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The Pliocene/Pleistocene Evolution of the Western Snake River Plain Near Grand View Idaho

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by

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Master of Science

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ABSTRACT

The Pliocene/Pleistocene Evolution of the Western Snake
River Plain near Grand View, Idaho

by

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Utah State University, 2009

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The Western Snake River Plain provides us with a unique opportunity to study the evolution of basaltic volcanism. In addition to studying the horizontal variation at the surface of the plain, erosion by the Snake River also allows the study of the vertical variation. With the aid of a USGS EDMAP grant we mapped the Dorsey Butte quadrangle and southern half of the Little Joe Butte quadrangle at a scale of 1:24,000. The quadrangles are located within both the Ada and Elmore counties of southwestern Idaho, approximately 30 km west of Mountain Home and 2 km north of Grand View. The two maps will extend westward the eight 7.5 minute quadrangles previously mapped by Shervais et al. (2002). The result of this work will be an area encompassing 530 square miles centered around Mountain Home that have been geologically mapped at a scale of 1:24,000. The geology of this area consists predominantly of basaltic volcanism, lake sedimentation, and quaternary faulting. Lava flows, shield volcanoes, and cinder cones dominate the landscape with a concentration of phreatomagmatic deposits along the cliffs of the Snake River.

An eight-meter stratigraphic column was generated from a phreatomagmatic outcrop within the Basaltic Tuff and Breccia of Hayland School. The base of the unit

consists of subaerial scoria fall deposits. Above the scoria deposits sedimentary material is present within cross-bedded and massive layers that may be the product of channel flow, subaqueous reworking of material, and/or subaqueous debris flow. The final stages of the Hayland School eruption involved a de-watering of the system resulting in an increase in the proportion of basaltic clasts and finally a basaltic lava flow. The periods of hydration and de-watering of the volcanic system are likely the product of damming of the ancestral Snake River and/or growth of the volcanic edifice above water level.

Geochemical data for the basalts present within and adjacent to the Dorsey Butte and Little Joe Butte quadrangles support the presence of two dominate magma types. The older basalts have compositions consistent with Fe-rich tholeiites while the younger basalts are transitional between olivine tholeiites and alkali olivine basalts. The younger basalts have higher alkali, Mg, and Cr concentrations and higher Mg/Fe ratios. These findings are consistent with previous work by Vetter and Shervais (1992) and White et al. (2002).

To my father, Brian DeRaps,

For instilling in me the strength and determination that completing this report required and that I will carry with me for the rest of my life.

ACKNOWLEDGMENTS

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A thank you is in order to Dr. Dave Liddell for his help sorting through all of the paperwork, answering my countless questions, and giving me valuable feedback on my report. Lori Hirshi also deserves my gratitude, she not only rescued me from more than one predicament, but was also there to listen and offer advice whenever I needed it (which happened to be quite often). A special thanks goes out to my four field assistants Erik, Michelle, Nikka, and Yuko. Erik and Michelle both worked in hot, dry, and dusty conditions pounding rocks and burning in the sun for little to no compensation. My two dogs Nikka and Yuko were an immense help by providing me with scale for my photographs, keeping me safe, and carrying an occasional rock or two.

In addition to work in the field, my boyfriend Erik was there for me every step of the way, from helping me with interpretations and editing my work to bringing late night pizza to my office and listening to my frustrations. His patience and support over the past two years have been truly incredible.

Finally, I would like to thank Derek, Breanne, Stacy, and my grandmother for all of their support. Their unfaltering belief in me gave me the courage to see this project to its completion.

Meagan DeRaps

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CHAPTER I

INTRODUCTION

Statement of the Problem

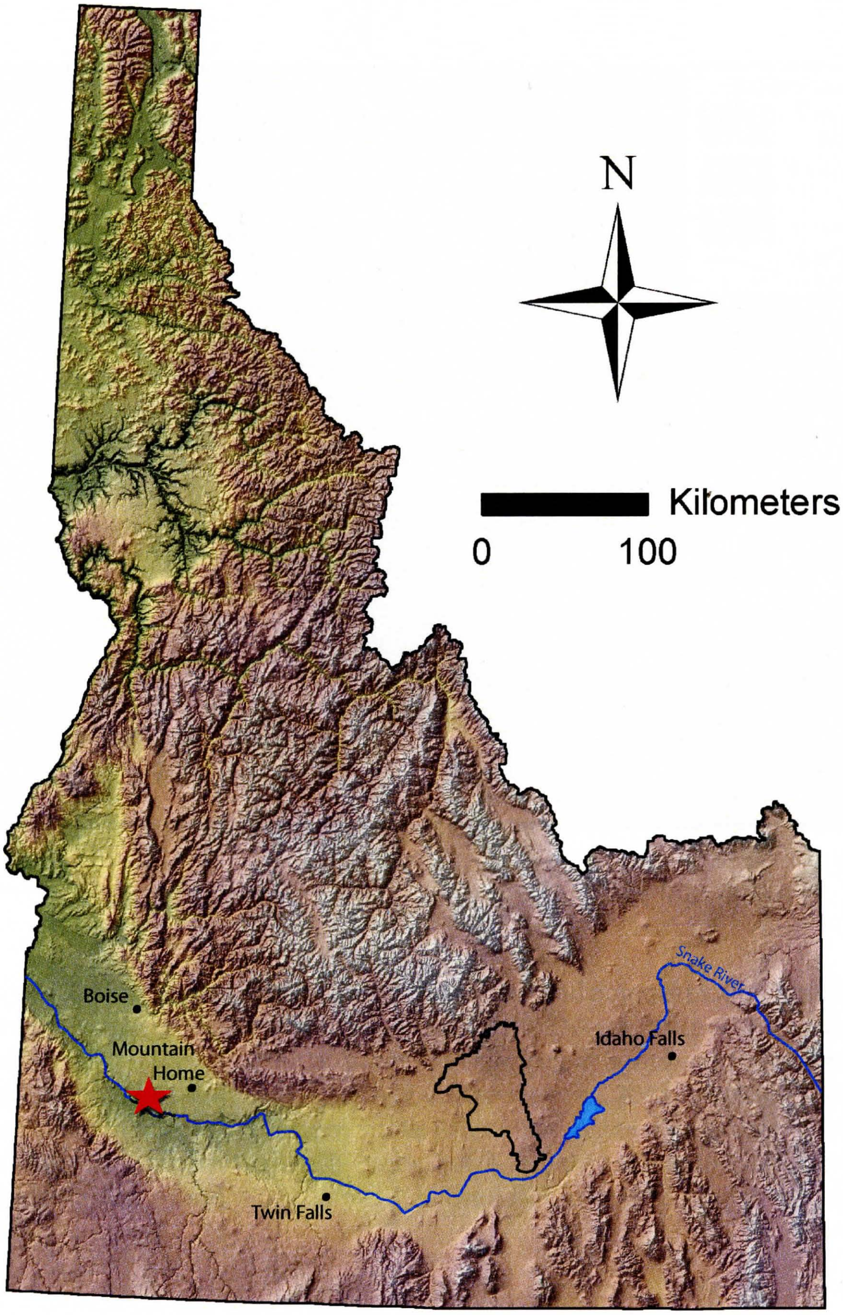
Located in southwestern Idaho, the Western Snake River Plain is a broad expanse of sagebrush-dominated desert. The arid climate coupled with relatively flat topography makes it an ideal location for the many military installations and training facilities that occupy the region. Beneath the seemingly lackluster surface of the plain lurks a complicated geologic history involving the dynamic interplay between water and volcanism. The complex relationship of these two natural forces has impacted the deposits of the Western Snake River Plain for millions of years. Recently the Snake River has cut through these deposits allowing geologists a unique opportunity to not only study the spatial distribution of volcanism at the surface, but also the vertical evolution of the plain.

The purpose of this project was to gain a better understanding of the complex volcanic and hydrologic processes involved in shaping the Western Snake River Plain. Detailed geologic maps, stratigraphic profiles, and geochemical analyses were created and compiled in order to arrive at an in depth view of the volcanic evolution of the plain.

Specific Location of study

The location that this study will primarily focus on is adjacent to the cliffs of the Snake River in the southern portion of the Western Snake River Plain (fig. 1). It is situated within both Ada and Elmore counties of southwestern Idaho, approximately 30 km west of Mountain Home and 2 km north of Grand View. Mountain Home is a small air force community off of Interstate 84, approximately 64 kilometers southeast of Boise and 112 kilometers northwest of Twin Falls.

The area previously mapped by Shervais et al. (2002) consists of eight 7.5 minute quadrangles spanning approximately 725 square miles around Mountain Home. The location of the quadrangles range from longitude 115°30'W to 116°0'W and from latitude 43°0'N to 43°15'N (Shervais et al., 2002). This study focuses on both the Dorsey Butte quadrangle and the southern portion of the Little Joe Butte quadrangle, which sit directly west of the area previously mapped (fig. 2). Bonnichsen and Godchaux (2006) completed a geologic map of this area in cooperation with the Idaho Geological Survey at a scale of 1:100,000. This study added to their work by further subdividing the surface flows and mapping smaller scale features at a scale of 1:24,000.



Basemap: USDA Forsest Service Image

Figure 1. Overview map of Idaho. Black outline represents Craters of the Moon National Monument and Preserve. Red star is study area.

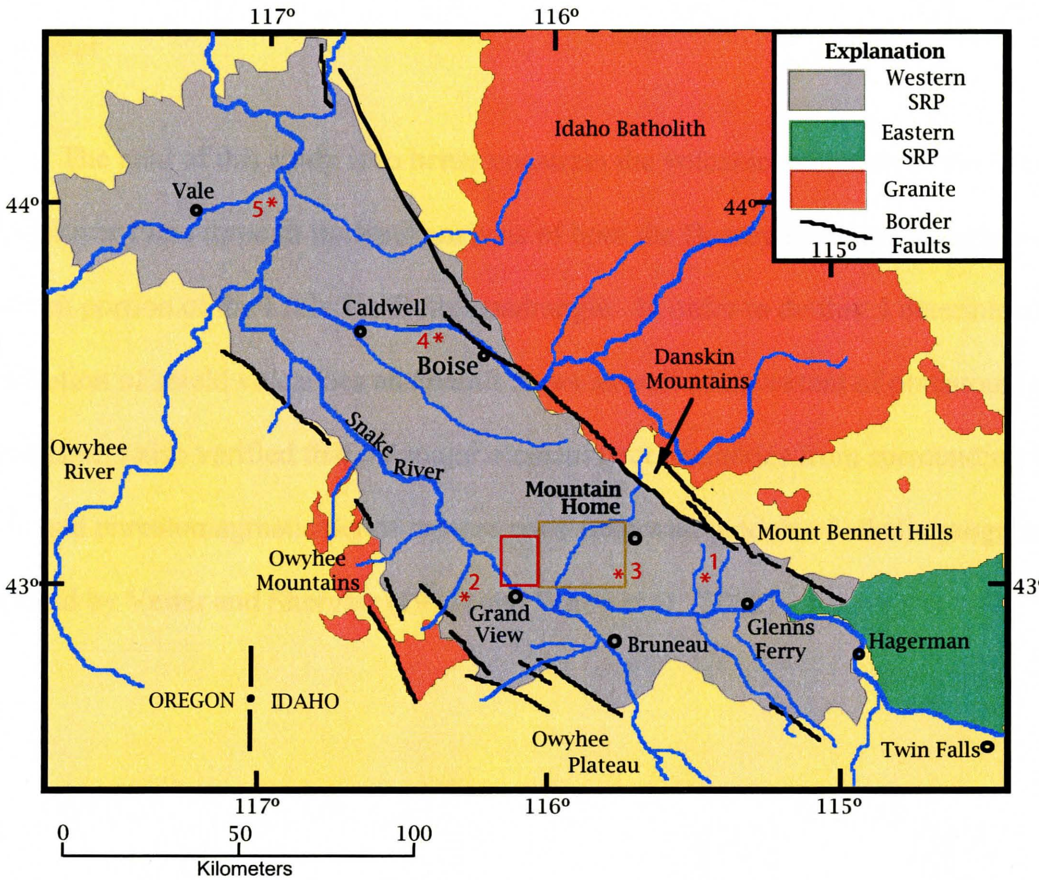


Figure 2. Map of the Western Snake River Plain and adjacent Idaho Batholith. Red rectangle represents the dimensions of the Dorsey Butte and southern portion of the Little Joe Butte quadrangles, adjacent light brown rectangle represents area previously mapped by Shervais et al., 2002. Black lines are bounding faults of the Western Snake River Plain. Asterisks represent wells where drill cores were taken, 1- Bostic 1-A, 2- Anschutz Federal 1, 3- Mountain Home Air Force Base, 4- J.N. James 1, 5- Ore-Ida 1 (modified from Shervais et al., 2002).

Objectives

The goal of this study is to better constrain the volcanic evolution of the Western Snake River Plain through in-depth analysis of both the Dorsey Butte quadrangle and the southern portion of the Little Joe Butte quadrangle. In order to do this, I determined the distribution of shield volcanoes and basalt flows as well as the extent of phreatomagmatic volcanism. I also verified that the major element geochemistries from surrounding lava flows and phreatomagmatic deposits were consistent with models of alkalic progression proposed by Vetter and Shervais (1992) and White et al. (2002).

CHAPTER II

BACKGROUND

Geologic Setting

The Western Snake River Plain (WSRP) is a large, 70 km-wide by 300 km-long intra-continent rift basin filled with volcanic and lacustrine deposits (fig. 2); (Wood, 2002). In comparison, the dimensions of the Lemhi and Grand Valley half grabens that lie to the north and south of the Eastern Snake River Plain (ESRP) are less than 30 km-wide by 100 km-long (Wood and Clemens, 2002). The WSRP is characterized by a positive gravity anomaly that runs along the entire width and a magnetic anomaly that is localized at its southern boundary. It is located within southwestern Idaho and shares a common northwest trend with several other crustal features across Nevada and Oregon (Glen, 2002).

Structurally, the western plain is a graben, bounded and internally deformed by normal faults. Extension across these faults dissected and buried parts of the southwestern margin of the Idaho Batholith. The bounding faults of the Western Snake River Plain trend N60°W, similar to the Lemhi and Grand Valley half grabens mentioned above. Faulting along the northern margin of the plain is for the most part continuous, while along the southern margin faulting occurs in small discontinuous segments (fig. 2). Offsets along these faults were measured by correlating volcanic units at the surface with their equivalents in the subsurface. On the south side of the Bennett Hills, offset on the northern bounding fault was measured to be 2.8 km. An offset of 2.2 km was measured for the southern bounding fault on the north side of the Owyhee Mountains (Wood and Clemens, 2002).

Within the plain itself, two to nine meters of throw have been measured on fault scarps crosscutting young (< 2.2 Ma) shield volcanoes and basalt flows (Shervais et al., 2002). Two fault sets dominate the region, one with a N85°W trend and the other parallel to the range front faults, N60°W; both are high angle normal faults and dip to the south (Shervais et al., 2002). The youngest basalt flows cut by these faults are approximately 1 Ma, therefore the faulting must have continued at least up until this time. Caliche accumulation exposed by fault trenching revealed five episodes of surface rupture over the past 26,000 years (Beukelman, 1997).

The Western Snake River Plain was once thought to be a geologic extension of the Eastern Snake River Plain (ESRP). Both plains have similar low elevations and basalt flows exposed at the surface, which make them appear to have similar tectonic and magmatic histories. However, the ESRP is composed of time-transgressive, silicic eruptive centers that are overlain with basalt. The WSRP does not show this same time transgressive pattern. Furthermore, the low elevation of the ESRP is not fault induced but caused by flexural down warping due to a high-density mafic sill (~10 km thick, 90 km wide) at depth (McQuarrie and Rodgers, 1998). The WSRP is a graben, down-dropped by normal faults along its margins (fig. 2). The total volumes of basalt produced during the late Neogene and Quaternary vary significantly for the eastern and western plains. In the eastern plain an estimated 40,000 cubic kilometers have erupted, while in the west only 300 cubic kilometers have erupted (Wood and Clemens, 2002).

