods at 49.51 ± 0.14 Ma (Blankenau, 1999).

Tqtv—Quartzite-bearing ash-flow tuff vitrophyre (Eocene)—Two dark-gray vitrophyres within *Tqt* southeast of Sal Mountain. Characterized by abundant angular dark-gray to black quartzite lithic fragments and less abundant plagioclase, quartz, and biotite phenocrysts.

Tcg_1—Basal conglomerate (Eocene)—Subrounded to well-rounded cobble to boulder, clast-supported conglomerate in southeast part of map near map boundary. Contains a white to gray ash matrix. Clasts are entirely quartzite. Equivalent to Tcg_1 unit of Blankenau (1999) but not previously mapped by him in the area immediately south of the Lemhi Pass fault.

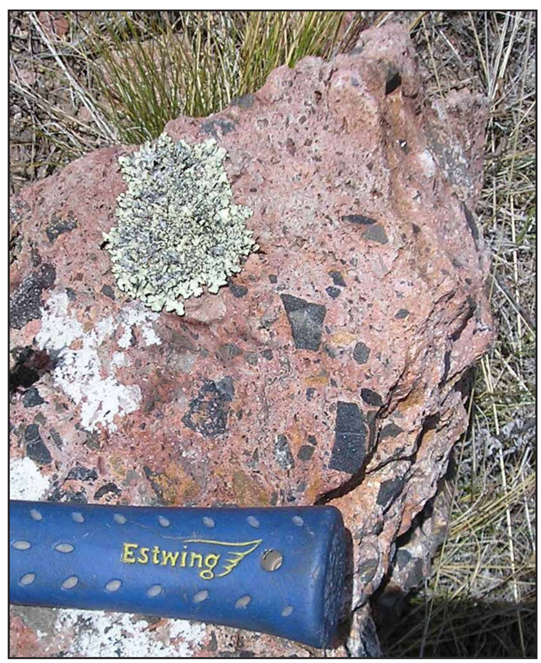


Figure 30. *Moderately welded lithic tuff (Tqt) south of Kenney Creek. Angular black and gray clasts are mostly quartzite similar to Yg exposed nearby.*

Figure 31. *Deformed sill-like body of Tdi in upper part of East Fork of Bohannon Creek. Intrusion is along west strand of Beaverhead Divide fault. Light-colored rock is quartzite (Ys).*

INTRUSIVE ROCKS

Tb—Basalt dike (Tertiary)—Single fine-grained mafic dike northeast of Goldstone Pass that appears to be less altered and thus younger than *Tdi*.

Ti—Tertiary intrusion (early Oligocene?)—Dark-red to gray andesitic intrusion north of the mouth of Kenney Creek. The intruded sediments (*Tsc*) may be as young as those 2.5 km (1.5 mi) to the southwest dated at 31 Ma where probable Oligocene volcanism also is documented by a mafic lava or sill intercalated with fine-grained sedimentary rocks (see *Twcb* description).

Tr—Rhyolite dikes (Eocene)—Light-gray porphyritic rhyolite dikes. Phenocrysts are quartz, plagioclase, potassium feldspar, and biotite. Sparsely porphyritic south of North Fork with quartz phenocrysts. Exposures northeast of Sal Mountain at the head of Mulkey Creek are interpreted as dikes, but may be thin rhyolite flows or tuffs.

Trq—Rhyolite dikes with quartzite clasts (Eocene)—Light-gray rhyolite with abundant clasts of Mesoproterozoic quartzite and siltite. Exposed on east flank of Sal Mountain. Dikes are 1-2 m (3-6 ft) wide and crosscut *Yg*. Clasts are dark, angular and as large as 20 cm.

Tdr—Dacite or rhyolite intrusions (Eocene)—Extensively altered porphyritic dacite or rhyolite interpreted as shallow intrusive bodies. Phenocryst mineralogy uncertain, but plagioclase, biotite, and hornblende are obvious in less-altered exposures. Includes the Bobcat Gulch stock, rocks along Highway 93 that appear to be coalesced dike swarms, and rocks across the Salmon River in Dry Gulch that Anderson (1959) assigned to the Challis volcanics and were not investigated during this study. Also includes two masses of dacite between Wagonhammer and Silverlead creeks that may be volcanic rather than intrusive.

Tdp—Porphyritic dacite dikes (Eocene)—Highly porphyritic dacite dikes with plagioclase, quartz, hornblende, and biotite phenocrysts. Proportions of phenocrysts vary.

Figure 32. *Carmen Creek stock. Inclusions range from equant as in this picture to elongate parallel to the southeast contact.*

Ta—Andesite dikes (Eocene)—Four north-northwest striking mafic dikes near the headwaters of Wimpey Creek. Euhedral plagioclase and hornblende as long as 1 mm and similarly short stubby pyroxene(?) crystals comprise the bulk of the rock. Also includes a greenish-gray dike northeast of Sal Mountain that cross-cuts *Tlm* unit.

Tqm—Quartz monzonite dikes (Eocene)—Fine-grained biotite-hornblende quartz monzonite dikes along the west flank of the Beaverhead Mountains. Compositions grade to monzonite. Characterized by low quartz content; plagioclase slightly in excess of potassium feldspar. Acicular hornblende 2-5 mm long, locally green. Dikes south-southwest of Goldstone Mountain have wide textural and possibly compositional variation on decimeter to meter scale, and locally contain xenoliths of vein quartz aligned with flow fabric suggesting intrusion into quartz vein system. Overall less mafic than *Tdi* dikes.

Tdi—Diorite dikes and sills (Eocene)—Medium- to fine-grained hornblende diorite. Typically very dark gray to green. Similar to rocks described by MacKenzie (1949) as meladiorite composed of altered hornblende, albite, biotite, chlorite, and clinozoisite, with andesine and orthoclase in some of the less altered rocks, and that Biddle (1985) termed "gabbronorite." Locally contains abundant magnetite. Occurs on both sides of and along the Beaverhead Divide fault. Along the west strand of the Beaverhead Divide fault, it and the country rock near that fault typically are foliated (Fig. 31) or it has sheared margins, or chloritized fractures within where it is less deformed. Sample from northwest of Goldstone Pass has U-Pb age of 46 ± 2 Ma (Richard Gaschnig, written commun., 2009; Lonn and others, 2009).

Tgr—Biotite granite (Eocene)—Light-gray, fine- to medium-grained, equigranular to porphyritic biotite granite of the Carmen Creek stock. Forms core of stock west of Carmen Creek and rare 1-3 m (3-10 ft) wide dikes.

Tgd—Granodiorite (Eocene)—Medium-grained hornblende-biotite granodiorite of the Carmen Creek stock, associated dikes, and to the east as part of the granodiorite unit of Kilroy (1981). Eastern part was described by MacKenzie (1949). Complexly zoned oligoclase (An_{25-35}), quartz, microcline, hornblende, and biotite are the major constituents, and dioritic inclusions (Fig. 32) are common (Anderson, 1959). A U-Pb zircon age of 49.2 ± 1.7 Ma was obtained from a sample collected east of the East Fork Tower Creek (lat 43.3482°N., long 113.8307°W.; Darin Schwartz, written commun., 2011). Eocene age also based on $^{40}Ar/^{39}Ar$ dating of biotite (47.7 ± 0.6 Ma) and hornblende (50.5 ± 1.8 Ma) from a sample collected along the ridge east of Carmen Creek (Kilroy, 1981), and biotite (49.4 ± 0.8 Ma) from a sample collected 0.7 km north of Lena Lake (Kilroy, 1981). The older hornblende age of 68.2 ± 1.7 Ma from the second sample was interpreted to result from excess argon inherited from the nearby quartz diorite (Kilroy, 1981).

Kqd—Quartz diorite (Cretaceous)—Biotite-hornblende quartz diorite. Part of the quartz diorite unit of Kilroy (1981) and composed of 45-55 percent andesine (An_{40-50}) along with hornblende, biotite, quartz, and orthoclase. Cretaceous age based on $^{40}Ar/^{39}Ar$ dating of hornblende from samples collected about 2.2 km due east of Squaw Mountain (81.5 ± 1.6 Ma) and from the cirque at the head of Slag-a-melt Creek near the contact with Kd (80.3 ± 2.2 Ma; Kilroy, 1981). These hornblende ages of about 81 Ma are considered the minimum for this unit. Younger $^{40}Ar/^{39}Ar$ ages of biotite from these two samples (51.1 ± 2.4 Ma and 70.0 ± 1.5 Ma, respectively; Kilroy, 1981) may reflect slow uplift and cooling, or reheating during the Eocene.

Kdi—Diorite (Cretaceous?)—Hornblende diorite equivalent to the hornblende meladiorite unit of Kilroy (1981). Composed of 50-75 percent hornblende along

Figure 33. *Porphyritic granite (Ygr) north-northwest of Salmon. Unit characterized by angular rapakivi microcline megacrysts typically 3-8 cm in length.*

with plagioclase, hypersthene, actinolite, quartz, and opaque minerals (Kilroy, 1981). Plagioclase is reversely zoned andesine (An_{48-40}). Contains small xenoliths, the least altered of which contain poikilitic augite enclosing hypersthene and hematite.

Ygr—Megacrystic granite (Mesoproterozoic)—Light-gray to pink, medium- to coarse-grained, porphyritic, slightly peraluminous granite (Fig. 33). Locally mylonitic (Fig. 34). Modes have 35 to 40 percent quartz and rapakivi microcline, 10 to 20 percent plagioclase, and 7 to 10 percent biotite as the only mafic mineral (Biddle, 1985). Microcline megacrysts typically range from 3 to 8 cm in length. Minor aplite most common near contacts, as are xenoliths. Unit occurs as the Diamond Creek pluton (Evans and Zartman, 1990) and a small outlier. These are the easternmost and perhaps least deformed and shallowest exposures of similar rock that extends west and northwest to Elk City and continues on to near Moscow, Idaho (Evans and Fischer, 1986; Lewis and others, 2005). Contact metamorphism of *Yg* produced a schist aureole only 2-3 m wide (Biddle, 1985). Outcrops weather to rounded shapes, producing coarse grus with whole microcline megacrysts. Boulders of this distinctive lithology are incorporated in proximal *Tkg* strata. They also reside in some local saddles and at least 65 km (40 mi) away along old drainages, likely Eocene (Janecke and others, 2000) but we think also Oligocene (see *Tkg* description). U-Pb zircon analyses yield ages of 1,380 - 1,370 Ma (Evans and Zartman, 1990; Doughty and Chamberlain, 1996; Aleinikoff and others, 2012). Rb-Sr systematics of samples were interpreted to reflect Sr loss due to heating at about 100 Ma (Evans and Zartman, 1990).

Figure 34. *Mylonitic Ygr northwest of Salmon with megacrysts deformed into augen.*

MESOPROTEROZOIC STRATA

All metasedimentary rocks in the area are Mesoproterozoic strata. In earlier work within and near this area, these rocks were assigned to units of the Belt Supergroup (e.g., Mt. Shields and Bonner formations), given names from the Salmon River Mountains (e.g., Yellowjacket Formation) or, more commonly, given names from the Lemhi Range (formations of the Lemhi Group). Figure 35 shows locations of type localities for some of those units on a simplified geologic map using our current understanding of correlation of units within and outside of the Salmon map. Figure 36 portrays in stratigraphic columns those correlations and names used in the following descriptions.

