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Areal Extent and Volumes of the Dinner Creek Tuff Units, Eastern Oregon Based on
Lithology, Bulk Rock Composition and Feldspar Mineralogy

by

Teresa Rae Hanna

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science
in
Geology

Thesis Committee:
Martin J. Streck, Chair
Robert Perkins
John Bershaw

Portland State University

2018

ABSTRACT

The Dinner Creek Tuff erupted during a period of rhyolitic volcanism coeval to the flood volcanism associated with the Columbia River Basalt Group. The High Rock Caldera Complex, Lake Owyhee and McDermitt volcanic fields account for ~90% of the rhyolites erupted between 16.7-15.0 Ma. Situated at the northern end of the Lake Owyhee volcanic field, the Dinner Creek Tuff was originally mapped as a ~2,000 km² single ignimbrite confined to the Malheur Gorge. Streck et al. (2015) correlated tuff outcrops previously mapped as generic Miocene welded tuff as well as local units such as the “Mascall” or “Pleasant Valley” tuff of eastern Oregon to individual cooling units that comprise the newly redefined Dinner Creek Tuff, enclosing an area of ~25,000 km². Areal extents defined in this study show that all outcrops now determined to be Dinner Creek Tuff enclose an area of ~31,800 km² not including any fallout deposits that likely extended beyond the defined area.

Although Dinner Creek Tuff rhyolites have nearly identical compositions, different ages and subtle geochemical and mineralogical differences exist and were used to divide the Dinner Creek Tuff into four discrete cooling units. Except for unit 4, the units are lithologically very similar. Unit 1 is the Dinner Creek Tuff unit associated with the Malheur Gorge type section. The four cooling units have ages of 16.15-16 Ma (unit 1), 15.6-15.5 Ma (unit 2), 15.46 Ma (unit 3) and 15.0 Ma (unit 4).

Areal extents were established for all four cooling units based on feldspar compositions along with lithological and bulk rock geochemical data. Minimal extents of individual units are as follows: ~22,590 km² (unit 1), ~17,920 km² (unit 2), ~14,170 km²

(unit 3) and $\sim 8,370 \text{ km}^2$ (unit 4). Using conservative thicknesses, determined erupted tuff volumes are $\sim 170 \text{ km}^3$ (unit 1), $\sim 125 \text{ km}^3$ (unit 2), $\sim 99 \text{ km}^3$ (unit 3) and $\sim 46 \text{ km}^3$ (unit 4), totaling $\sim 440 \text{ km}^3$ and dense rock equivalents are $\sim 152 \text{ km}^3$ (unit 1), $\sim 96 \text{ km}^3$ (unit 2), $\sim 76 \text{ km}^3$ (unit 3) and $\sim 31 \text{ km}^3$ (unit 4), totaling $\sim 356 \text{ km}^3$.

These extents and volumes are the absolute minimum based solely on the locations of exposed tuff sections and the inclusion of the source. Centering eruptive units on source areas where they are known, expands the tuff extents into a more radial pattern as would be expected for low-aspect ratio, high energy ash-flow tuff eruptions. These probable extents increase the areal extents of the individual units to: $\sim 36,900 \text{ km}^2$ (unit 1), $\sim 31,660 \text{ km}^2$ (unit 2), $\sim 17,290 \text{ km}^2$ (unit 3) and $\sim 10,150 \text{ km}^2$ (unit 4) distributed over a $\sim 43,490 \text{ km}^2$ area. Likewise, erupted tuff volume and dense rock equivalents also increase: volume— $\sim 277 \text{ km}^3$ (unit 1), $\sim 222 \text{ km}^3$ (unit 2), $\sim 121 \text{ km}^3$ (unit 3) and $\sim 56 \text{ km}^3$ (unit 4); DRE— $\sim 248 \text{ km}^3$ (unit 1), $\sim 170 \text{ km}^3$ (unit 2), $\sim 93 \text{ km}^3$ (unit 3) and $\sim 38 \text{ km}^3$ (unit 4).

New mapping confirms previous hypotheses that the Castle Rock caldera erupted unit 1 and identified the new Ironside Mountain caldera as the source for unit 2 while precise source areas for unit 3 and 4 are not yet known but are thought to lie within the Dinner Creek Eruptive Center. Minimal calculated caldera volumes for units 1 and 2 are $\sim 98.5 \text{ km}^3$ (unit 1) and $\sim 31.1 \text{ km}^3$ (unit 2). Adding the thick ponded intra caldera tuff volume to the determined and probable erupted tuff volumes determined in this study, increases the erupted volumes to $\sim 268 \text{ km}^3$ (determined) and $\sim 375 \text{ km}^3$ (probable) for unit 1 along with $\sim 157 \text{ km}^3$ (determined) and $\sim 253 \text{ km}^3$ (probable) for unit 2. DREs

increase to $\sim 251 \text{ km}^3$ (determined) and $\sim 347 \text{ km}^3$ (probable) for unit 1 along with $\sim 128 \text{ km}^3$ (determined) and $\sim 202 \text{ km}^3$ (probable) for unit 2.

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LIST OF ABBREVIATIONS

Ab. Albite—sodium rich feldspar end member

An. Anorthite—calcium rich feldspar end member

BPM. Blue Mountain Province

CRBG. Columbia River Basalt Group

DEM. Digital Elevation Model

DIT. Dinner Creek Tuff

DITEC. Dinner Creek Tuff Eruptive Center

DRE. Dense rock equivalent

EMP. Electron microprobe

GPS. Global Positioning System

HLP. High Lava Plains

HRCC. High Rock Caldera Complex

LAI. Low-aspect ratio ignimbrites

LIP. Large Igneous Province

LOVF. Lake Owyhee Volcanic Field

OIG. Oregon-Idaho Graben

Or. orthoclase—potassium rich feldspar end member

USGS. United States Geological Survey

INTRODUCTION

During mid-Miocene bimodal volcanism in eastern Oregon, southwest Idaho and northwest Nevada, flood basalts erupted in addition to voluminous rhyolitic ash-flow tuffs and lava flows, likely due to the Yellowstone hotspot (e.g. Lipman et al., 1972; Smith and Luedke, 1984; Hart and Carlson, 1987; Pierce and Morgan, 1992; Hooper et al., 2002; Shoemaker and Hart, 2002; Jordan et al., 2004; Humphreys and Coblentz, 2007; Wolff et al., 2008; Smith et al., 2009; Reidel et al., 2013, Camp, 2013; Ford et al., 2013). Voluminous flood basalts of the Columbia River Basalt Group (CRBG) dominated the initial phase of the Yellowstone hotspot eruptions, with the eruption of the Steens Basalt at ~16.6 Ma (Figure 1) (e.g. Hooper et al., 2002; Coble and Mahood, 2012; Nash and Perkins, 2012; Barry et al., 2013; Mahood and Benson 2017).

Associated silicic volcanism includes a series of voluminous rhyolites erupted coeval to the CRBG that progressed in age as the Yellowstone hotspot evolved toward its current location (Figure 1) (Coble and Mahood, 2012; Nash and Perkins, 2012; Streck and Ferns, 2012; Streck et al., 2015). Approximately 90% of the total volume of eastern Oregon and northern Nevada rhyolites erupted from three volcanic fields: Lake Owyhee, McDermitt and the High Rock Caldera Complex (HHRC) (Figure 1) (Rytuba and Vander Meulen, 1991; Cummings et al., 2000; Coble and Mahood, 2012). Lake Owyhee, McDermitt and the HHRC are situated near the edge of the Steens Basalts along a NNE trend close to the projection of the initial Sr ($^{87}\text{Sr}/^{86}\text{Sr}_i = 0.704$ isopleth considered to be the boundary between the transitional continental crust and the accreted oceanic terranes (Armstrong et al., 1977; Farmer and DePaolo, 1983;

Fleck and Criss 1985; Criss and Fleck 1987; Kistler and Lee 1989; Elison et al., 1990; Leeman et al., 1992; Manduca et al., 1992; Wooden et al., 1999; Evans et al., 2002; Fleck and Criss, 2007; Unruh et al., 2008; Gaschnig et al., 2011).

Figure 1. Regional overview modified from Benson and Mahood (2016). Columbia River Basalt Group member extents are after Reidel et al. (2013) and the generalized locations of feeder dikes after Tolan et al. (1989) and Camp et al. (2003). Red circle and lines delineate age progression of rhyolites in the High Lava Plains (HLP)/Newberry Trend from 0 to 10 Ma (left to right). Coeval silicic volcanism that occurred within the McDermitt, and Lake Owyhee Volcanic Fields and the High Rock Caldera Complex, approximate locations shown as black lined fields. Blue outlines indicate approximate locations of 16.4 to 0.6 Ma (left to right) silicic centers associated with the Snake River Plain–Yellowstone trend after Smith et al. (2009). Purple line—0.706 $^{87}\text{Sr}/^{86}\text{Sr}_i$ isopleths and pink line—0.706 $^{87}\text{Sr}/^{86}\text{Sr}_i$ isopleths are drawn using data from Armstrong et al. (1977), Farmer and DePaolo (1983), Fleck and Criss (1985), Criss and Fleck (1987), Kistler and Lee (1989), Elison et al. (1990), Leeman et al. (1992), Manduca et al. (1992), Wooden et al. (1999), Evans et al. (2002), Fleck and Criss (2007), Unruh et al. (2008), Pierce and Morgan, (2009) and Gaschnig et al. (2011). The black dashed outline on the 0.706 is where the line is inferred and on the 0.704 isopleth, indicates where it is poorly constrained due to Cenozoic volcanic cover.

The Dinner Creek Tuff (DIT), situated at the northern end of the Lake Owyhee Volcanic Field (LOVF), was originally mapped as discontinuous exposures of ash-flow tuff as early as 1937 by Gilully. The first mapped rhyolitic tuff separated older and younger mafic lava flows (Pardee and Hewett, 1941). Kittleman et al. (1965) initially named the Dinner Creek Welded Ash-flow Tuff type section after the marker bed referred to in the road log of geology along U.S. Highway 20 from Vale to Burns by Dole and Corcoran (1954). Additional mapping in area by Gray (1956) and Bowen (1956) referred to the DIT as the welded tuff in the Owyhee Basalt. The first methodical study of the DIT included descriptions of textural, mineralogical and chemical characteristics with an estimated extent of $\sim 2000 \text{ km}^2$ centered along the Malheur River Gorge by Haddock (1967) (Figure 2).

Streck et al. (2015) utilized extents, lithologic variations, geochemical compositions and eruptive ages to correlate eastern Oregon ignimbrites and ash-fall tuff deposits to a newly redefined DIT comprised of four geochemically distinct cooling units that erupted from a common source area referred to as the Dinner Creek Eruptive Center (DITEC). They also correlated outcrops previously mapped as generic Miocene welded tuff as well as local units such as the “Mascall” or “Pleasant Valley” tuff of eastern Oregon are now correlated to one of the cooling units, increasing the known extent to $\sim 25,000 \text{ km}^2$ (Figure 2).

Figure 2. A and B: Regional overview, extent of the Dinner Creek Tuff and locations of correlative fallout units from Streck et al. (2015). A: Yellow frame is areal coverage of C. Stars indicate fallout localities: M—Mascall Formation, PB—Paulina Basin, BU—Bully Creek Formation, SC—Succor Creek (after Nash and Perkins, 2012), UM—Umatilla (after Ferns, personal data). B: Stars indicate regional fallout localities after Nash and Perkins (2012): NV—Nevada, BC—Buffalo Canyon, C—Carlin, VV—Virgin Valley, ID—Idaho, WB—White Bird; WA—Washington; A—Asotin. Dark and light blue—CRBG after Camp and Ross, (2004); red—extent of 17–12 Ma rhyolites after Christiansen et al. (2002). C: Orange dots—investigated Dinner Creek Tuff locations; red—database of Oregon Department of Geology and Mineral Industries showing original Dinner Creek Tuff and unnamed tuffs correlated with Dinner Creek Tuff; thick orange line—envelope around most distal outcrops; dashed orange oval—likely source area of Dinner Creek Tuff eruptive center (DITEC); yellow—original extent of Dinner Creek Welded Tuff and previous generalized extents of local ignimbrites here correlated with Dinner Creek Tuff; Abbreviations: MG—Malheur Gorge, CR—Castle Rock, H—town of Harper, IS—Ironside Mountains, J—town of Juntura, PG—Picture Gorge, PB—Paulina Basin; T—tuff. The black triangle outlines represent the approximate locations of Castle Rock (CR) and Ironside Mountain (IS), the confirmed eruption sites for units 1 and 2, respectively.

Haddock (1967) and Wood (1979) hypothesized the DIT erupted from a single vent located in an area Rytuba and Vander Meulen (1991) considered to be part of the Castle Rock caldera. New mapping by Cruz (2017) partially confirms previous theories pertaining to the Castle Rock caldera which erupted unit 1 (Figure 2). Cruz (2017) also identified the new Ironside Mountain caldera as the source for unit 2 while precise source areas for unit 3 and 4 are still unknown (Figure 2).

Based on field work alone, tracing out the extent of the individual cooling units that comprise the DIT outcrop exposure area is difficult (Streck et al., 2015). Neogene faults with more than 1,000 m of cumulative vertical displacement severely break up the discontinuous outcrops with younger volcanic and other sediments covering much of the outcrop areas and in most circumstances only one cooling unit is exposed (Ferns et al., 2010). Observed outcrop thickness for the DIT range from 3 - 70 m thick, but 3 - 8 m is the typical range (Kittlemen, et al., 1965; Haddock, 1967; Davenport, 1970; Streck et al., 2015).

The findings of this study establish minimal areal extent of the individual cooling units while updating the overall known areal extent of the Dinner Creek Tuff utilizing sample lithology, bulk rock and feldspar geochemistry. In addition, minimal erupted tuff volumes and dense rock equivalents (DRE) are calculated. The results of this study aide in the understanding of the lesser studied silicic portion of bimodal volcanism associated with the Yellowstone hotspot emplacement in eastern Oregon, northern Nevada and eastern Idaho.

BACKGROUND

Geologic Setting

Blue Mountain Province and Accreted Terranes

Located in central and eastern Oregon, the Blue Mountains Province (BMP) is a middle Jurassic to late Jurassic (~159 - 154 Ma) amalgamation of deformed island-arcs and related sedimentary terranes that accreted onto the North American craton 141 - 124 Ma ago during a period of arc-arc collision events (Getty et al., 1993; Selverstone et al., 1992; Dorsey and LaMaskin, 2007, 2008; LaMaskin, 2009; Schwartz et al., 2010; Schwartz et al., 2011; Anderson, 2013). Prior to accretion, volcanic island arcs, like modern day Japan and Indonesia made up extensive areas of the western United States, including California, Nevada, Oregon and Washington (LaMaskin, 2009). It is unclear whether the BMP formed from a single island arc situated well off shore or multiple island arcs, both near and off shore (Vallier, 1995; Dickenson, 1979; Ave Lallemant, 1995; Dorsey and LaMaskin, 2007; LaMaskin et al., 2008, LaMaskin, 2009). Accretion age estimates vary widely and introduce uncertainties to tectonic and geochemical models for North American crustal growth (Lund and Snee, 1988; Selverstone et al., 1992; Gray and Oldow, 2005; Snee et al., 2007; Dorsey and LaMaskin, 2007; LaMaskin et al., 2008; LaMaskin, 2009). The units that comprise the BMP include: Wallowa Terrane, Baker Terrane, Olds Ferry Terrane and Izee Terrane (Figure 3).

Figure 3. Simplified geologic of the Blue Mountains Province showing pre-Cenozoic geology, from Dorsey and LaMaskin (2008). White areas represent Cenozoic rocks and deposits. BC, Baker City; BMB, Bald Mountain batholith; H, Huntington; IB, Idaho Batholith; IM, Ironside Mountain; JM, Juniper Mountain; O, Oxbow; PL, Pittsburg Landing; CM, Cuddy Mountains; CH, Coon Hollow; SDM, Seven Devils Mountains; SRB, Salmon River belt; WM, Wallowa Mountains and Wallowa batholith; WISZ, Western Idaho Shear Zone.

Wallowa Terrane

The northernmost terrane in the BMP is the Wallowa terrane. The Permian to early Jurassic rocks that comprise the Wallowa terrane record the evolution of an intraoceanic island arc system and change to clastic input from the Baker terrane (Vallier, 1977, 1995; Follo, 1986, 1992, 1994; LaMaskin et al., 2009; Anderson, 2013). Rock types associated with the Wallowa terrane include: volcanoclastic and volcanic rocks, primarily from the early Permian to late Triassic, Triassic and Jurassic aged sedimentary rocks and plutonic rocks from the Jurassic to the early Cretaceous

(Avé Lallemant, 1995; Vallier, 1995; Anderson, 2013). Magmatism associated with the Wallowa terrane consists of two main pulses. The initial pulse of silicic arc magmatism from ~265.4-248.8 Ma, followed by deformation and erosion of the Wallowa arc and a mafic to intermediate pulse between ~229.4-229.1 based on U-Pb zircon dating of the Cougar Creek Complex (Kurz et al., 2012). Occasional intermittent volcanism occurred until the end of the Middle Jurassic (~161 Ma) (Avé Lallemant, 1995; Vallier et al., 1977; Follo, 1994; White and Vallier, 1994; Anderson, 2013). While the terrane reached amphibolite-facies conditions in some localities, such as the Cougar Creek Complex, it exhibits regionally metamorphosed to greenschist facies conditions throughout (Vallier, 1995).

Olds Ferry Terrane

The Olds Ferry Terrane is comprised of middle Triassic to Lower Jurassic plutonic, volcanic, epiclastic and marine volcanoclastic rocks that formed in an island-arc setting that correlate to the Quesnel terrane in British Columbia, the Cordilleran fringing-arc system in western Nevada (Black Rock terrane) and eastern California (Brooks and Vallier 1978; Brooks 1979; Oldow et al., 1989; Vallier 1995; Wyld and Wright, 2001; Gray and Oldow, 2005; Dorsey and LaMaskin, 2007, 2008; Tumpane et al., 2008; LaMaskin, 2009). The island arc is lithologically like the Wallowa terrane with volcanic rocks from the late Triassic to early Jurassic and plutonic rocks mainly from the middle Triassic to late Triassic (Iron Mountain and Brownlee pluton), but dissimilar to the Wallowa terrane with poor exposure, the absence of a well-defined age and failure to exceed greenschist facies conditions (Brooks and Vallier, 1978;

Tumpane, 2010; Anderson, 2013). Dorsey and LaMaskin consider the Huntington and Weatherby Formations to be part of the Olds Ferry terrane and are comprised of clastic sedimentary rock, limestone and keratophyre rocks, generally defined as a felsic tuff or flow characterized by phenocrysts of quartz and albite as well as a high Na to K ratio (Anderson, 2013).

Baker Terrane

Situated between the Wallowa and Olds Ferry terranes, the Baker terrane is an accretionary complex comprised of three sub terranes: Bourne, Greenhorn and Burnt River Schists (Anderson, 2013). Early Jurassic Elkhorn Ridge Argillite, consisting mainly of disrupted chert and argillite with lesser amounts of tuffaceous argillite, limestone and conglomerate dominates the Bourne sub terrane (Schwartz et al., 2010; Schwartz et al., 2011b). The Greenhorn sub terrane is a serpentinite-matrix mélange enclosing large blocks of chert-argillite breccias, volcanoclastic breccias, keratophyre, meta-plutonic rocks with some amphibolitic rocks (Schwartz et al., 2011b). The Bourne subterrane is consistently lower greenschist facies in metamorphism while the Greenhorn sub terrane ranges from upper greenschist facies to lower amphibolite-facies (Schwartz et al., 2010). The Burnt River Schist is a heterogeneous sub terrane dominated by siliceous phyllite and slatey argillite that contains marble, metaplutonic rocks (ranging from felsic to mafic) and keratophyre rocks (Anderson, 2013). Metamorphism is greenschist facies, but a higher greenschist facies than the

Greenhorn sub terrane, and the contact metamorphism near the plutons reaches hornblende to hornblende-pyroxene hornfels facies (Ashley, 1995).

Izee Terrane

The Izee terrane consists mainly of Triassic to Jurassic aged clastic sedimentary rocks primarily exposed in the southern portion of the BMP (Dickinson, 1979; Avé Lallemant, 1995). Izee terrane sedimentary and rare volcanic rocks correlate with limestone and volcanic rocks from the Huntington and Weatherby Formations associated with the Olds Ferry terrane (Dickinson, 1979; Avé Lallemant, 1995; Dorsey and LaMaskin, 2007). Furthermore, work by Dorsey and LaMaskin (2007) correlated Jurassic age sediments with sediments from the Coon Hollow formation associated with the Wallowa terrane and suggest that the Izee terrane is not an actual terrane but a regional overlap assemblage of largely Jurassic sedimentary rocks which unconformably overlies the Baker and Olds Ferry terranes. The Izee terrane rarely exhibits metamorphism no higher than the greenschist facies (Dorsey and LaMaskin, 2007).

Columbia River Basalt Group

Large igneous provinces (LIP) are high volume ($>100,000 \text{ km}^3$) intraplate magmatic events comprised largely of flood basalts, dyke swarms and their associated plumbing, sill complexes, mafic-ultramafic layered intrusions and in some cases, silicic igneous rocks (e.g. Coffin and Eldholm 1994, 2001, 2005; Ernst and Buchan, 2001; Courtillot and Renne 2003; Ernst et al. 2005; Bryan and Ernst 2008).

Associated with the initial phase of the Yellowstone hotspot mantle plume, the Columbia River Basalt Group (CRBG) is the smallest (over 210,000 km² with an estimated basalt volume of ~210,000 km³) and youngest (16.7Ma - 5.5 Ma) LIP in the world (e.g. Nash and Perkins, 2012; Barry et al. 2013; Reidel et al., 2013). Excellent preservation and a well-defined stratigraphy exposed across the Pacific Northwest make the CRBG a commonly cited model for study of LIPs worldwide (Reidel et al., 2013) (Figure 1).

Basaltic flood lavas originated in a back arc setting between the Cascade volcanic arc and the Rocky Mountains (Reidel et al., 2013). The southern Oregon Plateau near the northern limit of Basin and Range extension is considered the initial eruption site, but eruptions sites swiftly migrated north creating a series of generally north-northwest–trending linear fissure systems (Reidel et al., 2013). Lava flows inundated the Columbia River Basin before heading westward through the Cascade Range, Willamette Valley and Coast Range before flowing into the offshore Miocene fore arc basins (Reidel et al., 2013).

While the CRBG erupted over a period of ~11 million years, ~93% erupted with a ~1.1 million-year period from 16.7 - 15.6 Ma (Reidel et al., 2013). This main eruptive phase produced the Steens, Imnaha, Grande Ronde, Prineville and Picture Gorge Basalts (Figure 4) (Reidel et al., 2013). The Grande Ronde eruptive period marks the height of the CRBG flood basalts with ~72% of the volume being erupted over ~400,000 years from 16 - 15.6 Ma (Barry et al., 2013; Reidel et al., 2013). Many of the flows that erupted during the main phase and into Wanapum time exceeded 1,000 km³ and extend hundreds of kilometers from their eruption sites (Tolan et al.,

1989; Reidel et al., 1989a; Reidel, 1998, 2005; Reidel and Tolan, 2013). In total, the CRBG consists of seven main formations that include those of the main phase as well as the Wanapum Basalt and Saddle Mountains Basalt in addition to various formal and informal members (Reidel et al., 2013).

Formation		Age (Ma)	Volume	
Columbia River Basalt Group	Yakima Basalt Subgroup	6.0		Waning Phase
			Saddle Mountains Basalt	
		15.0	12,175 km ³ 5.8%	Main Eruptive Phase
		15.6		
			Prineville Basalt	
			Grande Ronde Basalt	
			Picture Gorge Basalt	
			Imnaha Basalt	
		16.0	11,000 km ³ 5.3%	
		16.7	31,800 km ³ 15.2%	
		~16.8		

Figure 4. Major subdivisions of the Columbia River Basalt Group from Reidel et al. (2013).

Rhyolitic volcanism

Erupting coeval to the main phase of the CRBG, mid-Miocene silicic volcanism erupted a minimum of ~4,000 km³ of rhyolites from eruptive centers scattered over ~25,000 km² across eastern Oregon, northern Nevada and southeastern Idaho between 16.5 and 15.0 Ma (Christiansen and Yeats, 1992; Pierce and Morgan,

1992; Brueseke et al., 2008; Shervais and Hanan, 2008; Coble and Mahood, 2012; Streck et al., 2015; Benson and Mahood, 2016). While the eastward-younging silicic volcanism associated with the initial phase of the Yellowstone hotspot and the subsequent passage of the North American plate over the plume tail represents a significant amount of silicic volcanism in the area, the majority of rhyolites erupted from one of three major caldera complexes: the Lake Owyhee Volcanic Field (LOVF), McDermitt Volcanic Field and High Rock Caldera Complex (HHRC) (Figure 1) (Rytuba and McKee, 1984; Pierce and Morgan, 1992, 2009; Camp and Ross, 2004; Nash et al., 2006; Hooper et al., 2007; Leeman et al., 2008; Shervais and Hanan, 2008, Coble and Mahood, 2012; Benson and Mahood, 2016).

Lake Owyhee Volcanic Field

Rhyolitic volcanism in the northern section of the LOVF include distal air-fall tuffs and limited exposures of non-welded lithic tuff but are mainly comprised of large rhyolite ash-flow tuffs, rhyolitic lavas originating from eruptive centers and caldera complexes located near the center or in the southern part of the LOVF, most notable is the Dinner Creek Tuff associated with this study (Ferns et al., 2017). Also found in the northern part of the LOVF is the rhyolitic center at Dooley Mountain that is composed of ~2,400 m thick low to high-silica rhyolites consisting of welded tuff, tuff breccia with 2 m diameter clasts, pyroclastic dikes and rhyolitic lava domes (Reef, 1983; Whitsun, 1988; Bailey, 1990; Evans, 1992; Ferns and McClaughry 2013; Large, 2016). The onset of the eruption period at the Dooley Rhyolite complex occurred between 15.59 ± 0.04 Ma and 16.15 - 16.00 Ma, after the emplacement of DIT cooling

unit 1 and ended no later than $\sim 15.2 \pm 0.04$ Ma (Barry et al., 2013; Hess, 2014; Streck et al., 2015; Large, 2016).