Tectonic and Volcanic Evolution

The evolution of the WSRP consists of an initial stage of rifting and rhyolitic volcanism, followed by a phase of basaltic volcanism, lake deposition, and then a second phase of basaltic activity. The rhyolitic lavas exposed north and south of the graben erupted from fissures coincident with the onset of extension and show a trend of decreasing age to the southeast. The ages of the rhyolites range from 11.2-11.6 Ma in the northwest to 10-11.0 Ma in the southeast (Shervais, 2002). Dates for the onset of faulting in the WSRP were determined by correlating surficial volcanic units of known age in the footwall with their hanging wall equivalents in the subsurface (Wood and Clemens, 2002). Using this information Wood and Clemens determined that the majority of the offset along the bounding faults occurred from approximately 11 Ma to 9 Ma. During this time the slip rate on the fault segment south of the Bennett Mountains was approximately 2.8 mm per year while on the north side of the Owyhee Mountains the slip rate was approximately 2.2 mm per year. Faulting has continued since 9 Ma, but with an average slip rate of less than 0.1 mm per year (Wood and Clemens, 2002).

The second phase in the evolution of the WSRP involved basaltic volcanism that immediately followed the cessation of the silicic eruptions. These basalts, termed the Pre-Lake Idaho basalts, erupted from 9 Ma to 7 Ma. The initiation of faulting and volcanism in this area corresponds in time with the 11.5 to 8.0 Ma Bruneau-Jarbidge silicic volcanic center, which lies directly south of the plain (Wood and Clemens, 2002). Although these two localities share similar ages and locations, their basaltic compositions differ significantly. The Pre-Lake Idaho basalts have low alkali contents and very high iron and titanium, implying that the source for these rocks is depleted relative to ESRP basalts in large ion lithophile elements (LILE) and may have undergone Fe-Ti metasomatism (fig. 3); (Shervais et al., 2002). Little is known about these basalts because there is limited exposure along the northern edge of the graben and within the graben they are only found in core at a depth of approximately 2,100 meters (fig. 4). After this pulse of volcanism there was a five million year hiatus in volcanic activity (Wood and Clemens, 2002). During this hiatus a large Pliocene lake named Lake Idaho dominated the WSRP. Lacustrine sediments from this time constitute the Idaho Group. The Bostic 1-A drill core indicates that the thickness of these deposits is over 600 meters. They are characterized by fine-grained, calcareous, clay-rich muds and silts, with some sandy silts present higher in the section (Shervais et al., 2002). The age progressions of the lacustrine deposits, like the rhyolites, show a decrease in age to the southeast (Malde, 1991).

The most recent phase of volcanic activity occurred from 2.2 Ma to as recently as 100,000 years, producing approximately 300 cubic kilometers of basalt (Wood and Clemens, 2002). Four different stages make up the final phase of basaltic activity in the WSRP. The first stage consists of plateau forming basalts that sit directly upon the Idaho Group. These basalts are 2.5 to 10 meters thick and form laterally continuous outcrops. Some of these flows contain hyaloclastites, evidence of lava-water interaction (Godchaux

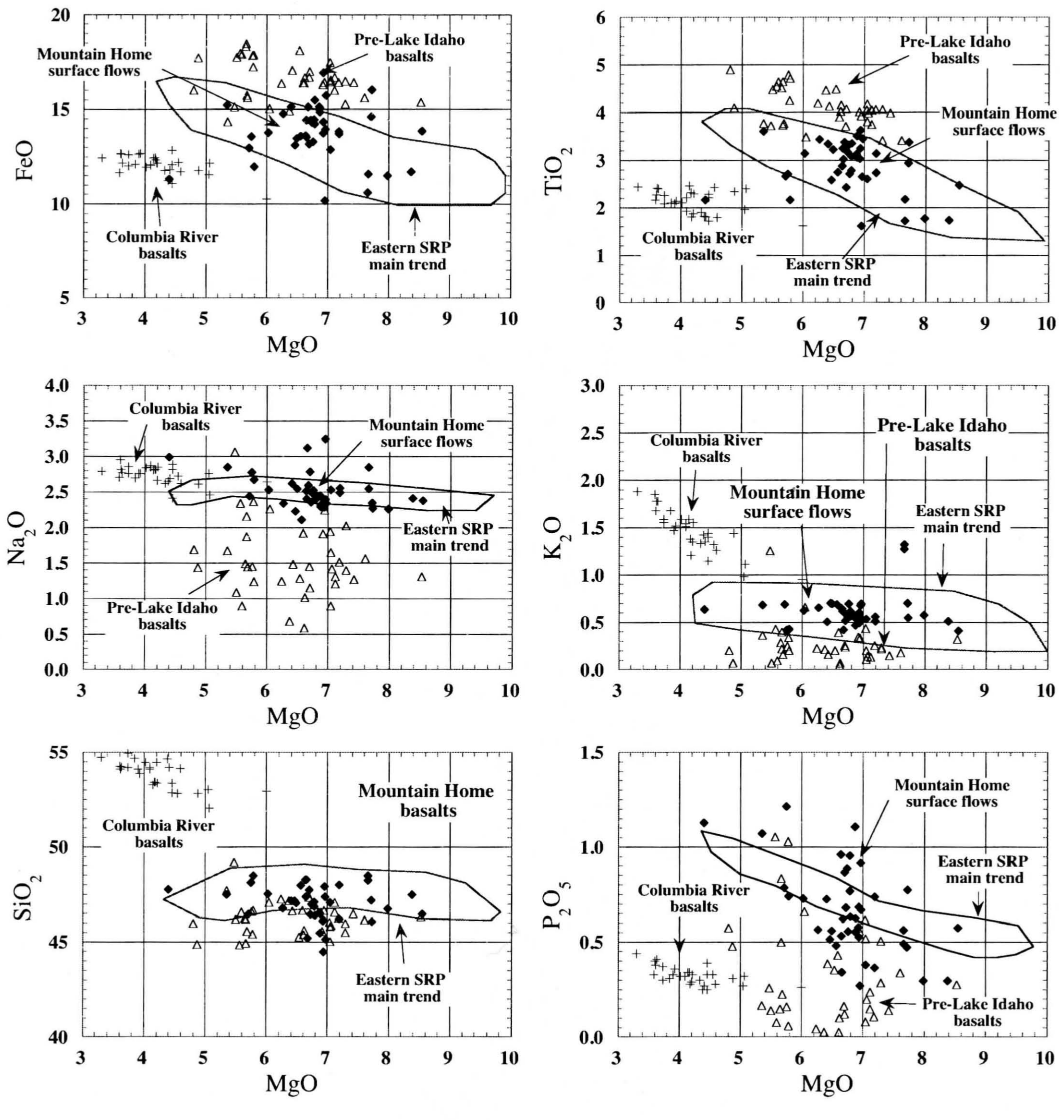


Figure 3. Major element variation diagrams comparing Snake River Plain and Columbia River Basalts (Shervais et al., 2002).

Cross Section of the Western Snake River Plain through the Mountain Home Air Force Base

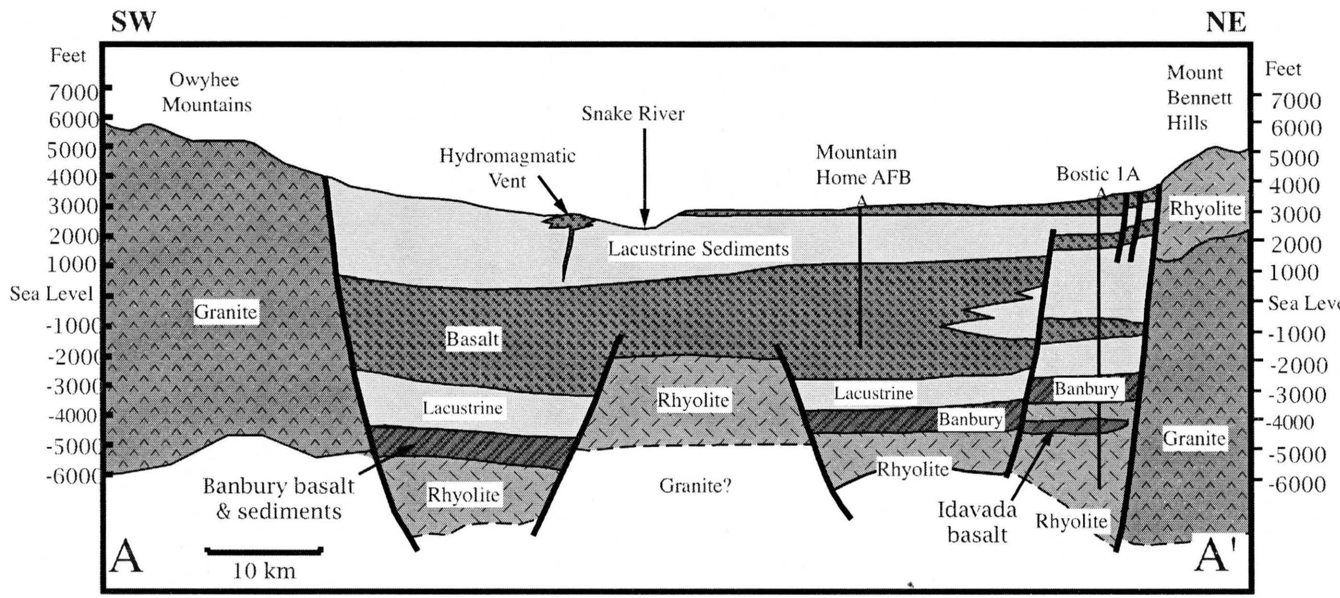


Figure 4. Interpretive cross section of the WSRP from Owyhee Plateau to the Mountain Home area; based on subsurface core data, gravity profiles, and surface mapping (Shervais et al., 2002).

and Bonnichsen, 2002). The second stage is composed of maar-like vents. These vents may have begun as phreatomagmatic eruptions in response to the presence of water. As time progressed the underlying vents de-watered and the volcanic eruptions transitioned to a fire fountain style of eruption forming abundant spatter and fine-grained cinders. The third stage of activity involved the eruption of 90 to 120 meter steep sided shield volcanoes, while the fourth and youngest stage created 45 to 90 meter tall cinder cones (Shervais et al., 2002).

Previous Work: Geophysics

Hill and Pakiser (1967) and Mabey (1976, 1982) were the first to quantify the geophysical parameters of the Western Snake River Plain. Hill and Pakiser studied the crust beneath the western plain using a seismic refraction profile from the Nevada Test Site to Boise, Idaho. They found that the total crustal thickness is approximately 13 km thicker (40-45 km) beneath the Western Snake River Plain and adjacent Owyhee Plateau than under the northern Basin and Range Province. They also found a 20 km thick layer with a seismic velocity consistent with crystalline bedrock beneath the Basin and Range, but not the Western Snake River Plain. Hill and Pakiser postulated that the thickened lower crust and the absence of a thin upper crustal crystalline layer represent the thinning of the original granitic crust and filling of the resulting fractures with basaltic material (Hill and Pakiser, 1967).

Mabey (1976) independently came to a similar conclusion relating to the subsurface of the Western Snake River Plain. He studied the gravity and magnetic anomalies across the plain and determined them to be the result of a layer of dense magnetic rock at depth. The large bouguer gravity anomaly aligns with the axis of the WSRP, while the magnetic high is concentrated at the southern end of the plain with a relatively low magnetic anomaly to the north (figs. 5 and 6) (Mabey, 1976). From these interpretations Mabey estimated that there was a large body of Miocene basalt with a density of 2.9 g/cm^3 at approximately 1.5 km beneath the surface (Mabey, 1976). Mabey explained the alignment of the maximum amplitude bouguer gravity (100 milligals) with the axis of the WSRP by proposing a model of crustal thinning and mafic magma injection. The pattern of high and low magnetic anomalies further support the presence of strongly magnetized rock at depth with an induced magnetization aligned in the direction of the Earth's present magnetic field (Mabey, 1982).

Previous Work: Phreatomagmatic Volcanism

Godchaux, Bonnichsen, and Jenks (1992) subdivided the phreatomagmatic volcanoes of the Western Snake River Plain into three groups: emergent, subaqueous, and subaerial. Emergent volcanoes begin by erupting underwater, but as the volcanic material builds around the vent they rise above the water level. These types of volcanoes form large, symmetrical edifices that produce primarily bedded tuffs and late effusive lava flows. Subaerial volcanoes form when magma intercepts an aquifer and erupt explosively. The common products of subaerial volcanism are small tuff rings and maars. Subaqueous volcanoes form relatively small and asymmetrical features, leaving behind basal, massive deposits (Godchaux et al., 1992).

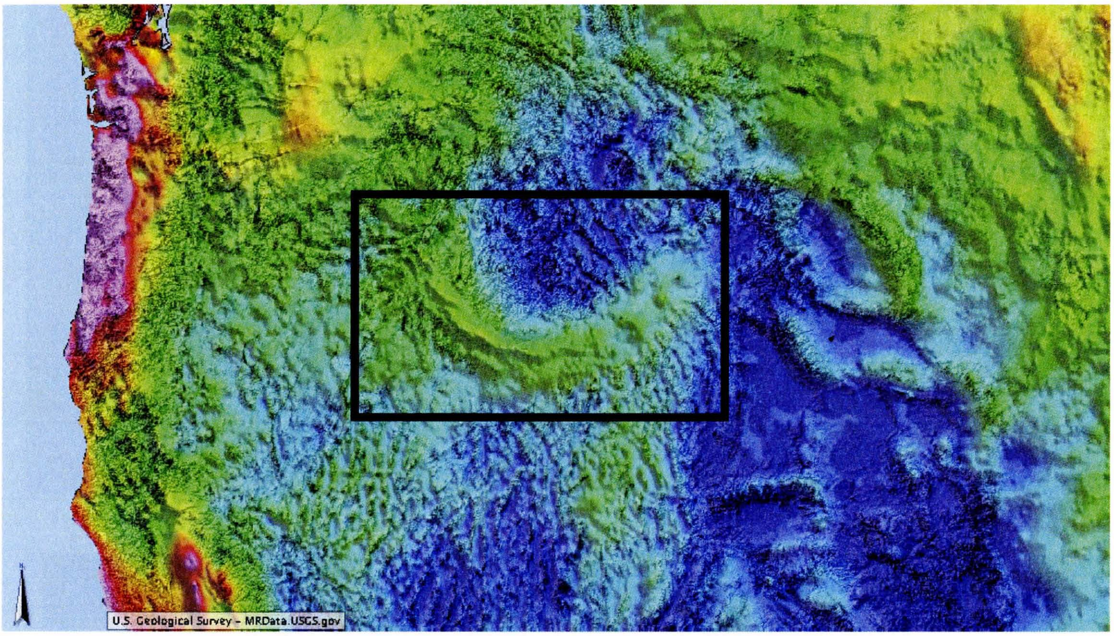


Figure 5. Bouguer gravity map of the northwestern United States; high gravity anomaly is present along the axis of the Western Snake River Plain, warmer colors represent larger gravity values (milligals), black rectangle represents approximate location of the Snake River Plain (Kucks, 1999).