Our mapping as part of an Idaho Geological Survey and Montana Bureau of Mines and Geology cooperative effort from 2007 through 2014 shows that a very thick east-facing succession (>9,000 m; 30,000 ft), mostly east of the state line, is above the Gunsight Formation at the top of the Lemhi Group. Key among the strata of this succession is a lithostratigraphic unit of poorly sorted, fine- to coarse-grained and locally pure quartzite similar to that mapped as Swauger Formation in the Lemhi Range. In gradational stratigraphic contact below this unit is finer grained, more feldspathic quartzite similar to the Gunsight Formation, which

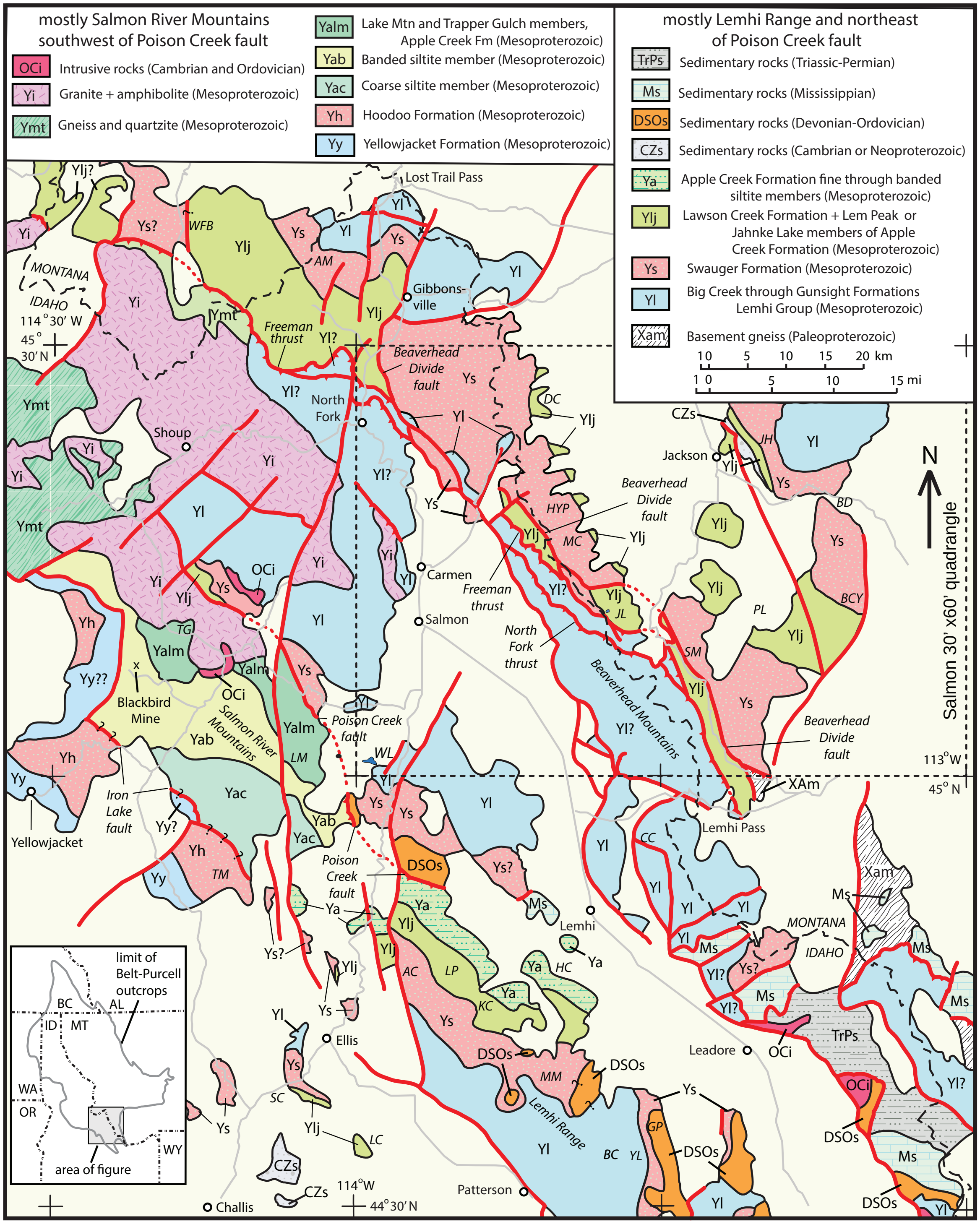


Figure 35. *Generalized geologic map of the greater Salmon area showing locations of type and reference sections and other points of interest. Type sections for Yellowjacket and Hoodoo formations are near Yellowjacket; those for the Lemhi Group formations are BC = Big Creek, YL = Yellow Lake (formerly Apple Creek Yellow Lake unit of Tysdal, 2000). Type section for Gunsight Formation is between YL and GP = Gunsight Peak. Reference section for Swauger Formation is MM = Mogg Mountain. Type section for the Lawson Creek Formation is LC. Type section for the Apple Creek Formation is near HC = Hayden Creek and reference section for its new Jahnke Lake member is JL. Other locations are: AC—Allison Creek; AM—Allan Mountain; HYP—Homer Youngs Peak; LM—Lake Mountain; LP—Lem Peak. Freeman and North Fork thrusts are from Lonn and others (2013a); other named faults from Evans and Green (2003).*

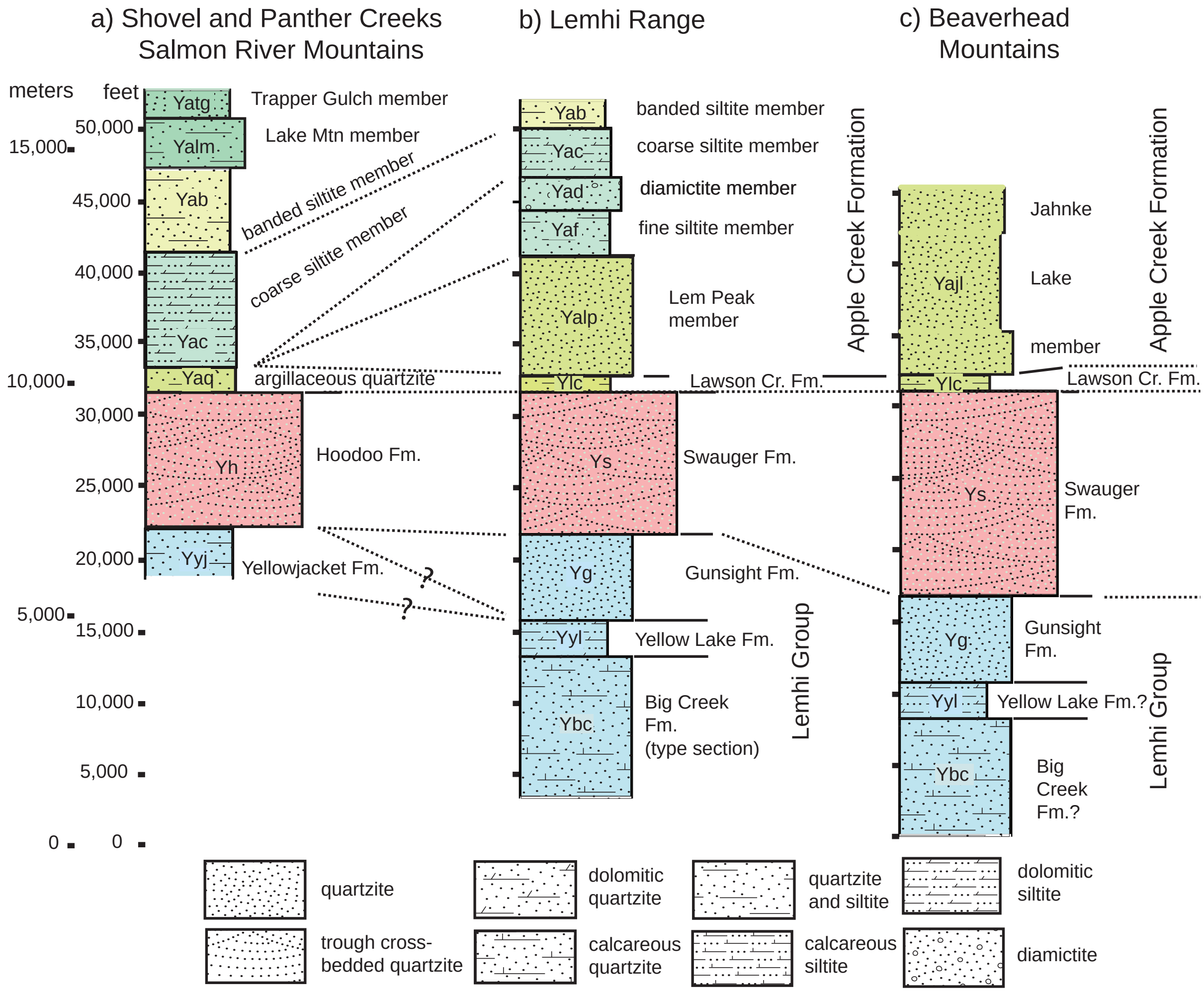


Figure 36. *Stratigraphic columns for a) Salmon River Mountains, b) Lemhi Range, and c) Beaverhead Mountains. For (a), backsliding on the Iron Lake fault is assumed to make net stratigraphic throw negligible. Lack of lateral continuity of the Apple Creek fine siltite and diamictite members and Gunsight Formation between (a) and (b) may reflect locally restricted environment of deposition, rapid lateral facies changes, or unrecognized unconformities.*

is stratigraphically below the Swauger in the Lemhi Range. Above this coarser lithostratigraphic unit is a thin interval of finer grained and argillaceous rock similar to the Lawson Creek Formation that overlies the Swauger Formation southwest of the Lemhi Range (Hobbs, 1980) and also in the northern Lemhi Range (Tysdal, 1996a; Tysdal and Moye, 1996). Gradationally above this finer grained interval are more than 5,000 meters (16,000 ft) of quartzite strata. We interpret the poorly sorted coarser grained unit to be Swauger Formation, the interval of thinner bedded and finer rock above to be the Lawson Creek Formation, and the quartzite strata above to be younger rocks previously and erroneously correlated with lower units and not recognized as an overlying sequence.

Recognition of this expanded stratigraphy evolved over the course of our work so structures and correlations on some earlier maps, based on misunderstanding of the stratigraphy, are not entirely correct. Most important is the authors' ecognition that the Apple Creek Formation at its type section is above the Lawson Creek Formation, not below the Gunsight, and that Apple Creek Formation is correlative with the quartzite succession above the Lawson Creek within, north and east of the Beaverhead Mountains. More complete explanations of this are in Burmester and others (2013) and Burmester and others (2016). The units presented below are based on Ruppel's (1975) work in the Lemhi Range to the extent possible, augmented with the overlying quartzite succession

Figure 37. *Black hematite laminations in Jahnke Lake member of the Apple Creek Formation (Yajl) near Jahnke Lake in the Beaverhead Mountains. Ice axe head is about 26 cm long.*

that we consider to be a member of the Apple Creek Formation. Field work in 2016 northwest of North Fork, in a swath mapped as Yellow Lake Formation, found that the rocks also resemble the banded siltite member of the Apple Creek Formation. Additional work is required to evaluate this observation, and its structural implications.

Yajl—Jahnke Lake member of the Apple Creek Formation (Mesoproterozoic)—Well-sorted, fine-grained, medium- to thick-bedded, pale-green to pale-pink to medium-gray, white-weathering, feldspathic quartzite and darker siltite and argillite. Lowest part, in the Goldstone Pass quadrangle where section is most continuous north of Jahnke Lake, is gray with bedding and cross bedding defined by specular hematite in discontinuous, non-uniform dark laminations commonly as thick as 2 mm, but locally much thicker (Fig. 37). Despite well-developed cleavage there, the dark laminations define large, low-angle trough cross bedding. High-angle planar, ripple, and climbing ripple cross lamination as well as flat laminations are less common. Some steep laminations (30°-60°) truncate underlying laminations, defining loads that apparently grew during deposition. Argillite is present as thin layers or skins (some discontinuous) on quartzite parting surfaces, as graded tops of darker siltite and argillite couples, and rarely as light-colored mud chips. Average feldspar content is 30 percent, with potassium feldspar comprising about 20 percent of that. Grades upward into strata with increasing siltite, decreasing dark laminations. Folding makes thickness estimate of 900 m (3,000 ft) problematic in this part of the section.

Overlying but discontinuously exposed strata include pale-green, fine-grained feldspathic quartzite in decimeter- to meter- thick beds of flat-laminated to non-laminated beds and varied dark-green siltite, most as graded tops to thick quartzite beds, and rare red argillite skins in upper part. Commonly weathers white but has surface stain of rusty red. Includes rare mud chips and muscovitic parting surfaces. Eleven samples averaged 40 percent feldspar, 10 percent of which was potassium feldspar. Some of the potassium feldspar is patchy and probably secondary. Grades with increase in grain size through a zone of alternating colors into overlying strata. Thickness approximately 2,200 m (7,000 ft).

Figure 38. *Thin-bedded quartzite and siltite of Lawson Creek Formation (Ylc) north of Twin Lakes. Beds typically 1-3 cm thick.*

Also poorly exposed, the highest strata east of Jahnke Lake contain medium- to fine-grained, well-sorted feldspathic quartzite that has a pinkish cast on fresh surfaces. Typically flat-laminated, decimeter to meter beds with little siltite or argillite. Includes more mud chips and muscovitic parting surfaces than underlying rocks. Average feldspar content of 20 samples is 30 percent, with potassium feldspar comprising about 25 percent of that, but some samples contained no potassium feldspar. Thickness at least 900 m (3,000 ft) to top of exposures.