In the southern portion of the LOVF, large rhyolite lava flows and caldera complexes extend over the northeastern Steens Basalt, east through the Malheur River gorge and into western Idaho, including the Littlefield Rhyolite (Kittleman et al., 1967; Webb et al., 2015, 2016; Ferns et al., 2017). Two geochemically distinct large-volume rhyolite lava flow packages that comprise the Littlefield Rhyolite known as the lower Littlefield Rhyolite (16.12 ± 0.04 Ma) and upper Littlefield Rhyolite (16.05 ± 0.04 Ma) (Webb et al., 2015, 2016; Ferns et al., 2017). The Littlefield Rhyolite most likely originated from a series of north-south trending dikes along the western margin of Oregon-Idaho graben and extend over a 1,200 km² area, overlying unit 1 of the DIT (Kittleman et al., 1967; Lees, 1994; Streck et al., 2015; Webb et al., 2015, 2016; Ferns et al., 2017). Theories suggest that Littlefield Rhyolite lava flows along the Malheur River are equivalent to the Cottonwood Mountain rhyolite described by Evans and Binger (1999) (Edwards, 2013; Webb et al., 2015, 2016). A caldera complex at Mahogany Mountain erupted both the Spring Creek Tuff (15.4 Ma) and the Leslie Gulch Ash-Flow Tuff Member of the Sucker Creek Formation (15.5 Ma) (Kittleman et al., 1967; Rytuba and others, 1985; Vander Meulen et al., 1987a, b; Rytuba and Vander Meulen, 1991; Marcy et al., 2013).

McDermitt Volcanic Field

The McDermitt Volcanic Field is comprised of basaltic to rhyolitic lavas, calderas and outflow sheets of associated rhyolitic ignimbrites (Benson and Mahood,

2017). The 0.704 $^{87}\text{Sr}/^{86}\text{Sr}_i$ isopleth extends through the complex, but the exact location is poorly constrained due to Cenozoic volcanic cover (Benson and Mahood 2016, 2017). Rytuba and McKee (1984) originally identified seven regionally extensive tuffs erupting from seven different calderas, but recent work by Benson and Mahood (2017) utilized new $^{40}\text{Ar}/^{39}\text{Ar}$ ages, the stratigraphic relations of ignimbrites, and geochemical correlations of outflow sheets to refine the stratigraphy to include only four significant ignimbrites: the Tuff of Oregon Canyon, zoned from high-silica alkali rhyolite to trachyte (16.468 ± 0.006 Ma), the Tuff of Trout Creek Mountains, zoned from high-silica alkali rhyolite to low-silica alkali rhyolite (16.415 ± 0.007 Ma), the Tuff of Long Ridge, zoned from high-silica alkali rhyolite to low-silica alkali rhyolite (16.328 ± 0.013 Ma) and the Tuff of Whitehorse Creek, a low-silica alkali rhyolite (15.556 ± 0.014 Ma).

High Rock Caldera Complex

The McDermitt volcanic field was frequently cited as the starting point of the Snake River/Yellowstone trend, but work by Coble and Mahood (2012) discovered that the HRCC contains the initial silicic center associated with the Yellowstone hotspot (Pierce and Morgan, 1992, 2009; Camp and Ross, 2004; Nash et al., 2006; Hooper et al., 2007; Leeman et al., 2008; Shervais and Hanan, 2008). In addition, the HHRC is comprised of four individual calderas and their associated eruptive products that decrease in age from northeast to southwest (Coble and Mahood, 2016). The Virgin Valley caldera is the oldest caldera (16.38 Ma) and largest (minimum of ~52 km³ DRE) and erupted the chemically zoned alkali rhyolite Idaho Canyon Tuff. The

16.34 Ma old Badger Mountain Caldera erupted the strongly porphyritic, low-silica rhyolite Summit Lake Tuff that overlaps the southern margin of the Virgin Valley caldera (Coble and Mahood, 2016). Approximately 55 km³ DRE of the crystal-poor alkali rhyolite Antelope lavas and compositionally comparable small-volume pyroclastic units denoted as the tuff of Big Mountain that vented along reactivated ring faults of the Virgin Valley caldera erupted ~100,000 years after the Summit Lake Tuff (Coble and Mahood, 2016). Curvilinear faults and vent alignments for 16.3 - 16.2 Ma crystal-poor alkali rhyolite lavas are found south of the Badger Mountain caldera adjacent to densely welded ignimbrites of comparable composition recently named tuffs of Coyote Spring (16.27 Ma) and Trough Mountain (16.25 - 16.15 Ma). The Hanging Rock caldera (16 Ma) is comprised of ~65 km³ DRE of strongly porphyritic, alkali rhyolite known as the Soldier Meadow Tuff (Coble and Mahood, 2016). Petrographically and geochemically similar alkali rhyolite lavas like the Soldier Meadow Tuff erupted within the caldera shortly after collapse. The youngest (15.70 Ma) and southernmost caldera, the Cottonwood Creek caldera formed during the eruption of the strongly zoned high-silica alkali rhyolitic tuff of Yellow Rock Canyon (~220 km³ DRE pre-caldera and post-caldera ring-fracture alkali rhyolite lava volume and ~50 km³ DRE outflow ignimbrite minimum volume) (Coble and Mahood, 2016).

Snake River Plane/Yellowstone Hotspot trend

The emplacement of the Yellowstone hotspot began when the ascending spheroidal plume head ~300 km in diameter reached the base of the North American plate, flattening outward into a disk ~1000 km in diameter ~17 Ma. The initial

emplacement initiated the CRBG, the intrusion of a large basaltic dike system and rhyolitic volcanism (Pierce and Morgan, 1990, 1992, 2009; Draper, 1991; Parsons et al., 1994; Camp, 1995; Parsons, 1995; Takahashi et al., 1998; Thompson, 1998; John et al., 2000; Glen and Ponce, 2002; Pierce et al., 2002; Camp and Ross, 2004; Jordan et al., 2004; Rowley, 2001). Rhyolitic volcanism associated with the Yellowstone hotspot trend is thought to have initiated ~16.4 Ma in the HRCC and extends northeast to modern day Wyoming (Figures 1 and 5).

Figure 5. Track of the Yellowstone hotspot (Y) from Smith et al. (2009) indicating the relative motion of age-transgressive ESRP silicic volcanic centers (Armstrong et al., 1975; Smith and Braile, 1984; Pierce and Morgan, 1990, 1992; Kuntz et al., 1992; Smith and Braile, 1994; Perkins and Nash, 2002) opposite to the direction of North America plate motion (large arrow) (Smith and Sbar, 1974). Green outline is the topographically low area occupied by the Snake River Plain. Yellow outlines are post-17 Ma silicic volcanic centers containing multiple caldera-forming eruptions (Christiansen, 1984, 2001). Columbia River flood basalts are gray (Perkins and Nash, 2002). Red dots are historic earthquake epicenters taken from compilations of the University of Utah of M1.5 – 7.5 earthquakes. Black lines show late Quaternary faults; Cenozoic basaltic dikes (age in Ma) are shown in yellow and orange (Zoback and Thompson, 1978; Camp, 1995; Glen and Ponce, 2002). $^{87}\text{Sr}/^{86}\text{Sr} = 0.706$ isotope boundary for the 0.706 values is shown as a black-dashed line and is interpreted to separate continental lithosphere to the east and oceanic lithosphere to the west (Armstrong et al., 1977; Farmer and DePaolo, 1983). The tectonic parabola is defined by the bow shaped pattern of high topography and seismicity surrounding the YSRP (yellow dashed lines) (Smith et al., 1985; Smith and Arabasz, 1991; Anders and Sleep, 1992). The Newberry trend of silicic volcanism extends northwest across southeast Oregon to the Newberry caldera (N) (MacLeod et al., 1976).

Oregon-Idaho Graben

The 50 - 60 km wide, 100 km long Oregon-Idaho graben evolved as part of a ~1,100 km long mid Miocene synvolcanic rift system extending from southeastern Washington to northern Nevada that includes the CRBG dike swarms, the Baker and La Grande basins and the Nevada rift (Figure 6) (Hooper and Swanson, 1990; Zoback et al., 1994; Cummings et al., 1994, 2000). Situated in the southern portion of the LOVF, the north to northwest trending graben formed during a period linked to east-west rifting, fading CRBG eruptions and widespread rhyolitic volcanism (~15.5 to ~10.5 Ma) (Cummings et al., 2000). After the initial subsidence, Cummings et al. (2000) describe the graben evolution through three stages. Stage 1 (15.3-14.3 Ma) features fluvial and lacustrine sediment deposition across the graben width. Stage 2 (14.3-12.6 Ma) coincides with synvolcanic collapse along intra-graben faults, subdivision of the graben into individual sub-basins by 15-20 km wide horsts and graben structures and intra-graben calc-alkalic magmatism. Sedimentation dominated stage 3 (12.6-10.5 Ma) with volcanic material, lacustrine and fluvial sediments filling the sub-basins across the width of the graben. By 10.5 Ma crustal extension migrated to the western Snake River Plain (Cummings et al., 2000).

Figure 6. Regional map showing the Oregon-Idaho graben (OIG) in context of the dike swarms of the Columbia River Basalt Group (CRBG dikes), the northern Nevada rift (NNR), and the western Snake River Plain (WSRP) after Cummings et al. (2000). Regional features near the Oregon-Idaho graben depicted by additional symbols as follows: BG—Baker graben; C—Crowley; CR—Castle Rock; DM—Dooley Mountain; GP—Graveyard Point; HB—Harney basin; HJ—Huntington Junction; HM—Hart Mountain; LOVF—Lake Owyhee volcanic field; MVF—McDermitt volcanic field; PM—Pueblo Mountains; SM—Steens Mountain; SCR—Silver City Range; SRP—Snake River Plain; WB—Westfall Butte; WR—Warner Range; UR—Unity Reservoir; Y—Yellowstone Plateau. WA—Washington; OR—Oregon; ID—Idaho; MT—Montana; WY—Wyoming; UT—Utah; NV—Nevada; CA—California. Numbers displayed along the Snake River plain (SRP) show the age progression of rhyolitic volcanism.

Dinner Creek Tuff

The DIT erupted during a period of rhyolitic volcanism coeval to the flood volcanism associated with the CRBG (Streck and Ferns, 2012; Streck et al., 2015) (Figure 7). Although DIT rhyolites have nearly identical compositions, Streck et al. (2015) discovered different ages, subtle geochemical and lithological differences that divide the DIT into four cooling units. Except for unit 4, the units are lithologically very similar (Figure 8). $^{40}\text{Ar}/^{39}\text{Ar}$ analysis indicates the unit ages: 16.15-16 Ma (unit 1), 15.6-15.5 Ma (unit 2), 15.46 Ma (unit 3) and 15.0 Ma (unit 4) (Streck et al., 2015; Streck, pers. comm., 2017).

Figure 7. Age relationships of ignimbrite and fallout tuffs originating from the Dinner Creek Tuff eruptive center in relation to eruption period of Grande Ronde Basalt lavas based on the Barry et al. (2013) and Jarboe et al. (2010) chronology after Streck et al., (2015). The DITEC on the y axis highlights the rhyolites that erupted from the DITEC; proposed age ranges for the Grande Ronde member of the CRBG are shown above.

DIT units range from welded, marked by a basal vitrophyre typically overlain by primarily devitrified zones, to only incipiently welded tuff sections throughout. All cooling units are crystal poor with phenocryst contents of <1% – 5% (Streck, et al., 2015). Outcrops range from pumice poor (~5%) to pumice rich (~30%); small pumice is typically ~2 – 4 cm in the longest dimension and rarely exceeds 15 cm. Pumice colors range from white to tan to dark gray, but in single outcrops only one or two colors are evident (Figure 8) (Streck, et al., 2015). Anorthoclase or Na-rich plagioclase feldspar dominate individual cooling unit mineralogy with subordinate amounts of titanomagnetite and extremely rare pyroxenes. Due to the crystal-poor nature of the units, exact accessory phase mineralogy is currently unknown (Streck et al., 2015).

Figure 8. Dinner Creek Tuff unit photographs by Martin Streck. A1: Unit 1 type section in Malheur Gorge. A2: Unit 1 sample with white pumices. B1: Unit 2 outcrop east of John Day, OR. B2: Unit 2 near John Day, OR. C1: Unit 3 outcrop previously identified as the Bully Creek Tuff. C2: Unit 3, the recently correlated Bully Creek Tuff. D1: Unit 4 outcrop. D2: Unit 4 with vesicular globules of tholeiitic andesite glass that resemble Hunter Creek Basalt (Streck et al., 2015).

Bulk tuff compositions vary from a high-silica rhyolite (unit 1) to low-silica rhyolites (units 2 and 3) to dacitic (unit 4) (Figure 9) (Streck, et al., 2015). Unit 1 FeO^* , MgO , TiO_2 and Al_2O_3 concentrations are lower than the other units (Streck, et al., 2015). Except for Sr (<60 ppm) unit 1 is enriched in trace elements concentrations (Streck, et al., 2015). Units 2 and 3 tend to be higher in FeO^* , MgO , TiO_2 and Al_2O_3 and enriched in Sr, Ba and Ti with unit 2 containing more Sr than unit 3. La, Ce, U and Rb concentrations are consistent with unit 1. Unit 4 is depleted in most trace elements, but enriched in Eu and Sr (Streck et al., 2015).

While bulk rock compositions distinguish unit 3 from unit 4 as well as from the other units, feldspar compositions for these units are indistinguishable. Unit 1 and unit 2 feldspar compositions differentiate them from one another as well as units 3/4 (Figure 10).

Figure 9. Sr, Y, FeO and TiO₂ vs. SiO₂ for all analyzed samples of Dinner Creek Tuff. Unit correlation based on feldspar composition, subtle chemical differences and available age dates. Unassigned samples are samples where feldspars have not been analyzed or other data are ambiguous (Streck, pers. comm., 2017).

Figure 10. Anorthite vs. orthoclase diagram indicating unit correlating feldspar compositions from this study.

METHODS

Sample Selection

Forty-six samples collected from outcrops across the extent area of the DIT were utilized for this study. Samples were collected mainly by Martin Streck with additional samples collected by Emily Hess, Aaron Steiner, Adam Large and one sample by Emily Cahoon (Figure 11).

Figure 11. Locations and names of all samples associated with this study. Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate location of the DITEC.

Chemical Analysis

Sample Preparation

Samples broken down with a rock pick before were further crushed in a mortar and pestle. Periodically during processing, the fine portions were sieved, and larger fragments returned to the mortar and pestle for further crushing to ensure minimal damage to the minerals. Processed samples were sequentially sieved into particle-size fractions of mesh sizes: >991 microns, 991-125 microns, <125 microns. Crushed material >991 microns underwent further crushing, until a majority to all the sample material passed through the 991-micron sieve. For the 991-125-micron size fractions, handpicking under the binocular microscope separated the feldspar crystals from the remaining sample. Selected feldspars crystals were then mounted in epoxy and the resulting plugs were progressively polished to 1 micron utilizing increasingly higher levels of grit prior to being covered with a 10-nm thick carbon coating.

Electron microprobe analysis

Chemical analyses of feldspar crystals were conducted using the CAMECA SX100 electron microprobe (EMP) at Oregon State University (OSU) controlled remotely from Portland State University. The following EMP parameters were used during analysis:

- Accelerating voltage of 15 KV
- 2 μ m beam

Session calibrations utilized natural rhyolitic standards, mostly Smithsonian and USGS, both of which are long term standards used by the EMP lab at OSU. Each crystal was analyzed from 1 - 4 points per crystal, depending on time constraints. A maximum of 10 crystals per sample were analyzed during any one of the three EMP sessions. If less than 10 crystals were present, then the total number of crystals within that sample group were analyzed. Major elements analyzed included Na, Si, Al, Ca, K, Mg and Fe in addition to the trace element Ba. Due to instrumental malfunction during first session, Ba values determined during that session were not accurate and therefore discarded. Two of the plugs analyzed during that initial session were reanalyzed during later sessions due to low totals (~72% - ~97%).

Unit Correlation

The resulting feldspar data were used to calculate end member components compositions and generate anorthite vs. orthoclase diagrams to determine unit designation for units 1, 2 and 3/4. Samples exhibiting single crystal anomalies where crystals plotted outside the unit designated by most of the sample crystals were excluded from unit designation but are discussed. Bulk rock geochemistry and lithology correlated samples plotted as units 3/4 to their individual unit.

Mapping

ArcGIS was utilized for all maps. One third arc second digital elevation models (DEMs) from the USGS's National Map platform were downloaded and used to create the base for all maps in this study, due to the high resolution (10 m) and

seamlessness derived from assorted source data that is processed to a single coordinate system and unit of vertical measure to represent the topographic bare-earth surface.

Polygons for each unit were created and edited to enclose the locations of all samples correlated to a specific unit determined in this study and previous studies (Figure 12).

The eruptive source or DITEC was included, but not centralized within each unit polygon. The polygon determining the total extent of the DIT traced the outer edges associated with individual unit polygons when all units were visible on one map.

Individual unit and total extent areas were calculated within ArcGIS.

Erupted tuff volumes and dense rock equivalent

Total erupted tuff volumes and dense rock equivalents (DRE) were calculated based on the unit areas determined in this study. Associated formulas, thicknesses and densities utilized in the calculations are discussed further in the corresponding discussion section.

Figure 12. Example of how each polygon was created to enclose the sample locations while including Castle Rock (unit 1 source), Ironside Mountain (unit 2 source) or the DITEC from Figure 2, but not centralizing the eruptive sources within the individual polygons. Solid dots indicate data from this study and hollow dots are data from Streck et al. (2015).

RESULTS

Results from this study on the DIT are organized into four different sections:

1) unit designation utilizing EMP feldspar data from this study combined with bulk tuff data from previous DIT studies, 2) unit designated feldspar geochemistry, 3) extent maps created from GPS coordinates from this study combined with previous DIT studies and 4) non-unit designating individual feldspar crystal classification.

Unit Designation

Of the 47 samples selected for this study, 37 samples yielded geochemical data sufficient for analysis (Figure 13). The remaining 10 samples either did not yield feldspar for analysis or analysis indicated non-unit designating feldspars.

Feldspar Crystal EMP Analysis

All samples containing unit designating feldspars were categorized by feldspar end member concentrations of anorthite vs. orthoclase using following ranges for units 1 to 4: unit 1 (An₁₀₋₁₅, Or₆₋₁₀), unit 2 (An₁₉₋₂₃, Or₄₋₆) and units 3/4 (An₃₋₆, Or₁₆₋₂₇) which are shown in Figures 14a and 14b. Samples were split between the two diagrams for ease of reading. While the anorthite and orthoclase concentrations in units 3 and 4 are clearly distinct from units 1 and 2, they are indistinguishable from each other based on anorthite vs. orthoclase alone. Appendices A-D contain end member concentrations and standard deviations for the individual samples as well as individual crystals by unit. Table 1 contains end member concentration statistics by unit.

Figure 13. The map shows the locations of the samples utilized in this study. Blue dots refer to samples that yielded sufficient mineral chemical data for unit correlation. Red dots refer to samples that either lacked feldspar for chemical analysis or analysis indicated non-unit designating feldspars. Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the north/south boundaries of the DITEC.

Figure 14a. Upper—anorthite vs. orthoclase diagrams correlating samples in this study to the cooling units. Lower—same diagram, but with error bars representing the individual sample standard deviations from Appendices A-D.

Figure 14b. Upper—anorthite vs. orthoclase diagrams correlating samples in this study to the cooling units. Lower—same diagram, but with error bars representing the individual sample standard deviations from Appendices A-D.

Table 1. Average feldspar end member component composition statistics by unit.

Unit	An	Ab	Or	Unit	An	Ab	Or
1				3			
Average	11.5	80.4	8.1	Average	4.1	77.5	18.3
Minimum	10.4	78.5	6.1	Minimum	3.9	73.3	16.6
Maximum	14.2	81.8	9.6	Maximum	4.4	79.1	22.7
Std. Dev.	1.3	0.8	1.1	Std. Dev.	0.2	2.8	2.9
2				4			
Average	20.9	74.3	4.8	Average	4.2	75.3	20.5
Minimum	19.2	72.8	4.0	Minimum	3.0	70.3	17.2
Maximum	22.7	76.1	5.8	Maximum	5.6	78.8	26.7
Std. Dev.	1.2	1.0	0.5	Std. Dev.	0.8	3.3	3.5

The 37 samples designations are as follows: unit 1—13 samples, unit 2—11 samples, units 3/4—13 samples. MS-10-23, MS-11-4.1 and MS-14-4.2 exhibited single crystal anomalies where a single crystal from each sample contained higher anorthite (~13.2% - ~14.5% vs. ~9% - ~13%) and lower orthoclase concentrations (~6.0% - ~6.4% vs. ~7% - ~10%) than the sample average.

Unit 3 and 4 designations

Lithology and Bulk Tuff Data

Lithology and bulk tuff composition can be used to distinguish unit 3 from unit 4. In appearance, the gray color of unit 3 varies with welding but samples with a similar degree of welding to unit 4 samples, tend to be lighter than unit 4 samples (Table 2). Darker gray unit 3 samples display a higher degree of welding and appear glassy (Table 2). Unit 4 is the only unit to contain vesicular globules of tholeiitic andesite glass (Figure 8). Silica content determined by the bulk rock analyses from Streck et al. (2015) differentiates the rhyolitic (>70% SiO₂) unit 3 from the dacitic

(<70% SiO₂) unit 4 for five of the samples in this study (Table 2). Nb and Sr concentrations also differentiate the units (Figure 15). Appendix F contains all bulk rock data available for unit designated samples in this study as well as data for previously correlated samples.

Table 2. Unit 3/4 designations

Sample	SiO ₂ (wt. %)	Description	Sample	SiO ₂ (wt. %)	Description
Unit 3			Unit 4		
MS-10-26	76.6	gray	MS-12-20	67.0	dark gray
EBC12-074	75.0	gray, glassy	MS-15-20a	69.0	dark gray
MS-12-33.1	75.1	light gray	MS-15-7c	N/A	dark gray
MS-14-22	N/A	light gray	DIT@Craft Point	N/A	dark gray
MS-13-08	N/A	light gray	MS-15-18-2T	N/A	dark gray
PFC-1513	N/A	gray, glassy			
MS-10-25	N/A	gray

Figure 15. Nb and Sr vs. SiO₂ diagrams from the bulk rock data also differentiate unit 3 from unit 4. Solid shapes correlate to unit 3 and hollow shapes to unit 4.

Unit designating feldspar major element geochemistry

Unit 1

Table 3 contains the average weight percent concentrations of the major elements for unit 1 designated feldspar crystals. Appendix A contains individual

crystal chemical data. With a few exceptions, the feldspars analyzed displayed little chemical variation among major elements. SiO₂ concentrations in MS-11-4.2 and PFC-15486 were the only samples to exceed one standard deviation. Iron concentrations were highest in sample PFC15486, ~0.33% and the highest concentration among all the units. Magnesium is generally below detection limit in all units. MS-11-4.1_xl1 and MS-10-23_xl5 contained the lowest barium concentrations, ~0.26% and ~0.28% respectively. Compared to other units, unit 1 contains the highest NaO (~9.61%) and FeO* (~0.33%) concentrations.

Table 3. Unit 1 average EMP major element feldspar chemical composition by sample.

Sample	Number of Crystals	SiO ₂ (wt. %)	SiO ₂ Std.	Al ₂ O ₃ (wt. %)	Al ₂ O ₃ Std	FeO* (wt. %)	FeO* Std.
MS-10-23 ¹	6	64.13	0.3	22.13	0.20	0.28	0.04
MS-10-23_xl5 ^{1,2}	1	63.46	0.2	22.73	0.13	0.25	0.07
MS-11-4.1 ¹	5	63.92	0.4	22.32	0.27	0.25	0.04
MS-11-4.1_xl1 ^{1,2}	1	63.33	0.2	22.54	0.02	0.29	0.07
MS-11-3	4	63.65	0.8	21.37	0.40	0.27	0.04
MS-11-4.2	4	65.44	1.1	21.22	0.26	0.25	0.03
MS-11-4.2_xl2	1	64.70	N/A	21.92	N/A	0.24	N/A
MS-12-23	7	67.46	0.6	21.50	0.24	0.25	0.03
MS-15-7a	7	66.78	0.6	21.47	0.12	0.25	0.02
MS-15-38	6	66.43	0.4	20.79	0.22	0.26	0.02
MS-15-32b	7	66.35	0.4	20.98	0.44	0.22	0.05
MS-15-34a	6	65.21	0.8	21.05	0.43	0.25	0.04
MS-12-30	9	65.76	0.8	21.66	0.44	0.24	0.03
MS-14-4d	10	65.56	0.7	21.56	0.27	0.24	0.04
PFC-15486	10	65.35	1.2	21.24	0.49	0.33	0.29
MS-14-22	1	65.54	0.2	21.24	0.17	0.25	0.02

Table 3 continued.

Sample	Number of Crystals	CaO (wt. %)	CaO Std.	Na₂O (wt. %)	Na₂O Std.
MS-10-23 ¹	6	2.17	0.09	9.35	0.11
MS-10-23_x15 ^{1,2}	1	2.94	0.11	9.25	0.04
MS-11-4.1 ¹	5	2.23	0.17	9.39	0.13
MS-11-4.1_x11 ^{1,2}	1	2.86	0.02	9.61	0.27
MS-11-3	4	2.17	0.14	8.95	0.20
MS-11-4.2	4	2.13	0.20	8.92	0.18
MS-11-4.2_x12	1	2.88	N/A	8.93	N/A
MS-12-23	7	2.14	0.18	8.95	0.11
MS-15-7a	7	2.16	0.12	8.68	0.29
MS-15-38	6	2.08	0.12	8.78	0.18
MS-15-32b	7	2.13	0.12	8.92	0.18
MS-15-34a	6	2.13	0.25	8.77	0.12
MS-12-30	9	2.33	0.45	8.73	0.17
MS-14-4d	10	2.23	0.19	8.81	0.15
PFC-15486	10	2.32	0.34	8.69	0.40
MS-14-22	1	2.21	0.15	8.94	0.11

Table 3 continued.