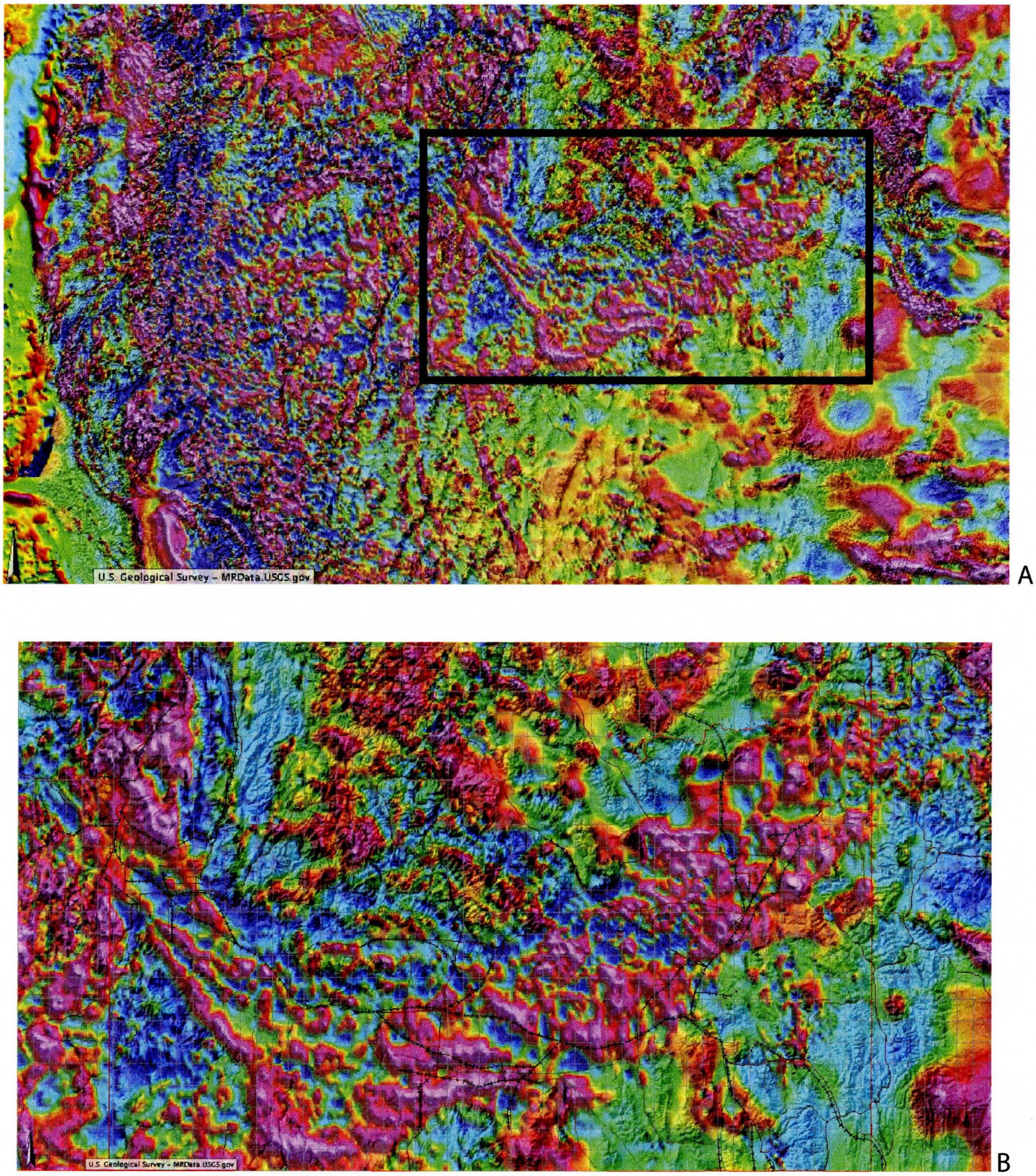


Figure 6. A- Magnetic anomaly map of the northwestern United States. B- Zoom in of the Western and Eastern Snake River Plain marked by the black rectangle in A. emphasizing the high magnetic anomaly along the southern margin of the WSRP, warmer colors represent higher magnetic anomalies (Kucks, 1999).

Sinker Butte is a prominent example of phreatomagmatism in the Western Snake River Plain. The butte is the erosional remnant of a Mid Pleistocene basaltic tuff cone. The location of Sinker Butte, approximately 33 kilometers northwest of the Dorsey Butte quadrangle, constitutes an excellent place to study phreatomagmatic volcanism. Large cliffs eroded by the Snake River allow for optimal viewing and study. Outcrop of Sinker Butte is vertically exposed for approximately 100 meters for a distance of up to 7 kilometers. Brand and White (2007) completed 23 detailed stratigraphic columns ranging in thickness from 20 to 100 meters and representing 180 degrees of the volcano's circumference. Using the stratigraphic columns as a guide they defined eight facies associations and three main rock units. They defined the facies associations based on variations in grain size, composition, and sedimentary structures. The three main rock units are as follows: a lower pahoehoe flow unit, a middle phreatomagmatic tephra deposit, and a top unit of welded spatter and flows. The phreatomagmatic tephras can further be subdivided into a subaerial and a subaqueous member. The subaqueously deposited tephras are grey in color and exhibit channel scour and fill, planar stratification, high and low angle cross-stratification, trough cross-stratification, and Bouma turbidite sequences. The deposits are consistent with deposition in shallow standing water or a braided stream. The subaerial deposits are brownish orange due to palagonization and most likely are the result of base surges, wet to dry pyroclastic fallout, and saturated debris flows (Brand and White, 2007).

The initial onset of phreatomagmatic volcanism at Sinker Butte was likely due to the damming of the Snake River by lava flows. Water began building behind the lava dam eventually gaining access to the vent and/or feeder dikes. This forced the eruption style to abruptly switch from effusive to explosive. The formation of Sinker Butte is likely linked to damming of the Snake River and not eruption into Lake Idaho because the earliest deposits associated with the butte postdate the draining of Lake Idaho (~2-4 Ma) by approximately 0.3 to 0.4 million years (Brand and White, 2007).

Previous Work: Drilling near Mountain Home

Two wells were drilled in close proximity to Mountain Home, Idaho. The first well, Bostic 1-A, was drilled to a depth of 2950 m (9670 ft) as an oil and gas wildcat in 1973 (figs. 2,4). It was not only unsuccessful at producing oil and gas, but also as a geothermal prospect and was therefore plugged and abandoned in 1978. Petrographic analyses of these rocks were performed at the Los Alamos National Laboratory in Los Alamos, New Mexico (Arney et al., 1984). They determined that the top of the well penetrates the Middle Pleistocene Bruneau Formation above sedimentary rocks of the Upper Pliocene Glenns Ferry Formation. Middle Miocene Banbury Basalt lies below these formations followed by a 105-meter interval of felsic volcanics. The lower 180 meters of basalt (2200 meter depth), labeled the Idavada basalt on the cross section in figure 4, has not been correlated with any other basalt lying at the surface of the plain. Geophysical results show that additional basalts lie below the well rather than the granitic rocks of the batholith (Arney et al., 1984). The second well was drilled eight miles southwest of Mountain Home at the Mountain Home Air Force Base. The well was drilled continuously below 300 meters down to 1,340 meters by the U.S. Air Force for the purpose of finding geothermal aquifers to provide heat for military housing (Lewis and Stone 1988). However the temperature of the fluids within the well were not high enough to economically support geothermal heat production. Within the core, rock above 162 meters is composed mainly of basalt with interbedded silt to coarse sand. From 162 to 580 meters silty sand and silty clay dominate, while below 580 meters the main constituent is basalt (fig. 4). Data on the lithology, geophysical properties, temperature, thermal conductivity, and chemical and isotopic analyses were reported and made available to the public by the U.S. Geological Survey in an Open-File report in 1988 (Lewis and Stone, 1988).

Previous Work: Basalt Geochemistry

The geochemical nature of the surface flows has been studied primarily by Shervais et al. (2002), Vetter and Shervais (1992), and White et al. (2002). Shervais et al. (2002) summarized the Neogene history of the Western Snake River Plain around Mountain Home, Idaho. Two episodes of basaltic volcanism took place during this time, each with different compositions. The first group, the Pre-Lake Idaho basalts (9-7 Ma) are very high in Fe and Ti, and low in alkalis, silica, and phosphorous. The younger, less than 2.2 Ma basalts, are surprisingly similar to the young surface flows in the ESRP (fig. 3). Both have similar amounts of iron, titanium, alkalis and silica. The WSRP basalts have only slightly more iron.

These results support a source for the older basalts that is enriched in iron and titanium, but depleted in the large ion lithophile elements. In comparison to the Pre-Lake

Idaho basalts (9-7 Ma), the Columbia River Plateau Basalts (CRPB) are lower in magnesium, iron, titanium, and phosphorous, and higher in silica and potassium (fig. 3); (Shervais et al., 2002). The geochemistry of the CRPB shows that they are more enriched in crustal component than the WSRP basalts. This suggests that they may have had more contamination of continental crust (Shervais et al., 2002).

Shervais et al. (2002) suggested that the first pulse of basaltic magmatism might be the result of sublithospheric flow of depleted plume source mantle originating beneath the Columbia River Plateau. They proposed that the second pulse of magmatism has a different origin due to age and compositional differences between the two volcanic episodes. Unlike the older (Pre-Lake Idaho) basalts, the younger surface flows owe their origin to extensional Basin and Range processes similar to the origin of basalts in the Eastern Snake River Plain (Shervais et al., 2002).

Vetter and Shervais (1992) found that the basalts of the Cenozoic Boise River Group located within the Boise River and Boise River South Fork drainages at the northern edge of the Western Snake River Plain range in age from 1.8 to 0.2 Ma. Based on their age and composition, Vetter and Shervais divided them into two groups. The oldest basalts (BRG 1) are chemically similar to Snake River basalts (olivine tholeiites) and are therefore probably derived from a similar enriched mantle lithosphere source. The second group of basalts (BRG 2) is younger than 0.7 Ma and their compositions are transitional between olivine tholeiites and alkali olivine basalts. The high Mg and Ni of these basalts cannot be attributed to enrichment by crustal assimilation, therefore this enrichment must be an attribute of the source. Vetter and Shervais (1992) suggested that the change in composition with time (older olivine tholeiites to younger transitional alkalic basalts) implies a change in the source location. The early magmas were most likely derived from a shallow lithospheric source while the younger rocks from a deeper asthenospheric source. They proposed that high degrees of partial melting beneath the thinned lithosphere of the WSRP prevented eruption of the deeper, asthenospheric magmas at the surface. Upwelling asthenospheric magmas would either mix with the partial melts or pond beneath them, never reaching the surface. Therefore the transitional alkalic basalts are only seen along the flanks of the plain where the lithosphere is cold and relatively un-extended (Vetter and Shervais, 1992).

White et al. (2002) studied the geochemistry of the basalts of the Western Snake River Plain centering on Melba, Idaho. Melba is located fifty miles to the west-northwest of Mountain Home on the western margin of the plain. The geochemical results of White et al. (2002) were very similar to that of Vetter and Shervais (1992). They also divided the basalts into groups based on age and geochemistry. The first group (M1) was active from 9-7 Ma with compositions consistent with olivine tholeiites. The second group was active between 2.0 and 0.4 Ma and produced basalts of two very distinctive compositions, strongly tholeiitic (M2) and mildly alkaline (M3). The more alkaline rocks were erupted more recently with the first occurrence dating around 0.8 Ma. Like Vetter and Shervais (1992), White et al. interpreted the M3 basalts to have a source that is divergent from M1 and M2 and most likely containing asthenospheric mantle. The M1 and M2 tholeiitic basalts show evidence of a shallow mantle source with a complex history of depletion and enrichment. White et al. (2002) argue that melting due to extension and thinning of the lithosphere can explain the transition to more alkaline volcanism, therefore the incorporation of a mantle plume is unnecessary.

Shervais and Vetter (in press) elaborate on the transition of these basalts to a more alkaline end member. They argue that the change from low-K tholeiitic basalt and ferrobasalt to high-K transitional alkali basalt was abrupt, occurring approximately 700 to 900 ka. The older, more tholeiitic basalts show traits similar to the olivine tholeiites of the Eastern Snake River Plain basalts and therefore Shervais and Vetter (in press) have attributed these basalts to sharing similar processes and a similar origin. Similarities between these two basalt groups are major element, trace element, and isotopic abundance. The mildly alkaline basalts do not show the same trend with ESRP basalts, but instead are similar to plume derived alkali basalts of ocean islands, for example Hawaii. Similarities between mildly alkaline and ocean island basalts include analogous major, trace, and isotopic compositions. Shervais and Vetter (in press) have attributed the transition to a more alkaline end member to either the erosion of pre-existing mantle lithosphere or the depletion of lithosphere in fusible components. The abruptness of the transition implies that its origin was most likely catastrophic. An example of a catastrophic process that could possibly cause the geochemical change we see in the basalts of the Western Snake River Plain is delamination of the lithosphere (Shervais and Vetter, in press).

CHAPTER III

METHODS

Three and a half weeks of fieldwork were completed in and around the Dorsey Butte and Little Joe Butte quadrangles during the summer of 2008. The majority of time spent in the field focused primarily on mapping the distribution of volcanic units and their associated vents and collecting samples. Sample collection of the basalt flows took precedence, however some phreatomagmatic samples were taken for comparison purposes. Care was taken when sampling to ensure that the samples were fresh and all weathered surfaces were removed. Unfortunately, these samples could not be geochemically analyzed for this study. However, 50 of the 56 samples collected were powdered and are ready for later analysis. Hand specimens and samples large enough to make thin sections are also available for later petrographic study.

One detailed stratigraphic column was done for the Basaltic Tuff and Breccia of Hayland School. The unit was divided into ten zones based on color, grain size, composition, and sedimentary structures. Each zone was described in great detail and photographed.

Major element data were gathered from several sources to compare units in close proximity to the Dorsey Butte quadrangle. Variation diagrams were created from these data to graphically demonstrate differences in composition.

CHAPTER IV

STRATIGRAPHY

The following is a description of units found in and around the Dorsey and Little Joe Butte quadrangles of the Western Snake River Plain. The units are broken into three categories: effusive volcanic units, phreatomagmatic volcanic units, and sedimentary units. Within each of these categories the units are listed in chronological order from oldest to youngest. Relative ages for most of the volcanic units can be found on the stratigraphic chart in figure 7. A geologic map of this area can be found in figure 8 as well as Plate 1 in the back cover of this volume.

Correlation of Units

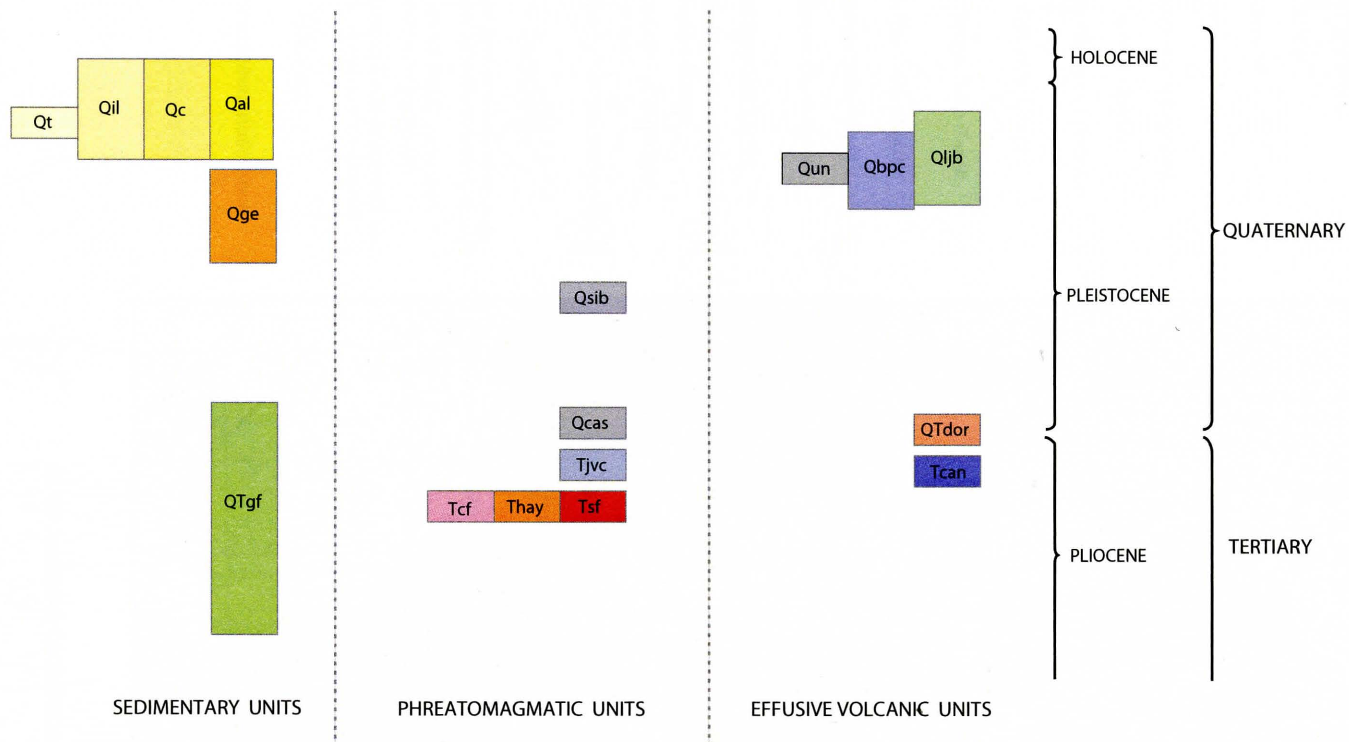


Figure 7. Stratigraphic age comparison chart. All units mentioned in this study are included. Tjvc, Qsib, and Qbpc have been radiometrically dated, all other ages are approximate and based on stratigraphic relationships.

