FIELD GUIDE TO MESOPROTEROZOIC TO ORDOVICIAN ROCKS EXPOSED EAST OF CHALLIS NEAR LEATON GULCH, IDAHO

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INTRODUCTION AND REGIONAL GEOLOGIC BACKGROUND

Recent work in central and east-central Idaho has resulted in substantial revision of the Mesoproterozoic (e.g., Burmester and others., 2016; Lonn and others, 2020) and Neoproterozoic–Lower Cambrian (Brennan and others, 2020) stratigraphic framework of the region. Primarily exposed as discrete map domains in the Lemhi Range, Beaverhead Mountains, and Salmon River Mountains, the relative stratigraphic positions of different exposed panels of a >18-km-thick succession of Mesoproterozoic Belt Supergroup-equivalent rocks has been a subject of debate (e.g., Burmester and others, 2016). One main point of contention in east-central Idaho is the stratigraphic position of the Apple Creek Formation and adjacent units. Prior workers preferred that these relatively fine-grained rocks were correlative with the Piegan Group of western Montana and northern Idaho (Winston and Link, 1993; Winston and others, 1999; Link and others, 2007) and stratigraphically below the Gunsight Formation, which is overlain by the distinctive medium-grained Swauger Formation and overlying Lawson Creek Formation (Ruppel, 1975).

In contrast, recent workers have proposed that much of the Lemhi Group was incorrectly correlated with the Apple Creek Formation by Ruppel (1975), therefore leaving two relatively fine-grained intervals below and above the Swauger Formation; further, these recent workers prefer that the entire sequence of east-central Idaho Belt rocks—rather than just the upper part—correlates with the Missoula Group (Burmester and others, 2016; Lonn and others, 2020; table 1). Recent correlations (Burmester and others, 2016; Lonn and others, 2020) suggest that the uppermost part of this succession consists of the Apple Creek Formation. Relatively young U-Pb detrital zircon maximum depositional ages (ca. 1390–1410 Ma; Link and others, 2016) obtained from strata included in the diamictite member of the Apple Creek Formation by Burmester and others (2016) tentatively support that these rocks constitute the upper part of the succession.

Eastward from Leaton Gulch to the Montana border, strata of the Belt Supergroup are unconformably overlain by Middle Ordovician strata, marking the “Lemhi arch” unconformity (Umpleby, 1917; Ross, 1934; Scholten, 1957; Ruppel, 1986; Poole and others, 1992); early workers extrapolated this stratigraphic relationship into the lesser-studied region of central Idaho toward the southwest and west.

However, recent work has demonstrated that Neoproterozoic and Cambrian rocks are present west and southwest of the Lemhi arch (Lund, 2004; Lund and others, 2003, 2010; Stewart and others, 2016; Milton, 2020; Brennan and others, 2020, in review). The Middle Ordovician on Belt Supergroup Lemhi arch unconformity is documented in the northern Lemhi Range. About 50 km to the west, near Bayhorse, Idaho (fig. 1), the Neoproterozoic and Cambrian section exceeds 3 km in thickness (Brennan and others, 2020; in review). The southern margin of the Lemhi arch is defined in the southern Lemhi Range and east-central Lost River Range, where the sub-Middle Ordovician, Cambrian, and Neoproterozoic section thickens toward the south and southwest into eastern and southern Idaho (Skipp and Link, 1993; Yonkee and others, 2014).

The northwestern margin of the Lemhi arch must occur in the northern Lost River Range and Pahsimeroi Mountains. Within this region, in the southern part of the Challis 1:62,500-scale quadrangle, McIntyre and Hobbs (1987), Hobbs and Hays (1990), and Hobbs and Cookro (1995) described an informal sequence of predominantly quartzose strata with lesser siltstone and dolostone; upper rocks are bioturbated. However, regional correlations were hindered by structural complexities, and thus the rocks were assigned a “Proterozoic(?) to Ordovician(?)” age based upon the presence of dolostone and trace fossils in the

Table 1. Belt–Purcell Supergroup correlations (modified from Lonn and others, 2020).

