GEOLOGIC MAP OF THE COYOTE CREEK 7.5' QUADRANGLE, SOUTHWESTERN MONTANA

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INTRODUCTION

The Coyote Creek 7.5' quadrangle is within the Salmon 30' x 60' quadrangle and links three 1:24,000-scale geologic maps: the west-adjacent Kitty Creek quadrangle (Lewis and others, 2009), the north-adjacent Peterson Lake quadrangle (Lonn and Lewis, 2011), and the east-adjacent Bachelor Mountain quadrangle (Janecke and others, 2005). Within the Coyote Creek quadrangle, fault-bounded blocks of Paleoproterozoic gneiss, Mesoproterozoic quartzites, and possible Cambrian, Neoproterozoic, or Mesoproterozoic quartzites are faulted against the Cenozoic sedimentary fill of the Horse Prairie basin. Ages, correlations, and structural settings of the older rock units have been controversial. U/Pb dating of detrital zircons provides new understanding of these relationships because previous correlations based on color, grain size, and feldspar ratios have proved unreliable.

Although there is evidence of Pleistocene glaciation on the north-adjacent Peterson Lake quadrangle (Lonn and Lewis, 2011), there is no evidence of glaciation within the Coyote Creek quadrangle (Alden, 1953).

DESCRIPTION OF MAP UNITS

Sample locations are shown on the map and listed in table 1. Feldspar count results are given in table 2. Detrital zircon probability density spectra are shown in figure 1, with supporting data in appendix 1.

Previous mapping relied on the predominance of potassium feldspars or plagioclase to distinguish the various quartzites (Lewis and others, 2009; Lonn and Lewis, 2011; Lonn and others, 2011). We have determined the relative abundance of potassium feldspar and plagioclase for nine samples as listed in table 2. All the quartzites are feldspathic with greater amounts of potassium feldspar than plagioclase except for one where the amounts were about the same. Thus, we find feldspar ratios not distinctive, and have used new detrital zircon age distributions to correlate and distinguish formations.

We dated detrital zircons from eight samples by uranium-lead laser ablation inductively coupled plasma mass spectrometry (U-Pb LA-ICP-MS). A gneiss sample from the mouth of Bloody Dick Creek was processed at the Washington State University Geoanalytical Laboratory using protocols described in Lewis and others (2010); all other samples were processed at the Arizona Laserchron Laboratory at the University of Arizona using protocols described in Link and others (2014).

CENOZOIC ROCKS

Qal **Alluvium (Holocene and Pleistocene)**—Unconsolidated clay, silt, and sand in Horse Prairie basin and along modern streams. Includes alluvial fan deposits and small landslide deposits.

QTqcw Quartz conglomerate, weathered (Quaternary and Tertiary)—Chaotic piles of rounded and subangular boulders, predominantly composed of coarse white (N9) quartzite. Occurrences occupy knobs near, but not immediately adjacent to, the Meriwether Lewis fault (the northwestern boundary fault of the Horse Prairie basin). The boulder piles occupy the same positions relative to the fault and the same stratigraphic position above the Everson Creek volcanic ash beds (*Tec*) as do the Tertiary quartzite boulder conglomerates (*Teqc*). The unit is interpreted to be the weathered remains of *Teqc*. Large, up to 6 x 6 x 6 ft (2 x 2 x 2 m) boulders lie on the sides of the knobs. Other locations where large numbers of white quartzite boulders occur are likely weathered areas of *Teqc,* but have not been mapped as such. One such location is the topographic ridge just north of the fossil beaver jaw location (table 1) in the south-central part of the quadrangle.

QTgr **Colluvium (Quaternary and Tertiary)**—Thick, unconsolidated, well to poorly sorted, silt to gravel deposits of various compositions. Occurs as gently sloping aprons in the eastern part of the quadrangle.

Tls **Landslides, undifferentiated (Quaternary and Tertiary)**—Landslides, slide blocks, slump blocks, debris flows, talus, and alluvial fans of weathered and decomposing quartzites. More extensive and thicker near the Meriwether Lewis fault. Materials at any given location reflect the type of nearby quartzite; predominantly white (N9) and light gray (N6) south of the Coyote Creek faults, and pale red (10R 6/2) and pinkish gray (5YR 8/1) north of the fault.

The unit appears to be locally interbedded with Tertiary sediments, indicating large-scale mass movements during the development of the Horse Prairie graben. Movement on the Meriwether Lewis fault likely contributed to slumping and sliding, which was facilitated by the intermittent deposition of tuffaceous materials.

Tbp **Bannock Pass beds (early to middle Miocene)**—Fine-grained sandstone, siltstone, reworked tephra, mudstone, and conglomerate. The clay-rich siltstones, mudstones, and reworked tephra contain dispersed sand grains, sheath-like shards of opaline silica, and oblong quartz pebbles. Mudstones are moderate yellowish brown (10 YR 5/4). Conglomerates are matrix-supported siltstone with volcanic pebbles up to 1 cm in diameter. Bedding is obscured by intense burrowing by gophers and badgers as well as slumped surface gravels.

South and west of Houlihan Springs, the unit includes hummocks of gravel-sized pale red (5R 6/2) quartzite and occasional boulders of white (N9) quartzite that enclose small springs.