Sample	Number of Crystals	K ₂ O (wt. %)	K ₂ O Std.	BaO (wt. %)	BaO Std.
MS-10-23 ¹	6	1.50	0.06	0.43	0.03
MS-10-23_xl5 ^{1,2}	1	1.09	0.09	0.28	0.03
MS-11-4.1 ¹	5	1.45	0.11	0.43	0.04
MS-11-4.1_xl1 ^{1,2}	1	1.11	0.00	0.26	0.02
MS-11-3	4	1.39	0.09	N/A	N/A
MS-11-4.2	4	1.42	0.10	N/A	N/A
MS-11-4.2_xl2	1	1.08	N/A	N/A	N/A
MS-12-23	7	1.45	0.09	0.48	0.04
MS-15-7a	7	1.41	0.03	N/A	N/A
MS-15-38	6	1.43	0.05	N/A	N/A
MS-15-32b	7	1.39	0.07	N/A	N/A
MS-15-34a	6	1.38	0.15	N/A	N/A
MS-12-30	9	1.35	0.21	0.42	0.08
MS-14-4d	10	1.39	0.10	0.44	0.03
PFC-15486	10	1.35	0.16	0.43	0.07
MS-14-22	1	1.47	0.09	0.47	0.03

1. Normalized values
2. Single crystal with two analysis points per crystal.

Unit 2

Table 4 contains the average weight percent concentrations of the major elements for unit 2 designated feldspar crystals. Appendix B contains individual crystal chemical data. Silica content was slightly lower than unit 1 with weight percent SiO₂ ranging from ~61.21% to ~64.38%. The feldspars analyzed displayed little chemical variation among the remainder of the major elements with only SiO₂ for sample MS-15-28.1b exceeding one standard deviation. Unlike unit 1, no individual sample showed significant contrast in major element concentrations compared to the

other samples. Sample MS-15-7b contained the lowest SiO₂ (~61.21%), Al₂O₃ (~21.0%), FeO* (~0.22%), Na₂O (~7.86) and BaO (~0.20%) concentrations. No individual sample contained the highest elemental concentrations across the major element concentrations. Compared to other units, unit 2 contains the highest Al₂O₃ (~23.64%) and CaO (~4.41%) concentrations and the lowest SiO₂ (~61.21%), K₂O (~0.75%) and BaO (~0.20%) concentrations.

Table 4. Unit 2 average EMP major element feldspar chemical composition by sample.

Sample	Number of Crystals	SiO ₂ (wt. %)	SiO ₂ Std.	Al ₂ O ₃ (wt. %)	Al ₂ O ₃ Std	FeO* (wt. %)	FeO* Std.
MS-15-7b ¹	7	61.21	0.21	24.23	0.11	0.25	0.04
MS-15-12	1	62.27	1.20	22.48	0.25	0.23	0.03
MS-10-20	2	63.92	0.84	23.64	0.32	0.23	0.04
MS-15-21a	7	63.41	0.56	22.77	0.14	0.24	0.04
MS-15-28	10	64.33	0.69	23.22	0.45	0.24	0.04
MS-15-28.1b	1	63.36	1.06	23.06	0.55	0.31	0.02
MS-15-12.4	3	64.38	0.45	23.00	0.09	0.23	0.04
MS-12-12.3	5	64.05	0.47	22.76	0.22	0.23	0.03
MS-15-18.2	6	62.33	0.91	22.62	0.29	0.23	0.03
MS-15-12.5 ²	2	63.96	0.58	22.75	0.32	0.23	0.02

Table 4 continued.

Sample	Number of Crystals	CaO (wt. %)	CaO Std.	Na ₂ O (wt. %)	Na ₂ O Std.
MS-15-7b ¹	7	4.13	0.14	7.86	0.15
MS-15-12	1	3.88	0.18	8.13	0.24
MS-10-20	2	4.41	0.21	8.09	0.01
MS-15-21a	7	4.10	0.25	8.16	0.18
MS-15-28	10	4.20	0.38	8.15	0.24
MS_15_28.1b	1	4.28	0.61	8.06	0.18
MS-15-12.4	3	4.03	0.08	8.39	0.16
MS-12-12.3	5	3.88	0.18	8.36	0.15
MS-15-18.2	6	3.87	0.20	8.19	0.20
MS-15-12.5 ²	2	3.84	0.32	8.54	0.27

Table 4 continued.

Sample	Number of Crystals	K ₂ O (wt. %)	K ₂ O Std.	BaO (wt. %)	BaO Std.
MS-15-7b ¹	7	0.75	0.05	0.20	0.02
MS-15-12	1	0.84	0.04	N/A	N/A
MS-10-20	2	0.79	0.01	0.21	0.03
MS-15-21a	7	0.81	0.03	N/A	N/A
MS-15-28	10	0.79	0.10	0.23	0.03
MS_15_28.1b	1	0.97	0.11	0.25	0.02
MS-15-12.4	3	0.85	0.02	0.24	0.02
MS-12-12.3	5	0.87	0.04	0.25	0.04
MS-15-18.2	6	0.84	0.05	0.23	0.04
MS-15-12.5 ²	2	0.89	0.04	0.27	0.04

1. Normalized sample

2. Data averaged from two individual samples.

Unit 3

Table 5 contains the average weight percent concentrations of the major elements for unit 3 designated feldspar crystals. Appendix C contains individual

crystal chemical data. Weight percent SiO₂ ranges from ~62.11% to ~68.28%, the largest variation among the major chemical elements. With a few exceptions, the feldspars analyzed displayed little chemical variation among major elements. MS-13-08 contained the lowest BaO concentration at ~0.56% and highest K₂O concentration at ~3.8%. No individual sample contained the highest or lowest elemental concentrations across the major element concentrations as well as across the units.

Table 5. Unit 3 average EMP major element feldspar chemical composition by sample.

Sample	Number of Crystals	SiO ₂ (wt. %)	SiO ₂ Std.	Al ₂ O ₃ (wt. %)	Al ₂ O ₃ Std.	FeO* (wt. %)	FeO* Std.
MS-12-33.1*	11	67.98	0.84	20.31	0.31	0.24	0.03
EBC-12-074	10	62.12	0.51	19.83	0.25	0.22	0.03
MS-14-12	10	67.18	0.64	20.54	0.23	0.21	0.03
MS-13-08	10	66.61	0.56	20.01	0.22	0.28	0.04
MS-10-26	1	65.88	N/A	20.07	N/A	0.24	N/A
MS-10-25	7	68.23	0.64	20.36	0.19	0.24	0.03
PFC-1513	10	63.58	0.81	20.13	0.24	0.23	0.05

Table 5 continued.

Sample	Number of Crystals	CaO (wt. %)	CaO Std.	Na ₂ O (wt. %)	Na ₂ O Std.
MS-12-33.1*	11	0.82	0.22	8.60	0.15
EBC-12-074	10	0.84	0.17	8.39	0.16
MS-14-12	10	0.79	0.11	8.91	0.15
MS-13-08	10	0.80	0.19	8.13	0.16
MS-10-26	1	0.69	N/A	7.78	N/A
MS-10-25	7	0.84	0.09	8.17	0.63
PFC-1513	10	0.85	0.09	8.39	0.11

Table 5 continued.

Sample	Number of Crystals	K ₂ O (wt. %)	K ₂ O Std.	BaO (wt. %)	BaO Std.
MS-12-33.1*	11	2.84	0.23	0.95	0.16
EBC-12-074	10	2.66	0.16	0.91	0.12
MS-14-12	10	2.89	0.11	0.98	0.07
MS-13-08	10	3.81	0.30	0.56	0.09
MS-10-26	1	3.99	N/A	N/A	N/A
MS-10-25	7	2.89	0.08	N/A	N/A
PFC-1513	10	2.78	0.09	0.93	0.07

*Data averaged from two individual samples.

Unit 4

Table 6 contains the average weight percent concentrations of the major elements for unit 4 designated feldspar crystals. Appendix D contains individual crystal chemical data. Weight percent SiO₂ ranges from ~66.79% to ~68.53%, the narrowest range among the units. With a few exceptions, the feldspars analyzed displayed little chemical variation among major elements. MS-15-7c contains the lowest concentrations of Al₂O₃ (~19.68%), FeO (~0.19%) and CaO (~0.58%) and the highest K₂O (~4.32%) concentrations of all the samples. No individual sample contained the highest or lowest elemental concentrations across the major elements. Compared to other units, unit 4 feldspars contain the highest concentrations of SiO₂ (~68.52%), K₂O (~4.32%) and BaO (~1.04%). Concentrations of FeO (~0.19%), Al₂O₃ (~19.68%), Na₂O (~7.53%) and CaO (~0.58%) are the lowest in unit 4, but the FeO* and Na₂O concentrations are comparable to the other units while the CaO concentrations are comparable only to unit 3.

Table 6. Unit 4 average EMP major element feldspar chemical composition by sample.

Sample	Number of Crystals	SiO ₂ (wt. %)	SiO ₂ Std.	Al ₂ O ₃ (wt. %)	Al ₂ O ₃ Std.	FeO* (wt. %)	FeO* Std.
MS-12-20	7	68.52	0.96	20.50	0.25	0.20	0.02
MS-15-18-2T	3	67.52	0.73	20.45	0.18	0.23	0.04
MS-15-7c	2	67.79	0.32	19.68	0.14	0.19	0.02
DIT@Craft Point	10	66.79	0.78	20.48	0.17	0.20	0.03
MS-15-20a	10	66.96	0.51	20.48	0.32	0.23	0.04

Table 6 continued.

Sample	Number of Crystals	CaO (wt. %)	CaO Std.	Na ₂ O (wt. %)	Na ₂ O Std.
MS-12-20	7	0.78	0.13	8.68	0.13
MS-15-18-2T	3	0.88	0.01	8.41	0.42
MS-15-7c	2	0.58	0.00	7.53	0.12
DIT@Craft Point	10	0.84	0.06	8.54	0.28
MS-15-20a	10	0.81	0.24	8.67	0.31

Table 6 continued.

Sample	Number of Crystals	K ₂ O (wt. %)	K ₂ O Std.	BaO (wt. %)	BaO Std.
MS-12-20	7	2.89	0.07	0.99	0.10
MS-15-18-2T	3	2.83	0.03	N/A	N/A
MS-15-7c	2	4.32	0.44	N/A	N/A
DIT@Craft Point	10	2.92	0.33	1.04	0.07
MS-15-20a	10	3.18	0.72	0.92	0.20

Unit 1

Figure 1 consists of two maps of the study area in Oregon. The left map shows the distribution of 20 sampling locations (blue diamonds) and 10 towns (black stars). The right map shows the same area with a blue shaded region indicating the area of study. The maps include latitude and longitude coordinates and a scale bar.

Left Map: Sampling Locations and Towns

Location	Symbol	Approx. Coordinates (N, W)
La Grande	Town (Star)	45.2°N, 117.8°W
Baker City	Town (Star)	44.8°N, 117.5°W
John Day	Town (Star)	44.5°N, 118.2°W
Ironside Mountain	Town (Star)	44.2°N, 118.0°W
Castle Rock	Town (Star)	44.0°N, 118.0°W
Vale	Town (Star)	44.0°N, 117.5°W
Burns	Town (Star)	43.8°N, 118.8°W
MS-11-27	Sampling (Diamond)	45.0°N, 117.5°W
MS-15-34a	Sampling (Diamond)	44.8°N, 117.5°W
MS-12-23	Sampling (Diamond)	44.6°N, 118.0°W
MS-12-26	Sampling (Diamond)	44.5°N, 117.8°W
MS-12-29	Sampling (Diamond)	44.2°N, 117.8°W
MS-15-32b	Sampling (Diamond)	44.1°N, 117.8°W
MS-12-30	Sampling (Diamond)	44.0°N, 117.8°W
MS-14-4d	Sampling (Diamond)	43.8°N, 117.8°W
MS-NEMT	Sampling (Diamond)	43.8°N, 118.0°W
MS-DIT1	Sampling (Diamond)	43.8°N, 118.2°W
MS-15-7a	Sampling (Diamond)	43.8°N, 118.5°W
MS-10-23	Sampling (Diamond)	43.8°N, 118.8°W
MS-15-38	Sampling (Diamond)	44.0°N, 118.8°W
MS-11-4	Sampling (Diamond)	44.0°N, 118.8°W
MS-11-4.1	Sampling (Diamond)	44.0°N, 118.8°W
MS-11-54	Sampling (Diamond)	44.0°N, 118.8°W
MS-11-54drk	Sampling (Diamond)	44.0°N, 118.8°W
MS-11-3	Sampling (Diamond)	44.0°N, 118.8°W
MS-11-3	Sampling (Diamond)	44.0°N, 118.8°W
MC2-09	Sampling (Diamond)	44.0°N, 118.8°W
MC1-09	Sampling (Diamond)	44.0°N, 118.8°W
CR-U31c	Sampling (Diamond)	44.2°N, 118.2°W

Right Map: Study Area

The right map shows the same area with a blue shaded region indicating the area of study. The shaded region covers the area around Baker City, John Day, Ironside Mountain, and Castle Rock. The towns of La Grande, Vale, and Burns are also shown.

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Unit 2

Figure 17 shows the locations of unit 2 designated samples and the overall extent of unit 1. Unit 2 covers an area of $\sim 17,920 \text{ km}^2$. Unit 2 is the second oldest (15.6-15.5 Ma) and second most widespread unit in terms of areal extent while extending further north than any of the units. GPS coordinates associated with the samples correlated to unit 2 in this study are found in Appendix B.

Figure 17. Areal extent of the Dinner Creek Tuff. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) while solid symbols represent samples from this study. Right: Overall areal extent of unit 2 covers an area of $\sim 17,920 \text{ km}^2$. Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Unit 3

Figure 18 shows the locations of unit 3 designated samples and the overall extent of unit 3. Unit 3 covers an area of $\sim 14,170 \text{ km}^2$. The third youngest (15.46 Ma) and third smallest of the units in terms of areal extent while extending farther south than any of the units. GPS coordinates associated with the samples correlated to unit 3 in this study are found in Appendix C.

Figure 18. Areal extent of the Dinner Creek Tuff. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) while solid symbols represent samples from this study. Right: Overall areal extent of unit 3 covers an area of $\sim 14,170 \text{ km}^2$. Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Unit 4

Figure 19 shows the locations of unit 4 designated samples and the overall extent of unit 4. Unit 4 covers an area of $\sim 8,370 \text{ km}^2$, the smallest in terms of areal extent and the youngest (15.0 Ma) of the units. GPS coordinates associated with the samples correlated to unit 4 in this study are found in Appendix D.

Figure 19. Areal extent of the Dinner Creek Tuff. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) and correlated samples collected by Aaron Steiner, while solid symbols represent samples from this study. Right: Overall areal extent of unit 4 covers an area of $\sim 8,370 \text{ km}^2$. Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Total extent

Overall, the DIT areal extent covers an area of ~31,800 km² (Figure 20).

Figure 20. Overall areal extent of the Dinner Creek Tuff covers an area of ~31,800 km². Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Non-unit Designating Feldspars

Samples from every unit contained non-unit designating feldspars, which are feldspars with anorthite and orthoclase concentrations that lie outside the concentrations used to correlate feldspars to an individual cooling unit: unit 1 (An_{10-15} , Or_{6-10}), unit 2 (An_{19-23} , Or_{4-6}) and units 3/4 (An_{3-6} , Or_{16-27}). Non-unit designating feldspar types include: albite, andesine, anorthoclase, bytownite, labradorite, oligoclase and sanidine (Figures 21-25). Unit 2 contains 35 non-unit designating feldspar crystals from 8 samples, the most of any unit followed by unit 4 with 12 crystals from 3 samples. Unit 3 contains 6 non-unit designating feldspar crystals from 2 samples, while unit 1 has the fewest with 3 crystals from 2 samples. Appendix E contains associated individual crystal chemical data and end member concentrations.

Figure 21. Non-unit designating feldspar endmember concentration diagram for samples associated with unit 1.

Figure 22a. Non-unit designating feldspar endmember concentration diagram for samples associated with unit 2.

Figure 22b. Non-unit designating feldspar endmember concentration diagram for samples associated with unit 2.

Figure 22c. Non-unit designating feldspar endmember concentration diagram for samples associated with unit 2.

Figure 23. Non-unit designating feldspar endmember concentration diagram for samples associated with unit 3.

Figure 24. Non-unit designating feldspar endmember concentration diagram for samples associated with unit 4.

Figure 25. Non-unit designating feldspar endmember concentration diagram for samples not correlated to a unit.

DISCUSSION

Erupted Tuff Volumes

Total volume (V_t) for each eruptive unit was calculated using two individual cylinder volumes (large: V_L and small: V_S) to approximate thinning of the tuff away from the source:

$$V_t = V_L + V_S. \quad \text{Equation 1}$$

The large cylinder volumes (V_L) were calculated by treating the unit areal extent as the area (A) of a circle and using conservative thicknesses (h) (Table 7). Thicknesses used are averages based on observed thicknesses from Kittlemen, et al. (1965), Haddock (1967), Davenport (1970) and Streck et al. (2015). Table 8 contains outcrop thicknesses observed during sample collection (Streck, pers. comm., 2017):

$$V_L = A (h). \quad \text{Equation 2}$$

The radius used to calculate the small circle area was half the radius of the large circle:

$$r_L = \sqrt{\frac{A}{\pi}} \quad \text{Equation 3}$$

$$r_S = 0.5r_L. \quad \text{Equation 4}$$

The resulting small circle radius and thicknesses in Table 7 were used to calculate small circle volumes utilizing Equation 2. Determined tuff volumes are ~170 km³ (unit 1), ~125 km³ (unit 2), ~99 km³ (unit 3) and ~46 km³ (unit 4), totaling ~440 km³.

Table 7. Unit thicknesses used in volume calculations.

Circle	Unit 1 (m)	Unit 2 (m)	Unit 3 (m)	Unit 4 (m)
Large	5	5	5	4
Small	10	8	8	6

Table 8. Observed thicknesses from distal outcrops of sample sites or sites proximal to sample location.

Sample	Thickness (m)	Sample	Thickness (m)
Unit 1		Unit 3	
MC1-09	12	MS-12-33.1	15
MS-15-34a	3	MS-12-38	10
MS-11-27	4		
Unit 2		Unit 4	
MS-10-1	15-20	AS-SV-214	8
PCIT1	12	MS-15-2T	10
MS-15-7b	5	MS-15-20a	7

Dense Rock Equivalent

DRE calculates magma volume utilizing individual unit densities (ρ_t), dense rock density ($\rho_{dr} = 2.34 \text{ g/cm}^3$) and erupted tuff volume for each unit (V) calculated in this study (Streck and Grunder, 1995; Streck, et al., 2015; Streck pers. comm., 2017). Like erupted tuff volumes, DREs decreases with unit size and age (Table 9).

Table 9. Unit densities and DRE.

	Unit 1 (g/cm ³)	Unit 2 (g/cm ³)	Unit 3 (g/cm ³)	Unit 4 (g/cm ³)
Unit density (g/cm ³)	2.1	1.8	1.8	1.6
DRE* (km ³)	152.1	96.5	76.3	31.5
*DRE = $\frac{\rho_t}{\rho_{dr}}(V)$				

Probable Extents

Areal extents were determined by enclosing sample locations within a polygon. The polygon also included the DITEC, but not in a centralized location. These factors lead to irregular shaped extents inconsistent with low-aspect ratio, high energy ignimbrites (LAI). Aspect ratio is determined by dividing the average thickness by the horizontal dimension of an ignimbrite (Walker, 1983). The response of an ash-flow to topography varies with aspect ratio. LAIs radiate outwards from the eruptive site, tending to travel a uniform distance in all directions, overtopping hills while blanketing the landscape rather than passively flowing through existing valleys (Walker, 1983; Freundt and Rosi, 1998; Sigurdsson et al., 2015). Based on the expertise and experience Martin Streck has accumulated during his extensive studies of eastern Oregon volcanism, the author of this study created probable areal extents for units 1-3 that are more in line with LIAs, centering the source areas within the polygons (Figures 26-29). Since the source for unit 3 is unknown and the DITEC is already located near the center of the extent area, only minimal adjustments were needed. An increase in areal extent also increases the eruptive volumes and DREs. Table 10 summarizes extent sizes, erupted tuff volumes and DREs associated with the determined and probable extents.

Table 10. Approximate determined and probable extent areal extents, volumes and DREs.

Unit	Determined Area (km ²)	Probable Area (km ²)	Determined Volume (km ³)	Probable Volume (km ³)	Determined DRE (km ³)	Probable DRE (km ³)
1	22,590	36,900	169.5	276.8	152.1	248.4
2	17,920	31,660	125.4	221.6	96.5	170.5
3	14,170	17,290	99.1	121.0	76.3	93.1
4	8,370	10,150	46.0	55.8	31.5	38.1
Total Extent	31,800	43,490	N/A	N/A	N/A	N/A

Unit 1

Figure 26. Probable areal extent of the Dinner Creek Tuff unit 1. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) while solid symbols represent samples from this study. Right: Solid shape—overall areal extent of unit 1 covers an area of ~22,590 km². Dashed line—probable extent covering an area of ~36,900 km². Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Unit 2

Figure 27. Probable areal extent of the Dinner Creek Tuff unit 2. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) while solid symbols represent samples from this study. Right: Solid shape—overall areal extent of unit 2 covers an area of ~17,920 km². Dashed line—probable extent covering an area of ~31,660 km². Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Unit 3

Figure 28. Probable areal extent of the Dinner Creek Tuff unit 3. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) while solid symbols represent samples from this study. Right: Solid shape—overall areal extent of unit 3 covers an area of $\sim 14,170 \text{ km}^2$. Dashed line—probable extent covering an area of $\sim 17,290 \text{ km}^2$. Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Unit 4

Figure 29. Probable areal extent of the Dinner Creek Tuff unit 4. Left: Sample names and locations utilized in determining the extent. Open symbols represent samples from Streck et al. (2015) and correlated samples collected by Aaron Steiner while solid symbols represent samples from this study. Right: Solid shape—overall areal extent of unit 4 covers an area of ~8,370 km². Dashed line—probable extent covering an area of ~10,150 km². Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Total Extent

Figure 30. Solid shape—Overall areal extent of the Dinner Creek Tuff covers an area of ~31,800 km². Dashed line—overall probable areal extent covers an area of ~43,490 km². Castle Rock and Ironside Mountain are the eruption sites for units 1 and 2, respectively. They also mark the approximate north/south boundaries of the DITEC.

Erupted tuff volumes and caldera deposits

Determined tuff volumes are $\sim 170 \text{ km}^3$ (unit 1), $\sim 125 \text{ km}^3$ (unit 2), $\sim 99 \text{ km}^3$ (unit 3) and $\sim 46 \text{ km}^3$ (unit 4), totaling $\sim 440 \text{ km}^3$. The determined volumes calculated did not take into consideration the thicker caldera deposits. Cruz (pers. comm., 2017) calculated the minimum caldera volumes of units 1 and 2 to be $\sim 98.5 \text{ km}^3$ and $\sim 31.1 \text{ km}^3$, respectively from the observations in Table 11. In these calculations, Cruz assumes that the calderas collapsed along vertical or near vertical faults but suggests this is probably inaccurate given caldera collapse models and observations in more eroded calderas. He also assumes that the caldera floor collapsed as a cohesive block. Cruz acknowledges that the true tuff thicknesses should be much greater than the observed tuff thicknesses since at other similar sized calderas, the intra-caldera tuff has been found to be between 1-2 km thick. Based on a thickness of 1 km, the volume of the intra caldera tuff for unit 1 at Castle Rock is $\sim 328.3 \text{ km}^3$ and $\sim 51.8 \text{ km}^3$ for unit 2 at Ironside Mountain. The densely welded nature of the caldera deposits means that the erupted tuff volume is equivalent to the DRE. Table 12 contains determined/probable volumes and DREs as well as volumes and DREs including intra caldera tuff volumes.

Table 11. Caldera observed thicknesses and axis used in minimal volume calculations*.

Observations (km)	Castle Rock Caldera	Ironside Caldera
Thickness (t)	0.3	0.6
Long axis radius (l)	11.0	5.5
Short axis radius (s)	9.5	3.0
* $V = t l s \pi$		

Table 12. Approximate determined and probable volumes and DREs including caldera deposits.

Unit	Determined volume (km ³)	Probable volume (km ³)	Determined volume with caldera volume (km ³)	Probable volume with caldera volume (km ³)
1	169.5	276.8	268.0	375.3
2	125.5	221.6	156.6	252.7
Unit	Determined DRE (km ³)	Probable DRE (km ³)	Determined DRE with caldera DRE (km ³)	Probable DRE with caldera DRE (km ³)
1	152.1	248.4	250.6	346.9
2	96.5	170.5	127.6	201.6

Samples with multiple feldspar compositions

Samples MS-11-4.1 and MS-15-34a are designated as unit 1, but both contain single crystal anomalies that correlated with unit 2. The average end member concentrations for samples MS-11-4.1 and MS-15-34a were calculated from 5 and 6 crystals, respectively. Figures 31a and 31b show the anorthite and orthoclase concentrations for the crystals within the sample used to calculate the sample averages (solid shapes), the average for each sample (x's) and the single crystal anomalies (open shapes). Error bars are associated with sample standard deviations and single crystal error bars represent standard deviation where there with two analysis points per crystal.

Figure 31a. Anorthite vs orthoclase diagram with single crystal anomalies that correlate to unit 2 when most of the crystals analyzed correlate to unit 1 for samples MS-11-4.1 and MS-15-34a. Solid shapes—individual crystals within a sample. Open shapes—anomalous crystals. X's average sample end member concentrations.

Figure 31b. Anorthite vs orthoclase diagram with single crystal anomalies that correlate to unit 2 when most of the crystals analyzed correlate to unit 1 for samples MS-11-4.1 and MS-15-34a. Error bars are associated with sample standard deviations and single crystal error bars represent standard deviation where there with two analysis points per crystal.

Non-unit designating feldspars

Sanidine crystals were found in all units, but only occasionally in units 1-4 (<2 crystals) and consistently (>2 crystals) in unit 4. Anorthoclase crystals, a slightly less potassium enriched feldspar than sanidine but richer in potassium than unit 3 and 4 anorthoclase compositions, were more common in unit 3 with 3 crystals and less common with only single crystals occurring in units 2 and 4. Albite was rare, only a single crystal occurrence in unit 3. While all units contain more anorthite richer plagioclase feldspars, they occurred more frequently in unit 2 (>3 crystals) than any other unit (<3 crystals). The occurrence of oligoclase, andesine, labradorite and bytownite within the units suggest the possibility that these feldspars crystallized from more mafic magmas and thus record the input of hotter and more mafic magmas into the rhyolitic reservoirs. This is corroborated by finding pumices and mafic globules ranging from dacite to andesite in unit 2, 3 and 4 (Streck, pers. comm., 2017).

CONCLUSIONS

Feldspar compositions successfully correlated samples to cooling units 1, 2 and 3/4. Results were consistent with Streck et al., 2015 and tuff units can be traced this way, but lithological and bulk compositions are needed to distinguishing unit 3 and 4.

