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# Field, Petrographic, and Geochemical Characteristics of Price Creek

BY RUSS MCCORMACK

Russ McCormack wrote this piece under the mentorship of Dr. Michael Krol.

## Abstract

**G**eologic mapping in the southeastern portion of the Blacktail Mountains has revealed a more diversified stratigraphic sequence than previously documented. Prior mapping of this area has shown it as a single volcanic unit composed of a maroon rhyolite tuff, possibly erupted from the Eocene Dillon volcanic center located ~50 km to the northwest. Our mapping allowed us to further subdivide this unit, which we term the Price Creek unit (PCu), into two distinct lithologies based on mesoscopic characteristics; 1) a basal volcanic breccia and 2) a rhyolitic tuff.

This study focuses on petrographic and geochemical analyses of the PCu in an effort to better define and elucidate its petrogenesis. The lowermost unit of the PCu is a maroon, coarse-grained, matrix-supported volcanic breccia that unconformably overlies Archean gneiss. It contains subangular clasts (1-10 cm) of predominately granitic gneiss with crystal fragments of quartz and feldspar. The contact between the basal breccia and the gneiss is sharp and highly irregular. Locally, maroon, aphanitic veinlets cross-cut and intrude parallel to the gneissic foliation in basement outcrops. The breccia is overlain by an aphanitic, maroon rhyolitic tuff. Petrographic analysis reveals it contains angular to subrounded lithic and dominantly quartz crystal fragments with rare euhedral quartz phenocrysts set in a microcrystalline groundmass.

Preliminary XRF analysis of PCu rhyolite tuff reveal a very high SiO<sub>2</sub> content (85%) and a severe depletion of all other major element oxides with the exception of aluminum and iron (<1 wt% K<sub>2</sub>O, Na<sub>2</sub>O, CaO, MgO). The extreme enrichment of silica, depletion in other elements, and hematitic staining strongly suggests major geochemical alteration and modification following the formation of the rhyolite. The precise timing and nature of this alteration event is poorly



constrained but may be related to the development and hydrothermal activity associated with the post-Laramide normal movement on the Jake Canyon fault. The Jake Canyon fault, which marks the range front at Price Creek, is highly silicified with large masses of vein quartz (locally 10s of meters in thickness) found along its trace. Hydrothermal fluids permeated footwall and hanging wall rocks causing hydrothermal alteration 100s of meters from the fault.

## Introduction

Southwestern Montana is characterized by a number of ancient magmatic centers that erupted throughout the Eocene (40-50 Ma). Rocks that occur at the southeastern end of the Blacktail Mountains in the Price Creek and Teddy Creek stream drainages have previously been mapped as a single stratigraphic unit composed of volcanic rhyolite tuff and lava flows resting unconformably on top of 2.7 Ga Archean gneiss (Lonn et al., 2000). These workers correlated these rhyolite tuff/lava units with volcanic rocks just west of the town of Dillon, MT and speculated they are related to activity associated with an Eocene-age (~41 Ma) magmatic center that is located approximately 50 km away. In an effort to elucidate the origins and geologic history of volcanic rocks in the Price Creek drainage we conducted detailed geologic mapping and performed a petrographic and geochemical comparison between the Dillon and Price Creek volcanics.

Our mapping in the southern end of the Blacktail range has revealed a more complex and distinctive stratigraphic sequence than previously recognized. On the basis of field relationships we have subdivided this unit, which we term the Price Creek unit (PCu) into: 1) a basal volcanic breccia; and 2) an overlying interlayered sequence of rhyolitic tuff and lava flows. The basal volcanic breccia displays characteristics suggestive of an intrusive relationship with the surrounding country rock. The overlying sequence of tuff and lava flows are characterized by textures and features indicative of sub-aerial eruption and deposition. Petrographic analysis reveals

the Price Creek volcanic rocks contain phenocrysts and phenoclasts of quartz set in a glassy and hematite-rich matrix. In contrast, field observations of the Dillon volcanic rocks show that they occur predominantly as felsic lava flows that are commonly deformed into overturned flow folds characteristic of a high viscosity lava. Petrographically, the Dillon volcanic rocks contain abundant phenocrysts of plagioclase, which are often chemically zoned, biotite, and minor quartz set within a cryptocrystalline matrix.

Preliminary geochemical analysis revealed that the Dillon volcanic rocks can be classified as rhyolite on the basis of their total alkali ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ) vs.  $\text{SiO}_2$  content (Le Bas et al., 1986). The Price Creek volcanics however, exhibit unusually high silica contents and a significant depletion of most major oxides. The geochemical signature recorded in the Price Creek rocks may be the result of post-crystallization hydrothermal alteration. Tysdal et al. (1990) documented a period of major hydrothermal activity along the trace of the Jake Canyon fault during Late Cretaceous time. We suggest this event may have affected volcanic rocks of the Price Creek unit resulting in the silicification and depletion of the major chemical oxides. If the alteration of the PCu is related to the hydrothermal activity along the Jake Canyon fault, then the PCu must be at least Late Cretaceous in age, and could not be the result of the magmatic activity associated with the Eocene-age Dillon volcanic center.

## Local Geologic Setting

The Blacktail Mountains occur within the Rocky Mountain Basin and Range province of the western U.S. Cordillera. The Blacktail range extends approximately 50 kilometers along a northwest-southeast trend and is between 5-6 kilometers wide (fig. 1A). The Blacktail Mountains are one of numerous basement-cored uplifted blocks that occur throughout southwest Montana. These uplifted blocks formed as a result of compressive stresses along the Jake Canyon fault during the Laramide Orogeny. The front of the



Blacktail range is marked by the Laramide-age Jake Canyon reverse fault and the younger Blacktail Deer Creek normal fault (Tysdal, 1990). The Blacktail Deer Creek fault is responsible for the recent uplift of the range and the present day topography.

