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Geology of the Purgatory Saddle 7.5 Minute Quadrangle, and Gravity and Magnetic Analysis of Accreted Terrane Boundary, Western Idaho

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GEOLOGY OF THE PURGATORY SADDLE 7.5 MINUTE QUADRANGLE, AND GRAVITY AND MAGNETIC ANALYSIS OF ACCRETED TERRANE BOUNDARY, WESTERN IDAHO

A Masters Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Geospatial Sciences in Geography and Geology

By

Sourav Krishna Nandi

May 2018

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ABSTRACT

Western Idaho (USA) contains deformation associated with the Mesozoic accretion of volcanic island arc terranes of the Blue Mountains Province to Laurentia. The near vertical boundary between the accretionary orogeny and Precambrian North America is represented by the transpressional western Idaho shear zone, which lies east of metamorphic rocks in the Salmon River suture zone. The Blue Mountains Province in western Idaho contains four accreted crustal blocks: the Wallowa, Olds Ferry, Baker, and Izee terranes. The purpose of this study is to understand the structural relationship of the pre-accretionary, syn-accretionary and post-accretionary tectonic features along the accreted terrane boundary in western Idaho. High resolution 7.5-minute geologic mapping of the Purgatory Saddle quadrangle reveals tectonic relationships of plutonism and deformation in the pre-accretionary, Oxbow-Cuprum shear zone in the Wallowa terrane. Gravity and magnetic analysis of the boundary between accretionary island arcs and Precambrian North America reveals subsurface relationship of the western Idaho shear zone and the Salmon River suture zone. We present 2.5-D crustal scale gravity models across the Salmon River suture zone and the western Idaho shear zone to constrain the subsurface geometry of the accretionary boundary, and propose a newer extent of the Salmon River suture zone to the south and a western extent of the western Idaho shear zone.

KEYWORDS: Blue Mountains Province, western Idaho shear zone, Salmon River suture zone, Purgatory Saddle quadrangle, Oxbow-Cuprum shear zone, gravity analysis

This abstract is approved as to form and content

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Matthew P. McKay, Ph.D.
Chairperson, Advisory Committee
Missouri State University

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Matthew P. McKay, Ph.D.: Chair

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DEDICATION

This thesis is dedicated to maa and baba.

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I would like to acknowledge the National Cooperative Geologic Mapping Program: U.S. Geological Survey, Society of Economic Geologists, and Missouri State University Graduate College for their financial support towards this research project.

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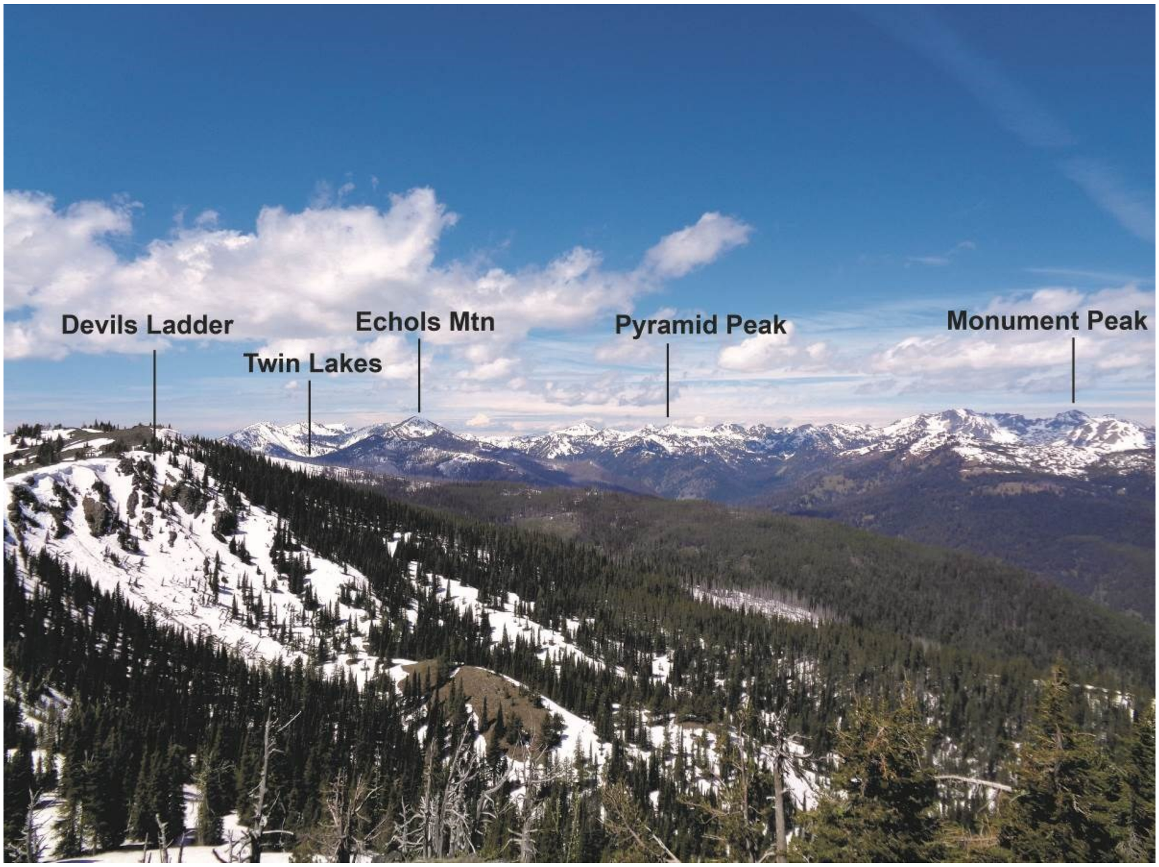
OVERVIEW

Deformation and metamorphism within shear zones record mountain building processes in the mid-to-lower crust during tectonic accretion. In western Idaho, the pre-collisional Laurentian margin between the accreted terranes of the Blue Mountains Province (BMP) and the Precambrian North America are separated by metamorphic rocks within the Salmon River suture zone (SRSZ), which grades toward the east into the dextrally transpressive western Idaho shear zone (WISZ) that is largely contained within Cretaceous plutons (Hamilton, 1963; Lund and Snee, 1988; Manduca et al., 1993; Giorgis et al., 2005). The accreted terranes of the BMP include the Wallowa, Baker, Izee, and Olds Ferry. The Wallowa and Olds Ferry terranes are Permian-Jurassic subduction-driven volcanic arcs (Figure 1) that may have amalgamated to each other around Late Jurassic time (159-154 Ma) (Vallier, 1995, 1998; Avé Lallemant, 1995; Schwartz et al., 2010). Permian-Late Triassic (252-222 Ma) magmatism within the Wallowa terrane is recorded within the Purgatory Saddle 7.5-minute quadrangle by penetratively deformed Permian-Triassic volcaniclastic strata and volcanic flows that are intruded by undeformed, yet elongate Late Triassic plutons. Deformation of Permian-Triassic strata is attributed to the Oxbow-Cuprum shear zone (OCSZ), which likely predates accretion of Wallowa to Olds Ferry or North America. To understand the tectonic history of the region, we investigate 1) the relationship of the OCSZ to the Late Triassic plutons using high resolution 1:24,000 scale geologic mapping and structural analysis, and 2) the crustal interaction of the syn-accretionary SRSZ and the post-accretionary WISZ using detailed gravity and magnetic modeling, and filtered gravity anomaly analysis of the region.

Using geologic mapping of the Purgatory Saddle quadrangle and U-Pb zircon geochronology of the elongated plutons we explore the relationship between the timing of deformation in the OCSZ, and the plutons, which were previously inferred as Permian (Walker, 1986; Lund, 2004) or Jurassic (White, 1968) in age. Gravity and magnetic models predict the subsurface geometry of the WISZ intruding into the high grade metamorphic rocks of the SRSZ fold and thrust belt, the possible protoliths of the SRSZ rocks from either Wallowa or Olds Ferry, and the relationship of the accreted terrane boundaries with each other.

PART 1: GEOLOGY OF THE PURGATORY SADDLE 7.5-MINUTE QUADRANGLE, IDAHO AND ADAMS COUNTIES, IDAHO



Cover: View of Purgatory Saddle quadrangle from Colds Spring Saddle, western Idaho

Abstract

The Purgatory Saddle quadrangle in Idaho and Adams Counties, Idaho is within the southern Seven Devil Mountains. The quadrangle lies in the easternmost portion of the Wallowa terrane, an oceanic volcanic arc terrane that underlies eastern Oregon and western Idaho in a northeast trending belt.

Permian basalt flows and volcaniclastic strata record early magmatism in the Wallowa island arc that continued into Triassic time. Permian-Triassic volcaniclastic strata are deformed by a Triassic shear zone which is subsequently intruded by Late Triassic and Cretaceous granitoid plutons and experienced lower greenschist grade metamorphism in during Cretaceous orogenesis.

Formal stratigraphic units mapped in the Purgatory Saddle quadrangle include the Hunsaker Creek Formation and Wild Sheep Creek Formation of the Seven Devils Group and the Imnaha Basalt of the Columbia River Basalt Group. Granitoid plutons and quaternary deposits, including alluvium and undifferentiated glacial sediment, were mapped based on field observations and aerial imagery.

Polymictic volcaniclastic rocks of the Permian Hunsaker Creek Formation are present and overlain by volcaniclastic sequences that are interbedded with limestones within the Wild Sheep Creek Formation. The Hunsaker Creek Formation is mylonitic in the central portion of the quadrangle within the NNE-SSW striking and is part of the Oxbow-Cuprum shear zone (OCSZ). The Oxbow-Cuprum shear zone is intruded by undeformed quartz diorite and diorite plutons that are Late Triassic (~222 Ma) in age based on U-Pb zircon geochronology. The Early Cretaceous Deep Creek and Echols Mountain plutons are exposed in the southern portion of the quadrangle and contain

marble/limestone roof pendants of the Wild Sheep Creek Formation within the plutons. Marble roof pendants throughout the Deep Creek pluton in the southwest part of the quadrangle hosted Cu-Au ore that was targeted during 19th and 20th century mining operations. The volcaniclastic strata in the quadrangle is present as folded synclinorium and anticlinorium. Miocene Imnaha Basalt of the Columbia River Basalt Group is exposed in the southeast corner of the quadrangle. Quaternary deposits include alluvium, glacial deposits, and landslides and undifferentiated colluvium deposits.

Introduction

The Purgatory Saddle quadrangle is located in Adams County, Idaho (Figure 2). The boundary between the Hells Canyon Wilderness and Payette National Forest is within the quadrangle. A single forest service recreational road, the Black Lake Road, provides seasonal access to the central and southern portions of the quadrangle. The dominant peaks in the quadrangle, Monument Peak (8940 feet), Black Imp (7509 feet), Casey Mountain (8740 feet) and Jackley Mountain (8757 feet), are part of the southern Seven Devils Mountains and frequently visited by the general public for recreation. Rural communities to the southwest (Bear and Cuprum) are connected through National Forest Road 105 and Black Lake Road. The nearest cities are Council, Idaho, 40 miles to the south-east and Copperfield, Oregon, 30 miles to the south-west, which is connected by the Kleinschmidt Grade. Major copper and gold mining districts within the quadrangle include the Creek, Black Lake, and Seven Devils districts. Mining activities in the area were active from ~1860 until ~1950 (Simmons et al., 2007; White, 1968; Bookstorm et al., 1998), and numerous abandoned mines, pits, quarries and closed shafts are present

throughout the area. The quadrangle contains ore deposits within the Wild Sheep Creek Formation and Hunsaker Creek Formation as mineralized shear zones, fissure veins, contact metamorphic and disseminated deposits (Varley et al., 1919), suggesting multiple ore emplacement mechanisms.

This report and accompanying map summarize the basic geologic data of the area, which may provide insight into the timing and mechanics of mineralization in the area. Relationships between lower greenschist facies volcaniclastic sequences, shear deformation, and plutonic complexes reported here may record pre-accretion orogenic events (Figure 1) and, therefore, are an important key to deciphering the Mesozoic history of western North America.

Location

The Purgatory Saddle 7.5-minute quadrangle (latitudes 45°15’ to 45°07’30’’; longitudes 116°37’30” to 116°30’) borders northernmost Adams County, Idaho (Figure 2). Access to the quadrangle is provided by Black Lake Road terminating at Black Lake in the center of the quadrangle and originating from U.S. Forest Service and county roads from Council, Idaho to the southeast and Copperfield, Oregon to the southwest through Cuprum, Idaho.

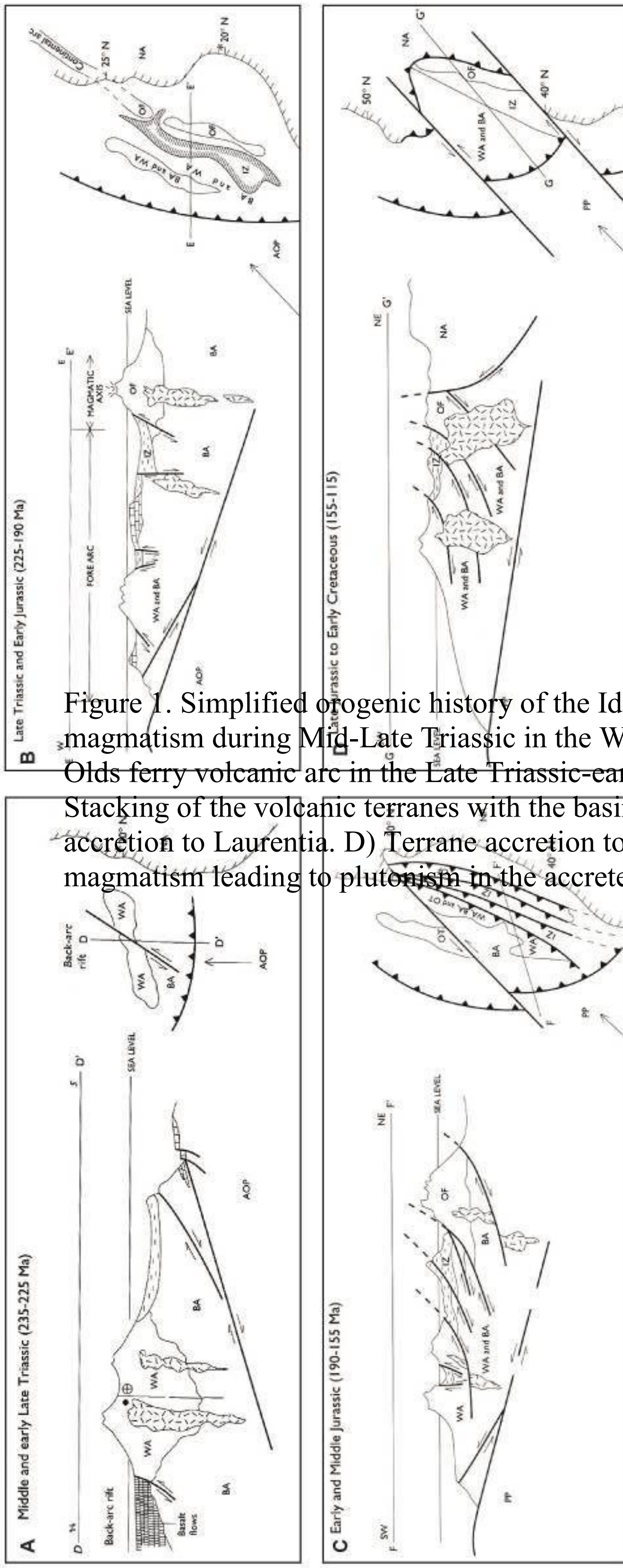


Figure 1. Simplified orogenic history of the Idaho-Oregon region. Modified from (Vallier, 1998
magmatism during Mid-Late Triassic in the Wallowa terrane and formation of a back-arc rift. B
Olds ferry volcanic arc in the Late Triassic-early Jurassic along with sedimentation leading to fo
Stacking of the volcanic terranes with the basins (Izee and Baker terranes) with each other in the
accretion to Laurentia. D) Terrane accretion to the Laurentia (pre-Mesozoic North America), wi
magmatism leading to plutonism in the accreted terranes and Laurentia.

The highest point in the quadrangle is Monument Peak at 8,957 feet. The lowest point is 5,280 feet above sea level and is within Deep Creek in the western part of the quadrangle. The central portion of the quadrangle contains rugged and steep northeast-southwest trending high ridges with multiple glacial cirques and moraines. Black Lake and Emerald Lake are the largest lakes in the quadrangle, located in the central portion of the map and have glacial origins. The mountains in the south show a linear east-west trend with gentle slopes and ample tree cover. The drainage is dominated by three major tributaries: Deep Creek and Granite Creek flowing northwest into the main Snake River, and Granite Fork flowing into the Rapid River to the east. Abandoned mining roads, pits, quarries, and adits from the Deep Creek, Black Lake, and Iron Springs mining regions are within the quadrangle. The quadrangle contains multiple peaks including Black Imp, Casey Mountain, Monument Peak, and the Jackley Mountain part of the southern Seven Devils mountains. This area is frequented for recreation as a backcountry backpacking destination and as winter sport area. Three major mining districts including Deep Creek, Black Lake and Seven Devils lie in the quadrangle and have been major source of copper and gold mining operations in the region from late-1800s into the mid-1900s. Although, there are currently no permanent residents, historical plaques near the trails suggest more than 5,000 residents lived here during a boom in mining activities, which separated into multiple small town settlements at Iron Springs, Paradise, Black Lake, Rankins Mill, and Placer Basin (Sparling, 2005).

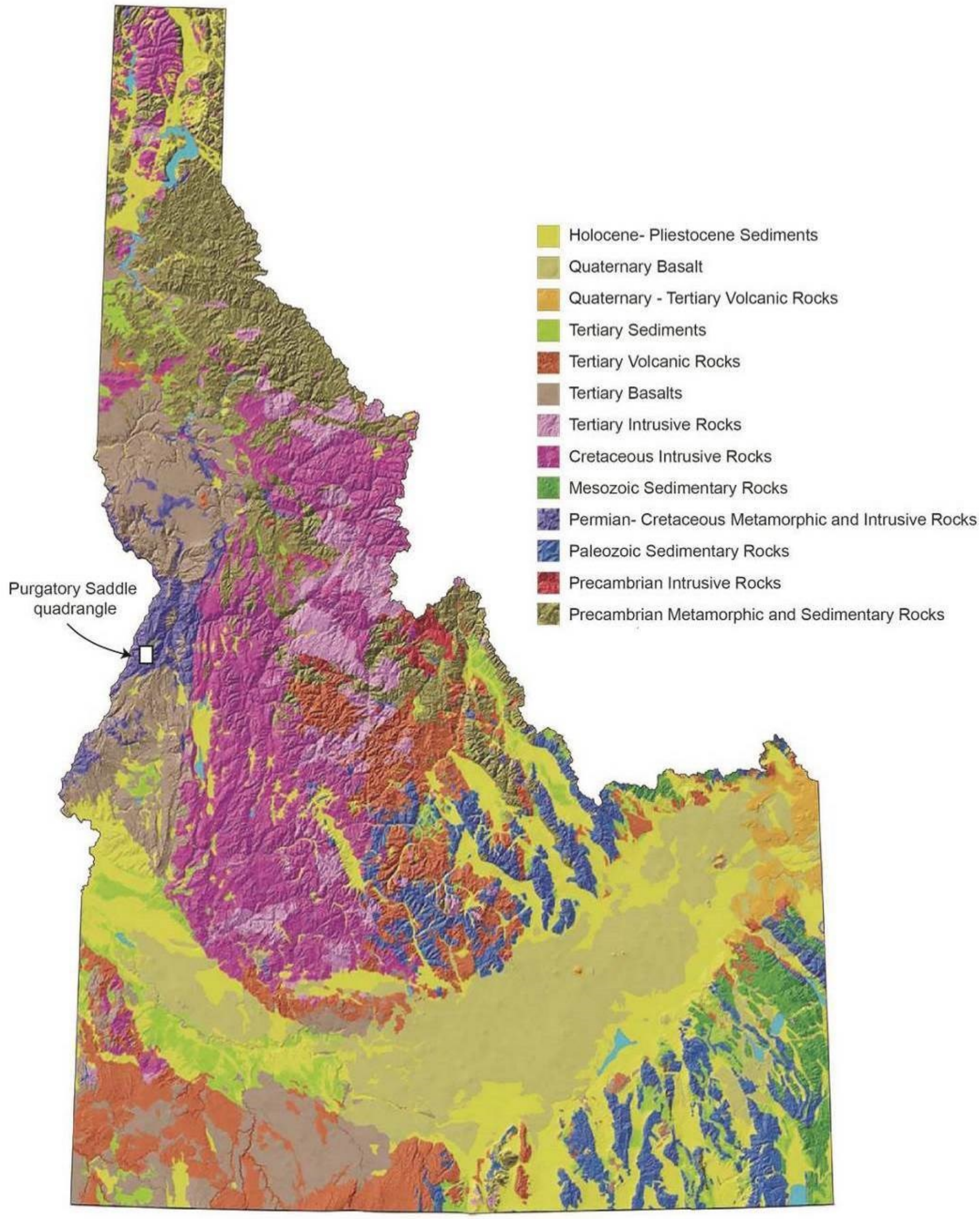
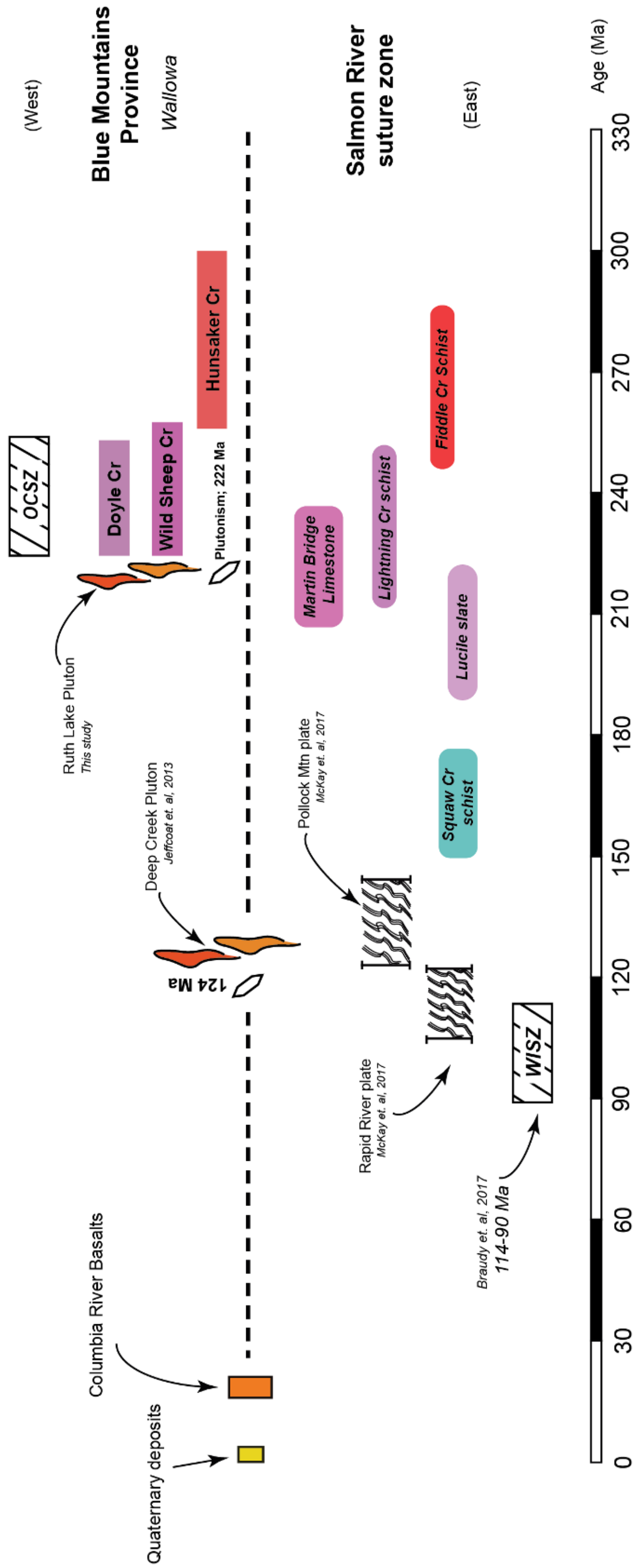


Figure 2. Simplified geologic map of Idaho, showing the location of the Purgatory Saddle 7.5-minute quadrangle (modified from Lewis et al., 2012).