Originally determined to have an areal extent of 2,000 km² by Haddock (1967), this study shows that all outcrops now determined to be Dinner Creek Tuff enclose an area of ~31,300 km² not including any fallout deposits that likely extended beyond the defined area. Minimal individual unit areal extents decrease with age and are as follows: ~22,590 km² (unit 1), ~17,920 km² (unit 2), ~14,170 km² (unit 3) and ~8,370 km² (unit 4). Minimal calculated erupted tuff volumes are: ~170 km³ (unit 1), ~125 km³ (unit 2), ~99 km³ (unit 3) and ~46 km³ (unit 4), totaling ~422 km³. Minimal calculated DRE are: ~152 km³ (unit 1), ~96 km³ (unit 2), ~78 km³ (unit 3) and ~31 km³ (unit 4), totaling ~356 km³.

These extents and volumes are the absolute minimal using only locations of exposed tuff sections and the source location. Centering eruptive units on source areas where they are known, extending tuff extents to make a more radial pattern as would be expected for low-aspect ratio, high energy ash-flow tuff eruptions and extending extent beyond several meter-thick outcrops increases the tuff and erupted magma volume. Finally, thick ponded tuff in caldera areas as observed needed to be added. Including probable extents and intra-caldera tuff yields erupted magma volumes of ~375.3 (unit 1) and ~252.7 (unit 2).

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APPENDIX A: UNIT 1 CHEMICAL DATA, STANDARD DEVIATIONS AND GPS COORDINATES

Table A1. Unit 1 average feldspar end member component composition, standard deviations and GPS coordinates by sample.

Sample	Number of Crystals	An	Ab	Or	An Std.	Al Std.	Or Std.	Latitude	Longitude
MS-10-23	6	10.4	81.0	8.6	0.4	0.3	0.4	43.8899	-119.0325
MS-10-23_xl5	1	14.0	79.7	6.2	0.5	0.1	0.6	43.8899	-119.0325
MS-11-4.1	5	10.7	81.1	8.3	0.8	0.3	0.7	44.0241	-119.1875
MS-11-4.1_xl1	1	13.3	80.6	6.1	0.2	0.3	0.1	44.0241	-119.1875
MS-11-3	4	10.7	79.8	9.6	0.8	0.3	0.5	44.0871	-119.2209
MS-11-4.2	4	10.7	80.8	8.5	1.1	0.6	0.5	44.0269	-119.1841
MS-11-4.2_xl2	1	14.2	79.4	6.4	N/A	N/A	N/A	44.0269	-119.1841
MS-12-23	7	11.9	78.5	9.6	0.8	0.4	0.6	44.5613	-118.0251
MS-15-7a	7	11.1	80.3	8.6	0.8	0.8	0.2	43.7526	-118.7989
MS-15-38	6	10.6	80.7	8.7	0.5	0.3	0.3	44.0106	-118.7819
MS-15-32b	7	10.8	81.8	7.4	0.5	0.3	0.5	44.0742	-117.7852
MS-15-34a	6	10.9	80.7	8.4	1.3	0.4	1.0	44.7506	-116.8918
MS-12-30	9	11.8	80.0	8.2	2.2	1.0	1.3	44.0747	-117.5385
MS-14-4d	10	10.4	81.2	8.5	1.0	0.6	0.6	43.5947	-117.8269
PFC-15486	10	10.9	80.8	8.3	1.7	1.0	1.1	44.0063	-118.8330
MS-14-22	1	11.0	80.3	8.7	0.8	0.4	0.5	44.1332	-118.8781

Table A2. Unit 1 EMP major element individual feldspar crystal chemical data.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-10-23¹									
xl_1a	63.87	22.28	0.28	0.000	2.14	9.51	1.51	0.42	100.0
xl_1b	64.24	22.11	0.25	0.000	2.16	9.30	1.53	0.41	100.0
xl_2a	64.08	22.14	0.29	0.001	2.09	9.48	1.48	0.44	100.0
xl_2b	63.98	22.34	0.27	0.000	2.29	9.38	1.36	0.37	100.0
xl_3a	63.94	22.15	0.30	0.000	2.20	9.45	1.52	0.43	100.0
xl_3b	63.86	22.45	0.20	0.009	2.22	9.30	1.48	0.48	100.0
xl_4a	64.15	22.10	0.25	0.000	2.25	9.35	1.48	0.42	100.0
xl_4b	64.46	21.85	0.29	0.000	2.12	9.31	1.51	0.45	100.0
xl_5a	63.29	22.83	0.30	0.003	3.01	9.28	1.03	0.26	100.0
xl_5b	63.62	22.64	0.20	0.000	2.86	9.22	1.16	0.29	100.0
xl_6a	64.15	22.03	0.35	0.030	2.15	9.25	1.61	0.44	100.0
xl_6b	63.82	22.36	0.28	0.000	2.35	9.33	1.43	0.43	100.0
xl_7a	64.67	21.86	0.31	0.000	2.00	9.12	1.56	0.48	100.0
xl_7b	64.33	21.92	0.29	0.000	2.12	9.40	1.50	0.43	100.0
MS-11-4.1¹									
xl_1a	63.16	22.55	0.24	0.011	2.88	9.80	1.11	0.24	100.0
xl_1b	63.49	22.53	0.34	0.000	2.84	9.42	1.11	0.27	100.0
xl_2a	64.30	21.99	0.22	0.000	2.05	9.31	1.63	0.49	100.0
xl_2b	63.54	22.61	0.26	0.000	2.62	9.39	1.22	0.37	100.0
xl_4a	64.28	22.03	0.21	0.001	2.16	9.37	1.53	0.43	100.0
xl_4b	63.73	22.29	0.24	0.000	2.27	9.62	1.44	0.41	100.0
xl_5a	63.81	22.53	0.23	0.000	2.33	9.34	1.36	0.41	100.0
xl_5b	64.59	22.06	0.21	0.000	2.08	9.14	1.47	0.44	100.0
xl_6a	63.95	22.05	0.30	0.000	2.11	9.52	1.58	0.48	100.0
xl_6b	63.84	22.44	0.27	0.003	2.11	9.43	1.44	0.46	100.0
xl_8a	63.55	22.69	0.28	0.000	2.23	9.45	1.41	0.39	100.0
xl_8b	63.63	22.54	0.31	0.000	2.33	9.37	1.41	0.40	100.0
MS-11-3									
xl_2	64.25	21.50	0.23	0.002	2.26	8.91	1.33	N/A	98.5
xl_3	64.36	20.85	0.24	0.000	2.00	8.86	1.46	N/A	97.8
xl_4	63.07	21.81	0.32	0.000	2.31	8.81	1.29	N/A	97.6
xl_5	62.94	21.34	0.28	0.000	2.09	9.24	1.47	N/A	97.4
MS-11-4.2									
xl_1	64.83	21.14	0.24	0.006	2.12	8.77	1.43	N/A	98.5
xl_2	64.70	21.92	0.24	0.003	2.88	8.93	1.08	N/A	99.7
xl_3	64.48	21.50	0.27	0.000	2.32	8.91	1.32	N/A	98.8
xl_4	65.48	20.90	0.28	0.000	1.86	9.17	1.56	N/A	99.2

Table A2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-11-4.2 cont.									
xl_5	66.96	21.33	0.21	0.000	2.24	8.82	1.39	N/A	100.9
MS-12-23									
xl_1a	67.65	21.71	0.26	0.000	1.96	9.08	1.56	0.48	102.7
xl_1b	67.40	21.35	0.24	0.014	2.11	8.95	1.48	0.51	102.0
xl_2a	67.37	21.51	0.31	0.004	2.18	9.07	1.42	0.47	102.3
xl_2b	66.96	21.65	0.26	0.008	2.35	9.01	1.32	0.42	102.0
xl_3a	67.34	21.39	0.24	0.000	2.07	8.84	1.48	0.52	101.9
xl_3b	66.41	21.64	0.23	0.000	2.65	9.08	1.22	0.42	101.6
xl_4a	67.77	21.26	0.29	0.000	2.10	8.73	1.46	0.43	102.0
xl_4b	67.94	21.49	0.21	0.008	2.12	8.90	1.53	0.49	102.7
xl_5a	67.36	21.80	0.23	0.000	2.13	8.86	1.42	0.47	102.3
xl_5b	67.53	21.18	0.24	0.000	1.98	8.88	1.57	0.57	101.9
xl_6a	68.48	21.51	0.25	0.004	1.95	9.04	1.41	0.44	103.1
xl_6b	68.23	21.02	0.24	0.000	2.04	8.93	1.49	0.50	102.4
xl_7a	67.20	21.87	0.27	0.003	2.17	8.92	1.46	0.50	102.4
xl_7b	66.74	21.59	0.23	0.000	2.14	9.05	1.44	0.44	101.6
MS-15-7a									
xl_1	66.40	21.55	0.25	0.000	2.28	8.32	1.35	N/A	100.2
xl_2	67.88	21.40	0.28	0.000	2.03	8.93	1.42	N/A	101.9
xl_3	66.36	21.57	0.25	0.000	2.25	8.48	1.39	N/A	100.3
xl_4	66.69	21.46	0.22	0.000	2.11	9.13	1.42	N/A	101.0
xl_5	66.31	21.64	0.24	0.000	2.31	8.53	1.41	N/A	100.4
xl_6	67.28	21.35	0.27	0.000	2.03	8.85	1.45	N/A	101.2
xl_7	66.58	21.32	0.23	0.000	2.09	8.49	1.41	N/A	100.1
MS-15-38									
xl_1	66.30	20.82	0.26	0.001	1.88	8.67	1.50	N/A	99.4
xl_2	66.54	21.18	0.25	0.002	2.20	8.80	1.44	N/A	100.4
xl_3	65.74	20.79	0.23	0.000	2.05	8.59	1.37	N/A	98.8
xl_4	66.56	20.66	0.27	0.000	2.09	8.75	1.45	N/A	99.8
xl_6	66.76	20.52	0.25	0.000	2.19	9.11	1.37	N/A	100.2
xl_7	66.67	20.79	0.29	0.000	2.08	8.78	1.45	N/A	100.1
MS-15-32b									
xl_1	66.27	20.97	0.15	0.000	2.13	8.93	1.40	N/A	99.9
xl_2	66.88	21.76	0.25	0.000	2.25	9.24	1.29	N/A	101.7
xl_3	66.53	20.95	0.26	0.000	2.18	8.72	1.37	N/A	100.0
xl_4	66.38	21.32	0.26	0.000	2.26	9.02	1.32	N/A	100.6

Table A2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-15-32b cont.									
xl_5	66.28	20.47	0.16	0.000	1.91	8.76	1.46	N/A	99.0
xl_6	65.56	20.75	0.19	0.002	2.10	8.80	1.37	N/A	98.8
xl_7	66.55	20.66	0.26	0.000	2.08	8.94	1.50	N/A	100.0
MS-15-34a									
xl_1	65.70	21.07	0.22	0.000	2.13	8.61	1.38	N/A	99.9
xl_2	65.55	20.96	0.28	0.002	2.10	8.69	1.37	N/A	101.7
xl_4	66.27	20.58	0.23	0.006	1.85	8.95	1.55	N/A	100.6
xl_5	65.14	21.27	0.21	0.000	2.26	8.79	1.34	N/A	99.0
xl_6	64.25	20.64	0.25	0.001	1.91	8.76	1.54	N/A	98.8
xl_7	64.35	21.75	0.30	0.004	2.55	8.85	1.12	N/A	100.0
MS-12-30									
xl_1a	66.35	21.33	0.23	0.001	1.97	8.73	1.55	0.49	100.7
xl_1b	66.64	21.38	0.25	0.000	1.94	8.70	1.57	0.44	100.9
xl_2a	66.25	21.82	0.20	0.003	2.53	8.66	1.26	0.37	101.1
xl_2b	66.09	21.39	0.29	0.003	2.02	8.68	1.52	0.43	100.4
xl_3a	64.72	22.10	0.26	0.010	3.04	8.54	1.03	0.32	100.0
xl_3b	65.37	22.01	0.22	0.000	2.78	8.60	1.10	0.32	100.4
xl_4a	66.80	21.20	0.28	0.006	2.04	8.87	1.51	0.45	101.2
xl_4b	66.36	21.07	0.22	0.000	1.81	9.00	1.70	0.53	100.7
xl_5a	66.88	21.41	0.19	0.001	2.14	8.67	1.46	0.49	101.2
xl_5b	65.56	21.60	0.22	0.000	2.07	8.50	1.43	0.49	99.9
xl_6a	64.83	22.54	0.22	0.000	3.31	8.54	0.94	0.25	100.6
xl_6b	65.90	21.45	0.24	0.002	2.29	8.57	1.36	0.43	100.2
xl_7a	64.68	22.73	0.31	0.003	3.18	8.91	1.01	0.31	101.1
xl_7b	65.18	21.70	0.28	0.000	2.36	8.82	1.25	0.41	100.0
xl_8a	65.12	21.55	0.21	0.000	2.21	8.61	1.38	0.42	99.5
xl_8b	66.55	21.45	0.24	0.000	2.04	9.04	1.43	0.43	101.2
xl_9a	65.98	21.69	0.25	0.004	2.12	8.93	1.43	0.46	100.9
xl_9b	64.46	21.38	0.24	0.001	2.09	8.81	1.45	0.45	98.9
MS-14-4d									
xl_1a	66.03	21.97	0.25	0.000	2.36	8.74	1.35	0.43	101.1
xl_1b	65.61	21.41	0.24	0.000	2.18	8.88	1.39	0.39	100.1
xl_2a	65.92	21.92	0.23	0.000	2.48	8.77	1.28	0.43	101.0
xl_2b	66.55	21.89	0.29	0.000	2.18	9.05	1.37	0.42	101.8
xl_3a	65.60	21.67	0.28	0.005	2.21	8.98	1.39	0.46	100.6
xl_3b	66.32	21.64	0.27	0.001	2.18	8.88	1.40	0.49	101.2

Table A2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-14-4d cont.									
xl_4a	66.28	21.27	0.26	0.002	2.05	8.82	1.45	0.41	100.5
xl_4b	64.92	21.54	0.24	0.000	2.44	8.64	1.39	0.42	99.6
xl_5a	65.78	21.52	0.22	0.010	2.36	8.79	1.30	0.44	100.4
xl_5b	65.36	21.35	0.34	0.000	2.12	8.77	1.47	0.45	99.9
xl_6a	65.40	21.24	0.21	0.000	2.07	8.81	1.48	0.47	99.7
xl_6b	65.62	21.59	0.20	0.000	2.03	8.83	1.47	0.43	100.2
xl_7a	65.73	21.61	0.20	0.000	2.21	8.86	1.41	0.44	100.4
xl_7b	65.50	21.08	0.22	0.000	1.96	8.71	1.60	0.47	99.5
xl_8a	66.09	21.26	0.25	0.000	2.12	8.72	1.49	0.48	100.4
xl_8b	65.10	21.81	0.25	0.000	2.29	9.19	1.36	0.44	100.4
xl_9a	63.55	21.90	0.18	0.013	2.78	8.47	1.08	0.40	98.4
xl_9b	65.64	21.30	0.23	0.000	2.04	8.81	1.42	0.40	99.8
xl_10a	64.72	21.90	0.30	0.000	2.35	8.71	1.42	0.44	99.8
xl_10b	65.43	21.40	0.21	0.004	2.22	8.76	1.33	0.42	99.8
PFC-15486									
xl_1a	65.85	21.16	0.25	0.005	1.97	8.73	1.49	0.56	100.0
xl_1b	66.52	21.15	0.21	0.000	2.08	8.78	1.52	0.45	100.7
xl_2a	65.44	22.12	0.30	0.000	3.25	8.57	0.97	0.27	100.9
xl_2b	64.76	21.91	0.27	0.000	3.00	8.80	0.99	0.29	100.0
xl_3a	65.21	21.81	0.30	0.009	2.31	8.65	1.40	0.40	100.1
xl_3b	60.95	19.96	1.56	0.177	2.25	7.09	1.30	0.39	93.7
xl_4a	65.77	20.78	0.29	0.000	1.99	8.75	1.52	0.50	99.6
xl_4b	66.59	21.22	0.26	0.002	2.03	9.13	1.54	0.51	101.3
xl_5a	65.58	21.18	0.25	0.006	2.25	8.92	1.40	0.43	100.0
xl_5b	65.15	20.56	0.29	0.007	2.08	8.73	1.44	0.48	98.7
xl_6a	65.34	21.27	0.19	0.000	2.16	8.56	1.37	0.47	99.4
xl_6b	66.15	21.37	0.22	0.000	2.30	8.85	1.34	0.39	100.6
xl_7a	65.50	21.22	0.24	0.000	2.43	8.98	1.33	0.42	100.1
xl_7b	65.92	20.80	0.27	0.000	2.26	8.60	1.43	0.42	99.7
xl_8a	65.66	21.56	0.26	0.000	2.49	8.90	1.26	0.41	100.5
xl_8b	64.18	21.65	0.30	0.005	2.84	8.69	1.11	0.36	99.1
xl_9a	65.22	21.44	0.30	0.000	2.32	8.91	1.41	0.44	100.0
xl_9b	65.25	21.30	0.20	0.000	2.22	8.62	1.40	0.43	99.4
xl_10a	65.87	20.85	0.29	0.000	1.99	8.72	1.52	0.47	99.7
xl_10b	66.17	21.48	0.27	0.000	2.24	8.75	1.34	0.46	100.7

Table A2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-14-22									
xl_1a	65.34	21.20	0.22	0.000	2.31	8.78	1.39	0.43	99.7
xl_1b	65.56	21.36	0.27	0.000	2.32	9.00	1.40	0.51	100.4
xl_1c	65.45	21.02	0.27	0.000	2.19	8.96	1.55	0.48	99.9
xl_1d	65.83	21.38	0.25	0.000	2.00	9.02	1.54	0.48	100.5
** Letters following crystal number indicate multiple analysis points per crystal.									
1. Normalized values.									

Table A3. Unit 1 individual feldspar crystal end member compositions.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-10-23 ¹			
xl_1a	10.15	81.33	8.53
xl_1b	10.40	80.81	8.80
xl_2a	9.97	81.58	8.45
xl_2b	11.02	81.21	7.78
xl_3a	10.46	80.95	8.60
xl_3b	10.72	80.78	8.51
xl_4a	10.78	80.77	8.45
xl_4b	10.22	81.09	8.71
xl_5a	14.37	79.79	5.84
xl_5b	13.70	79.67	6.63
xl_6a	10.38	80.40	9.23
xl_6b	11.25	80.58	8.18
xl_7a	9.88	80.99	9.14
xl_7b	10.17	81.26	8.58
MS-11-4.1 ¹			
xl_1a	13.15	80.81	6.04
xl_1b	13.45	80.32	6.24
xl_2a	9.89	80.79	9.34
xl_2b	12.46	80.61	6.94
xl_4a	10.35	80.92	8.73
xl_4b	10.63	81.32	8.06
xl_5a	11.20	81.02	7.79
xl_5b	10.26	81.12	8.62
xl_6a	9.97	81.13	8.90
xl_6b	10.15	81.61	8.25
xl_8a	10.63	81.33	8.05
xl_8b	11.16	80.80	8.05
MS-11-3			
xl_2	11.36	80.66	7.98
xl_3	10.15	81.00	8.85
xl_4	11.69	80.51	7.80
xl_5	10.21	81.25	8.55
MS-11-4.2			
xl_1	10.81	80.54	8.66
xl_2	14.20	79.45	6.35
xl_3	11.63	80.47	7.90
xl_4	9.18	81.65	9.19
xl_5	11.31	80.35	8.35

Table A3 continued.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-12-23			
xl_1a	9.69	81.11	9.21
xl_1b	10.56	80.62	8.83
xl_2a	10.76	80.87	8.38
xl_2b	11.66	80.53	7.82
xl_3a	10.46	80.64	8.90
xl_3b	12.95	79.96	7.10
xl_4a	10.72	80.41	8.88
xl_4b	10.62	80.26	9.14
xl_5a	10.75	80.68	8.57
xl_5b	9.95	80.65	9.41
xl_6a	9.78	81.77	8.45
xl_6b	10.23	80.83	8.95
xl_7a	10.85	80.47	8.69
xl_7b	10.62	80.88	8.51
MS-15-7a			
xl_1	12.09	79.38	8.54
xl_2	10.23	81.21	8.57
xl_3	11.71	79.66	8.64
xl_4	10.41	81.24	8.36
xl_5	11.91	79.41	8.68
xl_6	10.31	80.93	8.77
xl_7	10.94	80.26	8.81
MS-15-38			
xl_1	9.76	80.96	9.29
xl_2	11.13	80.22	8.66
xl_3	10.68	80.79	8.54
xl_4	10.66	80.50	8.85
xl_6	10.82	81.13	8.06
xl_7	10.61	80.59	8.81
MS-15-32b			
xl_1	10.72	80.89	8.40
xl_2	10.99	81.47	7.55
xl_3	11.17	80.46	8.37
xl_4	11.27	80.93	7.81
xl_5	9.81	81.24	8.96
xl_6	10.71	80.99	8.31
xl_7	10.40	80.66	8.95
MS-15-34a			
xl_1	11.04	80.44	8.53

Table A3 continued.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-15-34a cont.			
xl_2	10.83	80.73	8.45
xl_4	9.33	81.37	9.30
xl_5	11.49	80.44	8.09
xl_6	9.78	80.84	9.39
xl_7	12.86	80.39	6.76
MS-12-30			
xl_1a	10.05	80.48	9.47
xl_1b	9.96	80.46	9.60
xl_2a	12.87	79.47	7.66
xl_2b	10.38	80.34	9.29
xl_3a	15.46	78.29	6.26
xl_3b	14.20	79.14	6.67
xl_4a	10.31	80.65	9.05
xl_4b	9.05	80.84	10.13
xl_5a	10.99	80.10	8.93
xl_5b	10.82	80.24	8.95
xl_6a	16.68	77.66	5.66
xl_6b	11.81	79.84	8.36
xl_7a	15.54	78.60	5.87
xl_7b	11.95	80.53	7.53
xl_8a	11.41	80.13	8.47
xl_8b	10.17	81.35	8.49
xl_9a	10.63	80.83	8.55
xl_9b	10.62	80.62	8.77
MS-14-4d			
xl_1a	11.97	79.87	8.17
xl_1b	10.97	80.66	8.38
xl_2a	12.54	79.76	7.71
xl_2b	10.85	81.05	8.11
xl_3a	11.02	80.71	8.28
xl_3b	11.00	80.62	8.39
xl_4a	10.41	80.82	8.78
xl_4b	12.39	79.18	8.44
xl_5a	11.93	80.20	7.88
xl_5b	10.80	80.32	8.89
xl_6a	10.51	80.57	8.93
xl_6b	10.33	80.81	8.87
xl_7a	11.11	80.46	8.44
xl_7b	10.00	80.27	9.74

Table A3 continued.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-14-4d cont.			
xl_8a	10.82	80.16	9.04
xl_8b	11.19	80.88	7.94
xl_9a	14.40	78.97	6.64
xl_9b	10.39	80.97	8.65
xl_10a	11.88	79.52	8.60
xl_10b	11.35	80.59	8.07
PFC-15486			
xl_1a	10.11	80.78	9.12
xl_1b	10.53	80.31	9.17
xl_2a	16.39	77.78	5.83
xl_2b	14.96	79.15	5.89
xl_3a	11.81	79.69	8.51
xl_3b	13.58	77.08	9.35
xl_4a	10.19	80.57	9.25
xl_4b	9.99	80.98	9.03
xl_5a	11.26	80.42	8.33
xl_5b	10.64	80.59	8.78
xl_6a	11.25	80.25	8.52
xl_6b	11.59	80.38	8.03
xl_7a	12.02	80.16	7.83
xl_7b	11.59	79.66	8.76
xl_8a	12.45	80.07	7.49
xl_8b	14.34	79.00	6.66
xl_9a	11.58	80.08	8.36
xl_9b	11.43	79.97	8.61
xl_10a	10.20	80.50	9.31
xl_10b	11.42	80.42	8.17
MS-14-22			
xl_1a	11.67	79.96	8.38
xl_1b	11.50	80.28	8.23
xl_1c	10.85	80.02	9.14
xl_1d	9.96	80.89	9.15

** Letters following crystal number indicate multiple analysis points per crystal.

1. Normalized values.

2. $An = (CaO \cdot 0.714/40) / (CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$

3. $Ab = (Na_2O \cdot 0.74/23) / (CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$

4. $Or = (K_2O \cdot 0.83/39) / (CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$

APPENDIX B: UNIT 2 CHEMICAL DATA, STANDARD DEVIATIONS AND GPS COORDINATES

Table B1. Unit 2 average end member component composition and GPS coordinates by sample.