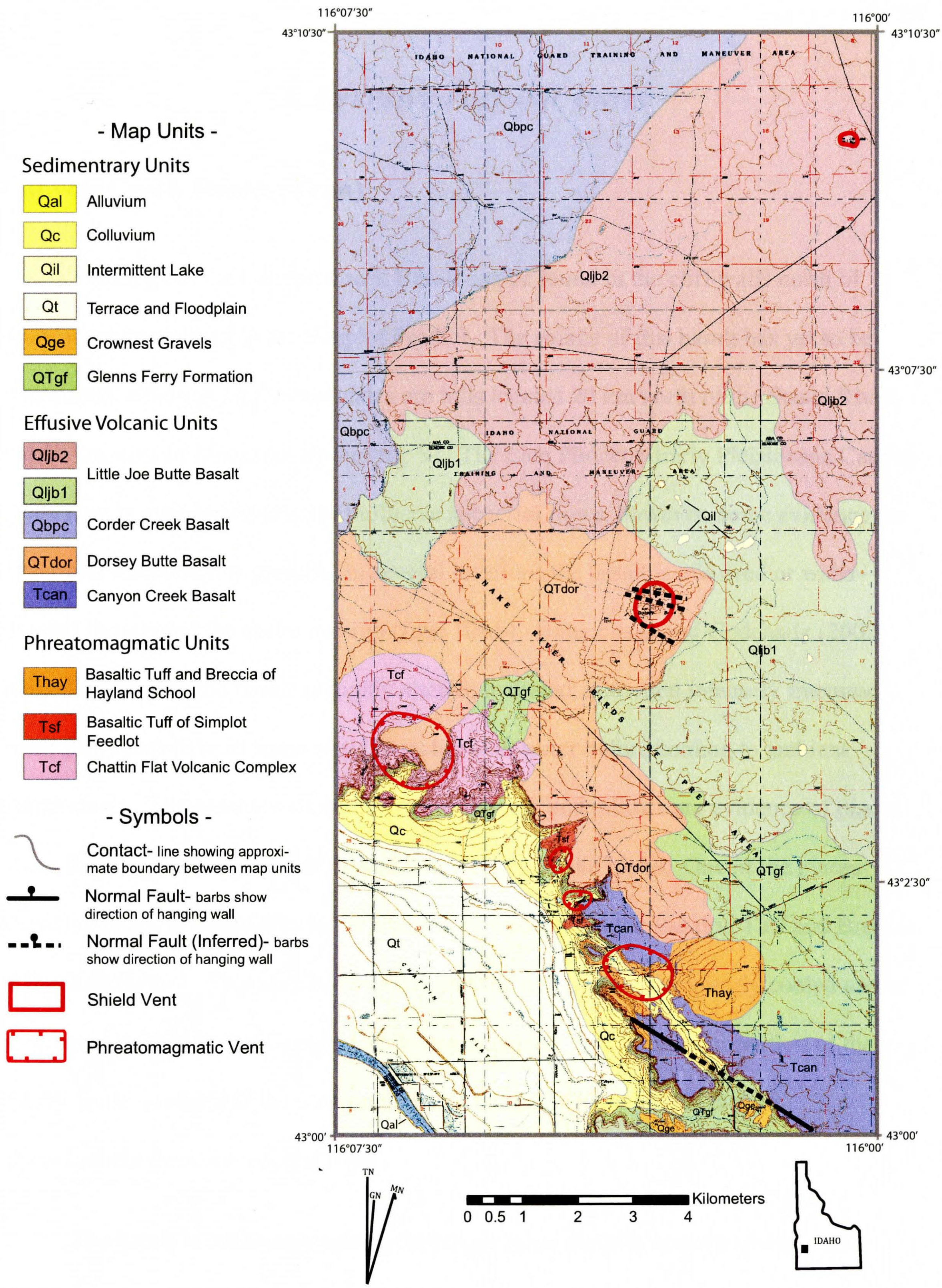


Figure 8. Geologic Map of the Dorsey Butte quadrangle and southern portion of the Little Joe Butte quadrangle, Ada County, Idaho

A. Effusive Volcanic Units

Canyon Creek Basalt (Tcan)

Outcrops of the Canyon Creek Basalt can be found in the cliff walls north of Bruneau and westward to the Simplot Feedlot. The source of this basalt has yet to be determined, although likely candidates are hills located 20 km north of the Snake River and 20 km west of Mountain Home (fig. 9). The Late Pliocene-Early Pleistocene Canyon Creek Unit is mainly comprised of effusive subaerial flows, however, some evidence for lava-water interaction is present. In several locations the basalt is pillowed or water-affected throughout the entire outcrop (figs. 10a,b). Bonnichsen and Godchaux (2002) defined water-affected basalt as highly altered, hydrated, and often intensely fractured basalt flows that have in some way interacted with water before cooling to ambient temperatures. The presence of water-affected basalts and pillows are evidence of places where the Canyon Creek Basalt flowed into Neogene Lake Idaho. One of the places where the basalt is water-affected is where it flowed around the Basaltic Tuff and Breccia of Hayland School. This may be evidence that the unit had not completely cooled and/or de-watered by the time of Canyon Creek emplacement. In the southern portion of the Dorsey Butte quadrangle the Canyon Creek is faulted. Offset on this fault is approximately three meters (fig. 10c).

The basalt is commonly aphyric although some samples contain sparse, small plagioclase crystals. The majority of samples analyzed from the Canyon Creek flow are

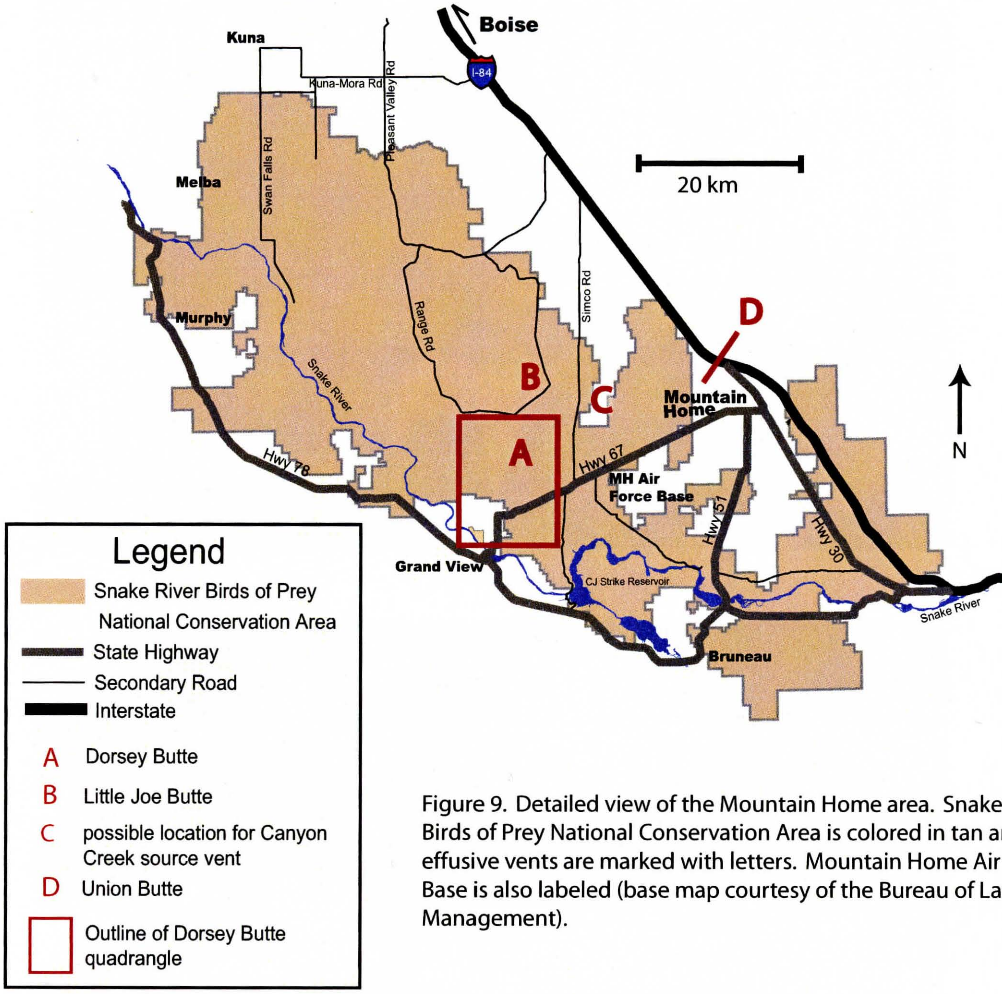


Figure 9. Detailed view of the Mountain Home area. Snake River Birds of Prey National Conservation Area is colored in tan and effusive vents are marked with letters. Mountain Home Air Force Base is also labeled (base map courtesy of the Bureau of Land Management).

a)

b)

Figure 10 a + b. Photographs of water-affected basalts from the Canyon Creek unit. Both pictures show the high degree of fracturing associated with these basalts and the resultant rounded weathering patterns.

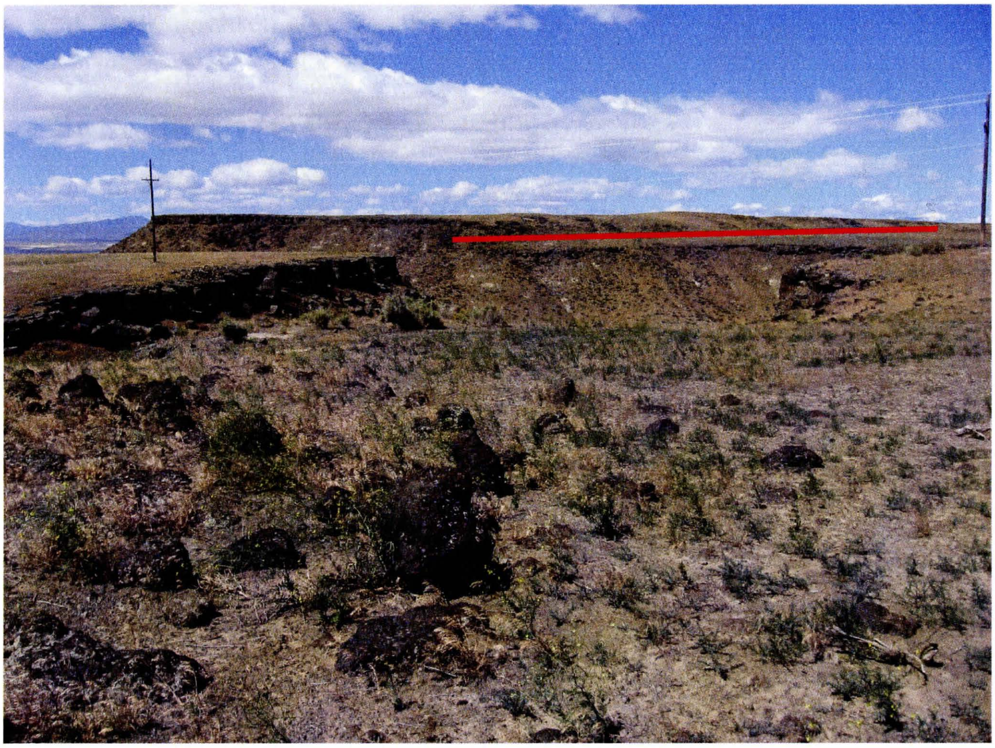


Figure 10c. Faulted Canyon Creek Basalt. Red line marks approximate location of fault.

Fe-enhanced, which by definition means that they contain between 15.0 and 15.99 percent Fe_2O_3 (Bonnichsen and Godchaux, 2002).

Dorsey Butte Basalt (QTdor)

The Late Pliocene-Early Pleistocene Dorsey Butte Basalt flow erupted from Dorsey Butte located approximately 11 km NNE of Grand View, Idaho (fig. 9). The Dorsey Butte shield volcano is not symmetrical, but elongated to the NE-SW with its long axis measuring approximately 2 km (fig. 11). The top of the shield is irregular and appears to be dissected by three southeast trending faults. Lavas flowed from this vent 6 km to the south and up to 12 km to the west (Bonnichsen and Godchaux, 2002). Like the Canyon Creek Basalt, the Dorsey flow is exposed in the cliffs on the east side of the Snake River. A segment of the flow appears to have entered the vent region of the phreatomagmatic Chattin Flat Volcanic Complex, giving the flow margins their unique shape.

The Dorsey Butte Basalt does not have abundant phenocrysts, although small olivine phenocrysts and minor plagioclase phenocrysts are present (fig. 11b). It is often altered and vesicles are commonly filled with $CaCO_3$ accumulation. The basalt commonly displays a diktytaxitic texture. A typical sample from this unit has a Snake River olivine tholeiite (SROT) composition (Bonnichsen and Godchaux, 2002). The major element geochemistry for the Dorsey Butte flow is provided in more detail in the geochemistry chapter of this paper.

Figure 11a. Dorsey Butte shield volcano looking toward the southeast.

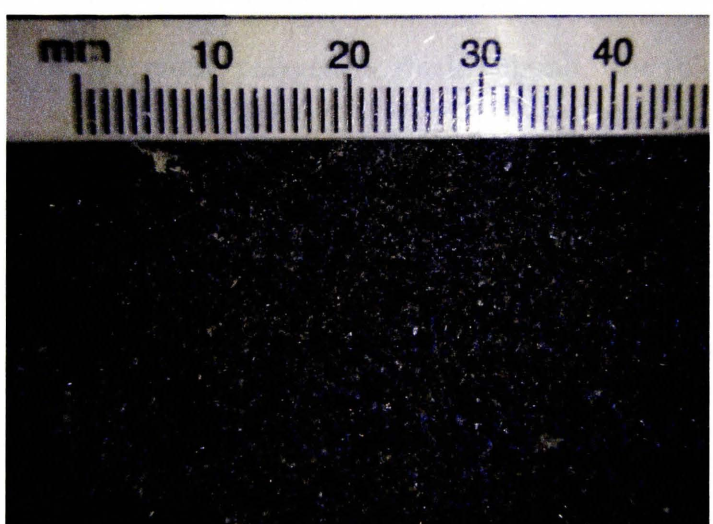


Figure 11b. Hand specimen taken from the Dorsey Butte flow; showing small percentage of plagioclase phenocrysts and diktytaxitic texture.

Union Buttes Basalt (Qun)

The Union Buttes Basalt erupted from two cinder cones approximately nine kilometers northwest of Mountain Home, Idaho (fig. 9). The flow does not reach the Dorsey Butte quadrangle, however it was included in this study for geochemical comparison. A representative sample has a glassy matrix with abundant olivine phenocrysts and minor plagioclase phenocrysts (Zarnetske, pers. comm.). The major element geochemistry for the Union Buttes Basalt is described in the geochemistry chapter of this paper.

Corder Creek Basalt (Qbpc)

The Corder Creek Basalt is a single flow within the larger Pleistocene Birds of Prey Basalt Field located NNW of Dorsey Butte (fig. 9). The Birds of Prey Basalt Field represents one giant, low profile polygenetic shield volcano. The volcano and its flows cover an area that is 30 km (N-S) by 40 km (E-W) (Bonnichsen and Godchaux, 2002). Amini et al. (1984) published K-Ar dates for several basaltic units in the Western Snake River Plain. He found an age of 0.47 Ma for what he termed the recent Big Foot Butte Flow. The coordinates of the sample collection correspond with the Corder Creek Basalt and therefore both units are likely synonymous.

