FIELD GUIDE TO THE LEMHI ARCH AND MESOZOIC-EARLY CENOZOIC FAULTS AND FOLDS IN EAST-CENTRAL IDAHO: BEAVERHEAD MOUNTAINS

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INTRODUCTION

This field trip will focus on a portion of the Rodinian rift margin on the western edge of Laurentia where Neoproterozoic to Lower Ordovician syn- and early post-rift clastic sedimentary rocks are absent. This region of missing stratigraphy, called the Lemhi arch, is in east-central Idaho, is roughly northwest-trending, and contains a belt of Cryogenian and Late Cambrian alkalic plutons (e.g., Lund and others, 2010). This region of thin or absent Neoproterozoic and lower Paleozoic strata correlates spatially with the boundary between the northern Wyoming salient and southwest Montana reentrant of the Mesozoic to early Cenozoic Sevier–Laramide fold-thrust belt (Armstrong, 1975) and likely influenced the transition from thin- to thick-skinned thrusting.

This field trip will contain two themes: (1) the Lemhi arch and its stratigraphic and magmatic expression in east-central Idaho; and (2) the structural style of the Mesozoic to early Cenozoic Sevier–Laramide fold-thrust belt within the Lemhi arch. The trip will begin with a visit to Skull Canyon in the southern Beaverhead Mountains, where we will examine the basal angular unconformity of the Lemhi arch between tilted Proterozoic sandstones of the upper Belt Supergroup and overlying Ordovician sandstones. We will then stop in lower Skull Canyon to see prominent folds in middle and upper Paleozoic carbonates; this style of folding seen here is characteristic of the structurally shallow levels of deformation within the Sevier fold-thrust belt in the region. This will be followed by a visit to Hawley Creek, east of Leadore, where an alkalic late Cambrian pluton intruded just prior to or during active exhumation of the Lemhi arch. This pluton was thrusted upon middle Paleozoic carbonates in Late Cretaceous time along the Hawley Creek thrust. The style of "basement involved" thrusting here is in contrast to the thin-skinned, detachment folding and thrusting in middle Paleozoic carbonate rocks observed in lower Skull Canyon.

GEOLOGIC SETTING

Neoproterozoic to early Paleozoic Stratigraphic Framework

Neoproterozoic to early Paleozoic rifting of the Rodinian supercontinent was fundamental in shaping what is now the western margin of North America. In addition to establishing the first-order geography, the rift geometry imposed the syn- and post-rift stratigraphic framework of western North America, which had a major influence on the subsequent geological evolution of the North American Cordillera. For much of the western margin of North America, the record of Neoproterozoic and early Cambrian rifting and the transition to passive margin sedimentation are well established (Stewart, 1972; Christie-Blick, 1982; Link and others, 1993; Yonkee and others, 2014). Early regional-scale studies proposed that syn-rift fill and westward thickening passive margin sedimentary rocks continued northward from southeastern Idaho into southeastern British Columbia (e.g., Stewart, 1972). However, the intervening region between the eastern Snake River Plain and southeastern British Columbia along the Idaho–Montana border seemed to not fit into that framework. There, workers documented Middle Ordovician rocks that unconformably overlie Mesoproterozoic Belt Supergroup rocks, and a completely missing Neoproterozoic to Lower Ordovician stratigraphic record (Ross, 1934, 1947; Sloss, 1954; Scholten, 1957). Neoproterozoic and lower Cambrian rocks are largely missing in southwestern Montana too, where middle Cambrian rocks of the Flathead Formation overlie Archean basement or rocks of the Belt–Purcell Supergroup (Deiss, 1941; Sloss, 1950; Bush and others, 2012), with likely Neoproterozoic to early Cambrian erosion prior to middle Cambrian deposition (Norris and Price, 1966).

A recent regional compilation of the tectonostratigraphic framework of early Laurentian rifting focused in Utah, southeastern Idaho, and Nevada recognized the major northward change in the character of the rift margin sedimentation pattern by demonstrating a consistent 6- to 7-km-thick clastic section of Neoproterozoic and Cambrian rocks from SE Idaho south to central Utah (Yonkee and others, 2014). In addition, rocks in northern Utah and SE Idaho established a final transition to drift from 580 to 540 Ma (Yonkee and others, 2014). This is in stark contrast to the margin in east-central Idaho and southwestern Montana, where alkalic magmatism (Evans and Zartman, 1988; Lund and others, 2010; Todt and Link, 2013) and regional tectonism (Link and others, in review) persisted into late Cambrian and Early Ordovician time (500 to 485 Ma), nearly 50 m.y. later than the transition to drift and passive margin sedimentation documented to the south.