Geologic Setting

The Purgatory Saddle quadrangle lies within the easternmost Blue Mountains Province, near the boundary of the accreted terranes (Silberling et al., 1987) to the cratonic North America. The pre-collisional Laurentian margin and the accreted arc terrane boundary currently lies in western Idaho (Armstrong et al. 1977). The oceanic arc terranes within the Blue Mountains Province: Wallowa, Izee, Olds Ferry, and Baker cross from Oregon to Idaho in a north-east trending belt, recording Late Paleozoic and Mesozoic sedimentation, deformation and magmatism (Vallier, 1977, 1995; Walker, 1986; Silberling et al., 1992).

This quadrangle contains Permian- Triassic sedimentation and subsequent Jurassic to Cretaceous metamorphism recorded in the Seven Devils Group, part of the Wallowa terrane (Figure 1 and 3), and Mesozoic magmatism. This is represented in two pulses: 1) pre-accretionary plutons (Triassic), and 2) post-accretionary plutons (Cretaceous). The Triassic series of plutons within the quadrangle intrude the Permian Hunsaker Creek Formation, part of the Seven Devils Group through the Oxbow-Cuprum shear zone representing some of the oldest deformation fabrics in the easternmost Blue Mountains. These plutons, trending predominantly northeast-southwest, are parallel to a major thrust fault within the Seven Devils Group.



rphism, deformation, plutonism, and deposition o

Previous Investigations

The first documentation of the rocks in the Purgatory Saddle quadrangle were early mining reports by various mine inspectors for the state of Idaho, who wrote on the geology of the area and ore deposits. Livingston and Laney (1920) reported on some of the earliest copper ores mined and other mining activities in the southern Seven Devils region. Earliest delineation of the plutons in the quadrangle were geologically mapped by Ralph S. Cannon Jr. and colleagues, summarized in Hamilton (1963, p. 15-16) and Cook (1954).

Hamilton (1963) produced the first geologic maps with significant interpretations of the tectonic history of the region. The Seven Devils volcanics were stratigraphically differentiated as the Seven Devils Group by Vallier (1967, 1977) in the eastern Blue Mountains region. The Seven Devils Group hasn't been differentiated in the quadrangle in 1: 24,000 scale until this mapping project, but has been mapped at 1:125,000 scale by Lund (2004). The plutons that intrude the Seven Devils Mountains in the quadrangle were investigated by White (1968) in a PhD dissertation. The Oxbow- Cuprum shear zone was described by Vallier (1967, 1977, 1995) as a foliated and mylonitic zone in the Wallowa mafic gneiss basement rocks. The nearest published geologic quadrangle is the Lucile 7.5-minute quadrangle (Lewis et al., 2011) which shows the metamorphic rocks of the Salmon River suture zone, but does not describe the Seven Devils Group. Aliberti (1988) discussed the mafic complexes and metamorphic rocks of the Salmon River suture zone with major fault boundaries immediately east of the Purgatory Saddle quadrangle. A geologic transect map over the arc-continent boundary by Gray (2013) on the northern Seven Devils mountains, north of the quadrangle describes the structural fabrics in the

differentiated Seven Devils Group in detail, which has been used as a proxy to compare the structural data collected (Appendix A) in the field area.

Stratigraphy

Formal stratigraphic units (Figure 4) in the Purgatory Saddle quadrangle include formations in the Permian-Triassic Seven Devils Group which is part of the Wallowa terrane, and the Miocene Imnaha Basalt of Columbia River Basalt Group. The Seven Devils Group includes the Windy Ridge Formation, Hunsaker Creek Formation, Wild Sheep Creek Formation, and Doyle Creek Formation (Vallier, 1977). These units have been named and described by Vallier (1977). The Purgatory Saddle quadrangle contains Hunsaker Creek Formation, Wild Sheep Creek Formation, and Doyle Creek Formation of the Seven Devils Group. The Windy Ridge Formation is not exposed at the surface in the quadrangle, but is present in the White Monument quadrangle to the west (Lund, 2004).

Seven Devils Group (Permian- Triassic). Hunsaker Creek Formation. The Lower Permian Hunsaker Creek Formation is the oldest stratigraphic unit exposed in the quadrangle. The Hunsaker Creek Formation was named and described by Vallier (1977) for exposures along the Hunsaker Creek, a tributary in the Snake River Canyon near Oxbow, Oregon and Homestead, Idaho. Hunsaker Creek Formation consists of siliceous greenstone facies metavolcaniclastics (pyroclastic breccia and conglomerate), with quartz clasts, gradational brecciated to medium grained tuff, and metabasalt flows with quartz porphyries. Clasts contained in the volcaniclastic rocks are basalt, some plutonic clasts and mostly sedimentary. Brachiopod faunas reported in the Hunsaker Creek Formation constrain an Early Permian age (Vallier, 1977). Near Hunsaker Creek the unit is ~2500

meters to ~780 meters thick. The estimated thickness of the Hunsaker Creek Formation in the Purgatory Saddle quadrangle is ~2200 meters (~7500 feet) is inferred from cross section construction. Hunsaker Creek Formation in the central portion of the map occurs in a northeast-southwest trend as a strongly to weakly foliated mylonite, greenstone to greenstone schist and polymictic metavolcaniclastics as described by White (1968) to be a part of the Oxbow-Cuprum shear zone.

Wild Sheep Creek Formation. The Wild Sheep Creek Formation conformably overlies the Hunsaker Creek Formation in the Purgatory Saddle quadrangle. Named and described by Vallier (1977), the Wild Sheep Creek Formation is exposed along the Snake River Canyon near Saddle, Cherry, Bull, and Wild Sheep Creeks. The Wild Sheep Creek Formation is inferred to be ~680 meters (2,500 feet) in the quadrangle based on cross section construction. Dark green to gray-green on fresh surfaces, the Wild Sheep Creek Formation is porphyritic plagioclase-rich greenstone facies basalt dominated with almost no quartz porphyry, basaltic andesite, and volcaniclastics dominated with limestone clasts. Clasts in the volcaniclastic facies are mostly sedimentary including, but not limited, to limestone, siltstone, and argillite. Apart from clasts, lenses of marble and limestone are present in the Wild Sheep Creek Formation. Weathering moderate brown and greenish black on rugged outcrops, the Wild Sheep Creek Formation is best exposed on the Black Lake Road outcrops near the base and summit of Smith Mountain.

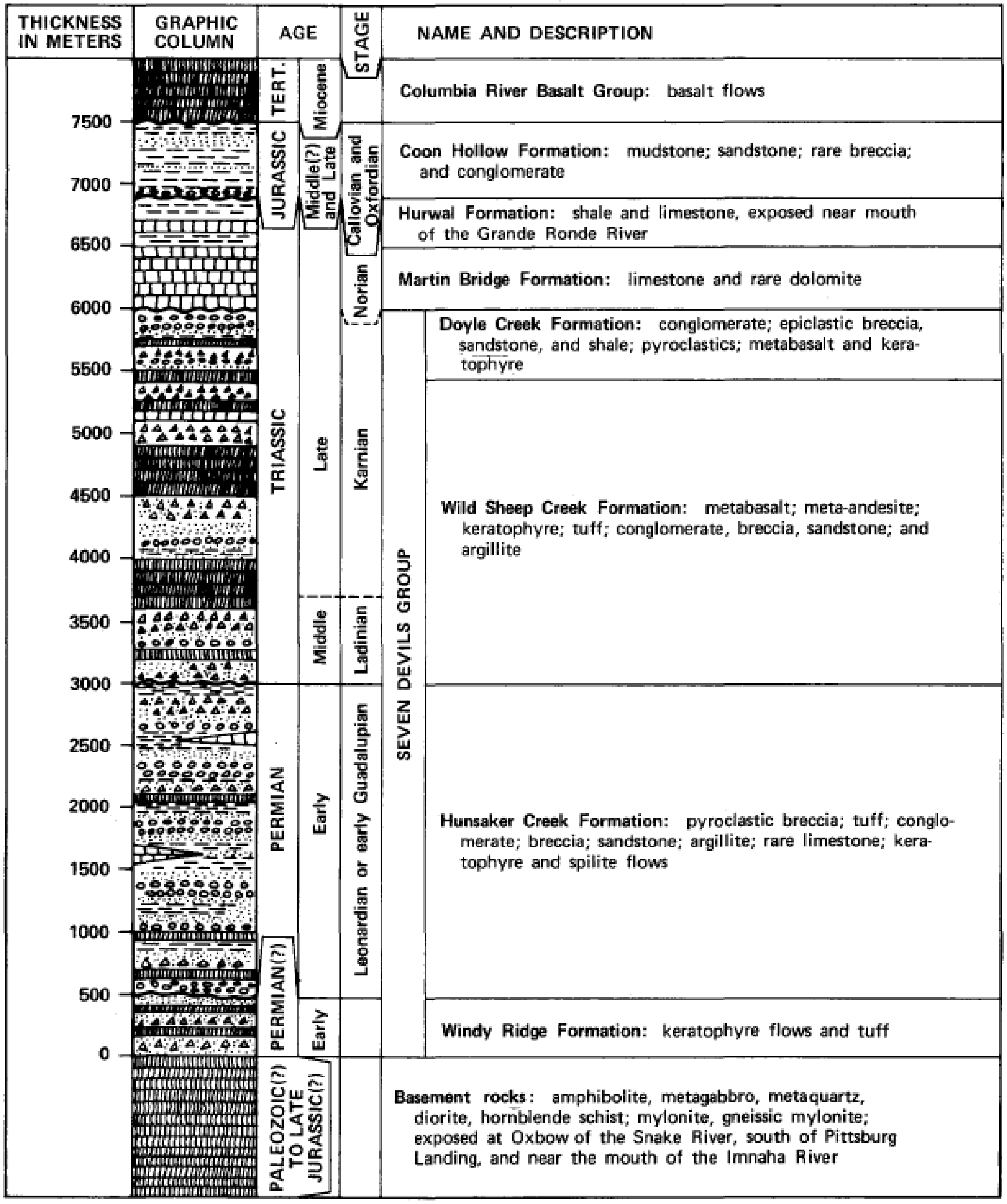


Figure 4. Generalized stratigraphic column of exposed stratigraphy in the Purgatory Saddle quadrangle and the Seven Devils mountains (Vallier, 1977)

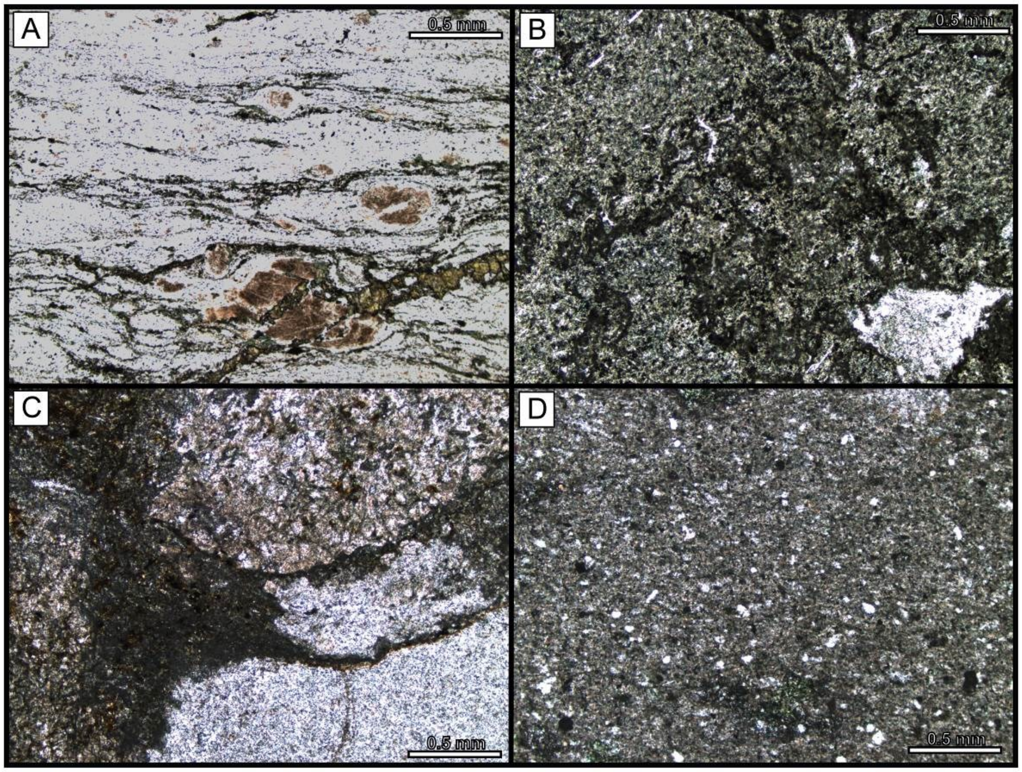


Figure 5. Thin sections of various units of Seven Devils Group with 2.97x2.23 mm field of view and 4x magnification A) mylonitic Oxbow-Cuprum shear zone, B) metabasalt of Hunsaker Creek Formation, C) volcaniclastics of Wild Sheep Creek Formation, and D) mudstone of Wild Sheep Creek Formation.

Doyle Creek Formation. The Doyle Creek Formation occurs in the westernmost portion of the quadrangle. Typically, the Doyle Creek Formation consists of green to red weathered metabasalts, volcaniclastics with increasing clastic fragments in the conglomerates throughout the Seven Devils region. It occurs in the quadrangle as green and red argillites, mudstones, and siltstones possibly correlative to the Kurry Creek Member best exposed near Pittsburg Landing, western Idaho (Lund, 2004).

Undifferentiated marble. Undifferentiated marble consists of gray to dark gray marbles, limestones, and skarn deposits. Limestone lenses and pods are present in the metavolcaniclastics of Wild Sheep Creek Formation throughout the Purgatory Saddle quadrangle, limestone deposits occur in the Doyle Creek Formation, and Martin Bridge

Formation limestones are found throughout the Seven Devils region (Lund, 2004). Although, the only mappable deposits of marble are present in the Deep Creek pluton as roof pendants alongside roof pendants of the Wild Sheep Creek Formation. It is inferred that the marble deposits in the Deep Creek plutons most likely belong to the Wild Sheep Creek Formation.

Columbia River Imnaha Basalt (Miocene). The Imnaha Basalt of the Columbia River Basalt Group is present mostly in the southeast corner of the Purgatory Saddle quadrangle approximately ~1400 feet thick and continues south to the Butterfield Gulch quadrangle. Three smaller exposures of Imnaha Basalt not exceeding ~700 feet across are present in the southwest part (SE¼, sec. 28, T. 21 N., R. 2 W.; NE¼, sec. 28, T. 21 N., R. 2 W.; and SW¼, sec. 21, T. 22 N., R. 2 W.) of the quadrangle. Miocene in age (McKee et al., 1981), the Imnaha Basalt is coarsely porphyritic basalt flow with mostly olivine and plagioclase phenocrysts ranging from 1-9 mm in diameter (Lund, 2004). The basalt commonly weathers into a brown color with reddish hue in the quadrangle. Originating from vents and dikes along the Oregon-Idaho border (Hooper and Swanson, 1990), the Imnaha Basalt at most exposures in the quadrangle is vesicular in texture due to the olivine phenocrysts weathering away, spheroidal weathering in fractured basalts can be observed sparsely at places weathering from dark gray to dark brown. Even though the earlier flows (Imnaha Basalt) of the Columbia River Basalt Group covered the lower elevation areas (Vallier, 1977, p. 53) and later flows (Grande Ronde Basalt; nonporphyritic basalt flow) covered the majority of the southern Seven Devils region, in the quadrangle, only Imnaha Basalt is observed at both the lowest ~6000 feet and highest ~7800 feet elevations.

Quaternary Deposits. Undifferentiated glacial deposits. Glacial deposits contain mineral deposits that were mined for placer gold (Lund, 2004) in the quadrangle. Multiple glacial cirques formed in the Holocene and Pleistocene and carved deep U-shaped valleys throughout the quadrangle. Glacial striations (Figure 6) are present near the flanks of most of the cirques within metavolcaniclastic sequences. Glacial deposits were not mapped with enough detail to delineate distinct glacial cycles and are based on general field observations. Glacial deposits are dominated by detritus from plutons and located near the highest peaks. These high peaks are unvegetated and fresh, indicating possible deposits from recent small-scale glaciations and mass wasting. Boulders brought down through glaciers range approximately from 3 x 6 feet to 0.5 x 1 foot and can be found predominantly around the Six-Lake Basin, and Ruth Lake.

Figure 6. Glacial striations on Hunsaker Creek Formation near Black Lake Rd and Echols Mountain pluton

Landslide/ undifferentiated colluvium deposit. Poorly sorted and non-stratified mass wasting deposits approximately range from 15 feet high to 30 feet wide boulders to silt and clay size deposits originating from northern slopes of Current Mountain and eastern slopes of Black Imp Mountain. Deposited by slumps, slides and debris flow, some more recent landslide scarps can be seen above the deposit near Black Lake (Figure 7) and Curren Mountain. Most of the landslides in the quadrangle post-date glaciation and suggest that modern mass wasting events are possible. The undifferentiated colluvium deposit near the eastern cirque of Black Imp Mountain is poorly sorted and poorly stratified sub-rounded gravel deposit.

Alluvium. Major creeks, including the Deep Creek, Granite Fork, Oxbow Creek, Paradise Creek, and Granite Creek contain Holocene and Pleistocene deposits of sand, gravel, clay and silt that are exposed along river banks. Gravel bars of 20 feet to 30 feet thicknesses are present along Deep Creek near the confluence with the Richie Gulch Creek. Mixed gravel and sand from nearby Deep Creek pluton, Big Lake pluton, and White Mountain pluton populate the gravel bars and banks along Deep Creek. Paradise Flat is covered mostly with black silts and clays originating from the metabasalt and metavolcaniclastics of nearby Seven Devils Group, distributed by Paradise Creek. Around 40 feet of silt, clay, and gravel can be observed along the banks of Granite Creek in the canyon between Casey Mountain and Monument Peak. Alluvial deposits along the banks of Oxbow Creek and Granite Fork in the lower elevations only show sand and silt derived from nearby metavolcaniclastics. Absence of the alluvial deposits in the cross section (Plate 1) is justified due to thicknesses less than 50 feet.

Figure 7. Landslide deposits of the dioritic Black Lake pluton near Black Lake area. Field assistant (Derek Spurgeon) for scale.

Plutons

Mesozoic plutons ranging from Early Cretaceous to Early Triassic in the Purgatory Saddle quadrangle intrude the mylonitic Oxbow-Cuprum shear zone, metavolcaniclastics, and metabasalts of the Seven Devils Group. The plutons have been named and categorized in accordance to White (1968) into mafic-intermediate suite and granitic suite. These plutons range from 5,200 feet to 13,200 feet in length and about 1,900 feet to 4,000 feet width. The formal intrusive plutons of the granitic suite include the Deep Creek pluton, Echols Mountain pluton, Crystal Lake pluton, Pactolian pluton, Big Lake pluton, and Ruth Lake pluton. The intrusive plutons of mafic-intermediate suite includes the Black Lake pluton, White Mountain pluton, Purgatory pluton, Satan Lake pluton, and Horse Pasture pluton. The Deep Creek and Echols Mountain plutons are Early Cretaceous in age (Jeffcoat et al., 2013), while elongate, closely spaced, northeast-southwest trending plutons that intrude the mylonitic Oxbow-Cuprum shear zone have

been inferred to range in age from Permian to Jurassic in age. U-Pb zircon ages from the Ruth Lake pluton (described below) indicates Triassic age for quartz diorite to diorite plutons in the central portion of the map. The Early Cretaceous plutons intrude the White Mountain pluton and the Oxbow-Cuprum shear zone. Most of the plutons lack deformation fabrics other than around the contacts of these plutons where some look shattered and contain slickens indicating post-emplacement deformation and faulting.

