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FIELD, PETROGRAPHIC, AND GEOCHEMICAL CONSTRAINTS ON THE GEOLOGIC HISTORY OF THE FEES RHYOLITE MEMBER: MOUNT ROGERS FORMATION, BLUE RIDGE PROVINCE, VA

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science with Honors in Geology from the College of William and Mary in Virginia

by

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May 1999

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ABSTRACT

The Neoproterozoic Mount Rogers Formation is a series of bimodal volcanic and sedimentary rocks associated with the ~750 Ma early phase rifting of Laurentia. The Fees Rhyolite Member crops out in a series of NE striking, SE dipping lenticular bodies in the Stone Mountain thrust sheet, in southwestern Virginia and adjacent North Carolina. The Fees is interbedded with metasedimentary rocks and greenstones of the lower Mount Rogers Formation, that unconformably overlies Grenvillian basement. Locally, the Fees is in direct unconformable contact with the basement, suggesting that it was originally emplaced on an uneven topographic surface. The Fees Rhyolite Member is a porphyritic metarhyolite with 20-35% phenocrysts of K-feldspar, quartz and locally plagioclase. Textures in the Fees indicate that it represents the ground flow portion of a pyroclastic flow, or series of closely related flows. Mineralogic and textural evidence indicate that the Fees was metamorphosed and deformed at greenschist facies conditions during Paleozoic orogenesis. The Fees exhibits broad similarities in major and trace element composition across the exposed length of the unit. Previous workers have suggested a possible correlation between the Fees Rhyolite Member and the Pond Mountain volcanic center. Comparisons of the Fees with existing data on the Pond Mountain and other rhyolites of the Mount Rogers Formation, indicate that the Fees and Pond Mountain rocks may have been derived from the same source. However, a stratigraphically meaningful correlation cannot be made based on existing data. A better understanding of the Mount Rogers Formation must await detailed isotopic age determinations for these units.

INTRODUCTION

The Neoproterozoic (~760 Ma) Mount Rogers Formation is a sequence of rift related volcanic and sedimentary rocks that are interpreted to have formed during the rifting of Laurentia and the opening of the Iapetus ocean. Early geochronologic work on the Mount Rogers volcanics by Rankin et al. (1969) yielded an age of 820 Ma from U-Pb analysis of zircons. This age was based on data derived from samples of the Mount Rogers rhyolites, the rhyolites of the Grandfather Mountain Formation in North Carolina, and the rhyolites of the Catoctin Formation from South Mountain, Pennsylvania, all of which were assumed to be contemporaneous. Rankin (1975) included the Mount Rogers volcanics, along with the Catoctin Formation (dominated by metabasalts), as part of his Crossnore Plutonic-Volcanic Group. The Crossnore Plutonic-Volcanic Group was correlated with other anorogenic plutonic and volcanic bodies in the Appalachians, and cited as evidence of Laurentian crustal extension (Ranking, 1975). Aleinikoff et al. (1995) determined new U-Pb zircon ages for the Mount Rogers (758 ± 12 Ma) and Catoctin (564 ± 9 Ma) Formations. Aleinikoff et al. (1995) suggested a two phase rifting history in which the Mount Rogers and other igneous bodies of similar age (Grandfather Mountain Formation, Robertson River Igneous Suite and others) made up the first phase of rifting, that failed to result in the opening of an ocean basin. The second phase of rifting produced the Catoctin and the successful opening of Iapetus. Fetter and Goldberg (1995) argued that the Mount Rogers Formation, and other ~750 Ma rift related igneous bodies were emplaced during an aborted rifting of the eastern margin of Laurentia, however, this rifting is too old to be directly associated with the later opening of Iapetus. They proposed that Neoproterozoic rifting along the eastern margin of Laurentia was tectonically related to the opening of the Proto-Pacific. The opening of the Proto-Pacific, recognized from ~750 Ma rift basins along the western margin of Laurentia, involved the rifting of Laurentia as it separated from the supercontinent of Rodinia (Fetter and Goldberg, 1995).

Although the Mount Rogers Formation has been used to develop tectonic models for the Neoproterozoic history of the Appalachians, much of this unit has not been studied in detail. Rankin (1993) divided the volcanic rocks of the Mount Rogers Formation into three volcanic centers (Mt. Rogers, Pond Mountain and Razor Ridge) and provided a detailed account of the Mt. Rogers volcanic center. Rankin (1993) also named and briefly described the Fees Rhyolite Member, a small body of porphyritic rhyolite near the base of the Stone Mountain thrust sheet, below the Mt. Rogers volcanic center. Rankin (1993) further noted the similarity of the Fees to rhyolites found in the Pond Mountain and Razor Ridge volcanic centers. Bailey and Rose (1998) documented the character and structural setting of the rocks of the Pond Mountain center. Based on their analysis of Pond Mountain rhyolites, and the description provided by Rankin (1993), Bailey and Rose (1998) suggested a possible correlation between the Fees Rhyolite and the Pond Mountain rhyolites. The purpose in studying the Fees Rhyolite Member is two fold: 1) provide a detailed analysis of the Fees and 2) determine the relationship between the Fees and other rhyolites in the Mount Rogers Formation, specifically the Pond Mountain rhyolites.

REGIONAL SETTING

Mount Rogers Formation

The Mount Rogers Formation is a suite of volcanic, volcaniclastic, and metasedimentary rocks that crops out in southwestern Virginia and adjacent North Carolina and Tennessee (Fig. 1). The Mount Rogers Formation nonconformably overlies granitic and gneissic basement rock (dated at 1.0-1.2 Ga by Fullagar and Odom, 1973), and is nonconformably overlain by the glaciogenic Konnarock Formation and the primarily clastic Chilhowee Group (Rankin, 1993). The Mount Rogers Formation is exposed in an imbricated stack of thrust sheets along the northwestern edge of the Blue Ridge basement thrust sheet (Rankin 1993). These thrust sheets carry older Grenvillian basement and Neoproterozoic cover rocks over the younger Paleozoic sedimentary rocks of the Valley and Ridge. The three volcanic centers of the Mount Rogers Formation are from northeast to southwest, are the Razor Ridge, Mt. Rogers and Pond Mountain centers (Fig. 1). The Mt. Rogers and Razor Ridge volcanic centers crop out primarily in the Stone Mountain thrust sheet, and the Pond Mountain volcanic center crops out in the Catface thrust sheet. All of the Mount Rogers Formation has undergone greenschist facies metamorphism during the Paleozoic, but by convention the 'meta' prefix is not used (Rankin, 1993, Bailey and Rose, 1998). Volcanic rocks are bimodal, with rhyolites making up 50-60 percent, and basalts 10-15 percent of the sequence. The remainder of the Mount Rogers Formation is composed of volcaniclastic and sedimentary rocks.

Rankin (1993) formally divided the rhyolites of the Mt. Rogers volcanic center into three members. The oldest is the Buzzard Rock Member, a perthite- and plagioclase-phyric, low silica, rhyolitic lava. The Whitetop Rhyolite (758 ± 12 Ma, Aleinikoff et al.,

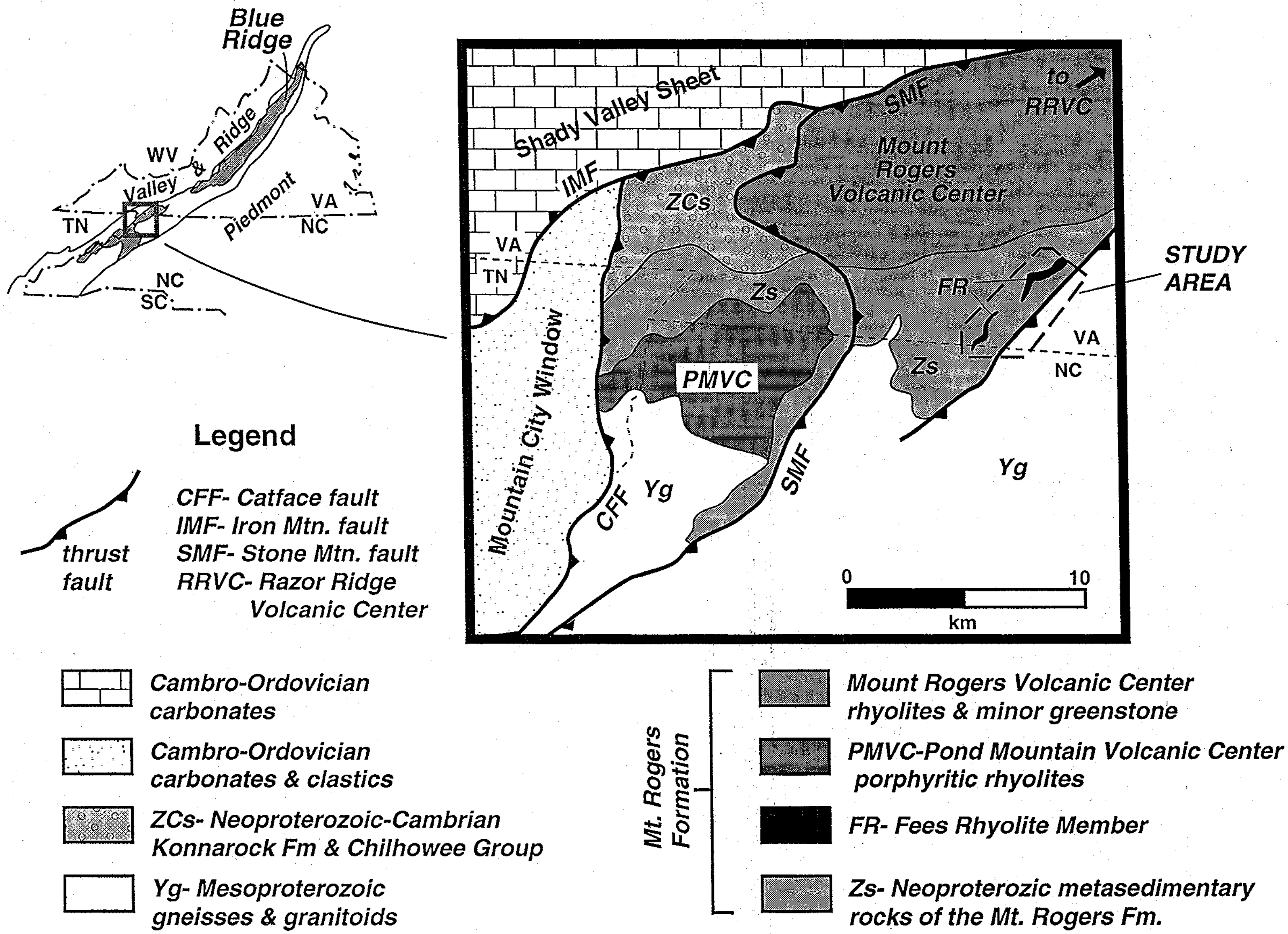


Figure 1. Generalized regional map and stratigraphy (modified from Bailey and Rose, 1998).

1995) consists predominantly of phenocryst-poor (<10% quartz and perthite), high silica, rhyolite lava. The Whitetop also contains sparse welded ash-flow tuffs. Some rhyolites in the upper part of the Whitetop Member have microphenocrysts of riebeckite, a sodium-rich amphibole commonly associated with peralkaline rocks (the Whitetop is metaluminous, Rankin et al., 1994). Tollo and Aleinikoff (1996) noted a similar occurrence of peralkaline minerals in the now metaluminous, rift-related plutons of the Robertson River Igneous Suite. Rift-related rocks are generally peralkaline, and Tollo and Aleinikoff (1996) speculated that the plutons were originally peralkaline and became metaluminous during metamorphism. The uppermost member of the Mt. Rogers volcanic center is the high silica Wilburn Rhyolite, characterized by ~30% quartz and perthite phenocrysts. The Wilburn is a zoned welded ash-flow sheet with characteristic fiamme (flattened pumice fragments). Microphenocrysts of riebeckite and acmite are also present in the basal part of the Wilburn. The Wilburn represents the culminating eruption of the Mount Rogers volcanic center, and this eruption probably resulted in a caldera collapse (Rankin, 1993). The Fees Rhyolite Member of the Mount Rogers Formation crops out in the Stone Mountain thrust sheet stratigraphically beneath the Mt. Rogers volcanic center. The field, petrographic and chemical characteristics of this unit will be discussed in detail in the following sections of my thesis.

The Pond Mountain volcanic center crops out in the Catface thrust sheet mostly in northwestern North Carolina (Figure 1). Bailey and Rose (1998) described this package of volcanic, plutonic, and volcaniclastic rocks, and identified three rhyolite units. The oldest is a grayish-blue to maroon, porphyritic rhyolite with 10 to 25 percent phenocrysts and is interlayered with volcaniclastic rocks. Another unit identified by

Bailey and Rose (1998) is a maroon rhyolite porphyry with 30 to 50 percent phenocrysts. The third unit is a fine-grained gray rhyolite with 10 to 20 percent phenocrysts. Quartz and alkali feldspar are the dominant phenocrysts in all of the units, with some samples showing minor amounts of plagioclase. All of the rhyolites are high in silicon, aluminum and potassium, and low in sodium, iron and calcium. Fiamme, dipyramdal (β form) quartz phenocrysts that are locally embayed, and the high phenocryst percentage support an ash flow origin for these rhyolites. Bailey and Rose (1998) also identified a small, alkali feldspar granite pluton (Whindling Ridge pluton) that has a similar bulk composition to the Pond Mountain rhyolites, and is interpreted to be the shallow intrusive equivalent of the rhyolites.

The Razor Ridge volcanic center crops out to the northeast of the Mt. Rogers volcanic center in the Stone Mountain thrust sheet (Rankin, 1993). The Razor Ridge volcanic center is dominated by felsic volcanic and volcaniclastic rocks. Due to similarities with the Fees, the Razor Ridge center is inferred to be stratigraphically below the Mount Rogers center (Rankin, 1993). To date, the Razor Ridge is the least studied of the three volcanic centers in the Mount Rogers Formation.