In the North Fork and Bird Creek quadrangles, rocks are pale-pink to medium-gray, fine- to very fine grained, medium- to thick-bedded, well-sorted, feldspathic quartzite and minor darker siltite and argillite. Red chert clasts and green "porcellanite" that is softer than chert, but not as soft as argillite, similar to what occurs in the Lawson Creek Formation elsewhere, are rare but unique to the unit there. Bedding and sedimentary structures are difficult to see, but flat laminations and ripple cross laminations are present locally. Feldspar content of the whole unit is about 35 percent with 20 percent of that being potassium feldspar. Top and base not exposed in a single section and thus thickness is uncertain; a minimum of 1,500 m (5,000 ft) is likely.

Ylc—Lawson Creek Formation (Mesoproterozoic)—Fine-grained, thin-bedded quartzite and siltite with thin argillitic interbeds (Figs. 38, 39). Rare pink to white, medium-grained, trough- and planar-crossbedded quartzite in beds 15 cm to 1 m thick, interbedded with 15 cm to 1 m-thick intervals of purple to green siltite and argillite in planar beds 0.6 to 5 cm-thick in upward-

Figure 39. *Outcrop of Ylc strata north of Twin Lakes showing uneven flaser bedding.*

fining sequences. Lower part is more thickly bedded white quartzite. Feldspar content of four samples was 20 percent with about 70 percent of that being potassium feldspar. Upper part is 15- to 30-cm-thick flat-laminated quartzite beds interbedded with 7- to 15-cm-thick green argillite and siltite. Fewer and more diffuse heavy mineral laminations, more argillite, and thinner beds than in the overlying *Yajl*. The upper contact with *Yajl*, e.g., north of

Figure 40. *Outcrop of Swauger Formation (Ys) quartzite on ridge north of Jumbo Mountain showing typical bedding character.*

Figure 41. *Large mud cracks in Ys on ridge west-southwest of Homer Youngs Peak, Beaverhead Mountains. GPS is approximately 10 cm long.*

Figure 42. *Dark mud chips in Ys on ridge west-southwest of Homer Youngs Peak, Beaverhead Mountains. Pen is approximately 14 cm long.*

Jahnke Lake, is obscured by strong northwest-striking, southwest-dipping cleavage developed at an acute angle to bedding, but *Ylc* appears to grade up section into *Yajl*. An alternate explanation is that the contact is a fault. Top and base of unit not present in same section, but thickness at least 600 m (2,000 ft).

Ys—Swauger Formation (Mesoproterozoic)—Fine- to coarse-grained, thick- to thin-bedded quartzite (Fig. 40). Characterized by poor sorting and well-rounded, spherical quartz grains, local granules, and rare pebbles. Feldspar content ranges widely, with some beds containing no obvious detrital feldspar. Locally feldspathic, with potassium feldspar in excess of plagioclase, commonly as rectangular grains. Rare pink to white, medium-grained, trough- and planar-crossbedded quartzite in beds 15 cm to 1 m thick, interbedded with 15 cm- to 1 m-thick intervals of purple to green siltite and argillite in planar beds 0.6 to 5 cm thick. Contains dark-gray argillite and siltite interbeds as thick as 15 cm. Some 1 cm-thick interbeds have quartzite-filled desiccation cracks about 1 cm wide that form polygons 10 cm across (Fig. 41). Dark argillite also as rare chunks or rip-up clasts (Fig. 42). Subdivisions of lower and upper conglomeratic and middle multicolored quartzite mapped in the Homer Youngs Peak quadrangle (Lonn and others, 2008) or lower, pebbly and upper non-pebbly parts in the Shewag Lake quadrangle (Stewart and others, 2014) were not recognized widely, probably due to lack of lateral continuity.

Lower part near Homer Youngs Peak (Lonn and others, 2008) is white to light-gray, poorly sorted, medium- to coarse-grained, trough- and planar-crossbedded, feldspathic quartzite in beds as thick as 18 dm with non-uniformly distributed floating pebbles as large as 2.5 cm in diameter of quartz, quartzite, and hornblende granite. Granitic pebbles are more angular, quartzite pebbles more rounded. Some conglomeratic beds are as thick as 60 cm. Lower part to the northwest contains quartzite pebbles along bedding planes (Stewart and others, 2014). Contains black argillite interbeds as much as 8 cm thick with desiccation cracks. Some carbonate cement present (Fig. 43), and some beds exhibit soft-sediment deformation. Feldspar content of 23 samples averaged 25 percent with about 60 percent of that being potassium feldspar. Thickness where mapped separately in the Homer Youngs Peak quadrangle estimated as 1,800 m (6,000 ft), and from cross sections to the northwest, 3,000 m (9,800 ft) (Stewart and others, 2014).

Figure 43. *Carbonate-cemented cross beds in Ys west of Homer Youngs Peak. View north of east-dipping strata. Pencil is about 14.5 cm long.*

Figure 44. *Quartz (vein quartz?) and gneissic pebbles in Ys east of Carmen Creek. The pencil at right is about 14.5 cm long.*

Figure 45. *Gunsight Formation (Yg) light quartzite and darker argillitic siltite near east edge of map, south of Park Creek. Quartzite is typically more graded up to siltite than shown in this photograph.*

Middle part where mapped separately as Yqmc (Lonn and others, 2008) is white, purple, dark-gray, and green, fine- to coarse-grained quartzite and siltite. Characterized by intervals of white to dark-gray (biotite-bearing?), flat-laminated, fine- to medium-grained quartzite in beds 30-60 cm thick alternating with intervals of quartzite, purple siltite, and black and green argillite in beds 1-3 cm thick. Ripple marks are common. Contains some small pebbles along bedding planes. Finer grained intervals contain some green calc-silicate minerals and scapolite. Some carbonate cement present, especially in coarser cross beds. Outcrops have a tabular-bedded appearance, but uneven beds and trough cross beds exist. Feldspar content of two samples about 35 percent, dominated by potassium feldspar. There also is an interval of thin and fine-grained strata within the Swauger Formation in the Lemhi Range (Tysdal, 1996b; 2000). Thickness approximately 2,100 m (7,000 ft) where mapped separately as Yqmc near Homer Youngs Peak (Lonn and others, 2008).

Upper part near Homer Youngs Peak (Lonn and others, 2008) and to the west contains abundant granule-sized grains and sparse floating pebbles (Fig. 44). Quartzite beds are 30-180 cm thick. Black argillite interbeds, some mudcracked, 1-2 cm thick. Large black mud rip-up clasts are common. Lavender quartz grains and rare granule-sized aggregates of lavender grains are present. Potassium feldspar only slightly in excess of plagioclase, with feldspar content of 12 samples about 20 percent. Large black mud rip-up clasts are common. Thickness approximately 1,800 m (6,000 ft) where mapped separately as Yqcu.

Previously assigned to the Swauger in the north by Anderson (1959). Overall averages 20 percent feldspar with potassium feldspar in excess of plagioclase. Upper contact placed where overlying thin and argillitic strata dilute the coarse-grained beds and are themselves overlain by finer grained, better sorted, and more feldspathic quartzite. Total thickness in the north estimated from cross sections as 6,000 m (19,700 ft) (Stewart and others, 2014), 5,400 m (17,700 ft) in the Homer Youngs Peak and Goldstone Pass quadrangles (Lonn and others, 2008; 2009).

Yg—Gunsight Formation (Mesoproterozoic)— Quartzite, siltite, and argillite. Quartzite is fine to very fine grained, very feldspathic, typically gray to dark green, but weathers light gray where not iron stained. Siltite and argillite are typically darker (Fig. 45) and highly cleaved. Most of Yg is south and west of the North Fork fault and west strand of the Bloody Dick Creek fault and ap-pears to become finer grained and thinner bedded to the north away from its upper contact with overlying Ys just off the map to the south (Fig. 35). However, folding and poor exposure make it difficult to determine if northward change is real and if so, if it reflects change going down section, lateral variation, or incorrect assignment of the strata southwest of the North Fork fault to the Gunsight Formation.

The thinner and finer strata exposed in the Beaverhead Mountains, and north of Salmon west of the Salmon River are dominated by dark siltite and green and dark gray argillite. Finer grained intervals contain laminated to thin-bedded dark siltite and darker argillite. Some zones are characterized by graded siltite and argillite couples. Thick siltite beds have more diffuse multi-millimeter to centimeter laminations that are planar, gently undulating (hummocky; Fig. 46), or disturbed by soft-sediment deformation. Locally decimeter-scale siltite layers are approximately equal in volume to centimeter-scale siltite and argillite couplets. Coarser intervals contain thick- to thin-bedded white quartzite (Fig. 47), dark siltite, and darker argillite. Quartzite also occurs as thin (centimeter-scale) bases of graded couples and thick beds, commonly in groups of several beds. Thicker beds typically have bedding defined by dark millimeter-scale laminations that are typically planar, but decimeter-thick stacks of centimeter-scale ripple cross lamination are more common in this unit than in any other, as are loads and convolute laminations. Argillite northwest of Salmon typically is very dark with white scapolite spots

Figure 46. *Locally graded uneven, hummocky beds of feldspathic quartzite and darker argillitic siltite of Yg near North Fork. These may alternatively be part of the Apple Creek Formation.*

Figure 47. *Stack of 1-5 dm-thick beds of Yg quartzite north of and near headwaters of Pattee Creek, about 1.2 km (0.75 mi) southwest of the Continental Divide.*

Figure 48. *White spots in Yg, presumed to be scapolite based on work of Tysdal and Desborough (1997) farther west. Distribution is sporadic, most commonly in darker, finer-grained tops of beds but also in coarser crossbeds as in this loose block located near the head of Bird Creek west of the Diamond Creek pluton.*

(Fig. 48) that suggest evaporite minerals in the protolith. Feldspar content of 41 quartzite samples in this part is about 35 percent, of which 15 percent is potassium feldspar. Thickness uncertain because of folding, but 2,400 m (8,000 ft) is possible.

The thicker, coarser, and possibly upper part of *Yg* in the southwestern part of the map is gray quartzite, darker siltite, and black and light-gray argillite. Quartzite is very fine to fine grained and feldspathic. Beds are typically 1-5 dm, some 2-3 m at bases of thinning upward stacks (Fig. 49). Rare, generally thick beds have rounded fine to medium quartz grains. Sharp bases locally loaded into siltite; rare tops have argillite in ripple troughs, small mud chips, or muscovite flakes (Fig. 50). Internal cross lamination and truncated lamination are observed rarely, probably due to common medium-to dark-brown weathering, iron staining, and extensive cleavage development. Some fine-grained quartzite may be recrystallized siltite. Siltite also occurs as separate, even parallel laminated beds 4 cm to 4 dm thick, and as graded tops, or less commonly bases, of 1-3 dm-thick quartzite beds. Argillite occurs as graded or discrete tops of quartzite or siltite beds, and rarely as 1-3 cm separate layers. More commonly, bed tops have low-angle cross lamination or grade to siltite above planar-laminated bases. Thickness uncertain because of deformation, but possibly 1,600 m (5,300 ft) based on a section southwest of Salmon. Upper contact off the map to the south and west, although obscured by talus of higher exposures of *Ys*, does not appear faulted.

Upper part northeast of the Freeman thrust in the northern part of the map is well-sorted, fine-grained, white to medium gray, light-weathering feldspathic quartzite and minor darker siltite and argillite. Quartzite beds 1 dm to 2 m thick. Lamination in quartzite includes large trough cross beds, ripple and climbing ripple cross lamination, as well as flat lamination. Dark specular hematite defines some of the laminations. Grading to darker, commonly green, siltite tops present in some meter-thick parallel-laminated beds. Argillite is present as thin layers or skins (some discontinuous) on quartzite parting surfaces, less commonly as thin mud chips or flakes along with muscovite on bedding surfaces, and as graded tops of darker siltite and argillite couples within the unit. Average feldspar content of 21 samples in the upper part is 34 percent, with about 25 percent being potassium feldspar. Grades upward into *Ys* over a few hundred meters with increase in coarse-grained quartzite and bed thickness as well as a decrease in feldspar.