The Bannock Pass beds are on the downthrown side of the Coyote Creek fault, in fault contact with and younger than the Everson Creek beds (*Tec)* on the upthrown side. *Tbp* is also continuous with beds to the east on the Bachelor Mountain 7.5' quadrangle that Janecke and others (2005) call "Bannack" [sic] Pass beds in reference to similar beds mapped on the Idaho–Montana border near Deadman Pass. Janecke and others (2005) correlated those beds with early to middle Miocene vertebrate fossil-containing beds exposed at Bannock Pass (the mudstone unit, *Tm*, of M'Gonigle, 1994; M'Gonigle and Hait, 1997). Bannack Pass is approximately 34 mi (55 km) southeast of Bannock Pass. Here we use the spelling of the pass most closely associated with the beds. Tops and bottoms are not exposed. Thickness is uncertain.

Tec **Everson Creek beds, undifferentiated (late Oligocene to early Miocene)**—Interbedded volcanic ash mudstone, tuffaceous shale, siltstone, sandstone, and conglomerate deposited by streams, landslides, and sheetwash into the Horse Prairie basin. Where well exposed, the siltstone and conglomerate units were mapped separately. All units can contain rounded quartz grains, pebbles, or cobbles of nearby older units including gneiss, quartzite, and on the eastern side of the quadrangle, volcanic scoria. Most beds contain a small amount of biotite and muscovite. Although predominantly very pale orange (10YR 8/2) or light brownish gray (5YR

6/1), the color can vary from yellowish gray (5Y 8/1) to pinkish gray (5YR 8/1) to light brown (5YR 6/1).

The unit is characterized by the predominance of badger holes. When wet, the tuffaceous beds are slippery, and syn- and post-depositional sliding and internal movement has occurred. Surface landforms such as the scalloped edges of much of the Everson Creek beds may indicate ongoing internal basinward slip. Such internal movement may be the reason that the bouldery quartzite conglomerates and their weathered counterparts occur some distance from the basin boundary fault. The top and bottom of the unit are not exposed, and thickness cannot be estimated.

A fossil from a very pale orange ash bed, near the top of this unit in the south-central part of the quadrangle in sec. 33, T. 9 S., R. 14 W., was identified by Alan Tabrum of the Carnegie Museum of Natural History, Pittsburgh, Pennsylvania (written commun., March 2011) as a fragment of a beaver jaw that preserved the two upper teeth (probably the last two upper molars M2 and M3). Based on similarity to a fossil from a nearby locality, he identified it as "*Castorid* sp., cf. *Neatocastor hesperus.*" The age range of *Neatocastor* is Arikareean (Korth, 1996), mid-Oligocene to early Miocene. Silicified wood, bark, twigs, and leaves were also found at this locality.

Teqc **Quartzite conglomerate of the Everson Creek beds (late Oligocene to early Miocene)**—Upper unit of the Everson Creek beds. Conglomerate of rounded and subangular pebbles, cobbles, and large boulders up to 3 x 3 x 3 ft (1 x 1 x 1 m) of white (N9) coarse-grained quartzite with some medium-sized cobbles of light brown (N6) and moderate yellowish brown (10 YR 5/4) medium-grained quartzite. Contains occasional cobbles of pale red (5R 6/2 and 10R 6/2) quartzite; there are no volcanic, metamorphic, or diabase clasts. Fine sand fills the interstices and the cement is silica; little or no volcanic ash is present. Interbeds of small cobbles, pebbles, and sand fine upward. Some beds consist wholly of haphazardly deposited large, 3 x 3 x 3 ft (1 x 1 x 1 m) angular brecciated boulders of coarse-grained white quartzite. Unit forms cliffs 13–20 ft (4–6 m) high. Massive blocks slump away from the cliffs, and nearby areas are littered with large white quartzite boulders. Occurrences of conglomerate overlie upper Everson Creek volcanic ash beds *(Tec*), occur very close but not immediately adjacent to the Meriwether Lewis fault (the northern boundary fault of Horse Prairie basin), and are interpreted to be cemented rock slides and talus piles resulting from movement on the fault with some water-deposited interbeds. Thickness is uncertain because outcrop is discontinuous.

Tecs **Sandstone unit of the Everson Creek beds (late Oligocene to early Miocene)**—Fine- to coarse-grained, well to poorly sorted, well to poorly consolidated, 3 ft to tens of ft (m to dm) thick, planar and trough-crossbedded sandstone with interbedded siltstone and mudstone. Grains are rounded to subangular and are typically: quartz, 85 percent; feldspar, 10 percent; muscovite and hematite, 5 percent. Locally contains white (N9), medium light gray (N6), moderate red (5R 4/6), pale red (5R 6/2), and brownish black (5YR 2/1) quartzite pebbles and volcanic clasts commonly up to 0.2 in (5 mm), with some up to 4 in (10 cm); contains rare, small, flat-pebble mud chips. Color ranges from dark grayish brown (5YR 3/2) to yellowish brown (10YR 4/2) to light brown (5YR 5/6) to greenish gray (5Y 7/2).

Tecc **Conglomeratic unit of the Everson Creek beds (late Oligocene to early Miocene)**—Predominantly a flat-pebble conglomerate in a quartzite pebble, sand, and mudstone matrix with silica cement and minor interbeds of sandstone, siltstone, tuffaceous mudstone, and paper shale. Beds are discontinuous. Flat pebbles are rip-up clasts of tuffaceous mudstone commonly up to 2 x 2 x 0.5 in (5 x 5 x 1cm) in size. Beds consist of up to 98 percent pebbles. Rounded to angular pebbles are of local gneiss; schist; white (N9), medium light gray (N6), moderate red (5R 4/6), pale red (5R 6/2), and brownish black (5YR 2/1) quartzite; basalt; and black (N1), pale brown (5 YR 5/2), light brown (5YR 5/6), and dark gray (N3) chert. Muscovite is common in the matrix. Flat pebbles are yellowish gray (5R 8/1) and weather to pale yellowish orange (10R 8/6). Pebbles can be flat-lying, but also occur in jumbles of varying attitudes without obvious imbrication. Beds are either well or poorly sorted. Sandstone interbeds are fine- to coarse-grained and may show graded bedding. All beds may have yard to tens of yards (m to dm) thick crossbedding. Petrified wood is common at some locations and readily weathers out. Outcrops are commonly covered in black lichen. Some outcrops east of and near the Monument Mine on the southern edge of the quadrangle in sec. 4, T. 10 S., R. 14 W. contain centimeter-size feldspar grains and have a pale olive (10Y 6/2) or pale yellowish green (10GY 7/2) cast because of weathered biotite and pervasive chlorite.