Grandfather Mountain Formation

The Grandfather Mountain Formation crops out to the south of the Mount Rogers Formation in the Grandfather Mountain Window in North Carolina. The Grandfather Mountain Formation is a series of interbedded sedimentary rocks and bimodal volcanic rocks also thought to have been emplaced during the early rifting of Laurentia. The Grandfather Mountain Formation lies nonconformably above Grenvillian basement and becomes younger to the northwest (Bryant and Reed, 1970). As in the

Mount Rogers Formation, original stratigraphic relations in the Grandfather Mountain Formation have been obscured by Paleozoic thrust faulting. Metarhyolites in the Grandfather Mountain Formation have been dated at 742 ± 2 Ma (U-Pb dating of zircons, Fetter and Goldberg, 1995), and temporally correlated with the Mount Rogers Formation. The 765 ± 7 Ma Brown Mountain Granite (U-Pb dating of zircons, Fetter and Goldberg, 1995) intrudes the Grenvillian basement, but not the Grandfather Mountain Formation (Bryant and Reed, 1970), providing a maximum age for basin formation in the Grandfather Mountain region.

FIELD RELATIONS

The Fees Rhyolite Member crops out in the Park, Grassy Creek, and Trout Dale 7.5 minute quadrangles in Virginia and North Carolina (Plate 1). In the study area, the Fees crops out in two NE-SW striking, SE dipping lenticular bodies (Plate 1, Fig. 2) that are essentially along strike with one another. The NE body is best exposed along the access road to Grayson Highlands State Park, Mill Creek Road, Big Wilson Creek Road, and also in associated stream beds. The SW body is exposed along Fees Branch and at the crest of Fees Ridge (Plate 1). The Fees is a porphyritic rhyolite with 20-35% phenocrysts of pink to white feldspars and gray quartz in an aphanitic maroon groundmass. Exposures of the Fees along the entrance road to Grayson Highlands State Park show considerable heterogeneity in the distribution of phenocrysts. Outcrops in this vicinity have zones (~5-10 cm in diameter) that contain few (<5%) phenocrysts (Fig. 3). Locally, the Fees also contains pockets (1-5 mm) of massive, pistachio green epidote (Fig. 4). Where the Fees is strongly foliated, phenocrysts are <5 mm across and the recrystallized groundmass is dominated by white mica, giving the rock a lighter purple

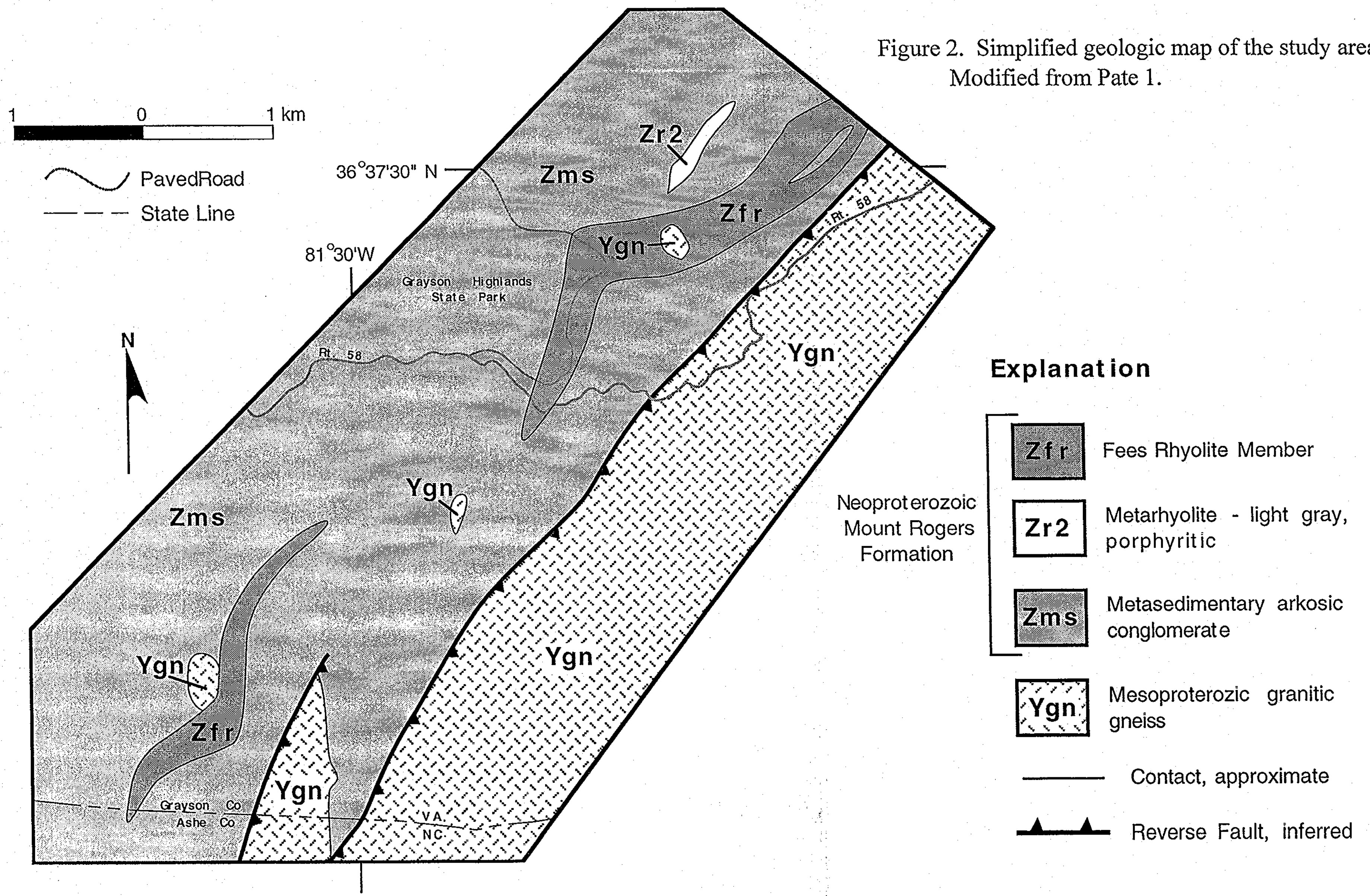


Figure 2. Simplified geologic map of the study area. Modified from Pate 1.

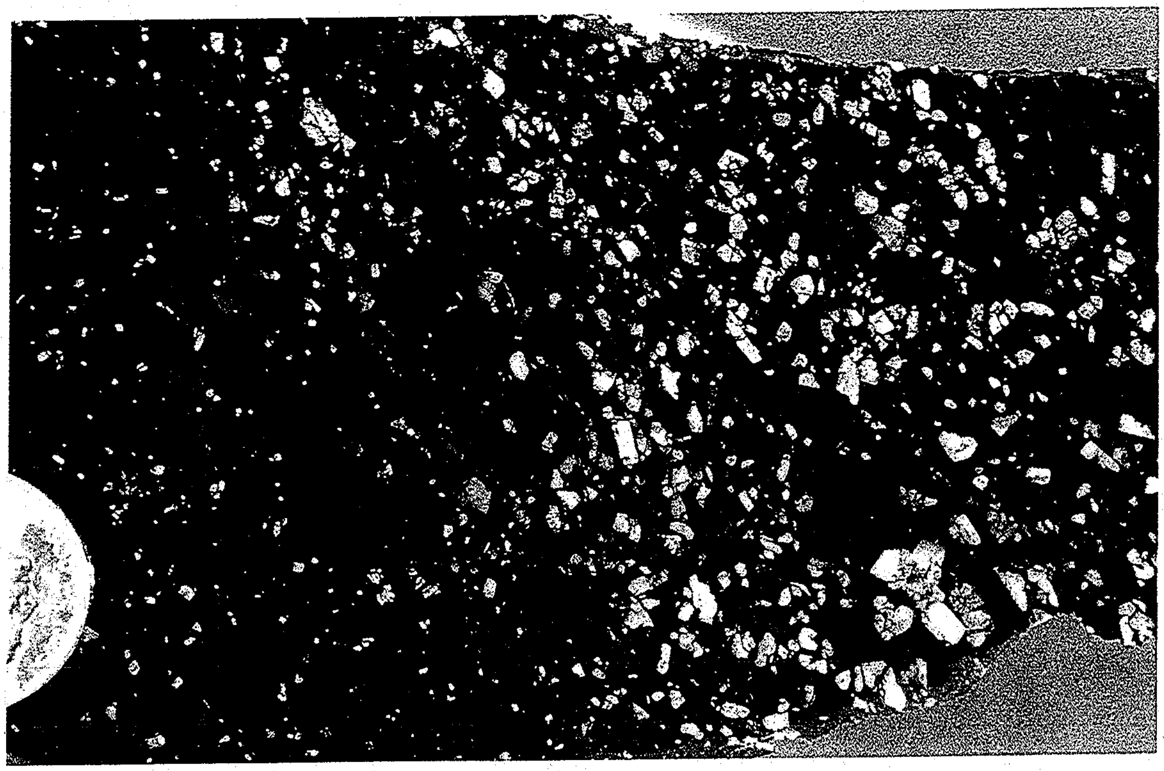


Figure 3. Photograph of Fees Rhyolite Member (sample FR - 4) with varying proportions of phenocrysts (edge of nickel for scale).

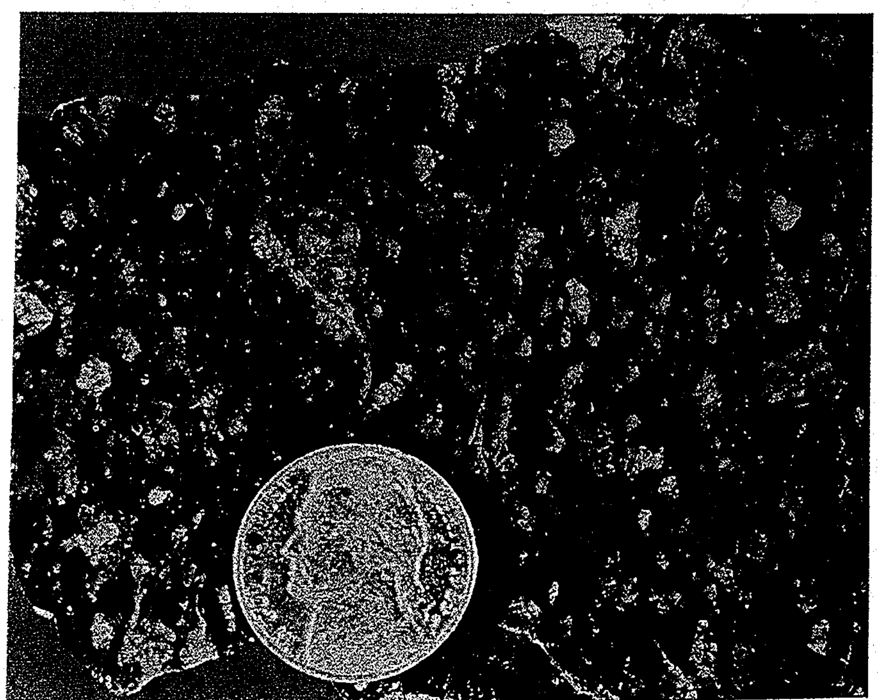


Figure 4. Photograph of altered Fees Rhyolite Member (sample FR - 11) with of epidote and fractured K-feldspar phenocrysts.

color (Fig. 5). Foliation in the Fees (defined by aligned micas and preferred grain shape alignment of phenocrysts) strikes NE-SW and dips moderately to the SE (Fig. 6). An additional light gray rhyolite (Zr2), containing quartz phenocrysts (1-2 mm across) crops out in the northern part of the study (Fig. 2). The relationship between this rhyolite and the Fees is unclear.

In the study area, the Fees interfingers with sedimentary rocks of the lower Mount Rogers Formation (Zms), and both are cut by greenstone dikes. Both units are unconformably above Grenvillian basement (gneiss with probable granitic protolith). Locally the Fees directly overlies the basement while at other locations sedimentary rocks lies between the basement and the Fees. These contact relations indicate an uneven topography at the time of eruption of the rhyolites (cross section A, Plate 1). Most metasedimentary rocks are arkosic, with pebble-to-cobble sized clasts of quartz, felsic volcanic rocks, and granite in a matrix of medium to fine grained, silty sandstone. Bedding in the metasedimentary rocks is rare, although where preserved the bedding dips more gently than the foliation, indicating the beds are stratigraphically right way up.

The major, NE-SW striking contact between the basement complex and the lower Mount Rogers Formation is marked by mylonites along Rt. 58. In addition, foliation in the sedimentary rocks steepens toward the contact. The occurrence of highly deformed rock and the steepening of foliation suggests the basement-cover contact is a ductile shear zone. Mineral stretching lineations in the sedimentary rocks trend to the SE (nearly at right angles to the contact), indicating dip slip movement of the sheer zone. Thus, the basement-cover contact is inferred to be a NE-SW striking, SE dipping thrust fault, that brings older basement rocks over the younger sedimentary and volcanic sequence (cross

Figure 5. Photograph of Fees Rhyolite Member (sample FR - 20) with well developed foliation defined preferred grain shape alignment of phenocrysts. Note reduced phenocrysts size.