The absence of Neoproterozoic and Cambrian rocks in east-central Idaho and missing Neoproterozoic to lower Cambrian rocks in western Montana likely reflects the presence of a regional paleotopographic high at the rift margin. Because of several different names that have been used to describe this feature, for simplicity, we refer to the region of very thin or missing Neoproterozoic and Cambrian rocks in east-central Idaho (variably called the Lemhi arch, Salmon River arch, or Skull Canyon disturbance) as the Lemhi arch (see McCandless, 1982 for a discussion). For additional discussion of Montana, which we consider a separate feature, see Bush and others (2012). This trip will examine the basal unconformity of the Lemhi arch and the Late Cambrian Beaverhead pluton intruded just prior to or during its exhumation.

Mesozoic to Early Cenozoic Retroarc Shortening

Southeast of the Montana/Idaho border, thrust traces in the Sevier fold-thrust belt transition northward from north–south trending within the Wyoming salient to northwest–southeast trending, defining the southwestern Montana reentrant (fig. 1). Many workers have concluded that similar salients and reentrants in thrust belts are controlled by the pre-deformational geology (e.g., Crosby, 1969; Allmendinger and Gubbels, 1996). Hypotheses for the dominant controls for the abrupt transition from thin- to thick-skinned shortening in the Sevier fold-thrust belt vary widely, including impingement of the thrust system against early basement-involved structures to the east (e.g., Perry and others, 1988) or Proterozoic basement (Armstrong, 1975) and thickness variations in the pre-deformational stratal thicknesses (Crosby, 1969).

This field trip will visit two localities that support a correlation between thrust belt geometry and stratigraphic architecture. At shallow stratigraphic levels from central Idaho out to southwestern Montana, thin-skinned décollement horizons occur in thick Devonian and Lower Mississippian flysch (Skipp and Hait, 1977; Perry and others, 1989). However, thrusts at deeper structural levels in this part of the fold-thrust belt are rare and appear to have accommodated shortening in a markedly different structural style. In contrast to much of the Wyoming salient to the south, where décollements exploit weak shales of the Cambrian Gros Ventre Formation (Royse and oth-

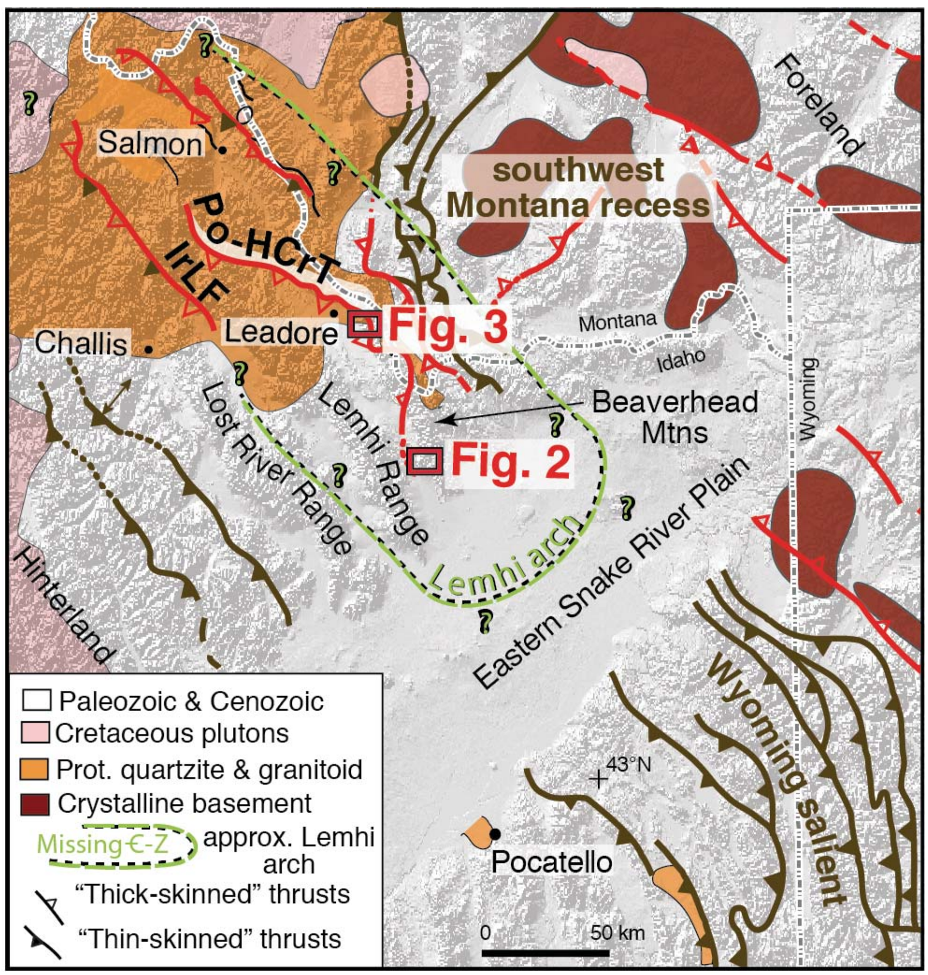

Figure 1. Index map of the geologic setting of the field trip localities (modified from Janecke and others, 2000). Po-HCrT: Poison-Hawley Creek thrust; IrLF: Iron Lake fault.