The core of the Blacktail range consists of 2.7 Ga Archean metamorphic granitic gneiss and interlayered amphibolite which are intruded by several presumably Proterozoic (1.4 Ga) mafic bodies. In the northwestern portion of the Blacktail Mountains, the basement rocks are overlain by a thick sequence of Paleozoic and Mesozoic sedimentary rocks with Cenozoic volcanic rocks at the extreme north end (fig. 1B). However, in the southern portion of the mountain range these rocks have been eroded away with only Cenozoic volcanic and sedimentary rocks resting unconformably on top of the Archean gneiss. Following deposition of the sedimentary and volcanic rocks this region experienced several phases of brittle deformation and the development of several large scale faults (fig. 1C; Muller & Krol, 2004).

## Field Relations and Petrographic Analysis

### Dillon Volcanics

The Dillon volcanic rocks exhibit different field characteristics and mineralogical composition than volcanic rocks of the PCu. The Dillon volcanics represent a series of rhyolitic lava flows extruded from a volcanic center at the NW end of the Blacktail range approximately 41 Ma (fig. 1A & B; Fritz et al., 1989). The unit displays well developed flow banding (fig. 4A) with layers commonly deformed into overturned and recumbent flow folds (fig. 4B-D).

Petrographic analysis of the Dillon volcanic rocks illustrate these rocks contain abundant phenocrysts of plagioclase, biotite, and quartz. Plagioclase occurs as euhedral and tabular crystals approximately 2.0-5.0 mm in size. Plagioclase phenocrysts are commonly chemically zoned (fig. 4E). These crystals are often embayed indicating resorption in the magma chamber. Biotite occurs as long needle-like phe-

nocrysts, 0.25-5.0 mm in size and commonly contain a rim of opaque minerals (fig. 4F). The matrix is composed of fine-grained quartz, microlites of plagioclase and flakes of biotite. The matrix is also composed of devitrified glass and displays pilotaxitic texture indicating that the groundmass was molten. Pilotaxitic texture is a texture that shows crystals in the matrix align and wrap around phenocrysts.

The Price Creek stream drainage contains rocks that display a more diversified stratigraphy than previously recognized. On the basis of our geologic mapping, we have identified a generalized stratigraphic sequence shown in figure 2. Archean metamorphic gneiss forms the crystalline basement of the range. Lying unconformably above the gneiss is a sequence of maroon colored volcanic rocks which we term the Price Creek unit (PCu). The PCu consists of two distinct lithologies; a basal volcanic breccia and an overlying interlayered sequence of rhyolite tuff and lava flows. Stratigraphically above the PCu is a previously unrecognized clastic sedimentary unit consisting of interlayered conglomerate, sandstone, and volcanic ash (Muller & Krol, 2004).

### PCu Volcanic Breccia Characteristics

The PCu breccia displays sharp and irregular contacts with the Archean gneiss,

contains xenoliths of the gneiss (fig. 3A), and numerous maroon veinlets cross-cut and intrude parallel to gneissic foliation (fig. 3B& C). The xenoliths within the breccia are typically 1-100 cm in size and consist mainly of granitic gneiss. These clasts are composed dominantly of microcline and quartz with minor biotite and muscovite mica.

Some of these clasts have small veinlets of chlorite. The breccia matrix is very fine-grained and largely stained by hematite. The total stratigraphic thickness of this unit is difficult to determine unequivocally but we estimate it to be a minimum of 10 meters.

On the basis of field observation (xenoliths, intruding veinlets) we interpret the basal breccia as intrusive into the



Archean crystalline gneiss. Thus, making its total thickness difficult to determine.

### PCu Tuff and Lava Flow Characteristics

A sequence of alternating tuff and lava flows (fig. 3D) overlies the volcanic

breccia everywhere within the study area. These rocks are ultra fine-grained with sparse phenocrysts and phenoclasts. The fine-grained rhyolites exhibit planar layering that has an average strike of N35°E and a dip of 15-20°SE.

Petrographic analysis of the Price Creek volcanic rocks illustrate they completely lack hydrous mineral phases like biotite or amphibole. These rocks are dominated by phenocrysts and phenoclasts of mono- and polycrystalline quartz set in an ultra fine-grained matrix of quartz or devitrified glass. The tuffs are fine-grained and contain abundant fragments of euhedral to anhedral, angular to sub-rounded quartz along with lithic fragments (fig. 3E). Quartz exhibits undulose extinction indicating they are internally deformed and thus may be relict crystals derived from deformed metamorphic gneiss. These tuff units display broken crystals and uneven distribution, a typical characteristic of rocks derived from explosive eruptions (Allen & McPhie, 2003).

Petrographic analysis of the lava flow samples illustrate these rocks contain euhedral quartz surrounded by an ultra fine-grained matrix with tiny crystals of quartz (microlites) and glass. Microlites form as a result of syn-eruptive crystallization of the magma accompanied by slow cooling from high temperature following emplacement (Allen & McPhie, 2003). Quartz crystals commonly display a resorbed boundary indicative of the crystal reacting with a molten matrix (fig. 3F). The matrix also appears to display flow banding, also indicative of movement of a siliceous liquid.

### Geochemistry

Whole rock geochemistry was applied to rocks of the Price Creek unit and the Dillon volcanics in an effort to char-

acterize and compare or contrast their chemical compositions. Three samples of the PCu tuff and lava flows samples were used to compare them to samples collected from the Dillon lava flows. Samples of the PCu and Dillon rocks were crushed into cm sized fragments using a jaw crusher. The samples were powdered using a SPEX industrial mill/mixer with a tungsten-carbide ball. The powders were then fused into glass disks and were analyzed using X-ray fluorescence.

On a total alkali content ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ) versus silica ( $\text{SiO}_2$ ) plot (fig. 5), the Dillon volcanics fall within the rhyolite field and reflect typical igneous chemistry (table 1). However, volcanic rocks of the Price Creek unit display an unusually high  $\text{SiO}_2$  content and are largely depleted in total alkalis (fig. 5; table 1).