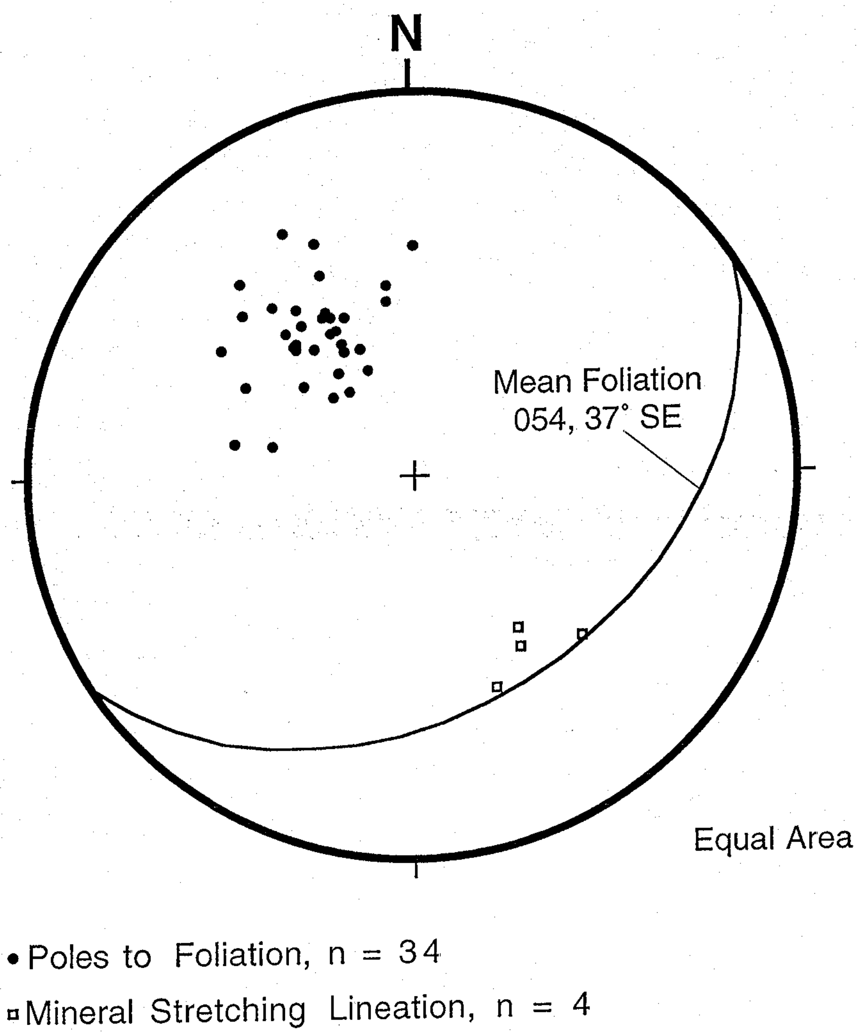


Figure 6. Stereogram of poles to foliation and mineral stretching lineations in the study area. The foliation strikes NE/SW and dips to the SE. Lineations plunge moderately to the SE.

section A, Plate 1). This map interpretation differs from that of Rankin (1993), who showed the Fees as a continuous body, and the basement-cover contact as an unconformity.

PETROGRAPHY

Petrographic features illustrate the volcanic, metamorphic and deformational histories of the Fees Rhyolite Member. Modal analysis of ten samples of the Fees was done to determine proportions of phenocryst to groundmass, and relative proportions of phenocryst types (Table 1). The Fees typically contains 20-35% phenocrysts, although highly deformed samples contain only ~10% phenocrysts (probably as a consequence of overall grain size reduction). K-feldspar (usually perthitic) is the dominant phenocryst phase, with most grains in the 1-10 mm size range. Quartz phenocrysts are typically slightly smaller than feldspar phenocrysts, generally less abundant than K-feldspar (Fig. 7). Three samples contain considerable plagioclase (Fig. 7). Electron microprobe analyses of plagioclase phenocrysts from sample FR-14 indicate that grains are nearly pure albite, and no clear pattern of zoning is apparent (see Appendix A for analytical techniques). Samples with plagioclase phenocrysts also contain massive aggregates of epidote (Fig. 8), and higher concentrations of fine grained epidote in the groundmass. The Fees also contains minor amounts of amphibole and opaque phenocrysts (Table 1). Trace amounts of zircon are also present in most samples. The Fees shows considerable heterogeneity in the concentration of alteration, ranging from virtually none to abundant greenschist facies assemblages. The groundmass is largely recrystallized. In unaltered samples it is composed primarily of fine-grained quartz and feldspar, whereas in highly altered samples it is dominated by fine-grained white mica and epidote (Fig. 9).

Table 1. Modal Compositions of Fees Rhyolite

Sample	FR-2	FR-4	FR-6	FR-7	FR-11	FR-13	FR-14	FR-19	FR-20	FR-23
Groundmass*	69.8	76.7	62.1	74.4	63.4	79.4	72.1	72.0	89.3	65.4
Phenocrysts	30.2	23.3	37.9	25.6	36.6	20.6	27.9	28.0	10.7	34.6
K - Feldspar**	16.0	12.3	28.9	14.9	13.1	9.9	19.3	22.1	6.7	10.9
Quartz**	12.5	8.2	6.6	7.3	4.1	9.6	2.3	4.8	4.0	13.1
Plagioclase**	0.4	0.2	0	0	11.8	0	3.3	0	0	2.7
Amphibole	0.1	0	0.1	0	0	0	0	0	0	0
Epidote ***	0.4	1.8	0.3	1.6	6.9	0.2	2.9	0.4	0	7.2
Opaque	0.1	0	0.1	0.2	0	0	0.1	0.1	0	0
Zircon	0	0	0	0.1	0.2	0	0	0	0	0
Other	0.4	0.8	1.8	1.4	0.6	0.9	0	0.6	0	0.7
Total # of counts	686	600	678	832	642	554	788	692	553	679

* The groundmass consists of fine grained quartz and feldspar in less altered samples, and quartz, white mica and epidote in highly altered samples.
** Counted only as phenocrysts.
*** Includes only larger grains and fibrous masses; fine grained, disseminated epidote was counted as groundmass.

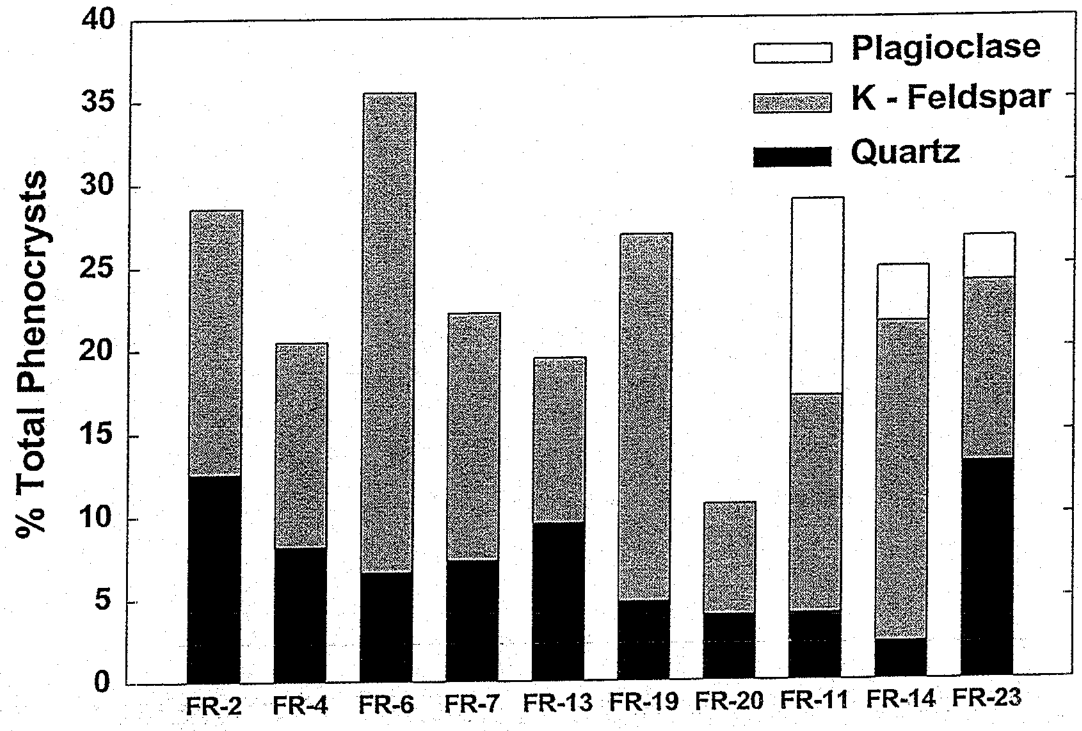


Figure 7. Relative proportions of phenocrysts in the Fees Rhyolite Member.

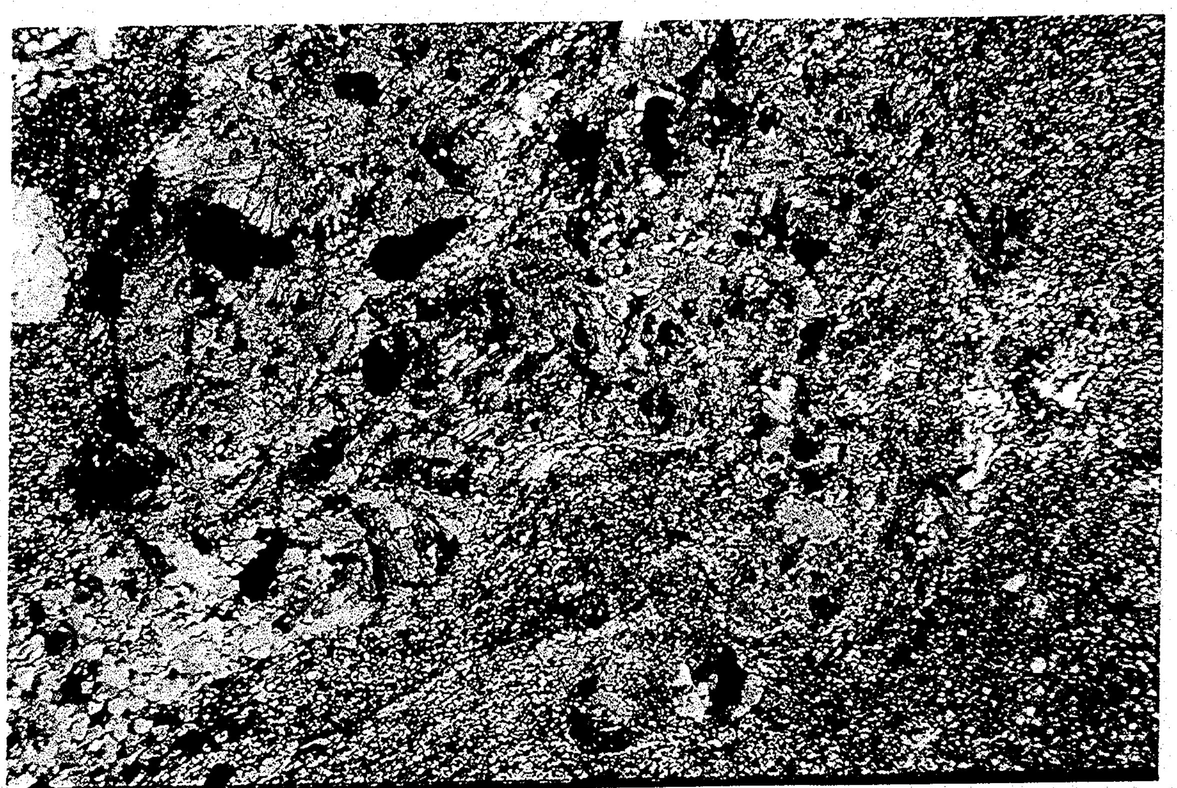


Figure 8. Photomicrograph of massive epidote, which is locally abundant in samples with modal plagioclase: sample FR - 14, Field of View (FOV) = 1.3 x 3 mm, cross polarized light (xpl).

a.

b.

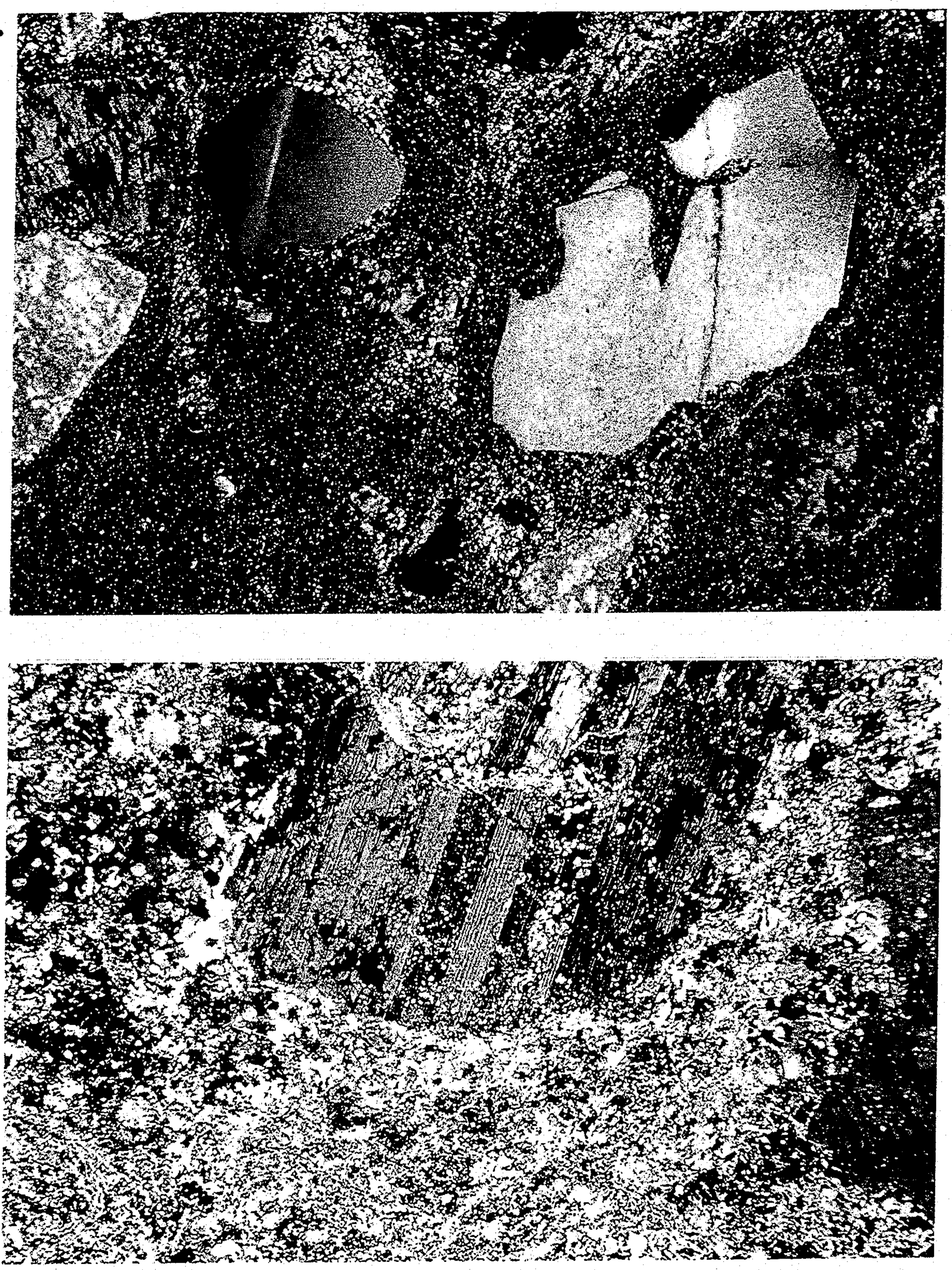


Figure 9. Photomicrographs illustrating heterogeneity of metamorphic overprinting in the Fees Rhyolite Member. (a) Relatively pristine matrix with embayed quartz: sample FR - 2, FOV = 3 x 4 mm, xpl. (b) Highly altered matrix with fine grained white mica and epidote: sample FR - 11, FOV = 3 x 4 mm, xpl.