Tecc can be overlain or underlain by *Tecs*, a result of locally different depositional conditions and influxes of sediment types in a subsiding basin.

Tba **Basalt (Tertiary)**—Bottom 10–15 ft (3–4 m) of a basalt flow with incorporated angular to rounded, gravel- to boulder-sized pieces of quartzite, schist, and other surficial debris from the surface of *Ysw* on which it flowed. It forms a minor cliff located in the southwestern part of the quadrangle in sec. 32, T. 9 S., R. 14 W.; the total outcrop area is less than one acre.

Tba is likely either Eocene or late Oligocene. The nearby outcrop of *Tgb* is Eocene(?). Weathered cobbles from a basalt flow rest on *Xgbd*, about 1.5 mi (2.4 km) to the south of the location of *Tba*, on the south-adjacent Everson Creek quadrangle (fig. 2). An apparent K/Ar age of 47.1 ± 2.9 Ma from a basalt sample 4 mi (6.4 km) west of these cobbles on the southwest adjacent Lemhi Pass quadrangle (see fig. 2) was obtained by Fritz and others (2007). Fritz and others (2007) obtained an apparent K/Ar age of 27.7 ± 0.7 Ma for a basalt sampled about 3.5 mi (5.6 km) to the east, northwest of Red Butte on the east-adjacent Bachelor Mountain quadrangle (see fig. 2). The 27.7 Ma age agrees with an $^{40}Ar/^{39}Ar$ age of 27.77 ± 0.24 Ma obtained by Janecke and others (2005) for a sample of the same basalt flow. Matoush (2002) and Kickham (2002) obtained similar ages on basalts to the northeast that cap the divide between Horse Prairie and Grasshopper Creeks. No basalts younger than late Oligocene have been age-dated in the Horse Prairie basin.

Tgb **Gabbroic dikes and sills (Eocene?)**—Medium dark gray (N4) diabase containing plagioclase laths in irregular masses of mafic minerals. Composition is typically 50 percent plagioclase, 40 percent augite, 5 percent hornblende, and 5 percent intergrowths of quartz and feldspar (Coppinger, 1974). The dikes are seen in the southwestern part of the quadrangle, along the northwest-striking Bloody Dick Creek normal fault in secs. 30 and 31, T. 9 S., R. 14 W. and along the ridge in sec. 30, T. 9 S., R. 14 W. where sill-like features are also present. The contacts of the dikes and sills with the host rock are commonly dark yellowish orange (10YR 6/6). The diabase weathers more readily than the host quartzites. On the northwest-adjacent Selway Mountain quadrangle (see fig. 2), there are two similar-trending dikes, one of which intruded a normal fault (Lonn and others, 2011). On the Goldstone Pass quadrangle, west-adjacent to the Selway Mountain quadrangle, a similarly oriented dike has been dated at 46 ± 2 Ma (Lonn and others, 2009).

PALEOZOIC OR PROTEROZOIC ROCKS

ЄZq **White quartzite**—Medium-grained feldspathic white (N9) quartzite caught up in the Houlihan Springs thrust fault in the northeastern part of the quadrangle north of Houlihan Springs (SW¼ SE¼ sec. 36, T. 8. S., R. 14 W.). The quartzite is poorly exposed and its extent cannot be determined because it is indistinguishable in the field from other white quartzites. A thin section from sample 2JS10 contained a total of 23 percent feldspar: 20 percent potassium feldspar and 3 percent plagioclase (table 2). Most quartz grains are highly strained, contain subparallel linear strings of angstrom-sized inclusions, and are intergrown with unstrained quartz.

Eighty detrital zircons from sample 2JS10 (fig. 1H) include 50 Late Mesoproterozoic (“Grenville”) grains with age peaks at 1032, 1141, and 1242 Ma, a small population of grains around 1400 Ma, and sparse Paleoproterozoic and Neoarchean (1800 to 2600 Ma) grains (Sherwin and others, 2011). The closest formation with a similar zircon age distribution is the Neoproterozoic Caddy Canyon Formation of the Brigham Group in the Portneuf Range south of Pocatello, Idaho (see sample 1JK08 in Yonkee and others, 2014, p. 71). Ages in the Brigham Group span the Late Proterozoic–Cambrian boundary (Link and others, 1987, 1993; Yonkee and others, 2014). Єzq is only shown in cross section B–B'.

Zircon age distributions for samples from *ЄZYqr* (1JS10) and *ЄZYqg* (JS1101) (described below) are nearly identical (figs. 1F and 1E). Except for color, their lithologies are also nearly identical. *ЄZYqr* crops out in the northeastern part of the quadrangle and *ЄZYqg* crops out in the southwestern part (table 1), and they are separated by other units with which they are in fault contact. Their depositional relationship is unknown.