Sample	Number of Crystals	An	Ab	Or	An Std.	Al Std.	Or Std.	Latitude	Longitude
MS-15-7b	7	19.2	76.1	4.8	0.7	0.6	0.3	43.7469	-118.7997
MS-15-12	1	21.3	73.9	4.8	N/A	N/A	N/A	45.3672	-118.1268
MS-10-20	2	22.1	73.1	4.7	0.8	0.8	0.0	44.3378	-117.9897
MS-15-21a	7	20.9	74.9	4.3	1.3	1.2	0.1	44.0092	-118.8238
MS-15-28	10	21.2	74.0	4.8	2.0	1.5	0.6	43.8754	-119.0177
MS-15-28.1b	1	21.4	72.8	5.8	2.2	1.3	0.9	43.9349	-119.0681
MS-15-12.4	3	20.0	75.0	5.0	0.5	0.6	0.1	45.5850	-117.8198
MS-12-12.3	5	19.4	75.4	5.2	0.9	0.8	0.3	45.7367	-117.8676
MS-15-18.2	6	19.7	75.2	5.1	1.2	1.0	0.3	43.7033	-118.8033
MS-15-12.5	3	19.0	75.7	5.2	1.7	1.5	0.3	45.5588	-117.9522

Table B2. Unit 2 EMP major element individual feldspar crystal geochemical data.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
<hr/>									
MS-15-7b ¹									
xl_1a	61.21	24.04	0.24	0.000	4.17	9.27	0.87	0.21	100.0
xl_1b	61.02	24.32	0.29	0.000	4.20	9.14	0.81	0.22	100.0
xl_2a	61.45	24.31	0.24	0.001	4.03	8.98	0.78	0.21	100.0
xl_2b	61.64	24.08	0.19	0.000	4.14	8.87	0.88	0.20	100.0
xl_3a	61.27	24.13	0.22	0.006	4.17	9.11	0.89	0.21	100.0
xl_3b	60.74	24.44	0.29	0.000	4.40	9.14	0.79	0.21	100.0
xl_4a	61.19	24.26	0.26	0.000	4.01	9.15	0.91	0.22	100.0
xl_4b	61.01	24.22	0.30	0.000	4.10	9.23	0.90	0.25	100.0
xl_5a	61.22	24.20	0.28	0.000	3.79	9.30	0.94	0.28	100.0
xl_5b	61.30	24.24	0.18	0.005	4.17	8.96	0.91	0.23	100.0
xl_6a	61.20	24.33	0.29	0.000	4.15	8.93	0.86	0.24	100.0
xl_6b	61.34	24.17	0.26	0.000	4.29	8.83	0.86	0.24	100.0
xl_7a	61.29	24.21	0.25	0.000	4.05	9.09	0.87	0.25	100.0
xl_7b	61.11	24.26	0.27	0.000	4.11	9.22	0.83	0.21	100.0
MS-15-12									
xl_1	62.93	23.46	0.25	0.000	4.25	8.19	0.80	N/A	99.9
MS-10-20									
xl_2a	64.51	23.86	0.20	0.001	4.26	8.09	0.79	0.18	101.9
xl_2b	63.32	23.42	0.26	0.001	4.56	8.10	0.80	0.23	100.7
MS-15-21a									
xl_1	62.96	22.68	0.23	0.003	4.42	8.10	0.79	N/A	99.2
xl_2	63.92	22.97	0.29	0.000	3.68	8.42	0.84	N/A	100.1
xl_3	64.05	22.69	0.20	0.000	3.83	8.37	0.85	N/A	100.0
xl_4	62.70	22.84	0.25	0.000	4.24	8.03	0.79	N/A	98.9
xl_5	63.58	22.86	0.21	0.002	4.23	7.93	0.81	N/A	99.6
xl_6	62.84	22.79	0.23	0.000	4.14	8.14	0.79	N/A	98.9
xl_7	63.79	22.55	0.30	0.000	4.12	8.10	0.78	N/A	99.7
MS-15-28									
xl_1a	65.12	22.63	0.24	0.000	3.82	8.37	0.92	0.24	101.3
xl_1b	64.34	22.93	0.26	0.000	4.12	8.18	0.83	0.23	100.9
xl_2a	65.41	22.90	0.20	0.002	3.95	8.32	0.87	0.23	101.9
xl_2b	64.72	22.91	0.22	0.000	3.98	8.06	0.88	0.28	101.1
xl_3a	63.49	23.79	0.29	0.002	4.84	7.87	0.61	0.21	101.1
xl_3b	63.50	23.53	0.26	0.000	4.84	7.58	0.64	0.23	100.6
xl_4a	65.49	23.40	0.29	0.000	4.18	8.23	0.86	0.24	102.7
xl_4b	65.11	23.56	0.28	0.004	4.16	8.35	0.82	0.22	102.5
xl_5a	64.38	22.74	0.20	0.000	3.88	8.12	0.78	0.29	100.4

Table B2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-15-28 cont.									
xl_5b	64.29	22.86	0.29	0.000	4.01	8.08	0.72	0.25	100.5
xl_6a	64.80	23.25	0.21	0.000	4.27	8.34	0.78	0.19	101.8
xl_6b	64.53	22.74	0.21	0.000	4.08	7.91	0.83	0.24	100.5
xl_7a	64.38	23.65	0.24	0.000	4.41	8.27	0.69	0.23	101.9
xl_7b	62.80	24.38	0.32	0.000	5.34	7.64	0.57	0.16	101.2
xl_8a	63.73	23.73	0.17	0.000	4.20	8.27	0.79	0.21	101.1
xl_8b	63.89	23.02	0.23	0.001	4.09	8.27	0.89	0.21	100.6
xl_9a	63.68	23.08	0.27	0.000	4.13	8.36	0.82	0.23	100.6
xl_9b	63.99	23.31	0.25	0.000	4.00	8.49	0.86	0.22	101.1
xl_10a	64.48	23.07	0.25	0.001	3.95	8.09	0.85	0.26	101.0
xl_10b	64.45	22.87	0.17	0.000	3.85	8.11	0.86	0.30	100.6
MS-15-28.1b									
xl_5a	62.61	23.46	0.30	0.003	4.71	8.19	0.89	0.24	100.4
xl_5b	64.11	22.67	0.33	0.006	3.85	7.93	1.04	0.26	100.2
MS-15-12.4									
xl_7a	64.09	22.99	0.22	0.000	4.11	8.46	0.89	0.27	101.0
xl_7b	64.97	23.13	0.17	0.008	4.08	8.16	0.85	0.23	101.6
xl_9a	64.49	22.93	0.24	0.000	3.95	8.46	0.83	0.22	101.1
xl_9b	63.97	22.94	0.27	0.004	3.97	8.49	0.83	0.24	100.7
MS-15-12.3									
xl_2a	63.97	22.50	0.22	0.000	3.49	8.41	0.99	0.31	99.9
xl_2b	65.22	22.85	0.19	0.005	3.66	8.64	0.86	0.26	101.7
xl_3a	63.72	23.02	0.22	0.000	3.94	8.10	0.82	0.24	100.1
xl_3b	63.76	22.48	0.29	0.000	3.92	8.30	0.86	0.22	99.8
xl_4a	63.87	22.67	0.23	0.000	3.91	8.34	0.90	0.24	100.2
xl_4b	63.61	23.04	0.28	0.000	4.10	8.31	0.81	0.21	100.4
xl_5a	64.10	23.29	0.23	0.000	4.19	8.42	0.87	0.23	101.3
xl_5b	63.94	22.86	0.21	0.000	3.93	8.24	0.84	0.22	100.3
xl_6a	64.86	22.52	0.16	0.000	3.58	8.50	0.92	0.36	100.9
xl_6b	63.32	22.58	0.21	0.000	3.87	8.05	0.86	0.24	99.1
xl_8a	64.08	22.70	0.18	0.000	3.90	8.37	0.86	0.22	100.3
xl_8b	64.21	22.71	0.23	0.000	3.99	8.31	0.86	0.23	100.5
xl_9a	63.92	22.81	0.26	0.000	4.05	8.38	0.89	0.27	100.6
xl_9b	63.90	22.65	0.26	0.004	3.73	8.51	0.87	0.22	100.1
xl_10a	63.88	22.61	0.25	0.006	3.83	8.31	0.87	0.23	100.0
xl_10b	64.45	22.81	0.25	0.000	3.95	8.57	0.89	0.23	101.1

Table B2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-15-8.2									
xl_1a	62.85	22.61	0.27	0.000	3.64	8.44	0.91	0.32	99.0
xl_1b	62.24	22.62	0.25	0.000	3.56	8.32	0.90	0.24	98.1
xl_2a	61.96	22.75	0.23	0.006	4.17	8.15	0.79	0.22	98.3
xl_2b	62.67	23.22	0.24	0.000	3.99	8.28	0.87	0.24	99.5
xl_4a	62.34	22.85	0.24	0.000	3.95	8.19	0.80	0.17	98.5
xl_4b	62.47	22.19	0.24	0.000	3.63	8.18	0.89	0.25	97.9
xl_5a	62.13	22.90	0.24	0.001	3.85	8.34	0.85	0.22	98.5
xl_5b	62.54	22.73	0.21	0.000	4.12	7.96	0.80	0.18	98.5
xl_6a	64.46	22.39	0.25	0.000	3.67	8.52	0.87	0.25	100.4
xl_6b	62.05	22.44	0.21	0.000	3.90	8.12	0.80	0.21	97.7
xl_7a	61.80	22.24	0.17	0.000	3.90	8.02	0.86	0.22	97.2
xl_7b	60.43	22.49	0.26	0.000	4.07	7.80	0.77	0.21	96.0
MS-15-12.5									
xl_4Ka	64.54	22.96	0.24	0.000	3.81	8.71	0.92	0.22	101.4
xl_4Kb	63.73	22.90	0.23	0.000	3.96	8.73	0.86	0.22	100.6
xl_4Kc	64.14	22.69	0.23	0.000	3.51	8.84	0.91	0.31	100.6
xl_8Ja	63.71	23.25	0.20	0.000	4.02	8.46	0.84	0.28	100.8
xl_8Jb	63.12	22.46	0.24	0.000	4.18	8.12	0.85	0.27	99.2
xl_9Ja	63.64	22.67	0.21	0.000	4.08	8.26	0.90	0.24	100.0
xl_9Jb	64.83	22.30	0.24	0.000	3.30	8.65	0.96	0.33	100.6
** Letters following crystal number indicate multiple analysis points per crystal.									
1. Normalized values.									

Table B3. Unit 2 individual feldspar crystal end member compositions.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-15-7b ¹			
xl_1a	19.04	76.25	4.72
xl_1b	19.41	76.15	4.45
xl_2a	19.08	76.52	4.40
xl_2b	19.56	75.51	4.94
xl_3a	19.25	75.87	4.89
xl_3b	20.17	75.52	4.32
xl_4a	18.58	76.42	5.01
xl_4b	18.80	76.30	4.90
xl_5a	17.48	77.35	5.17
xl_5b	19.50	75.46	5.05
xl_6a	19.51	75.66	4.83
xl_6b	20.21	74.95	4.85
xl_7a	18.86	76.32	4.82
xl_7b	18.94	76.52	4.55
MS-15-12			
xl_1	21.29	73.91	4.80
MS-10-20			
xl_2a	21.56	73.71	4.73
xl_2b	22.66	72.58	4.76
MS-15-21a			
xl_1	22.15	73.15	4.70
xl_2	18.56	76.42	5.02
xl_3	19.23	75.69	5.08
xl_4	21.57	73.64	4.79
xl_5	21.69	73.35	4.97
xl_6	20.96	74.26	4.78
xl_7	20.96	74.29	4.76
MS-15-28			
xl_1a	19.09	75.42	5.49
xl_1b	20.77	74.27	4.97
xl_2a	19.79	75.03	5.19
xl_2b	20.36	74.28	5.37
xl_3a	24.51	71.82	3.68
xl_3b	25.10	70.93	3.97
xl_4a	20.85	74.05	5.10
xl_4b	20.60	74.57	4.83
xl_5a	19.96	75.29	4.76
xl_5b	20.61	74.94	4.45

Table B3 continued.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-15-28 cont.			
xl_6a	21.10	74.32	4.58
xl_6b	21.13	73.77	5.11
xl_7a	21.89	74.01	4.10
xl_7b	26.97	69.57	3.46
xl_8a	20.96	74.34	4.70
xl_8b	20.41	74.32	5.27
xl_9a	20.45	74.72	4.83
xl_9b	19.65	75.28	5.07
xl_10a	20.21	74.58	5.21
xl_10b	19.75	74.97	5.29
MS-15-28.1b			
xl_5a	22.92	71.91	5.18
xl_5b	19.86	73.73	6.42
MS-15-12.4			
xl_7a	20.13	74.71	5.17
xl_7b	20.63	74.26	5.12
xl_9a	19.55	75.54	4.92
xl_9b	19.59	75.50	4.91
MS-15-12.3			
xl_2a	17.60	76.43	5.97
xl_2b	18.06	76.87	5.07
xl_3a	20.17	74.80	5.03
xl_3b	19.68	75.20	5.12
xl_4a	19.54	75.12	5.35
xl_4b	20.45	74.72	4.83
xl_5a	20.53	74.42	5.06
xl_5b	19.87	75.05	5.08
xl_6a	17.92	76.59	5.49
xl_6b	19.94	74.80	5.27
xl_8a	19.48	75.40	5.12
xl_8b	19.95	74.95	5.11
xl_9a	20.04	74.69	5.27
xl_9b	18.54	76.31	5.15
xl_10a	19.30	75.48	5.23
xl_10b	19.29	75.51	5.20
MS-15-18.2			
xl_1a	18.24	76.30	5.47
xl_1b	18.15	76.41	5.44
xl_2a	21.05	74.17	4.78

Table B3 continued.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-15-18.2 cont.			
xl_2b	19.98	74.82	5.21
xl_4a	20.09	75.04	4.88
xl_4b	18.67	75.86	5.48
xl_5a	19.32	75.58	5.10
xl_5b	21.19	73.88	4.93
xl_6a	18.29	76.52	5.20
xl_6b	20.03	75.07	4.90
xl_7a	20.13	74.60	5.28
xl_7b	21.34	73.81	4.85
MS-15-12.5			
xl_4Ka	18.50	76.19	5.31
xl_4Kb	19.09	75.98	4.93
xl_4Kc	17.11	77.61	5.28
xl_8Ja	19.81	75.24	4.95
xl_8Jb	21.07	73.85	5.08
xl_9Ja	20.37	74.27	5.36
xl_9Jb	16.46	77.83	5.72
** Letters following crystal number indicate multiple analysis points per crystal.			
1. Normalized values			
2. $An = (CaO \cdot 0.714/40)/(CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$			
3. $Ab = (Na_2O \cdot 0.74/23)/(CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$			
4. $Or = (K_2O \cdot 0.83/39)/(CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$			

APPENDIX C: UNIT 3 CHEMICAL DATA, STANDARD DEVIATIONS AND GPS COORDINATES

Table C1. Unit 3 average feldspar end member component composition and GPS coordinates by sample.

Sample	Number of Crystals	An	Ab	Or	An Std.	Al Std.	Or Std.	Latitude	Longitude
MS-12-33.1	12	4.2	78.7	17.1	1.1	0.7	1.3	44.0402	-117.5092
EBC-12-074	10	4.4	79.1	16.6	0.9	0.8	1.0	44.6639	-118.4302
MS-14-12	10	3.9	79.1	17.0	0.5	0.4	0.7	44.5066	-117.8920
MS-13-08	10	4.0	73.3	22.7	1.0	0.9	1.7	43.4379	-118.5243
MS-10-26	1	3.5	72.0	24.4	N/A	N/A	N/A	43.9226	-118.9579
MS-10-25	7	4.9	75.1	20.1	0.3	1.5	1.6	43.9025	-119.0301
PFC-1513	10	4.4	78.4	17.2	0.5	0.4	0.6	43.9985	-118.8488

Table C2. Unit 3 EMP major element feldspar chemical composition by sample.

Sample and crystal number**	SiO ₂	Al ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	BaO	Total
MS-12-33.1-C									
xl_2	67.65	21.11	0.28	0.000	0.91	8.82	2.69	0.98	102.5
xl_6	67.01	20.57	0.21	0.000	0.94	8.69	2.84	0.98	101.2
MS-12-33.1-H									
xl_1a	68.49	20.12	0.19	0.000	0.71	8.56	2.89	0.88	101.8
xl_1b	68.47	20.11	0.19	0.009	0.73	8.62	3.08	0.93	102.1
xl_2a	69.75	19.57	0.29	0.000	0.37	8.71	3.26	0.51	102.5
xl_2b	68.58	20.10	0.27	0.000	0.65	8.73	2.69	0.49	101.5
xl_3a	67.28	20.85	0.19	0.000	1.52	8.68	2.23	1.01	101.8
xl_3b	68.65	20.55	0.24	0.000	0.87	8.75	2.69	0.92	102.7
xl_4a	68.21	20.41	0.23	0.001	0.70	8.60	2.96	1.06	102.2
xl_4b	67.99	20.19	0.20	0.000	0.78	8.35	3.03	1.04	101.6
xl_5a	66.50	20.20	0.21	0.000	1.04	8.28	2.50	1.02	99.8
xl_5b	67.93	20.27	0.26	0.000	0.91	8.58	2.67	0.99	101.6
xl_6a	69.02	20.32	0.27	0.005	0.75	8.75	2.89	0.98	103.0
xl_6b	68.35	20.16	0.24	0.000	0.65	8.54	3.03	1.01	102.0
xl_8a	68.46	20.42	0.28	0.000	0.90	8.46	2.90	1.08	102.5
xl_8b	66.87	20.46	0.23	0.007	0.92	8.39	2.80	0.96	100.6
xl_9a	67.11	20.28	0.23	0.000	0.86	8.48	2.69	1.02	100.7
xl_9b	66.84	20.16	0.20	0.000	0.87	8.57	2.84	0.95	100.4
xl_10a	67.91	20.29	0.28	0.000	0.73	8.51	3.08	1.11	101.9
xl_10b	68.58	20.16	0.24	0.001	0.67	8.83	3.06	1.05	102.6
EBC12-074									
xl_1a	62.74	20.02	0.26	0.014	0.91	8.35	2.57	0.87	95.7
xl_1b	61.95	19.70	0.26	0.000	0.91	8.09	2.61	0.94	94.4
xl_2a	61.46	19.97	0.23	0.000	0.93	8.49	2.61	0.90	94.6
xl_2b	62.69	19.81	0.20	0.000	0.82	8.62	2.54	0.77	95.5
xl_3a	61.39	19.95	0.21	0.005	0.92	8.20	2.67	0.95	94.3
xl_3b	61.87	20.07	0.22	0.000	0.74	8.30	2.74	0.74	94.7
xl_4a	62.20	20.05	0.24	0.002	0.93	8.39	2.66	0.89	95.4
xl_4b	61.05	19.60	0.19	0.000	0.89	8.64	2.73	0.95	94.1
xl_5a	62.60	19.85	0.22	0.000	0.83	8.38	2.69	0.94	95.5
xl_5b	62.63	19.89	0.24	0.000	0.91	8.57	2.71	0.88	95.8
xl_6a	61.65	19.58	0.22	0.001	0.76	8.26	2.78	0.88	94.1
xl_6b	61.93	20.11	0.18	0.000	0.82	8.25	2.73	0.91	94.9
xl_7a	62.54	19.38	0.24	0.002	0.51	8.55	2.86	0.76	94.8
xl_7b	62.14	19.19	0.26	0.005	0.47	8.54	2.45	0.69	93.7
xl_8a	63.06	20.11	0.18	0.000	1.09	8.36	2.43	1.18	96.4

Table C2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
<hr/>									
EBC12-074 cont.									
xl_8b	61.96	19.86	0.20	0.000	1.09	8.18	2.28	1.11	94.7
xl_9a	62.29	19.97	0.17	0.000	0.99	8.43	2.60	0.91	95.4
xl_9b	62.47	19.90	0.26	0.005	0.93	8.59	2.64	0.92	95.7
xl_10a	61.98	19.92	0.23	0.000	0.76	8.28	2.80	0.88	94.8
xl_10b	61.78	19.58	0.26	0.000	0.52	8.24	3.02	1.11	94.5
<hr/>									
MS-14-12									
xl_1a	66.86	20.36	0.22	0.000	0.68	8.76	2.93	1.15	101.0
xl_1b	66.18	20.30	0.23	0.001	0.65	8.70	3.04	1.17	100.3
xl_2a	66.66	20.59	0.14	0.001	0.84	9.03	2.91	0.99	101.2
xl_2b	66.99	20.85	0.17	0.003	0.87	9.05	2.78	1.00	101.7
xl_3a	67.86	20.49	0.25	0.000	0.62	8.89	3.09	0.90	102.1
xl_3b	66.52	20.23	0.22	0.000	0.74	8.67	2.89	1.02	100.3
xl_4a	67.90	20.67	0.25	0.000	0.79	9.06	2.90	0.99	102.6
xl_4b	67.38	20.51	0.26	0.000	0.81	8.81	2.95	0.91	101.6
xl_5a	67.17	20.19	0.24	0.000	0.64	9.06	2.93	0.94	101.2
xl_5b	67.08	20.04	0.26	0.004	0.63	8.80	3.03	0.87	100.7
xl_6a	68.13	20.66	0.25	0.000	0.83	8.75	2.94	0.99	102.5
xl_6b	68.13	20.83	0.21	0.000	0.70	9.05	2.97	0.99	102.9
xl_7a	67.52	20.74	0.23	0.000	0.85	8.94	2.81	0.98	102.1
xl_7b	67.59	20.68	0.19	0.000	0.78	8.73	2.89	0.96	101.8
xl_8a	67.14	20.77	0.19	0.000	0.88	8.91	2.81	1.00	101.7
xl_8b	67.52	20.52	0.16	0.000	0.92	8.90	2.79	1.00	101.8
xl_9a	66.53	20.71	0.22	0.000	1.01	8.95	2.70	0.99	101.1
xl_9b	66.00	20.61	0.17	0.006	0.89	8.96	2.79	0.96	100.4
xl_10a	67.92	20.76	0.22	0.000	0.90	9.26	2.70	0.93	102.7
xl_10b	66.55	20.38	0.19	0.000	0.85	8.83	2.89	0.94	100.6
<hr/>									
MS-13-08									
xl_1a	65.87	19.92	0.24	0.001	0.79	7.88	4.03	0.66	99.4
xl_1b	66.48	19.85	0.29	0.001	0.70	8.13	4.00	0.66	100.1
xl_2a	66.28	19.74	0.34	0.000	0.66	8.06	3.95	0.45	99.5
xl_2b	66.69	19.88	0.32	0.000	0.65	8.33	4.08	0.45	100.4
xl_2c	66.01	19.61	0.27	0.004	0.65	8.17	3.90	0.50	99.1
xl_3a	66.14	19.76	0.24	0.000	0.80	7.98	3.80	0.62	99.3
xl_3b	65.98	20.31	0.27	0.000	0.82	8.10	3.80	0.61	99.9
xl_3c	66.66	19.95	0.32	0.002	0.70	8.18	3.95	0.52	100.3
xl_4a	65.67	20.26	0.23	0.000	1.25	8.10	3.20	0.76	99.5
xl_4b	65.98	20.42	0.31	0.001	1.21	8.40	3.16	0.71	100.2

Table C2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-13-08 cont.									
xl_4c	65.66	20.47	0.24	0.000	1.24	8.05	3.11	0.71	99.5
xl_5a	67.14	19.93	0.23	0.000	0.76	8.23	4.05	0.57	100.9
xl_5b	66.82	19.73	0.38	0.000	0.70	8.01	3.89	0.46	100.0
xl_5c	66.86	19.84	0.31	0.000	0.65	7.91	3.99	0.45	100.0
xl_6a	66.87	19.91	0.28	0.000	0.59	8.01	4.08	0.45	100.2
xl_6b	66.81	20.11	0.30	0.000	0.66	8.39	3.98	0.52	100.8
xl_6c	67.23	20.04	0.20	0.000	0.79	8.14	3.95	0.55	100.9
xl_7a	65.89	20.07	0.24	0.000	1.13	8.10	3.19	0.58	99.2
xl_7b	66.50	20.05	0.25	0.000	0.95	8.20	3.46	0.50	99.9
xl_7c	67.14	20.36	0.29	0.000	0.93	8.20	3.54	0.63	101.1
xl_8a	66.60	19.76	0.28	0.000	0.67	8.26	3.89	0.45	99.9
xl_8b	67.57	19.80	0.29	0.000	0.71	8.57	3.91	0.45	101.3
xl_8c	67.38	19.86	0.25	0.000	0.69	8.28	3.88	0.46	100.8
xl_9a	66.94	20.18	0.25	0.000	0.85	7.90	3.82	0.68	100.6
xl_9b	66.62	20.17	0.19	0.000	0.84	8.16	3.77	0.65	100.4
xl_9c	66.04	20.07	0.26	0.000	0.87	7.95	3.84	0.57	99.6
xl_10a	67.23	20.14	0.31	0.000	0.69	8.03	3.97	0.54	100.9
xl_10b	67.02	20.16	0.32	0.000	0.69	7.94	4.04	0.55	100.7
xl_10c	67.53	19.97	0.28	0.000	0.70	8.16	4.15	0.53	101.3
MS-10-26									
xl_2	65.88	20.07	0.24	0.002	0.69	7.78	3.99	N/A	98.7
MS-10-25									
xl_1	67.70	20.54	0.24	0.000	0.83	7.97	2.91	N/A	100.2
xl_2	68.51	20.36	0.17	0.000	0.95	8.57	2.84	N/A	101.4
xl_3	67.59	20.34	0.27	0.000	0.82	7.91	3.00	N/A	99.9
xl_4	68.68	20.38	0.21	0.000	0.91	8.84	2.79	N/A	101.8
xl_5	67.98	20.07	0.24	0.000	0.70	7.04	2.98	N/A	99.0
xl_6	69.35	20.19	0.27	0.000	0.77	8.81	2.84	N/A	102.2
xl_7	67.79	20.62	0.24	0.000	0.90	8.07	2.87	N/A	100.5
PFC-1513									
xl_1a	62.67	20.12	0.26	0.004	0.89	8.47	2.78	0.97	96.2
xl_1b	61.81	19.86	0.19	0.000	0.89	8.18	2.69	0.87	94.5
xl_2a	62.35	20.13	0.23	0.002	0.86	8.44	2.84	0.98	95.8
xl_2b	62.67	20.23	0.27	0.000	0.75	8.39	2.77	0.96	96.0
xl_3a	63.34	20.26	0.27	0.000	0.89	8.50	2.62	0.89	96.8
xl_3b	63.01	19.91	0.23	0.009	0.86	8.31	2.75	0.88	96.0
xl_4a	64.02	20.38	0.27	0.000	0.87	8.48	2.70	0.86	97.6

Table C2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
PFC-1513 cont.									
xl_4b	64.60	20.52	0.17	0.000	1.01	8.54	2.63	0.97	98.4
xl_5a	63.68	20.18	0.19	0.000	0.73	8.40	2.92	1.02	97.1
xl_5b	63.19	20.17	0.24	0.000	0.89	8.38	2.81	1.01	96.7
xl_6a	63.97	20.03	0.36	0.004	0.66	8.31	2.92	0.97	97.2
xl_6b	64.15	20.00	0.24	0.000	0.73	8.51	2.86	0.95	97.5
xl_7a	63.69	20.25	0.24	0.004	0.95	8.20	2.76	0.92	97.0
xl_7b	64.54	20.13	0.18	0.000	0.80	8.35	2.90	0.87	97.8
xl_8a	64.55	20.28	0.18	0.000	0.93	8.48	2.76	0.92	98.1
xl_8b	62.92	19.41	0.27	0.000	0.72	8.28	2.88	0.77	95.2
xl_9a	64.76	19.96	0.20	0.000	0.86	8.49	2.79	0.84	97.9
xl_9b	63.91	20.36	0.18	0.000	0.88	8.52	2.76	0.92	97.5
xl_10a	63.90	20.06	0.28	0.000	0.91	8.25	2.78	1.05	97.2
xl_10b	63.78	20.28	0.21	0.000	0.90	8.34	2.76	1.02	97.3
** Letters following crystal number indicate multiple analysis points per crystal.									
1. Normalized values.									