Original volcanic textures are preserved in many samples; embayed and dipyramidal (β) quartz phenocrysts are common (Fig. 9a & 10a). Glomerophyric (adherence of phenocryst grains to each other during growth) textures are also present in the Fees (Figure 10b). Objects that resemble fiamme may be present in several samples, but the deformation and recrystallization of the groundmass precludes a positive identification. Microstructures in the Fees also provide evidence of deformation. In many samples the groundmass appears to have flowed around the larger phenocrysts. K-feldspar phenocrysts in these samples have rotated and are locally boudinaged, while quartz phenocrysts display undulous extinction. K-feldspar phenocrysts also show small fractures, but these probably originated in the explosive eruption of the Fees.

CHEMICAL COMPOSITIONS

Major Elements

Major and selected trace element compositions of 10 samples were obtained by a combination of XRF and ICP-MS methods (by Chemex Labs, Inc. in Sparks, Nevada). Results are listed in Table 2, along with selected element ratios. Samples were collected throughout the study area (see Appendix B for sample locations), and these samples exhibit various degrees of metamorphic overprinting. Examples of relatively pristine and variably metamorphosed samples were analyzed. However, highly schistose samples were not analyzed due to the difficulty in obtaining large samples.

The major element compositions of the 10 samples are broadly similar. The Fees is a high - K (K_2O average 6 wt.%) rhyolite, with an average SiO_2 of 73.5 wt.% (Fig. 11) . Al_2O_3 and Fe_2O_3-T both decrease with increasing SiO_2 (Fig. 12), although this feature may be an artifact of closure. K_2O (4-8 wt.%) and Na_2O (1-4 wt.%) show significant

a.

b.

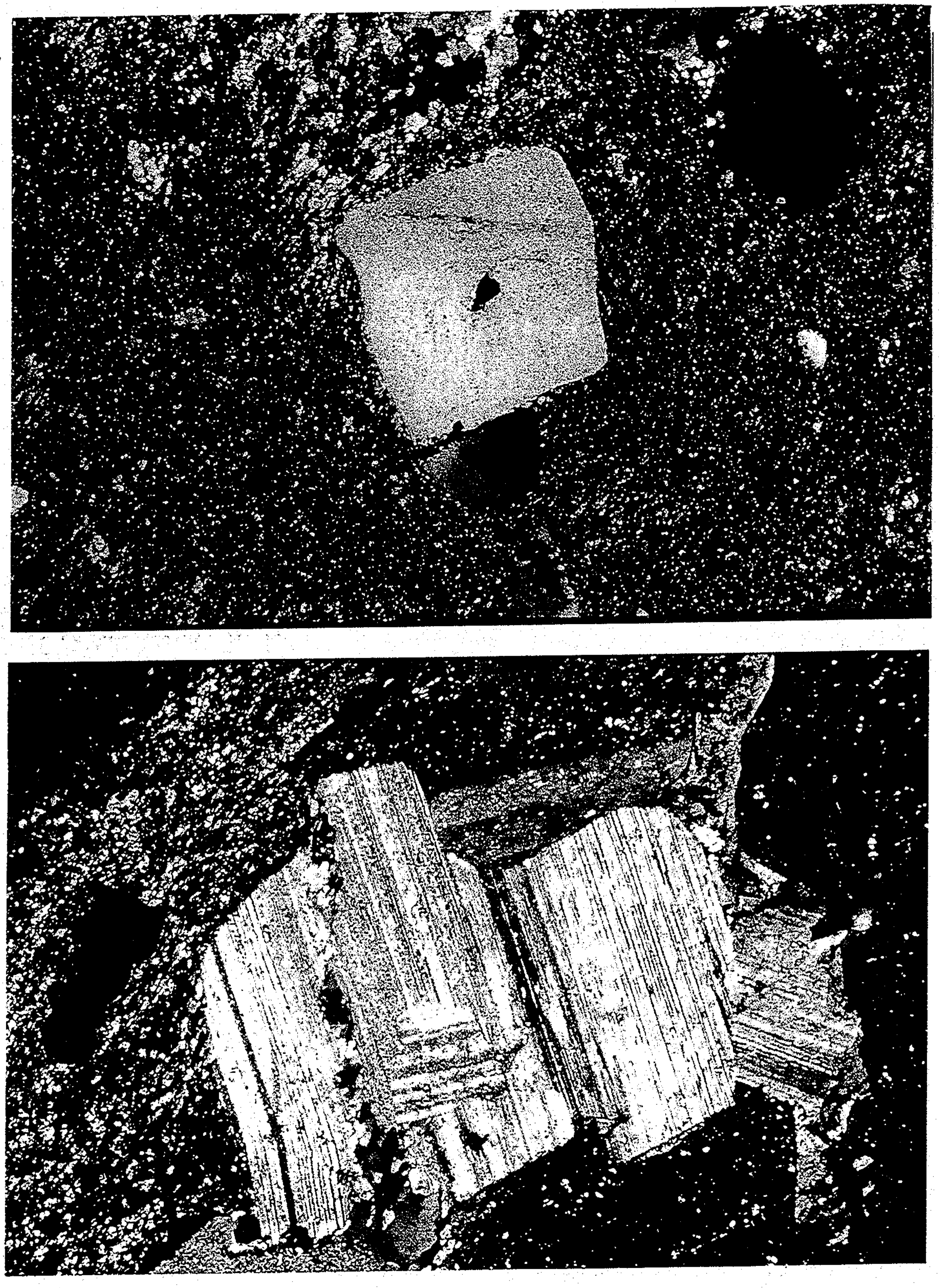


Figure 10. Photomicrographs of volcanic textures in the Fees Rhyolite Member (see also Figure 9a). (a) Dipyramidal quartz: sample FR - 2, FOV = 1.3 x 3 mm, xpl. (b) Glomerophyric texture (aggregate of plagioclase grains): sample FR - 14, FOV = 1.3 x 3 mm, xpl.

Table 2. Chemical Compositions of Fees Rhyolite Member Samples

Type	FR-2	FR-4	FR-6	FR-7	FR-11	FR-13	FR-14	FR-19	FR-20	FR-23
SiO_2	75.90	74.99	72.56	74.09	71.77	73.33	71.03	74.01	75.19	71.97
TiO_2	0.19	0.23	0.27	0.27	0.36	0.34	0.37	0.28	0.14	0.47
Al_2O_3	10.97	11.47	12.76	12.40	13.13	12.23	12.36	11.98	11.66	11.68
Fe_2O_3(T)*	2.47	2.75	3.00	2.96	3.56	3.40	3.83	2.94	2.63	4.41
MnO	0.02	0.03	0.04	0.03	0.07	0.03	0.05	0.03	0.02	0.04
MgO	0.05	0.12	<0.01	0.17	0.17	0.24	0.04	0.14	0.09	0.38
CaO	0.48	0.42	0.2	0.19	1.24	0.24	1.48	0.16	0.10	1.20
Na_2O	3.51	2.71	2.85	3.16	1.74	0.94	3.21	2.24	3.99	2.10
K_2O	4.49	5.74	5.81	5.18	6.16	7.54	5.42	6.31	4.09	5.20
P_2O_5	0.02	0.01	0.02	0.04	0.06	0.05	0.06	0.02	0.01	0.06
LOI	0.31	0.41	0.99	0.66	1.01	0.85	0.54	0.58	0.34	1.48
Total	98.41	98.88	98.50	99.15	99.27	99.19	98.39	98.87	98.26	98.99
A/CNK**	0.95	1.00	1.13	1.11	1.11	1.21	0.89	1.08	1.04	1.04
Rb	132	193	151	170	178	183	97	137	169	162
Sr	19	23	24	42	168	67	148	21	13	36
Y	121	141	62	515	116	69	110	72	194	92
Zr	626	783	869	802	679	583	635	747	756	637
Nb	68	79	63	62	32	28	28	50	90	48
Ba	94	176	65	172	1380	1320	1020	269	94	333
La	85	79	95	1145	158	79	102	75	52	78
Hf	20	25	22	22	18	15	16	19	28	17
Ta	6	6	4	4	2	2	2	4	9	4
K/Ba	396	271	742	250	37	47	44	195	361	130
K/Rb	282	247	319	253	287	342	464	382	201	266
Rb/Sr	7	8	6	4	1	3	1	7	13	5
Zr/Hf	31	31	40	37	38	39	40	39	27	37.5
Nb/Ta	11	13	16	16	16	14	14	13	10	12

Major oxides in wt. %, trace elements in ppm. Major oxides determined by XRF, trace elements by ICP-MS.
*Total Fe reported as Fe_2O_3.
**Molar $Al_2O_3/(CaO + Na_2O + K_2O)$.

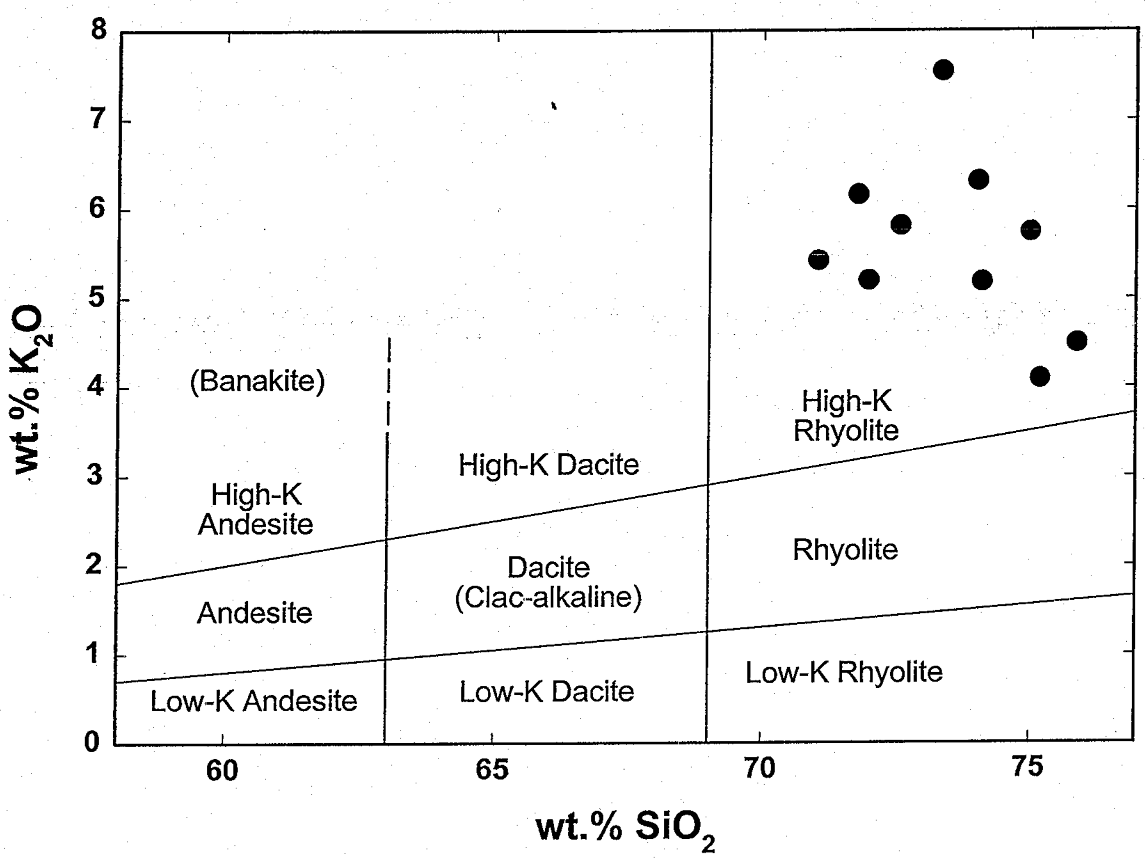


Figure 11. Fees Rhyolite Member samples plotted on K_2O - SiO_2 classification diagram (after Ewart, 1979 *in* Barker, 1981).