The extreme high  $\text{SiO}_2$  content found within the PCu, coupled with a severe depletion in all major oxides (with the exception of  $\text{Al}_2\text{O}_3$ ) suggest the Price Creek rocks were affected by a post-crystallization hydrothermal event (fig. 6). Major hydrothermal activity has been documented along the Jake Canyon fault (Tysdal et al., 1990). Tysdal et al. (1990) mapped the presence of large deposits of hydrothermal quartz bodies (up to 20 meters thick) along the Jake Canyon fault as well as significant alteration of the adjacent basement gneiss.

On the basis of apatite fission track dates from altered and unaltered rocks (ranging between 60 to 74 Ma), Tysdal et al. (1990) interpreted the hydrothermal event could be no younger than the apatite dates. In addition, they obtained a  $^{40}\text{Ar}/^{39}\text{Ar}$  whole rock date of  $48.1 \pm 0.3$  Ma from an unaffected basalt flow that caps the altered gneiss, which they interpret as a minimum age for the hydrothermal activity.

### Conclusions

A number of conclusions are drawn from our study:

1) On the basis of field and petrographic observations, as well as geochemical analysis, we interpret the Price Creek unit as a separate and distinct volcanic unit from the Dil-



lon rhyolite. Field evidence shows that the basal unit of the PCu represents an intrusive breccia into Archean granitic gneiss. The breccia contains clasts of Archean gneiss suggesting it may represent a localized magmatic center. Additionally, small aphanitic veinlets cross-cut and intrude parallel to gneissic layering, indicating the basement rocks were invaded by a molten phase and not simply a location of deposition of pyroclastic material. Overlying the breccia unit is a sequence of fine-grained volcanic tuff and lava flows indicating a change from a shallow level intrusion to a more extrusive style eruption.

2) Compositionally, volcanic rocks from the Price Creek unit and Dillon rhyolite are distinct. The PCu contains abundant quartz phenocrysts that are commonly embayed, indicating interaction with a still molten liquid, and are largely devoid of hydrous mineral phases suggesting they derived from a relatively dry magma. In contrast, the Dillon rhyolite contains hydrous phenocryst phases like biotite suggesting a more "wet" magma. In addition, abundant zoned plagioclase phenocrysts indicate a more calcium rich parental magma

than that of the highly siliceous Price Creek magma. However a more plausible explanation for the compositional diversity between the Dillon and the PCu might be the effects of post-crystallization hydrothermal alteration. Hydrothermal activity may have resulted in a removal of most major oxides and the significant silicification seen in the PCu. This hydrothermal activity may be related to movement along the Jake Canyon fault.

3) The age of magmatic activity in the southern end of the Blacktail range is uncertain. However, if the hydrothermal activity associated with the movement along the Jake Canyon fault is associated and correlative with the alteration of the PCu, then the PCu is most likely Late Cretaceous in age. In contrast, volcanism responsible for the Dillon rhyolite occurred approximately 41 Ma (Fritz et al., 1989). If our hypothesis is correct, the PCu unit represents a previously unknown and undocumented magmatic center that erupted in this portion of the Rocky Mountains.

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Table 1. Major oxide and trace element whole-rock geochemical data for the Dillon volcanics and Price Creek unit.

Sample #	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>
DV-4-0470.102	0.17	14.656	1.548	0.007	1.254	4.471	4.823	0.034	
DV-6-0472.034	0.175	15.242	1.631	-	1.246	4.305	5.105	0.046	
PCV-6-04	81.734	0.621	12.465	2.361	-	0.328	0.192	0.435	0.135
PC-11-04	84.066	0.158	11.009	1.008	-	0.146	0.028	0.188	0.011
PCV-15-04	86.964	0.086	9.513	0.009	-	0.144	0.074	0.156	0.018
PC-50c-05	86.996	0.302	6.124	1.836	-	2.076	0.159	0.425	0.009

Sample #	V	Rb	Sr	Y	Zr	Zn	Ba	Mn
DV-4-047.00	191.00	362.00	33.00	339.50	102.50	2008.00	315.00	
DV-6-043.00	180.90	374.40	33.00	347.80	106.90	2110.00	242.00	
PCV-6-04	110.80	115.69	367.10	35.71	280.28	104.30	97.00	0.00
PC-11-04	10.90	135.30	241.00	39.00	426.00	94.90	33.90	92.50
PCV-15-04	-	143.60	271.00	40.90	424.30	103.00	18.50	91.00
PC-50c-05	48.63	146.90	224.97	26.00	226.25	120.02	-	-

Trace elements reported in parts per million (ppm)