Western Montana-Northern Idaho (Winston & Link, 1993)		East Central Idaho (Burmester and others, 2015, 2016 Lonn, 2017)		East Central Idaho (Winston and others, 1999)		Eastern Washington (mod. from Winston and others, 1999 and Farooqui, 1998)
Missoula Group	Pilcher Fm		Apple Creek Fm			Deer Trail Group
	Garnet Range Fm; Libby Fm					
	McNamara Fm		Lawson Creek Fm		Lawson Creek Fm	?
	Bonner Fm		Swauger Fm; Hoodoo Fm		Swauger Fm	
	Mt Shields Fm	Lemhi Group	Gunsight Fm; Yellow-jacket Fm	Lemhi Group	Gunsight Fm	Stensgar Dolomite
	Shepard Fm; Upper Wallace Fm		Yellow Lake Fm; West Fk; Inyo Cr			McHale Slate
	Snowslip Fm		Big Creek Fm			Edna Dolomite
Piegan Group	Wallace Fm				Yellow Lake Fm; Apple Creek Fm	Togo Fm
	Helena Fm					
Ravalli Gp	St Regis Fm; Empire Fm				Big Creek Fm; Hoodoo Fm	
	Revett Fm					
	Burke Fm				West Fk Fm; Yellow-jacket Fm	
Lower Belt	Prichard Transition				Inyo Cr Fm	
	Prichard Fm					
pre-Belt	Gold Cup quartzite; Marble Creek quartzite					

upper part of the sequence as well as broad similarities with the Wilbert and Summerhouse Formations of Ruppel (1975) and McCandless (1982).

This field trip will focus on exposures of enigmatic quartzose strata in the northern Lost River Range/Pahsimeroi Mountains east of Challis, Idaho between Leaton Gulch and Pennal Gulch (figs. 1, 2). Because of the presence of bioturbation in the upper part of the succession, prior workers were confident that the strata span into Late Cambrian and/or Early Ordovician time; however, the age and/or potential regional correlations of underlying strata are far less certain.

The entire sequence of quartzose strata in the region (included bioturbated rocks) was originally mapped as "interbedded quartzite, dolomite, and argillite of Leaton Gulch and Pennal Gulch areas" and assigned an Ordovician(?) to Proterozoic(?) age (McIntyre and Hobbs, 1987; Hobbs and Hays, 1990; Hobbs and Cookro, 1995). Subsequent work in the eastern half of the map area shown in figure 2 subdivided the Leaton Gulch strata into informal lower (OZll) and upper (OZlu) parts (Carr and Link, 1999). Further work in the eastern half shown in figure 2 assigned the lower rocks to the Mesoproterozoic Belt Supergroup-equivalent Swauger and Lawson Creek Formations and inferred that the Swauger Formation was thrust upon the Lawson Creek Formation; unconformably overlying rocks were assigned a Neoproterozoic to early Cambrian age and correlated with the Wilbert Formation (Hargraves and others, 2007). In several localities near Leaton Gulch, quartzose strata are intensely brecciated; both Carr and Link (1999) and Hargraves and others (2007) interpreted that this brecciation may have been a direct or indirect result of a Neoproterozoic Beaverhead meteorite impact (Kellogg and others, 2003).