Yyl—Yellow Lake Formation? (Mesoproterozoic)—Laminated to thin-bedded, light-green siltite, dark-gray siltite and darker gray argillite, and minor white, carbonate-bearing fine-grained feldspathic quartzite. More gray and less green in upper part of unit. Siltite and argillite as distinct, laterally discontinuous laminae and graded couplets but deformation obscures these characteristics where unit becomes a light-colored

Figure 49. *Contact between two thinning and fining upward sequences in Yg 2 km (1.2 mi) east of K Mountain. Thick (2 m) quartzite bed has scour or load base.*

Figure 50. *Bedding surface of Yg with abundant small muscovite flakes, interpreted as detrital, and thin, commonly rounded mud chips or flakes. Pencil is about 14.5 cm long. Approximately 200 m stratigraphically above thick bed in Figure 49.*

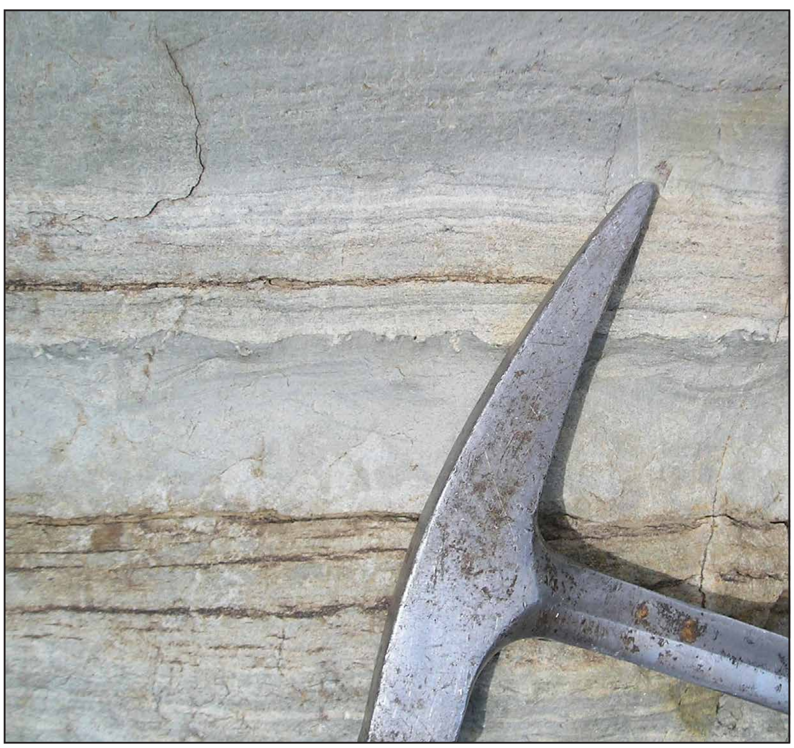


Figure 51. *Ptygmatically folded "crinkle cracks' in possible Yellow Lake Formation (Yyl) northwest of Goldstone Pass.*

Figure 52. *Brown-weathering carbonate-bearing beds in Yyl south-southwest of Cowbone Lake.*

phyllite. Some zones characterized by graded siltite and argillite couples and couplets of light-gray to light-green siltite that grades upward to dark-gray argillite. Desiccation cracks, mud rip-up clasts, and load casts present in some horizons; ptygmatically folded "crinkle cracks" (Fig. 51) present elsewhere. Other intervals contain light-gray decimeter-scale beds of flat-laminated and ripple cross-laminated quartzite. Quartzite is fine to very fine grained and feldspathic, with internal millimeter-scale wavy laminations and uneven scoured(?) bases, hummocky and thin ripple cross lamination, loads, and convolute bedding. Carbonate content within the quartzite (Fig. 52) varies from orange calcitic spots and wisps to distinct brown-weathering calcitic beds. Locally, some of these layers contain $MnCO_3$, judging by solubility in weak acid and chocolate-brown weathering, but some of this may be remobilized instead of original. Carbonate is most abundant near Cowbone Lake and may be more common low in the unit. Thicker skins of dark argillite have rare fluid escape structures as wide as 3 cm. Two samples of very fine grained quartzite averaged 33 percent plagioclase, appreciable magnetite, and no potassium feldspar. Along the ridge northeast of North Fork, several intervals of brown weathering calcitic and dolomitic strata contain 1-4 mm orange garnets. Garnet ages obtained are 1,173.2 ± 5.5 Ma and 1,136 ± 15 Ma (Lu-Hf), and 1,082 ± 21 Ma (Sm-Nd) (Jeffrey D. Vervoort, written commun., 2014). Those garnets predate the latest fabric, which reflects top-to-the-east oblique shear strain. Where contact metamorphosed near Tgd (Carmen Creek stock) includes centimeter-scale brown-weathering spots in white matrix (Fig. 53). Green and pink casts of non-spotted laminae suggest rock is calc-silicate. Phyllitic where highly cleaved, with cleavage locally axial planar to tight folds; some is deformed into west-vergent folds. Strong cleavage obscures internal laminations in some places. Terminology here follows that of Burmester and others (2016), in which rocks in the central Lemhi Range previously assigned to the Apple Creek Formation (Ruppel, 1975) are instead termed Yellow Lake Formation.Correlation with the Yellow Lake Formation is tentative. Also plausible is correlation with the banded siltite member of the Apple Creek Formation of the Salmon River Mountains (Evans and Green, 2003). Highly folded, but a minimum thickness of 800 m (2,600 ft) is likely.

Ybc—Big Creek Formation? (Mesoproterozoic)—Pale greenish-gray to uncommon pale-pink, very fine grained to rarely medium-grained quartzite and subordinate siltite (Fig. 54). Orange to white weathering. Locally contains carbonate cement, or voids between silicate grains formerly occupied by carbonate, particularly near the upper part of the unit and, in places, appreciable magnetite. Finer grained and more sheared (phyllitic) lower in section near the west strand of the Beaverhead Divide fault. Thirteen samples of quartzite in *Ybc* averaged 35 percent feldspar. Potassium feldspar accounted for about a third of the feldspar in three of those samples, but was absent or not obvious in the other 10. Upper contact placed where thicker, feldspathic and magnetite-bearing strata are overlain by thinner argillitic and carbonate-bearing beds. This contact on the map is approximate because of the complex folding and faulting of strata of the Beaverhead Mountains. Correlation with the Big Creek Formation is tentative, and based largely on presumed stratigraphic position and abundance of quartzite. Thickness uncertain due to folding and erosion, but approximately 700 m (2,300 ft).

Figure 53. *Contact metamorphosed and deformed Yyl near Carmen Creek stock. Hammer head is approximately 17 cm long.*

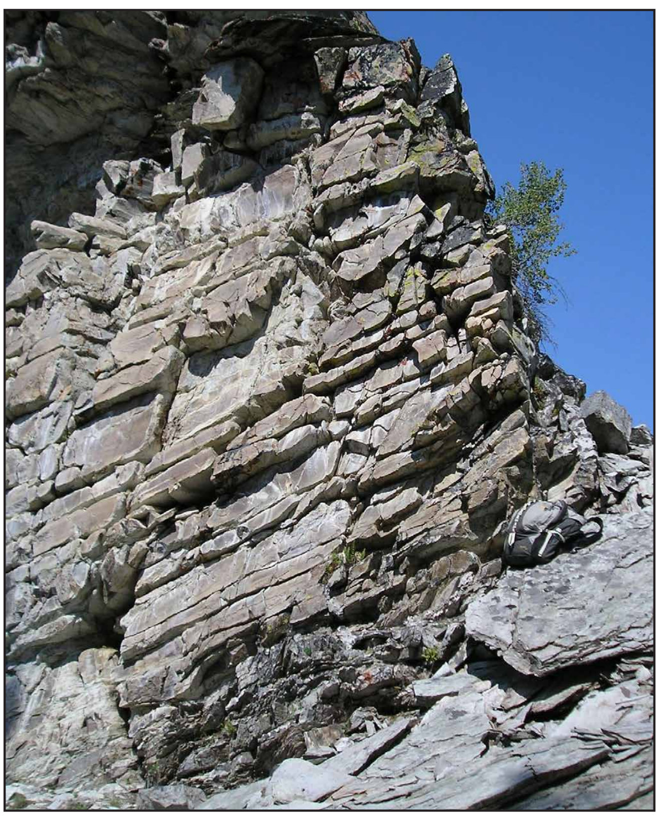


Figure 54. *Quartzite outcrop in possible Big Creek Formation (Ybc) northwest of the West Fork of Wimpey Creek.*

STRUCTURE

Overall, there appears to be a large-scale southeast-trending syncline-anticline-syncline fold system, with faults occupying some of the fold hinges, and deformation varied along their lengths. For a more detailed interpretation, especially of Cretaceous and younger history of the Beaverhead Mountains, see Lonn and others (2016). Immediately west of the map, Lemhi Group and younger strata young to the southwest (Fig. 35). That pattern is consistent southwest of the Freeman thrust to the Poison Creek fault in a panel of rock that continues southeast through the southwest part of the map. Southwest of the Poison Creek fault, the strata young to the northeast. The Poison Creek fault therefore occupies, omits, or obscures the hinge of a possibly southwest-verging syncline. The same Lemhi Group and younger strata northeast of the Freeman thrust young to the northeast. That pattern also continues southeast through the map, with the Freeman thrust, Beaverhead Divide, and Bloody Dick Creek fault systems obscuring or omitting the hinge of an east-verging anticline. Farther east, sense of younging reverses through an ill-defined syncline, but different levels of pre-Ordovician erosion across the hinge suggests that there may be a fault within it as well.

Structures range in age from Proterozoic to recent, with most deformation probably during Cretaceous Sevier contraction and Eocene-Oligocene extension. It is probable that there was syndepositional faulting in the Lemhi subbasin as there was during deposition of upper Purcell Supergroup strata in southeastern British Columbia (Gardner, 2008). This could account for lateral changes in thicknesses and lithologies of Apple Creek Formation members around the area (Figs. 35 and 36). Proterozoic deformation may have preceded, accompanied, and followed intrusion of the megacrystic granite (*Ygr*). Intrusion was reported to post-date regional metamorphism and folding of host strata (Evans and Zartman, 1990 and references therein). Tightness of folds in its country rock *Yg* compared to the relative smoothness of the intrusive contact in the western part of this map is consistent with some folding before intrusion, although many folds may have been formed or modified during Cretaceous contraction. Migmatite along the Salmon River to the north-northwest is the same age as the Proterozoic granite there, and the host rock possibly increased in burial depth from 14 to 20 km during prograde metamorphism (Doughty and Chamberlain, 1996). Thus it is probable that Mesoproterozoic structures are present in the area and may have controlled location of the intrusion and been reactivated during later deformation. A younger but still Mesoproterozoic event around 1,100 Ma is recorded by garnet growth in *Yyl* north and northwest of North Fork.

Differential erosion of Mesoproterozoic strata in different fault blocks is recorded by Oligocene Kinnikinic Formation (included in DSOs; Fig. 35) lying unconformably on Swauger south of the map in contrast to preservation of Apple Creek Formation in other places. This differential erosion or preservation is evident even within fault blocks. For example, south of the map, the upper part of the Swauger Formation and overlying strata northeast of the Poison Creek fault were eroded before deposition of the Ordovician Kinnikinic Formation but the lower part of the Lawson Creek Formation (included in *Ya*, Fig. 35) is preserved along strike to the northwest. This observed variation across the area lends support to the idea that tilting of large fault blocks accommodated differential erosion that preceded deposition of Ordovician strata (Hansen, 2015). Lack of a basal Cambrian succession suggests that erosion could have continued until the Ordovician, with the area being part of the Lemhi Arch (Sloss, 1954).

EAST-VERGENT CONTRACTIONAL STRUCTURES

These structures include the southeast-trending large folds described above and the similarly oriented faults. The Diamond Creek and Freeman thrusts share nearly east-west stretching lineations, resulting in oblique slip on those faults. The North Fork fault and Beaverhead Divide and Bloody Dick Creek faults probably accommodated similar east-west shortening but fault fabrics are complicated from later backsliding during Eocene and perhaps younger extension.

DIAMOND CREEK FAULT

This fault has been mapped as a continuation of the Brushy Gulch fault (Evans and Green, 2003), named about 30 km (20 mi) to the north-northwest where an intensely mylonitized zone separates higher grade rocks on the west that include a deformed version of *Ygr* against lower grade rocks east. We were unable to

Figure 55. *Southward view of mylonitized Yg quartzite along Diamond Creek Road north of Salmon in footwall of the Diamond Creek thrust fault.*

establish its continuity (Fig. 35) so rename it here for the creek whose headwaters it crosses, and because it forms the eastern contact of the Diamond Creek pluton (*Ygr*; Evans and Green, 2003). In detail, it is more a web of mylonite zones that cross *Ygr* and probably *Yg*. The main mylonite zone has fairly consistent dips of about 30° to 40° to the west (Fig. 55), westward-plunging stretching lineations, and top-to-the-east kinematic indicators. Displacement is uncertain but small, judging from similarity of lithologies and apparent metamorphic grade across it. It is probable that it repeats some of the Gunsight section, especially if the concentration of thick quartzite beds below the fault are from the more quartzitic upper Gunsight. Interpretation that heating at about 100 Ma reset Rb-Sr systematics of the Diamond Creek pluton (*Ygr*) (Evans and Zartman, 1990) is consistent with Cretaceous movement along the fault.