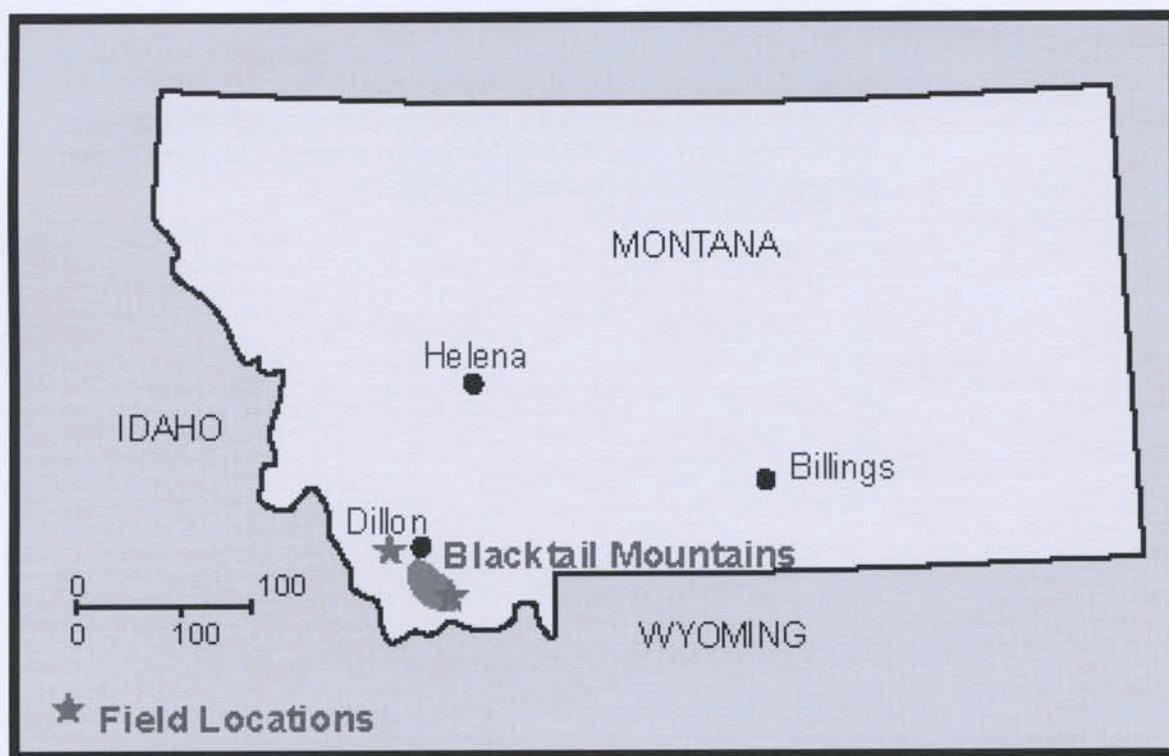
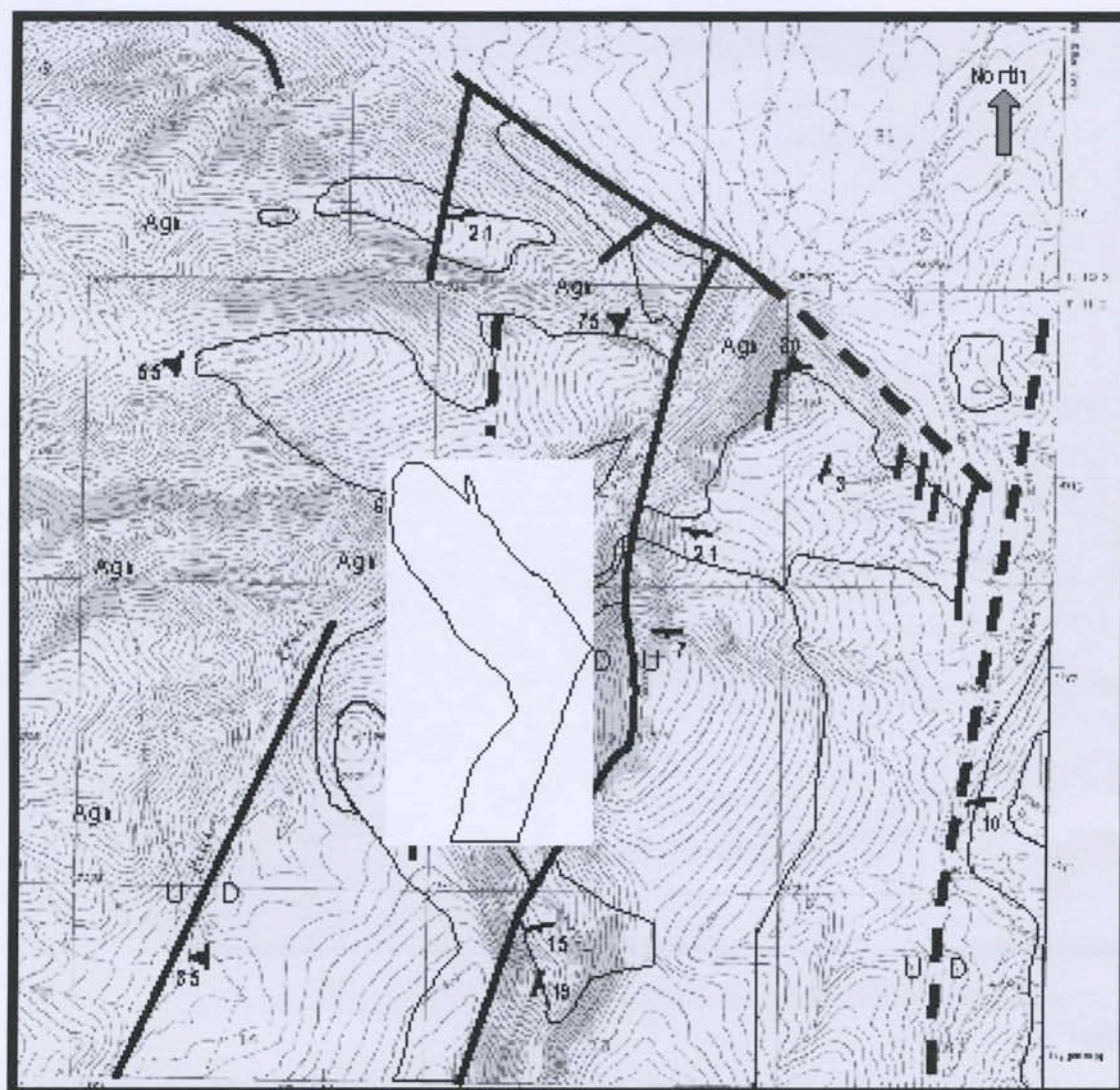








Figure 1A. Location of Blacktail Mountains and field locations for Price Creek and Dillon volcanic units.





### Lithologic

-  Quaternary alluvium
-  Six Mile Creek Formation
-  Renova
-  Teddy Creek
-  Price Creek Unit
-  Archean Gneiss

### Structural





-  strike & dip of
-  strike & dip of
-  fault (dashed where inferred)
-  geologic

Figure 1C. Geologic map of the SE portion of the Blacktail Mountains, Montana. Mapping of the Price Creek volcanic unit based on work of Muller & Krol, 2004; Rofe & Krol, 2004.