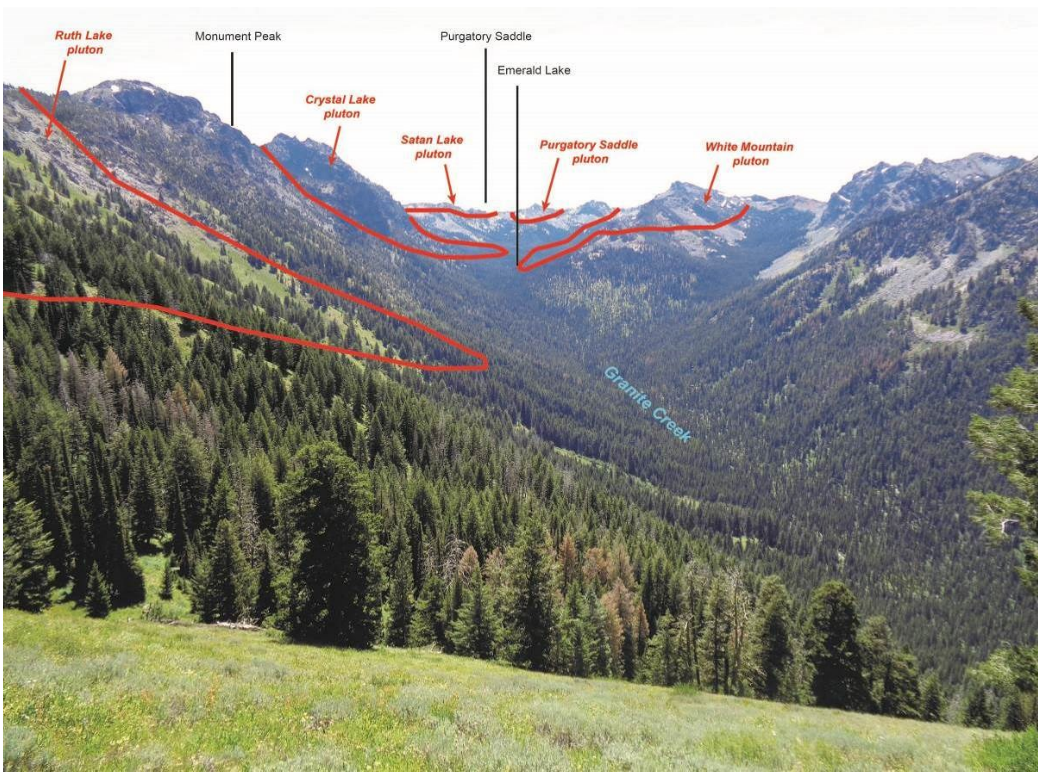


Figure 8. Shows a schematic location of Ruth Lake pluton, Crystal Lake pluton, Satan Lake pluton, Purgatory Saddle pluton and White Mountain pluton. Photo taken from trail south of Steven's Saddle.

Early Triassic Intermediate Intrusive Suite. The intermediate intrusive suite includes the Black Lake pluton, White Mountain pluton, Purgatory pluton, Satan Lake pluton, and Horse Pasture pluton. These plutons approximately range from 1000 feet to

4000 feet in width and 4700 feet to 16,000 feet in length trending northeast-southwest. Dark gray to greenish black in hand samples, these plutons range from fine to coarse grained quartz bearing gabbros and diorites with dominant hornblende and biotite (Figure 9) which occur in all plutons without any specific patterns. The only shear based deformation foliation in the plutons are found at the contact of the plutons with the Seven Devils Group or other plutons around it due to possible localized emplacement stresses. Intrusions of the compositionally differentiated mylonites (part of Oxbow-Cuprum shear zone) can be found around sharp boundaries of the Purgatory pluton, Horse Pasture pluton, Satan Lake pluton, and White Mountain pluton.

Black Lake pluton. Western Black Lake contains exposures of this diorite pluton in contact with dark gray to dark green metavolcaniclastic strata containing mafic and felsic clasts of the Hunsaker Creek Formation. The Black Lake pluton is principally diorite and quartz rich hornblende metagabbro. Best exposures of the Black Lake pluton are at eastern slopes of Pyramid Peak accessible by the old mining trails that split from the Six Lake Basin trail, and outcrops immediately west of Black Lake. The Black Lake pluton is approximately 4,200 feet long and 1,000 feet to 1,500 feet wide, and has a northeast-southwest elongated shape. Black Lake pluton contains coarse and fine grained rocks (White, 1968) and outcrops on top of Pyramid Peak show, where coarser plutonic rocks intruding the finer grained varieties of the pluton. Slip surfaces (slickensides) with serpentinite and epidote along the boundary between fine and coarse grained rocks are observed throughout the Black Lake pluton, suggesting internal deformation. A shear with cross fractures can be seen at the boundary of Black Lake pluton with the Hunsaker Creek Formation, with slickens at some outcrops. This shearing disappears after

approximately 4 feet from the contact suggesting possible emplacement fracturing of the pluton while intruding the Permian volcaniclastic units.

<u>White Mountain pluton.</u> Approximately 16,000 feet long and 3,000 feet to 4,000 feet wide, the White Mountain pluton, on the eastern side is in contact with mylonitic Hunsaker Creek Formation, part of the Oxbow-Cuprum shear zone and on the western side with the felsic, Big Lake pluton. This pluton starts from the Emerald Lake in the north and ends at Deep Creek in the southern part of the quadrangle. The White Mountain pluton is mostly diorite in composition but some parts contain quartz diorite pods. The best exposures of the White Mountain pluton are along the Six Lake Basin trail near Joe's Gap and the slopes of White Mountain. Mylonitic xenoliths along the boundary of the pluton can be seen near start of Horse Pasture trail (SE¼, sec. 4, T. 21 N., R. 2 W.) on the Six Lake Basin trail, suggesting the Oxbow-Cuprum shear zone pre-dates the intrusive White Mountain pluton with no deformation fabrics in the dioritic pluton. Greenish-gray igneous inclusions with fine matrix and mafic pods ranging 1 cm to 3 cm diameters can be seen in the saddle of Joe's Gap, middle of the pluton (Center, sec. 4, T. 21 N., R. 2 W.) along the Six Lake Basin trail. Epidote and serpentinite veins are common near the western boundary of White Mountain pluton with the felsic Big Lake pluton. Field based observations show a roof pendant of unsheared Wild Sheep Creek Formation, mapped by White (1968) as undifferentiated Seven Devils Group in the pluton, on a saddle north of Joe's Gap (SE¼, sec. 33, T. 22 N., R. 2 W.).

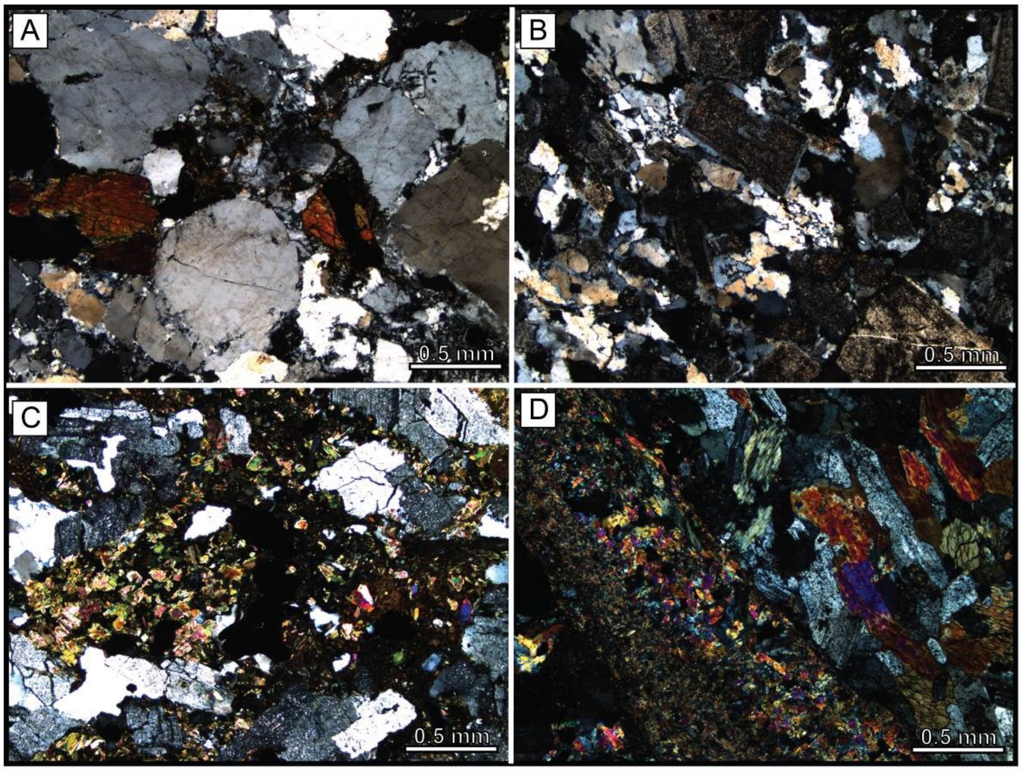


Figure 9. Thin sections of felsic and intermediate plutons cross- polarized with 2.97 x 2.23 mm field of view and 4x magnification. A) quartz diorite of Big Lake pluton, B) quartz diorite of Ruth Lake pluton, C) diorite of Horse Pasture pluton, and D) diorite of Purgatory Saddle pluton.

Purgatory pluton. The Purgatory pluton is approximately ~4,700 feet long and ~1,250 feet wide in a northeast and southwest trending orientation. This pluton is best exposed at Purgatory Saddle along the Six Lake Basin trail and the ridge northeast of the Purgatory Saddle along the Emerald Lake trail. The Purgatory pluton is bound to the east by the sheared mylonite of Oxbow-Cuprum shear zone and to the east by metabasalts and quartz bearing metavolcaniclastics of the Hunsaker Creek Formation. The Purgatory pluton is quartz-bearing hornblende augite diorite and metagabbro. No shear fabric in Purgatory pluton has been observed other than along the boundary of the pluton with both mylonite of the Oxbow-Cuprum shear zone and the unsheared Hunsaker Creek

Formation, which possibly is emplacement shear shown by almost east west trending fabrics. White (1968) reported crude hornblende banding restricted to exposures on the ridge northeast of the Purgatory Saddle. Inclusions of mylonite ranging up to 2 feet along the contact of the pluton and the Oxbow-Cuprum shear zone are present in the Purgatory pluton suggesting post-shear intrusion. Secondary fabrics and epidote surfaces along slickens (White, 1968) in the plutons between fine and coarse grained diorites suggest possibly multiple smaller pulses of plutonism in similar orientation to the deformation fabric in the Oxbow-Cuprum shear zone, most likely due to the plugs of finer and coarser grained diorites rising through the minimal stress zone of the mylonitic Oxbow-Cuprum shear zone.

Satan Lake pluton. The Satan Lake pluton is intruded by younger Crystal Lake pluton and separated into three distinct parts (White, 1968), two distinct parts in the northern and one in the southern portion of Crystal Lake pluton. Approximately, 6,800 feet in length and thickness varying from 500-1,000 feet in the southern lobe, this pluton is 3,700 long and 700-1,000 feet wide in the northern lobes. Best exposed on southern slopes of Middle Mountain and near Satan Lake, the contact between sheared metabasalts of Hunsaker Creek Formation and the Satan Lake pluton is sharp. The pluton is extremely fractured in the southern saddle of the Middle Mountain and outcrops as almost black with epidote veins. The northward swinging contacts at Satan Lake, creating zone contact foliation in the pluton with the scattered mylonitic zone inclusion in the pluton (White, 1968), suggests an intrusive origin. The Satan Lake pluton is composed of mostly quartz-bearing diorites and gabbros with some metadiorites near Satan Lake. Quartz diorite injections from the Crystal Lake pluton can be seen near the contact of

Satan Lake pluton with the Oxbow-Cuprum shear zone. The contact of the Satan Lake pluton is poorly exposed due the shattered nature of the Satan Lake pluton.

Horse Pasture pluton. Horse Pasture pluton is approximately ~13,200 feet long and ~3,500 feet in the southern and ~1,000 feet wide in the northern portion of the pluton. This pluton is best exposed on the northeastern slopes of Pyramid Peak near the cirque of Black Lake and on the southwestern slopes of the Pyramid Peak in the Horse Pasture Basin. The Cretaceous quartz diorite Deep Creek pluton intrudes the southern portion of the Horse Pasture pluton (SE¼, sec. 9, T. 21 N., R. 2 W.) near the Deep Creek valley. The Horse Pasture pluton is heterogeneous diorite and quartz diorite in composition. Coarser rocks are inferred to intrude and the finer equivalence in the plutons and suggested coarser intruding the finer, which is identical to field observations along the exposures in the Black Lake cirque in northeastern slopes of the Pyramid Peak (White, 1968). The best exposure of the ~2,400 feet of contact between Deep Creek pluton and the Horse Pasture pluton is along F.S. Trail 173. Inclusions of diorite from the Horse Pasture pluton are present around the contact of the quartz diorite of Deep Creek along with serpentinite veins, suggesting emplacement of Horse Pasture pluton pre-Cretaceous. Contact with the Hunsaker Creek Formation is mostly sharp throughout the pluton except where the pluton is in contact with the mylonitic Oxbow-Cuprum shear zone in the northwesternmost boundary of the Horse Pasture pluton, where epidote veins and highly eroded diorite were commonly observed.

Late Triassic Felsic Intrusive Suite. The Late Triassic felsic intrusive suite includes the Crystal Lake pluton, Pactolian pluton, Big Lake pluton, and Ruth Lake pluton. These plutons approximately range from 8,000 feet to 13,700 feet in length and

about 1,600 feet to 4,000 feet width trending northeast-southwest. Crystal Lake pluton is the only intrusive to share contacts with the mylonites of the Oxbow-Cuprum shear zone, the others share sharp contacts with the metavolcaniclastic rocks of the Hunsaker Creek Formation. These plutons are granitoids, light pink to gray with gradational contacts with the intermediate intrusive suite. Fracturing is prevalent at the contacts with the Seven Devils Group.

Crystal Lake pluton. Approximately 13,800 feet long and 4,000 feet wide, the Crystal Lake pluton trends northeast-southwest extending from southern saddle of Middle Mountain to Granite Creek. Crystal Lake pluton is best exposed on ridges and valleys south of Monument Peak. This pluton is the largest in the felsic intrusive suite. The Crystal Lake pluton shares most of its northwestern contact with undeformed Hunsaker Creek Formation, it can be observed as lighter granitoids of Crystal Lake pluton against dark colored metavolcaniclastic rocks of the Hunsaker Creek Formation (Figure 10). Best exposures of the Crystal Lake plutons can be found in the Granite Creek valley and the Paradise Creek cirque. The composition of the Crystal Lake pluton is principally granodiorite and hornblende-biotite quartz diorite. Most of the southern contact of Crystal Lake pluton in the Granite Creek valley with the mylonitic Oxbow-Cuprum shear zone has shear banded inclusions in the quartz diorite and quartz monazite dike (White, 1968) of the pluton. Dikes from the plutons intrude the mylonitic Oxbow-Cuprum shear zone ranging from 5 feet to 30 feet in width near the contact where intense foliation defined by biotite dipping steeply can be found (White, 1968). Field relationships between the Crystal Lake pluton and the Satan Lake pluton suggest that the Crystal Lake pluton intruded the later and shares parts of the northern and southern contacts.

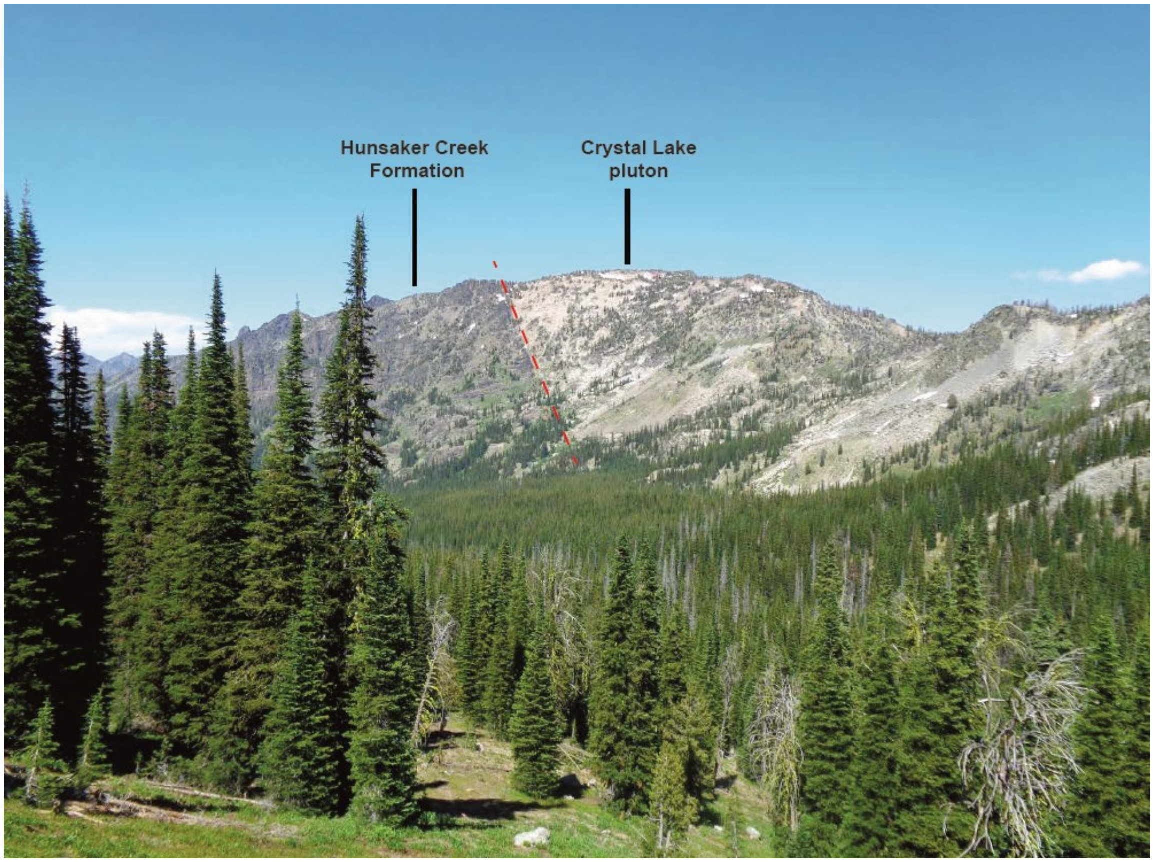


Figure 10. Crystal Lake pluton and Hunsaker Creek Formation contact (shown in red dashed line) eroded by Holocene and Pleistocene glaciers.

Pactolian pluton. Best exposures of the Pactolian pluton are between the Pactolian Gulch and Lake Fork (SE¼, sec. 35, T. 22 N., R. 2 W.). Axe shaped, Pactolian pluton is approximately ~ 10,500 feet long and ~ 2,800 feet wide in the southern portion and ~ 300 feet wide in the northern portion of the pluton. Tributaries of the Lake Fork separate the Black Lake pluton and the Pactolian pluton along multiple mining tunnels on the sheared volcaniclastic Hunsaker Creek Formation. The Pactolian pluton is hornblende quartz diorite in composition. Shear fabrics are present along the southwest boundary of the Pactolian pluton, but absent elsewhere, suggesting that deformation is unrelated to the Oxbow-Cuprum shear zone. Due to extensive mining activity and subsequent scree and

tailings along the northeastern boundary of the pluton, the contact with the Hunsaker Creek Formation is approximated.

Big Lake pluton. Approximately, 11,600 feet long and 2,500 feet wide in a northeast- southwest trending orientation, the Big Lake pluton shares its contact with Hunsaker Creek Formation on the western side and White Mountain pluton to the east. The Big Lake pluton is best exposed in the Six Lake Basin on the western slopes of the White Mountain. The Big Lake pluton is a biotite-hornblende quartz diorite with no visible foliation in the pluton or the country rock. The western contact is obscured by glacial till deposits ranging from boulders to unconsolidated sediments. The contact with White Mountain pluton is mostly gradational over tens of feet to hundreds of feet, except the sharper of the contacts along F.S. Trail 216 where a lighter quartz diorite can be seen intruding the darker dioritic rocks of the White Mountain pluton.

Ruth Lake pluton. The northern most pluton in the quadrangle, the Ruth Lake pluton, is relatively isolated from the rest of the plutons in the quadrangle. Approximately 10,100 feet long and 3,400 feet wide, this pluton is in contact with undeformed Hunsaker Creek Formation. Best exposures of the Ruth Lake pluton are in the Ruth Lake cirque where a sharp boundary with the almost black metabasalt unit and epidote veins. Monzonite dikes to occur near contact with the Hunsaker Creek formation where an abundance of platy flow structures are present in the pluton (White, 1968). The Ruth Lake pluton is a hornblende quartz diorite with quartz veins filling fractures, and minor shearing and elongation near the northernmost contact suggesting possible emplacement shear deformation. U-Pb zircon geochronology of the pluton (Figure 11; Appendix B) at

University of Arkansas Geochronology Lab revealed a 222.1 ± 5.8 Ma (Late Triassic) age.