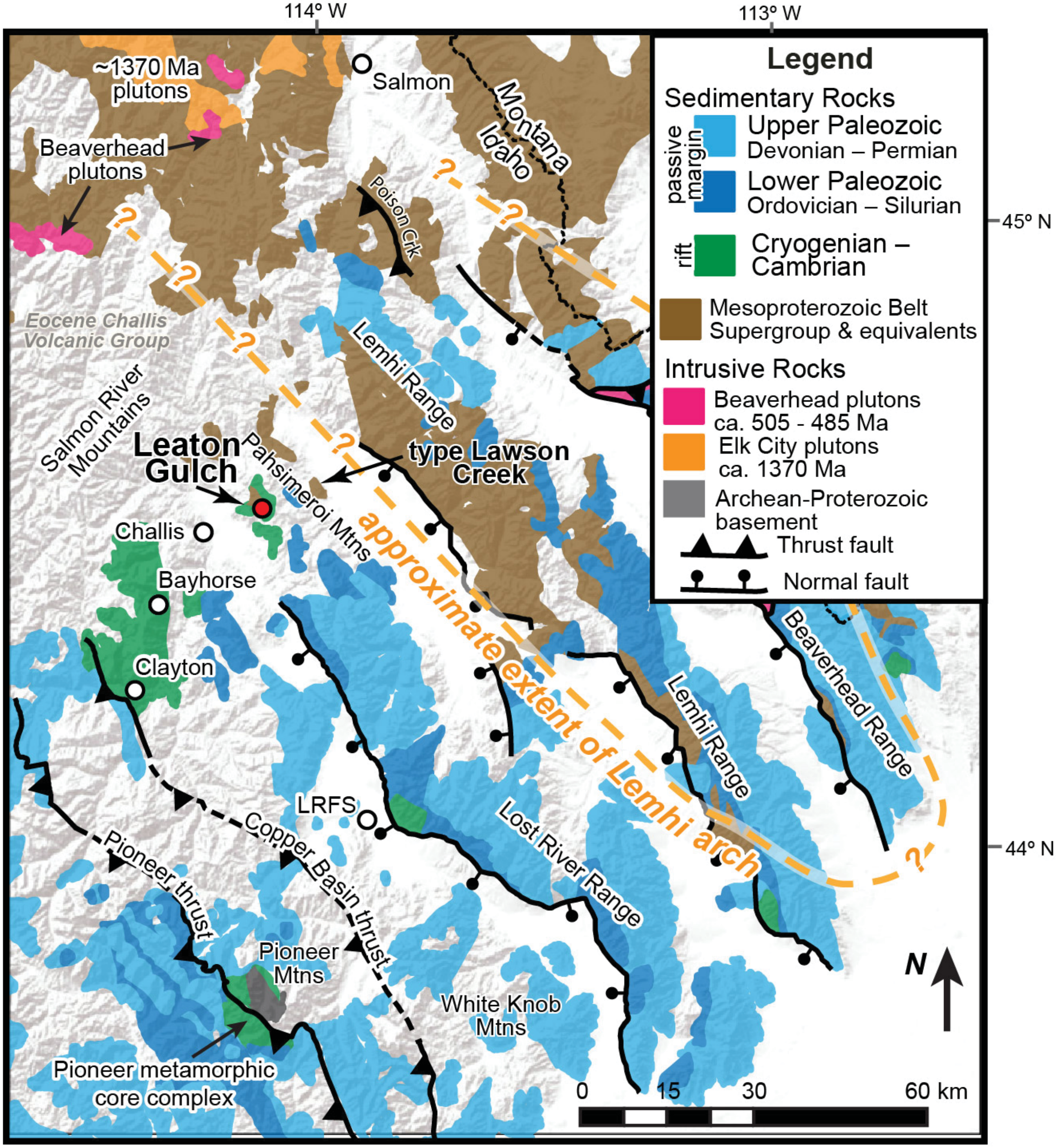

Figure 1. Index map showing Leaton Gulch area in the context of the regional geology of eastern Idaho (modified from Brennan and others, in review).