ЄZYqr **Red medium-grained quartzite (Cambrian, Neoproterozoic, or Mesoproterozoic?)**—Fine- to medium-grained feldspathic pale red (5R 6/2) quartzite that crops out as a weathered groundmass of angular to subangular chips. Sizes range from less than 0.5 to 6 in (1 to 15 cm) with most chips around 2 in (5 cm). Viewed from a distance of 300 ft (100 m), a slope cut by an unnamed stream appears to be outcrop of *ЄZYqr*, but no bedding or sedimentary features are visible. The unit crops out in the northeastern part of the quadrangle, north of Houlihan Springs (SW½ SE¼ sec. 36, T. 8. S., R. 14 W.), where it forms the lower plate of the Houlihan Springs thrust fault. South and west of Houlihan Springs, small knobs of gravel-sized pale red quartzite enclose small springs and meadows and are interpreted to be layers within *Tbp*.

A thin section of sample 1JS10 contained approximately 25 percent total feldspar with equal amounts of potassium feldspar and plagioclase (table 2). Quartz grains were strained and grain boundaries were sutured. No inclusions were observed and the amount of strain appeared to be far less than observed in the thin section of *ЄZq*.

Sample 1JS10 yielded 71 detrital zircons with a dispersed set of ages from 1730 to 1880 Ma and a maximum around 1780 Ma (fig. 1F). A small population of grains are around 1450 Ma and there are scattered peaks from 2400 to 2750 Ma with one 3050 Ma grain. Twenty-five percent of the grains are older than 2400 Ma. The rock could thus be Mesoproterozoic (1450 Ma) or younger. Link and others (2013) noted that this age signature is similar to that of the Missoula Group of the main Belt Basin and designated the strata “Bonner Formation” (Ruppel and others, 1993).

The age distribution of detrital zircons from 1JS10 resembles that of a blue-gray (5B 5/1) schistose feldspathic quartzite with quartzite pebbles from Carpp Ridge in the Anaconda Range, approximately 63 mi (100 km) almost due north of the Coyote Creek quadrangle (sample 62PL09, fig. 3). The quartzite at Carpp Ridge is attributed to the Silver Hill Formation (Lonn and Lewis, 2009), which is a calcareous shale and siliceous laminated limestone with minor interbedded calcareous quartzite (Pardee, 1918; Wallace and others, 1992). In the Anaconda Range, Wallace and others (1992) note that "the lower part [of the Silver Hill Formation] is dark greenish-gray and greenish-black shale and siltstone interbedded with yellowish-gray quartzite; quartzite beds are thin and unevenly bedded, and flaser structure is common in fine-grained quartzite and siltstone." To the north of Carpp Ridge in the Garnet Range, Pardee (1918) notes that in the "middle of the siliceous limestone [Silver Hill Formation] is a 6 ft (2 m) bed of conglomerate made up of well-rounded quartzite cobbles firmly cemented in a sandy, limy matrix."

The probability density spectra for 88 detrital zircons from sample 62PL09 was first presented by Sears and others (2010), and we include the supporting data here. Figure 1G shows a dispersed set of ages from 1730 to 1880 Ma, with a maximum around 1780 Ma. One grain is from around 1450 Ma, scattered grains are from 2400 to 2950 Ma, and six grains are from 3200 to 3350 Ma. Forty-four percent of the grains are older than 2400 Ma.

Although the lithologies of *ЄZYqr* and the Silver Hill Formation are dissimilar, similarities in their zircon age distribution spectra indicate similar sources of detrital zircons. Lacking definitive evidence to the contrary, the formations could be contemporary and *ЄZYqr* could be Cambrian. This possibility leads to designating this unit as possibly Cambrian, Neoproterozoic, or Mesoproterozoic.

The zircon age distribution for sample 1JS10 *CZYqr* is essentially the same as that for sample JS1101 *ЄZYqg* (see below), suggesting that the two units correlate.

ЄZYqg Gray medium-grained quartzite (Cambrian, Neoproterozoic, or Mesoproterozoic?)—Very fine- to medium-grained, very well to moderately well-sorted feldspathic quartzite. There are good outcrops close to and on both sides of the narrow valley of Bloody Dick Creek in the southwestern corner of the quadrangle. There are two distinct lithologies that were not mapped separately.

Lithology 1: northeast of Bloody Dick Creek, light gray (N6) to moderate yellowish brown (10YR 5/4) quartzite is interbedded with micaceous siltite. Bedding is difficult to distinguish from through-going joints. Bed thickness is commonly 1–4 in (2–10 cm) with some 6–12 in (15–30 cm). Micaceous siltite zones, 20–40 in (50 cm to 1 m) thick, are more thinly bedded. No sedimentary features were observed. A thin section of sample JS1101 from the southwestern part of the quadrangle near the mouth of Big Hollow contained 26 percent total feldspar, 23 percent potassium feldspar, and 3 percent plagioclase.

Figure 1E shows ages of 93 detrital zircons from sample JS1101. A dispersed set of ages from 1730 to 1900 Ma have a maximum around 1780 Ma. There are scattered peaks from 2400 to 2750 Ma, a small population of grains from around 1450 Ma, and one 3000 Ma grain. Thirty-two percent of the grains are older than 2400 Ma.

The zircon age distribution for sample JS1101 *ЄZYqg* is essentially the same as that for sample 1JS10 *ЄZYqr,* suggesting the two units correlate.

Lithology 2: Southwest of Bloody Dick Creek, meter- to decimeter-thick beds of flat-laminated and planar crossbedded, very light gray (N8) and pinkish gray (5YR 8/1) quartzite are interlayered with shaly siltite. Laminations are defined by heavy minerals. Bedding, though discontinuous, is conspicuous; quartzite beds are up to 48–60 cm thick; shaly interbeds 2–15 cm thick. Immediately to the south, in the Everson Creek quadrangle, the quartzite is yellowish gray (5Y 8/1), and mud chips are associated with laminar bedding.