A typical sample of the basalt has abundant plagioclase phenocrysts and to a lesser extent olivine phenocrysts. A common and distinguishing feature of the Corder Creek Basalt is the occurrence of these phenocrysts in glomerocrysts (fig. 12).

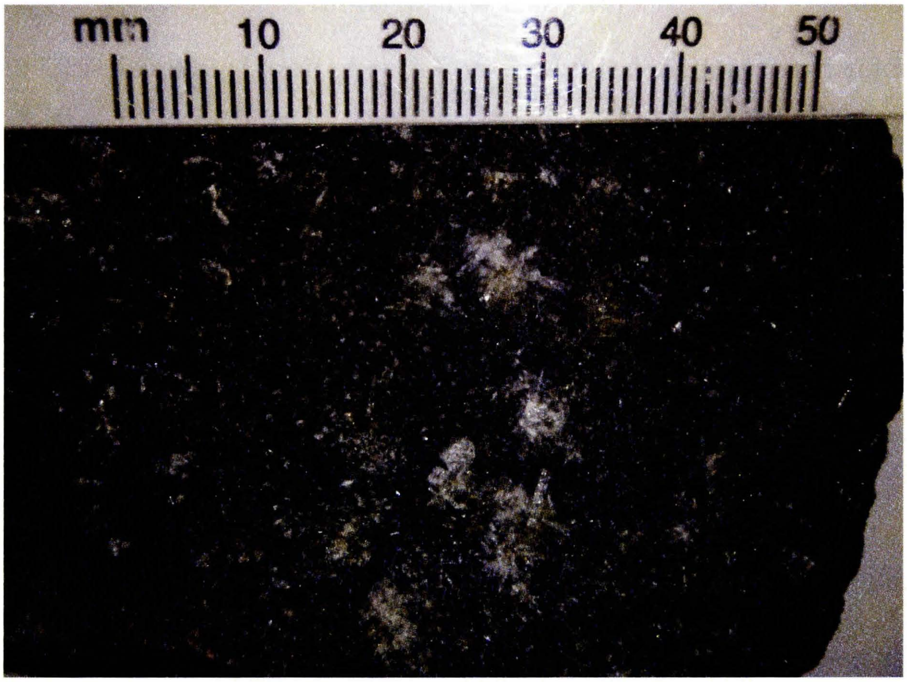


Figure 12. Hand specimen from the Corder Creek flow exhibiting glomerocrysts of plagioclase and olivine phenocrysts.

Little Joe Butte Basalt (Qljb1 and Qljb2)

The Little Joe Butte Basalt erupted from the Little Joe Butte shield volcano just south of the Birds of Prey Basalt Field (fig. 13a). The flows from Little Joe Butte cover an area 26 km (N-S) by 14 km (E-W). Little Joe Butte is located just within the southeast corner of the National Guard Training Facility Impact Area (fig. 9). The small shield lies within 100 feet of the Range Road making it difficult to access without military supervision. The basalt flows from this volcano predominantly flowed to the south. Some flowed far enough to reach the ancestral Snake River Valley and then followed the river downstream for approximately 8 km. The Little Joe Butte Basalt has also been termed the basalt of Dixie Ranch and the basalt of Strike Dam Road (Jenks et al., 1993, 1998; Shervais et al., 2002). Changes in topography, slope, and elevation, as well as the presence of well-defined flow margins are evidence that the Little Joe Butte Flow is comprised of two units of differing ages. The second Little Joe Butte unit did not travel as far as the older unit and changes in the petrography of the two units appear to be negligible.

The Little Joe Butte Basalt commonly has abundant phenocrysts of both olivine and plagioclase (fig. 13b). Analysis of the Little Joe Butte flow reveals that it has a SROT composition with relatively high Al and alkalis. It is similar to other Pleistocene basalts erupted from the central zone of the Western Snake River Plain including the basalts of the Birds of Prey Field (Bonnichsen and Godchaux, 2002). The geochemistry of this flow is described in more detail in the geochemistry chapter of this paper.

Figure 13a . Little Joe Butte shield volcano looking southwest; view from the National Guard training area range road.

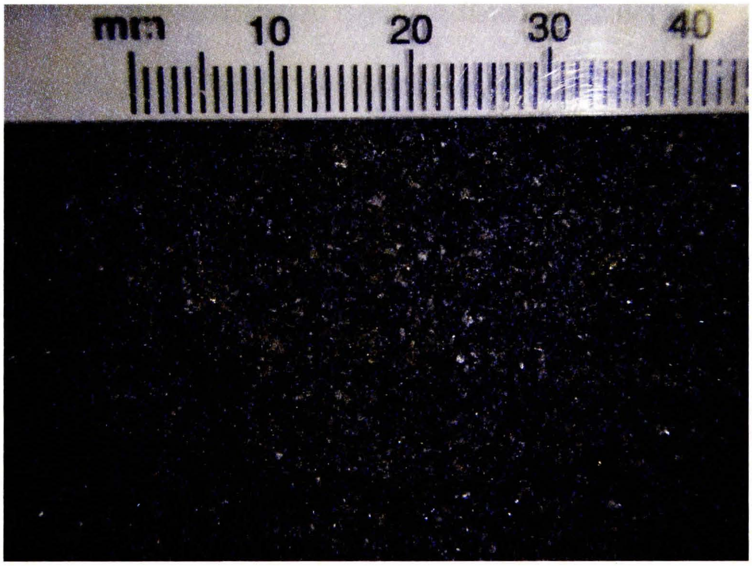


Figure 13b. Hand specimen from the Little Joe Butte flow exhibiting phenocrysts of both plagioclase and olivine.

B. PHREATOMAGMATIC UNITS

Small phreatomagmatic eruptions occurred frequently in the Western Snake River Plain during the late Pliocene and early Pleistocene. Explosive hydrovolcanic deposits dominate the cliff walls along the 80 km stretch of river from the Simplot Feedlot to Walters Ferry. The deposits consist of extensive beds of basaltic tuff mixed with sedimentary material produced predominantly by maars and tuff rings in wet, subaerial environments. Bonnichsen and Godchaux (2002) divided the phreatomagmatic deposits of the Western Snake River Plain into nine categories based upon effusion rate and water depth (fig. 14). Type I, II, and III refer to sublacustrine, emergent and subaerial, while A, B, and C refer to low, moderate, and high effusion rate. The effusion rate and depth of water associated with each eruption hold important implications for the type of volcanism produced and therefore these classification types are listed below for the phreatomagmatic deposits that lie within the Dorsey Butte quadrangle.

Neogene Lake Idaho provided a source of water for a good portion of these phreatomagmatic eruptions. The lake dominated the Western Snake River Plain graben from approximately 12 million to at the latest 1.6 million years ago (Wood and Clemens, 2002). After the draining of Lake Idaho, lava flows dammed the ancestral Snake River forming small, temporary lakes into which later volcanoes erupted (Brand and White, 2007).

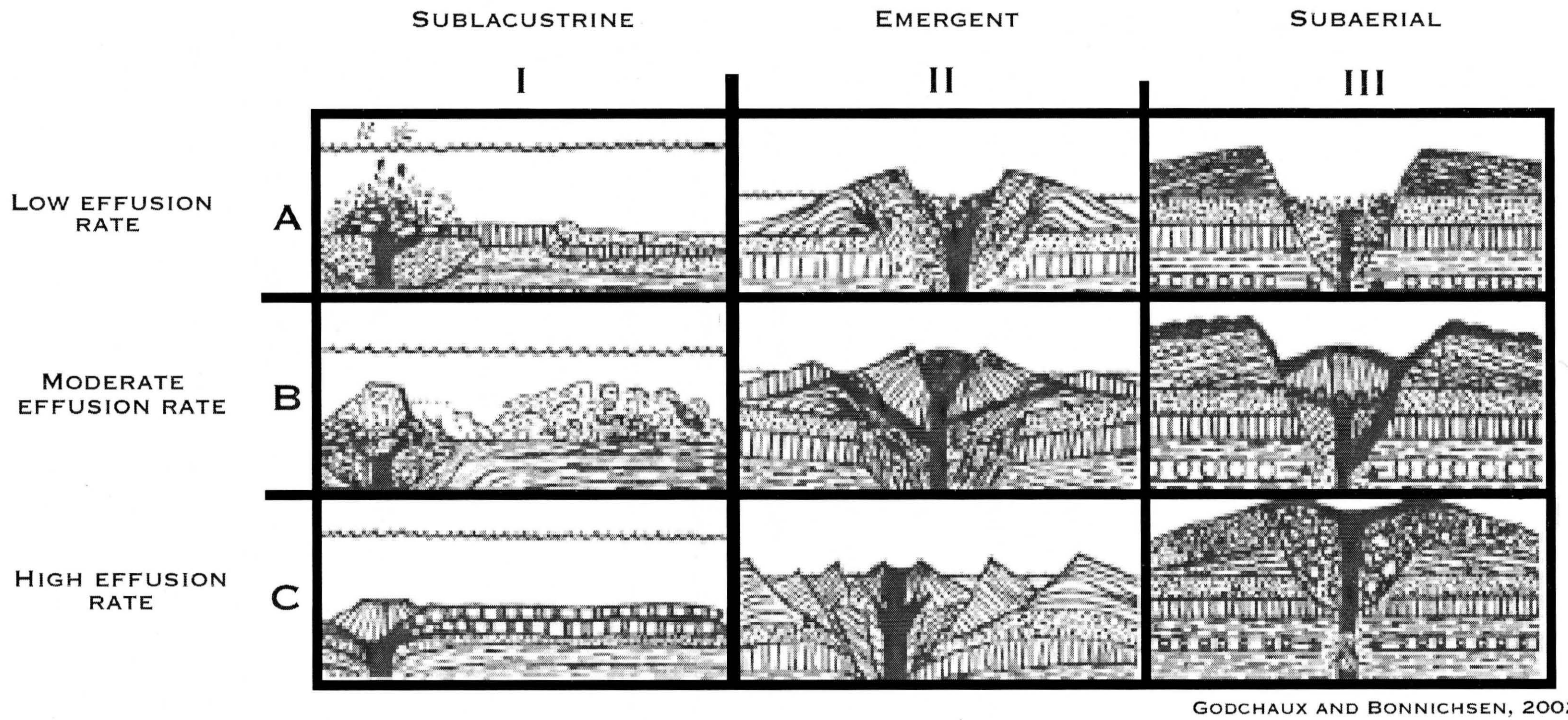


Figure 14. Classification of phreatomagmatic deposits (Bonnichsen and Godchaux, 2002).

Basaltic Tuff of the Feedlot (Tfl)

The Basaltic Tuff of the Feedlot erupted from maars and tuff ring complexes north of Grand View, Idaho. It can now be observed in the cliffs adjacent to the Simplot Feedlot. The basaltic spatter associated with the Feedlot Tuff is predominantly characterized as Snake River Olivine Tholeiite (SROT) although some from the Chattin Flat vent area is Fe-enhanced. The major element geochemistry of the Chattin Flat Basalt is described in the geochemistry chapter of this paper. The volcanic sources for the Feedlot tuff are from northwest to southeast: the Chattin Flat Volcanic Complex, the Basaltic Tuff of Simplot Feedlot, and the Basaltic Tuff and Breccia of Hayland School (fig. 15). An overview photograph of the phreatomagmatic deposits in the cliffs of the Snake River can be found on figure 16. Bonnichsen and Godchaux (2006) in their 1:100,000 Murphy 30 x 60 geologic map identified 4 vent sources associated with these regions. I also attributed these deposits to 4 vents; however, I disagree with their placement. The reasons for this and their revised locations are described below.

- ### Chattin Flat Volcanic Complex (Tcf)

The Chattin Flat Volcanic Complex is a tuff ring complex, the largest of the phreatomagmatic deposits in the Dorsey Butte quadrangle (fig. 15). Near the center of the deposit approximately 75% of beds dip steeply toward the vent and 25% have a shallow dip away from the vent (fig. 17). In order to determine the location of the vent, the dip of the beds and the circular nature of the cliffs were taken into account. Bonnichsen and Godchaux (2006) place an additional vent just to the southeast of the

Figure 15. Distribution of phreatomagmatic units and their associated vents. Yellow asterisk marks the location of the stratigraphic column (plate 2). Tcf- Chattin Flat Volcanic Complex, Tsf- Basaltic tuff of the Simplot Feedlot, and THay1 and THay2- Basaltic Tuff and Breccia of Hayland School.

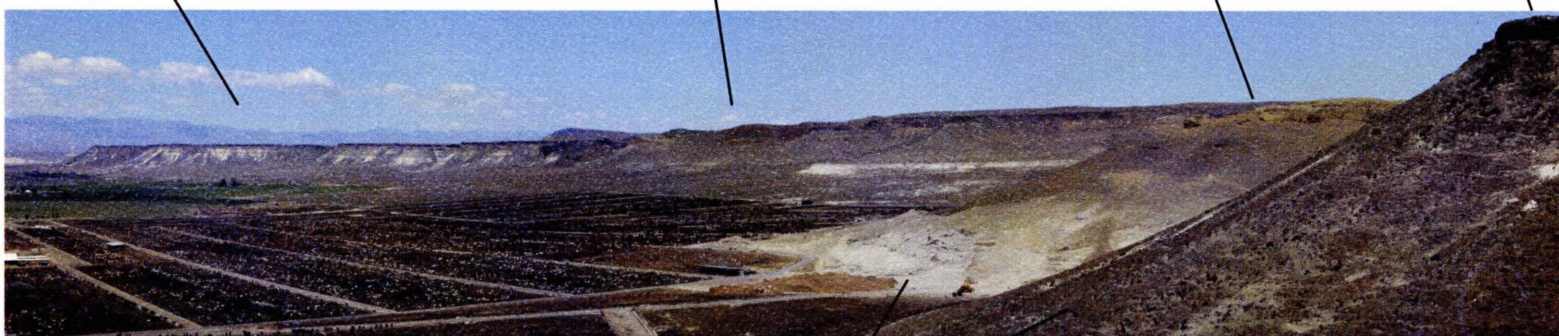


Figure 16 . Overview photograph of the cliffs along the Snake River. Picture is taken looking toward the northwest. Prominent units are labeled, and the cows of the Simplot Feedlot can be used for scale.

Figure 17. Chattin Flat Volcanic Complex looking west toward the Snake River. Vent is to the right of this photograph. Yuko, a medium 45 pound orange and white dog is in the foreground for scale.

first but there is not enough evidence to support a second vent. In this area the beds are flat lying and the overall shape of the complex supports the presence of one large vent, rather than two smaller vents.

The deposits of the Chattin Flat Volcanic Complex grade upward into two scoria cones, one to the north of the Dorsey flow lobe and one to the south. The presence of scoria near the top of the Chattin Flat Volcanic Complex is evidence that the system de-watered toward the end of its cycle. Based on Bonnichsen and Godchaux's (2002) classification scheme the Chattin Flat Volcanic Complex is a Type IIB volcano; a large emergent tuff cone with a late magmatic component (fig. 14).

- **Basaltic Tuff of Simplot Feedlot (Tsf)**

The Basaltic Tuff of Simplot Feedlot consists of two isolated phreatomagmatic deposits each with their own vent. Vent placement for these two eruptions was more difficult due to their size and relatively flat lying beds (fig. 16). Following the lead of Bonnichsen and Godchaux (2006) for the northern unit, the vent followed the circular pattern along the cliffs (fig. 15). Bonnichsen and Godchaux did not place a vent at the southern deposit, however I felt the pattern in the cliffs as well as the size of the deposit was evidence for a second vent. According to Bonnichsen and Godchaux's (2002) classification scheme the Basaltic Tuff of Simplot Feedlot is a Type IIA small tuff cone with no late magmatic component (fig. 14).