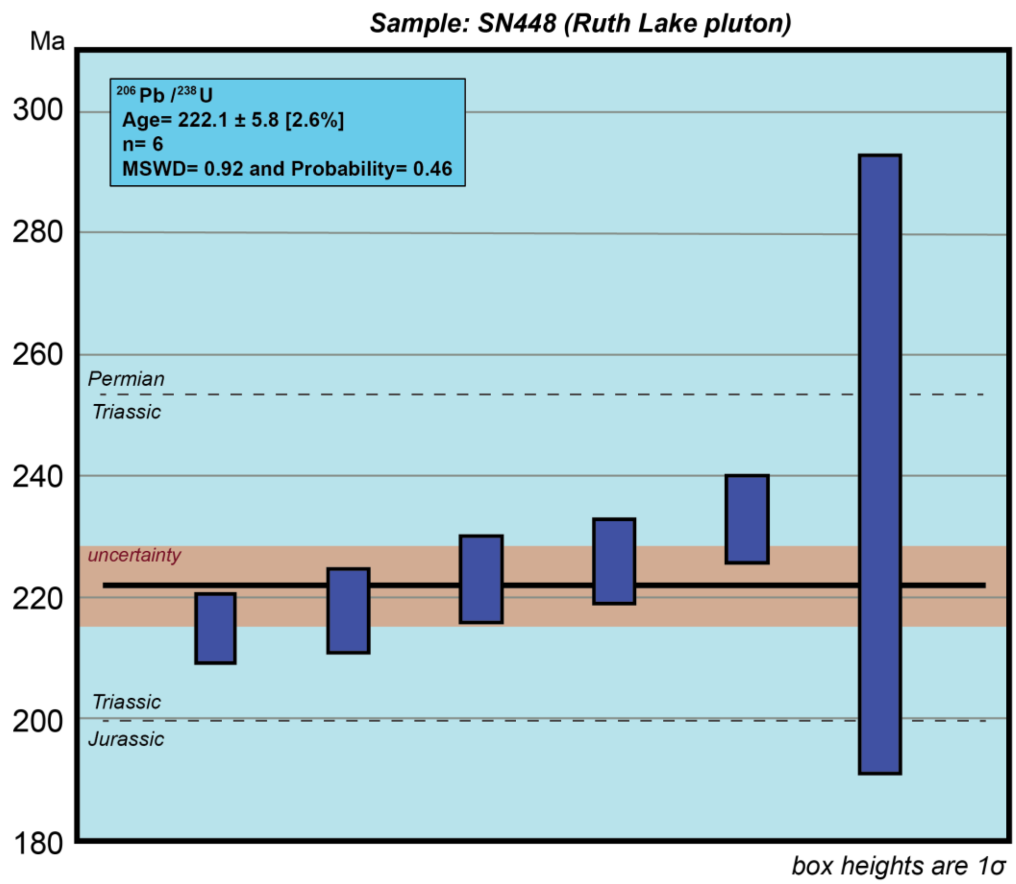


Figure 11. U-Pb geochronology of the Ruth Lake pluton. The age of Ruth Lake pluton is 222.1 ± 5.8 Ma.

Cretaceous Intrusive Suite. The Deep Creek pluton and the Echols Mountain pluton form the Cretaceous intrusive suite. These are the largest plutonic bodies in the Purgatory Saddle quadrangle and in the southern Seven Devils regions. Light gray to pink, these plutons are highly jointed, and are mainly quartz diorite in rock type with a generally equigranular texture. Essential minerals include potassium feldspar, quartz, plagioclase feldspar. Deep Creek pluton contains roof pendants of the Undifferentiated

marble near the Richie Gulch area where a hornblende diorite intrusive body (mapped as Kdr; Diorite of Richie Gulch) can be found covering almost a square kilometer area.

Deep Creek pluton. Approximately 1/3rd of the Deep Creek pluton is exposed in the quadrangle intruding the Seven Devils Group in an east-west trending orientation. Part of one of the largest intrusive bodies in the southern Seven Devil Mountains, the Deep Creek pluton is Early Cretaceous in age (123 Ma; Jeffcoat et al., 2013). This pluton is best exposed along intersection of the Black Lake Road and the Deep Creek. The Deep Creek pluton is hornblende-biotite bearing quartz diorite and tonalite (White, 1968; Hamilton, 1963; Lund, 2004) in composition. Roof pendants of the Wild Sheep Creek Formation and xenoliths of Hunsaker Creek Formation (Figure 12) can be found within the pluton.

Figure 12. Deep Creek pluton containing xenoliths of the volcaniclastic Hunsaker Creek Formation.

Foliation observed in the Deep Creek is mainly flow foliation (White, 1968), but tectonic origins of the foliations have also been interpreted (Cook, 1954; Hamilton, 1963). The Deep Creek pluton intrudes the dioritic Horse Pasture pluton, Wild Sheep Creek Formation, Hunsaker Creek Formation (Figure 12), and the Oxbow-Cuprum shear zone. Numerous marble xenoliths and inclusions in the pluton led to copper, silver and gold mining activities (White, 1968) in the Purgatory Saddle and the adjacent White Monument quadrangle, where a dioritic intrusive body (mapped as the diorite of Richie Gulch; Kdr; 123.1 Ma; Jeffcoat et al., 2013) can be observed covering almost a square kilometer. The origin of the marble inclusions is most likely from limestone lenses in the metavolcaniclastic rocks of the Wild Sheep Creek Formation or possibly from the Martin Bridge Formation (White, 1973; Lund, 2004). Detachment slickens (Figure 13) can be found in the pluton and by the contact with volcaniclastic Hunsaker Creek Formation along F. S. Trail 227 in the southern portion of the map.

Figure 13. Slickens on the Deep Creek pluton near detachment.

Echols Mountain pluton. The Echols Mountain pluton is best exposed near the intersection of the Lake Creek Fork and F.S. Trail 187 as an intrusive contact with the Hunsaker Creek formation (Figure 14). Approximately 3/4th of the pluton is exposed in the quadrangle in an east-west trending orientation intruding the Hunsaker Creek Formation and the Wild Sheep Creek Formation. Major slickens can be observed in two places: 1) near the contact of the pluton with the Hunsaker Creek formation along F.S. Trail 328, and 2) on top of the southern ridge of the twin lake cirque (Figure 15) originating possible from a domal effect during emplacement of the Echols Mountain pluton. The pluton is hornblende-biotite-bearing quartz diorite and tonalite (White, 1968; Vallier, 1977; Hamilton, 1963; Simmons et al., 2007), and is similar in composition and age (Lund, 2004; White, 1968) to the Deep Creek pluton, with less potassium feldspar content than Deep Creek pluton (White, 1968).

Figure 14. Contact of Echols Mountain pluton with the Hunsaker Creek Formation.

Although, two marble lenses were reported by White (1968), there were none at the mentioned sites possible due to past mining activities in the area. Foliation observed in the pluton is mainly flow foliation, other than in Hunsaker Creek formation near the contact of the pluton near the western edge of the map along F.S. Trail 187.

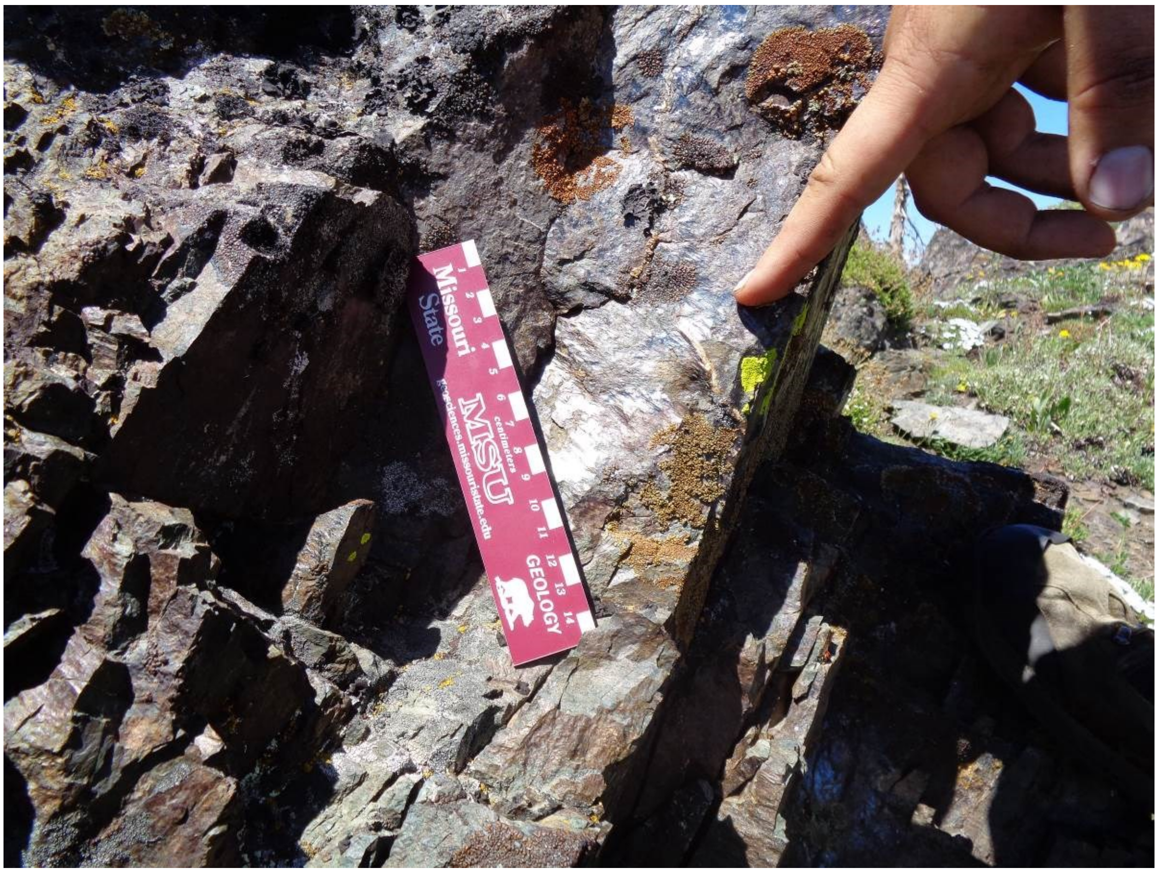


Figure 15. Slickens on top of the southern ridge of Twin Lakes cirque.

Structural Geology

The structural features in the quadrangle originate, in part, from Permian-Triassic active margin deformation, post-Triassic accretion of the terranes to Laurentia, and Cenozoic extension. The features are depicted in the map and A-A’ and B-B’ cross sections (Plate 1). The cross sections have not been restored or balanced due to the

ductile nature of the rocks present, and are therefore depicted as a straight forward interpretation of the structural features in the Purgatory Saddle quadrangle.

Oxbow-Cuprum shear zone. As the most distinctive feature in the quadrangle, the Oxbow- Cuprum shear zone, extends almost the entirety of the map as a 0.5-1 km thick zone in a northeast-southwest orientation. Foliation throughout the shear zone constantly appear to be steeply dipping, consistent with the joint and fracture sets. The Oxbow-Cuprum shear zone is a mylonitic zone (Figure 16) with gradational contacts along its boundaries that range from 10 feet to 150 feet. Best exposures can be found in the central portion of the map in the Granite Creek area where it outcrops as alternating light and darker gray-brown banded layers (Figure 16A, B). White (1968) defined this characteristic banded layer as a fluxion structure. The chemically differentiated banded occurs as a difference in the concentration of elongated and lineated hornblendes.

The mylonitic zone shows fine grain shearing (Figure 5A) and lenses of intensely sheared quartz (Figure 16B, C) throughout the Oxbow-Cuprum shear zone. Shearing decreases into visibly stretched quartz clasts to no shear sense in a graded sequence from the shear zone to the undeformed Hunsaker Creek Formation at most contacts. Due to this behavior it is possible that the nature of shearing is more radial with intense shearing in the central portions with decreasing outward shearing. In the northeastern corner of the map, the contact with the Hunsaker Creek Formation is more sharp than gradational. The Oxbow-Cuprum shear zone has been previous mapped (Taubeneck, 1966; Vallier, 1967; White, 1968; Lund, 2004) throughout this region with a characteristic foliation and intense shearing in a similar trend south of the map close to the Oxbow of the Snake River. The northern extent of the Oxbow-Cuprum shear zone is still debatable.

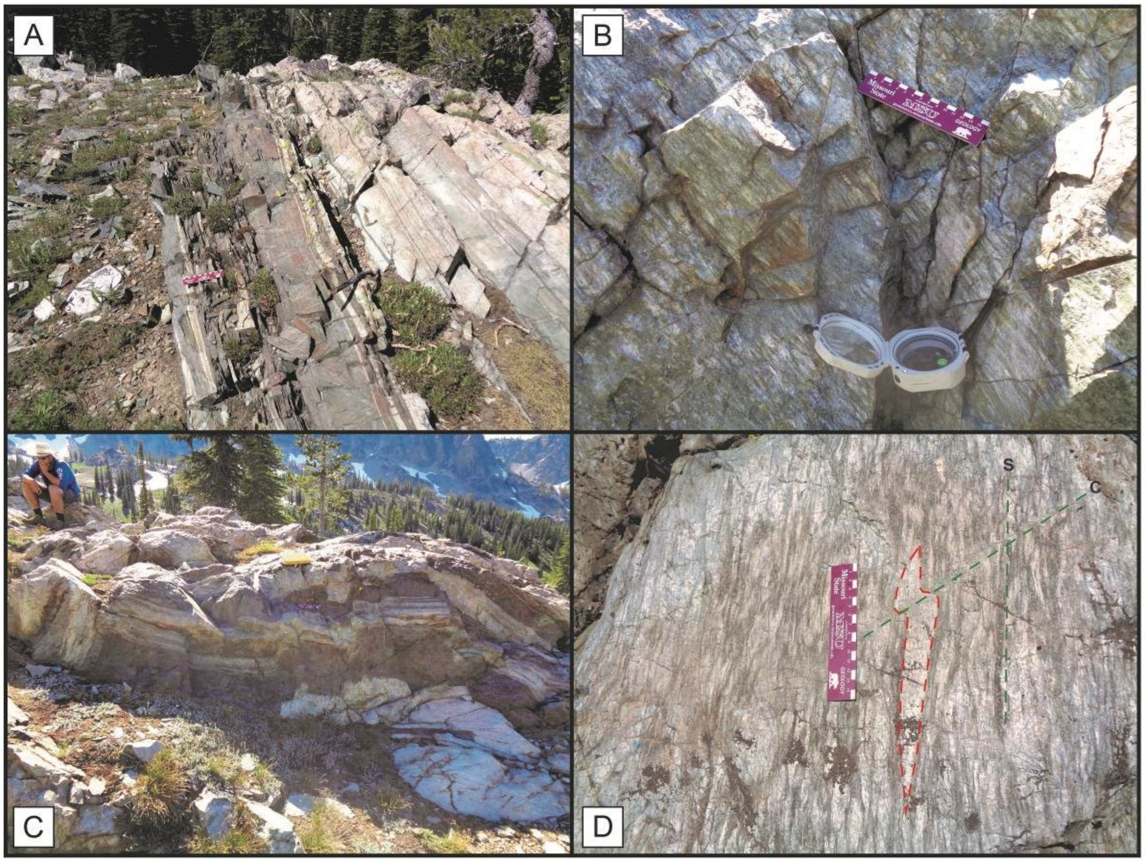


Figure 16. Shows an overall representation of the Oxbow-Cuprum shear zone in the Purgatory Saddle quadrangle. A and B show distinct light and dark color bands alternating with varying amounts of hornblende in the layers. C and D show stretched and sheared quartz clasts which is a characteristic feature of the outer gradational boundary with undeformed Hunsaker Creek Formation.

Pluton emplacement. The emplacement of the plutons in the map can be generalized into two parts, 1) the emplacement of the elongated pluton in and near the Oxbow-Cuprum shear zone, and 2) the emplacement of the massive Cretaceous plutons. The Triassic mafic and felsic plutons have a characteristic sharper contact with the country rock and the Oxbow-Cuprum shear zone that presently surrounds them. The metavolcanic country rock strike almost northeast-southwest trending parallel to the plutons. Extremely limited amount of country rock inclusions in the plutons suggests a possibly colder emplacement (White 1968). Overall, pluton orientations and structural

data suggest that magmas exploited a zone of structural weakness (Badgley, 1965) due to parallel foliation in the contact of the plutons with the metavolcanic rocks and the Oxbow-Cuprum shear zone, although post-emplacement regional metamorphism precludes identifying an actual mode of emplacement.

The Echols Mountain and the Deep Creek plutons occur in an east-west trend with an intrusive body (Diorite of Richie Gulch) in the western Deep Creek which occurs in a northeast southwest trend, possibly due to the nearby zone of weakness, from the Oxbow-Cuprum shear zone. Due to internal and external detachment faults in both of the Cretaceous plutons, possibly due to a more magmatic and ductile nature of intrusion (White, 1973), a characteristic domal effect has been observed. Xenoliths of the nearby metavolcanic rocks can be observed (Figure 14 and 15) throughout Deep Creek and Echols Mountain plutons, which are also suggestive of a magmatic pulse type intrusion (White, 1968, 1973). Near-concentric flow patterns in both of the plutons and suggested a upward and then outward movement of magma (White, 1968). The similarity in texture and mineralogy, and proximity of these massive plutons suggest a possible subsurface interaction as illustrated in the cross section (Plate 1).

Smith Mountain synclinorium. The Smith Mountain synclinorium appears to be possibly relation to the Curren Mountain synclinorium but due to deformation and regional plutonism, it does not outcrop to be connected. This has been previously mapped as Doyle Creek Formation by Lund (2004), and undifferentiated Seven Devils Volcanics by Hamilton (1963) and White (1968). The syncline in the southwest corner of the map is intruded by the Deep Creek pluton, and the overturned and steeply dipping strata can be best observed from the Black Lake Rd looking south at the Smith Mountain, on top of

which the stratigraphic contact between the Wild Sheep Creek Formation and Hunsaker Creek Formation can be observed.

Curren Mountain synclinorium. The Curren Mountain synclinorium represents the folded Wild Sheep Creek Formation plunging to the north-northeast, previously mapped as the Doyle Creek Formation by Lund (2004), and undifferentiated Seven Devils Volcanics by White (1968) and Hamilton (1969). The structure is tightly folded with smaller scale parasitic folds and overturned beds, best exposed near the Curren Mountain area. The Wild Sheep Creek Formation stratigraphically overlies the Hunsaker Creek Formation which may have shown up folded in the central portion of the map before emplacement of the Jurassic-Triassic plutons along the Oxbow-Cuprum shear zone, as part of an anticlinorium, as suggested by the presence of the Smith Mountain synclinorium to the south. Much of the stratigraphy in the entire map has been folded and faulted (along the southern boundaries of the Cretaceous plutons) due to domal effects and overturning of beds from plutonism in the region.

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PART 2: GRAVITY AND MAGNETIC ANALYSIS OF ACCRETED TERRANE BOUNDARY, WESTERN IDAHO.

Cover: Sourav Krishna Nandi taking gravity readings near Hells Canyon, Idaho. Columbia River Basalt Group exposures can be seen in the background.

Abstract

The western Idaho shear zone exposes mid-crustal deformation that overprints metamorphic tectonites in the Salmon River suture zone, a Mesozoic metamorphic belt that separates accreted terranes of the Blue Mountains Province from pre-Mesozoic continental North America. To investigate the structural relationships between the western Idaho shear zone and Salmon River suture zone, I present a 2.5-dimensional gravity and magnetic modeling, and filtered gravity anomaly maps. Residual gravity anomaly maps provide insight into the steepness and relationship of the two volcanic terranes (Wallowa and Olds Ferry) and two basinal terranes (Baker and Izee), that have undergone overlapping deformation and metamorphism at depth. Recent geologic mapping, U-Pb zircon and garnet geochronology, geochemistry, structural analysis, and seismic velocity models have been used to constrain the tectonic interference of the Wallowa terrane of the Blue Mountains Province with Salmon River suture zone (SRSZ) and western Idaho shear zone (WISZ), respectively. The 2.5-D geophysical models suggest east-west shortening geometry of the easternmost Salmon River suture zone, caused by kinetics of the western Idaho shear zone, ~7 km offset in the Moho at the boundary of western Idaho shear zone and cratonic North America as suggested by the EarthScope Idaho-Oregon (IDOR) project, and propose a new southern extent of the Salmon River suture zone that is obscured by Columbia River Basalt Group and not exposures at the surface. We discuss a tectonic model of the easternmost accreted terranes of the Blue Mountains Province with the continental North America in western Idaho, consistent with timing of tectonism reported by previous studies in the area.

Introduction

The western Blue Mountains Province contains four accretionary arc terranes: Wallowa, Old Ferry, Baker, and Izee (Silberling et al., 1992). These terranes have collided with Precambrian North America (Figure 17), while undergoing continuous deformation, metamorphism (Hamilton, 1963; Lund and Snee, 1988), and changes in the regional crustal architecture. In western Idaho, the boundary between Precambrian North America and the accreted terranes (Wallowa, Olds ferry, Baker and Izee) is exposed as a broad zone of mid-crustal deformation and ductile metamorphism called the Salmon River suture zone (SRSZ), where the above terranes are juxtaposed against continental North America. These terranes have gone through overlapping deformation before getting "stacked" against each other and going through low grade metamorphism and ductile deformation (Walker, 1986; Vallier, 1995) during amalgamation. During the mid-Cretaceous, the SRSZ was reactivated and underwent a considerable amount of shortening due to a steeply-dipping dextrally transpressive system called the western Idaho shear zone (WISZ); (McClelland et al., 2000; Tikoff et al., 2001; Giorgis et al., 2008), which currently marks the boundary between the accreted island arc terranes and the Precambrian North American craton.

To understand the tectonic evolution of these accreted terranes, a series of 2.5 dimensional geophysical models were constructed to study the present crustal scale structures of the SRSZ and the WISZ. Detailed gravity data were collected (Figure 17) within the Wallowa terrane into the SRSZ and the WISZ boundary to constrain the geometry of the suture zone and its relationship the western Idaho shear zone. With a compilation of new structural analysis data, updated geologic maps, U-Pb age dates,

geophysical studies, analytical data (Braudy et al., 2017; Schmidt et al., 2017; Giorgis et al., 2017; Davenport et al., 2017; McKay et al., 2017; Part 1, this study), and gravity and magnetic anomaly maps and models, we provide a tectonic model that discusses the correlative origins of the SRSZ from sedimentation and metamorphism from either Wallowa and Olds Ferry terrane, its correlation to the WISZ geometry, and provide insight into the boundaries of the overlapping island arc terranes with each other. Although, the timing component of the SRSZ and the WISZ is still debated as separate events (Tikoff et al., 2001; Giorgis et al., 2008; Blake et al., 2009) or as a continuous tectonic event (Selverstone et al, 1992; Snee et al., 1995; Gray et al., 2013), due to the amount of crustal shortening as shown in the geometry of the SRSZ affected by the dextral transpression of the western Idaho shear zone, we imply an increasing intensity of deformation during the span of tectonism and magmatism around 114-90 Ma (Braudy et al., 2017).