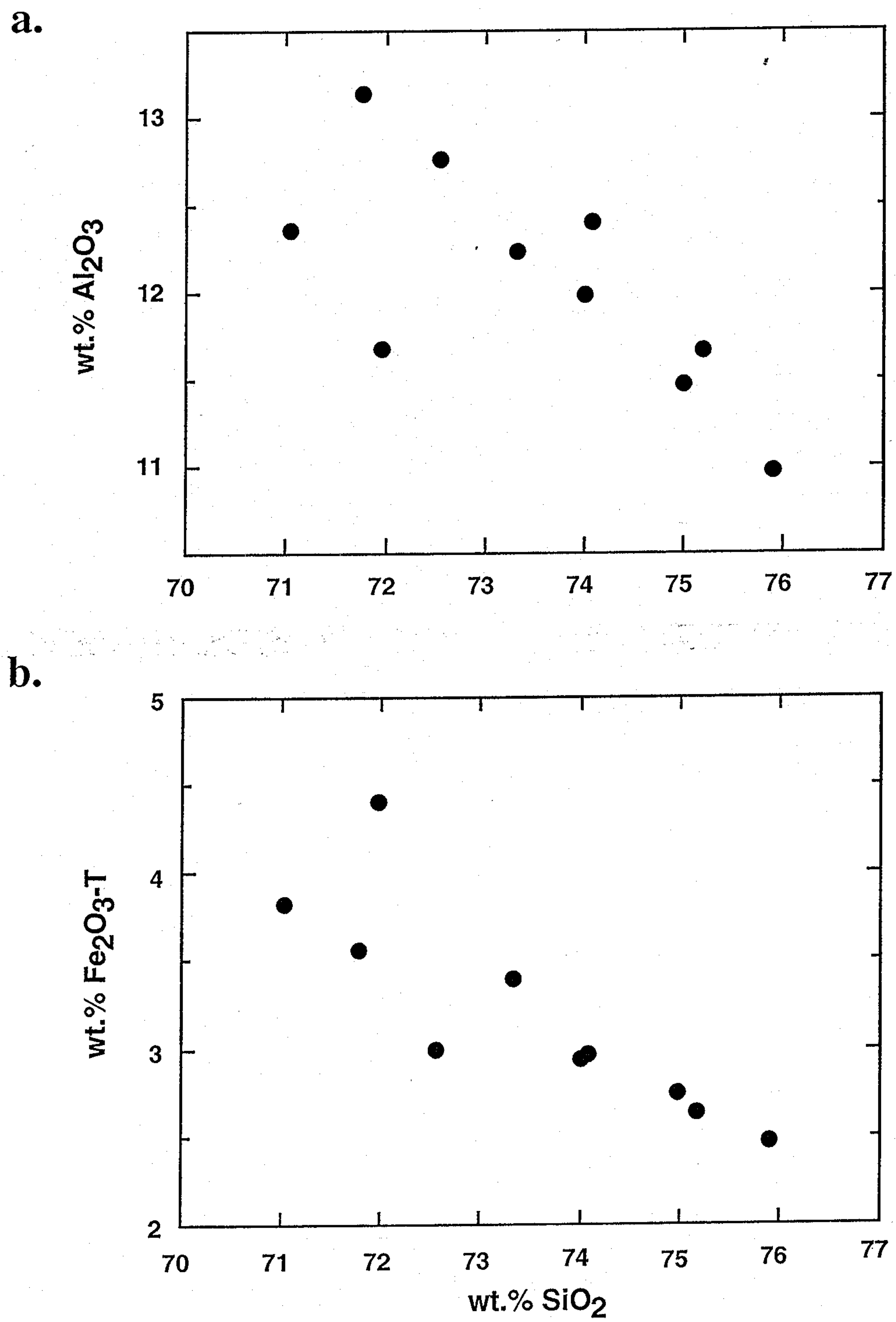


Figure 12. Plots of wt.% Al_2O_3 vs. wt.% SiO_2 (a) and wt.% Fe_2O_3 - T vs. wt.% SiO_2 (b) for the Fees Rhyolite Member. Al_2O_3 and Fe_2O_3 - T decrease with increasing SiO_2, but this is may be due to closure rather than a real fractionation effect.

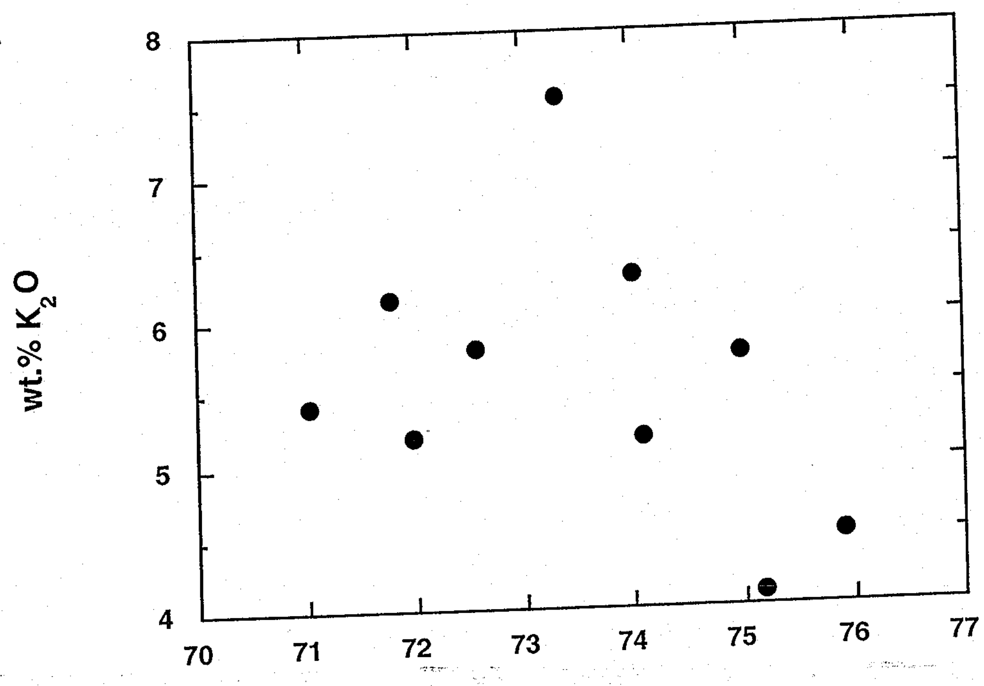
variability, that does not correlate with silica content (Fig. 13). Most samples contain <0.5 wt.% CaO, but three that contain plagioclase phenocrysts have higher CaO (up to 1.5 wt.%) (Fig. 14). Samples range from metaluminous to peraluminous types, but aluminum saturation (A/CNK) values show a crude positive correlation with loss on ignition (LOI) (Fig. 15), possibly indicating a slight loss of CaO, Na_2O, and K_2O during greenschist facies metamorphism. Samples with the highest LOI also contain the highest amounts of fine grained epidote and white mica.

The normative mineralogy of the Fees (Table 3) is dominated by orthoclase (average 34.5 wt.%), quartz (average 32.6 wt.%), and albite (average 24.8 wt.%). The average normative anorthite for samples with elevated CaO is 6 mole %, but only 0.7 mole % for all other samples. Average hypersthene is 3 mole % and all samples except two are corundum normative. Normative values of quartz, orthoclase, and albite + anorthite (normalized to 100) for the Fees fall in the rhyolite field of the QAP classification diagram (where A is orthoclase and P is albite + anorthite) (Fig. 16).

Trace Elements

Samples from the SW area of the Fees (FR-11, 13, & 14) show elevated levels of Ba and Sr, and lower levels of Nb and Ta relative to the other samples (Fig. 17). K/Ba values (average = 247) for most samples are high relative to the average upper crust (K/Ba = 51, Taylor and McLennan, 1985). However, the samples from the SW have K/Ba ratios close to the upper crust average. Concentrations of Rb range from 100-190 ppm, and K/Rb values (average = 304) are slightly higher than average upper continental crust (K/Rb = 252, Taylor and McLennan, 1985). There is no correlation between CaO and Sr. The Fees shows little variation in levels of Zr (580-869 ppm) and Hf (15-30 ppm); Zr/Hf

a.



b.

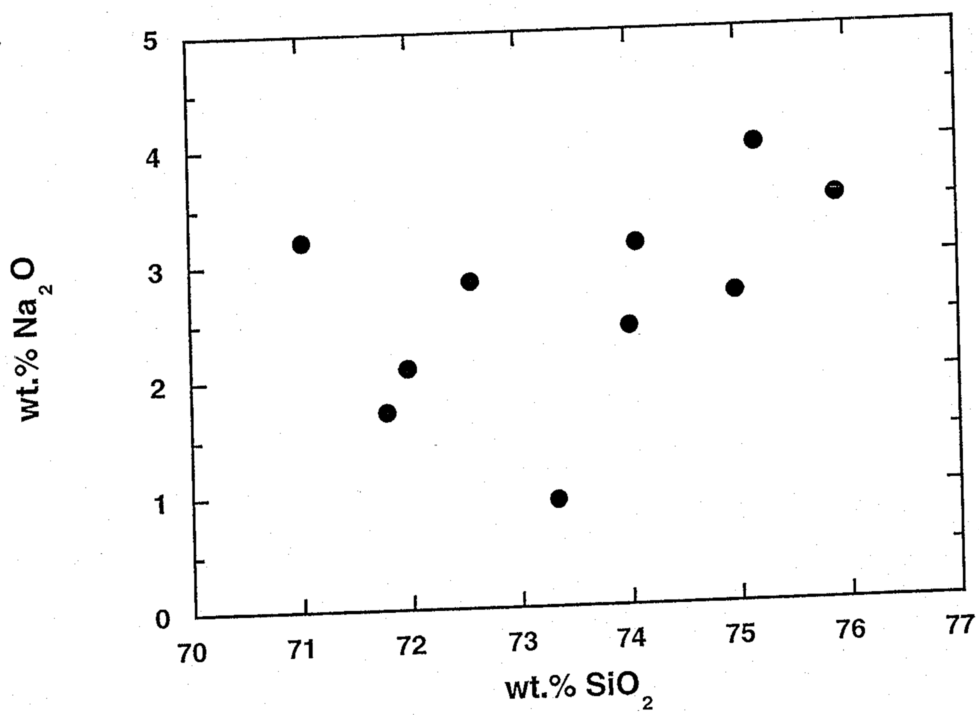


Figure 13. Plots of wt.% K_2O vs. wt.% SiO_2 (a) and wt.% Na_2O vs. wt.% SiO_2 (b) for the Fees Rhyolite Member. K_2O and Na_2O values are variable and do not correlate with SiO_2.

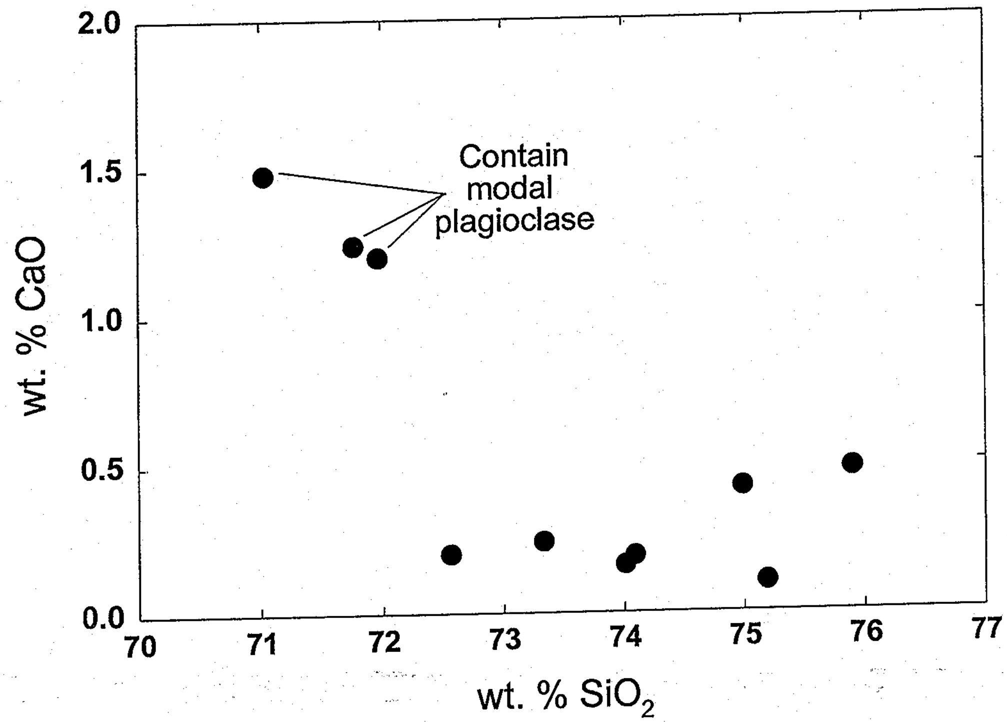


Figure 14. Plot of wt.% CaO vs. wt.% SiO_2 for the Fees Rhyolite Member. CaO concentrations for most of the Fees are <0.5 wt.%, but samples with modal plagioclase have concentrations of 1-1.5 wt.% CaO.

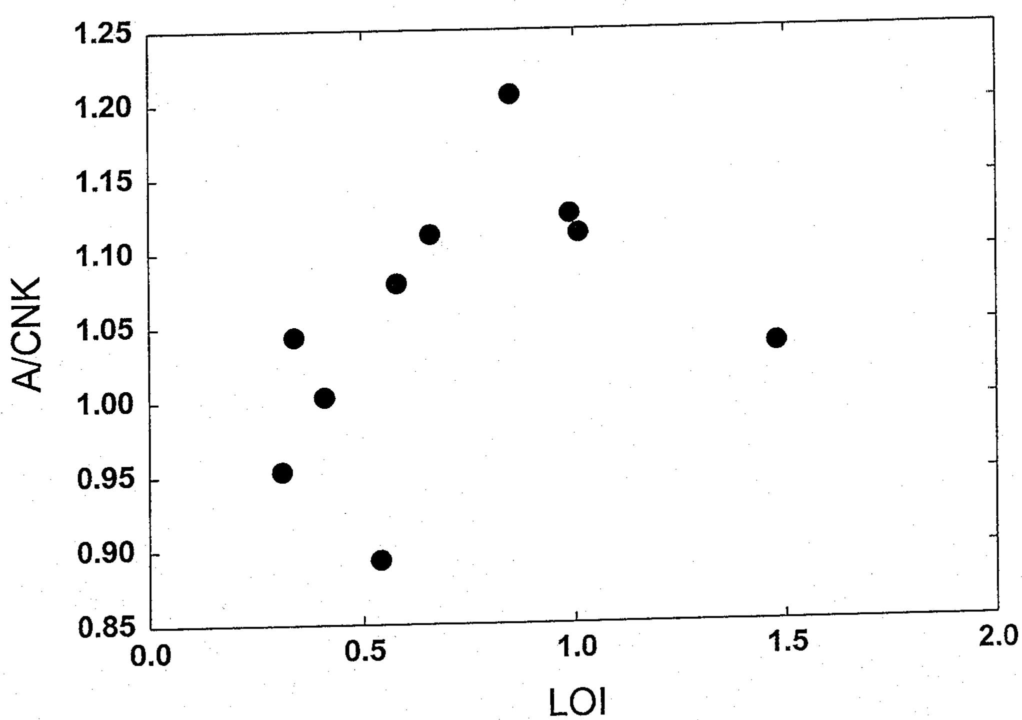


Figure 15. Aluminum saturation (A/CNK) vs. LOI for the Fees Rhyolite Member. Note crude positive correlation.