Table C3. Unit 3 end member composition by sample.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-12-33.1-a			
xl_2	4.56	79.41	16.04
xl_6	4.70	78.37	16.95
MS-12-33.1-b			
xl_1a	3.65	78.77	17.60
xl_1b	3.66	77.92	18.44
xl_2a	1.85	78.70	19.46
xl_2b	3.33	80.31	16.38
xl_3a	7.65	78.96	13.41
xl_3b	4.39	79.46	16.16
xl_4a	3.54	78.60	17.88
xl_4b	4.02	77.43	18.58
xl_5a	5.49	78.81	15.72
xl_5b	4.63	79.10	16.28
xl_6a	3.77	79.00	17.25
xl_6b	3.32	78.31	18.38
xl_8a	4.58	77.81	17.62
xl_8b	4.76	78.02	17.24
xl_9a	4.44	79.01	16.56
xl_9b	4.42	78.42	17.18
xl_10a	3.72	77.73	18.57
xl_10b	3.31	78.70	18.01
EBC12-074			
xl_1a	4.79	79.13	16.10
xl_1b	4.90	78.41	16.71
xl_2a	4.80	79.15	16.07
xl_2b	4.22	80.15	15.64
xl_3a	4.89	78.30	16.83
xl_3b	3.88	78.91	17.22
xl_4a	4.85	78.66	16.50
xl_4b	4.53	78.98	16.51
xl_5a	4.31	78.93	16.77
xl_5b	4.67	78.86	16.49
xl_6a	4.02	78.55	17.45
xl_6b	4.31	78.52	17.18
xl_7a	2.65	79.73	17.63
xl_7b	2.52	81.95	15.55
xl_8a	5.74	79.10	15.17
xl_8b	5.87	79.49	14.66
xl_9a	5.13	78.78	16.10

Table C3 continued.

Sample and crystal number**	An²	Ab³	Or⁴
EBC12-074 cont.			
xl_9b	4.78	79.15	16.09
xl_10a	4.00	78.47	17.55
xl_10b	2.74	78.31	18.97
MS-14-12			
xl_1a	3.42	79.11	17.49
xl_1b	3.28	78.56	18.18
xl_2a	4.10	79.08	16.84
xl_2b	4.25	79.58	16.18
xl_3a	3.03	78.88	18.11
xl_3b	3.76	78.85	17.41
xl_4a	3.83	79.36	16.83
xl_4b	4.01	78.63	17.38
xl_5a	3.12	79.82	17.08
xl_5b	3.11	78.91	17.99
xl_6a	4.11	78.48	17.43
xl_6b	3.42	79.38	17.21
xl_7a	4.18	79.32	16.51
xl_7b	3.92	78.82	17.28
xl_8a	4.34	79.16	16.51
xl_8b	4.51	79.10	16.41
xl_9a	4.94	79.26	15.81
xl_9b	4.35	79.33	16.33
xl_10a	4.31	80.24	15.46
xl_10b	4.20	78.77	17.05
MS-13-08			
xl_1a	3.98	71.76	24.28
xl_1b	3.48	72.85	23.69
xl_2a	3.31	73.04	23.67
xl_2b	3.17	73.17	23.68
xl_2c	3.25	73.53	23.24
xl_3a	4.05	72.98	22.99
xl_3b	4.11	73.20	22.71
xl_3c	3.49	73.16	23.37
xl_4a	6.35	74.29	19.38
xl_4b	6.02	75.27	18.73
xl_4c	6.35	74.62	19.06
xl_5a	3.71	72.69	23.62
xl_5b	3.56	73.02	23.44
xl_5c	3.33	72.51	24.18

Table C3 continued.

Sample and crystal number**	An²	Ab³	Or⁴
MS-13-08 cont.			
xl_6a	2.95	72.62	24.45
xl_6b	3.23	73.69	23.10
xl_6c	3.89	72.76	23.37
xl_7a	5.81	74.76	19.45
xl_7b	4.80	74.45	20.77
xl_7c	4.65	74.21	21.17
xl_8a	3.30	73.76	22.97
xl_8b	3.41	74.20	22.41
xl_8c	3.39	73.79	22.84
xl_9a	4.34	72.48	23.21
xl_9b	4.18	73.41	22.43
xl_9c	4.41	72.46	23.16
xl_10a	3.46	72.78	23.78
xl_10b	3.48	72.26	24.29
xl_10c	3.43	72.29	24.30
MS-10-26			
xl_2	3.54	72.05	24.44
MS-10-25			
xl_1	4.46	76.98	18.58
xl_2	4.80	78.10	17.12
xl_3	4.38	76.43	19.21
xl_4	4.49	79.04	16.49
xl_5	4.15	74.93	20.94
xl_6	3.84	79.26	16.92
xl_7	4.76	77.13	18.13
PFC-1513			
xl_1a	4.55	78.43	17.04
xl_1b	4.73	78.28	17.01
xl_2a	4.43	78.19	17.39
xl_2b	3.89	78.92	17.21
xl_3a	4.60	79.29	16.13
xl_3b	4.52	78.35	17.15
xl_4a	4.47	78.95	16.59
xl_4b	5.15	78.80	16.06
xl_5a	3.78	78.26	17.98
xl_5b	4.61	78.11	17.29
xl_6a	3.43	78.35	18.23
xl_6b	3.74	78.75	17.52
xl_7a	4.99	77.72	17.31

Table C3 continued.

Sample and crystal number**	An²	Ab³	Or⁴
PFC-1513 cont.			
xl_7b	4.12	78.01	17.88
xl_8a	4.76	78.38	16.88
xl_8b	3.76	78.24	18.02
xl_9a	4.42	78.53	17.06
xl_9b	4.53	78.64	16.84
xl_10a	4.76	77.90	17.35
xl_10b	4.70	78.19	17.12

** Letters following crystal number indicate multiple analysis points per crystal.

1. Normalized values

2. $An = (CaO \cdot 0.714/40)/(CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$

3. $Ab = (Na_2O \cdot 0.74/23)/(CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$

4. $Or = (K_2O \cdot 0.83/39)/(CaO \cdot 0.714/40 + Na_2O \cdot 0.74/23 + K_2O \cdot 0.83/39) \cdot 100$

APPENDIX D: UNIT 4 CHEMICAL DATA, STANDARD DEVIATIONS AND GPS COORDINATES

Table D1. Average feldspar end member component composition and GPS coordinates by sample.

Sample	Number of Crystals	An	Ab	Or	An Std.	Al Std.	Or Std.	Latitude	Longitude
MS-12-20	7	3.9	78.8	17.3	0.7	0.6	0.4	44.4843	-118.0869
MS-15-18-2T	3	5.6	72.8	21.6	0.2	0.9	0.7	43.6988	-118.8014
MS-15-7c	2	3.0	70.3	26.7	0.1	2.2	2.3	43.7241	-118.8013
DIT@Craft Point	10	4.2	78.1	17.7	0.3	2.1	2.0	43.7883	-118.7550
MS-15-20a	10	4.0	77.3	18.7	0.7	0.6	0.4	43.7799	-118.0233

Table D2. Unit 4 EMP major element feldspar chemical data by sample.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
MS-12-20									
xl_1a	68.05	20.79	0.21	0.008	0.76	8.73	2.94	1.04	102.5
xl_1b	68.26	20.62	0.22	0.000	0.64	8.68	2.96	1.02	102.4
xl_2a	67.53	20.49	0.20	0.002	0.88	8.65	2.75	0.96	101.5
xl_2b	67.84	20.36	0.20	0.006	0.87	8.69	2.82	1.01	101.8
xl_3a	67.78	20.81	0.20	0.000	0.96	8.76	2.95	1.14	102.6
xl_3b	67.27	20.25	0.17	0.000	0.82	8.62	2.86	1.07	101.1
xl_5a	68.98	20.87	0.21	0.008	0.88	8.72	2.78	0.95	103.4
xl_5b	70.73	20.20	0.22	0.002	0.54	9.00	2.92	0.80	104.4
xl_6a	69.06	20.66	0.20	0.001	0.88	8.57	2.83	1.03	103.2
xl_6b	68.79	20.10	0.23	0.004	0.65	8.59	2.93	0.92	102.2
xl_7a	69.47	20.36	0.16	0.000	0.62	8.69	2.97	0.84	103.1
xl_7b	68.43	20.55	0.22	0.000	0.86	8.44	2.91	1.09	102.5
MS-15-18-2T									
xl_3	68.01	20.29	0.27	0.000	0.87	8.77	2.82	N/A	101.0
xl_6	66.68	20.41	0.21	0.000	0.87	7.94	2.82	N/A	98.9
xl_7	67.88	20.64	0.21	0.000	0.89	8.51	2.87	N/A	101.0
MS-15-7c									
xl_2	67.56	19.78	0.18	0.001	0.58	7.61	4.01	N/A	99.7
xl_5	68.01	19.58	0.20	0.006	0.58	7.44	4.63	N/A	100.5
DIT@Craft Point									
xl_1a	66.16	20.43	0.16	0.000	0.90	8.41	2.78	1.04	99.9
xl_1b	66.73	20.32	0.21	0.004	0.87	8.56	2.78	1.03	100.5
xl_2a	67.32	20.56	0.21	0.000	0.92	8.54	2.84	1.05	101.5
xl_2b	66.94	20.61	0.23	0.000	0.81	8.61	2.90	1.09	101.2
xl_3a	66.04	20.61	0.18	0.000	0.81	8.54	2.87	1.11	100.2
xl_3b	67.56	20.45	0.21	0.000	0.78	8.49	2.91	1.04	101.4
xl_4a	65.32	20.34	0.17	0.004	0.87	8.40	2.78	1.10	99.0
xl_4b	66.18	20.65	0.21	0.001	0.95	8.56	2.67	0.95	100.2
xl_5a	65.72	20.67	0.19	0.000	0.81	8.61	2.95	1.10	100.0
xl_5b	66.83	20.29	0.22	0.000	0.80	8.63	2.96	1.16	100.9
xl_6a	67.49	20.76	0.23	0.003	0.89	8.57	2.75	0.96	101.7
xl_6b	67.35	20.64	0.20	0.000	0.91	8.73	2.83	0.94	101.6
xl_7a	67.76	20.62	0.20	0.000	0.74	8.66	2.98	1.04	102.0
xl_7b	66.25	20.39	0.27	0.001	0.92	7.47	4.26	1.00	100.6
xl_8a	66.86	20.42	0.23	0.000	0.75	8.85	2.76	0.89	100.8
xl_8b	66.16	20.51	0.17	0.000	0.82	8.57	2.87	1.02	100.1
xl_9a	66.51	20.19	0.19	0.000	0.77	8.44	2.98	1.04	100.1

Table D2 continued.

Sample and crystal number**	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
DIT@Craft									
Point cont.									
xl_9b	66.95	20.22	0.24	0.000	0.80	8.67	2.89	1.11	100.9
xl_10a	68.62	20.27	0.18	0.001	0.82	8.85	2.84	1.01	102.6
xl_10b	67.11	20.66	0.13	0.000	0.77	8.56	2.88	1.03	101.2
MS-15-20a									
xl_1a	67.24	20.36	0.22	0.000	0.82	8.54	3.23	1.11	101.5
xl_1b	66.79	20.43	0.26	0.000	0.84	8.55	3.49	1.09	101.4
xl_2a	67.26	20.63	0.23	0.000	0.91	8.93	2.88	0.96	101.8
xl_2b	67.57	20.75	0.16	0.000	0.91	8.86	2.74	1.02	102.0
xl_3a	66.87	20.92	0.29	0.000	1.01	8.90	2.70	1.03	100.0
xl_3b	65.91	20.36	0.22	0.000	0.95	8.78	2.80	0.94	101.4
xl_4a	67.16	20.49	0.15	0.000	0.95	8.84	2.75	1.01	101.0
xl_4b	66.50	20.82	0.20	0.000	0.96	8.79	2.72	1.01	101.2
xl_5a	67.36	20.38	0.26	0.000	0.79	8.63	2.92	0.84	103.1
xl_5b	68.14	20.84	0.24	0.000	0.83	9.27	2.95	0.88	101.2
xl_6a	66.79	20.54	0.21	0.006	0.85	9.01	2.81	0.94	101.0
xl_6b	66.58	20.83	0.24	0.000	0.94	8.69	2.74	0.99	101.2
xl_7a	67.41	19.78	0.26	0.000	0.14	8.10	5.11	0.39	100.9
xl_7b	67.17	19.83	0.25	0.000	0.19	8.09	5.02	0.34	101.4
xl_8a	66.25	20.16	0.23	0.000	1.03	8.32	2.69	1.04	99.7
xl_8b	66.92	20.89	0.22	0.000	0.99	8.67	2.69	0.99	101.4
xl_9a	67.13	20.43	0.27	0.000	0.86	8.49	3.48	0.93	101.6
xl_9b	67.07	20.50	0.25	0.000	0.87	8.25	3.82	0.91	101.7
xl_10a	66.83	20.28	0.26	0.000	0.61	8.81	2.95	1.00	100.7
xl_10b	66.32	20.28	0.26	0.000	0.72	8.94	3.08	1.04	100.6

** Letters following crystal number indicate multiple analysis points per crystal.
1. Normalized values.

Table D3. Unit 4 end member compositions by sample.

Sample and crystal number**	An ²	Ab ³	Or ⁴
MS-12-20			
xl_1a	3.82	78.70	17.50
xl_1b	3.25	78.94	17.82
xl_2a	4.47	78.95	16.59
xl_2b	4.39	78.74	16.89
xl_3a	4.73	77.93	17.36
xl_3b	4.16	78.59	17.27
xl_5a	4.44	78.91	16.66
xl_5b	2.65	80.15	17.21
xl_6a	4.47	78.40	17.14
xl_6b	3.32	78.91	17.79
xl_7a	3.15	78.98	17.89
xl_7b	4.42	77.87	17.72
MS-15-18-2T			
xl_3	4.33	78.92	16.76
xl_6	4.71	77.20	18.11
xl_7	4.51	78.10	17.41
MS-15-7c			
xl_2	3.04	71.94	25.04
xl_5	2.96	68.77	28.29
DIT@Craft Point			
xl_1a	4.63	78.26	17.12
xl_1b	4.45	78.66	16.91
xl_2a	4.67	78.16	17.19
xl_2b	4.12	78.41	17.49
xl_3a	4.11	78.47	17.44
xl_3b	3.97	78.28	17.76
xl_4a	4.50	78.34	17.17
xl_4b	4.87	78.87	16.27
xl_5a	4.08	78.24	17.70
xl_5b	4.01	78.26	17.75
xl_6a	4.55	78.78	16.69
xl_6b	4.53	78.65	16.84
xl_7a	3.70	78.49	17.83
xl_7b	4.75	69.18	26.09
xl_8a	3.78	79.77	16.47
xl_8b	4.17	78.47	17.38
xl_9a	3.97	77.89	18.16
xl_9b	4.00	78.67	17.34

Table D3 continued.

Sample and crystal number**	An ²	Ab ³	Or ⁴
DIT@Craft Point cont.			
xl_10a	4.07	79.13	16.82
xl_10b	3.94	78.57	17.50
MS-12-20			
xl_1a	4.06	76.75	19.20
xl_1b	4.11	75.53	20.38
xl_2a	4.44	78.76	16.82
xl_2b	4.50	79.32	16.20
xl_3a	4.96	79.19	15.86
xl_3b	4.72	78.71	16.59
xl_4a	4.71	79.03	16.28
xl_4b	4.80	79.06	16.16
xl_5a	3.99	78.47	17.56
xl_5b	3.92	79.39	16.70
xl_6a	4.15	79.49	16.38
xl_6b	4.72	78.84	16.46
xl_7a	0.68	70.09	29.26
xl_7b	0.91	70.30	28.82
xl_8a	5.34	77.98	16.70
xl_8b	5.00	78.87	16.15
xl_9a	4.21	75.40	20.41
xl_9b	4.28	73.29	22.46
xl_10a	3.03	79.41	17.58
xl_10b	3.53	78.59	17.90

** Letters following crystal number indicate multiple analysis points per crystal.

1. Normalized values.

2. $An = (CaO * 0.714 / 40) / (CaO * 0.714 / 40 + Na_2O * 0.74 / 23 + K_2O * 0.83 / 39) * 100$

3. $Ab = (Na_2O * 0.74 / 23) / (CaO * 0.714 / 40 + Na_2O * 0.74 / 23 + K_2O * 0.83 / 39) * 100$

4. $Or = (K_2O * 0.83 / 39) / (CaO * 0.714 / 40 + Na_2O * 0.74 / 23 + K_2O * 0.83 / 39) * 100$

APPENDIX E: NON-UNIT DESIGNATING FELDSPAR CHEMICAL DATA

Table E1. Non-unit designating EMP major element chemical data by feldspar type.

Feldspar type, sample and crystal number**	Sample Unit	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
albite										
MS-12-33.1_xlC1	3	67.28	20.97	0.25	0.005	1.43	9.34	1.57	0.38	101.2
andesine										
MS-10-20_xl1a	2	59.72	26.52	0.30	0.000	7.71	6.84	0.39	0.03	101.5
MS-10-20_xl1b	2	61.50	26.29	0.25	0.000	6.68	7.32	0.46	0.10	102.6
MS-14-20a_xl1a	N/A	57.10	27.65	0.32	0.020	9.22	6.16	0.36	0.06	100.9
MS-14-20a_xl1b	N/A	58.98	25.38	0.28	0.016	7.50	6.96	0.48	0.11	99.7
MS-12-20_xl4a	4	59.72	26.52	0.30	0.000	7.71	6.84	0.39	0.03	101.5
MS-12-20_xl4b	4	61.50	26.29	0.25	0.000	6.68	7.32	0.46	0.10	100.7
MS-15-12_xl2	2	61.29	24.68	0.27	0.006	6.04	7.27	0.67	N/A	100.2
MS-15-12_xl3	2	58.25	26.69	0.20	0.010	7.95	6.41	0.44	N/A	99.9
MS-15-12_xl5	2	56.32	27.74	0.11	0.000	8.76	6.09	0.20	N/A	99.2
MS-15-38_xl5	1	58.64	26.26	0.21	0.001	7.94	6.52	0.31	N/A	99.9
MS-15-12.4_xl1a	2	59.38	25.72	0.23	0.008	7.31	6.53	0.54	0.12	99.8
MS-15-12.4_xl1b	2	59.19	25.96	0.22	0.010	7.80	6.36	0.51	0.08	100.1
MS-15-12.4_xl3a	2	59.87	25.14	0.20	0.001	6.82	6.96	0.62	0.14	99.8
MS-15-12.4_xl3b	2	61.82	24.51	0.25	0.000	5.95	7.18	0.70	0.11	100.5
MS-15-12.4_xl5a	2	63.05	24.13	0.21	0.000	5.44	7.66	0.80	0.20	101.5
MS-15-12.4_xl5b	2	59.88	25.43	0.19	0.000	7.35	6.70	0.57	0.07	100.2
MS-15-12.4_xl6a	2	60.78	24.71	0.17	0.003	6.15	7.22	0.64	0.15	99.8
MS-15-12.4_xl6b	2	61.46	24.16	0.21	0.013	5.49	7.36	0.75	0.10	99.5
MS-15-12.4_xl8a	2	61.12	24.80	0.24	0.007	6.39	6.99	0.58	0.10	100.2
MS-15-12.4_xl8b	2	59.46	25.93	0.22	0.000	7.55	6.42	0.51	0.06	100.2
MS-15-12.4_xl10a	2	58.45	26.05	0.28	0.003	8.34	6.40	0.38	0.06	100.0
MS-15-12.4_xl10b	2	58.04	26.85	0.32	0.003	8.66	6.01	0.40	0.06	100.3
MS-15-12.5_xlJ2a	2	58.14	26.08	0.28	0.013	8.31	6.14	0.43	0.07	99.5
MS-15-12.5_xlJ2b	2	57.64	26.48	0.27	0.000	8.46	6.16	0.39	0.05	99.4
MS-15-12.5_xlJ3a	2	56.92	26.65	0.26	0.000	9.04	5.86	0.33	0.04	99.1
MS-15-12.5_xlJ3b	2	58.25	25.98	0.31	0.001	7.83	6.24	0.44	0.04	99.1
MS-15-12.5_xlJ5a	2	62.68	23.88	0.19	0.003	5.76	7.31	0.76	0.13	100.7
MS-15-12.5_xlJ5b	2	61.35	25.18	0.25	0.008	6.60	7.05	0.56	0.08	101.1
MS-15-12.5_xlJ6a	2	60.24	24.50	0.23	0.001	6.48	6.89	0.65	0.09	99.1
MS-15-12.5_xlJ6b	2	61.70	24.73	0.18	0.005	6.31	7.17	0.66	0.09	100.8
MS-15-12.5_xlJ7a	2	58.41	26.38	0.26	0.000	8.43	6.07	0.39	0.04	100.0
MS-15-12.5_xlJ7b	2	58.38	26.95	0.25	0.008	8.59	6.27	0.39	0.06	100.9
MS-15-12.5_xlJ10a	2	60.41	25.20	0.22	0.000	7.13	6.71	0.55	0.09	100.3

Table E1 continued.

Feldspar type, sample and crystal number**	Sample Unit	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
andesine cont.										
MS-15-12.5 xlJ10b	2	60.35	25.47	0.24	0.008	7.23	6.66	0.55	0.09	100.6
MS-15-12.5 xlK1a	2	59.06	25.96	0.27	0.010	7.37	6.96	0.38	0.07	100.1
MS-15-12.5 xlK1b	2	58.43	26.53	0.32	0.012	8.11	6.98	0.37	0.03	100.8
MS-14-4b xl1a	N/A	54.39	26.86	0.28	0.023	8.89	5.77	0.41	0.05	96.7
MS-14-4b xl1b	N/A	54.35	26.50	0.23	0.009	8.54	5.96	0.41	0.04	96.0
MS-15-28.1b xl3a	2	57.19	28.46	0.29	0.027	9.79	5.56	0.34	0.07	101.7
MS-15-28.1b xl3b	2	56.98	27.18	0.31	0.029	9.14	5.82	0.39	0.11	100.0
MS-15-28.1b xl6a	2	59.22	26.30	0.16	0.016	8.07	6.38	0.38	0.04	100.6
MS-15-28.1b xl6b	2	57.85	26.25	0.26	0.007	7.93	6.02	0.41	0.00	98.7
anorthoclase										
MS-10-26_xl5	4	67.11	19.52	0.31	0.004	0.38	7.08	5.42	N/A	99.8
MS-12-33.1_xlC4	3	69.86	19.78	0.24	0.000	0.22	8.22	4.66	0.55	103.5
MS-12-33.1 xlH7a	3	67.55	19.29	0.21	0.000	0.24	7.66	5.20	0.60	100.8
MS-12-33.1 xlH7b	3	68.01	19.44	0.18	0.000	0.21	7.59	5.19	0.50	101.1
MS-15-28.1b_xl4a	2	67.46	19.97	0.23	0.003	0.40	7.42	4.93	0.39	100.8
MS-15-28.1b_xl4b	2	67.92	19.99	0.26	0.001	0.55	7.59	4.66	0.43	101.4
bytownite										
MS-14-20a_xl2a	N/A	49.32	31.99	0.50	0.137	15.23	2.73	0.16	0.02	100.1
MS-14-20a_xl2b	N/A	51.73	29.93	0.53	0.113	13.27	3.69	0.18	0.02	99.5
MS-14-20a_xl3a	N/A	47.22	33.87	0.50	0.107	16.71	1.81	0.06	0.02	100.3
MS-14-20a_xl3b	N/A	48.90	32.52	0.52	0.126	15.77	2.53	0.08	0.02	100.5
MS-14-20a_xl5a	N/A	49.48	32.38	0.41	0.117	15.20	2.87	0.12	0.00	100.6
MS-14-20a_xl5b	N/A	51.32	30.28	0.47	0.122	13.55	3.52	0.21	0.01	99.5
MS-15-18-1T_xl2a	N/A	49.90	32.12	0.52	0.185	15.04	2.76	0.09	N/A	100.6
MS-15-18-1T xl2b	N/A	50.12	31.59	0.53	0.187	15.01	2.91	0.10	N/A	100.4
MS-15-18-1T_xl4a	N/A	50.78	32.12	0.46	0.191	14.91	3.03	0.08	N/A	101.6
MS-15-18-1T xl4b	N/A	51.76	30.54	0.92	0.303	13.65	3.22	0.12	N/A	100.5
MS-15-18-1T_xl5a	N/A	54.73	29.00	0.92	0.193	11.69	4.70	0.21	N/A	101.4
MS-15-18-1T xl5b	N/A	50.57	3.54	10.03	$\frac{13.87}{4}$	19.89	0.31	0.00	N/A	98.2
MS-15-18-1T xl6a	N/A	50.83	31.54	0.58	0.199	14.46	3.06	0.09	N/A	100.8
MS-15-18-1T xl6b	N/A	51.87	30.44	0.54	0.236	13.87	3.51	0.11	N/A	100.6
MS-15-12.3 xl7a	2	50.72	31.41	0.58	0.151	14.93	3.05	0.09	0.03	101.0
MS-15-12.3 xl7b	2	50.84	31.46	0.49	0.147	14.71	3.06	0.08	0.00	100.8
bytownite										
MS-15-18.2 xl8a	2	48.58	31.16	0.48	0.150	14.02	3.16	0.11	0.00	97.7
MS-15-18.2 xl8b	2	49.16	31.13	0.52	0.141	14.28	3.05	0.09	0.02	98.4
MS-15-18.2 xl9a	2	48.58	31.03	0.53	0.134	14.43	3.02	0.09	0.03	99.4
MS-15-18.2_xl9b	2	49.17	31.53	0.64	0.151	14.13	3.12	0.07	0.00	96.9

Table E1 continued.