Lewis and others (2009) on the west-adjacent Kitty Creek quadrangle mapped *ЄZYqg lithology 1 and ЄZYqg lithology 2* as one unit, their "central sequence," and correlated it to the Mesoproterozoic Gunsight Formation. However, the two lithologies differ sharply in the short distance across Bloody Dick Creek, which conceals their relationship. It is possible that they are two different formations in fault contact. Lacking thin section or Pb/U age data on *ЄZYqg lithology 2,* we have not mapped it separately. More recently, Burmester and others (2013) indicated that the "central sequence" is younger than previously thought and may correlate with one of two units that crop out northeast of Salmon, Idaho—the Lawson Creek Formation and the Jahnke Lake unit of the Apple Creek Formation. However, the detrital zircon age distributions for both these units have sharp peaks at 1730 Ma and very few grains older than 2000 Ma (Link and others, 2016), which is a signature of the upper Belt Supergroup from Idaho. The age distributions of *ЄZYqg* and *ЄZYqr* more closely resemble age distribution spectra of the Swauger Formation (fig. 1). For example, 3 percent, 1 percent, and 2 percent of grains from samples JS1103 (*Ysw),* 2PL11 (*Ysmc),* and 6PL11 (*Ysmc)* (figs. 1B, 1C, and 1D, respectively) are older than 2000 Ma. Similarly, 6 percent of the grains from sample 8PL12 of the Jahnke Lake unit and 5 percent of the grains from sample 12RL214 of the Lawson Creek Formation are older than 2000 Ma (Link and others, 2016). In comparison, 25 percent of sample JS1101 (*ЄZYqg),* and 34 percent of sample 1JS10 (*ЄZYqr),* are grains older than 2000 Ma.

PROTEROZOIC ROCKS

The zircon age distributions for samples from the two units described below, *Ysmc* (6PL11 and 2P11) and *Ysw* (JS1103), are nearly identical. Except for color, their lithologies are also nearly identical. The zircon age distributions (figs. 1D, 1C, and 1B) are similar. We consider the contact between them to be a normal fault; their depositional relationship is unknown. The lithologies correspond to strata correlated with the Swauger Formation, informally called "Big White" quartzite (Link and others, 2016; Steel, 2013; Stewart and others, 2010; Stewart, 2009).

Ysmc Multi-colored quartzite of the Swauger Formation (Mesoproterozoic)—Thick-bedded, predominantly coarse-grained, feldspathic quartzites north and east of the Coyote Creek fault.

The upper part is fine- to medium- to coarse-grained, m-scale laminar and crossbedded, feldspathic quartzite. The quartzite is predominantly pinkish gray (5YR 8/1) but grades irregularly and gradually within beds and across crossbedding from white (N9) to pale red (10R 6/2) and greenish gray (5GY 6/1). Rock appears very light gray (N8) on some fresh surfaces. Heavy minerals define laminar bedding with load structures about 3 cm long and 1.5 cm deep. This unit forms the top of ridges in the northeastern part of the quadrangle. Three thin sections contained 22–27 percent total feldspar: 17–25 percent potassium feldspar and 5–10 percent plagioclase (table 2).

Ninety-two detrital zircons from sample 6PL11 taken north of Painter Creek (table 1) were dated by U/Pb methods. The results (fig. 1D) show a strong unimodal age peak at about 1730 Ma with sparse grains as young as 1400 Ma and as old as 2700 Ma.

The lower part consists of medium- to coarse-grained 30- to 60-cm-thick beds of white (N9) feldspathic quartzite interbedded with 2–3 m of fine- to medium-grained, 2- to 10-cm-thick beds of grayish orange (10YR 7/4) feldspathic quartzite. The white quartzite beds weather into large (0.5–1 m x 0.5 m x 0.5 m), angular, irregular, and blocky pieces; the grayish orange interbeds weather into small chips and soil. Weathered quartzite forms subdued ridges, primarily in sec. 36, T. 8. S., R. 14 W. A thin section from sample 2PL11 taken north of

Houlihan Springs (table 1) contained 15 percent total feldspar, 12 percent potassium feldspar, and 3 percent plagioclase (table 2). The quartz grains are strained and grain boundaries are sutured. No inclusions are observed and strain appears to be far lower than in *ЄZq*.

Figure 1C shows the ages of 47 detrital zircons from sample 2PL11, which was collected north of Houlihan Springs in the northeastern part of the quadrangle. There is a strong age peak at about 1730 Ma, a secondary peak at about 1860 Ma, a few grains as young as 1400 Ma, and one 2460 Ma grain. The age distribution matches that in the Swauger Formation (Link and others, 2016).

Lonn and Lewis (2011) mapped a continuation of this unit on the north-adjacent Peterson Lake quadrangle as (*Yqcu, Upper coarse-grained quartzite*) and correlated it with the Swauger Formation that stratigraphically overlies the Gunsight Formation in the Lemhi Range (Ruppel, 1975).