ers, 1975), in the absence of these rocks in east-central Idaho due to the Lemhi arch, thrusts display a structural style reminiscent of thick-skinned, basement-involved fold-thrust belt deformation. This structural style is characterized by inversion of older normal faults (Hansen and Pearson, 2016), large-wavelength folding (Lucchitta, 1966; Tysdal, 2002; Lonn and others, 2016), and involvement of crystalline basement rock and Proterozoic Belt Supergroup in thrust sheets (Skipp, 1988). This trip will examine the thin-skinned structural style exhibited by middle and upper Paleozoic carbonates as well as the more deeply rooted Hawley Creek thrust, which carries Late Cambrian hypabyssal plutons and may correlate along-strike to the northwest with the inverted Poison Creek thrust.

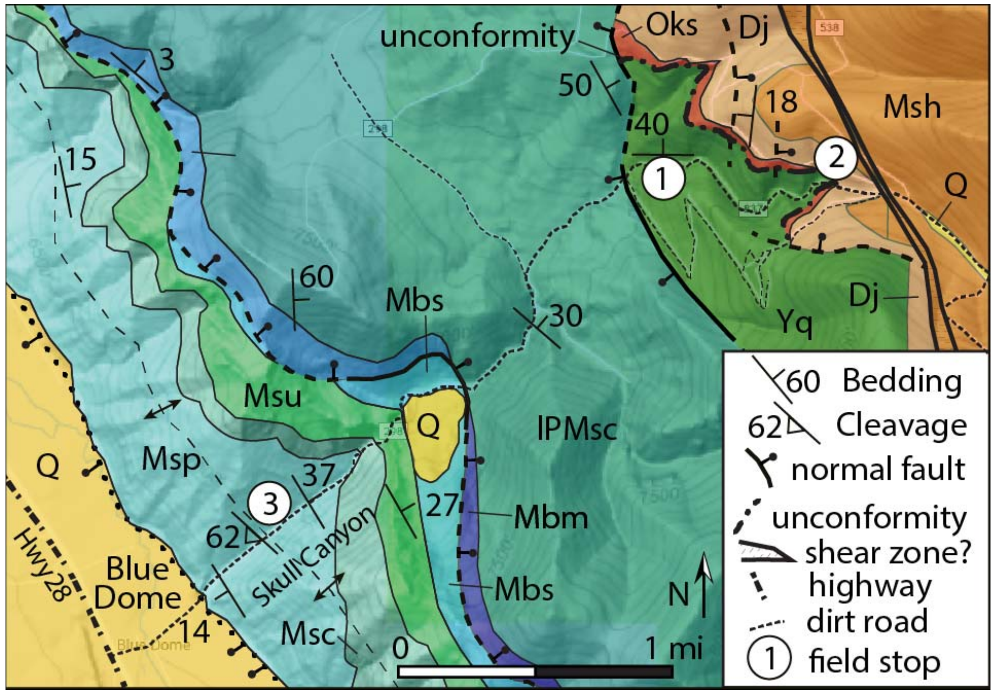

Figure 2. Simplified geologic map of the Skull Canyon area showing field trip Stops 1, 2, and 3 (modified from Scholten and Garmezy, 1980; Embree and others, 1983). Unit abbreviations: Yq-quartzite of likely Mesoproterozoic age; Oks-Ordovician sandstone of the Kinnikinic Formation and possible Summerhouse Formation; Dj-Devonian Jefferson Formation; Msh-undivided lower Scott Peak, Middle Canyon, and McGowan Creek formations; Msp-Mississippian Scott Peak Formation; Msc-Mississippian South Creek Formation; Msu-Mississippian Surrett Formation; Mbs-Mississippian Big Snowy Formation; Mbm-Mississippian Bluebird Mountain Formation; IPMsc-Pennsylvanian/Mississippian Snaky Canyon Formation; Q-undifferentiated Quaternary sediments.