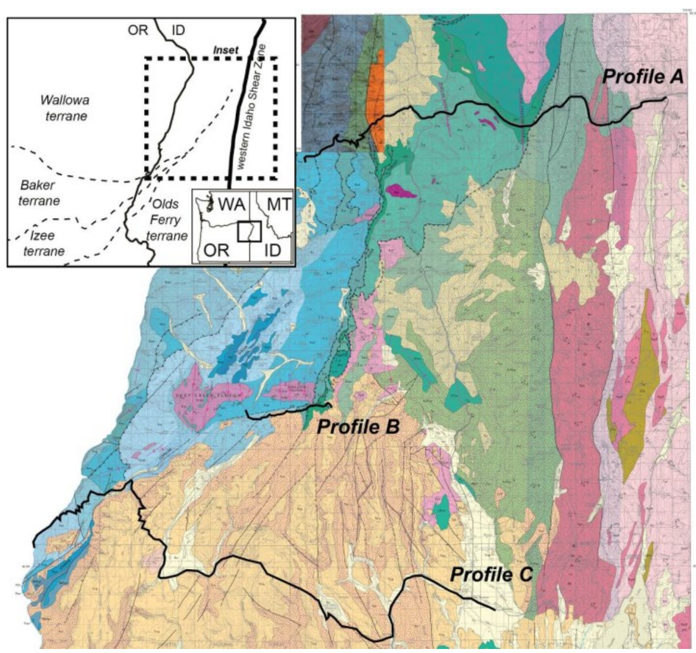

Figure 17. Gravity profiles A, B and C shown over the geologic maps of the Payette National Forest by Lund (2004), and the Riggins area by Hamilton (1969) scaled to western portion of Profile A.

Geologic and Tectonic Background

Blue Mountains Province. The Blue Mountains Province consists of four island arc terranes (Figure 18) that underwent overlapping deformation with each other while accreting to the western edge of mostly passive margin dominated (Bond et. al., 1984) Paleozoic North America. These four (Wallowa, Olds ferry, Baker and Izee) pre-Cenozoic tectonostratigraphic assemblages record magmatism, sedimentation, deformation, and metamorphism (Dickinson, 1979; Walker, 1986; Vallier, 1977; Schwartz et al., 2010) both pre- and post- accretion. In western Idaho, the initial Sr 0.706 isopleth (marks the boundary between the cratonic North America ($^{87}Sr/^{86}Sr>0.706$) and the accreted terranes ($^{87}Sr/^{86}Sr<0.706$) in the easternmost Blue Mountains Province. The Wallowa terrane shares this isotropic boundary which runs parallel to the western Idaho shear zone (Armstrong et al., 1977), with the western portion Salmon River fold-and-thrust belt, also known as the SRSZ.

The two volcanic arc terranes, Wallowa (Permian- Jurassic), and Olds Ferry (Triassic-Jurassic) represent subduction related volcanism (Vallier, 1995, 1998; Avé Lallemant, 1995; Kurz et al., 2012), and record Late Jurassic (159-154 Ma) amalgamation offshore (Schwartz et al., 2010, 2011). The Wallowa terrane contains Permian-Triassic volcanic and metavolcaniclastic packages of greenschist facies (Vallier, 1977,1995) which record no sediment from continental sources suggesting a juvenile and intraoceanic arc (LaMaskin et al., 2008; LaMaskin, 2008; Kurz, 2010), but contain clastic input from the Baker terrane (Vallier, 1977,1995; Follo, 1992, 1994). The Olds Ferry terrane is suggestive of a fringing arc due to the correlative Middle to Late Triassic volcanic rocks to the Quesnel terrane in British Columbia and the fringing-arc system in

Nevada and eastern California (Oldow et al., 1989; Wyld and Wright, 2001; Gray and Oldow, 2005; Dorsey and LaMaskin, 2007), as it has also been similarly compared to modern-day Aleutian volcanic arc (Vallier, 1995). The Baker terrane represents deformation in a subduction related forearc and accretionary complex of the Olds Ferry terrane (Avé Lallemant, 1995; Brooks, 1979; Dickinson, 1979; Ferns and Brooks, 1995; Schwartz et al., 2010, 2011). Deposited in a forearc-intra-arc basin system (Dickinson and Thayer, 1978; Dickinson, 1979, Vallier, 1995) on top of the Olds Ferry terrane, the Izee terrane contains Jurassic-Triassic rocks of sedimentary origins from all three terranes (Dickinson and Thayer, 1978; Brooks and Vallier, 1978; Dickinson, 1979).

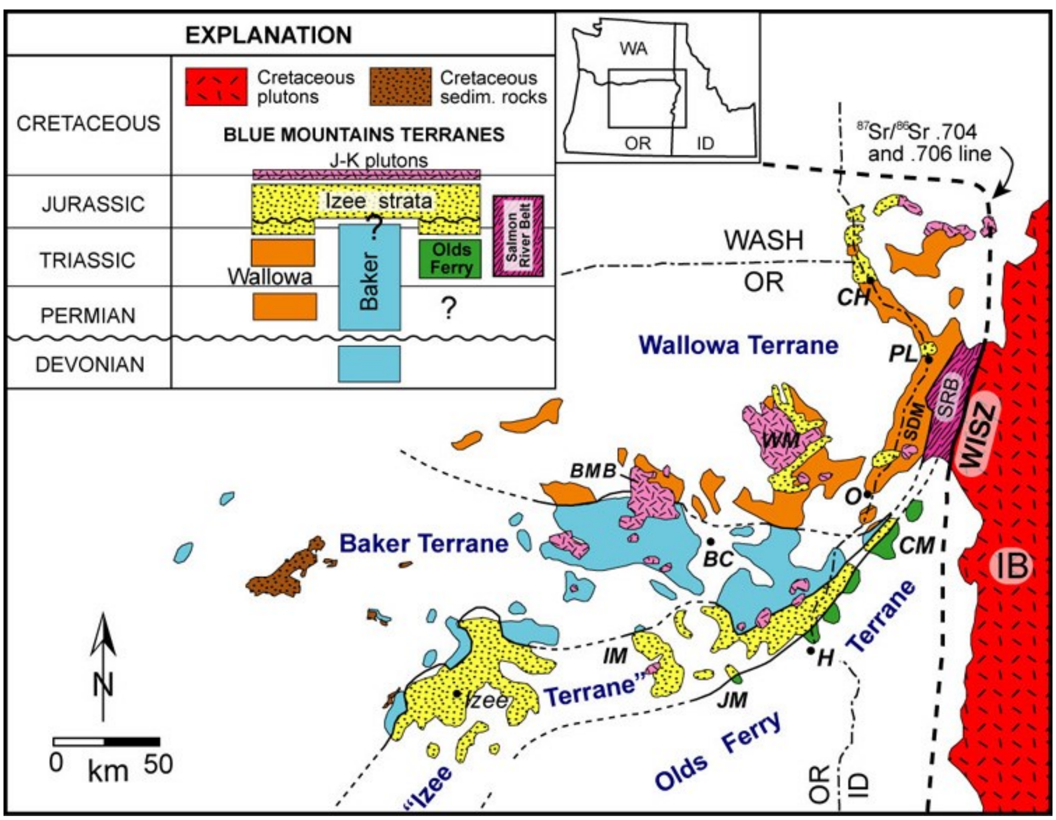

Figure 18. Simplified geologic map of the Blue Mountains Province (from Dorsey and LaMaskin, 2007). Salmon River Belt (SRB) is interchangeably used with Salmon River suture zone.

Post docking of the Blue Mountains Province to inboard Laurentia, a series of amalgamation and accretionary (Selverstone et al., 1992; Getty et al., 1993) events occurred along its western edge led to the formation and metamorphism of the SRSZ (141-124 Ma; Lund and Snee, 1988; Gray and Oldow, 2005; McKay et al., 2017), and clockwise rotation (126 Ma; Wilson and Cox, 1980; Žák et al., 2015) to its current position. Displacement of the Blue Mountains Province (~100 to ~1000 km) mainly northward, has gone through several reconstructions (Oldow, 1984; Wyld and Wright, 2001; Wyld et al. 2003, 2006; Dickinson, 2004; Gray and Oldow, 2005; Housen and Dorsey, 2005; LaMaskin et al., 2011) to accommodate local and regional shortening in the area.

Salmon River suture zone and western Idaho shear zone. The Salmon River suture zone shares its western boundary consisting of greenschist and amphibolite facies rocks along the east-dipping Heavens Gate fault (Gray and Oldow, 2005; Gray, 2013) and Rapid River fault (Hamilton, 1963) with the Wallowa terrane in west-central Idaho. The Salmon River suture zone shares it eastern contact with granitoids of the Idaho batholith (Taubeneck, 1971; Gaschnig et al., 2010); (Figure 20). Although, the shortening in the SRSZ has not been quantified to date, the suture zone underwent crustal scale shortening and thickening exposing the mid-crustal grade rocks, which increases the metamorphic grade towards the east along its thrust faults (Lund and Snee, 1988; Selverstone et al., 1992; Getty et al., 1993; Gray and Oldow, 2005; Blake et al., 2009; Gray et al., 2012; McKay et al., 2017). In this study, we have treated these metamorphic rocks throughout the entire SRSZ exposed near Riggins, Idaho as three distinct thrust fault bound structural plates (Heavens Gate, Rapid River and Pollock Mountain) during

the modeling process, similarly as represented in McKay et al. (2017). From west to east of the SRSZ (Figure 19): 1) the Heavens Gate plate contains upper greenschist facies rocks with potentially correlative protoliths from Middle-Late Triassic upper volcaniclastic units of the Wallowa terrane (Gray, 2013; Kauffman et al., 2014), 2) the Rapid River plate structurally overlies the Heaven's Gate plate, which mostly contains upper greenschist to amphibolite facies rocks (Hamilton, 1963, 1969), and 3) the Pollock Mountain plate contains the highest grade of metamorphic rocks of, high-grade amphibolites and orthogneisses, and is the structurally highest plate in the Salmon River fold and thrust system. The motion in the Rapid River plate noted in rotated garnets (McKay et al., 2017) is kinematically induced along the Rapid River thrust fault. The interaction of the intrusions of the WISZ with the SRSZ within the study area is in the easternmost Pollock Mountain plate. In this region, the Hazard Creek complex was intruded into the Pollock Mountain amphibolite after cessation of metamorphism as suggested by Getty et al. (1993) using a hornblende $^{40}Ar/^{39}Ar$ age of 119 Ma.

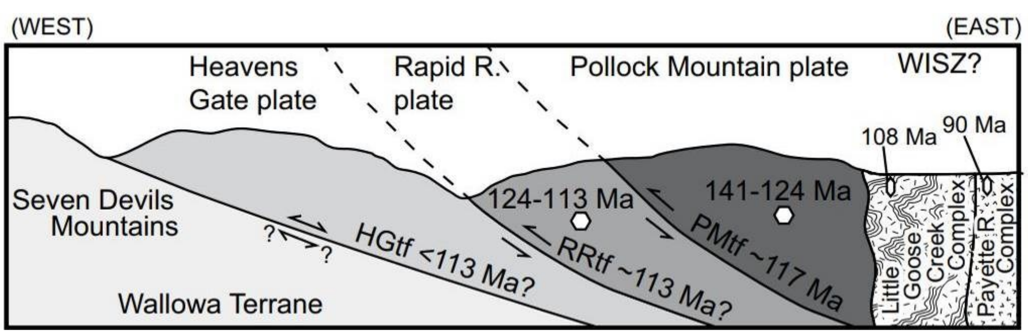

Figure 19. Simplified cross section of the Salmon River suture zone and western Idaho shear zone interaction in west central Idaho (from McKay et al., 2017). HGtf- Heavens Gate thrust fault; RRtf- Rapid River thrust fault; PMtf- Pollock Mountain thrust fault.

Formation of the subvertical and steeply dipping WISZ within the SRSZ represents mid-Cretaceous deformation in the suture zone sub-parallel to the initial Sr 0.706 isopleth. Strong east-west shortening has been noted by Giorgis and Tikoff (2004) and Giorgis et al. (2005) due to the dextral transpressive nature of the WISZ system (McClelland et al., 2000; Giorgis et al., 2017) with north-northeast trending foliation. Intrusive suites of 1) the Hazard Creek complex, which contains two major compositions, tonalite-quartz dioritic orthogneiss and tonalite-trondhjemite (Manduca et al., 1993; Unruh et al., 2008), 2) the Payette River tonalite, which is a syntectonic sill and also the youngest intrusion in the WISZ, and 3) the Little Goose Creek complex, primarily a granitiod-granite orthogneiss (Giorgis et al., 2008) near McCall, Idaho best represent the characteristic deformation in the WISZ. Deformation (118-90 Ma; Manduca et al., 1993; Giorgis et al., 2008; Unruh et al., 2008) and metamorphism (98 Ma; Braudy et al., 2017) associated with the WISZ is well constrained, and spatially and temporally overprints structures like the SRSZ, which was active (McKay et al., 2017) during WISZ deformation. However, the amount of structural imprint along this crustal boundary, through a single long (Gray et al., 2012) or multiple distinct tectonic events is still debated. Any motion along the WISZ is suggested to have ended by 90 Ma (Giorgis et al., 2008) using intrusive fabric analysis and due to truncation by the Orofino shear zone (Manduca et al., 1993; McClelland and Oldow, 2007; Benford et al., 2010), although Schmidt et al., (2017) has suggested that the Syringa embayment is at its current position due to kinematic compatibility with the dextral transpression of the WISZ, but was terminated due to accommodation of contractional and dextral shear stresses by the

Mount Idaho and the Ahsahka shear zone, rather the Syringa embayment transpressionally terminating the WISZ as proposed by Lund (2008).

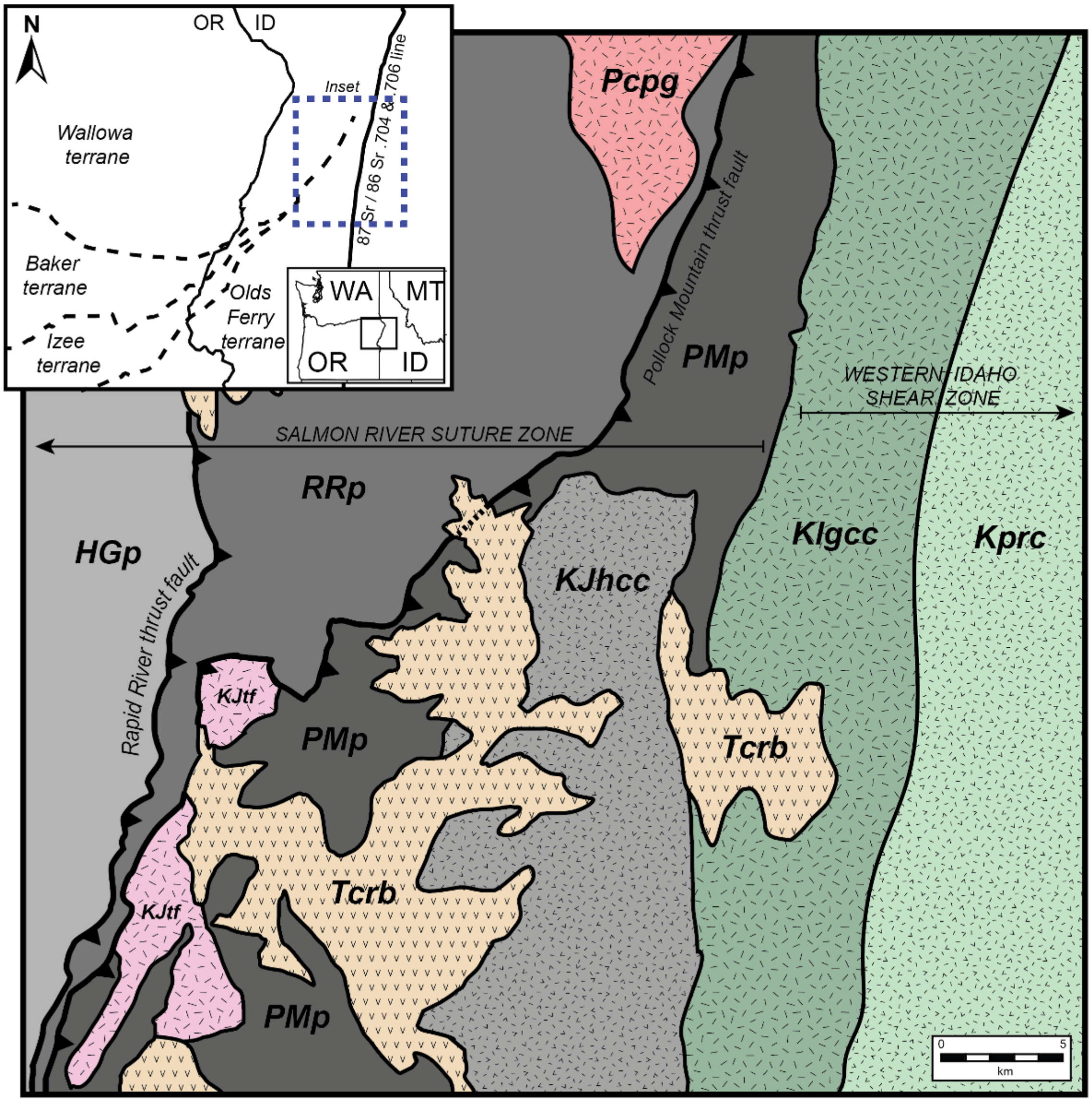

Figure 20. Simplified geologic map of the Salmon River suture zone and western Idaho shear zone boundary. The Salmon River suture zone is divide into three plates; 1) HGp- Heavens Gate plate, 2) RRp- Rapid River plate, and 3) PMp- Pollock Mountain plate. Units include KJtf- Cretaceous-Jurassic plutons, Tcrb- Columbia River basalt, KJhcc- Hazard Creek complex, and Pcpg- Chair point pluton. The Cretaceous intrusions of western Idaho shear zone include Klgcc- Little Goose Creek complex, and Kprc- Payette River complex. For description of inset see Figure 18.

Methodology

Gravity and Magnetic Data and Processing. The gravity data used for this study were obtained from the National Geospatial and Imaging Agency (NGIA), and data collected in this study. Due to the uneven distribution throughout the region, approximately 120 gravity stations were collected (Appendix C) along three (62 km, 18 km, and 100 km) transects, perpendicular to the structures of interests and parallel to the seismic refraction survey of the EarthScope IDOR (Idaho-Oregon); (Stanciu et al., 2016; Davenport et al., 2017). Most of the new gravity stations were collected along backcountry roads due to difficult terrane changes and scarce access with a 1-2 km spacing along transects from 1) French Creek, Idaho to Seven Devils lookout, Idaho, 2) northern base of Smith Mountain, Idaho to Ant Basin trailhead, Idaho, and 3) Homestead, Oregon to intersection of Idaho state highway 55 and US-95. The stations were collected using a LaCoste Romberg gravity meter and locations and elevations were determined using dual frequency differential GPS methods. A local base station in Cascade, Idaho was established to tie it into the absolute gravity base station in Grangeville, Idaho.

All the gravity datasets were merged into a single database with ~38,000 points and reduced to Free-air and complete Bouguer gravity anomalies using the 1967 International Gravity formula, 2.67 gm/cc as reduction density and sea-level as a datum. Terrain corrections were made using a 30 meter DEM, 2.67 gm/cc terrain density and the method of Plouff (1977). The merged complete Bouguer gravity anomaly data were gridded at a spacing of 2 km using the minimum curvature algorithm (Briggs, 1974) and contoured at 10 mGal to construct a complete Bouguer gravity anomaly map (Figure 21).

Aeromagnetic data were obtained from the USGS, with a flight line spacing of 1.6 km (Bankey et al., 2002). The original aeromagnetic data were obtained in 1980 with a flight line of 1.6 km. The data were upward continued to 300m above the terrain. This dataset had the International Geomagnetic Reference Field (IGRF) removed from it. The resultant residual aeromagnetic anomaly data were gridded at 2 km interval and reduced to the pole (Earth's dipolar effect). The reduced to the pole grid was contoured at 200 gamma to produce a reduced to the pole magnetic intensity anomaly map.

Gravity and Magnetic Data Analysis. To understand the subsurface structural relationships using gravity and magnetic methods, identifying individual geologic feature with variable anomalies is essential. Due to small contrasts in magnetic susceptibilities and densities between most geologic features, there is a need for techniques like wavelength filtering, polynomial trend surfaces, isostatic residual method to amplify the anomalies due to the desired geologic features. Since this study mainly focusses on the crustal (upper crust) architecture of western Idaho, the isostatic residual gravity method (Simpson et al., 1986) was used as it has been applied in many regions highlight crustal scale anomalies. This method uses geologically based parameters including the depth of compensation (35 km), density of topography (2.67 g/cc), density contrast across the crustal root (0.30 g/cc) that were obtained from estimations based on the IDOR EarthScope seismic refraction models (Stanciu et al., 2016; Davenport et al., 2017). The resultant isostatic residual anomaly map (Figure 22) best represents anomalies caused by crustal sources, and is used to discuss the major structures (WISZ, SRSZ, and OCSZ) in western Idaho.

The complete Bouguer gravity anomaly map (Figure 21) can be broadly separated into three main anomaly regions, in accordance to the regional geology of the area: 1) the Idaho batholith that corresponds to a low amplitude gravity anomaly, with values less than -200 mGal slowly increasing in amplitude up to -151 mGal in a south to north trend in eastern Idaho, 2) the Snake River Plain which corresponds to high amplitude gravity anomaly values that covers parts of Idaho and Oregon, and 3) the Columbia River Basalt region that corresponds to a gravity high in parts of Idaho, Washington, and Oregon. Gravity highs over the Snake River Plain and Columbia River Basalts have been noted by several researchers (Mabey, 1982; Mohl and Thiessen, 1995; Mabey et al., 2007). The earliest delineation of the steep gravity gradient in the region was noted by Thiessen et al. (1992), which is related to the cratonic margin in the western U.S., although the Mohl and Thiessen (1995) suggested that the highs were not consistent or parallel with the initial Sr 706 isopleth due to anomalies near the SRSZ region which most likely represented high grade metamorphic rocks, and mafic and ultramafic bodies at the surface.

A more detailed analysis of the complete Bouguer gravity anomaly map reveals isolated gravity lows such as the Wallowa batholith (WB, Figure 21) and the intrusive plutonic suites of Cuddy Mountains. High amplitude, short wavelength gravity highs and lows in the western portion of the study correlate to the accreted terranes of the easternmost Blue Mountains Province.