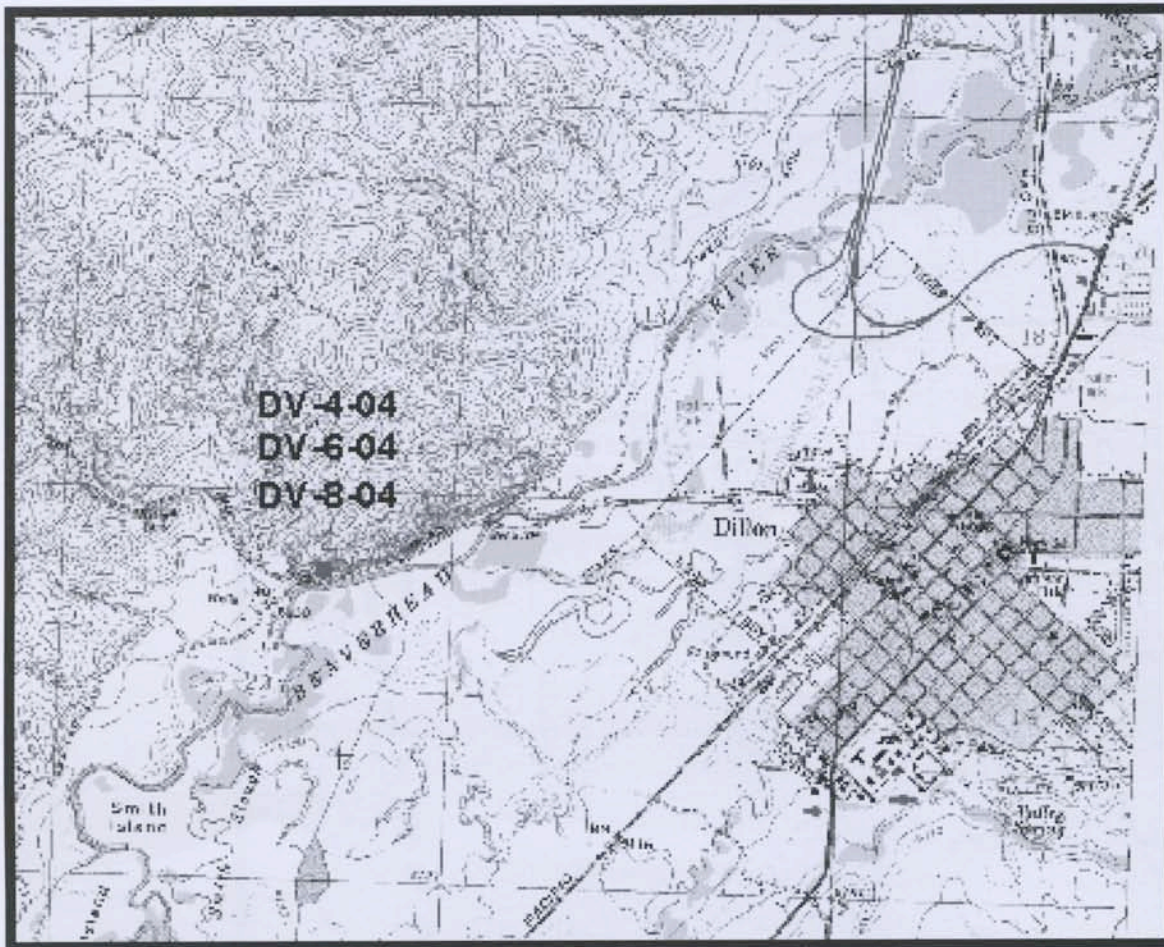


Figure 1B. Portion of the 1:24,000 Dillon West 7½ minute quadrangle showing sample locations of Dillon volcanic lava flow used in comparison with Price Creek volcanic rocks.