ROAD LOG

The road log begins in Blue Dome, Idaho, which is located along Highway 28 approximately 45 mi southeast of Leadore and 32 mi northwest of Mud Lake. Reset your odometer at the intersection of Skull Canyon Road and Highway 28 (44.159779°N, 112.914156°W) and proceed northeast into Skull Canyon. Near the mouth of Skull Canyon, the road becomes USFS Road 298. Continue on the main road and stay right at the fork at 1.5 mi (44.179871°N, 112.883627°W), proceeding on USFS Road 837. Continue on this road until mile 2.2 at a sign for USFS Road 837 (44.185018°N, 112.876481°W), where a smaller jeep road branches to the right. Park on the northwestern side of the road intersection adjacent to the sign for USFS Road 837.

Skull Canyon Overview

Stops 1 and 2 involve a ~0.9 mi walk up USFS Road 837 to view likely Proterozoic sandstone (Belt Supergroup) and Ordovician sandstone that lies in angular unconformity above it. Rocks near this locality have been described by Scholten (1957), Beutner and Scholten (1967), McCandless (1982), and Skipp and Link (1992). Intrepid drivers with high-clearance vehicles who prefer not to walk can drive this portion of the trip. Stops 1 and 2 will be followed by a drive back down Skull Canyon toward Highway 28 to Stop 3. Stop 3 within lower Skull Canyon will focus on the style of deformation in structurally shallow, middle Paleozoic carbonates, which involves major detachment folding and fault-propagation folding. This is a regional décollement horizon that continues from central Idaho out to southwestern Montana (Skipp and Hait, 1977). In contrast to the thin-skinned style of deformation within the Paleozoic carbonates, structurally deeper rocks appear to have accommodated low-magnitude shortening in a basement-involved structural style. Preliminary geologic mapping of the area was conducted by Embree and others (1983) and Scholten and Garmezy (1980) (fig. 2).

STOP 1 (44.185995°N, 112.873151°W)

Stop 1 consists of a visit to the first prominent outcrops of Precambrian sandstone exposed in upper Skull Canyon (fig. 2). The outcrop we will visit is on the northwestern side of the drainage off USFS Road 837, ~0.2 mi from the parking locality described above. The descriptions provided here are partly from Skipp and Link (1992). Outcrop here consists of dominantly thin-bedded, red, fine- to medium-grained arkosic to subarkosic sandstone that dips northward at ~40°. Parallel laminae and small-scale cross-laminations of iron oxide are common and there are local intercalated grayish-green mudstone or siltstone beds. Bedding plane concentrations of mudstone rip-up clasts locally are common. Most workers consider these rocks to be equivalent to Mesoproterozoic Belt Supergroup (Beutner and Scholten, 1967; McCandless, 1982), possibly the Gunsight Formation (Skipp and Link, 1992).

In the middle fork of Skull Canyon in the next drainage to the north of Stop 1, Beutner and Scholten (1967) described ~9 m of thicker-bedded, red, texturally immature, very fine-grained to very coarse-grained and locally conglomeratic sandstone that may overlie Belt Supergroup-equivalent rocks. Though these rocks match the general description of Neoproterozoic to Cambrian rocks of the Wilbert Formation (Ruppel, 1975), their similarities with underlying sandstones and their stratigraphic position below a distinctive angular unconformity suggest that they are probably also correlative with the Belt Supergroup (McCandless, 1982). Detrital zircon age-populations from Wilbert Formation exposed at several localities in the southern Beaverhead Mountains have a strong 1,720 to 1,740 Ma age-peak (Link, unpublished) and are statistically indistinguishable (may be reworked) from upper Belt Supergroup quartzites exposed throughout much of east-central Idaho and southwest Montana (Link and others, 2016).

STOP 2 (44.184839°N, 112.862333°W)

Walk back to USFS Road 837 and proceed an additional ~0.7 mi up the road to Stop 2 (total ~0.9 mi from the parking area). Intermittent outcrops and float of the Proterozoic sandstone can be found in and adjacent to the road. At Stop 2, on the northern and southern sides of the road are excellent exposures of the angular unconformity between Mesoproterozoic rocks of the Belt Supergroup and overlying Ordovician sandstones. The best outcrops are in cliffy exposures on the northern side of the drainage 10–20 m from the road. Underlying sandstones dip 20–40° to the north and northeast and are overlain by medium-bedded, white, coarse and pebbly quartz sandstone that grades upward into vitreous white, well-sorted, medium-grained sandstone of the Middle Ordovician Kinnikinic Quartzite (Beutner and Scholten, 1967; McCandless, 1982). McCandless (1982) considers the basal, coarse sandstone to be correlative to the Ordovician Summerhouse Formation exposed beneath the Middle Ordovician Kinnikinic Formation in the southern Lemhi Range.