Table 3. Molecular Normative Compositions of Fees Rhyolite Member Samples

Normative Mineral	FR-2	FR-4	FR-6	FR-7	FR-11	FR-13	FR-14	FR-19	FR-20	FR-23
Quartz	34.98	33.57	30.96	32.53	32.65	35.76	25.74	32.71	33.30	34.19
Corundum	0.00	0.06	1.67	1.52	1.70	2.53	0.00	1.05	0.58	0.64
Orthoclase	27.54	35.21	35.89	31.65	38.10	46.84	32.99	38.81	25.03	32.50
Albite	32.72	25.26	26.76	29.35	16.36	8.87	29.69	22.62	37.11	19.95
Anorthite	0.95	2.10	0.90	0.70	6.03	0.91	6.21	0.69	0.45	5.88
Diopside	1.11	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00
Hypersthene	1.85	2.84	2.73	3.13	3.72	3.73	3.13	3.03	2.74	5.03
Magnetite	0.54	0.60	0.66	0.64	0.78	0.75	0.82	0.64	0.57	0.98
Ilmenite	0.27	0.33	0.39	0.39	0.53	0.50	0.53	0.41	0.20	0.69
Apitite	0.04	0.02	0.04	0.09	0.13	0.11	0.13	0.04	0.02	0.13
Norm Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Q+Or+Plag	96.19	96.14	94.51	94.23	93.14	92.38	94.63	94.83	95.89	92.52
% An/(An+Ab)	3	8	3	2	27	9	17	3	1	23

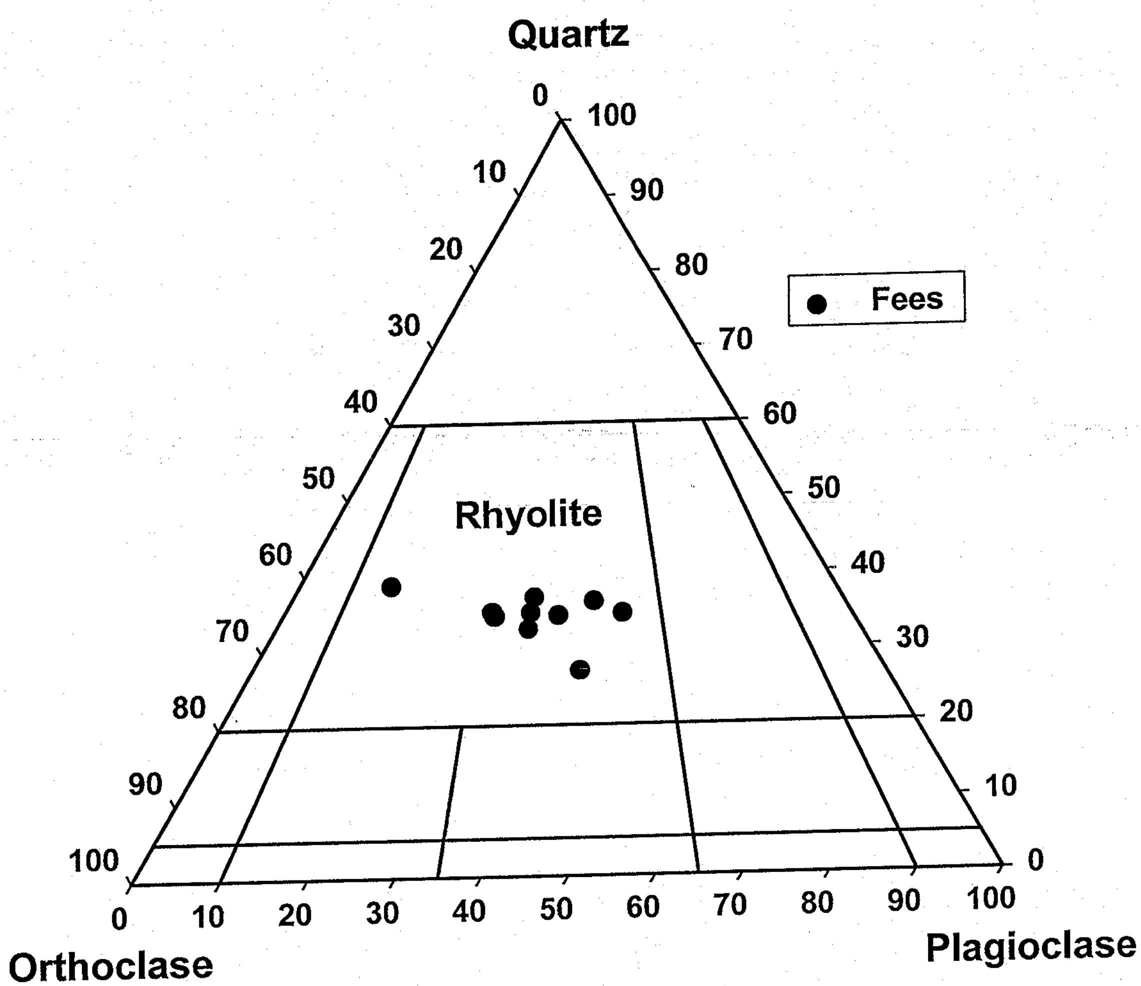


Figure 16. Normative proportions of quartz, orthoclase and plagioclase (albite + anorthite) (Field boundaries after Streckeison, 1976).

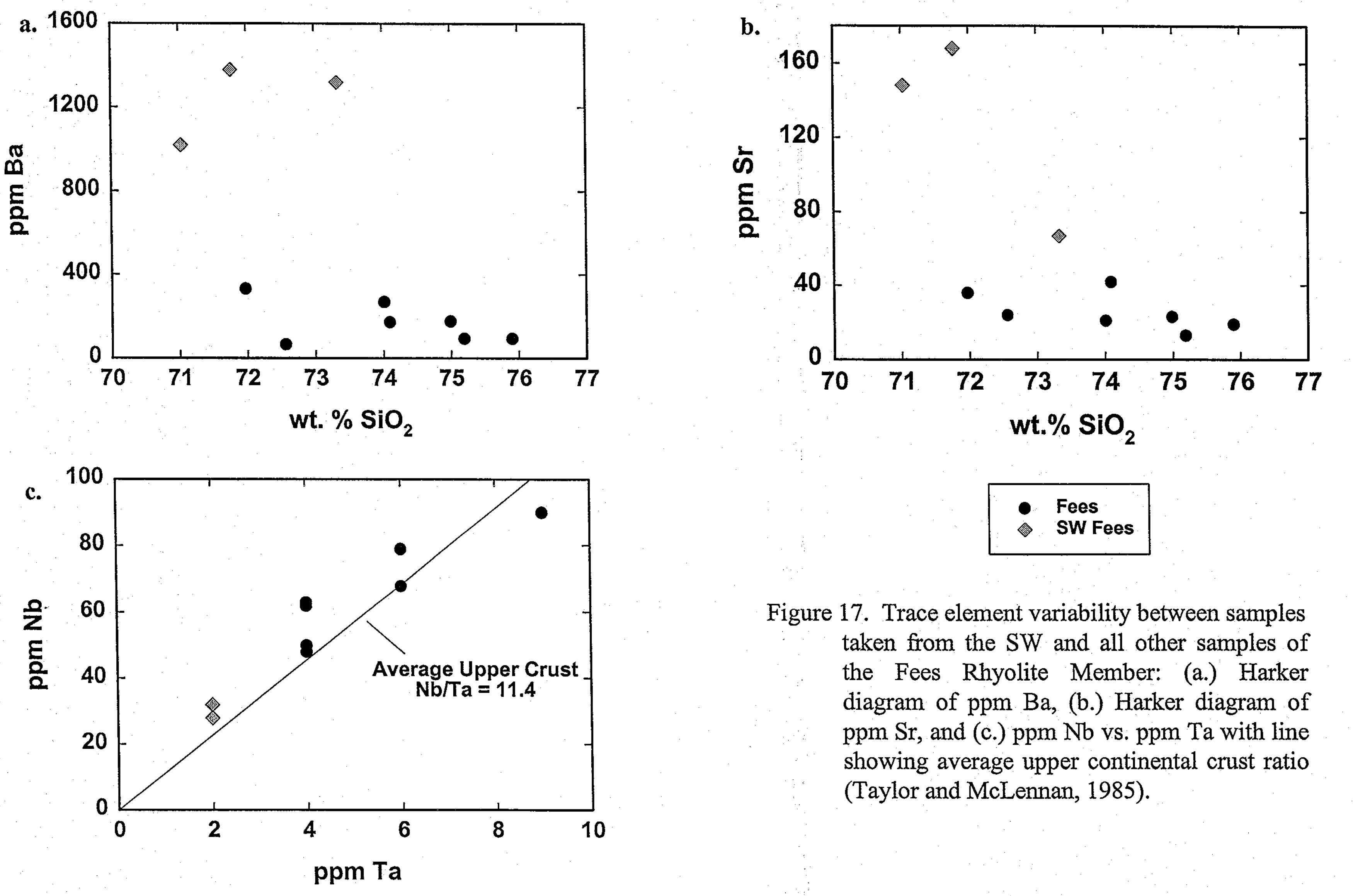


Figure 17. Trace element variability between samples taken from the SW and all other samples of the Fees Rhyolite Member: (a.) Harker diagram of ppm Ba, (b.) Harker diagram of ppm Sr, and (c.) ppm Nb vs. ppm Ta with line showing average upper continental crust ratio (Taylor and McLennan, 1985).

values (~36) are close to that of average upper crust (33, Taylor and McLennan, 1985). Complete REE data were not obtained for the Fees, but concentrations of La and Y were measured. La and Y (with an ionic radius similar to that of Ho, a heavy rare earth) were used to gain a general idea of the REE pattern of the Fees (Fig. 18). Eight of ten samples have very similar chondrite-normalized patterns, with an average La_N/Y_N of 5.8. One sample (FR-7) shows a much flatter pattern. Another sample (FR-20) has anomalously high levels of La and Y, which may reflect the presence of monazite, or some other REE-rich phase (although no such phase could be positively identified in thin section).

DISCUSSION

Fees Rhyolite Member

Petrographic evidence indicates that the Fees Rhyolite Member formed as a pyroclastic flow deposit. Although now completely recrystallized, the fine grained nature of the groundmass suggests that it was originally glassy. The presence of embayed quartz, β quartz, fiamme and glomerophyric textures all also indicate an extrusive origin for the Fees. Due to their high viscosity, lava flows of rhyolitic magmas are less common than ash-flows, and flow-layering has not been observed in the Fees. In addition, the phenocryst-rich magma would further suppress the escape of gases and increase viscosity, favoring an explosive eruption (Fig. 19a). Once erupted, the slurry of hot gases, fine glassy fragments, larger crystals and rock fragments collapsed under its own weight and flowed down hill as a pyroclastic flow (Fisher et al., 1997) (Fig. 19b). Larger particles filtered down to the base of the flow and separated from the lighter, more dilute upper flow (Fisher et al., 1997) (Fig. 19c). The dense ground flow would have been confined to flowing down valleys, while the lighter upper flow could have flowed over

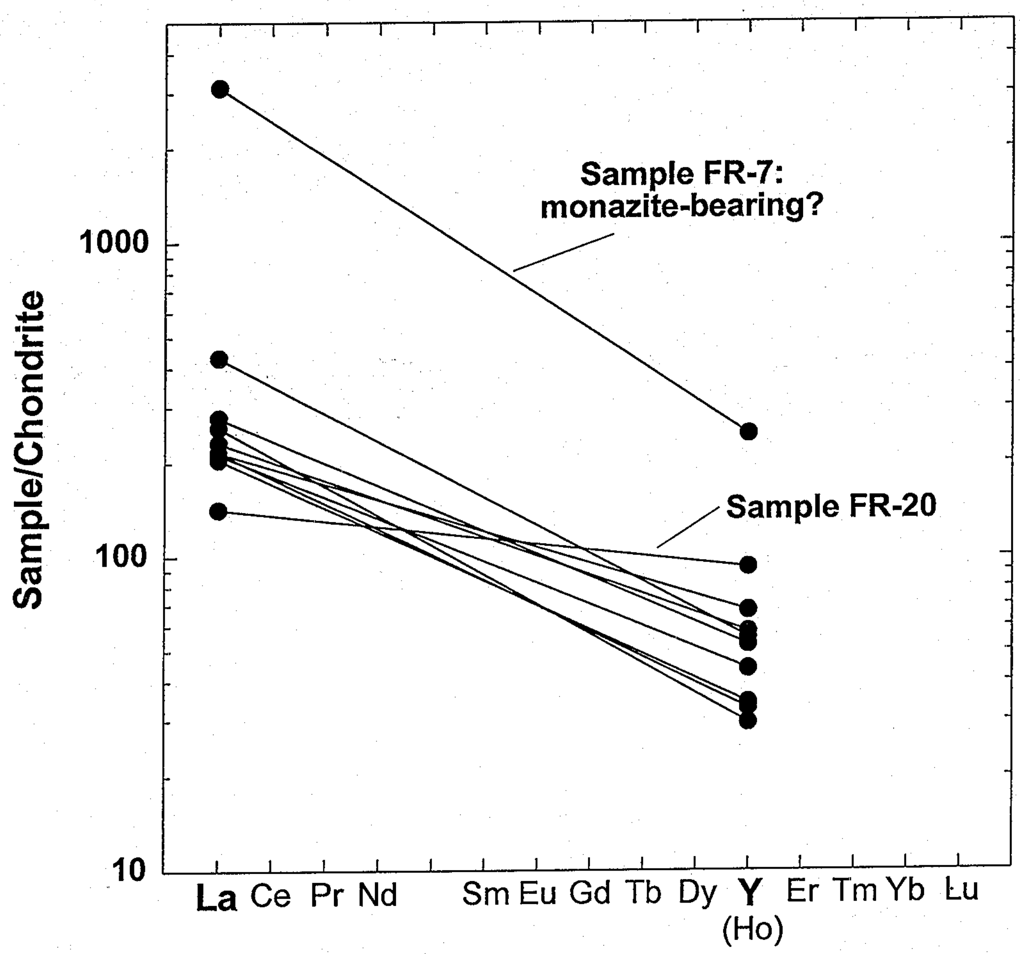


Figure 18. Chondrite-normalized diagram illustrating La and Y concentrations in the Fees Rhyolite Member. Such a diagram provides insights into the overall REE patterns for these samples. Y is plotted in the position of Ho. Chondrite values from Taylor and McLennan (1985).