NORTH FORK FAULT

The North Fork fault crosses Highway 93 about 2.5 km (1.5 mi) north of North Fork, where it places thinly bedded siltite and very fine grained quartzite (*Yg?*) over more thinly bedded garnet-bearing phyllite (*Yyl?*). It is best exposed on the ridge west of Little Silverlead Creek. There it strikes west-northwest, dips gently southwest and exhibits mostly brittle deformation. It is mapped to the southeast along an ill-defined zone of faulting across the west-central part of the Beaverhead Mountains, separating *Yg* from units to the east. Structural style changes along the structure with ductile (thrust-related?) deformation dominant in the central and northwestern part of the map, but quartz veining and possibly more brittle deformation present to the southeast. There the fault may have had later normal motion. Locally it is characterized by well-foliated rock. Lineations or definitive shear sense indicators were not found in most outcrops. The North Fork fault is interpreted to have originated as a thrust but with recovery of some or all of the shortening during later extension. Variation in fabric and kinematics along it is attributed to variation of extensional displacement along the structure, but could also result from our combination into one structure of multiple reverse and normal faults with different not coincident fault surfaces.

FREEMAN THRUST

The Freeman thrust, named in the Homer Youngs Peak quadrangle (Lonn and others, 2008), bounds the northeast side of the carbonate-bearing *Yyl* and *Ybc* units. The presence of garnet in the hanging wall

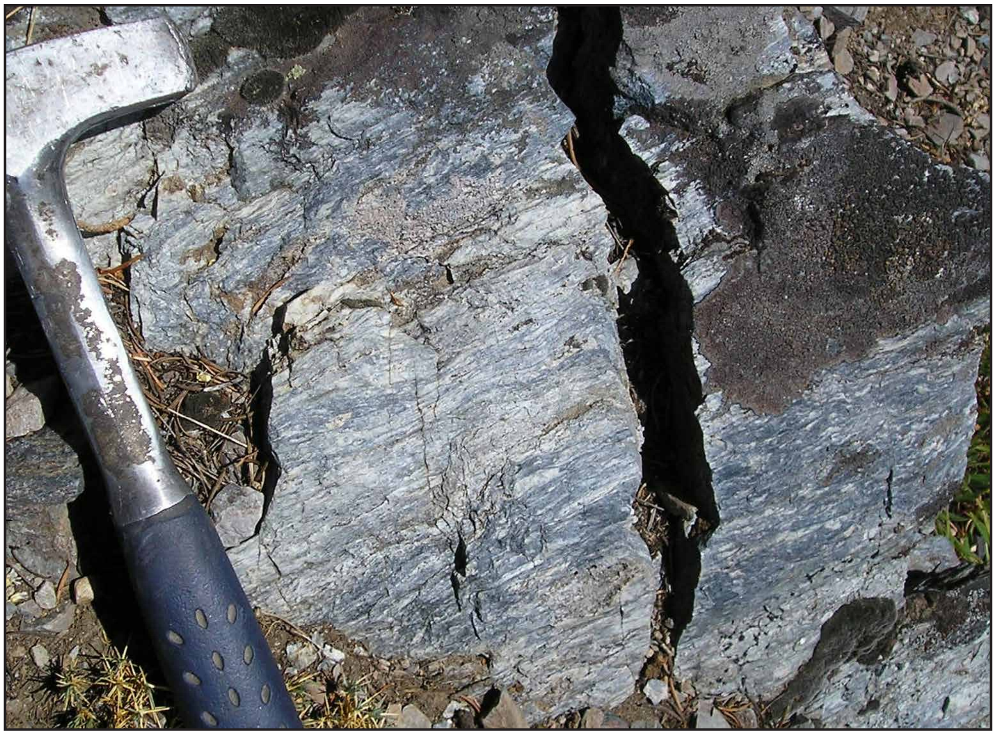


Figure 56. *Typical dark mylonite of the Freeman thrust. Locality is north of Freeman Creek at lat 45.2784°N, long 113.7248°W.*

Figure 57. *View north at Ybc? in hanging wall of a splay of the Freeman thrust near top of ridge north of Geertson Creek. Tops-east kinematics are indicated.*

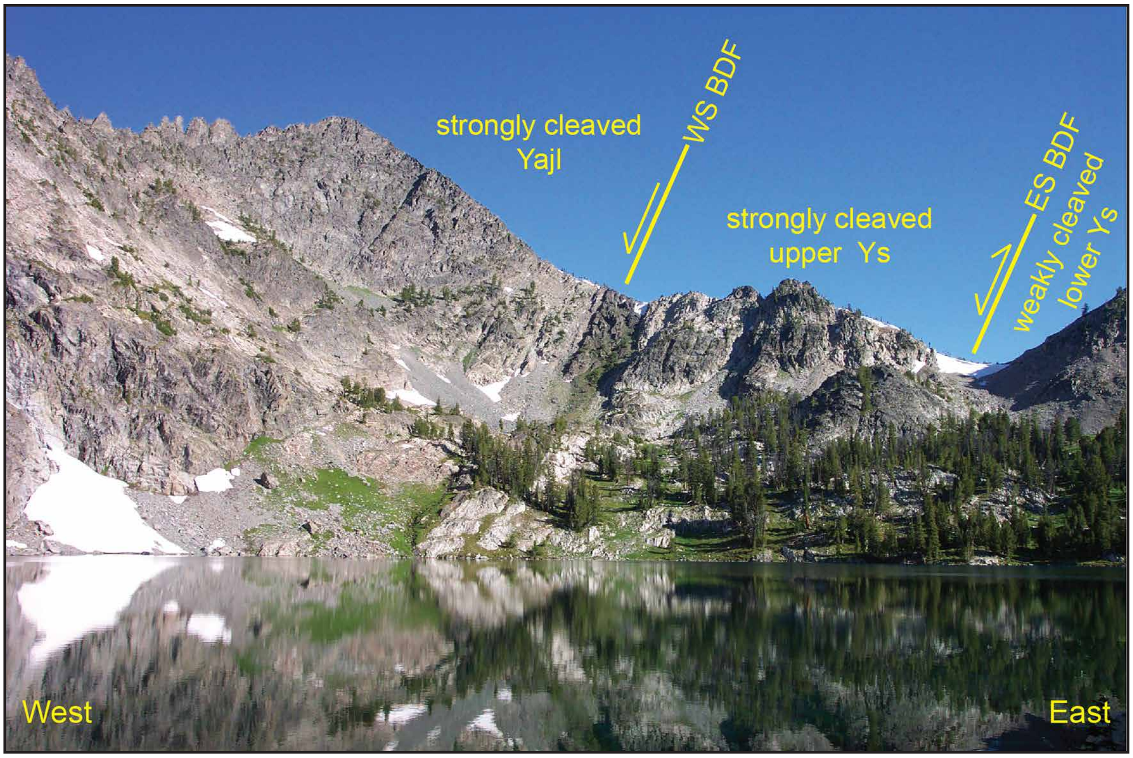


Figure 58. *View north-northwest across Upper Miner Lake at east strand (ES) and west strand (WS) of the Beaverhead Divide fault (BDF). Hanging wall is Yajl to the west; footwall is east-facing overturned Ys with Tdi (dark swath near center).*

suggests movement was postmetamorphic, consistent with thrusting in the Cretaceous. This structure appears on the Salmon National Forest geologic map (Evans and Green, 2003), although in a slightly different location. Its strike varies across the map, from nearly east-west to southeast; its dip is generally less than 45° southwest, and its fabric is mylonitic (Fig. 56). Lineations are poorly to moderately developed with west plunges where strike is southeast, to rarely east where strike is more easterly. Shear sense indicators where found are consistently top to the east (Fig. 57). In the Freeman Creek and North Fork Kirtley Creek areas, steep beds in the footwall quartzite appear dragged into parallel with the fault consistent with reverse movement. Locally in *Yg* some outcrop-scale, asymmetric, east-verging folds that may be related to the Freeman thrust are interpreted to have an axial planar cleavage that is later than the regional cleavage. A few thumbnail-sized S-type porphyroclasts observed within the mylonitic fabric show the same shear sense. This fault also appears to have been deformed by later folding. To the southeast near Goldstone Pass it merges with the west strand of the Beaverhead Divide fault.

BEAVERHEAD DIVIDE FAULT ZONE

The Beaverhead Divide fault was first described by MacKenzie (1949) who referred to the structure as the Miner Lakes fault. Anderson (1959) mapped its extension northwest of Miner Lakes and Tucker (1975) extended it southeast. Ruppel and others (1993) interpreted it as a major structure separating the Missoula Group to the northeast from the Mesoproterozoic Yellowjacket Formation and Lemhi Group to the southwest. Evans and Green (2003) mapped it as a thrust reactivated as a normal fault, separating Missoula Group from Lemhi Group. More recently, O'Neill (2005) interpreted it as a low-angle normal fault that had been rotated to vertical, with non-metamorphosed upper plate rocks now to the northeast and metamorphosed lower plate rocks now to the southwest. Our mapping to the south and east indicates that the Beaverhead Divide fault is a zone of both ductile and brittle deformation. We mapped two strands of the Beaverhead Divide fault. The east strand strikes southeast to east, dips southwest to south (Fig. 58), and is characterized by chloritic breccia containing a mixture of strongly foliated and non-foliated clasts. The portions of the fault that are more southeasterly are interpreted as having reverse shear during Cretaceous compressional deformation, while the more easterly trending portions are likely to have had a large component of left-lateral motion during that time. Brittle deformation probably post-dates thrusting, and may record reactivation of the thrust as a normal fault. The west strand is a zone of 25°-65° southwest-dipping mylonitic foliation that parallels the southeast to east strike of the zone. This ductile shear zone contains mafic dikes (*Tdi*) that exhibit foliation parallel to that of the shear zone (Fig. 58). Lineation within and especially at the contacts of these dikes plunges to the southwest with S-C fabric indicating top-to-the-west normal motion. Thus, at least some parts of the west strand accommodated extension during or after 46 Ma intrusion of *Tdi*. Similar dikes persist west of the Carmen Creek stock in a zone of shear and brecciation that may be the northwestern continuation of the Beaverhead Divide fault zone. There *Ys* and *Yg* are not as foliated as to the southeast and locally are not separated by a fault. This is evidence that the fault does not separate different formations or groups as previously thought.

The apparent continuation of the Beaverhead Divide fault system to the south is the Bloody Dick Creek fault zone. It also consists of two major parallel strands, The west strand of the Bloody Dick Creek fault is a poorly exposed shear zone several hundred meters in width that is largely confined to the west side of Bloody Dick Creek. At one locality north of the mouth of Brenneis Creek a mylonitic foliation within the fault dips 25° west and a mylonitic lineation there is down dip. Breccia is present along the west strand near the south map boundary. We interpret the structure in the Kitty Creek quadrangle to be an east-directed thrust fault.

The east strand includes a splay 7 km (4 mi) long, referred to as the Dutch Creek fault, described separately because of evidence for Quaternary motion along this portion of the fault system. The fault is along the range front east of Bloody Dick Creek where its morphology is clearly visible for several kilometers on air photos and Google Earth imagery. At Dutch Creek the fault is expressed by a 2-3 meter scarp on a moraine crest composed of older till (*Qgto*) and breccia along strike to the north between Terrell and Hopps creeks. Janecke and others (2001) classified this portion of the fault as an active or potentially active normal fault in the current tectonic regime and noted that the age of initial slip is uncertain. To the south (Fig. 35) the fault may continue as the western boundary of a sliver of Paleoproterozoic or early Mesoproterozoic basement rocks caught up in the Bloody Dick Creek fault system.

Figure 59. *Looking southeast at mylonite of the Pattee Creek thrust on the southeast side of Pattee Creek. Pen is about 7 mm in diameter.*

PATTEE CREEK THRUST

A mylonite zone exposed in the canyon of Pattee Creek near the south edge of the map is termed the Pattee Creek thrust (Lewis and others, 2011). The fault is a subhorizontal mylonite zone nearly 100 m (300 feet) thick developed in both Mesoproterozoic rocks and quartz veins (Fig. 59). The mylonite has lineations almost due east, tops-to-the-east kinematic indicators, and is locally folded. It is shown as a structural window exposing *Yajl*, although less than 100 m (300 ft) of footwall section is exposed. We suspect that this structure is the Freeman thrust, which daylights on the other side of the Beaverhead Mountains about 10 km (6 mi) to the east as the west strand of the Bloody Dick Creek fault.