The complete absence of Neoproterozoic and Cambrian syn- and early post-rift clastic sedimentary rocks in east-central Idaho is in stark contrast to in southeast Idaho and northern Utah, south of the Snake River Plain (Sloss, 1954; Scholten, 1957; Ruppel, 1986; Link and others, in review). In the central Lemhi Range and southern Beaverhead Mountains, the unconformity consists of Mesoproterozoic Belt Supergroup-equivalent sandstone and quartzite, with a very thin (<300 m) overlying section of Middle Ordovician Kinnikinic Formation. In southwestern Montana, Ruppel (1998) mapped Ordovician Summerhouse Formation (and overlying Kinnikinic) unconformably above Archean and Paleoproterozoic gneisses of Maiden Peak (Anderson, 2017). Overall, the thin region of Neoproterozoic and early Paleozoic strata within the Lemhi arch is northwest-trending and separates a thicker section of equivalent rocks on the southwestern side of the Lemhi arch in central Idaho from a thicker section of lower Paleozoic rocks in southwestern Montana (Sloss, 1950, 1954). In east-central Idaho, the Lemhi arch may represent the exhumed footwall of a Rodinian rift fault (Hansen and Pearson, 2016), with Cambrian and Ordovician carbonate and siliciclastic rocks of the Bayhorse assemblage (Hobbs and Hays, 1990; Krohe, 2016) deposited in the hanging wall of the west-dipping normal fault.

In addition to the thin Neoproterozoic and Paleozoic strata, the Lemhi arch contains Neoproterozoic to early Paleozoic alkalic magmatic rocks (Lund, 2008; Lund and others, 2010). The alkalic belt of plutons defining this magmatism is called the Big Creek–Beaverhead belt. In the central and southern Beaverhead Mountains these consist of a northwest-trending, Late Cambrian to Early Ordovician alignment of hypabyssal plutons that parallels the Lemhi arch (Lund and others, 2010). The overlying Middle Ordovician Kinnikinic and correlative sandstones that overlie the unconformity within the Lemhi arch contain far-traveled detritus, likely from the Peace River arch of western Canada, as shown by detrital zircon data (all grains >1,800 Ma) from across Idaho and south to Nevada (Baar, 2009; Linde and others, 2014, 2016; Hansen, 2015; Krohe, 2016; Beranek and others, 2016).

The spatial coincidence of the Lemhi arch and the geometry of the Mesozoic and early Cenozoic Sevier–Laramide fold-thrust belt suggests that they are related. Armstrong (1975) hypothesized that the presence of crystalline basement (called the "Salmon River arch" by him) acted as a buttress and hindered propagation of the fold-thrust belt to the east–northeast. Alternatively, an absence of fine-grained, Neoproterozoic and Cambrian shales that were exploited as the basal décollement within much of the Wyoming salient (e.g., Royse and others, 1975), may have inhibited propagation of the fold-thrust belt within the region of the southwest Montana reentrant and promoted a thick-skinned style of deformation in east-central Idaho and southwestern Montana (Pearson and Becker, 2015).

After viewing the Skull Canyon unconformity, return to the cars. Quick hikers can continue hiking up Skull Canyon to a prominent shear zone within shales of the McGowan Creek Formation mapped by Embree and others (1983) (fig. 2), which may represent the tilted basal décollement of detachment folds that we will see at Stop 3. We will revisit the topics of alkalic Cambrian plutonism and the structural style of the Mesozoic and early Cenozoic fold-thrust belt in later stops.

STOP 3 (44.166538°N, 112.902861°W)

Stop 3 can be reached by driving 1.9 mi southwestward from the parking area at Stop 1 to where a small side road parallels USFS Road 298 on its northwestern side. This locality was passed on the way into upper Skull Canyon for Stops 1 and 2. From the parking area for Stop 3, walk northward to outcrops of thick-bedded Mississippian Scott Peak Formation. On the northern and southern walls of the canyon, one can view a large (~1 km wavelength), northeast-verging, concentric fold. In addition to the regional-scale fold visible in the bottom of Skull Canyon, smaller wavelength (10–100 m), parasitic folds occur on both fold limbs and verge toward the crest of the major fold (Scholten and Garmezy, 1980). At the outcrop scale, thick-bedded Scott Peak Formation exhibits steeply southwest-dipping, axial planar, pressure solution cleavage. The orientations of fold axes and pressure solution cleavage in the southern Beaverhead Mountains suggest a bulk southwest–northeast shortening direction.