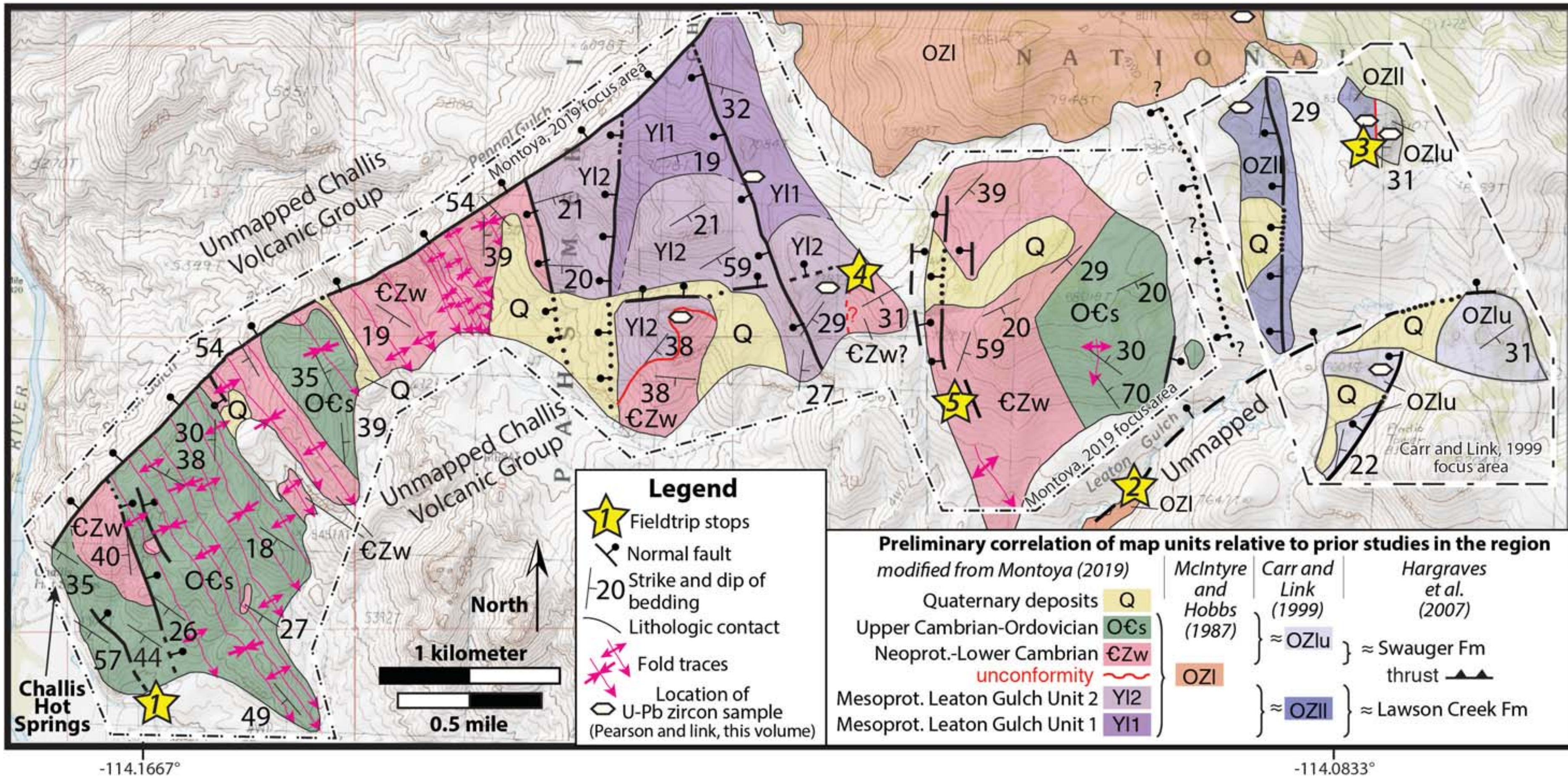

Figure 2. Geologic map of the field trip region showing stops (modified from Montoya, 2019).

Montoya's (2019) M.S. thesis project at Idaho State University focused on creation of a regional balanced cross section from the northern Lemhi Range to the west of Bayhorse, Idaho. She conducted 1:24,000-scale structural mapping of rocks beneath the Challis Volcanic Group exposed in the area between Leaton and Pennal gulches in the northern Lost River Range and Pahsimeroi Mountains east of Challis (fig. 2); her map area included difficult-to-access areas west of prior work by Carr and Link (1999) and Hargraves and others (2007). Her primary goals were to define the structural style of Mesozoic shortening, identify any major contractional faults (e.g., Hargraves and others, 2007), and better constrain the ages of rocks along this part of her transect. In addition to her mapping (fig. 2), Montoya (2019) created a schematic stratigraphic column of Leaton Gulch rocks (also see Pearson and Link, this volume).

Montoya (2019) proposed that the younger part of the succession [upper part of the formation of Leaton Gulch of Carr and Link (1999) and including the Wilbert Formation and parts mapped as the Swauger and Lawson Creek Formations by Hargraves and others (2007)] is exposed over a wider region than prior workers; she favored a correlation of these rocks with Neoproterozoic to Ordovician rocks described by McCandless (1982) and Brennan and others (2020). This proposed correlation of the younger strata is similar to Carr and Link (1999) and Hargraves and others (2007). For deeper strata [lower part of the formation of Leaton Gulch of Carr and Link (1999) and parts mapped as the Swauger and Lawson Creek Formations by Hargraves and others (2007)], Montoya (2019) designated the informal Leaton Gulch 1 (deepest exposed unit) and Leaton Gulch 2 (gradationally overlies Leaton Gulch 1) units. She preferred a Neoproterozoic—rather than Mesoproterozoic—age for these rocks and suggested that the lower part of the formation of Leaton Gulch may be missing from the Bayhorse area across an unconformity documented by Brennan and others (2020). She also investigated the hypothesized thrust fault of Hargraves and others (2007) but found no substantive evidence of thrusting and thus favored a stratigraphic contact to separate Hargraves and others' (2007) hypothesized "Swauger" and "Lawson Creek" Formations.

Link and colleagues have been assembling detrital zircon results from quartzites at Leaton Gulch for two decades (Link and others, 2017; Pearson and Link, this volume). The new results presented here—including ca. 1336 Ma U-Pb zircon dates from a green porcellanite interbedded within the lower part of the formation of Leaton Gulch that we interpret as a reworked tuff—indicate that some of the rocks here are >30 m.y. younger than the youngest established age (ca. 1370 Ma) of Belt Supergroup strata in Idaho and western Montana. Therefore, these rocks contain a record of post-1370 Ma sedimentation in the northern Rockies. They are well exposed, preserve many fantastic sedimentary and deformational structures, and represent an important locality for establishing the regional stratigraphy on the western side of the Lemhi arch.

This field trip will examine several significant features in the region between Leaton Gulch and Pennal Gulch, including five stops: (1) a lithologically heterogeneous succession of rocks in the upper part of the formation of Leaton Gulch with abundant evidence of bioturbation; (2) widespread brecciation within quartzites of the lower part of the succession along Leaton Gulch itself; (3) an important 10–15° angular unconformity separating the lower from the upper parts of the formation of Leaton Gulch, (4) quartzose strata with an interbedded ca. 1336 Ma porcellanite that are overlain by strata with many interesting sedimentary structures; and (5) an optional stop to see a quartzite cobble conglomerate with a strikingly dark matrix.