NORTHEAST-STRIKING BRITTLE FAULTS

A set of northeast- to east-striking brittle faults of various dips postdates the ductile fabrics. One fault in the southernmost part of the quadrangle clearly offsets both strands of the Beaverhead Divide fault zone. Some of these northeast structures have been intruded by

Figure 60. *View north-northeast across the Salmon River from northeast of Williams Lake. Repetition of the east-dipping Tlm section in the foreground and Tlm that forms the dark banding across the river is attributed to normal faults in the valley. Motion is the same but much smaller than on the Salmon River fault that is out of the picture to the right.*

mafic dikes. One northeast-striking dike near Ajax Lake northwest of Homer Youngs Peak is strongly foliated parallel to the attitude of the dike. Gold-silver-lead mineralization in the Homer Youngs Peak quadrangle is typically associated with these dikes and faults.

CARMEN CREEK FAULT

The upper part of Carmen Creek is controlled by a steep fault that appears to be one of a set of northeast- to east-striking brittle faults that postdate the ductile fabrics. That fault is younger than the 49 Ma Carmen Creek stock, whose southern part intrudes the Beaverhead Divide fault. Fault displacement in the north was down on the west based in part on the greater proportion of septae in the northwest part of the stock than in the northeast. Fault displacement is also indicated in the south by the extent of *Ys* to the west versus *Yyl* to the east. Offset of the Beaverhead Divide fault in the opposite sense may reflect an earlier history, down-on-the-south motion on a fault that was intruded by Tgr, or possibly net motion down on the east. The relationship to the Salmon Basin detachment is unclear, but the Carmen Creek fault is interpreted to be older.

SALMON RIVER FAULT

A set of down-to-the-west normal faults traverse the southwest corner of the map. The most prominent fault crosses the upper part of Tenmile Creek and forms the range front from there north-northeast to Salmon Hot Springs; to the south, it apparently connects with a north-south structure termed the Salmon River fault (Tysdal, 2002) or the Allison Creek fault (Link and Janecke, 1999). It is clearly later than most of the Challis volcanic units. It and other faults in this set (Fig. 60) accommodated listric rotation of the hanging wall block, indicated by gentle east dips and eastward younging of some of those units, e.g., between Perreau and Williams creeks. It appears to have been inactive when *Tsc* was deposited.

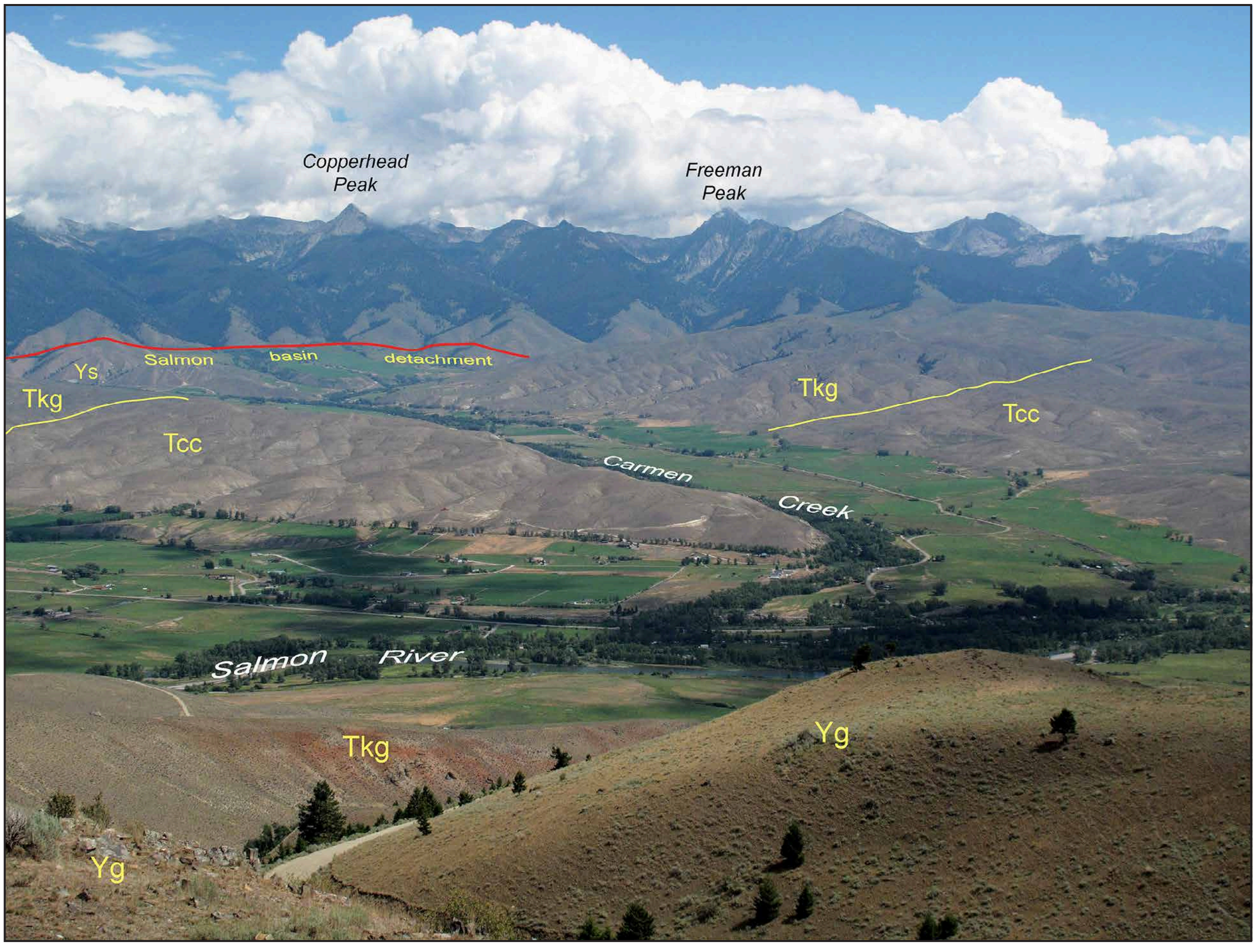


Figure 61. *View east-northeast from the Salmon River Mountains to the Beaverhead Range. The closer green area is Qam and Qtg_1 along the Salmon River; the one curving away to the left is the same, plus Qtg_2 along Carmen Creek. Foreground rocks and hill on the right are Yg. Red slopes on far side of Derier Creek this side of the Salmon River, and most of the "peninsula" between the river and Carmen Creek as well as the higher hills beyond Carmen Creek, are Tkg. The Salmon Basin detachment runs mostly along the far side of Tkg, which is unconformable on Ys. The divide on the skyline is held up by Ys, but the prominent peaks this side (west) of the divide are Yajl. Picture is from road south of Deriar Creek, about 3.3 km (2 mi) west of Carmen.*

NORTHWEST-STRIKING BRITTLE FAULTS

Blankenau (1999) discussed extensional faults in the Salmon basin in detail. They are shown in a simplified map by Janecke and others (2001). These faults typically bound Tertiary units and controlled their distribution.

SALMON BASIN DETACHMENT

The most continuous extensional structure on this map, the Salmon basin detachment, was mapped by Tucker (1975) and later interpreted as a low-angle detachment fault by Blankenau (1999). It forms the range front east of the Salmon River in the north (Fig. 61) and Lemhi River in the south (Fig. 62). The fault repeats *Ys* on both sides of Carmen Creek, and *Yajl* plus *Tdi* southeast of there. The hanging wall occurrences were carried by the fault from the northeast to the southwest a minimum of 4 km. The detachment is exposed in the road northwest of the intersection with the Carmen Creek fault. There the fault is characterized by gouge and a foliation defined by numerous closely spaced shear surfaces dipping roughly 35° to the south. To the northwest, it drops conglomerate (*Tkg*) and volcanic deposits (*Tct*) down on the southwest against *Yajl*. Dominant northeast dip of *Tct* is consistent with listric rotation of the fault's

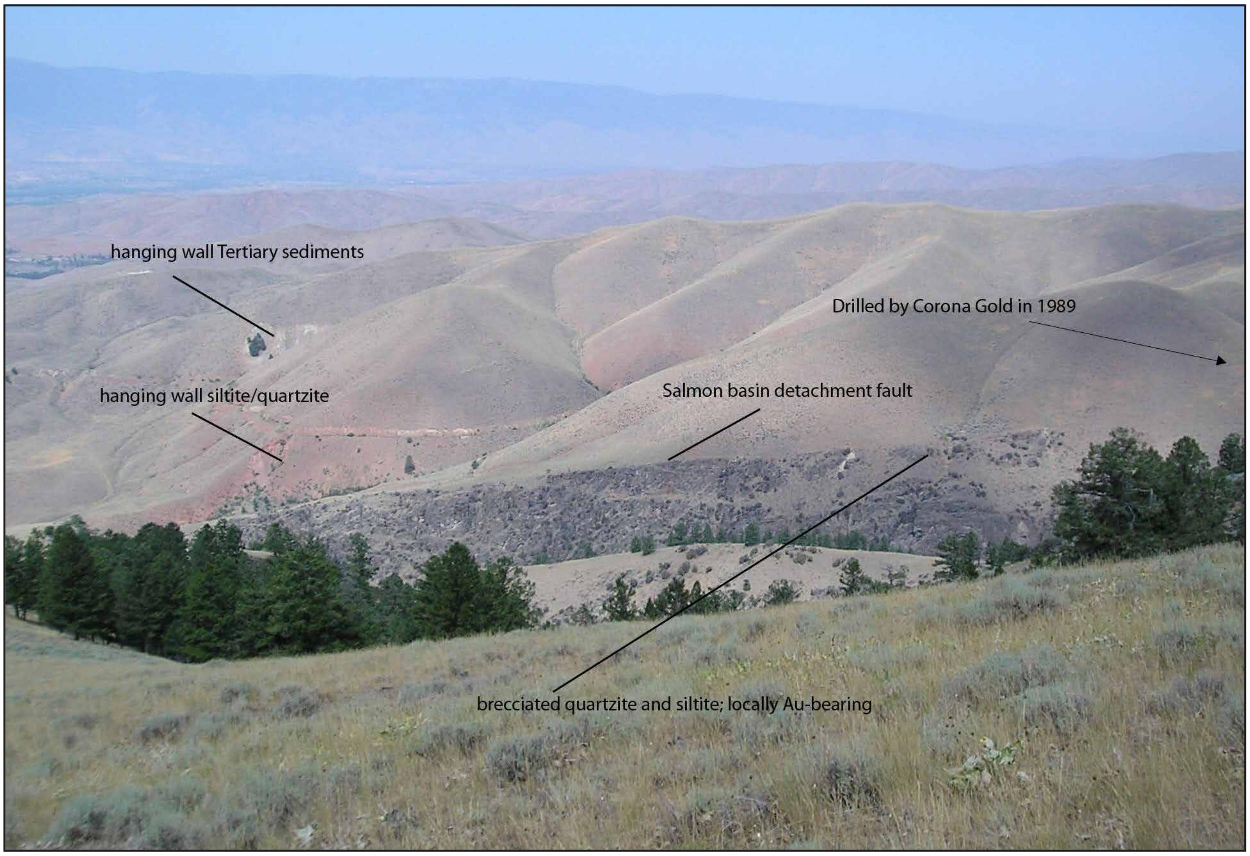


Figure 62. *View northwest over Yg bedrock canyon of Wimpey Creek. Hanging wall has Tkg over weathered and poorly exposed metasedimentary rock also mapped as Yg. From Lewis and Burmester (2013).*

Figure 63. *View northward across Kenney Creek at Tkg in hanging wall above Yg in the footwall of the Salmon Basin detachment fault.*

hanging wall. The detachment may be a reactivated segment of an earlier thrust that placed *Yg* over *Yajl* and *Ys*. The fault apparently steepens northward from the range front southeast of Salmon to the North Fork area. The northward extent of the fault is uncertain, but it may become the fault that continues northward out of the quadrangle just west of the North Fork of the Salmon River. That fault juxtaposes Swauger Formation to the east in its footwall against the younger Jahnke Lake member of the Apple Creek Formation in its hanging wall, just as does the Beaverhead Divide fault system at the crest of the Beaverhead Mountains. Possibly, the Salmon Basin detachment reactivated the Beaverhead Divide fault in this area. To the southeast, it is well exposed along Kenny Creek where conglomerate is in contact with cataclasite formed from Proterozoic rocks (Fig. 63). There the detachment has a dip of less than 15°. The fault in Kenny Creek is also described by Tucker and Birdseye (1989) who interpreted the hanging-wall deposits as an Eocene synvolcanic alluvial fan complex. The poorly exposed “C” fault of Blankenau (1999) is interpreted to form the northeast margin of a second (more southwesterly) Tertiary basin.