## Generalized Lithologic Column Price and Teddy Creek Area

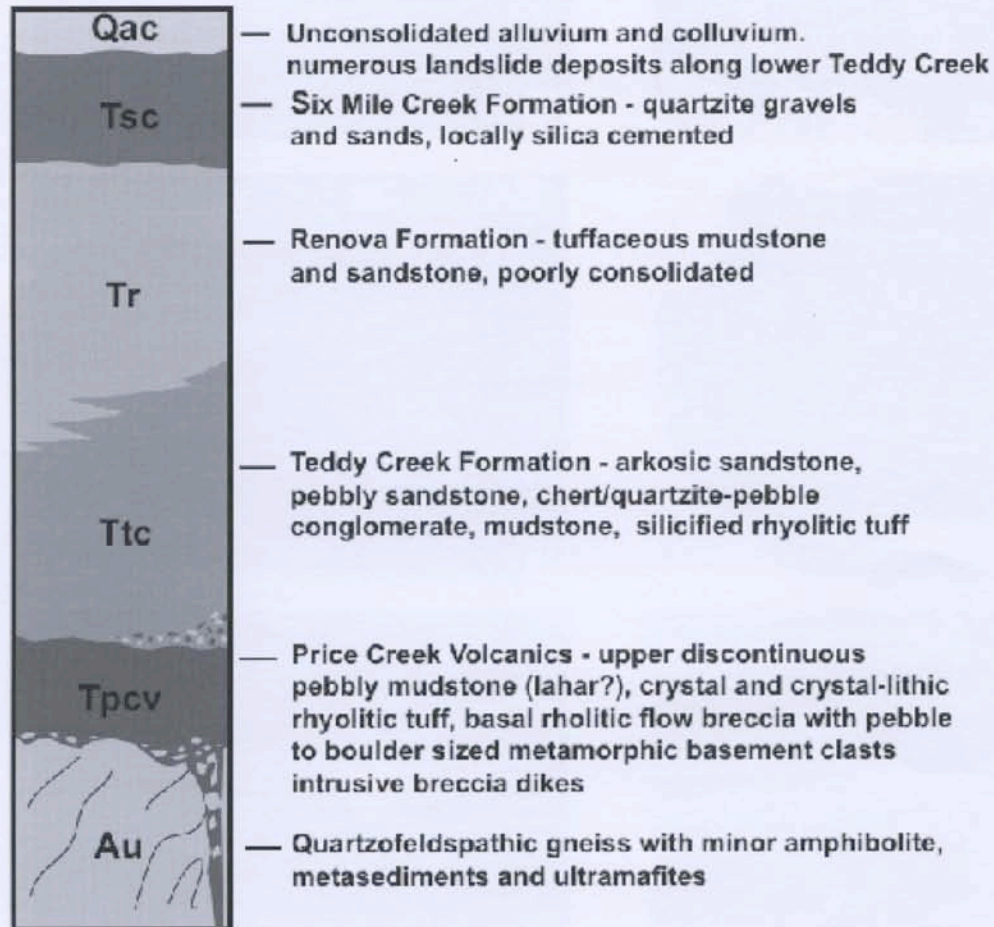


Figure 2. Generalized stratigraphic column showing the units present in the southern portion of the Blacktail Mountains.

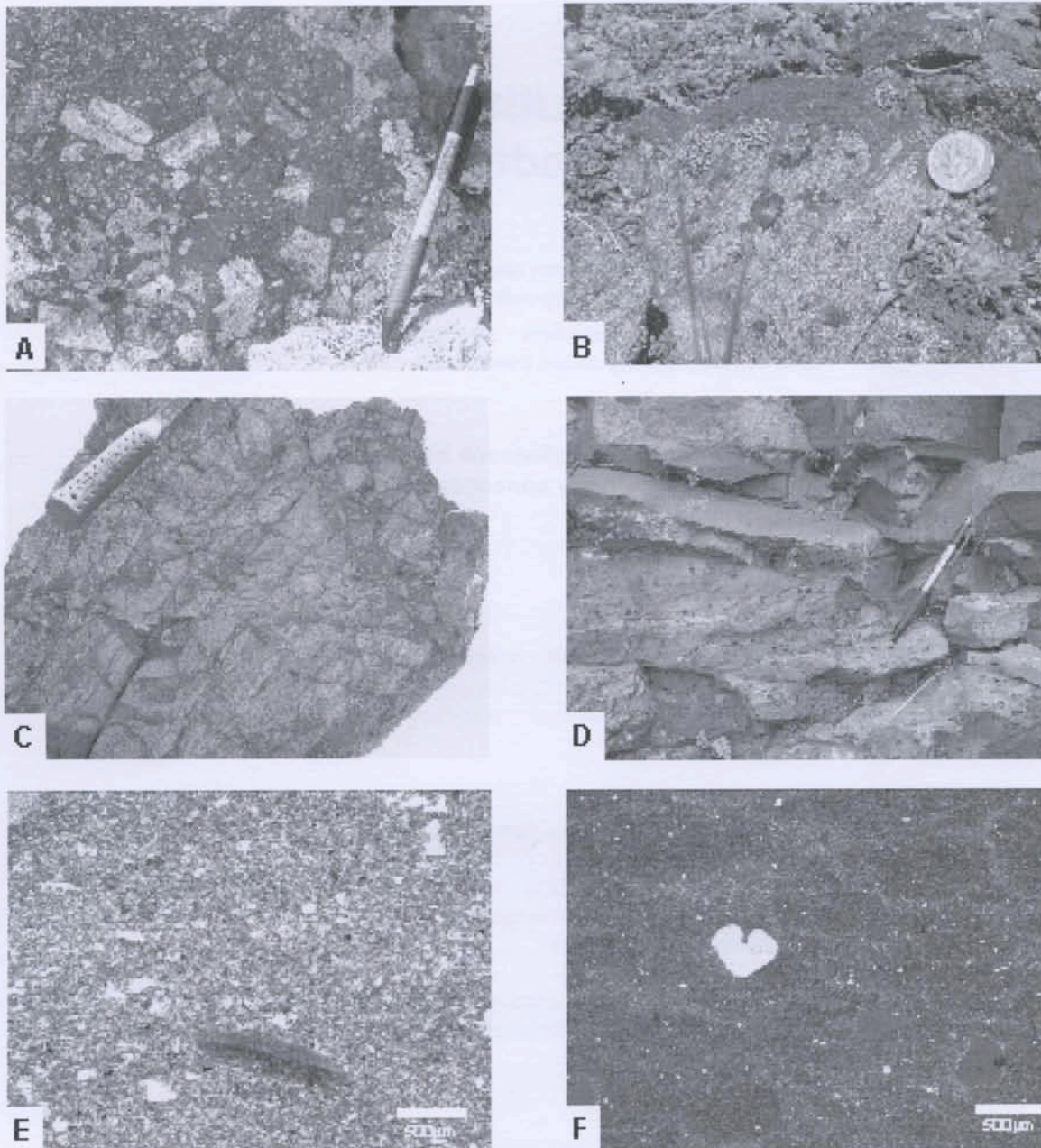


Figure 3. A) Typical basal, maroon colored breccia of the Price Creek unit. Clasts consist mainly of granitic gneiss and crystal fragments. B) Small aphanitic veins intruding basement gneiss. C) Contact between Archean gneiss and Price Creek breccia is nearly subvertical. D) Fine-grained volcanic tuff and lava flow unit that overlies the breccia unit. Note the possible presence of vesicles. E) Photomicrograph of Price Creek tuff. Note small lithic fragment and angular quartz crystal fragments (PPL). F) Embayed quartz phenocryst in a darkened glassy matrix from a lava flow layer (XPL).