ROAD LOG

This field guide includes driving on some very rough roads (particularly to get to Stops 4 and 5). This requires a skilled driver, a high clearance vehicle, and rugged tires. The trip also involves short (<0.5 mile one-way walks), off-trail hiking on uneven ground. The Road Log begins southeast of Challis, Idaho at the intersection of Highway 93 and Hot Springs Road (44.4662°N, 114.1835°W). Reset your odometer and proceed northeast on Hot Springs Road for 2.7 miles. Turn left onto Challis Hot Springs Road and proceed 1.9 miles to the private entrance to Challis Hot Springs (challishotsprings.com). Park on the pulloff on the right (east) side of the road. The pullout is on Bureau of Land Management land, but the first stop involves a brief walk on Challis Hot Springs private property. Please obtain permission if you wish to visit Stop 1 via the route of this field guide. Alternatively, to remain on public land, walk due north from the pullout to the first prominent ridge.

STOP 1
(44.5213°N, 114.1682°W)

Stop 1 consists of the upper part of the succession near Leaton Gulch that we correlate with the Neoproterozoic and Lower Cambrian Wilbert Formation and overlying Upper Cambrian to Lower Ordovician Summerhouse Formation (fig. 2; Hargraves and others, 2007; Montoya, 2019). The best view of this stack of rocks begins at the southern nose of the ridge (on private property; obtain permission first!), followed by an ~0.25-mile hike up toward the top of the ridge and along the top toward the northeast. The stop coordinates are at the crest of the ridge near a prominent sandstone outcrop. Hargraves and others (2007) described these upper rocks as follows: "a heterogeneous sequence of thin beds of yellowish brown, light gray, and pale or grayish pink, fine- to medium-grained quartzitic sandstone and interbedded olive gray, platy argillite and shale, grayish red thinly laminated sandstone, and grayish brown, partly laminated, partly algal dolomite and dolomitic sandstone." The walk (fig. 2) begins in red blocky cliffs of recrystallized dolostone and proceeds downsection through several intervals of bioturbated sandstone. Along the walk, the moderately southwest-dipping section is folded into several northeast-plunging folds and cut by several minor normal faults. Exposed fine-grained intervals also display a steeply southwest-dipping pressure solution cleavage that we interpret as Cretaceous in age.

The presence of Skolithos and Planolites trace fossils confirm a Cambrian or younger age for these rocks; interbedded carbonate is consistent with a correlation with the Ella/Summerhouse Formation exposed in the Clayton/Bayhorse area to the west (Krohe and others, 2020; Brennan and others, 2020) and in the central Lost River and Lemhi ranges to the south (McCandless, 1982; Milton, 2020).

Detrital zircon results from sandstone beds in a similar stratigraphic position elsewhere near Leaton Gulch (see Pearson and Link, this volume) yield a distinctive ca. 500 Ma age-peak that indicates the sands were derived from rapidly exhumed Late Cambrian Beaverhead plutons and their Belt Supergroup host rocks within the Lemhi arch (Link and others, 2017; Milton, 2020). Carbonate-bearing strata are only locally present in the Leaton Gulch region.

Continued walking ~0.1 miles to the northeast along the ridge leads to float and some outcrops of spectacular Planolites trace fossils southwest of a significant east–northeast-dipping normal fault with a thicker succession of orange, laminated carbonate and siltstone in its eastern hanging wall (fig. 2). Intrepid hikers can walk to the drainage to the north to find the contact (contact exposed here: 44.5258°N, 114.1675°W) between overlying, carbonate-bearing and bioturbated rocks interpreted as the Ella/Summerhouse Formation and underlying, pink, medium- to thick-bedded and cross-bedded sandstones that we interpret as Wilbert Formation. This contact is faulted at this locality, but our interpretation is that it is fundamentally an unconformity. We will not visit this contact on this field trip due to the rough topography and time constraints. Walk back to the cars.

STOP 2
(44.5278°N, 114.0993°W)

From the parking area at Stop 1, turn around to head south–southeast on Challis Hot Springs Road for 1.9 miles. Turn left onto Hot Springs Road. After 0.5 miles, follow the road along a sharp left curve onto Upper Hot Springs Road; after another 0.2 miles, turn right onto Forest Road 111/Leaton Gulch Road and proceed through the open gate. Follow the main dirt road for 4.1 miles, pass several turnoffs, and follow a left and right switchback in the main road to Stop 2. This stop is described by Willsey (2017). There is not much space on the road for passing cars, so use your discretion to park in a location off the main part of the road.

The relevant outcrops here are highly brecciated quartzite (primarily float) blocks interpreted as the lower part of the formation of Leaton Gulch (Carr and Link, 1999). Quartzitic breccias are common near Leaton Gulch and are enigmatic. We interpret these breccias at this locality as fault-related. Elsewhere near Leaton Gulch, other breccias were interpreted by Carr and Link (1999) and Hargraves and others (2007) to have been eroded from the rim of a ca. 850–900 Ma meteorite impact crater. We will see one of these sedimentary breccias at Stop 3. There are several different types of quartzite breccia in the Leaton Gulch area, which guarantees lively discussion. Walk back to the cars and proceed to Stop 3.