Northwest–southeast-trending parallel or kink folds, and upright to moderately overturned folds that are akin to this fold, are common in middle and upper Paleozoic carbonates in the southern Beaverhead Mountains, and Lemhi and Lost River Ranges (Ross, 1947; Skipp and Hait, 1977; Skipp, 1988; Anastasio and others, 1997). In the central Lost River Range, folds in upper Paleozoic carbonate rocks are demonstrably decoupled from underlying stratigraphy along a bedding plane-parallel décollement in thin-bedded siltstones and argillites of the Lower Mississippian McGowan Creek Formation (Anastasio and others, 1997). This style of folding is called detachment folding (Jamison, 1987). Some tight folds in the Lost River Range and southern Beaverheads also have apparent fault-propagation folds in their hinge zones (Fisher and Anastasio, 1994). In the Lost River Range, detachment and fault-propagation folding accommodated ~22% shortening (Anastasio and others, 1997). Detachment and fault-propagation folding above Devonian and Mississippian décollements is present northeastward into southwestern Montana (Perry and others, 1988; Skipp, 1988; Tysdal, 1988). In contrast to substantial shortening accommodated by folding and bedding-parallel slip that is typical of a thin-skinned structural style, structurally deeper rocks (i.e., Proterozoic to Devonian strata) within these same ranges do not exhibit the same magnitude of folding and instead accommodated shortening along discrete thrusts associated with large-wavelength folding; the latter structural style is similar to basement-involved, thick-skinned thrusting and will be discussed during later stops.

Hawley Creek Overview

Following the visit to Skull Canyon (Stops 1, 2, and 3), the trip will then travel northwestward along Highway 28 to Hawley Creek, Idaho. There, we will view the Late Cambrian Beaverhead pluton of the Big Creek–Beaverhead belt of plutons intruded within the Lemhi arch. We will also view the basement-involved Hawley Creek thrust and folded carbonates in its footwall. These rocks were mapped: as part of a Ph.D. dissertation by Lucchitta (1966); with a focus on phosphate resources by Oberlindacher and Hovland (1979); and at 100,000-scale by Ruppel (1998) and Evans and Green (2003).

STOP 4 (44.660465°N, 113.204454°W)

From the intersection of Skull Canyon Road and Highway 28, it is 46.2 mi to Stop 4. Reset the trip odometer and proceed northwestward on Highway 28 for 36.4 mi and turn right on Eighteenmile Road (44.573207°N, 113.310398°W). At 38.4 mi, stay left on the main road, and at 39.8 mi, stay right on the main road and proceed through Oxbow Ranch. At 40.4 mi at the “T,” turn left. At 42.4 mi, stay right at the “Y,” and continue straight to Hawley Creek. The road eventually becomes USFS road 275. Stop 3 is 10–20 m up canyon of the Hawley Creek bridge. Park along the pull-out to the right (44.660465°N, 113.204454°W). The most accessible place to view the Beaverhead pluton and the Hawley Creek thrust is on the northwestern side of the road, north of the Hawley Creek bridge, adjacent to a small, mineral exploration pit.

The Beaverhead pluton crops out on the southwestern portion of the prominent ridge on the north side of Hawley Creek (fig. 3). It consists of pink, medium- to coarse-grained, equigranular to subporphyritic biotite alkali-feldspar granite, with lesser alkali-feldspar syenite to alkali-feldspar quartz syenite (Scholten and Ramspott, 1968; Evans and Zartman, 1988; Lund and others, 2010). The granitoid commonly contains miarolitic cavities, which are suggestive of a shallow level of emplacement. Near Eighteenmile Creek, enclaves of quartzite in the Beaverhead pluton were interpreted as Kinnikinic Quartzite, and thus the Beaverhead pluton was considered to be post-Middle Ordovician in age (Scholten and Ramspott, 1968; Skipp, 1984). However, a discordant U-Pb age of ~483 Ma was obtained using isotope-dilution thermal ionization mass spectrometry and questioned the relative timing of the Kinnikinic Quartzite and Beaverhead pluton (Evans and Zartman, 1988). More recent U-Pb zircon geochronometry applied to the Beaverhead pluton conducted by sensitive high-resolution ion microprobe yielded one age of 488 ± 5 Ma (Lund and others, 2010); laser ablation–multicollector–inductively coupled plasma–mass spectrometry ages for two samples from the Beaverhead pluton are 496 ± 2 Ma and 500 ± 3 Ma (Todt and Link, 2013). In addition, initial εHf of zircons from the Beaverhead pluton range from -6.3 ± 1.1 to 2.7 ± 1.4 (Todt and Link, 2013). Reexamination of the contact between the Beaverhead Pluton and the Kinnikinic Quartzite near Eighteenmile Creek demonstrates that the contact is planar with no contact metamorphism, which is consistent with the Middle Ordovician Kinnikinic Quartzite nonconformably overlying the Late Cambrian Beaverhead pluton (Link and others, in review).