Feldspar type, sample and crystal number**	Sample Unit	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
labradorite										
MS-10-26_xl1	4	54.97	29.19	0.61	0.098	11.32	4.78	0.22	N/A	101.2
MS-14-20a_xl4a	N/A	50.61	31.76	0.48	0.123	14.62	2.94	0.12	0.03	100.7
MS-14-20a_xl4b	N/A	51.81	30.13	0.54	0.105	12.96	3.83	0.20	0.03	99.6
MS-14-20a_xl6a	N/A	53.25	29.73	0.60	0.111	12.54	4.32	0.17	0.03	99.5
MS-14-20a_xl6b	N/A	51.16	30.36	0.57	0.121	13.33	3.91	0.17	0.00	100.8
MS-15-12.3 xl1a	2	54.30	29.34	0.51	0.089	11.69	4.55	0.18	0.00	100.7
MS-15-12.3 xl1b	2	50.20	31.19	0.60	0.097	14.01	3.34	0.14	0.03	99.6
MS-15-18.2 xl3a	2	50.71	30.85	0.55	0.166	13.40	3.58	0.12	0.01	99.4
MS-15-18.2 xl3b	2	48.83	30.07	0.55	0.146	13.81	3.37	0.11	0.00	96.9
MS-15-12.5 xlK3a	2	55.89	28.54	0.35	0.024	10.31	5.47	0.26	0.03	100.9
MS-15-12.5 xlK3b	2	54.69	28.39	0.29	0.024	10.59	5.31	0.28	0.01	99.6
MS-15-18-2T xl1	4	56.11	28.63	0.61	0.075	11.35	4.89	0.23	N/A	101.9
MS-15-18-1T xl3a	N/A	55.15	28.49	0.60	0.086	10.73	5.22	0.22	N/A	100.5
MS-15-18-1T xl3b	N/A	55.63	28.30	0.61	0.086	10.48	5.43	0.25	N/A	100.8
MS-15-28.1b xl7a	2	55.01	29.30	0.38	0.047	11.27	4.81	0.19	0.05	101.1
MS-15-28.1b xl7b	2	56.08	28.68	0.38	0.046	10.67	5.06	0.27	0.03	101.2
oligoclase										
MS-11-4.1_xl7a ¹	1	60.61	24.74	0.17	0.000	4.66	8.81	0.80	0.22	100.0
MS-11-4.1_xl7b ¹	1	60.54	24.75	0.23	0.006	4.72	8.79	0.80	0.17	100.0
MS-12-33.1_xlC5	3	62.23	24.64	0.23	0.018	5.43	8.11	0.51	0.10	101.3
MS-15-12.5_xlJ4a	2	61.50	23.85	0.24	0.000	5.52	7.70	0.63	0.12	99.6
MS-15-12.5_xlJ4b	2	62.59	24.12	0.23	0.000	5.24	8.00	0.67	0.15	101.0
MS-15-12.4_xl2a	2	62.13	23.99	0.24	0.000	5.87	7.31	0.73	0.11	100.5
MS-15-12.4_xl2b	2	62.68	23.84	0.23	0.011	5.46	7.52	0.75	0.18	99.8
MS-15-12.4_xl4b	2	61.50	23.85	0.24	0.000	5.52	7.70	0.63	0.12	99.6
MS-15-12.4_xl4b	2	62.59	24.12	0.23	0.000	5.24	8.00	0.67	0.15	101.0
MS-15-12_xl4	2	55.84	21.86	0.23	0.000	5.56	7.38	0.62	N/A	91.5
sanidine										
MS-11-4.1_xl3a ¹	1	62.71	20.82	0.02	0.000	0.22	4.52	9.67	2.04	100.0
MS-11-4.1_xl3b ¹	1	63.25	20.65	0.08	0.000	0.18	4.89	8.98	1.98	100.0
MS-10-26_xl3	4	66.67	19.29	0.22	0.005	0.30	6.70	6.25	N/A	99.4
MS-10-26_xl4	4	66.91	19.15	0.20	0.000	0.23	6.06	7.03	N/A	99.6
MS-12-21_xl2a ¹	N/A	77.64	14.45	0.77	0.050	0.72	2.82	3.46	0.08	100.0
MS-12-21_xl2b ¹	N/A	77.45	14.49	0.84	0.036	0.69	3.05	3.40	0.04	100.0
MS-12-33.1_xlC3	3	67.84	19.81	0.22	0.000	0.00	7.16	6.61	0.16	101.8
MS-15-18-2T_xl2	4	66.34	19.55	0.00	0.001	0.08	3.45	11.50	N/A	100.9
MS-15-18-2T_xl5	4	68.57	19.07	0.19	0.005	0.17	6.66	6.63	N/A	101.3
MS-15-28.1b_xl2a	2	66.10	20.11	0.16	0.001	0.62	6.06	7.01	0.21	100.3

Table E1 continued.

Feldspar type, sample and crystal number**	Sample Unit	SiO₂	Al₂O₃	FeO*	MgO	CaO	Na₂O	K₂O	BaO	Total
sanidine cont.										
MS-15-28.1b_xl2b	2	66.31	19.97	0.17	0.001	0.89	6.30	6.56	0.23	100.4
MS-15-7c_xl1	4	68.10	19.00	0.18	0.000	0.16	5.47	8.17	N/A	101.1
MS-15-7c_xl3	4	68.30	19.31	0.17	0.000	0.22	6.29	7.15	N/A	101.4
MS-15-7c_xl4	4	68.14	19.45	0.15	0.000	0.21	5.95	7.69	N/A	101.6
MS-15-7c_xl7	4	68.57	19.31	0.21	0.000	0.28	6.58	6.44	N/A	101.4
** Letters following crystal number indicate multiple analysis points per crystal.										
1. Normalized values										

Table E2. Non-unit designating end member composition by feldspar type.

Feldspar type, sample and crystal number**	Sample Unit	An ²	Ab ³	Or ⁴
Albite				
MS-12-33.1 xIC1	3	7.11	83.62	9.28
Andesine				
MS-10-20 xI1a	2	37.61	60.12	2.27
MS-10-20 xI1b	2	32.71	64.61	2.69
MS-14-20a xI1a	N/A	44.46	53.50	2.04
MS-14-20a xI1b	N/A	36.38	60.87	2.75
MS-12-20 xI4a	4	37.61	60.12	2.27
MS-12-20 xI4b	4	32.71	64.61	2.69
MS-15-12 xI2	2	30.30	65.69	4.01
MS-15-12 xI3	2	39.71	57.70	2.59
MS-15-12 xI5	2	43.85	54.94	1.21
MS-15-38 xI5	1	39.60	58.57	1.83
MS-15-12.4 xI1a	2	37.05	59.66	3.29
MS-15-12.4 xI1b	2	39.25	57.70	3.05
MS-15-12.4 xI3a	2	33.93	62.39	3.68
MS-15-12.4 xI3b	2	30.17	65.61	4.22
MS-15-12.4 xI5a	2	26.94	68.35	4.72
MS-15-12.4 xI5b	2	36.57	60.05	3.39
MS-15-12.4 xI6a	2	30.85	65.32	3.84
MS-15-12.4 xI6b	2	27.95	67.51	4.54
MS-15-12.4 xI8a	2	32.49	64.00	3.51
MS-15-12.4 xI8b	2	38.28	58.63	3.10
MS-15-12.4 xI10a	2	41.02	56.76	2.22
MS-15-12.4 xI10b	2	43.36	54.29	2.36
MS-15-12.5 xIJ2a	2	41.78	55.63	2.59
MS-15-12.5 xIJ2b	2	42.26	55.44	2.30
MS-15-12.5 xIJ3a	2	45.19	52.84	1.98
MS-15-12.5 xIJ3b	2	39.94	57.37	2.69
MS-15-12.5 xIJ5a	2	29.03	66.39	4.59
MS-15-12.5 xIJ5b	2	33.02	63.64	3.34
MS-15-12.5 xIJ6a	2	32.94	63.13	3.93
MS-15-12.5 xIJ6b	2	31.53	64.56	3.92
MS-15-12.5 xIJ7a	2	42.49	55.20	2.32
MS-15-12.5 xIJ7b	2	42.23	55.51	2.26
MS-15-12.5 xIJ10a	2	35.87	60.81	3.33
MS-15-12.5 xIJ10b	2	36.35	60.37	3.28
MS-15-12.5 xIK1a	2	36.19	61.60	2.21
MS-15-12.5 xIK1b	2	38.39	59.55	2.07

Table E2 continued.

Feldspar type, sample and crystal number**	Sample Unit	An²	Ab³	Or⁴
andesine cont.				
MS-14-4b xl1a	N/A	44.90	52.60	2.50
MS-14-4b xl1b	N/A	43.19	54.34	2.47
MS-15-28.1b xl3a	2	48.41	49.57	2.02
MS-15-28.1b xl3b	2	45.49	52.18	2.32
MS-15-28.1b xl6a	2	40.31	57.42	2.27
MS-15-28.1b xl6b	2	41.16	56.32	2.53
anorthoclase				
MS-10-26 xl5	4	1.96	65.14	32.93
MS-12-33.1 xlc4	3	1.06	71.96	27.00
MS-12-33.1 xlH7a	3	1.18	68.21	30.63
MS-12-33.1 xlH7b	3	1.07	68.13	30.83
MS-15-28.1b xl4a	2	2.06	68.07	29.90
MS-15-28.1b xl4b	2	2.77	69.17	28.09
bytownite				
MS-14-20a xl2a	N/A	74.86	24.20	0.93
MS-14-20a xl2b	N/A	65.90	33.03	1.07
MS-14-20a xl3a	N/A	83.36	16.26	0.38
MS-14-20a xl3b	N/A	77.18	22.32	0.49
MS-14-20a xl5a	N/A	74.11	25.20	0.68
MS-14-20a xl5b	N/A	67.25	31.49	1.26
MS-15-18-1T xl2a	N/A	74.70	24.75	0.55
MS-15-18-1T xl2b	N/A	73.64	25.77	0.58
MS-15-18-1T xl4a	N/A	72.81	26.71	0.48
MS-15-18-1T xl4b	N/A	69.64	29.63	0.73
MS-15-18-1T xl5a	N/A	57.27	41.50	1.23
MS-15-18-1T xl5b	N/A	97.22	2.76	0.02
MS-15-18-1T xl6a	N/A	72.01	27.48	0.51
MS-15-18-1T xl6b	N/A	68.22	31.14	0.64
MS-15-12.3 xl7a	2	72.71	26.79	0.51
MS-15-12.3 xl7b	2	72.38	27.14	0.47
bytownite				
MS-15-18.2 xl8a	2	70.67	28.69	0.64
MS-15-18.2 xl8b	2	71.82	27.63	0.54
MS-15-18.2 xl9a	2	72.22	27.21	0.56
MS-15-18.2 xl9b	2	71.21	28.37	0.42
labradorite				
MS-10-26 xl1	4	56.05	42.67	1.28
MS-14-20a xl4a	N/A	72.86	26.44	0.70

Table E2 continued.

Feldspar type, sample and crystal number**	Sample Unit	An²	Ab³	Or⁴
labradorite cont.				
MS-14-20a xl4b	N/A	64.44	34.35	1.21
MS-14-20a xl6a	N/A	61.06	37.94	0.99
MS-14-20a xl6b	N/A	64.78	34.26	0.96
MS-15-12.3 xl1a	2	58.15	40.76	1.09
MS-15-12.3 xl1b	2	69.34	29.81	0.85
MS-15-18.2 xl3a	2	67.06	32.25	0.70
MS-15-18.2 xl3b	2	69.02	30.33	0.65
MS-15-12.5 xIK3a	2	50.32	48.15	1.53
MS-15-12.5 xIK3b	2	51.65	46.72	1.63
MS-15-18-2T xl1	4	55.58	43.11	1.31
MS-15-18-1T xl3a	N/A	52.57	46.13	1.31
MS-15-18-1T xl3b	N/A	50.96	47.61	1.43
MS-15-28.1b xl7a	2	55.88	42.98	1.14
MS-15-28.1b xl7b	2	53.04	45.37	1.59
oligoclase				
MS-11-4.1 xl7a ¹	1	21.68	73.92	4.41
MS-11-4.1 xl7b ¹	1	21.92	73.66	4.43
MS-12-33.1 xIC5	3	26.31	70.73	2.97
MS-15-12.5 xIJ4a	2	27.41	68.89	3.70
MS-15-12.5 xIJ4b	2	25.62	70.50	3.87
MS-15-12.4 xl2a	2	29.48	66.16	4.37
MS-15-12.4 xl2b	2	27.41	68.13	4.47
MS-15-12 xl4	2	28.36	67.85	3.79
sanidine				
MS-11-4.1 xl3a ¹	1	1.09	40.97	57.97
MS-11-4.1 xl3b ¹	1	0.90	44.77	54.36
MS-10-26 xl3	4	1.53	60.92	37.57
MS-10-26 xl4	4	1.19	55.92	42.93
MS-12-21 xl2a ¹	N/A	7.23	51.27	41.52
MS-12-21 xl2b ¹	N/A	6.71	53.75	39.56
MS-12-33.1 xIC3	3	0.00	62.14	37.89
MS-15-18-2T xl2	4	0.41	31.08	68.54
MS-15-18-2T xl5	4	0.87	59.83	39.33
MS-15-28.1b xl2a	2	3.11	54.90	42.02
MS-15-28.1b xl2b	2	4.45	56.59	38.99
MS-15-7c xl1	4	0.79	49.95	49.30
MS-15-7c xl3	4	1.09	56.47	42.47
MS-15-7c xl4	4	1.02	53.38	45.63

Table E2 continued.

Feldspar type, sample and crystal number**	Sample Unit	An²	Ab³	Or⁴
sanidine cont.				
MS-15-7c xl7	4	1.42	59.86	38.75
** Letters following crystal number indicate multiple analysis points per crystal.				
1. Normalized values.				
2. $An = (CaO * 0.714 / 40) / (CaO * 0.714 / 40 + Na_2O * 0.74 / 23 + K_2O * 0.83 / 39) * 100$				
3. $Ab = (Na_2O * 0.74 / 23) / (CaO * 0.714 / 40 + Na_2O * 0.74 / 23 + K_2O * 0.829 / 39) * 100$				
4. $Or = (K_2O * 0.83 / 39) / (CaO * 0.714 / 40 + Na_2O * 0.74 / 23 + K_2O * 0.83 / 39) * 100$				

APPENDIX F: BULK ROCK CHEMICAL DATA

Table F1. Unit 1 bulk tuff major and trace element geochemical data from Streck et al., (2015).

Sample	CR- U20b	CR- U21	CR- U22b	CR- U22d	MS-DIT 1	MS- NEMT	MS- MC1-09	MS- MC2-09
XRF normalized (weight %)								
SiO ₂	78.1	76.1	76.2	75.8	75.8	75.9	75.7	76.1
TiO ₂	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Al ₂ O ₃	12.5	13.0	12.4	12.7	12.3	12.6	12.3	12.3
FeO*	0.4	1.7	2.0	2.2	2.1	1.9	1.9	2.1
MnO	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
MgO	0.0	0.1	0.0	0.2	0.1	0.1	0.2	0.1
CaO	0.2	0.6	0.6	0.7	0.6	0.6	1.0	0.8
Na ₂ O	4.7	4.5	3.7	3.1	2.7	2.5	3.6	2.7
K ₂ O	3.9	3.8	4.9	5.2	6.2	6.2	5.1	5.5
P ₂ O ₅	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
XRF unnormalized (ppm)								
Ni	0.0	2.0	0.0	0.2	0.0	0.0	2.2	4.5
Cr	2.0	4.5	1.4	3.0	1.9	2.5	2.9	2.7
Sc	3.5	4.9	3.8	5.1	3.6	3.7	4.3	4.1
V	1.1	15.4	3.7	8.3	1.4	3.3	4.7	7.6
Ba	1487.5	1405.6	1400.3	1366.5	1349.8	1350.8	1318.0	1325.5
Rb	75.5	73.1	74.3	71.4	78.4	87.3	70.6	73.7
Sr	29.1	43.6	25.5	31.0	25.6	29.2	71.7	39.8
Zr	431.0	416.1	412.0	416.4	405.5	410.5	417.6	422.3
Y	125.6	91.4	90.3	85.8	94.2	87.6	90.5	93.9
Nb	24.8	22.7	23.1	23.3	23.6	22.8	22.2	24.1
Ga	20.8	20.6	20.2	20.7	21.2	20.9	20.4	21.3
Cu	0.0	4.6	0.5	1.3	2.3	0.7	3.7	6.1
Zn	65.4	209.1	149.7	152.8	169.4	141.6	145.1	139.5
Pb	14.5	16.3	16.1	17.6	17.1	16.7	17.4	18.1
La	67.4	51.3	45.3	43.3	47.4	43.5	45.1	44.7
Ce	132.1	103.9	95.0	89.6	101.2	91.6	93.2	97.1
Th	11.3	9.2	9.2	10.0	9.6	9.0	7.8	6.9
Nd	65.6	52.2	45.8	44.3	50.8	48.0	46.6	48.8
U	2.7	2.6	2.6	3.3	3.3	3.5	2.9	2.3

Table F1 continued.

Sample	CR- U20b	CR- U21	CR- U22b	CR- U22d	MS-DIT 1	MS- NEMT	MS- MC1-09	MS- MC2-09
ICP-MS (ppm)								
La	69.8	51.7	45.8	43.8	49.1	44.7	44.6	46.2
Ce	137.8	106.2	96.7	93.1	102.1	94.6	93.5	96.1
Pr	17.1	13.7	12.3	11.8	13.2	12.0	11.8	12.3
Nd	69.5	54.9	48.9	47.1	52.2	48.2	47.4	49.2
Sm	15.8	12.7	11.5	11.2	12.2	11.2	11.1	11.5
Eu	2.1	2.0	1.7	1.6	1.6	1.6	1.6	1.7
Gd	16.8	13.3	12.0	11.7	12.9	11.6	11.4	12.1
Tb	3.0	2.4	2.3	2.2	2.4	2.2	2.2	2.3
Dy	20.0	16.2	15.3	14.8	16.3	14.9	14.8	15.5
Ho	4.4	3.5	3.4	3.3	3.6	3.3	3.2	3.4
Er	12.7	10.1	10.1	9.6	10.5	9.7	9.7	10.2
Tm	1.9	1.6	1.6	1.5	1.6	1.5	1.5	1.6
Yb	12.0	10.0	10.3	9.9	10.7	10.0	9.9	10.2
Lu	2.0	1.6	1.6	1.6	1.7	1.6	1.6	1.7
Ba	1528.0	1443.1	1429.5	1398.3	1362.5	1365.9	1347.2	1346.6
Th	8.2	7.8	7.8	7.8	7.7	7.6	7.6	7.7
Nb	24.5	23.1	23.1	23.0	22.8	22.7	22.7	23.8
Y	125.3	89.9	89.1	86.1	93.0	86.2	87.4	90.5
Hf	12.0	11.5	11.6	11.7	11.4	11.4	11.3	11.5
Ta	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4
U	3.9	3.5	3.5	3.3	3.4	3.4	3.3	3.4
Pb	15.8	16.2	17.3	17.1	17.1	16.7	16.4	16.7
Rb	76.3	73.0	73.8	72.2	77.7	86.8	70.0	73.2
Cs	1.2	2.9	2.9	2.8	2.9	3.0	2.7	2.8
Sr	29.9	43.7	26.7	31.7	25.9	31.9	72.5	40.8
Sc	3.6	4.9	4.0	4.7	3.8	4.2	4.4	4.7
Zr	459.7	438.5	434.0	436.1	419.8	427.5	419.6	432.3
* Unnormalized values.								

Table F1 continued.

Sample	MS-10-23	MS-11-3	MS-11-27	MS-11-27	MS-11-54 lit	MS-11-54 drk	MS-12- 29.1
XRF normalized (weight %)							
SiO ₂	76.6	75.7	73.1	73.0	75.5	75.6	76.3
TiO ₂	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Al ₂ O ₃	12.4	12.8	16.0	16.1	13.6	13.6	12.3
FeO*	2.0	2.8	2.7	2.7	2.5	2.3	2.0
MnO	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MgO	0.1	0.1	0.3	0.2	0.0	0.1	0.0
CaO	0.6	0.6	0.7	0.7	0.7	0.5	0.6
Na ₂ O	3.4	3.2	3.3	3.4	3.3	3.0	3.8
K ₂ O	4.6	4.5	3.7	3.7	4.2	4.6	4.7
P ₂ O ₅	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
XRF unnormalized (ppm)							
Ni	1.1	3.5	1.3	4.6	3.8	0.5	2.4
Cr	3.4	4.8	4.1	2.8	2.8	5.3	3.4
Sc	3.7	3.4	4.2	5.0	3.8	4.5	4.1
V	4.7	7.2	8.2	11.7	4.8	7.4	3.1
Ba	1374.0	1315.7	1164.0	1262.7	1331.8	1324.6	1411.0
Rb	74.9	75.4	57.7	59.3	69.6	78.2	74.2
Sr	29.5	30.9	30.5	32.6	27.8	28.9	27.6
Zr	427.0	424.2	531.4	548.0	463.8	459.2	428.8
Y	91.7	90.6	93.6	95.0	86.2	84.8	93.0
Nb	23.9	22.8	28.1	28.8	26.2	25.2	24.2
Ga	20.6	21.7	26.0	27.1	22.3	21.7	21.5
Cu	2.7	4.3	5.6	6.7	2.0	3.5	1.4
Zn	148.7	151.1	152.5	157.3	166.1	152.7	152.4
Pb	19.4	18.7	22.9	24.7	19.7	18.2	18.7
La	43.6	45.1	48.0	50.3	42.3	40.3	47.4
Ce	91.3	83.8	117.9	122.0	95.9	95.6	91.9
Th	6.6	7.9	9.6	9.6	9.6	7.1	7.6
Nd	46.4	49.4	53.2	53.5	47.3	46.5	49.5
U	3.3	2.9	3.7	2.5	3.5	1.9	4.7

Table F1 continued.

Sample	MS-10-23	MS-11-3	MS-11-27	MS-11-27	MS-11-54 lit	MS-11-54 drk	MS-12- 29.1
ICP-MS (ppm)							
La	47.4	48.7	51.0	51.0	44.6	44.0	46.7
Ce	99.6	90.8	126.8	122.1	100.1	95.5	93.3
Pr	12.6	12.7	13.7	13.7	12.1	12.0	12.4
Nd	50.1	50.6	55.2	54.6	47.8	47.4	49.5
Sm	11.7	11.8	12.8	12.8	11.3	11.2	11.6
Eu	1.7	1.8	1.9	1.9	1.9	1.7	1.7
Gd	12.1	12.4	13.2	13.0	11.6	11.4	12.3
Tb	2.3	2.3	2.4	2.4	2.2	2.2	2.3
Dy	15.4	15.4	16.2	16.3	14.8	14.5	15.6
Ho	3.4	3.4	3.6	3.5	3.2	3.2	3.4
Er	10.0	9.8	10.4	10.4	9.5	9.6	10.1
Tm	1.6	1.5	1.6	1.6	1.5	1.5	1.6
Yb	10.3	9.8	10.7	10.8	9.7	9.7	10.2
Lu	1.7	1.6	1.8	1.8	1.6	1.5	1.6
Ba	1470.8	1340.8	1179.8	1276.6	1362.4	1359.4	1419.1
Th	7.8	7.7	9.7	10.0	8.4	8.2	7.8
Nb	24.2	20.5	27.3	28.0	25.1	24.6	23.3
Y	90.3	89.8	92.0	90.7	83.6	83.5	90.3
Hf	11.8	11.4	14.2	14.9	12.4	12.4	11.6
Ta	1.4	1.2	1.7	1.8	1.5	1.5	1.4
U	3.5	3.5	3.1	3.2	3.7	3.5	3.5
Pb	17.4	17.5	21.6	22.1	18.4	16.6	17.5
Rb	77.2	74.8	57.0	58.1	68.4	78.5	74.6
Cs	3.0	2.9	2.5	2.6	3.1	3.0	2.9
Sr	30.3	32.7	31.8	34.5	28.7	30.6	30.9
Sc	5.6	4.3	4.2	4.3	4.1	4.4	3.8
Zr	461.3	450.8	557.0	551.5	491.5	490.6	438.9

* Unnormalized values.

Table F1 continued.

Sample	STRM MS- 12-26	MS15-32*	MS15-34A*	MS15-38*	PFC1548*	CR- U31c
XRF normalized (weight %)						
SiO ₂	76.2	76.1	75.7	75.5	75.9	77.2
TiO ₂	0.2	0.2	0.2	0.2	0.2	0.2
Al ₂ O ₃	12.4	12.3	12.4	12.7	12.3	12.8
FeO*	1.9	2.2	2.4	2.4	2.1	1.2
MnO	0.1	0.1	0.0	0.1	0.1	0.0
MgO	0.1	0.1	0.3	0.2	0.0	0.1
CaO	0.6	0.5	0.6	0.7	0.5	0.4
Na ₂ O	3.3	3.1	2.1	2.5	2.8	4.2
K ₂ O	5.2	5.5	6.4	5.9	6.0	3.8
P ₂ O ₅	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	95.3	95.1	94.6	95.8	100.0
XRF unnormalized (ppm)						
Ni	2.1	3.0	2.4	1.9	1.1	2.2
Cr	2.6	4.0	1.8	0.8	3.7	4.5
Sc	4.3	3.3	4.9	4.3	4.3	3.2
V	7.3	6.8	4.2	5.9	4.6	13.5
Ba	1412.4	1365.2	1326.7	1372.2	1445.1	1405.8
Rb	74.5	77.1	89.4	90.7	81.8	72.8
Sr	33.1	29.5	33.1	35.3	28.9	37.3
Zr	429.8	424.9	431.4	448.7	441.8	436.4
Y	93.7	114.3	94.3	106.3	92.2	94.6
Nb	24.2	23.6	24.2	24.4	23.9	24.5
Ga	22.0	20.8	20.6	21.1	20.7	21.5
Cu	2.4	2.9	3.8	4.4	2.6	3.1
Zn	156.4	154.4	147.7	168.8	150.6	111.7
Pb	19.1	17.7	17.3	18.1	19.7	16.4
La	48.5	63.2	47.8	56.2	48.1	42.9
Ce	97.3	98.6	95.8	99.4	92.5	92.7
Th	8.1	8.2	8.3	6.8	7.6	8.2
Nd	49.6	63.8	51.8	59.5	47.8	46.2
U	4.4	2.9	4.0	4.1	3.5	3.2

Table F1 continued.

Sample	MS-12-26	MS15-32	MS15-34A	MS15-38	PFC1548	CR-U31c
ICP-MS (ppm)						
La	47.1	64.8	50.6	61.5	46.6	43.7
Ce	98.6	105.7	97.6	102.7	95.7	91.7
Pr	12.5	17.3	13.3	15.7	12.4	11.5
Nd	50.4	69.2	53.2	62.5	49.7	45.5
Sm	11.6	16.1	12.3	14.4	11.7	10.8
Eu	1.7	2.2	1.7	2.2	1.7	1.8
Gd	12.3	16.5	12.6	15.2	12.3	11.3
Tb	2.3	3.1	2.4	2.8	2.3	2.2
Dy	15.6	20.4	16.0	18.6	15.5	15.0
Ho	3.4	4.4	3.5	4.0	3.4	3.4
Er	10.0	12.7	10.2	11.8	10.2	10.0
Tm	1.6	2.0	1.6	1.8	1.6	1.6
Yb	10.3	12.7	10.4	11.7	10.5	10.3
Lu	1.7	2.1	1.7	1.9	1.7	1.7
Ba	1418.9	1414.2	1381.4	1425.9	1474.4	1423.4
Th	7.9	8.0	8.1	8.1	7.8	8.1
Nb	23.5	23.8	24.2	24.2	23.5	24.1
Y	88.7	113.7	92.6	106.6	90.6	89.1
Hf	11.6	11.8	11.9	12.2	12.0	11.8
Ta	1.4	1.4	1.5	1.5	1.4	1.5
U	3.5	3.6	3.4	3.6	3.5	3.6
Pb	17.7	17.6	17.0	17.9	17.1	14.9
Rb	73.1	76.2	88.1	88.9	81.4	72.8
Cs	3.0	2.9	2.9	3.0	3.0	2.3
Sr	34.9	31.3	34.2	37.2	30.9	36.8
Sc	3.8	4.0	3.6	4.0	3.3	5.0
Zr	433.6	437.0	442.0	457.9	449.2	445.3
* Unnormalized values.						