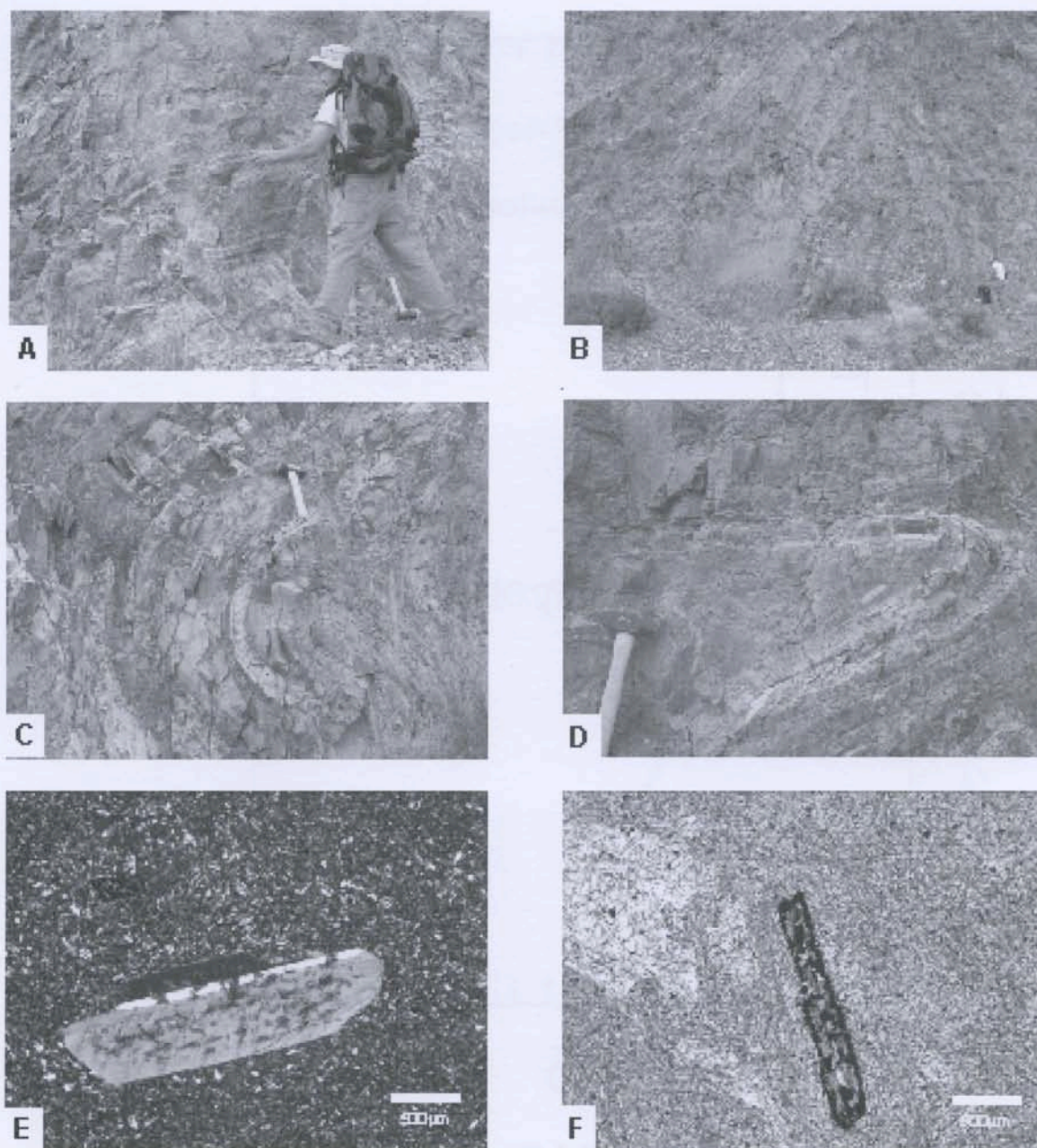


Figure 4. A) Flow banding in Dillon lava flow. B) Layering and large overturned flow folds in Dillon lava. C & D) Recumbent flow folds in Dillon lava flows. E) Zoned plagioclase phenocryst within a finer-grained groundmass of plagioclase, quartz, and biotite (XPL). F) Biotite phenocryst set in a glassy matrix and finer-grained biotite groundmass. Note the radiating nature of crystallites in matrix (PPL).