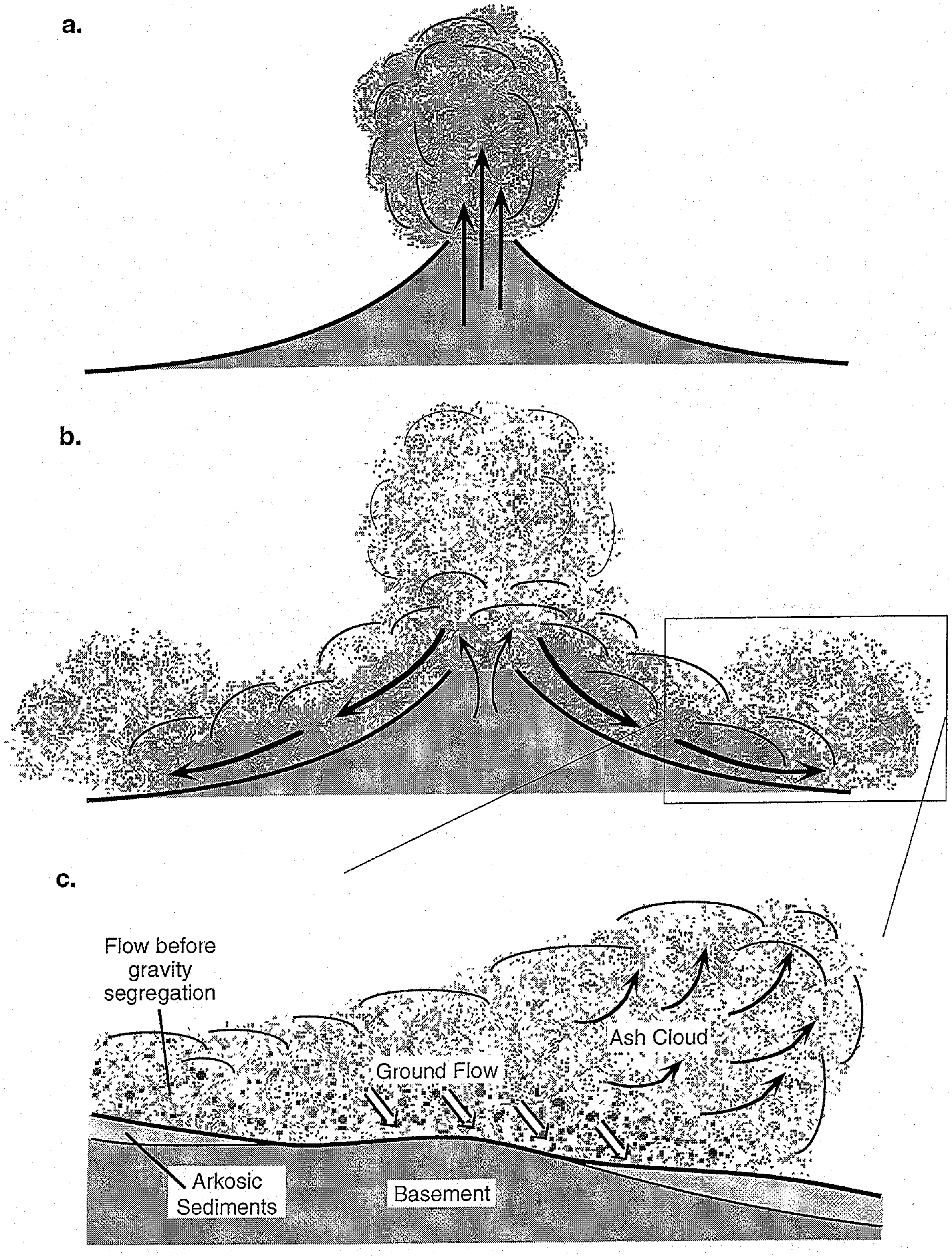


Figure 19. Schematic illustration of the eruption of the Fees Rhyolite Member. (a) Initial eruption column. (b) Column collapses due to density; moves down slope of volcano as a pyroclastic flow. (c) Gravity segregation of coarser ground flow from lighter ash cloud (modified from Fisher and Schmincke, 1984).

ridges. The flow slowed as gases escaped, resulting in the deposition of the coarser material. As material piled up, the overlying weight compressed the still hot deposit causing a flattening of pumice fragments (formation of fiamme) and welding of ash particles to form the groundmass.

The exact timing of Paleozoic metamorphism and deformation of the Mount Rogers Formation has not been tightly constrained. However, the limited available evidence suggests that Mount Rogers Formation was not significantly disturbed until the Alleghanian Orogeny (Mississippian - Pennsylvanian). U-Pb age determinations from zircons in the Whitetop Rhyolite Member (Aleinikoff et al., 1995) are vary nearly concordant, and thus have imprecise lower intercepts (25 ± 367 Ma and 371 ± 112 Ma). Detailed analyses of the time of metamorphism and deformation have been done in the Grandfather Mountain Window (Stewart et al., 1997). Comparison diagrams of various major and trace elements for the rhyolites in the Grandfather Mountain Formations and the Mount Rogers Formation show almost complete overlap (and are thus not shown). In the Grandfather Mountain Window, thrust sheets that exhibited only pervasive lower greenschist facies metamorphism were shown to have been disturbed during Alleghanian thrusting (Stewart et al., 1997). The Stone Mountain and Catface thrust sheets have experienced only greenschist facies metamorphic conditions, similar to those in the Grandfather Mountain Window, and perhaps corresponds to Alleghanian disruption. However, isotopic analyses (Rb/Sr from greenstones, or $^{40}Ar/^{39}Ar$ from muscovite) of rocks from the Mount Rogers Formation are necessary to definitively ascertain the timing of metamorphism and deformation.

The Fees shows considerable range in concentration of most major elements (Figs. 12, 13, and 14). These variations probably reflect the heterogeneous distribution of various phenocrysts phases, and are thus a primary feature. In the case of CaO, samples with > 1 wt.% also have plagioclase phenocrysts (3-12%, Fig. 7) and massive epidote (3-7%, Table 1). Normative calculations predict that these phenocrysts should be oligoclase, but microprobe analysis shows that they are albite. These observations and data suggest that plagioclase grains lost most of their Ca as a consequence of epidote growth during greenschist facies metamorphism. Petrographic inspection shows a correlation between LOI and the degree of alteration in the groundmass (samples with high LOI also show the highest proportion of white mica and epidote in their matrix). This feature, coupled with the observed positive correlation between LOI and aluminum saturation (Fig. 15) suggests that the Fees experienced a net loss of alkalis during metamorphism. Unlike the major elements, trace element variations in the Fees show some correlation with geographic position. Specifically, samples from the SW exposure of the Fees show the highest levels of Ba and Sr and the lowest levels of Nb and Ta (Fig. 17).

The petrographic and compositional heterogeneity of the Fees calls into question the validity of treating this rock body as a single unit. Although these differences may be due to magmatic differentiation, it is conceivable that the two mapped bodies represent separate, albeit closely related, eruptions. Nonetheless, the Fees as a whole is clearly distinct from other rhyolites exposed in the study area, as well as other rhyolites of the Mt. Rogers volcanic center. Differences in phenocryst proportions, or the incorporation of foreign rock fragments, could produce significant differences in the level of trace elements. While the Fees cannot be definitively said to be one flow, the broad similarities across the entire unit suggest that if it does represent multiple flows, these flows were closely related. Thus, treating the Fees as a single units seems reasonable.

Comparisons with other Mount Rogers Rhyolites

The Fees is here compared with Pond Mountain rhyolites [major and selected trace elements for three samples from Rose (1996), and major elements for three samples from Rankin (pers. com.)] and the Wilburn Rhyolite [major elements for 21 samples, selected trace elements for 15 samples (Rankin, pers. com.)]. Analyses of the Pond Mountain rhyolites are taken from two of the units (Zv2 & Zv3) described by Bailey and Rose (1998). However, because these units were defined primarily on the basis of field characteristics and show broad geochemical similarity, they are here treated as one unit. Overall, the Fees and Pond Mountain samples are very similar, spanning approximately the same ranges in SiO_2, Al_2O_3, and CaO (Fig. 20). However, for a given level of SiO_2, the Pond Mt. samples tend to contain more K_2O and less Na_2O than the Fees (Fig. 21).

Geochemical trends in the rhyolites of the Mount Rogers Formation show some similarities with trends in other rift-related rhyolites. Moyer and Nealey (1989) described geochemical trends in Tertiary rhyolites from bimodal, rift related volcanic suites in the Colorado Plateau. The rhyolites were divided into high (>73 wt.%) and low (68-73 wt.%, ranging up to 74.5 wt.%) silica groups (Moyer and Nealey, 1989). The low silica rhyolites (LSR) are metaluminous to slightly peraluminous, enriched in Ba, Sr, Zr and LREE and depleted in Rb and Y relative to the high silica rhyolites (HSR) (Moyer and Nealey, 1989). A similar, although less pronounced, pattern can be seen in the rhyolites of the Mount Rogers Formation, if the Fees is considered a LSR and the Wilburn a HSR. The Fees generally fits the LSR profile, despite having a slightly higher

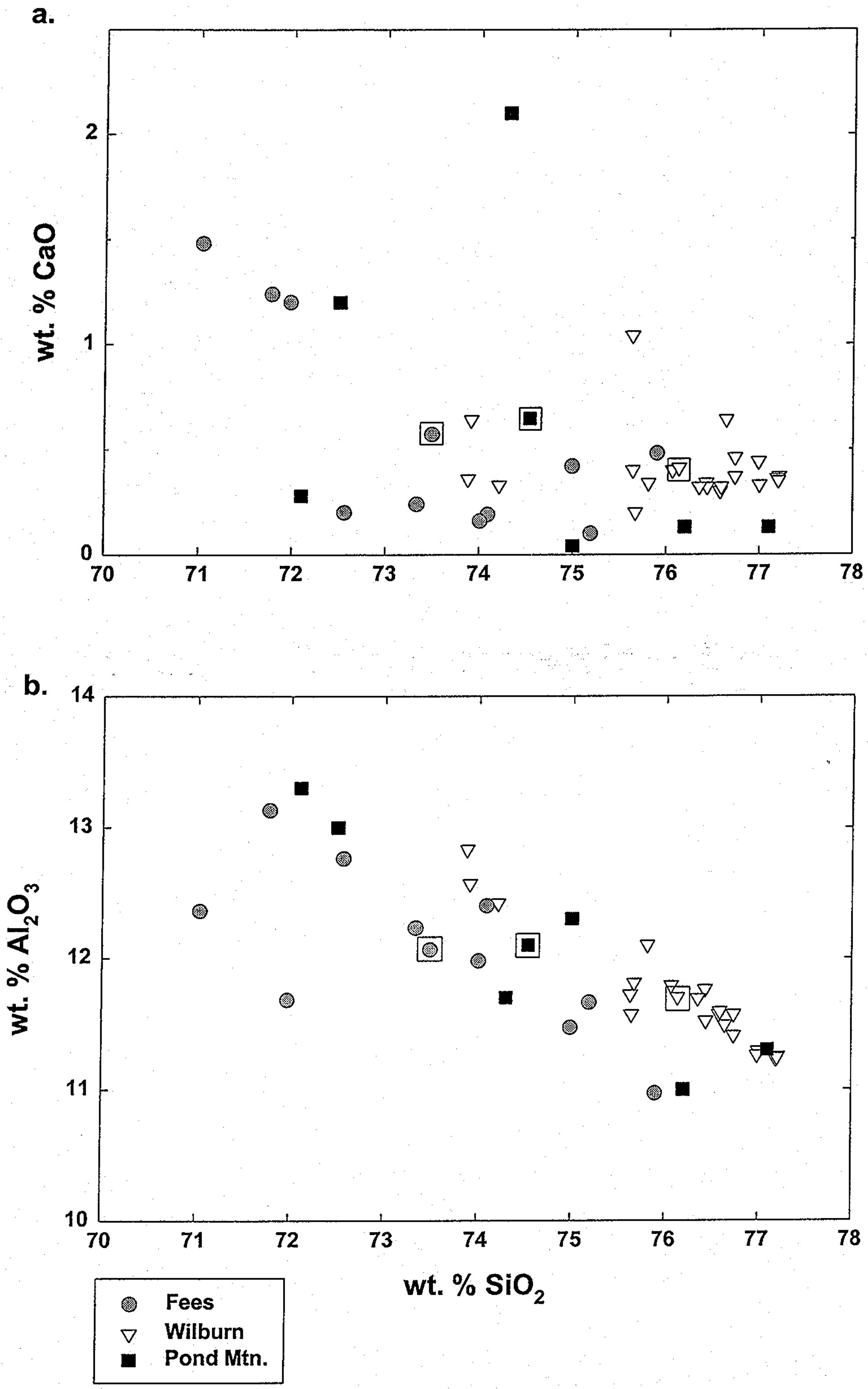


Figure 20. Harker diagrams of CaO (a) and Al_2O_3 (b) for the Wilburn, Fees, and Pond Mtn. Rhyolites. Data points enclosed in squares represent average values for each unit: Wilburn, n = 21, Fees, n = 10, Pond Mtn., n = 6.