Together with the Cryogenian Big Creek belt of plutons, alkalic plutons of the Beaverhead belt define two temporally distinct northwest-trending pulses of magmatism within and adjacent to the Lemhi arch at ca. 665–650 Ma and 500–485 Ma (Lund and others, 2010). These plutons are thought to be extension-

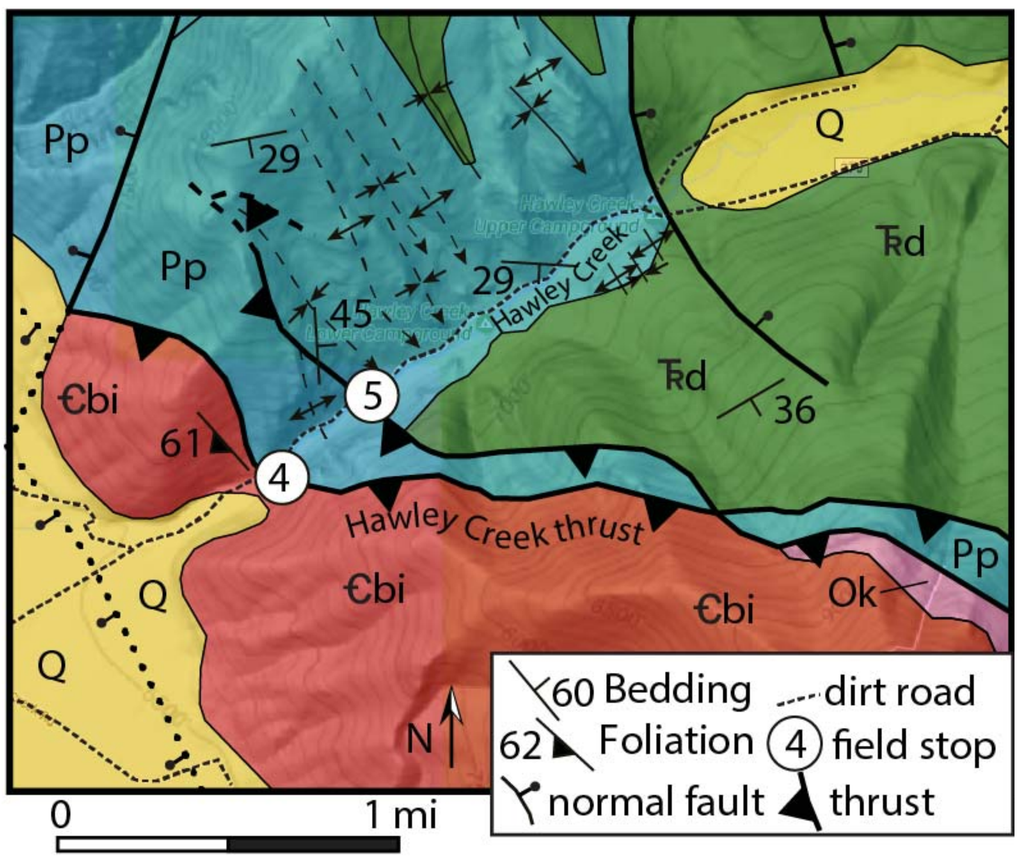

Figure 3. Simplified geologic map of the Hawley Creek area showing field trip localities Stops 4 and 5 (modified from Lucchitta, 1966; Hovland and Oberlindacher, 1979; Ruppel, 1998; and Evans and Green, 2003). Unit abbreviations: Ꞓbi-Cambrian Beaverhead pluton; Ok-Ordovician Kinnikinic Formation; Pp-Permian Phosphoria Formation; Ŧd-Triassic Dinwoody Formation; Q-undifferentiated Quaternary sediments.

related; together with the thinned Neoproterozoic and early Paleozoic stratigraphy within this portion of the Laurentian rift margin, the results have been used to advocate for a detachment fault model in which along-strike changes in the character of the rift were proposed to result from a changing dip direction of a major, lithospheric detachment fault (Lister and others, 1986) across a transfer structure in the modern location of the eastern Snake River Plain (Lund, 2008; Lund and others, 2010). Considered in this context, the Lemhi arch and Big Creek–Beaverhead plutonic belt would have intruded into a largely intact hanging wall of a major detachment fault that accommodated rifting of the western Laurentian rift margin (Lund and others, 2010).