- **Basaltic Tuff and Breccia of Hayland School (Thay)**

The Basaltic Tuff and Breccia of Hayland School is a large phreatomagmatic deposit located both north and south of Grandview Road. The unit is often overlain by the basalt of Canyon Creek. In some places the Canyon Creek flow appears to be interbedded with the Hayland School deposit however after close inspection it is more likely that the basalt wraps around the phreatomagmatic deposit, rather than being contained within it (fig. 18). The placement of the vent for this phreatomagmatic eruption was determined by the distribution of deposits, circular pattern of the contours, and high rate of erosion. Some of the beds dipped slightly to the north, but dip was less than 10° and not consistent for all beds. The Basaltic Tuff and Breccia of Hayland School is Type IIB according to Bonnichsen and Godchaux's (2002) classification scheme, it is a large emergent tuff cone with a late magmatic component (fig. 14).

An eight-meter stratigraphic column was generated from an outcrop within the Basaltic Tuff and Breccia of Hayland School (fig. 19, plate 2). It was taken from a scoria borrow pit near the middle of the unit on the north side of Grandview Road (fig. 19a). The exact location where the stratigraphic column was taken is marked with a yellow asterisk on figure 15.

The bottom three meters of the unit consist of a massive, clast supported, medium to poorly sorted scoria deposit (fig. 19b). The base is dark red in color but transitions to dark grey about two-thirds of the way up. The composition of this portion of the unit is 95% scoria and 5% consolidated ash or tuff; with the change in color the abundance of

Figure 18. Cliffs of the Basaltic Tuff and Breccia of Hayland School above the Glenns Ferry Formation.

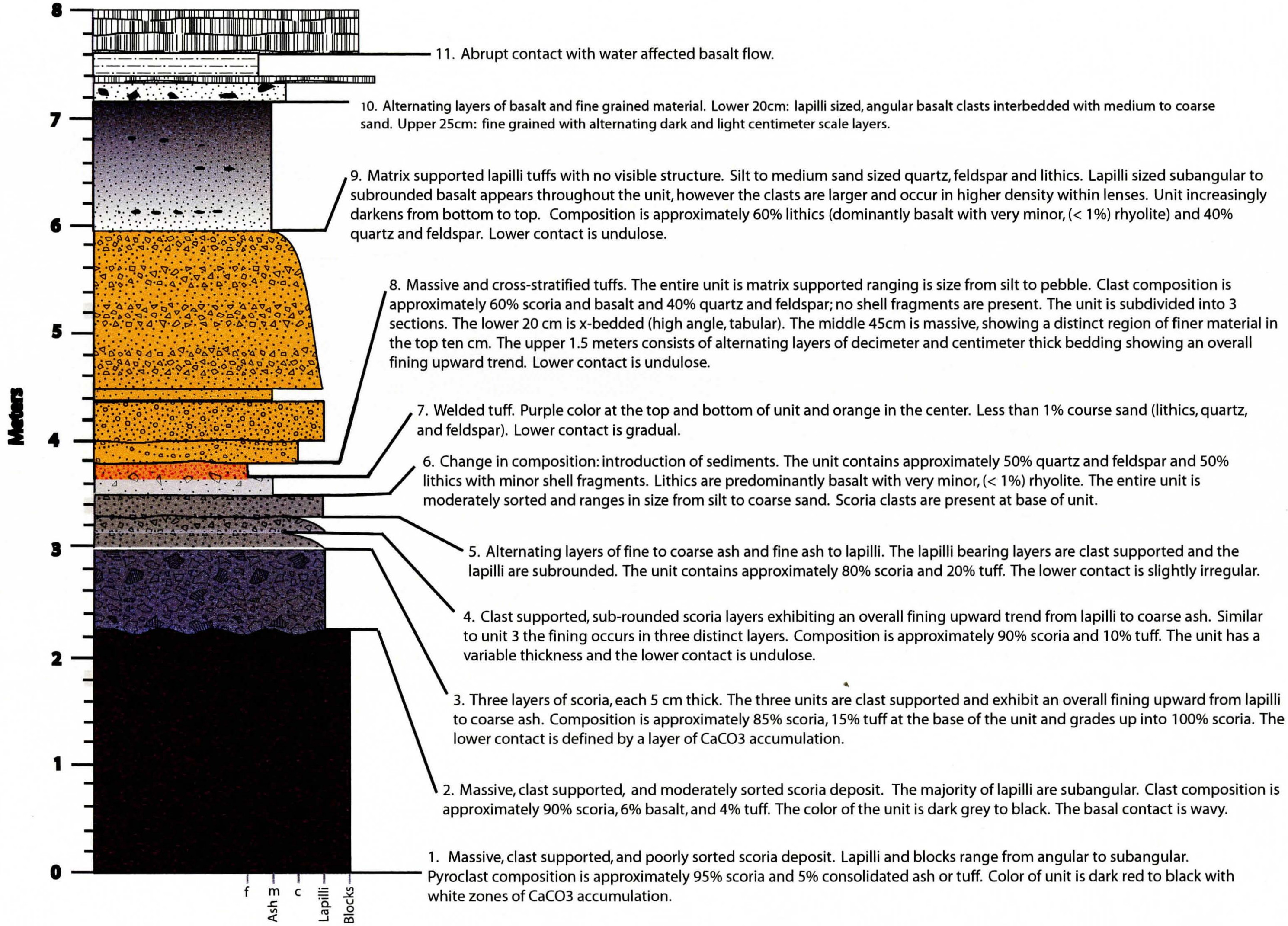
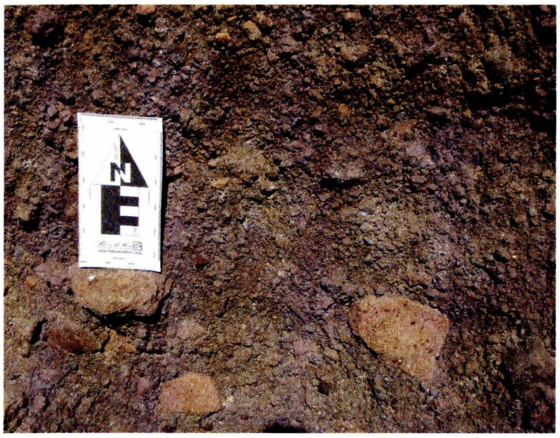


Figure 19. Stratigraphy of the Basaltic Tuff and Breccia of Hayland School, Western Snake River Plain, ID

Figure 19a. Photograph of outcrop where the stratigraphic section was taken. Reference staff is two meters high with red and white divisions occuring every twenty centimeters. View is toward the north.



b.

c.

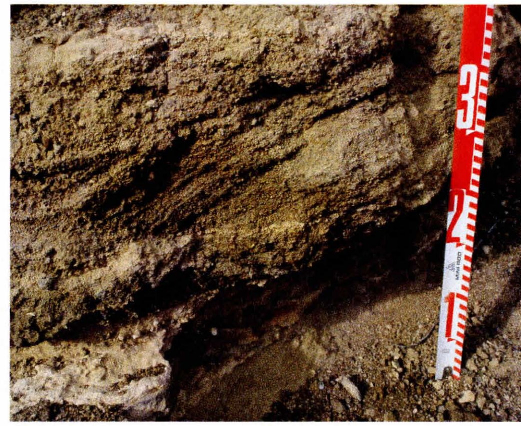
d.

19 b, c, and d. Photographs taken from the base of the Hayland stratigraphic column. (b) shows the basal scoria deposits, (c) shows the fining upward sequence of the upper scoria deposits and (d) shows both the basal scoria deposits and the upper layered scoria deposits as well as the introduction of sedimentary material above them, the transition from red to dark grey in the basal scoria is evident.

scoria decreases and basaltic fragments appear. Following the basal scoria deposit are two more 15 cm thick scoria sections exhibiting an overall fining upward trend (figs. 19c,d). Above that is a zone 20 cm thick of alternating layers of fine to coarse ash and fine ash to lapilli. At 3.5 meters there is a significant change in composition. This marks the introduction of sedimentary material into the system. At this point the unit is moderately sorted and contains silt to coarse sand sized material. The composition is approximately 50% quartz and feldspar, 50% lithics, and to a lesser extent shell fragments. The lithics are dominantly basalt but minor rhyolite is present as well. Scoria clasts are present at the bottom of this section directly above the scoria deposits (fig.19e). Following the change in composition at 3.5 meters is a 15 cm welded tuff (fig. 19f), followed by a 2.15-meter section with 60% scoria and basaltic fragments, 40% quartz and feldspar, and no shell fragments. The grain size of this section ranges from silt to pebble. High-angle, tabular cross-bedding is present in the lower 20 cm and is followed first by a massive unit and then transitions to small scale layering (figs. 19f,g). Above the layered unit is a 1.2-meter thick section of silt to medium sand sized quartz and feldspar (40%) and basaltic fragments (60%). Lapilli sized sub-angular to sub-rounded basalt clasts are also present throughout although more prominent in lenses (fig. 19h). Above the section with a high concentration of basaltic fragments lie alternating layers of basalt and finer grained material. The stratigraphic column is topped by an abrupt contact with a water-affected basalt flow (fig. 19i).

The basal scoria deposits were erupted during a time when water did not have access to the volcanic vent. The scoria were deposited as scoria fall deposits from a

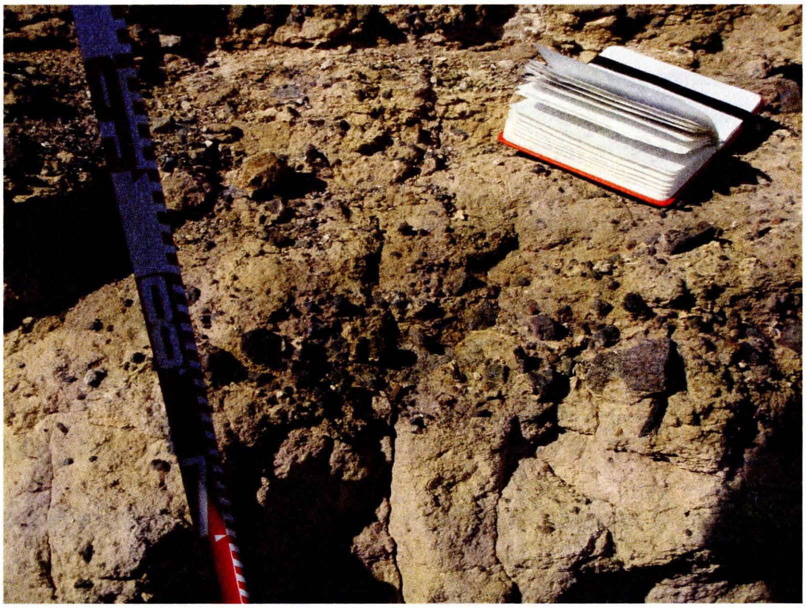
e.



f.

g.

Figure 19 e, f, and g. Photographs taken from the middle of the Hayland School stratigraphic column. (e) shows scoria clasts at the base of the introduction of sedimentary material, (f) shows tabular cross-bedding above the welded tuff, and (g) shows the massive and layered deposits.



h.

i.

Figure 19h and i. Photographs taken from the top of the Hayland School stratigraphic column. (h) shows the high abundance of basaltic fragments and their tendency to concentrate in lenses, (i) shows the transition to water-affected basalt at the top of the unit.

scoria cone. Higher in the section the scoria display fine scale layering and a fining upward trend. This upper part of the scoria unit was likely deposited into shallow standing water. The introduction of sedimentary material above the scoria deposits may be due to the introduction of external water, for example a river or lake. The addition of the water may have been rapid and forceful; evidence for this is the presence of scoria clasts above the contact between scoria deposits and the introduction of sediment. A river overtopping a lava dam could explain the rapid water inundation of the system. The cross-bedded and massive tuffs may be the product of channel flow, subaqueous reworking of material, and/or subaqueous debris flows. The presence of basaltic layers and lenses toward the top of the unit is evidence of the de-watering of the system.

Jackass Butte Volcanic Field (Tjvc)

Jackass Butte Volcanic Field is located approximately 7 km west of the Chattin Flat Volcanic Complex (fig. 20). The volcanic field straddles both the east and west side of the Snake River and contains five maar and tuff ring complexes. Deposits from Jackass Butte contain accidental blocks of both the underlying Brooks Ranch Basalt, the Feedlot Tuff, and abundant sedimentary material. The names of the five complexes that make up this volcanic field from SE to NW are: Jackass Butte SE, Jackass Butte NE, Rabbit Creek Canyon, Big Foot Bar East, and Birthday Gulch. The geochemistry of these basalts lie in the SROT field. Godchaux and Bonnichsen (2002) took a representative sample from Rabbit Creek Canyon. The major element geochemistry of this sample is listed in the geochemistry chapter of this paper. Rabbit Creek Canyon

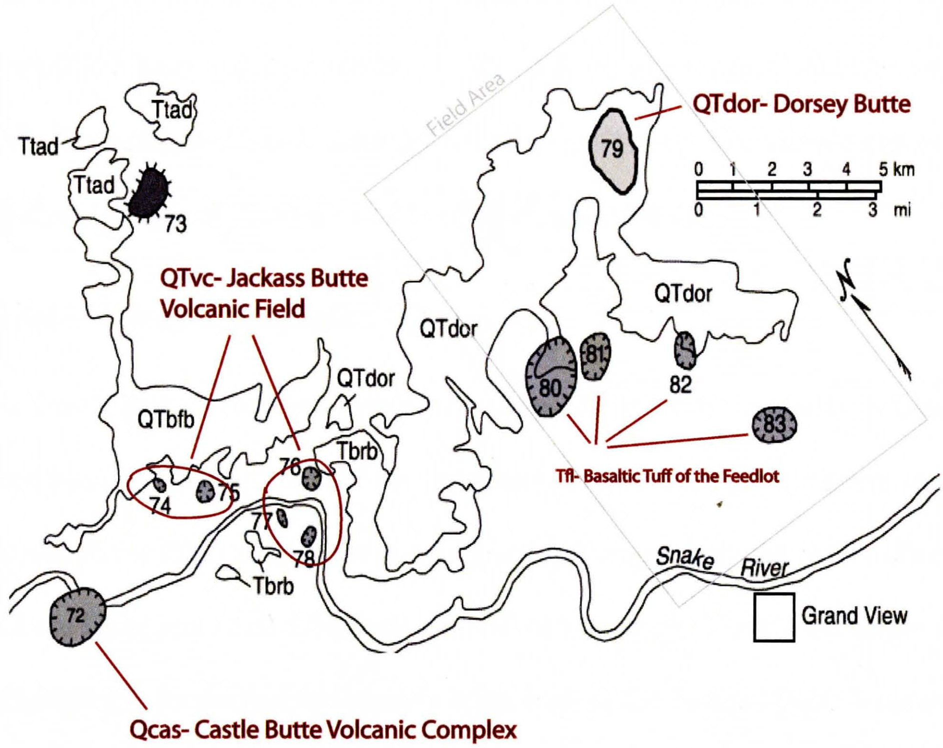
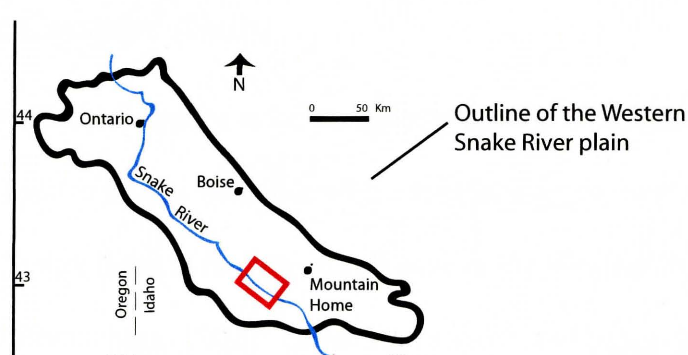


Figure 20. Location map of phreatomagmatic vents used in geochemical analyses. Individual volcanic centers are as follows: 72- Castle Butte, 74- Big Foot Bar East, 75- Birthday Gulch, 76- Rabbit Creek Canyon, 77- Jackass Butte NE, 78- Jackass Butte SE, 79- Dorsey Butte, 80 and 81- Chattin Flat, 82- Simplot Feedlot, 83- Hayland School (modified from Bonnichsen and Godchaux, 2002)



began as an emergent tuff cone and, as it de-watered, began building late stage cinder and spatter cones (Godchaux and Bonnichsen, 2002). A K-Ar age for this field was taken from Jackass Butte, labeled Black Butte by Amini et al. (1984). For sample number 79H4-2 he found an age of 2.18+/-0.18 Ma (Amini et al., 1984).