STOP 3
(44.5448°N, 114.0801°W)

From Stop 2, continue driving northeast on Leaton Gulch Road for 1.8 miles. Then follow the road to the left that heads toward the top of the ridge. After 0.5 miles (approximately here: 44.5440°N, 114.0809°W; before the top of the ridge), turn right onto a dirt road that ends quickly in a group of open trees. Park here and walk ~250 feet to the south to the base of a small, west-facing cliff. Keep your eyes out for a lower sedimentary breccia peppered with paleomagnetic drillholes and containing quartzite clasts. This is Stop 3.

Here, you will see a sedimentary breccia/conglomerate with cobble to boulder quartzite clasts on a scoured surface; above the conglomerate, laminated sandstones appear to drape the underlying irregular surface. Carr and Link (1999) interpreted the contact between the conglomerate/breccia and overlying sandstone at this locality as an unconformity between the upper and lower parts of the formation of Leaton Gulch. Carr and Link (1999) and Hargraves and others' (2007) preferred interpretation for the origin of this breccia is that it was eroded from the rim of the 850–900 Ma Beaverhead meteorite impact crater. Carr and Link (1999) described a thin section in which planar deformation features cut across quartz detrital grain boundaries. These deformation features were interpreted to have formed during a Neoproterozoic meteorite impact, dated by Kellogg and others (2003) by the Idaho–Montana border at >900 Ma.

A similar unconformity, with underlying sandstones and overlying conglomerate and sandstone, was documented within Montoya's (2019) map area, directly west of this field guide's Stop 4 (fig. 2). At that locality, there is an ~15–20° angular discordance between overlying sandstones and conglomerates and underlying quartzites (see fig. 3 of Pearson and Link, this volume). U-Pb detrital zircon samples were collected across the unconformity and preliminary results are reported in Pearson and Link (this volume; see their fig. 2). In short, underlying rocks of Carr and Link's (1999) lower part of the formation of Leaton Gulch near the Stop 3 locality contain DZ age peaks at ~1720 and 1440 Ma and are very similar to Belt Supergroup quartzites elsewhere in east-central Idaho (cf. Link and others, 2016). Though the unconformity was not directly observed at this field guide's Stop 4, Montoya (2019) hypothesized that it should occur there because the units above and below the unconformity at the well-exposed locality are similar (fig. 2).

In rocks that are interpreted to occur below the unconformity at Stop 4, Pearson and Link (this volume) obtained U-Pb zircon results from an interbedded green porcellanite sample, and the layer is ca. 1336 Ma. This suggests that at least locally, strata directly beneath the unconformity are younger than the >1370 Ma Belt Supergroup.

In contrast to samples below the unconformity, two samples collected from sandstones directly above the unconformity—including one locality within Montoya's (2019) map area as well as directly to the north of this Stop 3 locality—have the two (~1720 and 1440 Ma) Belt DZ peaks, but also contain a small but statistically significant population of ca. 670 Ma DZs. This ca. 670 Ma age-peak is common in Neoproterozoic—but not Cambrian—sandstones elsewhere in central and southeastern Idaho and northern Utah and may represent a roughly syndepositional volcanic source (e.g., Yonkee and others, 2014; Brennan and others, 2020; Milton, 2020). Thus, the lithological similarity of these supra-unconformity sandstones with those of the Neoproterozoic to Cambrian Wilbert Formation (e.g., Ruppel and others, 1975; McCandless, 1982) and correlative Clayton Mine Quartzite (Brennan and others, 2020) leads us to a tentative correlation with those rocks.

One significant difference between the DZ age-peaks obtained for the Wilbert Formation sandstones at Leaton Gulch compared to other Neoproterozoic sandstones along the rift margin of Idaho and northern Utah is that the additional age-peaks in the Leaton Gulch rocks are not predominantly ca. 1000–1300 Ma in age, but are instead dominated by the ca. 1720 and 1440 Ma Belt Supergroup age-peaks. This suggests that in Neoproterozoic time, sediments at this locality may have been recycled from proximal, actively eroding Belt

Supergroup quartzites rather than Grenville-aged sources in eastern Laurentia (cf. Brennan and others, 2020).

At Stop 3, strata that overlie the basal conglomerate and sandstones at the bottom of the upper part of the formation at Leaton Gulch are poorly exposed but consist of fine- to medium-grained sandstone and siltstone, which is similar to overlying rocks above the unconformity within Montoya's (2019) map area. Return to the cars and proceed to Stop 4.