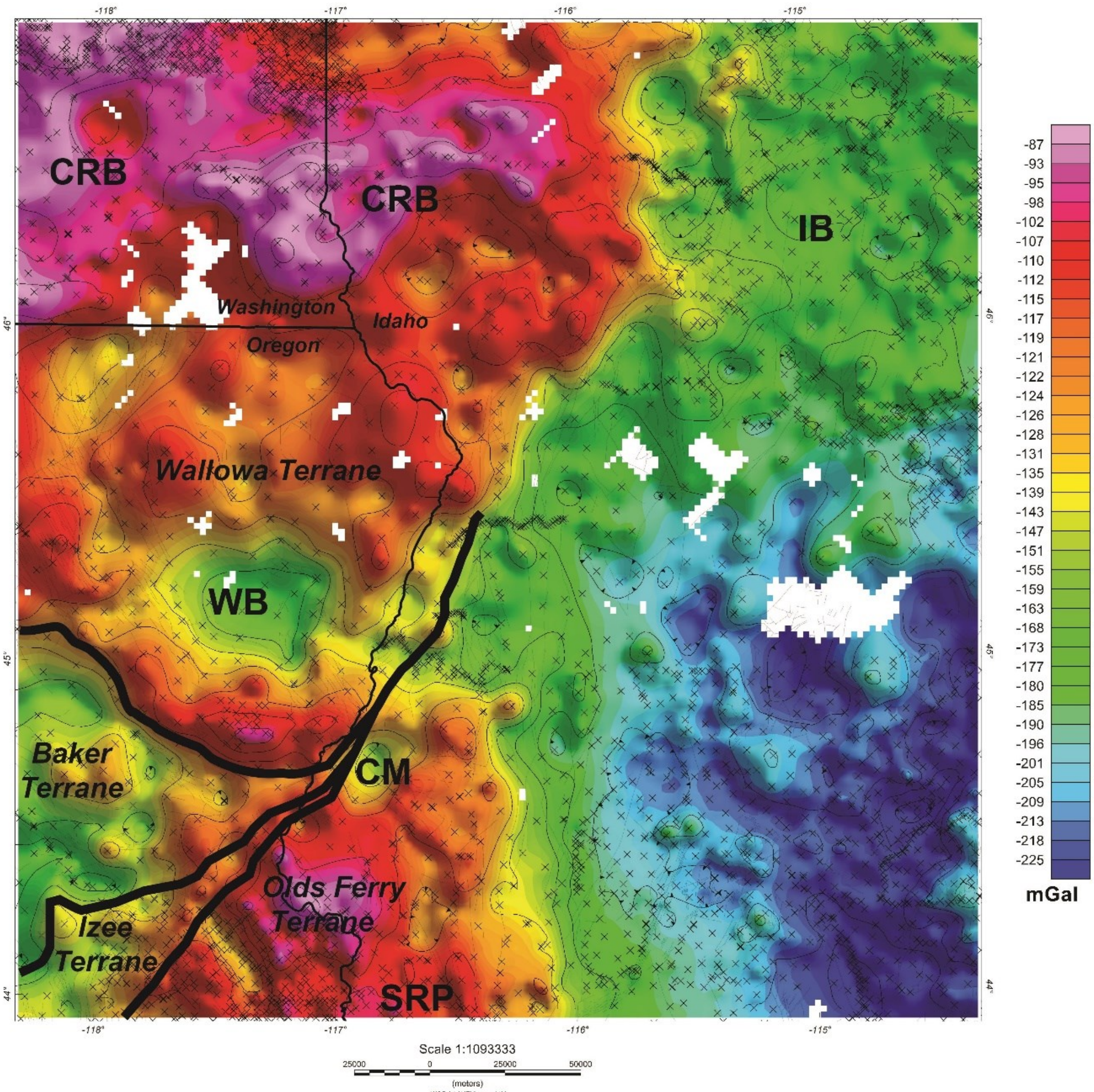

Figure 21. Complete Bouguer anomaly map. Contour interval 20 mGal. Geologic features in the map include WB- Wallowa batholith, CM- Cuddy Mountain, SRP- Snake River Plain, IB- Idaho batholith, and CRB- Columbia River basalt. The “X”s represent gravity stations in the region, and the bold lines represent the accreted terrane boundaries.

When juxtaposed on the complete Bouguer gravity anomaly and isostatic residual anomaly map (Figure 21 and 22), the geologically drawn boundaries of the arc terranes based on ages, composition, geochemistry, metamorphism and deformation, correlate to gravity highs and lows in the metavolcanic terranes (Wallowa and Olds Ferry) and

metasedimentary terranes (Baker and Izee) respectively. The lows generally associated in the Wallowa and Olds Ferry terranes are Cretaceous-Triassic plutonic bodies (e.g. Wallowa batholith), or sedimentary packages on top of the volcanic terranes. The terrane boundaries were initially overlain in accordance to a compilation of surficial exposure studies in the region by Dorsey and LaMaskin (2007), however during the evaluation and further processing of the gravity and aeromagnetic data, updated geophysically-based boundaries were drawn on the complete Bouguer and isostatic residual anomaly maps. There is considerable overlap with terrane boundaries that were based on surficial outcrop mapping. Gravity maps, however, provide enhanced resolution in areas with poor exposure compared to surficial mapping. Thus, we present an updated map of terrane boundaries that represents the extent of terranes at the crustal scale. The close correlation of surficial and geophysically defined terrane boundaries at places could suggest high steepness of the terrane boundaries with each other, at the particular spot.

The most prominent gravity anomaly feature in the isostatic residual anomaly map (Figure 22) and the complete Bouguer anomaly map (Figure 21) is the boundary between the accreted arc terranes of Blue Mountains Province and Precambrian North America with gravity minima with values less than -185 mGal and maxima vales higher than -100 mGal, mostly trending north-south and it is noted by a steep gravity gradient.

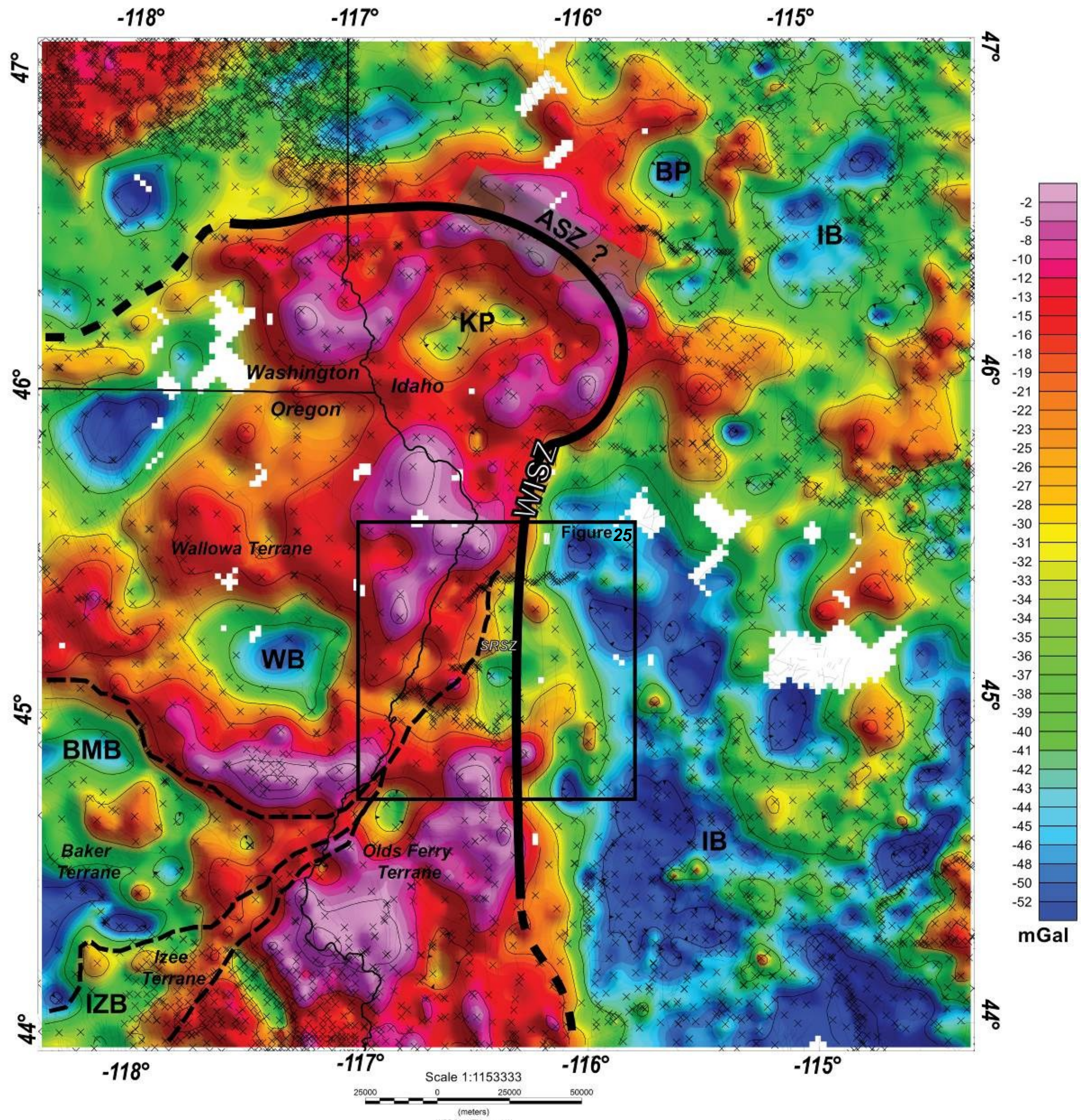

Figure 22. Isostatic residual gravity anomaly map. Contour interval 20 mGal. Geologic features include WB- Wallowa batholith, BMB- Bald Mountain batholith, BP- Bunglow pluton, IB- Idaho batholith, KP- Cretaceous plutons, ASZ- Ahsahka Shear zone, and IZB- Izee basin sediments. The "X"s represent gravity stations in the region, the dotted line represent the accreted terrane boundaries, and the bold line represents the WISZ.

This boundary has been noted by Thiessen et al. (1992) and Mohl and Thiessen (1995) in their gravity studies of the region. EarthScope seismic refraction studies by Davenport et al. (2017) and Stanciu et al. (2016) provide a broader model of the crust and

show a ~7 km offset in the Moho boundary at this gravity anomaly gradient and related this to WISZ. Eager et al. (2011) shows similar offset (Figure 23) in the Moho boundary as mentioned above. The western Idaho shear zone on the isostatic residual anomaly map can be traced to the north, past the northwest- southeast trending gravity maxima of value -87 mGal possibly related to the Ahsahka shear zone (Giorgis et al., 2017, Schmidt et al., 2017) near Orofino, where deformation occurred simultaneously along with the WISZ between 116-92 Ma (Schmidt et al., 2017).

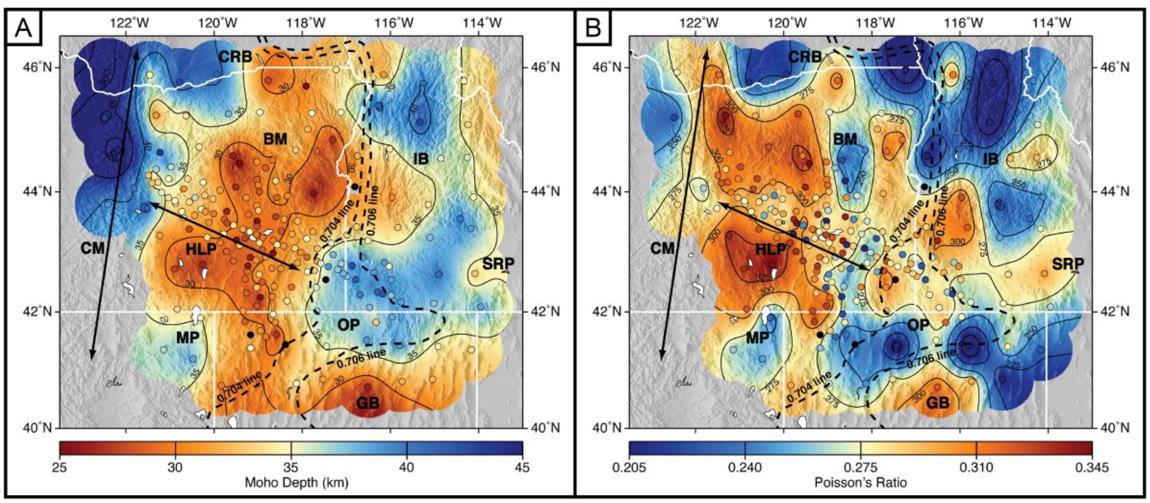

Figure 23. Receiver function analysis from Eager et al., (2011). A) Depth to Moho, and B) Poisson's ratio. Colored circles represent single station results. Geologic provinces represented include Blue Mountains (BM), Idaho batholith (IB), Snake River Plain (SRP), Cascade volcanic arc (CM), High Lava Plains (HLP), Columbia River basin (CRB), Owyhee Plateau (OP), Modoc Plateau (MP), and Great Basin (GB).

The reduced-to-the-pole magnetic anomaly map (Figure 24) was analyzed without the need of enhancement techniques to locate lateral contrasts in magnetic susceptibility boundaries. The map is divided into two anomaly trends that were previously identified on the complete Bouguer gravity anomaly map (Figure 21) as the accreted terrane and the

Precambrian North America, with extensive change in magnetic anomaly maxima and minima in the accreted terrane region. These indicate high magnetizations of the metavolcaniclastics of Wallowa and Olds ferry terrane, and low magnetizations of the metasedimentary basements of Baker and Izee terranes (Figure 24), and a lower trend of magnetization (70 nT to -138 nT) in the Idaho batholith near the contact of the cratonic North America. Highest magnetic intensities observed in the southern, western, and north-western portion of the map (Figure 24) is mostly due to the Columbia River Basalt Group (Mabey, 2007).

A series of gravity minima align with several Early Cretaceous-Late Jurassic granitic bodies such as the Bald Mountain Batholith, Bunglow pluton, Cretaceous plutonic complexes such as Hazard Creek complex, Deep Creek and Echols Mountain plutons, Wallowa batholith, and Cuddy Mountain (Figure 22). The metasedimentary suites of the Baker terrane and Izee terranes show similar gravity anomalies to the metasedimentary suites in the SRSZ ranging from -180 mGal to -151 mGal.

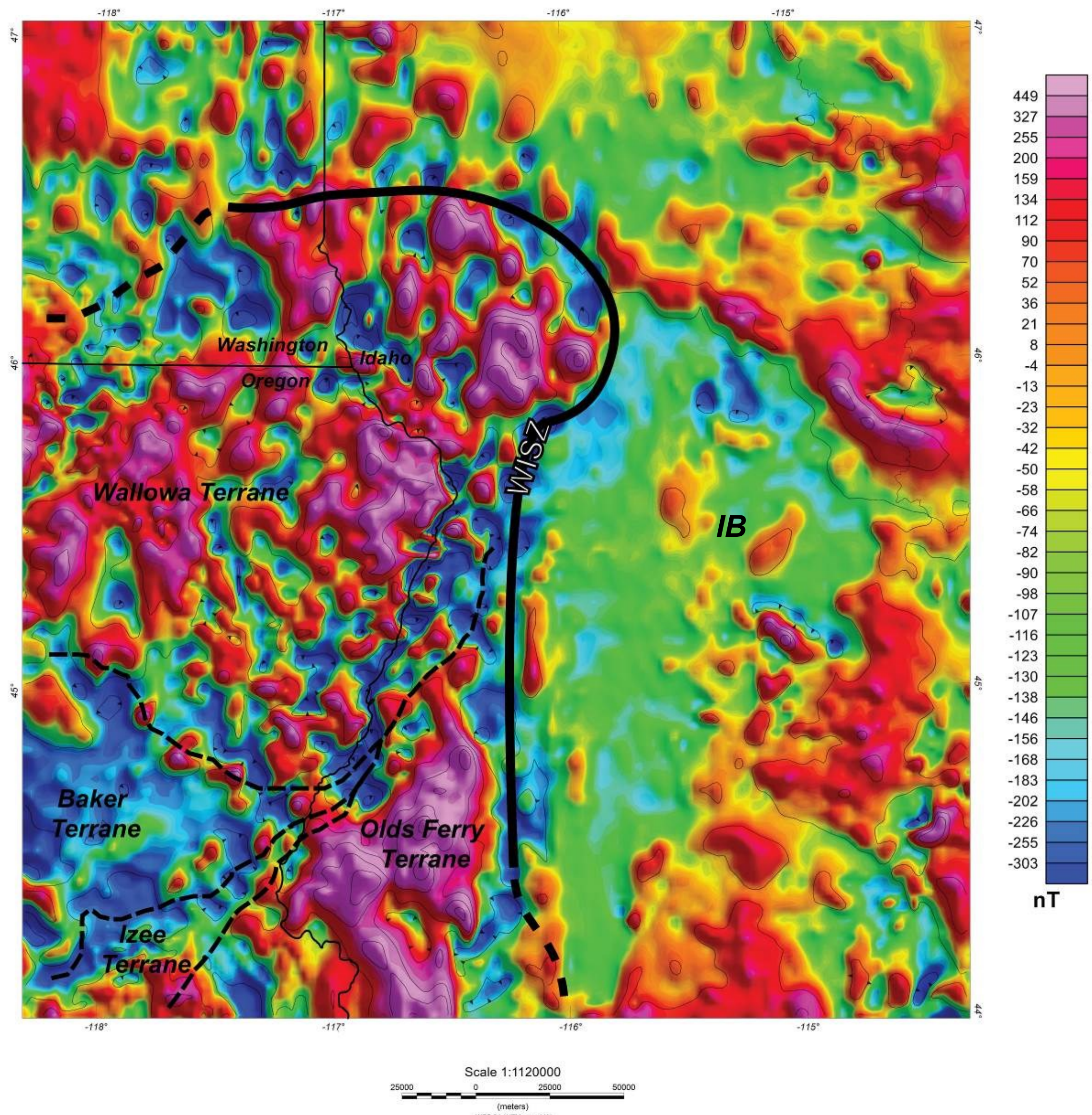

Figure 24. Reduced-to-pole aeromagnetic map with terrane boundary overlain. Contour interval 200 gamma. Geologic feature include WISZ- western Idaho shear zone, and IB- Idaho batholith. The dotted line represent the accreted terrane boundaries, and the bold line represents the WISZ.

A closer look (Figure 25) at the anomalies over SRSZ and WISZ boundary highlights minima over the WISZ intrusions and Idaho batholith and maxima over the Wallowa and Olds Ferry terrane. The Salmon River suture zone contains a distinct anomaly that has been described by Mohl and Thiessen (1995) as a gradient between

highs and lows at the boundary of accreted arc terranes and cratonic North America. Similar gradients can be seen on Figure 22 over the Izee and Baker terranes. Protoliths of the SRSZ rocks are still debated, modeling of gravity data listed below along profile A (Figure 26) suggests that the SRSZ could be itself a part of the Olds Ferry terrane with sedimentation from either Wallowa or the Olds Ferry terranes that has undergone ductile deformation and have been metamorphosed.

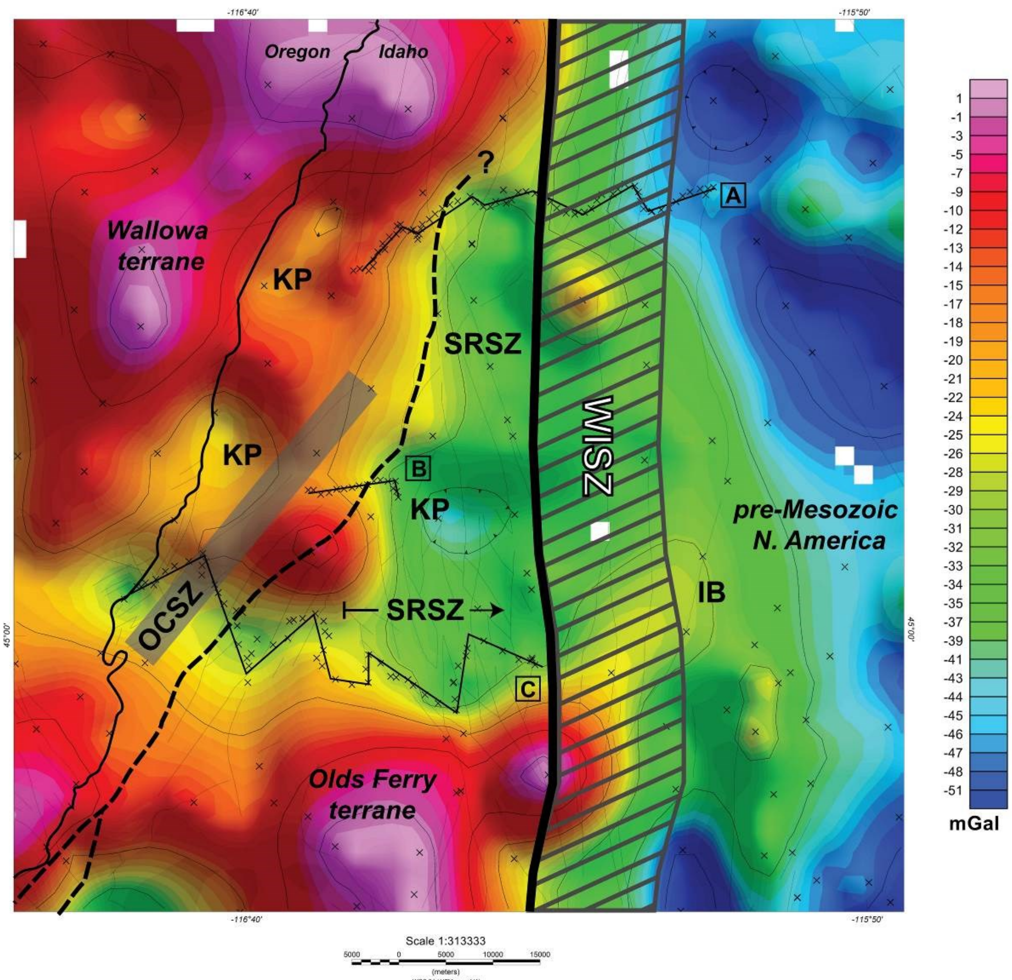

Figure 25. Isostatic residual gravity anomaly map of the region modeled. Profiles A, B, and C shown. Contour interval 20 mGal. The hashed region is the region proposed to have been affected in the Salmon River suture zone (SRSZ) by the western Idaho shear zone (WISZ) through 2.5-D geophysical modeling. Geologic features include KP-Cretaceous plutons, OCSZ- Oxbow-Cuprum shear zone, and IB- Idaho batholith. The dotted line represent the accreted terrane boundaries, and the bold line represents the WISZ.