Castle Butte Volcanic Complex (Qcas)

The Castle Butte Volcanic Complex is composed of a tuff ring below a layer of Fe-enhanced basaltic spatter. Most of the Fe-enhanced phreatomagmatic deposits in the Western Snake River Plain erupted from maars and tuff rings along the Snake River between Castle Butte and Lizard Butte (2 km NW of Marsing). The Castle Butte Volcanic Complex is located approximately 6 km west of the Jackass Butte Volcanic Field on the southern margin of what was once possibly a large maar (fig. 20). The Bonneville Flood is thought to have dissected this maar leaving only two erosional remnants, one on each side of the Snake River. There are no radiometric dates for the Castle Butte Volcanic Complex, but stratigraphy and geochemistry imply an age between 2.0 and 1.8 Ma (Godchaux and Bonnichsen, 2002).

Sinker Butte Volcanic Complex (Qsib)

The Sinker Butte Volcanic Complex is located approximately 13 km east of Murphy, Idaho. The butte itself is a large tuff cone with a lava lake approximately 1 km in diameter sitting on top. Sinker Butte is the largest tuff cone in the Western Snake River Plain (Godchaux and Bonnichsen, 2002). Basalt flows above and below the complex were dated using 40Ar-39Ar, constraining the beginning and end of the Sinker

Butte eruption. The lower basalt, the Swan Falls Reservoir Basalt is 1.25 +/- 0.22 Ma and the upper basalt, the Sinker Butte Basalt is 1.17 +/- 0.18 Ma (Brand and White, 2007). Basalt of the unit ranges from Fe-enhanced basalt to ferrobasalt (Godchaux and Bonnichsen, 2002).

C. SEDIMENTARY UNITS

Glenns Ferry Formation (QTgf)

The Glenns Ferry Formation is a Pliocene collection of nonindurated, complexly intertonguing, lake and stream deposits of great areal extent and thickness. The formation is commonly found in the cliffs of the Snake River (fig. 16). The exposed thickness of this unit is over 600 meters at its type location, the town of Glenns Ferry. It crops out almost continuously west from Glenns Ferry to Homedale, Idaho. Fossil evidence suggests that the presence of stratigraphic equivalents may mean that the unit covers several thousand square miles. Three principal facies are present within the Glenns Ferry: lacustrine, fluvial, and floodplain. The facies are rarely continuously exposed and involve complex intertonguing. The lacustrine facies accounts for the majority of Glenns Ferry deposits. Seventy percent of the unit is comprised of silts and muds. It consists of fine-grained, calcareous and clay-rich mudstones and minor amounts of fine to medium grained sand, micritic carbonate layers, volcanic ashes and basalt flows, and diatomites. The fluvial facies is composed mainly of thick, even layers of brownish grey sand with minor silt. Some layers are cross-bedded and ripple marked with parallel bedding planes. Floodplain deposits contain 1-3 foot thick fine-grained beds. Calcareous pale olive silt is present in the lower part and dark clay in the upper part. The lacustrine facies is likely related to deposition associated with Neogene Lake Idaho. The Glenns Ferry Formation is part of the Idaho Group that underlies much of the Western Snake River Plain. The age of the unit can be constrained to the late Pliocene/early Pleistocene. Mollusks in the formation were alive during the late Pliocene and vertebrates in the early Pleistocene (Malde, 1962).

Crowsnest Gravel (Qge)

Late Pleistocene gravel deposit consisting of three dominant clasts: basalt, quartzite, and chert. Less abundant clasts are sandstone, weathered basalt, granite, and dacite. Clasts range in size from granules to cobbles, are rounded to well rounded, and are commonly elongate. Caliche is present on the bottom of most clasts. The unit is matrix supported and poorly sorted with a high density of clasts. Size of matrix ranges from silt to medium sand. There is no obvious bedding present. Crude imbrication of clasts suggests paleo-flow to the south (fig. 21).

The lithology of the Crowsnest Gravel suggests that the deposit was mostly derived from a tributary valley rather than the ancestral Snake River. The tributary valley likely had a course similar to the current course of the Big Wood River, which currently carries gravel predominantly consisting of quartzite and granite. The basalt within the Crowsnest Gravel was most likely derived locally.

a)

b)

Figure 21a + b. Photographs of the Crowsnest gravel. (a) is a representative view of the deposit, (b) shows crude imbrication of the clasts suggesting flow to the south.

Terrace and Floodplain deposits (Qt)

This unit consists of terrace and floodplain deposits from the Snake River that were modified by the Bonneville Flood approximately 14 ka. The effects of the Bonneville Flood can be seen today in the Western Snake River Plain as heavily eroded cliffs, hummocky terrain, and boulder fields.

Colluvium (Qc)

This unit is concentrated at the base of cliffs cut by the Snake River. The mass wasting deposit consists of basalt, Glenns Ferry formation, phreatomagmatic deposits, and loess shed from the upper reaches of the cliffs.

Alluvium (Qal)

This unit consists of river sediments deposited by the Snake River. In the Dorsey Butte quadrangle alluvium is concentrated in a very fine swath directly adjacent to the Snake River.

Intermittent Lake Deposits (Qil)

Intermittent lake deposits consist predominantly of windblown silt concentrated in depressions in lava flows. They differ from merely windblown silt concentrations in that they have undergone periods of hydration and evaporation similar to a playa. These areas can be easily identified using satellite imagery.

CHAPTER V

GEOCHEMISTRY

Major element data for six volcanic units are presented in (Table 1). Analyses for the Union Butte and the Little Joe Butte flows were taken from Shervais and Vetter (in press) and were made using an x-ray fluorescence spectrometer (XRF) at the University of South Carolina. Analyses for the Dorsey Butte flow, Basaltic Tuff of the Feedlot, Jackass Butte Volcanic field, and Castle Butte Volcanic Complex were taken from Bonnichsen and Godchaux (2002). Their samples were analyzed by XRF at both the University of Massachusetts at Amherst and Washington State University. Each unit was plotted on a TAS (total alkalis vs. silica) diagram for classification purposes (fig. 22). The rocks all similarly plot in the upper portion of the basalt field, classifying them as well within the range for basaltic lavas.

The major element data was plotted on variation diagrams with MgO weight percent on the x-axis (figs. 22, 23). They were not plotted on Harker variation diagrams (with SiO_2 on the x-axis) because SiO_2 is the most abundant oxide and varies little in basalts. This can lead to a negative tendency, spurious correlations, and reduced scatter as SiO_2 increases (Rollinson, 1993). MgO on the x-axis is more appropriate for comparison when dealing with abundant mafic members, where the range in SiO_2 is typically small. The weight percent MgO for these basalts ranged from 5 to 8%.

Trends on variation plots show higher alkali (Na_2O and K_2O) concentrations and Mg/Fe ratios for the Union Butte and the Little Joe Butte flows than the other four units

Table 1. Major Element weight percent oxide concentrations for selected basaltic units of the Western Snake River Plain

Sample #	Unit	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
96SRP-38-2	Qun	48.24	2.18	15.65	11.53	0.18	7.64	9.44	3.03	1.29	0.56	99.75
SRP 119	Qun	48.40	2.25	15.40	11.53	0.19	6.60	9.68	2.83	1.30	0.69	98.88
SRP 109	Qun	48.60	2.22	15.49	11.63	0.19	6.59	9.88	2.82	1.36	1.14	99.93
SRP 110	Qun	49.02	2.08	15.27	11.12	0.19	6.51	10.21	2.86	1.28	0.59	99.13
SRP 111	Qun	48.49	2.16	15.54	11.32	0.18	6.42	10.04	2.80	1.29	0.55	98.78
SRP 121	Qljb	47.17	2.67	14.77	13.07	0.21	6.89	10.52	2.89	1.03	0.71	99.94
SRP 122	Qljb	46.92	2.62	14.97	13.45	0.21	7.29	9.87	2.81	1.09	0.68	99.90
SRP 112	Qljb	47.37	2.53	15.22	13.22	0.20	8.07	9.63	3.06	1.06	0.61	100.97
SRP 120	Qljb	47.62	2.16	15.30	11.56	0.18	7.19	10.53	2.79	1.21	0.61	99.14
I-3033	QTdor	47.34	2.94	15.09	13.04	0.21	6.90	10.23	2.56	0.61	0.67	99.60
I-3028	Tfl	46.84	3.35	14.38	14.27	0.22	6.77	10.34	2.49	0.47	0.66	99.79
I-2996	Tjvc	48.87	2.96	14.10	13.23	0.20	5.80	11.34	2.39	0.71	0.76	100.36
I-2831	Qcas	48.71	3.59	14.04	13.69	0.21	5.13	10.34	2.53	0.71	0.64	99.59

Data sources: Qun and Qljb- XRF analyses from University of South Carolina, Shervais and Vetter (in press);
Qtdor, Tfl, Tjvc, and Qcas- XRF analyses from University of Massachusetts at Amherst and Washington State University, Bonnichsen and Godchaux (2002)

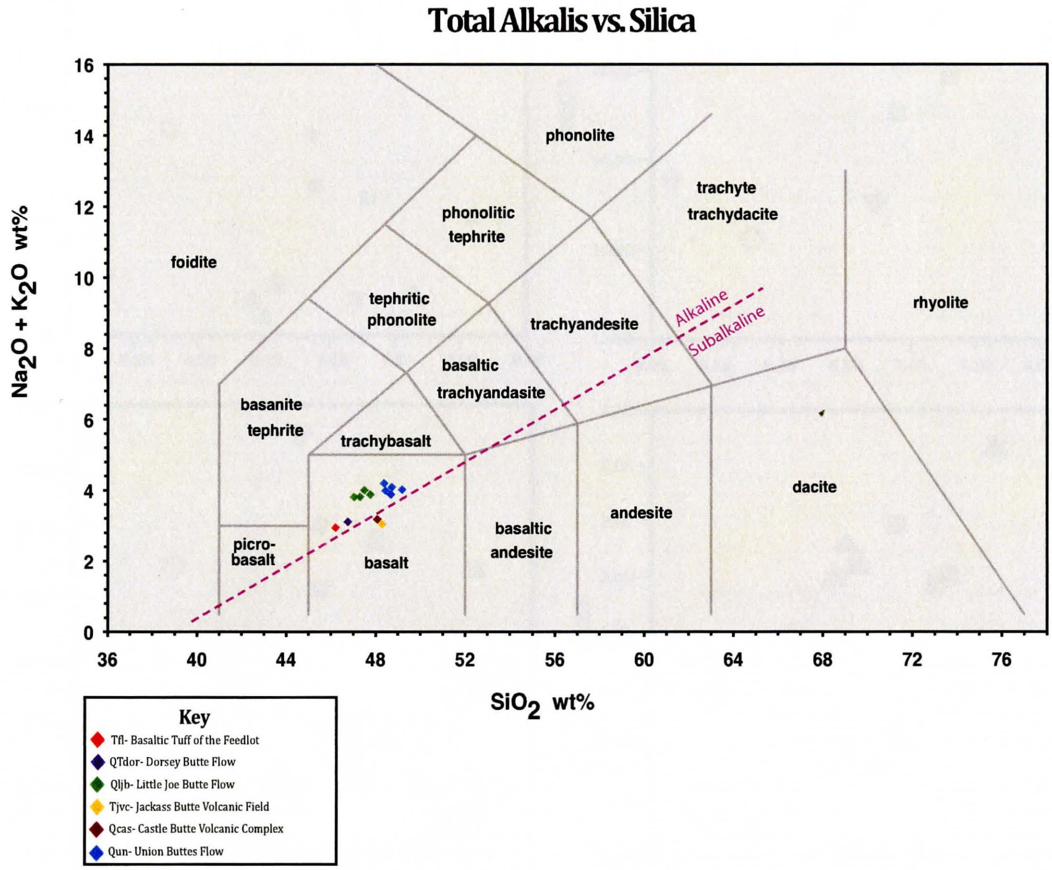
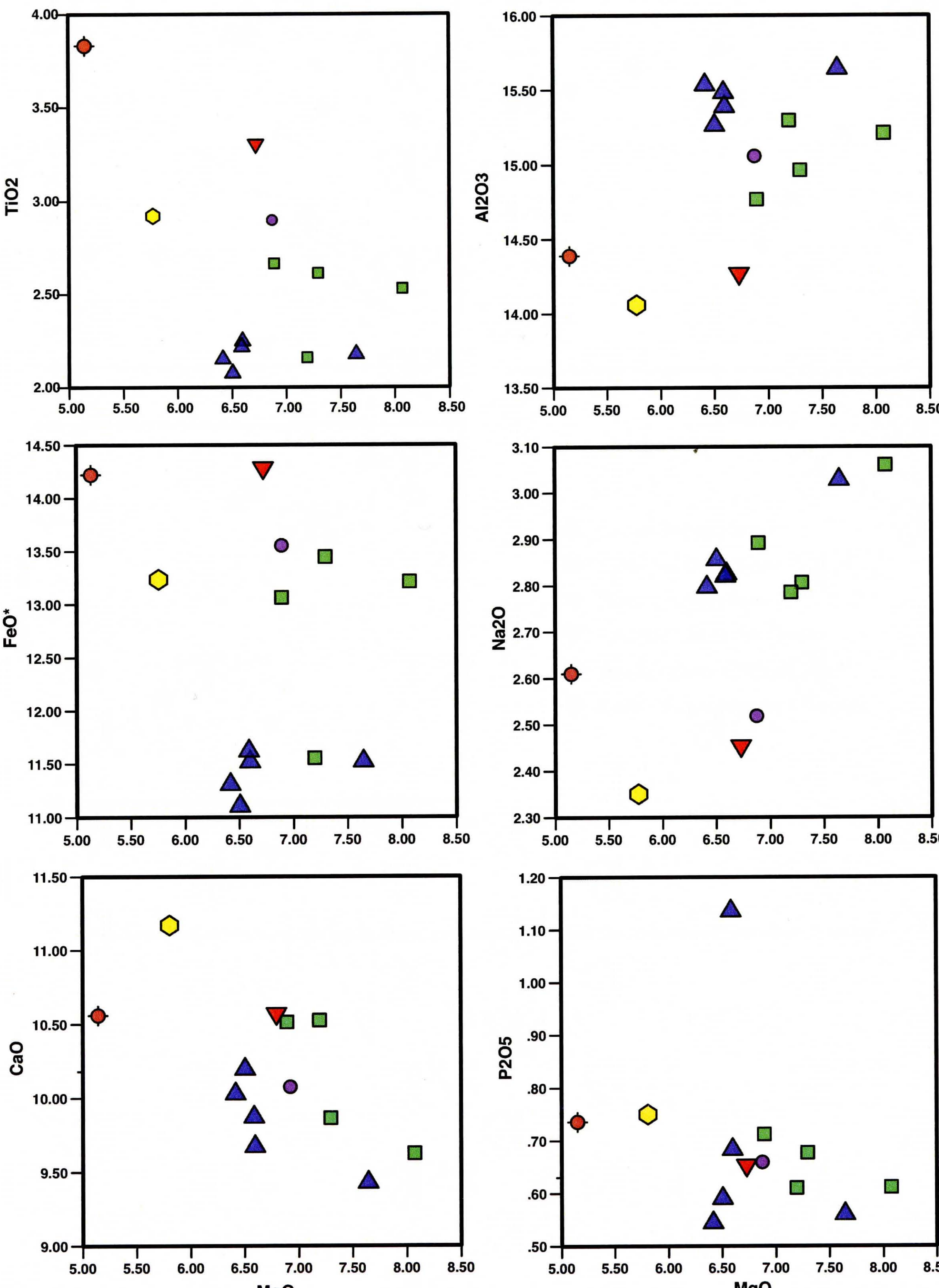


Figure 22. Total alkalis vs. silica diagram showing that the geochemistries for all of the volcanic units in this study fall into the basalt field. The dividing line between alkaline and subalkaline was taken from MacDonald (1968) in Rollinson (1993).