Ysw **White quartzite of the Swauger Formation (Mesoproterozoic)**—Thick-bedded, predominantly coarse-grained feldspathic quartzites south of the Coyote Creek fault. White (N 9) to light brownish gray (5 YR 6/1), medium- to coarse-grained feldspathic quartzite with 3 ft to tens of yards (m–dm) planar and trough crossbedding. Ripple marks are present but rare. Contains scattered interbeds of very light gray (N8) to light greenish gray (5 GY 8/10), fine- to medium-grained feldspathic quartzite and rare beds of grayish red-purple (5 RP 5/2), coarse-grained, trough-crossbedded quartzite. Bedding is 4 in to 3 ft (10 cm to 1 m) thick; 1 ft (30 cm) thick beds are most common; most interbeds are thinner. Lavender quartz grains are present. Two thin sections from samples taken between Roberts and Sullivan Gulches near the southwestern corner of the quadrangle (secs. 32 and 33, T. 9 S., R. 14 W.) contained 35–38 percent total feldspar: 28–30 percent potassium feldspar and 7–8 percent plagioclase (table 2).

Figure 1B shows the age distribution of 93 detrital zircons from sample JS1103. There is a strong unimodal age peak at about 1730 Ma. Sparse grains are as young as 1400 Ma, and a few are as old as 2650 Ma.

The *White quartzite of the Swauger Formation, Ysw,* occurs in a horst bounded by two basin and range normal faults: the Bloody Dick Creek fault and the Coyote Creek fault.

Lewis and others (2009) mapped a continuation of this unit on the west-adjacent Kitty Creek quadrangle (*Yqcu, Upper coarse-grained quartzite*), and Lonn and Lewis (2011) mapped it in the north-adjacent Petersen Lake quadrangle *(Yqcu, Upper coarse-grained quartzite of the Swauger Formation).*

Upper and lower contacts are not exposed and the likelihood of internal minor folding and bedding plane slippage makes thickness estimates problematic. Lewis and others (2009) report a thickness of at least 1,500 m in the west-adjacent Kitty Creek quadrangle.

Xgbd **Gneiss of Bloody Dick Creek (Paleoproterozoic)**—Finely banded biotite gneiss with local zones of medium-grained augen gneiss. Biotite schist occurs within both gneisses. The primary mineralogy of the gneisses and the schist is biotite, quartz, and plagioclase with minor garnet and altered pyroxenes (Coppinger, 1974). The protolith was likely sedimentary. Numerous centimeter- to meter-thick quartz veins occur throughout. Southwest of the Monument fault, and subparallel to it, there is a 200 ft (60 m) wide silicified breccia zone. Mineralization, predominantly azurite and malachite, is associated with the silicified zone and with the fault, but also occurs at other places within the unit (Hansen, 1983). Silicification after metamorphism is indicated by blebs of metamorphic rock incorporated in the quartz. The Monument Mine in sec. 4, T. 10 S., R. 14 W., was active in the early 1900s; 43 tons of ore containing 3,208 lbs of copper and 76 oz of silver was shipped in 1917; the mine has been inactive since (Geach, 1972). Prospect pits associated with quartz veins are scattered about, commonly along the edges of the unit.

The unit occurs in the southwestern corner of the quadrangle as a fault-bounded wedge with the Monument fault on the northeast, the Bloody Dick Creek normal fault on the west, and the Meriwether Lewis fault on the east.

Figure 1A shows the age distribution of more than 100 zircons from sample 08RL647 from the north side of the mouth of Bloody Dick Creek, several meters onto the south-adjacent Everson Creek quadrangle (fig. 2). The <10 percent discordant zircons include metamorphic zircons [low thorium/uranium (Th/U) ratios] around 1800 Ma. The youngest cluster of non-metamorphic zircons places the maximum age of Xgbd at around 1830 Ma. This unit does not correlate with the nearby granite gneiss of the Maiden Peak Spur (fig. 2) on the southeast-adjacent Jeff Davis Peak quadrangle, which is considered to be late Archean (M'Gonigle and Hait, 1997).

GEOLOGIC SETTING AND STRUCTURE

Exposures in the western and northern three-fifths of the Coyote Creek quadrangle are highlands composed of Paleoproterozoic, Mesoproterozoic, and Paleozoic(?) rocks, whereas exposures in the eastern and southern two-fifths are of Cenozoic sediments of the Horse Prairie basin. The Horse Prairie basin extends south of the quadrangle (fig. 2); other basins containing Cenozoic sediments are the Grasshopper to the east and northeast and the Medicine Lodge to the southeast. The Beaverhead Mountains that form the Continental Divide are to the west and south.

Structural features consist of compressive thrust faulting and folding of the Proterozoic and Paleozoic(?) rocks associated with Cordilleran tectonism during the late Cretaceous and early Eocene, followed by formation of extensional basins (Janecke and others, 2005) in the late Eocene through the Miocene. The most recent structures are normal faults subparallel to present day Basin and Range faults.

COMPRESSIVE FEATURES

Houlihan Springs thrust fault—This fault is the least obvious, but arguably the most important structural feature in the Coyote Creek quadrangle. North of Houlihan Springs, the fault is expressed at the surface where the *Multi-colored quartzite of the Swauger Formation (Ysmc)* is thrust over the *Red medium-grained quartzite (ЄZYqr)*. It is otherwise concealed by landslides and gravel, but its location in the subsurface is suggested by extensive seeps, springs, and swampy areas. The fault plane appears to be horizontal and has discontinuous pieces of *White quartzite (ЄZq)* caught up in it. Deformation is extensive in quartz grains from where the fault is most clearly defined (samples *ЄZYqr*, 1JS10 and *ЄZq*, 2JS10) (Sherwin and others, 2011). The fault was likely not recognized previously due to the extremely poor rock exposures, the thrusting of quartzites on quartzites, and the lack of zircon analyses.