Modeling and Discussion

To understand and quantify the isostatic residual and complete Bouguer gravity anomalies (Figure 22) that represent the WISZ and SRSZ interaction in the subsurface, crustal-scale gravity models were constructed along profiles A, B and C (Figure 26, 27 and 28), that cross this major boundary between the Wallowa terrane and Precambrian North America. The models were derived using a 2.5-dimensional, forward-modeling algorithm (Lai, 1984) in which the calculated gravity anomalies are obtained using the gravity station elevations. Due to the non-unique nature of gravity models, to construct geologically sound models constraints such as rock densities, lateral distribution of lithologies, depths to various rock units, and the thickness of the lithologies from previously mapped regions must be determined. Due to the nature of the study, only the upper crust is modeled for the Wallowa terrane with an estimated density for the mid-crust. The results from EarthScope IDOR project and receiver function analysis from Eager et al. (2011) as shown in Figure 23 were used to determine the crustal thickness of the WISZ, which also suggested that other than the gravity high over the WISZ due to the ~7 km offset (Davenport et al., 2017) in the Moho, it is probably safe to assume while quantifying the anomalies that most of the observed gravity anomalies reflect the upper crustal density sources. The near-surface rock densities used in the models were estimated and calculated with a combination of averaged densities (Telford et al. 1990) from rock samples measured worldwide, densities of rocks in the Idaho region reported by Mabey (2007), and from rock samples collected from the mapped region by the author. The density of the mid-crustal and lower-crustal blocks, and the mantle were estimated using *P*-wave velocities (Davenport et al., 2017) and experimental

density/velocity relationships (Nafe and Drake, 1957). Constraints on lateral location of lithologies and thickness of rock units were provided by compilation of the geological maps in the region (Hamilton, 1963,1969; Lund, 2004; Gray, 2013; Blake et al., 2016; Plate 1: Part 1). Due to the nature of the complex heterogeneous distribution and deformation, the stratigraphy of the lithologies representative in the SRSZ and the Seven Devils Group has been simplified for modeling purposes.

Through a trial and error method (Mickus and Montana, 1999) to match the calculated gravity value with the observed gravity values, the gravity models (Figure 26, 27 and 28) were obtained with the geological and geophysical constraints. The final models are non-unique in nature, but are reasonable in respect to evaluated cross sections from aforementioned maps, and acquired geologic constraints. Magnetic susceptibility values were used alongside density to constrain bodies at the surface and subsurface while modeling. The geologic features modeled along the profiles were mainly created to aid locating the crustal scale extent and relationship of the WISZ and the SRSZ. The main points and unique aspects of every profile modeled will be described separately. The density and magnetic susceptibility values for every lithologic unit modeled is listed in Table 1, 2 and 3.

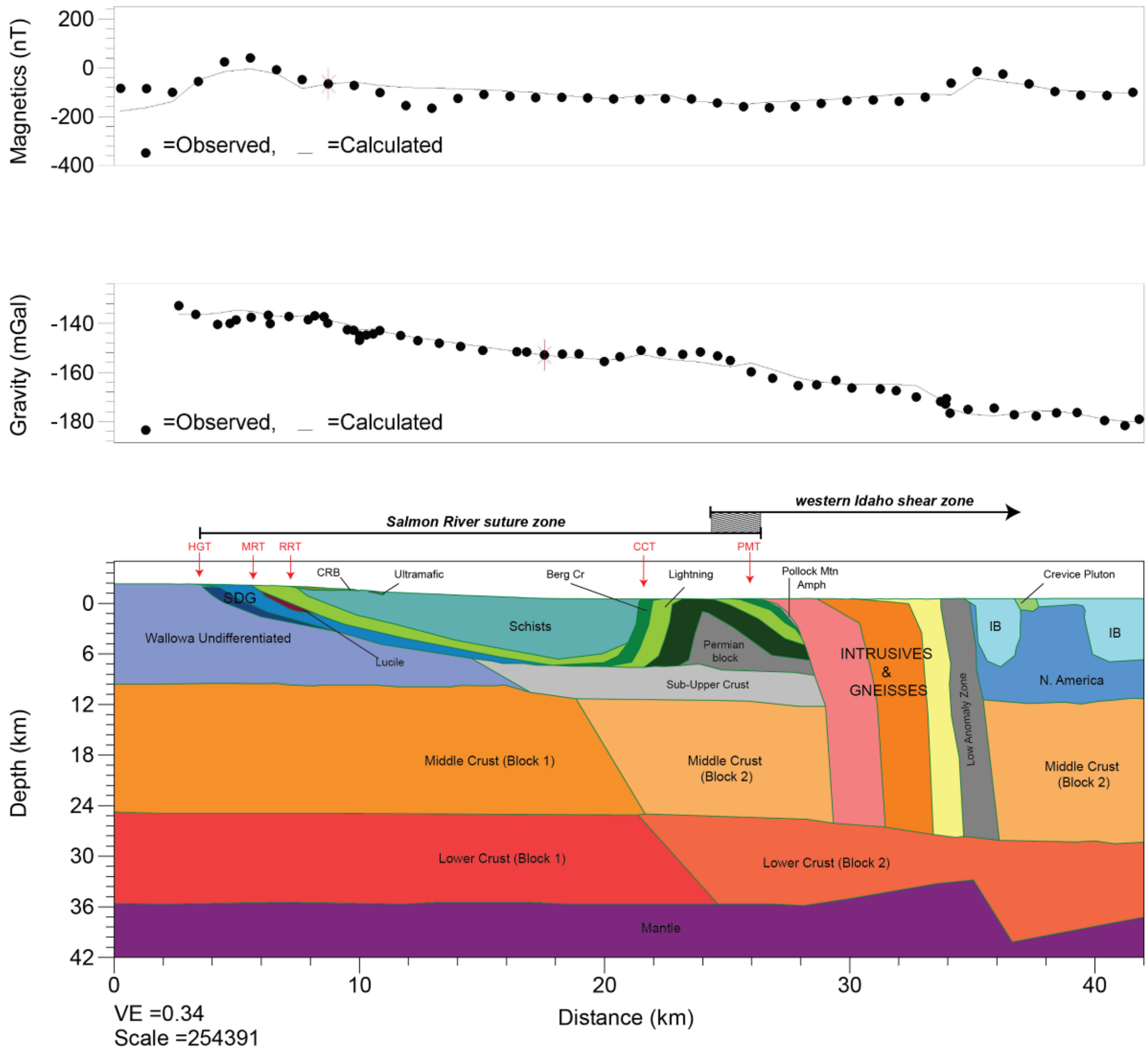

Figure 26. 2.5-D gravity and magnetic model of Profile A. The thrust faults represented are: HGT- Heavens Gate thrust, MRT- Morrison Ridge thrust, RRT- Rapid River thrust, CCT- Cat Creek thrust, and PMT- Pollock Mountain thrust. Densities and magnetic susceptibility values are shown in Table 1. The ~7 km offset at Moho is shown at the WISZ and Precambrian North American boundary.

Profile A. Profile A (Figure 26) is approximately 42 km long and crosses two major tectonic features, the WISZ and the SRSZ. This line includes 61 gravity stations, with the complete Bouguer gravity anomaly values ranging from approximately -150 mGal to -182 mGal, and 40 aeromagnetic data points, with values ranging from 50 nT to -150 nT. The thickness of the crust ranges from ~40 km to ~33 km. This ~7 km of

discrepancy of the Moho over the WISZ is consistent with the model proposed in Davenport et al., (2017).

Table 1. Density and magnetic susceptibility values used in the Profile A. All the values shown were measured from samples collected during the gravity survey, and generalized values of major rock types in Simmons et al. (2007).

Profile A	**Blocks/ Units/ Layers**	**Density (g/cm^3)**	**Susceptibility (emu)**
	Columbia River Basalt (CRB)	2.94	0.0008
	Ultramafic pod	2.89	0.000002
	Wallowa Undifferentiated	2.725	0.0016
Seven Devils Group	Hunsaker Cr	2.65	0.0006
	Wild Sheep Cr	2.82	0.0006
	Pollock Mtn Amphibolite	2.98	0.00001
	Schist	2.71	0.0006
	Berg Cr Schist	2.9	0.0005
	Fiddle Cr Schist	2.77	0.00001
	Lightning Cr Schist	2.73	0.00001
	N. America	2.7	0.0002
	Lucile pod	2.75	0.0009
	Idaho batholith (IB)	2.6	0.0002
	Crevice pluton	2.66	0.000001
	Low Anomaly Zone	2.56	0.0008
	Van Ridge Gneiss	2.84	0.0005
Intrusive suite	Granodiorites	2.71	0.0005
	Spring Creek tonalite	2.73	0.0006
	Permian Block	2.77	0.003

Overall, the gravity values decrease from west (easternmost Blue Mountains Province) to the east (pre-Mesozoic North America). Higher gravity values mostly correspond to thrust faults related to the SRSZ, with exceptions including the area of juxtaposition (although, the exact location is still yet to be determined) of the WISZ into the SRSZ. Although the high gravity anomaly could be due to the Pollock Mountain

thrust. The magnetic anomalies show two prominent highs on the profile, 1) over the western boundary of the SRSZ with the Wallowa terrane, and 2) over the WISZ boundary with the North American craton. The geometry in the upper crust represented in the model is consistent with east-west shortening (Giorgis and Tikoff, 2004; Giorgis et al., 2005) increasing in amplitude from west of the model to the east, associated with the WISZ and the SRSZ. Coincidentally, the deformation and metamorphism in the SRSZ also increases from west to east (Lund and Snee, 1988; Selverstone et al., 1992; Getty et al., 1993; Gray and Oldow, 2005; Blake et al., 2009). The upper crust in the model shows a west trending top shear, best shown over the intrusive of WISZ. Although, the clockwise rotation of the Blue Mountains Province (Wilson and Cox, 1980; Žák et al., 2015) could possibly suggest this top shear, it is mostly likely related to the final accommodation of the dextral shear stresses at the termination of motion (Manduca et al., 1993; McClelland and Oldow, 2004, 2007; Lund, 2008; Schmidt et al., 2017) of the WISZ.

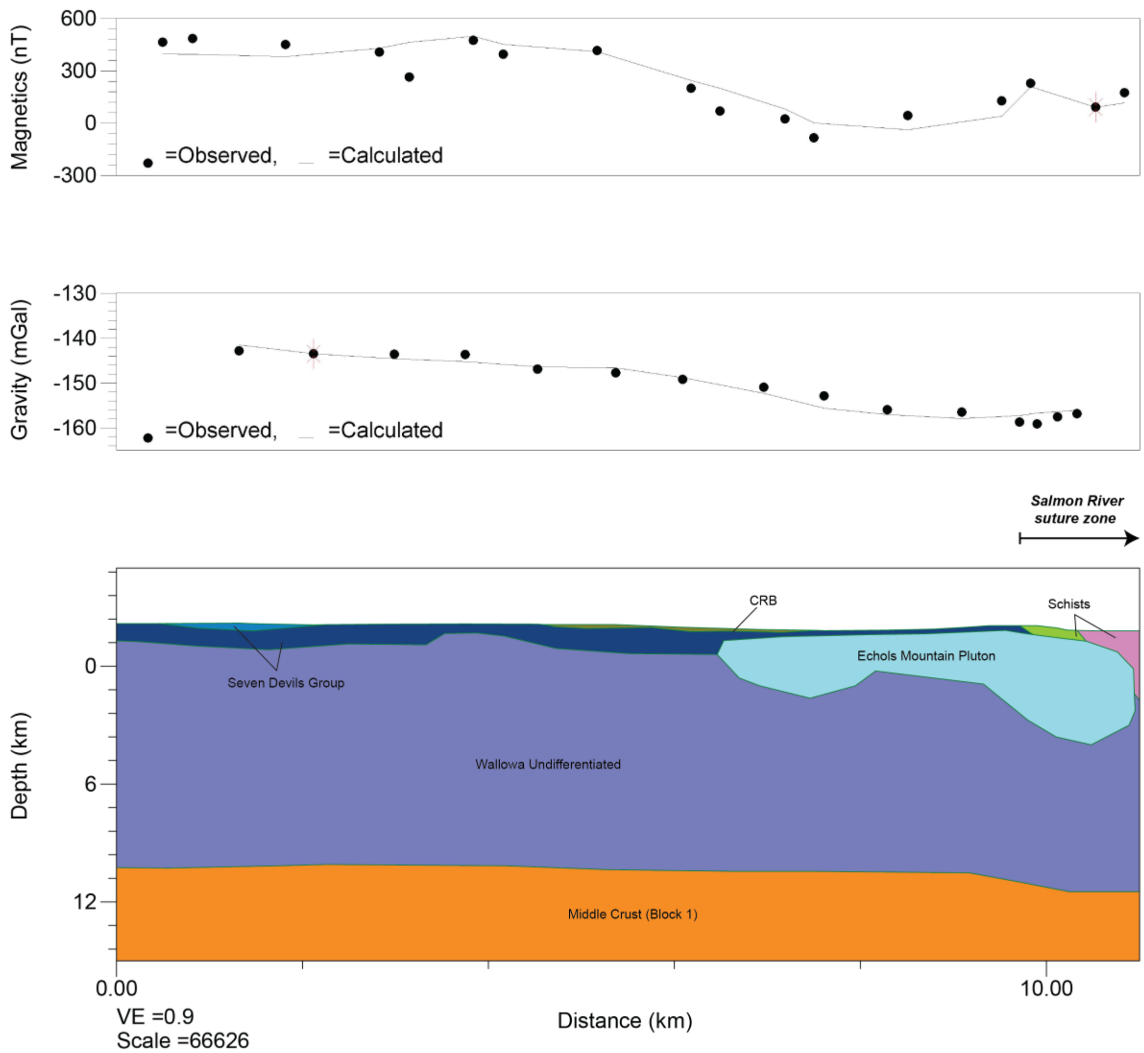

Figure 27. 2.5-D gravity and magnetic model of Profile B. Densities and magnetic susceptibility values are shown in Table 2.

Profile B. Profile B (Figure 27) is approximately 12 km long and crosses the Heavens gate and Rapid River thrust fault at the eastern edge of the transect. This line includes 15 gravity stations, with complete Bouguer gravity anomaly values ranging from approximately -144 mGal to -160 mGal, and 17 aeromagnetic data points with values ranging from approximately -100 nT to 500 nT. The middle and lower crust modeled in profile A (Figure 26) was found to be similar in profile B. The entire upper crust is

modeled as part of the Wallowa terrane of the Blue Mountains Province due to minimal differences in gravity values over the profile.

Table 2. Density and magnetic susceptibility values used in the Profile B. All the values shown were measured from samples collected during the gravity survey, and generalized values of major rock types in Simmons et al. (2007).

Profile B	Blocks/ Units/ Layers	Density (g/cm3)	Susceptibility (emu)
	Columbia River Basalt (CRB)	2.94	0.003
	Echols Mountain pluton	2.56	0.000001
Seven Devils Group	Wild Sheep Cr	2.82	0.0004
	Hunsaker Cr	2.65	0.0001
	Schists (green)	2.71	0.0033
	Schists (pink)	2.7	0.0016
	Sub-Upper Crust	2.7	0.003
	Upper Crust	2.67	0.005
	Mid Crust (Block 1)	2.82	0.004
	Mid Crust (Block 2)	2.78	0.004
	Lower Crust (Block 1)	2.94	0.003
	Lower Crust (Block 2)	2.96	0.003
	Mantle	3.31	0.003

The overall gravity values decrease from west (eastern edge of the Blue Mountains) to east (western edge of the SRSZ). The magnetic maxima and gravity minima over the Heavens Gate plate most likely represents the Blue Mountains Province and SRSZ boundary exposed at the surface as a fault (Morrison Ridge thrust) which thrusts lower greenschist grade rock on top of the volcanics of the Seven Devils Group. The most prominent feature on the model is the Cretaceous Echols Mountains pluton, which is interpreted to intrude the Heavens Gate and Rapid River plate. The folded geometry of the Seven Devils Group aligns with the geologic cross section (Plate 1: Part

1) of the Purgatory Saddle quadrangle which also contains highest exposure of the Echols Mountain pluton at the surface near the transect.

Profile C. Profile C (Figure 28) is approximately 47 km long and excluding the westernmost part of the model, almost all of the lithology exposed at the surface along the transect is Columbia River flood basalt (CRB). This profile models the probable extent of interaction of the Wallowa terrane and the SRSZ to the south. This line includes 50 gravity stations, with Bouguer gravity anomaly values ranging from approximately -136 mGal to -164 mGal, and 54 aeromagnetic data points with values ranging from approximately -400 nT to 300 nT. Profile C has same general crustal characteristics as Profile A and B, hence only the upper crustal features of the model are displayed and explained.

The gravity values generally increase, and magnetic values generally decrease from east to west. Two distinct gravity maxima have been modeled: 1) the Oxbow-Cuprum shear zone (OCSZ), and 2) SRSZ. The Oxbow-Cuprum shear zone has been mapped (Taubeneck, 1966; Vallier, 1967; White, 1968; and Lund, 2004) along and around the western edge of the model. It has been previously interpreted to be a part of the Wallowa terrane pre-accretion to Laurentia (Vallier, 1967; White, 1968; Lund, 2004). In the profile, the Oxbow- Cuprum shear zone (2.87 g/cm^3) has been modeled similarly to the orientation mapped at the surface (Plate 1: Part 1). A high amplitude gravity anomaly along with a magnetic minima to the east of the Oxbow-Cuprum shear zone has been modeled as a fault that pre-dates the shear zone itself and, thrusts the Seven Devils Group on it itself. Block 2 has been modeled to adjust the gravity maxima ~4 km to the west of the Oxbow-Cuprum shear zone, with a density of 2.86 g/cm^3. This block could be a part

of the shear zone itself, due to similarities in density, which would suggest that the Oxbow-Cuprum shear zone is wider in the subsurface by a factor of 2, than is exposed at the surface, or could be a high density body within the Wallowa terrane that is not exposed. The gravity maxima in the middle of the transect (26-28 km) has been modeled as an interaction of the western edge of the Blue Mountains Province and the high grade metamorphic rocks of the SRSZ.

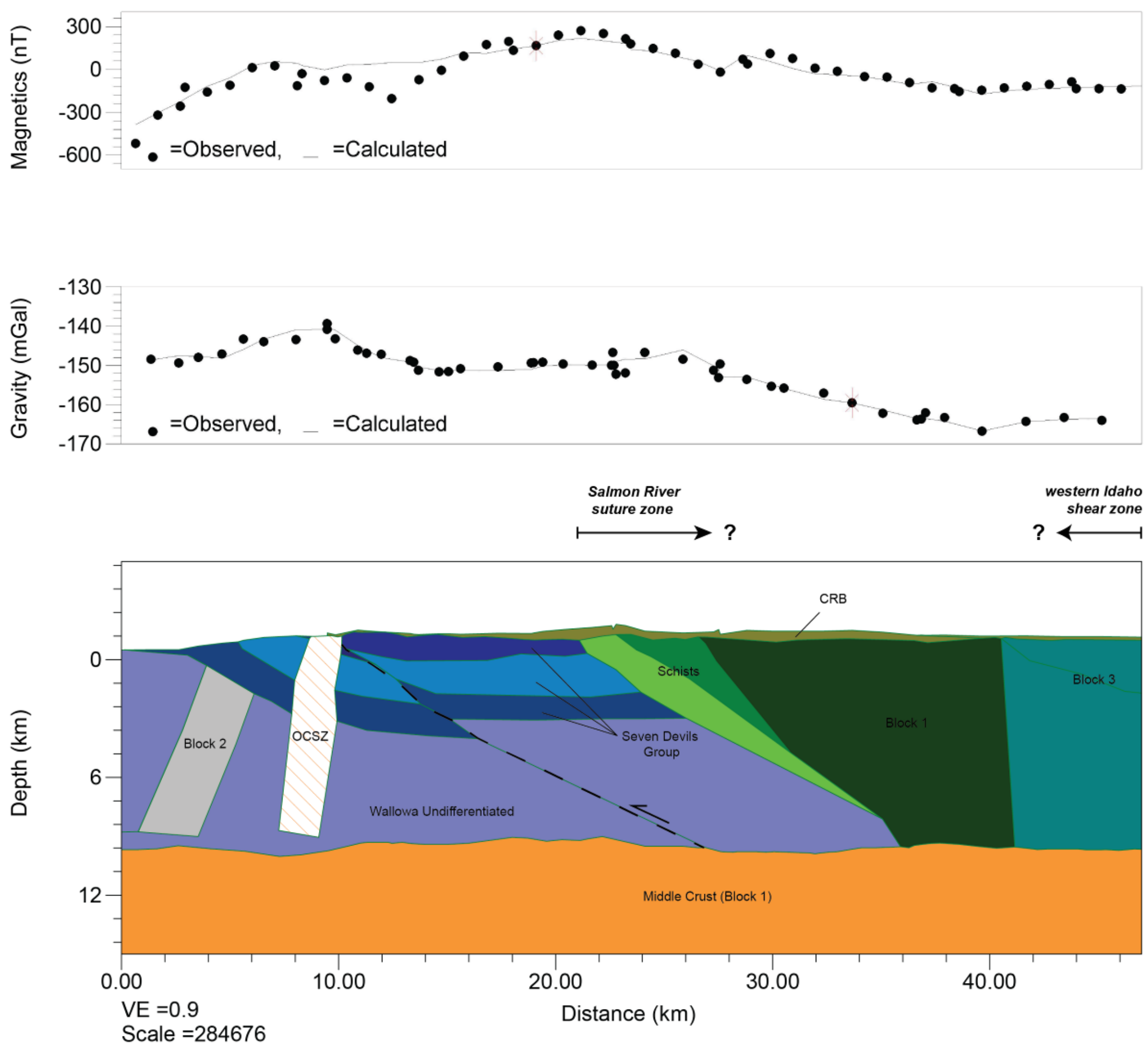

Figure 28. 2.5-D gravity and magnetic model of Profile C. Densities and magnetic susceptibility values are shown in Table 3.

Table 3. Density and magnetic susceptibility values used in the Profile C. All the values shown were measured from samples collected during the gravity survey, and generalized values of major rock types in Simmons et al. (2007).