STOP 4
(44.5381°, 114.1138°)

The drive from Stop 3 to Stop 4 (and beyond) is very rough, but worth it. To get from Stop 3 to Stop 4, return from the small parking area from Stop 3 to the main road and proceed back down the road you came on. Turn left at the main road, proceed 0.5 miles south, and turn right (southwest) on the main Leaton Gulch road. Continue for 3.2 miles on the main Leaton Gulch road, passing Stop 2 and finally reaching an opening with a small road turnoff on the right (here: 44.5200°N, 114.1149°). Turn right on this small road. This small road is steep, narrow, and rocky and should not be attempted in wet weather. It is approximately 1.4 miles total to Stop 4 along this rough road. The road begins by straddling a narrow drainage and then proceeds left up a steep, loose rocky section toward the top of the ridge. After ~0.46 miles, a small road branches off to the left; do not take this road, but stay on the main road to the right. This turnoff is the last opportunity to turn around before the roughest stretch of road ahead. After passing this small road, proceed on the "main" road, navigate through some rocky and intimidating sections of Challis Volcanic Group and continue along the ridge. Approximately 1 mile from the turnoff from the Leaton Gulch road, stay right to pass another small road on the left and continue on the ridge to the gate at the top of a loose, rocky climb. Beyond this gate, at the saddle, is where we will meet for Stop 4 (44.5381°N, 114.1138°W).

Park here and walk ~1,800 feet to the west–northwest toward the top of the ridge to the locality (44.5394°N, 114.1200°W) near where the green porcellanite sample was collected. This rock is interpreted as an interbedded and reworked, ca. 1336 Ma tuff.

While walking toward the top of the ridge, the apple-green porcellanite can be seen as at least one (likely two) discontinuous and brecciated layers interbedded within a fine- to medium-grained orange to pink, medium- to thick-bedded quartz sandstone, exposed on the south-facing aspect of the ridge prior to arriving at the top of the ridge. Though the unconformity was not directly observed at this locality, these and overlying rocks were interpreted by Montoya (2019) to be correlative with strata exposed below the unconformity ~0.8 km to the west (fig. 2). Thus, the ca. 1336 Ma tuff (Pearson and Link, this volume) is hypothesized to be interbedded with rocks below the unconformity. These rocks were mapped by Hargraves and others (2007) near the western boundary of their map area as the Lawson Creek Formation, which they described as "a heterogeneous interbedded sequence of reddish purple and maroon to medium brown, fine-grained, feldspathic and hematitic quartzite, impure quartzitic sandstone, siltstone, and argillite. It is mostly in beds 0.5 to 3 ft (0.15 to 1 m) thick, with mudcracked argillite bedding partings."

Montoya (2019) mapped this same interval as two units (renamed from Montoya's Zl1 to Yl1 on fig. 2): she called the lowest unit "Leaton Gulch 1" and described it as: "medium-grained sandstone interbedded with shale and siltstone. Sandstone is dark purple (hematitic) sub-lithic arenite. Thinly bedded. Other sedimentary structures include ripples, syneresis cracks, and mud cracks. Underlies Leaton Gulch 2 in a gradational contact. Unit is approximately 700 m, but the true thickness is unknown as base is covered."

Excellent exposures of unit Leaton Gulch 1 of Montoya (2019) can be found by walking ~0.7 miles to the north–northwest down the ridge (to approximately 44.5442°N, 114.1250°W); exposures of the gradational contact with the overlying unit (Leaton Gulch 2) can be found by walking across the drainage toward the west over a buried normal fault (interpreted to be minor).

The overlying "Leaton Gulch 2" (renamed from Montoya's Zl2 to Yl2 on fig. 2) was described as:

"Medium-grained sandstone. Sandstone is light orange-pink and medium-thick bedded. Rare pebble-sized, matrix supported conglomeritic beds are also present. Trough cross-bedding and variably sized ripples are present. Beds are lenticular… Approximately 375 m thick."

The similarity in lithology to Hobbs' (1980) description and proximity to the type locality of the Lawson Creek Formation, as well as by Hargraves and others' (2007) proposed correlation to that unit are intriguing. At its type locality ~10 km east of this field guide's Stop 4, the Lawson Creek Formation also contains two apple-green porcellanite beds and was interpreted to gradationally overlie coarser-grained and more lithologically homogeneous quartzites of the Swauger Formation (Hobbs, 1980). At Leaton Gulch, however, Hargraves and others' (2007) coarser-grained "Swauger Formation" structurally overlies the lower strata that they correlated with the Lawson Creek Formation. To explain this, Hargraves and others (2007) interpreted that "the Lawson Creek Formation is overridden by a Late Cretaceous thrust plate of brecciated and intensely fractured Swauger Formation quartzite. The thrust plate, in turn, is overlain disconformably by the Wilbert Formation and the Kinnikinic Quartzite." The geometry of the inferred thrust between the Swauger and structurally lower Lawson Creek Formation was described as "a planar and nearly flat surface" (Hargraves and others, 2007).