Though no volcanic equivalents of the Beaverhead plutons have been recognized, during Late Cambrian time, up to 300 m of feldspathic sandstone was deposited into a thick section of carbonate rocks in southeastern Idaho (Todt and Link, 2013; Link and others, in review). Utilizing U-Pb and Lu-Hf isotopic fingerprinting of zircons from these sandstones as well as those of the Beaverhead belt of plutons, Todt and Link (2013) showed that following shallow emplacement within and adjacent to the Lemhi arch, Late Cambrian plutons were rapidly exhumed along with their Belt Supergroup-equivalent country rocks and were the source of the anomalous feldspathic sand.

Hansen and Pearson (2016) mapped a likely Neoproterozoic or early Paleozoic normal fault that was inverted during Mesozoic shortening. This fault may locally bound the southwestern margin of the Lemhi arch and thus may have accommodated a portion of its exhumation (Hansen, 2016). Ongoing magmatism, faulting, and uplift and exhumation within the Lemhi arch attests to active tectonism in Late Cambrian time, ~40 m.y. after the transition to drift and slow, thermally driven subsidence in southeastern Idaho and northern Utah (Yonkee and others, 2014).

In its current configuration, the Beaverhead pluton exposed at Hawley Creek is in the hanging wall of a major Mesozoic thrust fault, the Hawley Creek thrust (Lucchitta, 1966; Skipp, 1988). Here, the thrust fault displaced the late Cambrian pluton against folded Permian and Triassic rocks of the Phosphoria and Dinwoody formations and thus has at least 3 km of stratigraphic separation (Lucchitta, 1966; Oberlindacher and Hovland, 1979). The thrust contact between the Beaverhead pluton and structurally lower Phosphoria Formation in its footwall is not directly exposed here, but a three-point problem yields a fault dip of ~40° to the southwest. Rare quartz stretching lineations in the pluton suggest transitional brittle-ductile deformation. Occasional slivers or phacoids of quartzite are also exposed within the fault zone. At Stop 4, a dioritic dike that crops out adjacent to the small mineral exploration pit apparently intruded the Hawley Creek fault zone here; it is presumably Eocene, associated with the Challis magmatic pulse. The Hawley Creek thrust exhibits some characteristics of a thick-skinned structural style. In addition to its involvement of crystalline basement of the Beaverhead pluton, the fault appears to have developed concurrently with several-kilometer-scale, northeast-vergent fault propagation folds, preserving its final configuration with an overturned hanging wall anticlinorium and footwall synclinorium (Lucchitta, 1966). This structural style differs markedly from the detachment folding at shallow structural levels that was seen at Stop 3.

The Hawley Creek thrust has been considered by some to be the along-strike equivalent of the Poison Creek thrust exposed in the northern Lemhi Range south of Salmon (Skipp, 1987, 1988; Janecke and others, 2000). There, despite the clear observation that the fault is a thrust by the juxtaposition of Mesoproterozoic Belt quartzites upon Ordovician Kinnikinic Quartzite (Tysdal, 2002), younger Mesoproterozoic Belt Supergroup occurs in the hanging wall relative to older Belt Supergroup rocks in the footwall; this is suggestive of a normal fault relationship prior to thrusting and suggests that the fault is a reactivated normal fault formed during Rodinian rifting (Hansen and Pearson, 2016). Two samples collected from the hanging wall of the Poison Creek thrust yielded zircon (U-Th)/He cooling ages (closure temperature ~180°C) of 68–57 Ma, which is interpreted as the timing of exhumation during thrusting along the fault (Hansen and Pearson, 2016). The structural style exhibited by the Poison Creek thrust southeast of Poison Peak includes truncation of an anticline-syncline pair of large-wavelength (>10 km), northeast-vergent, overturned folds (Tysdal, 2002) that are reminiscent of fault-propagation folds, and thick-skinned reactivation of an earlier normal fault (Hansen and Pearson, 2016). Thus, the structural style at deeper structural levels within the Lemhi arch is more characteristic of a thick-skinned deformation style rather than shallower Devonian and Lower Mississippian detachment folding, which is similar to the thin-skinned structural style exhibited by much of the Sevier fold-thrust belt. The spatial coincidence of the thick-skinned structural style and the Lemhi arch suggests that the arch may have controlled the northern end of the Wyoming salient and southwest Montana reentrant.

STOP 5 (44.662357°N, 113.201839°W)

If there is remaining time, we will walk northeastward up Hawley Creek road to view a southeast-plunging, northeast-verging fold train and several small, west-dipping imbricate thrusts within footwall rocks of the Phosphoria and Dinwoody formations (Lucchitta, 1966; Oberlindacher and Hovland, 1979). These folds likely developed synchronously with faulting along the structurally overlying Hawley Creek thrust (Lucchitta, 1966).

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