The Houlihan thrust fault may be part of the Medicine Lodge thrust. Ruppel and others (1981), Ruppel and Lopez (1984), and Ruppel (1998, revised 1999, 2014) show the leading edge of the Medicine Lodge thrust plate near where we map the Houlihan thrust fault. According to their interpretation, the Swauger Formation of the Lemhi Group forms the Medicine Lodge plate and is thrust eastward over the Missoula Group rocks of the Grasshopper plate. The Grasshopper plate underlies the Grasshopper basin to the east (Kickham, 2002; Janecke and others, 2005).

South of the Horse Prairie basin the Medicine Lodge thrust plate has been identified by M'Gonigle and Hait (1997), Ruppel and others (1981), Ruppel and Lopez (1984), and Ruppel (1998, revised 1999, 2014). Skipp and Link (1992) identified locations in the southern Beaverhead Mountains where Lemhi Group rocks are thrust by the Medicine Lodge and Cabin Creek faults eastward over the Neoproterozoic/Cambrian(?) Wilbert Formation. Skipp and Link also describe the lithologic similarities between the Wilbert Formation and the Brigham Group south of the Snake River plain in southeastern Idaho. As previously noted, the detrital zircon age distribution of the *White quartzite (Єzq)* caught up in the Houlihan Springs thrust fault is similar to that of the Caddy Canyon quartzite of the Brigham Group. Skipp and Link (1992) (fig. 2) show the Medicine Lodge/Cabin Creek thrust fault continuing northward into the Coyote Creek quadrangle, beneath the southern portion of the Horse Prairie basin.

The Medicine Lodge thrust plate is presumed to exist beneath the Horse Prairie basin. M'Gonigle and Hait (1997) report "Low-angle, west-dipping reflectors visible on proprietary seismic data in the Grasshopper, Medicine Lodge, and Horse Prairie basins." They interpret the reflectors to be detachment faults and speculate that they merge at depth with older thrust faults. VanDenburg (1997) and Kickham (2002) present seismic lines from the Grasshopper and Horse Prairie basins and interpret faults that are steeply dipping at the surface to be listric and to merge with thrust faults at depth.

Monument thrust fault—In the southwest corner of the quadrangle, the right-lateral, transpressional Monument fault dips steeply to the south and has thrust the Paleoproterozoic *Gneiss of Bloody Dick Creek* (*Xgbd*) northeast over the *White quartzite of the Swauger Formation (Ysw).* Orientation of banding and schistosity within the gneiss is variable and likely reflects more than one period of deformation. However, near the thrust the schistosity in *Xgbd* becomes subparallel and quartz grains in *Ysw* become deformed and elongated subparallel to the fault. The thrust itself can be no older than late Mesoproterozoic, and is most likely to be a thrust slice of basement rocks caught up in the Medicine Lodge thrust. Ruppel (1982, p. 7 and 1978, p. 18) conjectures that crystalline basement rocks exposed to the south in the Beaverhead Mountains are bounded by such imbricate thrusts and are part of the Medicine Lodge thrust.

Folds—Minor folding in thin quartzite beds was observed in the *White quartzite of the Swauger Formation* (*Ysw*) and the *Gray medium-grained quartzite (ЄZYqg).* In conjunction with the minor folding, it is likely that layer-parallel shortening by slip along bedding planes has also occurred.

In the western part of the quadrangle, *Ysw* gives the overall impression of dipping to the west–southwest; in the northeastern part of the quadrangle, the *Multi-colored quartzite of the Swauger Formation (Ysmc)* gives the overall impression of dipping to the east–northeast. The result is that the *Swauger Formation (Ysw)* appears to be broadly folded with a northwest–southeast axis parallel to Coyote Creek. Such a fold would be consistent with a ramping up of the Medicine Lodge thrust in this area, and the ramp location could have controlled the location of the much younger Coyote Creek normal fault.

EXTENSIONAL FEATURES

Meriwether Lewis fault—This normal fault extends across the quadrangle from northeast to southwest and forms the boundary that separates the Proterozoic and Paleozoic(?) strata exhibiting Cordilleran-age compressive features from the Tertiary extensional Horse Prairie basin filled with Cenozoic strata (Janecke and others, 2005). In the southwest it forms a clear boundary between Proterozoic and Paleozoic(?) rocks and is marked by sharp, steep changes in topography along the easternmost exposure of *Ysw* and by faceted faces along the southeastern extent of the X*gbd.* Its northeastern extent is concealed beneath the landslides, debris flows, and thick colluvium of *Tls*.

Although the fault appears to be a high-angle normal fault at the surface, interpretation of seismic data indicates that it flattens at a depth of about 2 km to become a detachment fault and merge with older thrust faults (M'Gonigle and Hait, 1997; VanDenburg, 1997; Kickham, 2002; Janecke and others, 2005). Hanna and others (1993) show a gravity low below the Tertiary sediments in the Coyote Creek quadrangle and estimate the thickness of the sediments in the Horse Prairie graben to be about 1.2 mi (2 km).

According to VanDenburg and others (1998), and Janecke and others (2005), movement of the fault occurred over an approximate 25–30 m.y. period beginning in mid-Eocene and ceasing by mid-Miocene. Concealment of the fault beneath *Tbp* confirms the conclusion of VanDenburg and others (1998) that movement had stopped by mid-Miocene (Barstovian) time 16.3–16.6 Ma.

Bloody Dick Creek normal fault—In the southwestern corner of the quadrangle, this fault forms the southwestern boundary of the thrust slice and separates *Xgbd* from *ЄZYqg.* It is clearly exposed on both sides of Big Hollow (sec. 31, T. 9 S., R. 14 W.) and can be followed along strike northwest into the west-adjacent Kitty Creek quadrangle and southeast across Bloody Dick Creek into the south-adjacent Everson Creek quadrangle. On the north side of Big Hollow and to the northwest, the fault is intruded by a diorite dike that weathers with characteristic limonite-stained aureoles.