Because Montoya (2019) was interested in identification of possible contractional structures within the Leaton Gulch area, she investigated Hargraves and others' (2007) hypothesized mapped thrust. She concluded that: "this investigation found no such thrust, but the same area where Hargraves and others (2007) mapped the trust trace is… a planar zone of boulder-clast size conglomerate." More work is needed!

Perhaps most importantly, the new U-Pb zircon age of the interbedded ca. 1336 Ma porcellanite indicates that these rocks are younger than the >1370 Ma Belt Supergroup. If these rocks are indeed correlative to the Lawson Creek Formation, then this suggests either that the younger part of the Belt Supergroup is >35 m.y. younger than previously suggested (cf. Evans and Zartman, 1990; Doughty and Chamberlain, 1996) or that there is an important, post-Belt Supergroup succession of rocks that present an opportunity to elucidate a poorly understood interval of the geologic history of the northern Rockies (see table 1).

The situation is greatly complicated by the redesignation of the Apple Creek Formation to be younger than the Lawson Creek Formation in the northern Lemhi Range (fig. 1, table 1; Burmester and others, 2016). If the rocks at Leaton Gulch do indeed correlate with the Lawson Creek Formation, then roughly 5 km of overlying quartzites of the (post-Belt Supergroup!?) Apple Creek Formation (Burmester and others, 2016) are missing here in the northern Lost River Range.

After viewing the interpreted upper part of Leaton Gulch 2, proceed eastward back along the ridge in the same direction from which you came toward the cars. An important question is whether there is a normal fault between this stretch of outcrop and the continuous ~30° southeast-dipping panel of rocks exposed closer to the cars; Hargraves and others (2007) and Montoya (2019) did not map a fault there (see fig. 2). Instead, Montoya (2019) interpreted that the angular unconformity should occur here, which farther west separates lower (Leaton Gulch 1 and 2) from overlying sandstones that contain distinctive ca. 660 Ma DZs, which we interpret as the Wilbert Formation (fig. 2). This unconformity is hypothesized to correlate with the one observed at Stop 3 of this field guide.

After arriving at the stratigraphically lowest outcrops along the continuation of the ridge toward the southeast (roughly here: 44.5396°N, 114.1185°W), we will walk the stratigraphy and observe some spectacular sedimentary structures, including mudcracks, symmetrical ripples, climbing ripples, mudballs, halite cube molds, and syneresis cracks. This unit is one of the most sedimentologically interesting and distinctive intervals exposed in the Leaton Gulch area.

After the walk through these strata, walk back to the cars for a rough ride back the way we came.

STOP 5 (Optional)
(44.5328°N, 114.1100°W)

Drive south on the main road through the gate and down the short, steep, cobbly road for ~0.4 miles. Near the turnoff to another dirt road on the right, park the car (roughly here: 44.5329°N, 114.1145°W) and walk down the hill toward the east (left side of the road if you are heading south) and up the other side to Stop 5 (roughly 0.2 miles of off-trail walking), which is located near the base of a cliff. Here, one can see a beautiful cobble- to boulder conglomerate with a striking, dark purple matrix.

Montoya (2019) described this unit as follows: "Clast-supported cobble-boulder conglomerate. Matrix is composed of medium-grained sandstone and clasts are composed of sandstone and vein quartz. The matrix is dark purple, and the clasts vary in color (light pink, brown, tan, light yellow, dark purple, white, gray). Clasts are sub-well-rounded and have moderate sphericity. Channels are present within the conglomerate. Underlies [overlying rocks] in a gradational contact. Approximately 50 m thick." Minor, steeply west-dipping normal faults disrupt the outcrop locally.

Similarly to the sedimentary structure-rich unit at Stop 4, this unit is also distinctive. Because of its stratigraphic position, we correlate these rocks with the Neoproterozoic and Cambrian Wilbert Formation (fig. 2). The finer-grained intervals of this unit are involved in southeast-plunging fold trains southeast of this locality and west of Leaton Gulch unit 2 exposures near the center of Montoya's (2019) map area (fig. 2). Walk back to the car and proceed down the road.

Stay left at the fork in the road to stay on the main ridge road, proceeding past the rocky and intimidating outcrops of Challis Volcanic Group, and continuing to the intersection of the main Leaton Gulch Road (Forest Road 111). Turn right and drive ~2.9 miles to the gate and intersection with Upper Hot Springs Road. Turn right on Hot Springs Road and follow it ~3.2 miles to the intersection of Highway 93 and the starting point of the trip.

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