LEMHI PASS FAULT

Only a short segment of the Lemhi Pass fault, traced west-northwest from Lemhi Pass, appears at the south edge of the map. VanDenburg (1997) and Blankenau (1999) interpreted it as a 22°-24° south-dipping detachment fault. Blankenau speculated that the Lemhi Pass fault is offset to the north by the Salmon basin detachment, an interpretation tentatively adopted for this map although we place the western segment slightly farther north.

METAMORPHISM

Mesoproterozoic rocks suffered regional greenschist facies metamorphism, and locally, contact metamorphism. Redistribution of iron from oxides to silicates during metamorphism may account for the dark color of some units (e.g., *Yg*). Contact metamorphism of *Yg* to schist is confined to 2-3 m from *Ygr* (Biddle, 1985), suggesting that the country rock was cool and perhaps not metamorphosed then, although gently folded (Biddle, 1985). It is unknown whether genesis of scapolite near the Diamond Creek pluton (Fig. 48) is related to that igneous event or more regional biotite grade metamorphism. Garnet with ages around 1.1-1.2 Ga (see *Yyl* description) in the hanging wall of the Freeman thrust north of North Fork attests to higher grade rocks being exhumed by that fault, and date an event that may have affected rocks elsewhere, too. Much later contact metamorphism around the Carmen Creek stock was accompanied by local deformation (Fig. 53).

MINERALIZATION AND HYDROTHERMAL ALTERATION

An early description of the mines and prospects of the region was provided by Umpleby (1913), who had access to workings that are now caved, as well as first-hand accounts of mining activity. Ross (1925) followed with a description of the copper deposits in the area. Copper demands during World War II prompted a subsequent report by Anderson (1943) on the Pope-Shenon mine near the Salmon River fault south of Salmon. Anderson (1956, 1957, and 1959) visited many of the mines and prospects in the region and described gold, copper, and thorium and rare earth element occurrences. Exploration for uranium commenced in the area south of Salmon soon after Anderson released his 1956 report, and prospectors found anomalous concentrations at several localities in the Williams Lake quadrangle (U.S. Geological Survey, 2012). These localities, which are within the upper part of the Challis Volcanic Group, are shown on the Williams Lake map (Lewis and others, 2013a). Anderson (1958) reported on the uranium, thorium, columbium, and rare earth mineralization in the region, including the Th-REE occurrences in the Diamond Creek area northwest of Salmon. More recently, Biddle (1985) studied the Diamond Creek area in greater detail.

Proterozoic rocks in the northwestern part of the quadrangle south of North Fork are pervasively iron stained as a result of hydrothermal alteration. Sericite is common. The alteration appears to be centered on the shallow intrusive rocks (*Tdr*) of the Bobcat Gulch stock and associated felsic dikes. The most extensively altered rocks are outlined on the Bird Creek quadrangle map (Burmester and others, 2012) but local areas of alteration persist for several kilometers both southward and northward. Areas near the stock were drilled for copper-porphyry mineralization in 1980 (Nisbet and Scales, 1989). A second less-pervasive zone of alteration east of the Diamond Creek fault extends northwestward from the center of sec. 25 to the center of sec. 23, T. 23 N., R. 21 E. (Burmester and others, 2012). This zone of alteration is at least a kilometer in width and appears to be associated with southwest-dipping shears, at least some of which are mylonitic. Biddle (1985) mapped this zone, which he characterized as sericitic alteration, as well as additional altered areas to the northwest and southwest.

Placer deposits were extensively exploited along the front of the Beaverhead Range in Kirtley Creek and Bohannon Creek (see unit *p* on map). Efforts included hydraulic mining and dredging (Anderson, 1956; 1957). The source of at least some of the gold is likely zones of silicified and brecciated metasedimentary rocks along the Salmon basin detachment. Such gold-bearing rock is exposed in the footwall of the detachment along the southeast side of Kenney Creek (Brewer and Krasowski, 2013) and in the footwall of the detachment in Wimpey Creek (Lewis and Burmester, 2013). The Wimpey Creek locality was drilled by Corona Gold in 1989; there has been little exploration in that area since then. Placer deposits in the northwest corner of the map along Hughes Creek are likely derived from mineralized zones immediately outside the map area.

ACKNOWLEDGMENTS

Mapping and compilation were supported by the U.S. Geological Survey STATEMAP program. Extensive discussions with Don Winston and Paul Link regarding the regional stratigraphy have been greatly beneficial. Dave and Eric Stewart assisted with some of the 7.5' mapping that was used in the compilation effort.

REFERENCES

Aleinikoff, J.N., Slack, J.F., Lund, Karen, Evans, K.V., Fanning, C.M., Mazdab, F.K., Wooden, J.L., and Pillers, R.M., 2012, Constraints on the timing of Co-Cu ± Au mineralization in the Blackbird District, Idaho, using SHRIMP U-Pb ages of monazite and xenotime plus zircon ages of related Mesoproterozoic orthogneisses and metasedimentary rocks: Economic Geology, v. 107, p. 1143–1175.

Anderson, A.L., 1943, Copper mineralization near Salmon, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 60, 19 p.

Anderson, A.L., 1956, Geology and mineral resources of the Salmon quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 106, 102 p.

Anderson, A.L., 1957, Geology and mineral resources of the Baker quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 112, 71 p.

Anderson, A.L., 1958, Uranium, thorium, columbium, and rare earth deposits in the Salmon region, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 115, 81 p.

Anderson, A.L., 1959, Geology and mineral resources of the North Fork quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 118, 92 p.

Anderson, A.L., Unpublished geologic mapping in the Baker quadrangle, Lemhi County, Idaho, circa 1960: on file at Idaho Geological Survey, scale 1:30,900.

Anderson, A.L., Unpublished geologic mapping in the Salmon quadrangle, Lemhi County, Idaho, circa 1960: on file at Idaho Geological Survey, scale 1:30,900.

Axelrod, D.I., 1998, The Oligocene Haynes Creek flora of eastern Idaho: University of California Publications in Geological Sciences, v. 143, 99 p.

Biddle, J.H., 1985, The geology and mineralization of part of the Bird Creek quadrangle, Lemhi County, Idaho: University of Idaho M.S. thesis, 119 p.

Blankenau, J.J., 1999, Cenozoic structural and stratigraphic evolution of the southeastern Salmon basin, east-central Idaho: Utah State University M.S. thesis, 143 p., 3 plates.

Brewer, Brian, and Krasowski, Dennis, 2013, Gold mineralization at Kenney Creek, Lemhi County, Idaho: Northwest Geology, v. 42, p. 375-380.

Brown, D.C., 1973, Fold geometry in the Belt sequence, Salmon, Idaho: Franklin and Marshall College M.S. thesis, 71 p.

Burmester, R.F., Lewis, R.S., Othberg, K.L., Lonn, J.D., Stanford, L.R., and McFaddan, M.D., 2011, Geologic Map of the Badger Spring Gulch quadrangle, Lemhi County, Idaho: Idaho Geologic Survey Digital Web Map 132, scale 1:24,000.

Burmester, R.F., Lewis, R.S., Othberg, K.L., Stanford, L.R., McFaddan, M.D., and Lonn, J.D., 2012, Geologic map of the Bird Creek quadrangle, Lemhi County, Idaho: Idaho Geological Survey Digital Web Map 153, scale 1:24,000.

Burmester, R.F., Lonn, J.D., Lewis, R.S., and McFaddan, M.D., 2013, Toward a grand unified theory for stratigraphy of the Lemhi subbasin of the Belt Supergroup: Northwest Geology, v. 42, p. 1-19.

Burmester, R.F., Lonn, J.D., Lewis, R.S., and McFaddan, M.D., 2016, Stratigraphy of the Lemhi subbasin of the Belt Supergroup, *in* J.S. MacLean, and J.W. Sears, eds., Belt Basin: Window to Mesoproterozoic Earth: Geological Society of America Special Paper 522, p. 121-138, doi:10.1130/2016.2522(01).

Cohen, K.M., and Gibbard, P.L., 2011, Global chronostratigraphical correlation table for the last 2.7 million years: Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy), Cambridge, England. Available at: http://www.quaternary.stratigraphy.org.uk/charts (accessed 12 December 2016).

Coppinger, Walter, 1974, Stratigraphy and structural study of Belt Supergroup and associated rocks in a portion of the Beaverhead Mountains, southwestern Montana and east-central Idaho: Miami University Ph.D. thesis, 224 p.

Doblas, Miguel, 1998, Slickenside kinematic indicators: Tectonophysics, v. 295, p. 187–197.

Doughty, P.T., and Chamberlain, K.R., 1996, Salmon River arch revisited: new evidence for 1370 Ma rifting near the end of deposition in the Middle Proterozoic Belt basin: Canadian Journal of Earth Sciences, v. 33, p. 1037-1052.

Evans, K.V., and Fischer, L.B., 1986, U-Pb geochronology of two augen gneiss terranes, Idaho—new data and tectonic implications: Canadian Journal of Earth Science, v. 23, p. 1919-1927.

Evans, K.V., and Green, G.N., 2003, Geologic map of the Salmon National Forest and vicinity, east-central Idaho: U.S. Geological Survey Geologic Investigations Series Map I-2765, scale 1:100,000, 2 sheets, 19 p. text.

Evans, K.V., and Zartman, R.E., 1990, U-Th-Pb and Rb-Sr geochronology of Middle Proterozoic granite and augen gneiss, Salmon River Mountains, east-central Idaho: Geological Society of America Bulletin, v. 102, p. 63–73.

Fisher, F.S., McIntyre, D.H., and Johnson, K.M., 1992, Geologic map of the Challis quadrangle, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1819, scale 1:250,000.

Gardner, D.W., 2008, Sedimentology, stratigraphy, and provenance of the upper Purcell Supergroup, southeastern British Columbia, Canada: implications for syn-depositional tectonism, basin models, and paleogeographic reconstructions: University of Victoria M.S. thesis, 76 p., http://hdl.handle.net/1828/911

Hansen, Connor, 2015, An investigation into the Poison Creek thrust: A Sevier thrust with Proterozoic implications: Idaho State University, M.S. thesis, 80 p.

Hansen, P.M., 1983, Structure and stratigraphy of the Lemhi Pass area, Beaverhead Range, southwest Montana and east-central Idaho: The Pennsylvania State University, M.S. thesis, 112 p.

Harrison, S.L., 1985, Sedimentology of Tertiary sedimentary rocks near Salmon, Idaho: University of Montana Ph.D. dissertation, 175 p.

Hipple, Karl, Langersmith, Karen, Dal Ames, Winward, and Duncan, Bradley, 2006, Soil survey of Custer-Lemhi area, Idaho, parts of Blaine, Custer, and Lemhi counties: United States Department of Agriculture, Natural Resources Conservation Service, 1270 pages, soil maps at http://websoilsurvey.nrcs.usda.gov/app/.

Hobbs, S.W., 1980, The Lawson Creek Formation of Middle Proterozoic age in east-central Idaho: U.S. Geological Survey Bulletin 1482-E, 12 p.

Janecke, S.U. and Blankenau, J.J., 2003, Extension folds associated with Paleogene detachment faults in SE part of the Salmon Basin, *in* D.R. Lageson and R.B. Christner, eds., 2003, Tobacco Root Geological Society Field Conference at the Belt Symposium IV: Northwest Geology, v. 32, p. 51-73.

Janecke, S.U., VanDenburg, C.J., Blankenau, J.J., and M'Gonigle, J.W., 2000, Long-distance longitudinal transport of gravel across the Cordilleran thrust belt of Montana and Idaho: Geology, v. 28, no. 5, p. 439–442.

Janecke, S.U., Blankenau, J.J., VanDenburg, C.J., and Van Gosen, B.S., 2001, Map of normal faults and extensional folds in the Tendoy Mountains and Beaverhead Range, southwest Montana and eastern Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-2362, scale 1:100,000.

Kilroy, K.C., 1981, $^{40}Ar/^{39}Ar$ geochronology and geochemistry of the Carmen Creek stock, and related intrusions of the northern Beaverhead Mountains, Idaho-Montana: Ohio State University M.S. thesis, 100 p.

Lane, E.W., 1947, Report of the subcommittee on sediment terminology: Transactions of the American Geophysical Union, v. 28, no. 6, p. 936-938.