Profile C	Blocks/ Units/ Layers	Density (g/cm3)	Susceptibility (emu)
	Schists (light green)	2.71	0.00001
	Schists (green)	2.97	0.000016
	Oxbow-Cuprum shear zone	2.87	0.00004
Seven Devils Group	Hunsaker Cr	2.65	0.0001
	Wild Sheep Cr	2.82	0.000001
	Doyle Cr	2.71	0.000001
	Wallowa Undifferentiated	2.725	0.0033
	Columbia River Basalt (CRB)	2.94	0.0022
	Block 3	2.84	0.00001
	Block 2	2.86	0.0003
	Block 1	2.73	0.00001

The leading edge of the subbasalt SRSZ boundary to the west is marked by the Morrison Ridge thrust fault and is likely comprised of schists (similar gravity values to the schists in Profile A) that are compatible with belonging to the Rapid River thrust plate. Gravity changes mark a significant boundary defining the western edge of Block 1 with density of 2.73 g/cm^3 and Block 3 with density of 2.84 g/cm^3 to the east. These bodies could belong to SRSZ or the WISZ. The gravity and magnetic low at the intersection of Block 1 and Block 3 corresponds to similar complete Bouguer gravity values (approximately -160 mGal) seen at the intersection of the SRSZ and the WISZ in Profile A, thus suggests a southern interaction of these tectonic features. This interpretation would suggest that Block 1 is part of the Pollock Mountain plate of SRSZ containing the highest grade of metamorphism rocks with high densities (>2.84 g/cm^3), and Block 3 is part of the Cretaceous intrusions (lower density) corresponding to the WISZ.

Figure 29 illustrates a simplified tectonic model based on the three profiles (Profile A, B and C). This model is consistent with the tectonic model proposed by Tikoff et al. (2017), which is interpreted from recent geophysical and geochronological studies (Fayon et al., 2017; Byerly et al., 2017; Kurz et al., 2017; Davenport et al., 2017). It suggests a ~7 km offset of the Moho due to the WISZ, and proposes a relationship of the Wallowa terrane with the SRSZ. The Salmon River suture zone is modeled to originate from either from the Wallowa or the Olds Ferry terrane. The Salmon River suture zone has intermediate to low gravity signatures as observed in complete Bouguer gravity anomaly map (Figure 21) and isostatic residual gravity anomaly map (Figure 22), which is compatible with being correlated to either Baker or Izee terrane. Tumpane (2010) suggested a probable correlation of Wallowa and Olds Ferry sedimentation prior to collision, although McKay (2011) has discussed the possibility of either or neither being a protolith for the SRSZ rocks due to the suture zone's possible relationship to a lost back-arc basin which would erase any deformational correlation of the Olds Ferry and Wallowa terranes during a polydeformational collisional sequence.

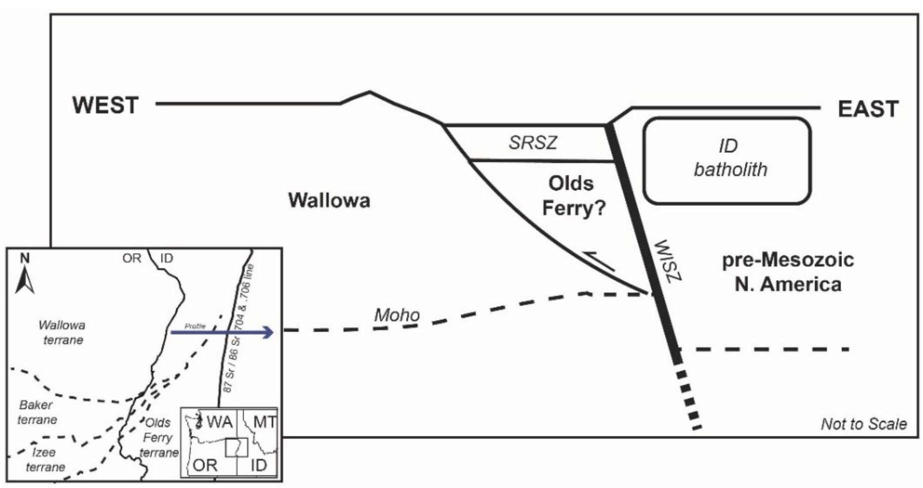

Figure 29. Tectonic model of easternmost Blue Mountains Province's boundary with cratonic North America.

Conclusion

Gravity and magnetic anomaly analysis using Bouguer and residual anomaly maps, and 2.5-D models of the boundary of easternmost Blue Mountains Province with the SRSZ and WISZ in western Idaho reflects a ~7 km offset in the Moho below the WISZ. The accreted terranes in the eastern Blue Mountains Province form a steep boundary with each other at mid-lower crustal depths. The intrusions of WISZ in the SRSZ reveals an east-west shortening increasing from west to east of the suture zone.

Models help constrain a regional tectonic model of the accreted arc terrane boundary and reveal new localized and regional details, while confirming previous conclusions in tectonic studies.

1. The western Idaho shear zone dips steeply to the east along the North American craton as modeled in Profile A (Figure 26) along Riggins, Idaho.
2. Changes in density of the sub-upper crust, lower-middle crust below the SRSZ along the western boundary of the steeply east dipping Wallowa terrane extending to the lower crust is interpreted as the Olds Ferry terrane.
3. The crustal thickness from west to east decreases from ~36 km for the Wallowa terrane to ~32 km for the Olds Ferry terrane below the Salmon river suture zone, and increases to ~40 km at the cratonic North America.
4. An older (Permian) thrust fault (Figure 28) has been modeled south of the Seven Devils Mountains in the upper Wallowa terrane to be deformed

close to the surface by the west dipping Oxbow-Cuprum shear zone, with N-NE oriented foliations.

5. A new southern extent of the Rapid River plate in the SRSZ has been proposed (Figure 28) to thrust higher grade metamorphic rocks onto the upper Wallowa terrane, presently covered by the Miocene Columbia River Basalt Group.

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SUMMARY

Geologic mapping of the Purgatory Saddle quadrangle shows a structural link between the Late Triassic plutons and the OCSZ. The plutons intruded the Seven Devils Group in the upper Wallowa terrane through a zone of weakness and deformation (OCSZ) confirmed by structural and petrologic analysis of the undeformed plutonic rocks and mylonitic OCSZ rocks. The elongated along strike geomorphology of the plutons is also suggestive of this intrusive relationship of the plutons to the OCSZ. U-Pb zircon geochronology revealed a Late Triassic (222.1 ± 5.8 Ma) age of the elongated plutons. During accretion the Wallowa terrane gets intruded by Cretaceous plutons represented in the quadrangle as the Deep Creek and Echols Mountain plutons with an irregular and massive geomorphology creating a domal effect during emplacement leading to detachments along the Seven Devils Group around both the plutons.

Gravity and magnetic filtered anomaly maps revealed steep geophysical boundaries of the accreted terranes (Wallowa, Old ferry, Baker and Izee) with each other. Due to the minimal exposure of the terranes on the surface and being mostly covered with Columbia River Basalt flows, the complete Bouguer anomaly and the isostatic residual anomaly maps (Figure 21 and 22) constrain this crustal scale interaction better than the previously drawn boundaries based on geochemical and structural analysis. The isostatic map (Figure 22) also helps constrain the extent of WISZ, and the boundary of the accreted terranes with the Precambrian North America. 2.5-dimensional gravity and magnetic modeling presented the geometry of the WISZ and the SRSZ thrust faults, and showed 1) an east-west shortening increasing from west to east, also observed by Giorgis and Tikoff (2004) and Giorgis et al. (2005), and 2) a west trending top shear in the

instrusives of the WISZ possible due to final accommodation of the dextral shear stresses at the termination of WISZ or the clockwise rotation of BMP, also observed at a smaller scale by Gray et al. (2013) in the Crevice pluton. Profile B (Figure 27) suggested Echols Mountain pluton intruding the Heavens Gate and Rapid River plates. Profile C (Figure 28) introduced the OCSZ as a crustal scale feature deforming the Seven Devils group in the upper Wallowa terrane, and proposed a southern interaction of the SRSZ and the WISZ unexposed at the surface with due Columbia River Basalt cover. The geologic mapping, and the gravity and magnetics analysis help constrain the pre-, syn-, and post-accretionary tectonic features, OCSZ, SRSZ, and WISZ, respectively, that help better understand the complex boundary between the accreted terranes of the Blue Mountains Province and the North American craton.

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APPENDICES

Appendix A: Geologic map of the Purgatory Saddle quadrangle

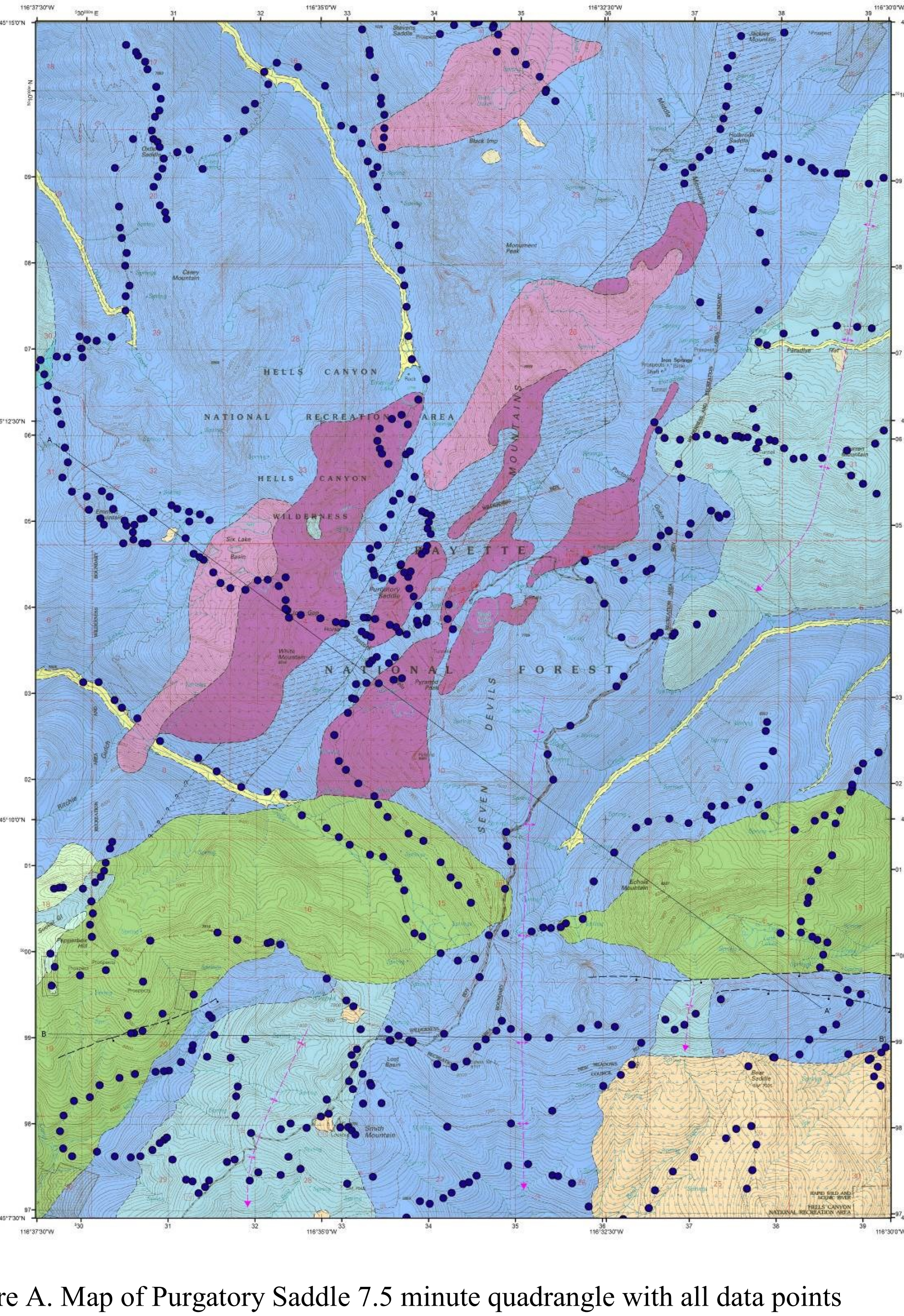

Figure A. Map of Purgatory Saddle 7.5 minute quadrangle with all data points (count=637) collected during Summer 2017 field season. Blue dot represents one data point.

Appendix B: U-Pb Zircon ages for SN 448 (Ruth Lake pluton)

Analysis	**Raw U/Th**	**$^{207}Pb/^{235}U$**	**±**	**$^{206}Pb/^{238}U$**	**±**	**Best age**	**±**
		Age (Ma)	**(Ma)**	**Age (Ma)**	**(Ma)**	**(Ma)**	**(Ma)**
SN448.01	3.225	236	15	214.9	5.7	214.9	5.7
SN448.02	0.776	1080	210	242	51	242	51
SN448.03	4.597	330	20	217.9	6.9	217.9	6.9
SN448.04	4.132	232	17	232.9	7.3	232.9	7.3
SN448.05	5.101	251	19	225.8	6.8	225.8	6.8
SN448.06	5.71	253	14	223	7.1	223	7.1

Appendix C: Gravity and magnetic analysis

Collected gravity station data is tied to the absolute gravity base station at Grangeville, Idaho post office, with a value of 980382.520 mGal. The values in the table below represent gravity stations along three gravity transects, that were modeled and discussed in the previous sections.

The following are the explanation of the columns:

Lat:	Latitude north in decimals.
Long:	Longitude west in decimals.
cBoug:	Bouguer anomaly in mGal.
ElevFt:	Station elevation in feet above sea level.
obsGrav:	Observed gravity in mGal.
ID#:	Station number

Collected gravity station data are as follows:

Lat	Long	cBoug	ElevFt	obsGrav	ID#
45.347363	-116.51759	-132.83	7497.4	980056.75	a1
45.349144	-116.50901	-136.41	7485.5	980054.94	a2
45.347183	-116.4968	-140.55	7364.8	980056.5	a3
45.35133	-116.49135	-140.13	7273	980062.69	a4
45.357323	-116.48996	-138.71	7166.9	980071	a5
45.365108	-116.48439	-137.65	7005.1	980082.06	a6
45.367348	-116.47483	-140.26	6995	980081.69	a7
45.372929	-116.47769	-136.76	6805.2	980098.62	a8
45.379482	-116.46869	-137.25	6608.7	980109.5	a9
45.38187	-116.45908	-138.59	6452.1	980117.62	a10
45.389717	-116.45795	-136.98	6242.3	980133.81	a11
45.391045	-116.45351	-137.38	6053.3	980145.69	a12
45.386024	-116.44995	-140.04	5834	980156	a13
45.385071	-116.43913	-142.67	5594	980167.75	a14
45.38623	-116.43608	-142.88	5388	980180.88	a15
45.380344	-116.43102	-145.11	5176.5	980188.69	a16
45.381828	-116.42807	-144.86	4988.1	980201.12	a17
45.376915	-116.43008	-146.95	4936	980200.62	a18
45.386974	-116.42589	-144.45	4773.8	980216.69	a19
45.391022	-116.42368	-143.05	4495.8	980233.94	a20
45.395885	-116.41411	-145.09	4169.2	980253.5	a21
45.40099	-116.40632	-147.11	3897.5	980268.19	a22
45.406109	-116.39648	-148.15	3535.9	980287.31	a23
45.40984	-116.38622	-149.45	3180.6	980306.75	a24
45.413021	-116.37537	-151.12	2816.6	980324.69	a25
45.417496	-116.35857	-151.61	2337.7	980351.25	a26
45.412037	-116.35163	-151.74	2165.4	980360.62	a27
45.407467	-116.34074	-152.89	1942	980370	a28
45.407528	-116.33108	-152.66	1787.1	980379.06	a29
45.412323	-116.32385	-152.53	1767.3	980380.5	b1
45.410656	-116.30961	-155.65	1729.6	980375.19	b2
45.413788	-116.30232	-153.71	1707	980381.12	b3
45.420769	-116.29305	-151.09	1721.6	980384.25	b4
45.42168	-116.28265	-151.62	1737.9	980379.44	b5
45.419567	-116.27042	-152.69	1804.5	980373.88	b6
45.415901	-116.25982	-151.76	1732.5	980376.06	b7
45.411304	-116.24931	-153.33	1745.1	980371.75	b8
45.405594	-116.24091	-155.2	1804.9	980364.25	b9
45.400757	-116.22813	-159.87	1778.3	980359.38	b10
45.39954	-116.2164	-162.4	1756	980359.44	b11

45.401241	-116.20321	-165.42	1760.2	980353.56	b12
45.404991	-116.19444	-165.07	1780.5	980354.19	b13
45.412685	-116.18646	-163.27	1787.4	980358.56	b14
45.418076	-116.17961	-166.36	1811.4	980359.31	b15
45.418423	-116.16456	-166.83	1820.9	980360.62	b16
45.423046	-116.15749	-167.44	1798.3	980360.81	b17
45.42783	-116.14817	-170.06	1804.2	980357.81	b18
45.426029	-116.1346	-171.89	1820.8	980354.38	b19
45.420113	-116.12981	-170.72	1816.9	980352.12	b20
45.411514	-116.12759	-173.04	1828.7	980350.81	b21
45.404045	-116.12298	-176.68	1826.7	980342.62	b22
45.401134	-116.11235	-175.16	1836.6	980341.62	b23
45.402946	-116.09899	-174.6	1838.6	980347.88	b24
45.404457	-116.08872	-177.25	1849.7	980342.62	b25
45.410522	-116.07884	-177.83	1850.4	980338.88	b26
45.415882	-116.06973	-176.5	1881.8	980339.62	b27
45.419556	-116.05969	-176.45	1919.5	980337.88	b28
45.422386	-116.04598	-179.63	1891.1	980337.19	b29
45.422604	-116.0351	-181.75	1881.4	980335.94	b30
45.423927	-116.02781	-179.18	1900.1	980337.69	b31
44.969963	-116.27607	-163.97	3835.2	980221.69	c1
44.975048	-116.29783	-163.26	3839.2	980222.56	c2
44.983387	-116.3197	-164.27	3975.6	980214.44	c3
44.993309	-116.34479	-166.74	3955.7	980213.94	c4
44.986332	-116.3672	-163.25	4123.8	980206.81	c5
44.96962	-116.37951	-162.04	4083.3	980209	c6
44.954151	-116.38572	-163.84	4083.4	980205.25	c7
44.93774	-116.38435	-163.69	4118.2	980201.88	c8
44.934006	-116.40702	-162.21	4608	980172.69	c9
44.942219	-116.42459	-159.51	4907.9	980159.88	c10
44.95118	-116.44048	-157.09	4769.4	980171.69	c11
44.959	-116.46328	-155.81	4759.6	980173.88	c12
44.960037	-116.47064	-155.35	4785.3	980172.69	c13
44.972717	-116.48422	-153.57	4887.8	980169.31	c14
44.980728	-116.5003	-153.16	5033.8	980161.81	c15
44.967098	-116.50407	-151.24	4618.4	980185.56	c16
44.954205	-116.50104	-149.65	4236.3	980208.19	c17
44.952324	-116.52303	-148.49	4440.7	980196.69	c18
44.957596	-116.54511	-146.71	4759.5	980180.5	c19
44.970325	-116.563	-146.75	5088.2	980161.94	c20
44.985458	-116.56136	-150	5381.1	980143.38	c21
44.999031	-116.55367	-151.91	5665.2	980126.38	c22
45.003235	-116.55891	-152.24	5920.5	980110.75	c23
45.013126	-116.56078	-150	5682.4	980126.69	c24
45.020332	-116.57172	-149.91	5387	980146	c25

45.015846	-116.589	-149.67	5029.7	980167.69	c26
45.014545	-116.60111	-149.17	4735.2	980185	c27
45.013233	-116.60661	-149.34	4460.6	980200.69	c28
44.996792	-116.60898	-149.38	4369.6	980205.75	c29
44.990772	-116.629	-150.41	4416.2	980202.19	c30
44.996258	-116.65048	-150.85	4248.1	980211.81	c31
44.982613	-116.65836	-151.59	4324.4	980206.25	c32
44.978161	-116.66428	-151.68	4349.1	980204.56	d1
44.991379	-116.67557	-151.26	4208.7	980214.5	d2
45.009075	-116.67727	-149.21	4260.3	980214.75	d3
45.023499	-116.67852	-148.8	4387	980209.12	d4
45.030125	-116.69488	-147.19	4654.9	980194.75	d5
45.040546	-116.70285	-146.9	4803.1	980186.81	d6
45.048393	-116.70756	-146.15	4934	980180.5	d7
45.057396	-116.7249	-140.89	4474.6	980207.38	d8
45.070457	-116.71932	-143.25	4136.6	980230.94	d9
45.066677	-116.7244	-139.41	3996.7	980238.62	d10
45.070625	-116.74241	-143.5	3982.9	980239	d11
45.066109	-116.76159	-143.97	3715.8	980250.62	d12
45.061081	-116.77385	-143.32	3246.8	980278.94	d13
45.053516	-116.78693	-147.16	2770.7	980300.56	d14
45.050274	-116.801	-147.98	2277.6	980325.69	d15
45.046761	-116.81268	-149.41	1664.2	980357.25	d16
45.034683	-116.82978	-148.46	1679.1	980355.5	d17
45.13818	-116.58054	-142.36	7517.2	980030.12	e1
45.138065	-116.57336	-142.81	7207.1	980051.44	e2
45.133968	-116.56362	-143.46	6891.9	980068.56	e3
45.135574	-116.55228	-143.57	7034.6	980059.88	e4
45.138733	-116.54215	-143.67	7084.3	980056.25	e5
45.139183	-116.5321	-146.91	7048.9	980058.12	e6
45.14027	-116.52113	-147.72	6975.6	980061.81	e7
45.141945	-116.51168	-149.22	6507.5	980088.69	e8
45.14286	-116.5004	-150.94	6124.5	980110.38	e9
45.1464	-116.49162	-152.84	5969.9	980118.94	e10
45.147228	-116.48283	-155.94	6032.5	980112.94	e11
45.145996	-116.47273	-156.46	6471.1	980085.19	e12
45.146339	-116.46229	-159.1	6795	980062.75	e13
45.139164	-116.46575	-158.69	6760.5	980064.56	e14
45.136391	-116.46085	-157.54	6405.3	980086.94	e15
45.130764	-116.45892	-156.86	6012.6	980109.56	e16