Table F2. Unit 2 bulk tuff major and trace element geochemical data from Streck et al., (2015).

Sample	CR-U1ab	CR-U2a	CR-U2b-2	CR-U2e	CR-U9b	CR-U9c
XRF normalized (weight %)						
SiO ₂	74.4	74.7	74.9	74.9	71.6	71.8
TiO ₂	0.2	0.2	0.2	0.2	0.5	0.6
Al ₂ O ₃	13.3	13.4	13.1	13.6	13.9	14.0
FeO*	2.5	2.3	2.3	2.9	4.3	3.7
MnO	0.1	0.1	0.1	0.1	0.1	0.1
MgO	0.1	0.0	0.0	0.1	0.2	0.2
CaO	1.0	0.9	1.0	1.1	1.7	1.8
Na ₂ O	3.9	3.0	3.4	1.9	4.5	4.7
K ₂ O	4.5	5.4	5.1	5.3	3.1	3.1
P ₂ O ₅	0.0	0.0	0.0	0.0	0.2	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0
XRF (ppm)						
Ni	0.0	0.0	0.0	0.0	0.3	0.2
Cr	6.3	1.5	1.4	1.6	4.4	3.2
Sc	3.5	2.8	3.3	3.3	14.1	13.7
V	3.7	2.8	1.8	6.4	18.6	17.7
Ba	1565.7	1557.0	1565.0	1568.0	1379.3	1407.1
Rb	71.4	74.8	74.2	76.6	54.7	51.4
Sr	90.5	89.2	82.0	89.5	175.1	178.9
Zr	387.0	384.1	376.8	383.9	324.7	337.5
Y	71.6	70.8	72.2	74.3	54.9	65.8
Nb	21.0	20.4	20.9	19.9	19.7	20.0
Ga	20.6	22.1	21.0	20.9	22.7	21.5
Cu	2.5	2.5	1.6	3.3	3.9	4.2
Zn	139.1	136.6	134.7	141.6	141.6	146.9
Pb	15.0	13.9	15.2	15.2	12.4	11.7
La	43.6	43.2	43.0	45.9	35.5	42.4
Ce	89.5	85.8	89.3	95.6	74.7	74.8
Th	8.3	9.5	8.6	9.8	6.8	7.0
Nd	45.7	43.2	44.6	47.3	36.1	41.4
U	1.8	2.4	3.2	2.1	1.9	2.3

Table F2 continued.

Sample	CR-U1ab	CR-U2a	CR-U2b-2	CR-U2e	CR-U9b	CR-U9c
ICP-MS (ppm)						
La	42.5	42.8	43.7	46.1	35.8	39.8
Ce	88.1	88.8	89.9	96.0	77.5	78.8
Pr	11.2	11.3	11.6	12.2	9.7	10.8
Nd	44.7	45.3	46.1	48.9	38.9	44.4
Sm	10.5	10.6	10.8	11.4	9.1	10.5
Eu	2.0	2.0	2.1	2.2	2.5	2.7
Gd	10.3	10.6	10.8	11.5	8.9	10.5
Tb	1.9	1.9	2.0	2.1	1.6	1.9
Dy	12.5	12.6	12.7	13.1	10.0	12.0
Ho	2.7	2.7	2.7	2.8	2.1	2.6
Er	7.7	7.7	7.9	8.1	6.0	7.3
Tm	1.2	1.2	1.2	1.2	0.9	1.1
Yb	7.4	7.6	7.6	7.8	6.0	7.3
Lu	1.2	1.2	1.2	1.3	1.0	1.2
Ba	1590.0	1568.6	1589.9	1586.5	1402.2	1427.8
Th	7.1	7.0	7.0	7.1	6.0	6.1
Nb	21.5	21.2	20.9	20.4	19.8	20.5
Y	70.8	70.8	72.2	74.0	54.7	65.5
Hf	10.2	10.4	10.1	10.4	8.6	8.9
Ta	1.3	1.4	1.3	1.3	1.2	1.2
U	2.9	3.0	2.9	2.9	2.5	2.7
Pb	15.4	15.3	15.3	14.8	12.7	13.5
Rb	73.2	75.8	74.9	77.3	56.0	51.6
Cs	3.1	3.1	3.1	3.1	2.1	2.2
Sr	89.3	89.3	81.9	89.4	177.2	180.5
Sc	3.0	3.4	2.8	3.3	14.0	14.9
Zr	404.5	403.8	394.2	398.4	337.0	350.0
* Unnormalized values.						

Table F2 continued.

Sample	CR-U10a	CR-U10b	CR-U11a	MS-PICT 1-A	MS-PICT 1-X1	CR-U28a
XRF normalized (weight %)						
SiO ₂	72.4	75.4	73.8	73.8	74.5	70.7
TiO ₂	0.4	0.2	0.3	0.3	0.2	0.4
Al ₂ O ₃	14.3	13.6	13.5	13.6	13.0	17.3
FeO*	3.4	0.8	2.9	2.9	2.4	4.3
MnO	0.0	0.0	0.0	0.0	0.1	0.1
MgO	0.2	0.2	0.1	0.3	0.0	0.1
CaO	1.5	0.7	1.1	1.0	0.9	1.1
Na ₂ O	4.7	5.0	4.1	2.3	3.9	2.2
K ₂ O	2.9	4.1	4.2	5.6	4.9	3.9
P ₂ O ₅	0.1	0.0	0.0	0.1	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
XRF (ppm)						
Ni	2.3	0.0	0.0	3.8	0.0	6.5
Cr	7.0	3.4	1.9	4.0	1.6	10.6
Sc	7.5	3.1	5.8	5.1	3.1	7.3
V	24.7	0.8	6.1	10.0	1.4	28.6
Ba	1504.8	1673.1	1662.0	1382.4	1591.1	1301.3
Rb	37.0	74.1	70.0	79.1	75.7	62.9
Sr	156.1	119.3	108.0	104.2	87.1	87.0
Zr	356.7	393.0	376.2	384.3	384.1	457.6
Y	84.9	86.1	81.3	76.5	71.3	69.0
Nb	20.2	21.5	20.6	20.1	20.9	24.3
Ga	22.3	22.4	22.6	21.5	22.1	26.7
Cu	5.0	0.0	1.7	5.2	2.4	9.7
Zn	179.6	57.3	171.6	84.5	136.7	137.2
Pb	15.0	13.8	15.3	14.6	16.3	19.1
La	47.6	50.2	53.1	47.6	41.1	43.6
Ce	87.4	94.6	90.0	94.1	84.6	105.6
Th	7.5	9.8	7.8	8.4	9.3	8.4
Nd	51.0	50.4	53.6	46.5	43.4	49.7
U	2.3	3.6	3.4	3.1	1.3	3.2

Table F2 continued.

Sample	CR-U10a	CR-U10b	CR-U11a	MS-PICT 1-A	MS-PICT 1-X1	CR-U28a
ICP-MS (ppm)						
La	48.6	50.4	54.6	46.8	43.1	46.1
Ce	89.5	97.9	91.2	94.9	88.7	104.6
Pr	13.0	13.6	13.8	12.3	11.4	12.7
Nd	52.9	54.6	55.3	49.4	45.7	50.6
Sm	12.6	12.7	12.5	11.5	10.6	11.5
Eu	2.6	2.3	2.5	2.2	2.0	2.3
Gd	13.0	12.8	12.8	11.9	10.8	10.9
Tb	2.4	2.3	2.3	2.1	1.9	1.9
Dy	15.4	15.0	14.5	13.5	12.6	12.2
Ho	3.3	3.2	3.0	2.9	2.7	2.6
Er	9.4	9.2	8.6	8.1	7.7	7.3
Tm	1.4	1.4	1.3	1.2	1.2	1.1
Yb	9.1	9.1	8.3	7.8	7.6	7.0
Lu	1.5	1.5	1.3	1.2	1.2	1.1
Ba	1532.1	1717.8	1699.8	1400.6	1623.3	1312.3
Th	6.7	7.5	7.0	7.0	7.1	8.5
Nb	20.4	21.2	21.2	19.8	20.9	24.2
Y	84.1	84.4	81.6	74.3	70.2	66.0
Hf	9.5	10.8	10.0	10.3	10.3	11.7
Ta	1.3	1.4	1.3	1.3	1.3	1.5
U	3.0	3.1	2.9	3.0	3.0	2.7
Pb	14.7	14.0	16.0	15.2	17.3	18.3
Rb	38.1	73.8	70.7	78.5	75.4	61.1
Cs	1.4	1.8	3.0	2.8	3.1	2.5
Sr	157.7	119.3	109.3	101.2	86.5	86.0
Sc	7.6	2.8	4.8	5.3	2.8	7.2
Zr	368.2	412.2	390.5	396.1	398.8	459.5

Table F2 continued.

Sample	CR-U28b	CR-U28f	MS-10-1	MS-10-1 LI1	MS-10-20.2	MS-11- 30drk
XRF normalized (weight %)						
SiO ₂	73.2	73.5	70.5	74.5	70.1	74.2
TiO ₂	0.2	0.3	0.5	0.2	0.2	0.3
Al ₂ O ₃	14.1	13.3	13.5	13.0	14.1	13.3
FeO*	4.0	3.5	5.0	2.7	3.0	2.6
MnO	0.1	0.1	0.1	0.1	0.1	0.1
MgO	0.1	0.1	1.1	0.1	0.5	0.3
CaO	0.9	1.0	2.3	1.0	4.4	1.0
Na ₂ O	1.9	2.6	3.4	3.7	3.1	2.7
K ₂ O	5.5	5.6	3.4	4.7	4.4	5.6
P ₂ O ₅	0.0	0.0	0.1	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
XRF (ppm)						
Ni	2.8	1.2	8.4	1.8	0.0	2.8
Cr	3.7	10.1	19.8	2.5	2.9	4.4
Sc	4.0	6.0	13.1	4.3	6.3	3.6
V	14.6	8.8	32.9	3.3	5.7	8.2
Ba	1483.9	1710.0	1188.3	1539.1	1102.2	1445.1
Rb	93.2	75.2	62.7	74.8	72.2	76.4
Sr	83.9	100.6	189.4	87.4	269.6	93.8
Zr	418.8	392.1	308.1	390.5	317.9	390.4
Y	67.3	69.5	59.4	70.8	48.6	73.4
Nb	21.9	21.2	17.8	21.9	12.4	21.7
Ga	23.4	22.3	20.7	21.7	19.7	21.2
Cu	6.8	3.9	9.6	2.8	3.2	5.5
Zn	165.2	122.8	143.6	128.9	144.7	134.3
Pb	15.6	25.6	13.4	13.4	9.0	15.8
La	38.9	40.3	33.4	43.4	25.0	44.5
Ce	83.0	85.4	68.9	81.9	47.9	90.7
Th	8.7	7.6	5.2	7.2	6.9	6.4
Nd	42.2	42.5	39.5	40.7	29.1	44.6
U	2.7	3.2	2.3	3.1	1.9	4.1

Table F2 continued.

Sample	CR-U28b	CR-U28f	MS-10-1	MS-10-1 LI1	MS-10- 20.2	MS-11- 30drk
ICP-MS (ppm)						
La	41.0	40.5	34.3	41.7	29.3	43.9
Ce	85.6	82.1	70.8	86.7	57.3	90.7
Pr	11.0	10.7	9.3	11.0	8.0	11.6
Nd	44.2	42.3	37.8	43.8	32.0	46.7
Sm	10.3	10.0	8.9	10.1	7.4	10.9
Eu	1.7	1.8	2.1	1.9	1.4	2.2
Gd	10.3	10.3	9.2	10.4	7.7	11.1
Tb	1.8	1.8	1.6	1.9	1.4	2.0
Dy	11.9	12.0	10.5	12.2	9.1	12.8
Ho	2.5	2.6	2.2	2.6	2.0	2.8
Er	7.2	7.4	6.3	7.6	5.6	7.8
Tm	1.1	1.1	0.9	1.1	0.9	1.2
Yb	7.0	7.1	6.0	7.4	5.5	7.6
Lu	1.1	1.2	1.0	1.2	0.9	1.2
Ba	1512.4	1741.0	1226.0	1610.9	1228.4	1483.5
Th	7.6	7.1	5.7	7.1	7.3	7.2
Nb	21.3	21.1	17.2	20.4	12.6	21.1
Y	65.4	67.2	56.7	67.3	50.8	71.9
Hf	10.7	10.2	8.0	10.2	9.1	10.3
Ta	1.4	1.3	1.1	1.3	0.9	1.3
U	2.8	2.9	2.4	3.0	3.1	3.0
Pb	14.8	25.5	12.1	11.8	7.6	15.4
Rb	91.3	74.4	60.8	74.7	76.7	76.3
Cs	3.1	3.0	2.4	3.0	3.9	3.2
Sr	84.8	99.6	187.7	86.5	279.9	96.8
Sc	4.0	5.8	13.9	4.3	6.7	4.0
Zr	424.9	399.0	317.9	404.1	351.7	424.7
*Unnormalized values.						

Table F2 continued.

Sample	MS-11-30 lit	MS-11-32	MS 14-24b*	MS15-21A*	MS15-25A*
XRF normalized (normalized weight %)					
SiO ₂	74.5	75.1	75.1	74.2	75.6
TiO ₂	0.2	0.2	0.2	0.2	0.2
Al ₂ O ₃	13.3	13.4	12.6	12.9	13.3
FeO*	2.7	2.2	3.2	2.7	1.5
MnO	0.1	0.0	0.0	0.1	0.0
MgO	0.2	0.0	0.1	0.1	0.1
CaO	1.0	0.8	0.6	0.9	0.4
Na ₂ O	3.1	3.2	4.5	3.0	4.7
K ₂ O	5.0	4.9	3.7	6.0	4.1
P ₂ O ₅	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	99.0	95.4	98.1
XRF (ppm)					
Ni	1.3	1.8	4.5	3.8	2.4
Cr	3.8	3.3	3.9	1.2	2.0
Sc	4.6	2.9	3.1	2.3	2.7
V	5.1	2.8	3.8	1.9	6.0
Ba	1452.3	1559.3	1574.2	1566.9	1665.4
Rb	78.9	72.3	74.3	84.0	73.3
Sr	100.1	87.9	88.8	93.5	89.8
Zr	391.3	397.8	392.9	391.8	423.2
Y	70.2	72.9	55.6	72.4	49.7
Nb	22.3	21.6	22.1	21.3	23.1
Ga	22.9	22.5	22.2	21.5	22.7
Cu	4.4	2.7	2.9	3.3	2.0
Zn	135.3	128.7	115.0	137.1	113.4
Pb	16.1	17.3	12.5	15.8	14.8
La	43.3	41.3	38.8	41.1	30.8
Ce	88.2	86.9	74.5	88.6	64.0
Th	7.2	6.8	7.2	7.6	7.8
Nd	46.5	42.8	40.6	43.3	36.7
U	2.6	4.0	2.5	3.3	1.5

Table F2 continued.

Sample	MS-11-30 lit	MS-11-32	MS 14-24b	MS15-21A	MS15-25A
ICP-MS (ppm)					
La	44.5	44.3	39.3	43.9	37.2
Ce	89.9	88.9	77.1	90.4	67.5
Pr	11.8	11.8	10.5	11.6	9.8
Nd	47.0	47.2	41.2	46.4	39.3
Sm	10.9	10.9	9.6	10.6	9.0
Eu	2.2	2.1	2.1	2.1	2.2
Gd	11.0	10.8	9.1	10.9	8.4
Tb	2.0	2.0	1.6	2.0	1.5
Dy	12.6	12.9	10.3	12.7	9.5
Ho	2.7	2.7	2.2	2.7	1.9
Er	7.6	7.9	6.3	7.9	5.5
Tm	1.1	1.2	1.0	1.2	0.8
Yb	7.3	7.6	6.2	7.7	5.3
Lu	1.2	1.2	0.9	1.2	0.8
Ba	1484.8	1587.8	1608.4	1632.8	1733.6
Th	7.1	7.2	7.2	7.3	7.7
Nb	20.1	20.4	20.5	21.4	22.8
Y	68.7	71.6	53.3	71.7	49.1
Hf	10.4	10.6	10.3	10.4	11.2
Ta	1.3	1.3	1.3	1.4	1.4
U	2.8	3.0	2.8	3.0	2.4
Pb	15.0	15.7	12.1	15.7	14.3
Rb	79.7	72.3	74.1	81.9	71.9
Cs	3.3	3.0	2.6	3.3	1.5
Sr	103.7	91.3	90.0	95.7	94.5
Sc	4.0	3.0	2.8	2.9	2.8
Zr	418.9	433.6	395.7	402.1	433.5
* Unnormalized values.					

Table F3. Unit 3 bulk tuff major and trace element geochemical data from Streck et al. (2015) and Streck pers. comm. (2017).

Sample	MS-10-26	MS-10-BCT1	MS-U35a	MS12-33.1
XRF normalized (weight %)				
SiO ₂	76.6	71.2	74.1	75.1
TiO ₂	0.2	0.7	0.3	0.4
Al ₂ O ₃	12.1	13.3	13.2	13.1
FeO*	1.6	4.8	2.6	3.6
MnO	0.1	0.1	0.1	0.1
MgO	0.1	1.2	0.1	0.1
CaO	0.4	1.8	0.5	0.8
Na ₂ O	3.3	2.7	3.2	1.9
K ₂ O	5.7	3.9	6.1	4.8
P ₂ O ₅	0.0	0.3	0.0	0.0
Total	100.0	100.0	100.0	100.0
XRF unnormalized (ppm)				
Ni	2.0	8.0	4.0	4.1
Cr	4.0	14.6	3.4	5.9
Sc	5.0	12.5	1.7	5.2
V	6.0	52.8	6.3	18.4
Ba	797.0	816.2	1815.4	1168.4
Rb	89.0	71.1	84.6	78.4
Sr	16.0	91.8	54.4	47.1
Zr	306.0	341.3	390.2	372.6
Y	88.0	57.4	62.1	61.5
Nb	27.5	22.7	24.3	23.0
Ga	20.0	18.9	22.0	20.3
Cu	1.0	11.4	2.9	3.9
Zn	108.0	123.2	149.1	138.9
Pb	18.0	14.9	15.1	15.4
La	41.0	38.9	44.6	40.1
Ce	91.0	84.1	82.8	85.1
Th	8.0	5.6	6.6	7.3
Nd	49.0	40.9	43.7	43.1
U	3.0	1.6	1.8	3.7

Table F3 continued.

Sample	MS-10-26	MS-10-BCT1	MS-U35a	MS12-33.1
ICP-MS (ppm)				
La	41.8	41.4	46.3	39.6
Ce	95.5	85.0	92.0	82.9
Pr	12.5	10.8	11.7	10.4
Nd	50.1	42.2	46.2	41.2
Sm	13.1	9.4	10.3	9.3
Eu	1.7	1.9	1.9	1.6
Gd	13.3	9.1	9.9	8.9
Tb	2.5	1.6	1.8	1.6
Dy	15.8	10.1	11.2	10.5
Ho	3.4	2.2	2.4	2.2
Er	9.4	6.0	6.7	6.3
Tm	1.4	0.9	1.0	1.0
Yb	9.1	5.9	6.7	6.2
Lu	1.4	1.0	1.1	1.0
Ba	825.0	835.3	1985.3	1175.2
Th	7.7	6.6	7.4	7.1
Nb	28.4	22.0	23.9	22.1
Y	86.2	56.5	62.0	58.4
Hf	9.3	8.7	10.3	9.6
Ta	1.8	1.3	1.3	1.4
U	3.3	2.6	3.3	4.3
Pb	17.4	12.5	15.2	13.8
Rb	91.0	72.0	88.6	77.8
Cs	3.2	2.6	2.9	3.6
Sr	16.0	91.4	52.8	49.0
Sc	6.0	13.2	4.8	4.6
Zr	328.0	355.8	423.9	374.7
* Unnormalized values.				

Table F3 continued.

Sample	MS-12-38	CR-U33c	EBC12-074*
XRF normalized (weight %)			
SiO ₂	73.3	72.2	75.0
TiO ₂	0.6	0.2	0.2
Al ₂ O ₃	13.7	14.2	12.8
FeO*	4.1	2.9	2.6
MnO	0.1	0.1	0.0
MgO	0.4	0.6	0.0
CaO	1.2	2.1	0.3
Na ₂ O	1.4	3.3	2.5
K ₂ O	4.9	4.3	6.5
P ₂ O ₅	0.1	0.1	0.0
Total	100.0	100.0	94.0
XRF unnormalized (ppm)			
Ni	7.4	1.1	N/A
Cr	9.1	1.7	N/A
Sc	9.9	6.0	N/A
V	40.6	6.8	N/A
Ba	784.0	1083.7	N/A
Rb	122.4	77.0	N/A
Sr	71.4	122.2	N/A
Zr	373.4	348.6	N/A
Y	55.6	61.8	N/A
Nb	23.6	14.0	N/A
Ga	21.2	20.8	N/A
Cu	12.1	2.9	N/A
Zn	120.2	148.4	N/A
Pb	15.0	13.5	N/A
La	41.0	27.8	N/A
Ce	83.5	65.5	N/A
Th	6.9	7.0	N/A
Nd	40.1	34.9	N/A
U	3.1	2.9	N/A

Table F3 continued.

Sample	MS-12-38	CR-U33c	EBC12-074*
ICP-MS (ppm)			
La	41.4	33.0	N/A
Ce	84.9	67.8	N/A
Pr	10.7	9.0	N/A
Nd	41.8	36.8	N/A
Sm	9.2	8.7	N/A
Eu	1.7	1.4	N/A
Gd	8.7	9.0	N/A
Tb	1.5	1.6	N/A
Dy	9.9	10.5	N/A
Ho	2.1	2.3	N/A
Er	5.8	6.5	N/A
Tm	0.9	1.0	N/A
Yb	5.8	6.4	N/A
Lu	0.9	1.0	N/A
Ba	781.6	1105.2	N/A
Th	7.3	6.9	N/A
Nb	22.7	13.6	N/A
Y	53.0	60.0	N/A
Hf	9.4	9.3	N/A
Ta	1.3	0.9	N/A
U	2.8	3.4	N/A
Pb	14.2	12.7	N/A
Rb	118.2	76.9	N/A
Cs	3.5	3.4	N/A
Sr	73.0	121.7	N/A
Sc	10.3	6.6	N/A
Zr	370.5	366.7	N/A
* Unnormalized values.			

Table F4. Unit 4 bulk tuff major and trace element geochemical data from Streck et al., (2015).

Sample	MS-11-11	MS-11-20	MS-12-20*	MS-15-20A*	MS-10-20.1
XRF normalized (weight %)					
SiO ₂	66.6	68.0	67.0	69.0	70.0
TiO ₂	1.2	1.1	1.2	0.7	0.4
Al ₂ O ₃	14.8	14.5	14.7	14.0	14.5
FeO*	7.1	5.7	6.2	4.8	4.9
MnO	0.2	0.1	0.2	0.1	0.1
MgO	1.6	1.1	0.9	1.1	0.4
CaO	3.0	3.0	3.2	2.3	2.7
Na ₂ O	2.5	3.1	2.5	4.0	2.5
K ₂ O	2.7	3.0	3.4	3.7	4.4
P ₂ O ₅	0.4	0.4	0.7	0.3	0.2
Total	100.0	100.0	93.3	95.3	100.0
XRF unnormalized (ppm)					
Ni	6.0	3.6	4.1	3.1	1.2
Cr	12.5	6.9	5.6	1.1	4.2
Sc	17.3	16.4	17.2	11.0	12.3
V	84.6	68.7	67.5	46.0	10.1
Ba	1026.5	1296.4	1234.6	1485.5	1289.0
Rb	47.8	54.1	59.6	59.2	75.0
Sr	207.8	233.6	234.7	176.1	227.4
Zr	255.2	272.4	277.6	317.6	294.3
Y	48.4	50.5	52.1	60.0	57.3
Nb	16.2	17.7	18.2	20.6	14.4
Ga	19.9	21.3	19.7	20.4	21.5
Cu	9.6	6.6	11.4	4.7	5.4
Zn	139.5	140.8	141.9	147.2	175.8
Pb	10.0	10.6	11.4	11.8	12.6
La	28.6	33.7	32.2	38.3	29.1
Ce	70.2	67.7	71.8	72.3	59.4
Th	4.7	5.6	5.8	5.8	6.1
Nd	38.1	39.0	39.2	42.0	31.9
U	2.9	1.8	2.5	2.6	1.8

Table F4 continued.

Sample	MS-11-11	MS-11-20	MS-12-20	MS-15-20A	MS-10-20.1
ICP-MS (ppm)					
La	30.6	33.5	34.3	39.8	29.1
Ce	65.2	69.9	71.6	79.6	59.2
Pr	8.6	9.1	9.6	10.6	8.0
Nd	35.8	37.9	39.4	42.9	32.4
Sm	8.2	8.8	9.0	9.8	7.8
Eu	2.3	2.4	2.4	2.5	1.7
Gd	8.3	8.8	9.0	9.7	8.2
Tb	1.4	1.5	1.5	1.7	1.5
Dy	8.7	9.2	9.4	10.6	9.7
Ho	1.8	1.9	1.9	2.2	2.1
Er	5.0	5.3	5.4	6.3	6.0
Tm	0.7	0.8	0.8	1.0	0.9
Yb	4.6	5.0	5.1	6.1	5.8
Lu	0.8	0.8	0.8	1.0	1.0
Ba	1021.3	1319.0	1234.1	1519.5	1330.8
Th	4.9	5.3	5.4	6.2	6.7
Nb	15.7	17.3	17.4	20.4	13.5
Y	46.8	50.1	50.6	59.5	55.5
Hf	6.4	7.1	7.1	8.4	7.8
Ta	1.0	1.1	1.1	1.3	0.8
U	2.2	2.5	2.4	2.9	2.8
Pb	9.7	10.6	11.5	12.3	12.0
Rb	45.9	53.7	57.3	57.2	75.1
Cs	2.1	2.3	2.4	2.0	3.6
Sr	211.4	239.3	239.7	181.0	226.3
Sc	17.2	16.5	16.4	11.0	12.4
Zr	251.0	278.2	273.4	327.2	307.5
* Unnormalized values.					