Lewis, R.S., 2016, Major oxide and trace element analyses for igneous rock samples from the Salmon 30' x 60' quadrangle, Idaho: Idaho Geological Survey Digital Analytical Data 15.

Lewis, R.S., and Burmester, R.F., 2013, The Salmon basin detachment fault in the Wimpey Creek area, east-central Idaho: Northwest Geology, v. 42, p. 337-342.

Lewis, R.S., Bush, J.H., Burmester, R.F., Kauffman, J.D., Garwood, D.L., Myers, P.E., and Othberg, K.L., 2005, Geologic map of the Potlatch 30 x 60 minute quadrangle, Idaho: Idaho Geological Survey Geologic Map Geologic Map 41, scale 1:100,000, 30 p.

Lewis, R.S., Burmester, R.F., Stanford, L.R., Lonn, J.D., McFaddan, M.D., and Othberg, K.L., 2009a, Geologic map of the Kitty Creek quadrangle, Lemhi County, Idaho and Beaverhead County, Montana: Idaho Geological Survey Digital Web Map 112 and Montana Bureau of Mines and Geology Open-File Report 582, scale 1:24,000.

Lewis, R.S., Othberg, K.L., Burmester, R.F., Lonn, J.D., Stanford, L.R., and McFaddan, M.D., 2009b, Geologic map of the Bohannon Spring quadrangle, Lemhi County, Idaho and Beaverhead County, Montana: Idaho Geological Survey Digital Web Map 113 and Montana Bureau of Mines and Geology Open-File Report 583, scale 1:24,000.

Lewis, R.S., Othberg, K.L., Stanford, L.R., Burmester, R.F., Lonn, J.D., and McFaddan, M.D., 2011, Geologic map of the Goldstone Mountain quadrangle, Lemhi County, Idaho: Idaho Geological Survey Digital Web Map 134, scale 1:24,000.

Lewis, R.S., Othberg, K.L., Burmester, R.F., Stanford, L.R., McFaddan, M.D., and Lonn, J.D, 2012, Geologic Map of the Salmon quadrangle, Lemhi County, Idaho: Idaho Geologic Survey Digital Web Map 154, scale 1:24,000.

Lewis, R.S., Othberg, K.L., McFaddan, M.D., Burmester, R.F., Stewart, D.E., Stanford, L.R., and Stewart, E.D., 2013a, Geologic map of the Williams Lake quadrangle, Lemhi County, Idaho: Idaho Geological Survey Digital Web Map 162, scale 1:24,000.

Lewis, R.S., Othberg, K.L., Burmester, R.F., Stanford, L.R., and McFaddan, M.D., 2013b, Challis volcanics, younger strata, and landslides in the Williams Lake area near Salmon, Idaho: Northwest Geology, v. 42, p. 343-352.

Lewis, R.S., Othberg, K.L., Stanford, L.R., Burmester, R.F., Lonn, J.D., Stewart, D.E., and Stewart, E.D., 2014, Geologic Map of the Sal Mountain quadrangle, Lemhi County, Idaho: Idaho Geologic Survey Digital Web Map 170, scale 1:24,000.

Link, P.K., and Janecke, S.U., 1999, Geology of east-central Idaho: Geologic roadlogs for the Big and Little Lost River, Lemhi and Salmon River valleys, *in* S.S. Hughes and G.D. Thackray, eds., Guidebook to the Geology of Eastern Idaho: Pocatello, Idaho Museum of Natural History, p. 295-334.

Lonn, J.D., Burmester, R.F., Lewis, R.S., and Stanford, L.R., 2008, Geologic map of the Homer Youngs Peak quadrangle, Lemhi County, Idaho, and Beaverhead County, Montana: Idaho Geological Survey Digital Web Map 95 and Montana Bureau of Mines and Geology Open-File Report 575, scale 1:24,000.

Lonn, J.D., Stanford, L.R., Lewis, R.S., Burmester, R.F., and McFaddan, M.D., 2009, Geologic map of the Goldstone Pass quadrangle, Lemhi County, Idaho, and Beaverhead County, Montana: Idaho Geological Survey Digital Web Map 114 and Montana Bureau of Mines and Geology Open-File Report 584, scale 1:24,000.

Lonn, J.D., Lewis, R.S., Burmester, R.F., and McFaddan, M.D., 2013a, The complex structural geology of the northern Beaverhead Mountains, Montana and Idaho, *in* R.S. Lewis, M.M. Garsjo, and R.I. Gibson, eds., Belt Symposium V and other Papers: Northwest Geology, v. 42, p. 111-130.

Lonn, J.D., Othberg, K.L., Lewis, R.S., Burmester, R.F., Stanford, L.R., and Stewart, D.E., 2013b, Geologic map of the North Fork quadrangle, Lemhi County, Idaho: Idaho Geological Survey Digital Web Map 160, scale 1:24,000.

Lonn, J.D., Stanford, L.R., McFaddan, M.D., Lewis, R.S., and Burmester, R.F., 2013c, Geologic map of the Jumbo Mountain 7.5' quadrangle, Beaverhead County, Montana, and Lemhi County, Idaho: Montana Bureau of Mines and Geology Open-File Report 634, scale 1:24,000.

Lonn, J.D., Burmester, R.F., Lewis, R.S., and McFaddan, M.D., 2016, Giant folds and complex faults in Mesoproterozoic Lemhi strata of the Belt Supergroup, northern Beaverhead Mountains, Montana and Idaho, *in* MacLean, J.S., and Sears, J.W., eds., Belt Basin: Window to Mesoproterozoic Earth: Geological Society of America Special Paper 522, p. 139-162, doi:10.1130/2016.2522(06)

Lonn, J.D., Elliott, C.G., Lewis R.S., Burmester R.F., McFaddan M.D., Stanford, L.R., Janecke, S.U., and Othberg, K.L., in press, Geologic map of the Montana part of the Salmon 30' x 60' quadrangle, southwestern Montana: Montana Bureau of Mines Geology Open-File Report, scale 1:100,000.

Lopez, D.A., O'Neill, J.M., and Ruppel, E.T., 2006, Preliminary geologic map of the Montana parts of the Goldstone Pass and Goldstone Mountain quadrangles, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 536, scale 1:24,000.

Ludwig, K.R., 2012, Isoplot, a geochronologic toolkit for Microsoft Excel: Berkeley Geochronology Center Special Publication no. 5, http://www.bgc.org/isoplot_etc/isoplot.html

MacKenzie, W.O., 1949, Geology and ore deposits of a section of the Beaverhead Range east of Salmon, Idaho: University of Idaho M.S. thesis, 65 p., scale 1:31,000.

McKee, E.D., and Weir, G.W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geological Society of America Bulletin, v. 64, p. 381-390.

Nisbet, Phillip, and Scales, W.G., 1989, Descriptive road log, northeastern Leesburg basin-Bobcat project area, *in* F.J. Moye, ed., Geology and Ore Deposits of the Trans-Challis Fault System/Great Falls Tectonic Zone: Tobacco Root Geological Society Fifteenth Annual Field Conference, p. 45-54.

Noranda, unpublished mapping, 1982, Geologic map, western part of North Fork quadrangle, project 0484, Idaho cobalt belt reconnaissance: Noranda Exploration Inc., on file at Idaho Geological Survey, scale 1:24,000.

O'Neill, J.M., 2005, Newly recognized Chief Joseph metamorphic core complex and younger structures in the north-central Beaverhead Mountains-expanding the temporal and spatial limits of post contractional extension in the northern Rocky Mountains: Geological Society of America Abstracts with Programs, v. 37, no. 6, p. 4.

Othberg, K.L., Stanford, L.R., and Lewis, R.S., 2010, Geologic map of the East of Salmon quadrangle, Lemhi County, Idaho: Idaho Geological Survey Digital Web Map 125, scale 1:24,000.

Othberg, K.L., Lewis, R.S., Stanford, L.R, Burmester, R.F., and McFaddan, M.D., 2011, Geologic map of the Baker quadrangle, Lemhi County, Idaho: Idaho Geological Survey Digital Web Map 141, scale 1:24,000.

Petit, J.P., 1987, Criteria for the sense of movement on fault surfaces in brittle rocks: Journal of Structural Geology, v. 9, p. 597-608.

Ross, C.P., 1925, The copper deposits near Salmon, Idaho: U.S. Geological Survey Bulletin 774, 44 p.

Ruppel, E.T., 1975, Precambrian Y sedimentary rocks in east-central Idaho: U.S. Geological Survey Professional Paper 889-A, 23 p.

Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1º x 2º quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1803-H, scale 1:250,000

Scott, W.W., 1982, Surficial geologic map of the eastern Snake River Plain and adjacent areas, 111° to 115°W., Idaho and Wyoming: U.S. Geological Survey Map I-1372, scale 1:250,000.

Simpson, C., and Schmid, S.M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geological Society of America Bulletin, v. 94, p.1281-1288.

Sloss, L.L., 1954, Lemhi arch, a mid-Paleozoic positive element in south-central Idaho: Geological Society of America Bulletin, v. 65, no. 4, p. 365-368.

Steel, T.D., 2013, Stratigraphic and structural studies of Mesoproterozoic strata in the Shewag Lake quadrangle, Idaho and Montana: Idaho State University M.S. thesis, 102 p.

Stewart, E.D. Steele, T.D., Stewart, D.E., Link, P.K., and, 2014, Geologic Map of Gibbonsville, Shewag Lake, and Allan Mountain quadrangles, and parts of the Lost Trail Pass and Big Hole Pass quadrangles, Lemhi County, Idaho, and Ravalli and Beaverhead counties, Montana: Idaho Geologic Survey Technical Report T-14-2, scale 1:40,000.

Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 1-33.

Tucker, D.R., 1975, Stratigraphy and structure of Precambrian Y (Belt?) metasedimentary and associated rocks, Goldstone Mountain quadrangle, Lemhi County, Idaho, and Beaverhead County, Montana: Miami University Ph.D. dissertation, 221 p., scale 1:48,000.

Tucker, D.R., and Birdseye, R.U., 1989, An Eocene synvolcanic alluvial fan complex in east-central Idaho: stratigraphic relationships and structural implications: The Mountain Geologist, v. 6, p. 23-30.

Tysdal, R.G., 1996a, Geologic map of the Lem Peak quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1777, scale 1:24,000.

Tysdal, R.G., 1996b, Geologic map of parts of the Hayden Creek and Mogg Mountain quadrangles, Lemhi County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series I-2563, scale 1:24,000.

Tysdal, R.G., 2000, Stratigraphy and depositional environments of Middle Proterozoic rocks, northern part of the Lemhi Range, Lemhi County, Idaho: U.S. Geological Survey Professional Paper 1600, 40 p.

Tysdal, R.G., 2002, Structural Geology of western part of Lemhi Range, east-central Idaho: U.S. Geological Survey Professional Paper 1659, 33 p.

Tysdal, R.G., and Desborough, G.A., 1997, Scapolitic metaevaporite and carbonate rocks of Proterozoic Yellowjacket Formation, Moyer Creek, Salmon River Mountains, central Idaho: U.S. Geological Survey Open-File Report 97-268, 28 p.

Tysdal, R.G., and Moye, Falma, 1996, Geologic map of the Allison Creek quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1778, scale 1:24,000.

Umpleby, J.B., 1913, Geology and ore deposits of Lemhi County, Idaho: U.S. Geological Survey Bulletin 528, 182 p.

U.S. Geological Survey, 2012, Defense Minerals Exploration Administration (DMEA) available at: http://minerals.usgs.gov/dockets/dmea.htm# (accessed 27 February 2013).

VanDenburg, C.J., 1997, Tectonic and paleogeographic evolution of the Horse Prairie half graben, southwest Montana: Utah State University M.S. thesis, 152 p.

Walker, J.D., Geissman, J.W., Bowring, S.A. and Babcock, L.E., compilers, 2012, Geologic Time Scale v. 4.0: Geological Society of America, doi: 10.1130/2012.CTS004R3C.

Walker, M. J., Berkelhammer, C. M. , Bjorck, S., Cwynar, L. C., Fisher, D. A. , Long, A. J., Lowe, J. J., Newnham, R. M. , Rasmussen, S. O. , and Weiss, H., 2012, Formal subdivision of the Holocene Series/Epoch: a Discussion Paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy): Journal of Quaternary Science, v. 27, no. 7, p. 649–659.

Winston, Don, 1986, Sedimentation and tectonics of the Middle Proterozoic Belt Basin, and their influence on Phanerozoic compression and extension in western Montana and northern Idaho, *in* J.A. Peterson, ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, p. 87-118.