Along strike on the northwest side of Big Hollow, the Bloody Dick Creek normal fault cuts off the Monument thrust fault (sec 30, T. 9 S., R. 14 W.) and then forms the contact between *Ysw* and *ЄZYqg*. The junction of the two faults is covered with talus and slope debris. Where it forms the contact between *Xgbd* and *Ysw,* the fault is clearly visible and there is but a slight dip in the topography where it crosses the ridges on either side of Big Hollow. Where it forms the contact between *Ysw* and *ЄZYqg,* the fault is concealed. There, late Cenozoic/Quaternary(?) movement is indicated by the dropping of *ЄZYqg* to the west, a change in altitude of several thousand feet, and truncated spurs with triangular facets of *Ysw* to the east. Fault movement indicates *ЄZYqg* is younger than *Ysw*. The abrupt change in surface expression of the Bloody Dick Creek normal fault is problematic. The change occurs at its intersection with the Monument fault and could be caused by interference of the two faults with each other, changes in lithologies, or perhaps scissor-type movement of the Bloody Dick Creek normal fault with more recent movement to the northwest.

Coppinger (1974) mapped the Bloody Dick Creek normal fault as a thrust fault and considered it to separate distinctly different terranes. Lewis and others (2009) on the west-adjacent Kitty Creek quadrangle mapped the continuation of the Bloody Dick Creek (their Dutch Creek) normal fault to the northwest as a normal fault consisting of several closely spaced strands with all movement within *Ysw*. Lonn and others (2011) and Lewis and others (2009) portray the contact between *Ysw* and *ЄZYqg* as a concealed thrust based on the southeastward continuation of the Beaverhead Divide–Bloody Dick fault zone from the northwest-adjacent Selway Mountain quadrangle. More recently, Lonn and others (2013) extend the Bloody Dick Creek normal fault northwestward as the eastern strand of the Beaverhead Divide fault.

Although we have mapped *ЄZYqg* on both sides of Bloody Dick Creek as one unit, *lithology 1* to the east and *lithology 2* to the west could be two different units in fault (either thrust or normal) contact. The existence of a thrust fault (see above) is postulated by Lonn and others (2013), who interpret the Bloody Dick Creek normal fault to be a part of a continuation of the Freeman–North Fork and Beaverhead Divide fault zones, a complex fault zone comprised of a large-displacement Cretaceous fault overprinted and reactivated by sub-parallel Tertiary normal faults. We agree that if there is a thrust fault in this location, it would have to predate the Bloody Dick Creek normal fault because the Bloody Dick Creek normal fault continues on strike to the southeast into the south-adjacent Everson Creek quadrangle.

The Beaverhead Divide–Bloody Dick fault zone has been interpreted by Ruppel and others (1993) as a major structure that separates the Missoula Group of the Belt Supergroup to the northeast from the Lemhi Group to the southwest. O'Neill and others (2007) interpret the Bloody Dick Creek normal fault to be part of a left-lateral strike-slip shear zone. With the possible exception of a thrust fault concealed beneath Bloody Dick Creek as the contact between the two lithologies of *ЄZYqg,* there is no evidence of thrust or strike-slip faulting in this portion of the Coyote Creek quadrangle. Although we disagree with some formation correlations and fault locations, we agree with Burmester and others (2011) that the Beaverhead Divide–Bloody Dick fault zone is not a terrane boundary separating the Belt Supergroup and the Lemhi Group. Link and others (2016) come to the same conclusion, comparing interfingering detrital zircon probability density spectra from east-central Idaho and southwestern Montana.

Coyote Creek Fault—The northwest-trending, down-to-the-northeast Coyote Creek fault extends diagonally, northwest to southeast across the quadrangle. It displaces the Proterozoic and Paleozoic(?) quartzites, the Houlihan Springs thrust fault, and the Tertiary basin fill, and offsets the northeast–southwest trending, basin-bounding Meriwether Lewis fault. Outcrops of *Tbp* on the northeast but not southwest side of the fault indicate that movement was down to the northeast. The offset of the Meriwether Lewis fault may indicate minor right-lateral transtensional movement. The fault location may coincide with the axis of a broad anticline.

The character of the Cenozoic basin fill differs on either side of the Coyote Creek fault. To the north, in addition to *Tbp*, there are large areas of colluvium *(QTgr);* Everson Creek beds *(Tec)* are absent. To the south within *Tec*, the basin fill contains very coarse conglomerates (*Teqc)* indicating little transport of material, and coarse conglomerates with rip-up clasts (*Tecc); Tbp* is absent as is *Qtgr*. Landslide/debris flow material (*Tls*) is mapped as continuous across the fault, indicating that movement occurred during and before the end of the Tertiary.

The Bloody Dick Creek normal fault is subparallel to the Coyote Creek fault and has an opposite sense of movement. The two faults create a northwest-trending horst composed of *White quartzite of the Swauger Formation* (*Ysw)* and *Gneiss of Bloody Dick Creek (Xgbd)*.

LANDSLIDES AND SLIDE BLOCKS

In the east-central part of the Coyote Creek quadrangle, landslides and numerous ash beds that are slick when wet allow speculation that the northern part of the quadrangle was the source area for the Red Butte and Round Butte allochthonous slide blocks identified by Janecke and others (2005). Red Butte and Round Hill are in the center of Horse Prairie basin and in the southwest corner of the east-adjacent Bachelor Mountain quadrangle.

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