TiO2
4.00
3.50
3.00
2.50
2.00
Al2O3
16.00
15.50
15.00
14.50
14.00
13.50
FeO*
14.50
14.00
13.50
13.00
12.50
12.00
11.50
11.00
Na2O
3.10
3.00
2.90
2.80
2.70
2.60
2.50
2.40
2.30
CaO
11.50
11.00
10.50
10.00
9.50
9.00
P2O5
1.20
1.10
1.00
.90
.80
.70
.60
.50
5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50
MgO
MgO

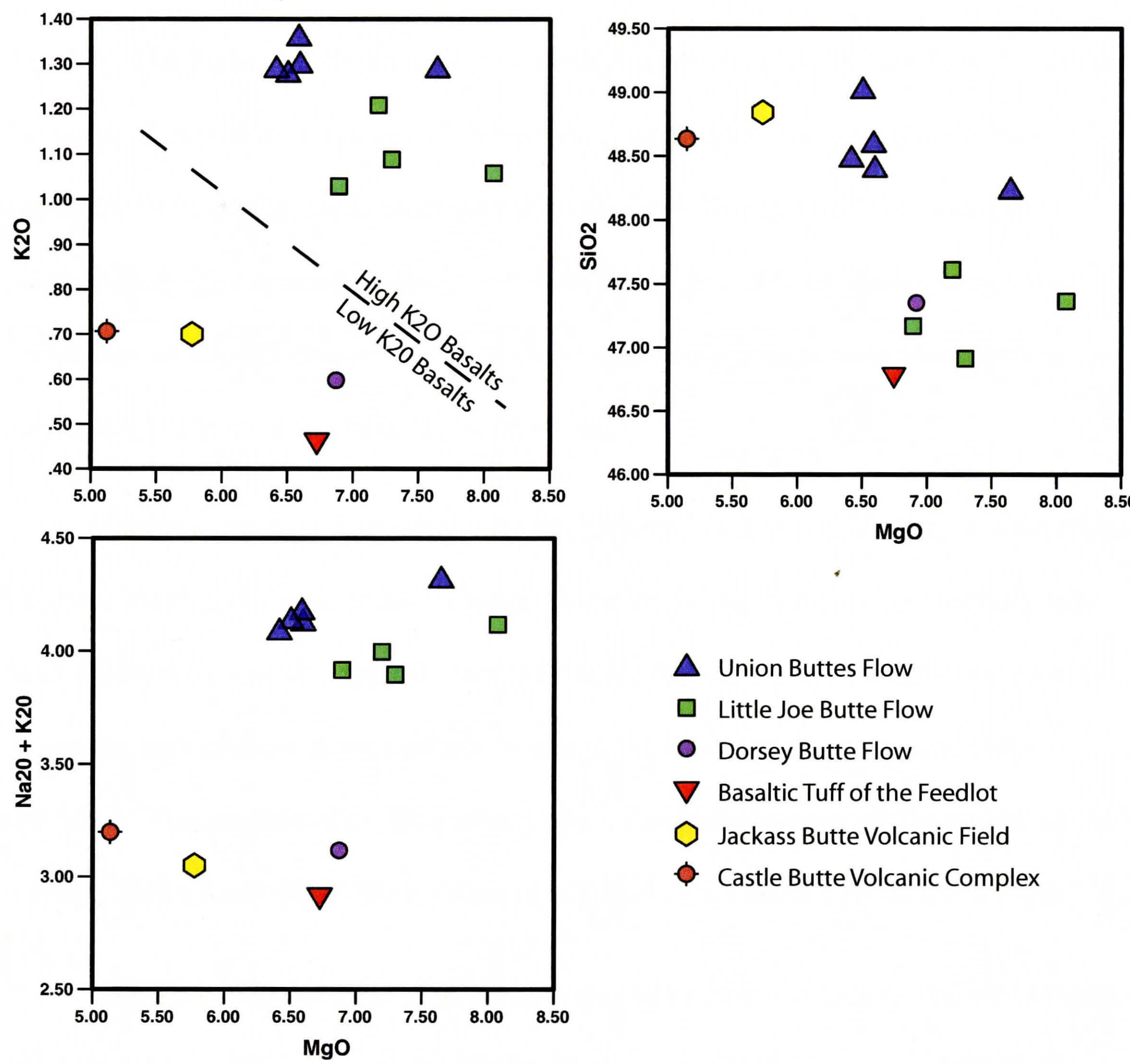


Figure 23. Major element variation diagrams, axes represent the weight percent of each oxide.

(fig. 23). The higher Mg/Fe ratios are evidence that the increase in Na_2O and K_2O is not the result of crustal assimilation. The Na_2O and Al_2O_3 plots show a clear positive correlation with MgO, this is consistent with the crystallization and separation of plagioclase in the magmatic system. For both flows the CaO plot shows a negative correlation with MgO, this cannot be readily explained by plagioclase fractionation, but may instead be related to olivine crystallization.

Analyses for the Dorsey Butte Basalt, Basaltic Tuff of the Feedlot, Jackass Butte Volcanic Field, and Castle Butte Volcanic Complex are for comparison purposes only. Each analysis represents a typical composition for that unit. Because only one point is shown for each of these compositions, trends in the variation diagrams cannot be identified. The purpose of plotting these units is solely for comparing the basalts of the Western Snake River Plain lying within or adjacent to the Dorsey Butte quadrangle.

The sample location, type of volcanism, and geochemical classification for each unit is listed in Table 2. Geochemical classifications are based on the guidelines of Bonnichsen and Godchaux (2002), Vetter and Shervais (1992), and White et al. (2002). The latitude and longitude of the sample collection is listed for both the Union Butte Flow and the Little Joe Butte Flow. The exact location of collection is unknown for the other four units. The Jackass Butte deposit was sampled from Rabbit Creek Canyon, the northeastern most vent complex located on the eastern side of the Snake River (fig. 20). The analysis from the Basaltic Tuff of the Feedlot was taken from the Chattin Flat Complex vent area.

Table 2. Location, type, and geochemical classification for selected basaltic units of the Western Snake River plain.

			Sample Location				Geochemistry		
Unit	Name	Sample #	Latitude North	Longitude West	Quadrangle USGS 7.5'	Volcanic edifice	Bonnichsen and Godchaux (2002)	Vetter and Shervais (1992)	White et al. (2002)
Qun	Union Butte Flow	96SRP-38-2	43.16	115.75	Crater Rings	cinder cone	SROT	BRG2	M3
.	.	SRP 119	43.12	115.88	.	.	SROT	BRG2	M3
.	.	SRP 109	43.14	115.78	.	.	SROT	BRG2	M3
.	.	SRP 110	43.15	115.78	.	.	SROT	BRG2	M3
.	.	SRP 111	43.15	115.77	.	.	SROT	BRG2	M3
Qljb	Little Joe Butte Flow	SRP 121	43.08	115.94	Little Joe Butte	shield	SROT	BRG2	M3
.	.	SRP 122	43.09	115.99	.	.	SROT	BRG2	M3
.	.	SRP 112	43.00	115.98	.	.	SROT	BRG2	M3
.	.	SRP 120	43.11	115.90	.	.	SROT	BRG2	M3
Qtdor	Dorsey Butte Flow	I-3033			Dorsey Butte	shield	SROT	BRG1	M2
Tfl	Basaltic Tuff of the Feedlot	I-3028	*Chattin Flat vent area		Dorsey Butte	maar/tuff ring	Fe-enhanced	BRG1	M2
Tjvc	Jackass Butte Volcanic Field	I-2996	*Rabbit Creek Canyon		Jackass Butte	maar/tuff ring	SROT	BRG1	M2
Qcas	Castle Butte Volcanic Complex	I-2831			Castle Butte	tuff ring	Fe-enhanced	BRG1	M2

** approximate location of sample collection*

Bonnichsen and Godchaux (2002) based their geochemical categories on the abundance of iron and aluminum in the basalt. The idea behind this is that with the crystallization and separation of plagioclase and olivine, the percentage of Al decreases and the percentage of Fe increases in the remaining magma. Therefore, highly-evolved magmas will have low concentrations of Al and high concentrations of Fe. They used five categories with varying percentages of Al and Fe to explain the variations in basalt compositions, high-Al, Al-enhanced, SROT, Fe-enhanced, and Ferrobasalt. Most of the basalts in the Snake River Plain fall into the range of Snake River Olivine Tholeiites (SROT). The conditions that must be met in order to satisfy an SROT composition are 15.99% or less Al_2O_3 and 14.99% or less Fe_2O_3. Eleven out of the thirteen samples in Table 2 fall into the SROT category. The Basalt of Little Joe Butte and the Union Butte Basalt are labeled SROT, but have unusually high Al and alkali contents for that category. The Basaltic Tuff of the Feedlot and the Castle Butte Volcanic Complex both are classified as Fe-enhanced basalt meaning they have elevated Fe concentrations falling between 15 and 15.99% Fe_2O_3.

Vetter and Shervais (1992) divided the Boise River Group into two categories based on major and trace elements. Boise River Group 1 (BRG1) are silica-saturated olivine tholeiites. They have low alkalis, low Mg/Fe ratios, and low Ni concentrations. They also have high concentrations of high field strength elements, high 87/86 Sr, low 143/144 Nd, and high 208/204 Pb (heavy isotopes). BRG2 are younger, less than 0.7 Ma, and are transitional between olivine tholeiites and alkali olivine basalts. They have high alkali concentrations, higher Mg/Fe ratios, and high concentrations of Ni. They also have lower high field strength concentrations and have 87/86 Sr and 143/144 Nd isotopic compositions near bulk earth. The Dorsey Butte Basalt, Basaltic Tuff of the Feedlot, Jackass Butte Volcanic Field, and Castle Butte Volcanic Complex all correlate with BRG1. They have low alkalis, low Mg/Fe, and are older than 0.7 Ma (figs. 7, 23). The Union Butte and Little Joe Butte flows more closely resemble the BRG2 basalt. They have high alkali abundances, high Mg/Fe, and are relatively young (figs. 7, 23).

White et al. (2002) divided the Western Snake River basalts near Melba, ID into three different groups, M1, M2, and M3. The first group, M1 are olivine tholeiites that erupted 9-7 Ma with moderate TiO_2, low K_2O, and $^{87}Sr/^{86}Sr$ ratios between 0.706 and 0.707. The M2 group (equivalent to BRG1 of Vetter and Shervais, 1992) erupted from 2.0 to 0.4 Ma and produced strongly tholeiitic basalts. They have low Si and Al, high Fe, Ti, and P. They also have low LILE/HFSE ratios and $^{87}Sr/^{86}Sr$ ratios around 0.707. M3 basalts (equivalent to BRG2 of Vetter and Shervais, 1992) are slightly alkaline with greater K, Na, Rb, and Sr, they also have higher LILE/HFSE ratios and lower $^{87}Sr/^{86}Sr$ ratios. The transition from M2 to M3 type lavas likely took place around 0.8 Ma. The Union Butte and the Little Joe Butte flows both fall into the M3/BRG2 group while the rest of the samples from Table 2 fall into the older M2/BRG1 group.

CHAPTER VI

DISCUSSION

The Western Snake River Plain began to take on its modern shape around 12 million years ago with the inception of hotspot activity to the south at the Bruneau-Jarbidge eruptive center. As the hotspot continued east the lithosphere beneath the Western Snake River Plain cooled and subsided creating the accommodation space for Neogene Lake Idaho. Thick deposits of sediments were deposited during this time as well as eruption of phreatomagmatic volcanism beneath and adjacent to Lake Idaho. The Basaltic Tuff of the Feedlot, Jackass Butte Volcanic Field, and Castle Butte Volcanic Complex are all examples of phreatomagmatic volcanism that erupted during this time.

The stratigraphic column from the Basaltic Tuff and Breccia of Hayland School offers insight into the evolution of phreatomagmatic volcanism in this area. From the stratigraphic column it is evident that episodes of hydration and de-watering are important factors in the evolution of these volcanoes. In the early stages of Hayland School volcanism water was not present. During this time the volcano behaved similarly to a scoria cone. At some point water entered the system resulting in the reworking of material and subaqueous debris flows. As the system de-watered the percentage of basaltic clasts increased, finally culminating in an effusive lava flow. Although stratigraphic columns were not made for the other deposits in this study, it is likely that phreatomagmatic volcanoes nearby underwent similar processes.

In the late Pliocene, effusive volcanism was also active in the Western Snake River Plain. The Tertiary Canyon Creek Basalt flowed from a vent northeast of where the phreatomagmatic volcanism was currently taking place. As it flowed to the south down a paleo-river channel it came into contact with Lake Idaho and its associated water-saturated sediments resulting in alteration, pillows, and regions of intense fracturing. Where the flow wrapped around the Basaltic Tuff and Breccia of Hayland School, alteration and fracturing are prominent. This is evidence that the Basaltic Tuff and Breccia of Hayland School had not completely cooled and de-watered by the time of Canyon Creek emplacement.

As the hotspot continued its eastward migration the catchment area of the lake enlarged by as much as 50,000 square kilometers. The increased volume of water caused spillover of Lake Idaho at Hell's Canyon approximately 4 million years ago. Once past Hell's Canyon the Snake River was captured by the Columbia River and carried to the Pacific Ocean. The draining of Lake Idaho was not a quick process; it remained in some form or another up until 1.7 Ma when continuous gravels were present throughout the entire Western Snake River Plain (Wood and Clemens, 2002).

During the Late Pliocene/Early Pleistocene the Dorsey Butte shield volcano began erupting effusive lava flows that traveled as far as 6 km to the south and 12 km to the west. In the northwest corner of the Dorsey Butte quadrangle the flow entered the eroded vent of the Chattin Flat Volcanic Complex. There is no evidence of features consistent with lava-water interaction within the Dorsey Butte flow and therefore the complex most likely had cooled and de-watered by the time the flow was emplaced. Similar to other flows and phreatomagmatic eruptions from this time period, the Dorsey Butte Basalt is a silica-saturated olivine tholeiite characterized by low alkali abundances and low Mg/Fe ratios.

Even after Lake Idaho ceased to dominate the Western Snake River Plain, phreatomagmatic eruptions continued. One of these post Lake Idaho eruptions was Sinker Butte Volcano approximately 1.2 million years ago. Since Lake Idaho was no longer present, the initiation of these hydrated eruptions was likely due to the damming of the Snake River.

Around 0.8 million years ago volcanism in the Western Snake River Plain transitioned from Fe-rich tholeiitic basalts to basalts containing higher concentrations of potassium. Basalts from this time period are transitional between olivine tholeiites and alkali olivine basalts; they have higher alkali, Mg, and Cr concentrations and higher Mg/Fe ratios. The basalts of Corder Creek, Little Joe Butte, and Union Buttes are examples of these high potassium basalts.

CHAPTER VII

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The evolution of the Western Snake River Plain involved the complex interplay of water and volcanism. Effusive lavas flowed into bodies of water, over saturated sediment, and into phreatomagmatic complexes. Phreatomagmatic vents underwent cycles of hydration and de-watering, mixed with sediments, and produced effusive flows. These complexities make deciphering the processes that shaped the Western Snake River Plain difficult to ascertain. The work shown in this report has merely scratched the surface.

In order to fully understand the processes at work in the Western Snake River Plain, the stratigraphy, geochemistry, and ages of the units need to be better constrained. With more stratigraphic columns, comparisons could be made between phreatomagmatic complexes increasing our understanding of hydration and de-watering episodes and the processes that created them. The major element data presented in this study are a good first approximation, however in order to identify trends and recognize relationships, more samples should be analyzed and trace element and isotopic data should be incorporated. Radiometric dates are also a necessity in identifying the timing of volcanic activity. Only a few of the samples described in this study have been dated, the rest have only approximate ages identified from stratigraphic relationships.

Although there is still much to learn from the Western Snake River Plain, this study has uncovered some of the major processes at work and the order in which they occurred. Phreatomagmatic volcanism, effusive lava flows, and hydrologic processes worked together to create the unique and complex environment we see in the Western Snake River Plain today.

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