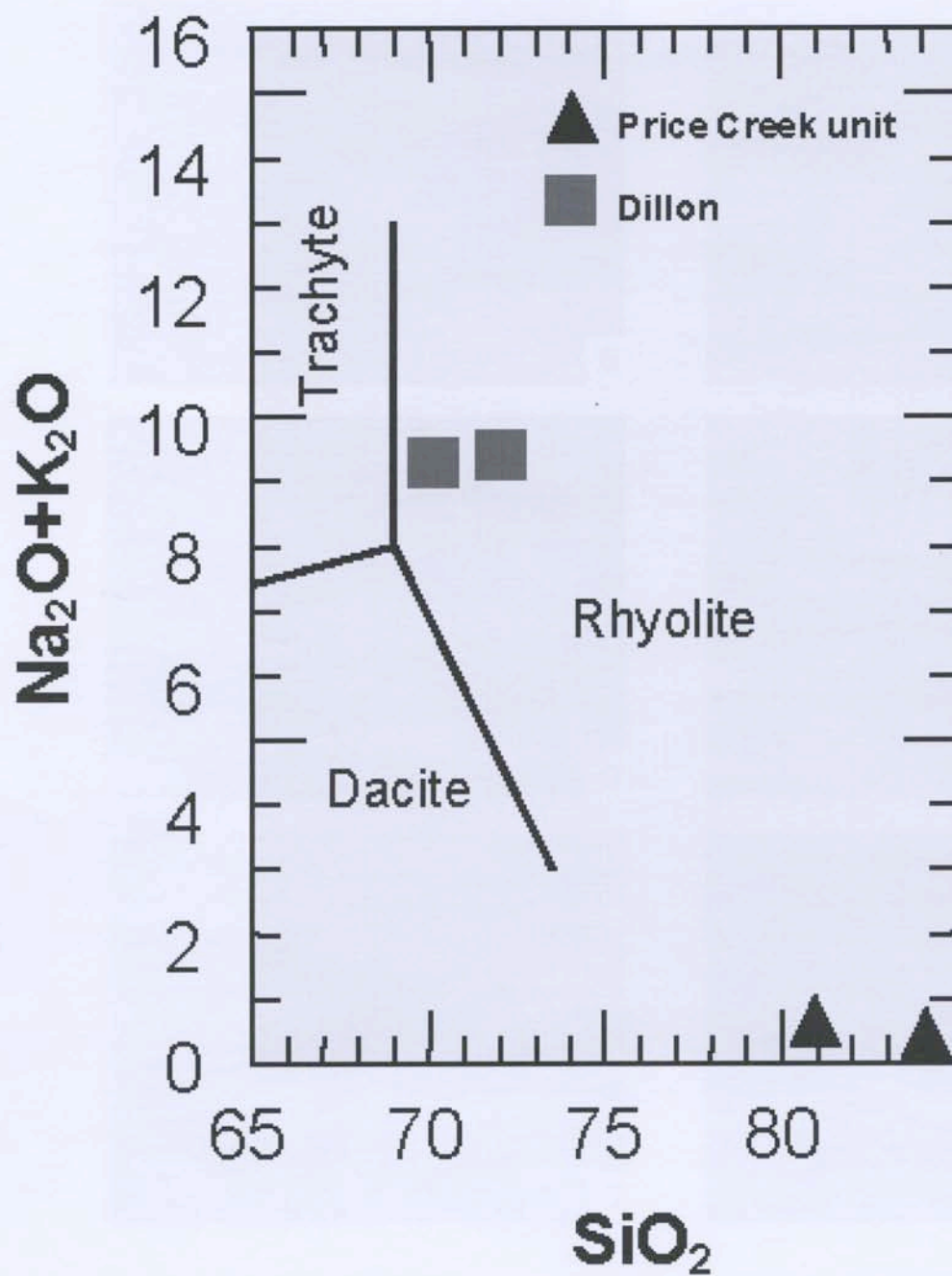


Figure 5. Total Alkalis versus  $\text{SiO}_2$  diagram for the Dillon volcanic rocks and the Price Creek unit. Dillon rocks plot as a typical rhyolite whereas the Price Creek rocks plot at extremely low alkali contents and high silica (LeBas et al., 1986)



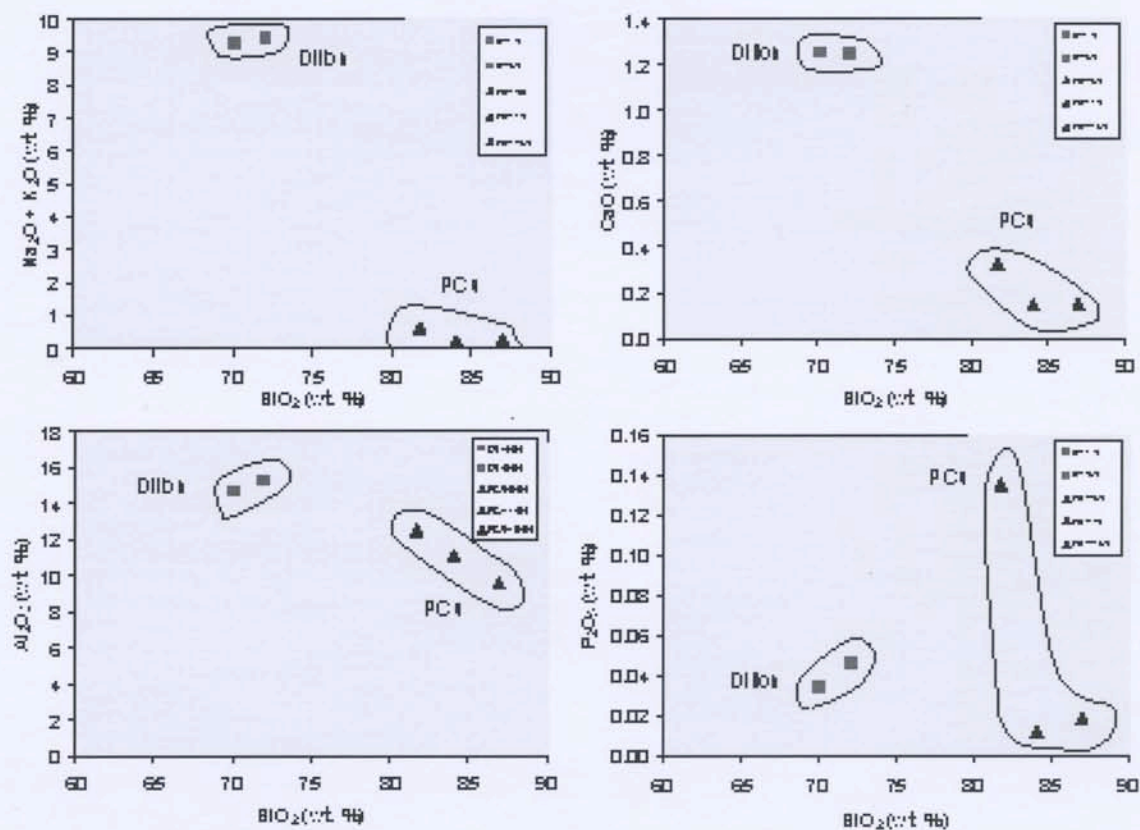


Figure 6. Major oxide versus  $\text{SiO}_2$  diagrams for the Dillon volcanic rocks and the Price Creek unit. Dillon rocks display typical igneous chemical signatures whereas, the Price Creek unit displays a significant depletion in most major oxides and much higher concentrations in  $\text{SiO}_2$  content.