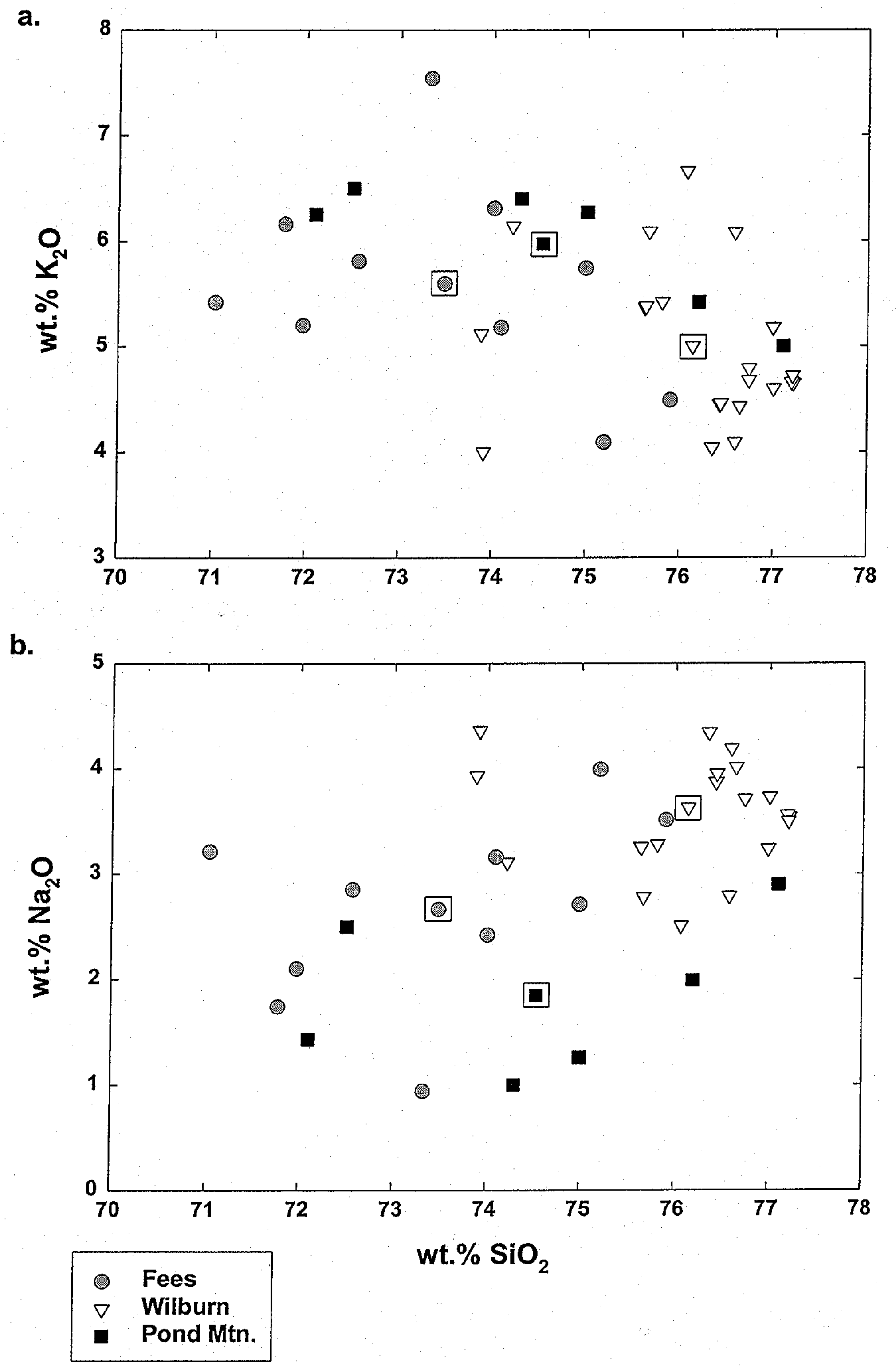


Figure 21. Harker diagrams of K_2O (a) and Na_2O (b) for the Wilburn, Fees, and Pond Mtn. Rhyolites. Data points enclosed in squares represent average values for each unit: Fees, n = 10, Wilburn, n = 21, Pond Mtn., n = 6.

silica, as do the Pond Mtn. rhyolites. Ba levels provide the clearest contrast between the Fees (and Pond Mtn.) and Wilburn rhyolites (Fig. 22a). The Wilburn is clearly depleted in Ba relative to the Fees and Pond Mountain rhyolites, and the average upper crust (Fig. 22a). Rb levels for all units are similar, although the Fees has a slightly higher average K/Rb than the other units (Fig. 22b). The Fees and Pond Mtn. rhyolites are also enriched in Sr relative to the Wilburn, which is consistent with the Moyer and Nealey (1989) model. However, the three units span a similar range in Zr levels (Figure 23b). The similarities between the Mount Rogers and Colorado Plateau rhyolites suggest that the Wilburn is the product of a more chemically evolved magma than the Fees or Pond Mountain (Moyer and Nealey, 1989). Although this observation may indicate that the Fees and Pond Mountain were derived from the same source, this interpretation seems tenuous in light of the high degree of overlap in the geochemical signatures of these units. Furthermore, the degree of overlap between the rhyolites of the Mount Rogers Formation indicates that geochemistry alone, cannot be used to unequivocally establish a stratigraphic correlation between the Fees Rhyolite and any of the Pond Mountain rhyolites. Nonetheless, none of my observations or data preclude such a correlation.

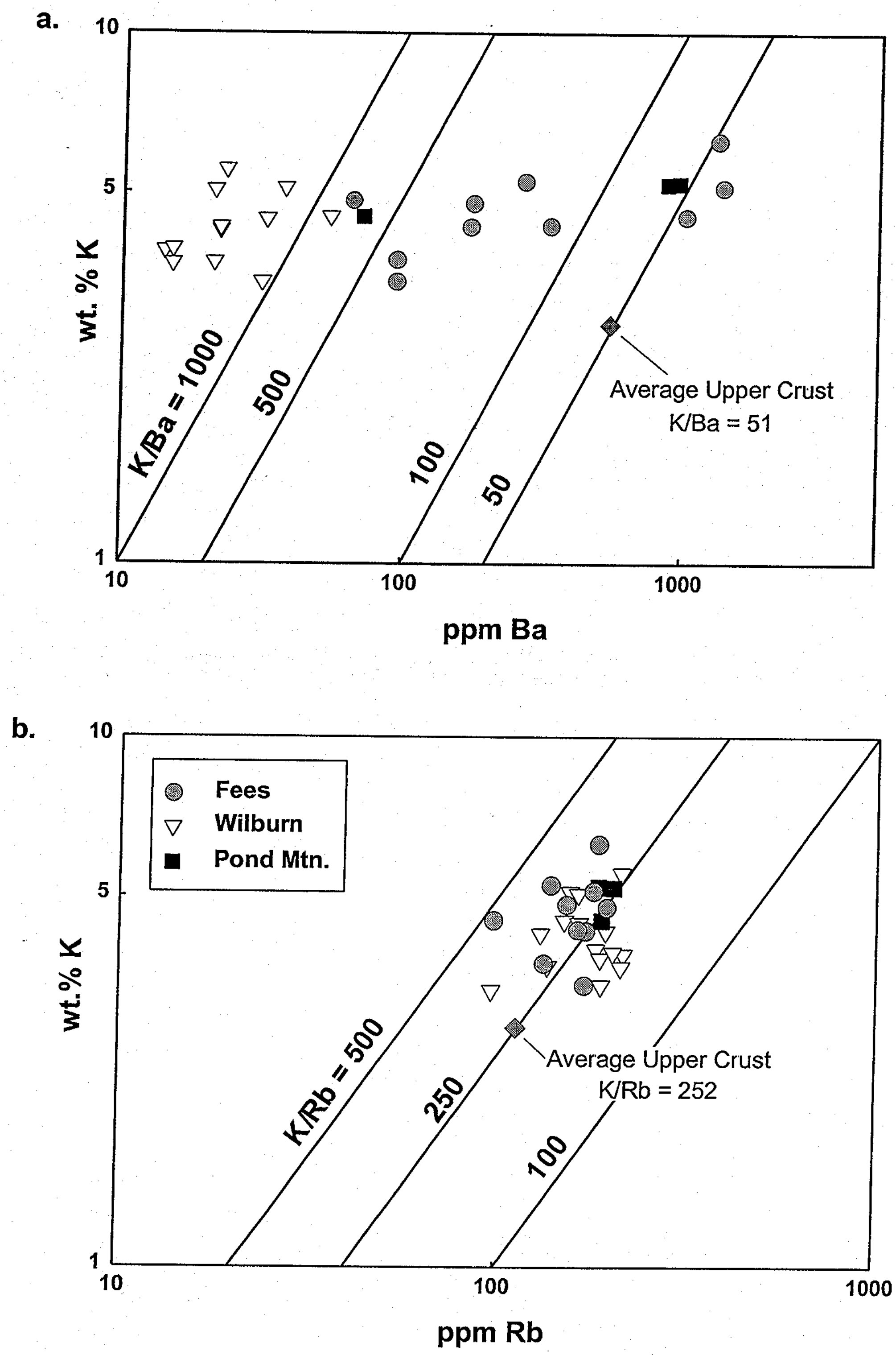


Figure 22. K/Ba (a.) and K/Rb for the Wilburn, Fees and Pond Mountain Rhyolites. Average upper crust values from Taylor and McLennan, 1985.

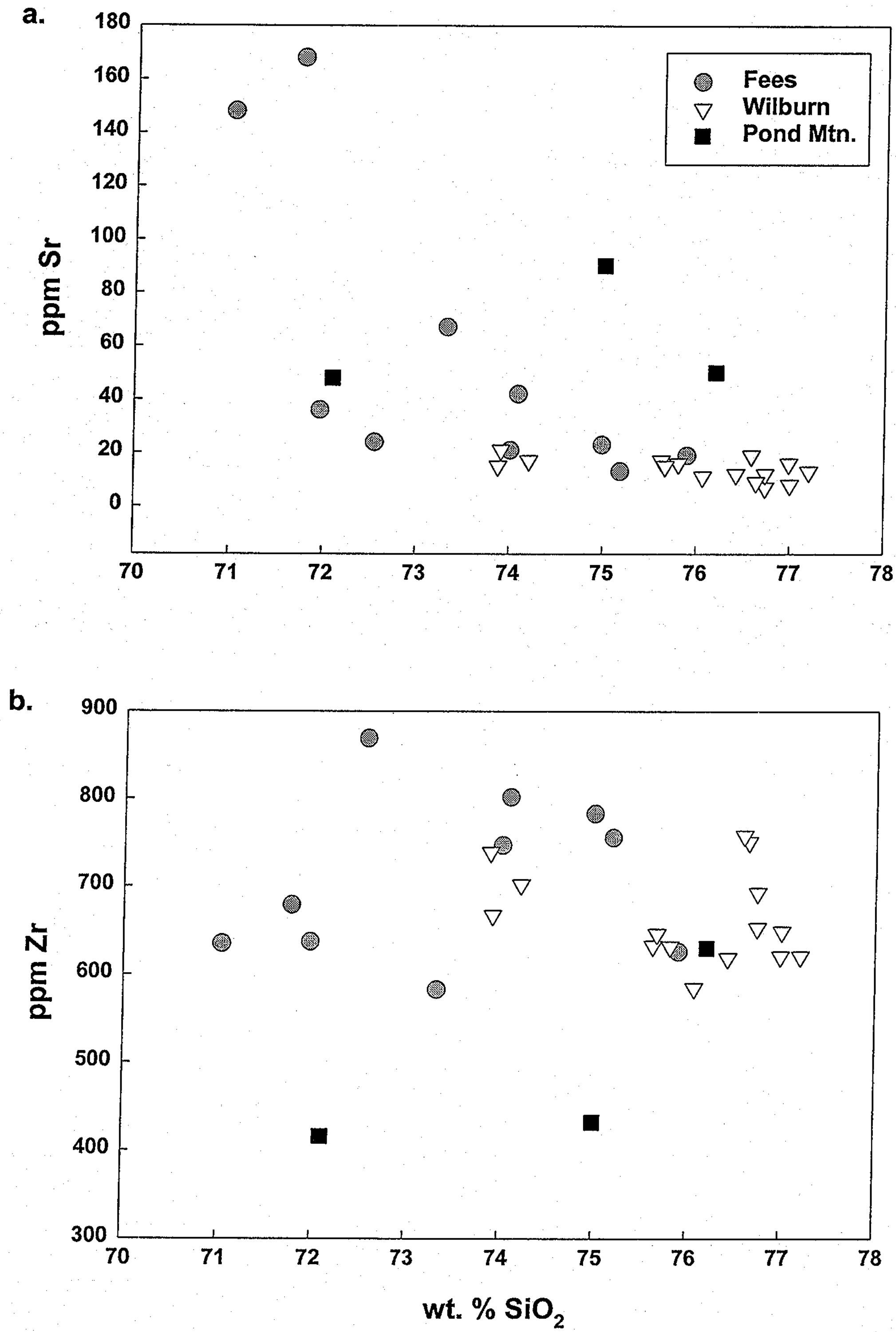


Figure 23. Harker diagram of Sr (a) and Zr (b) for the Wilburn, Fees, and Pond Mountain Rhyolites.

CONCLUSIONS

The Fees Rhyolite Member crops out as a series of NE striking, SE dipping lenticular bodies in southwestern Virginia and adjacent North Carolina. The Fees is a porphyritic metarhyolite, with a massive, fine grained, maroon matrix and 20-35% phenocrysts of K-feldspar, quartz and in some samples plagioclase. The Fees Rhyolite Member was originally extruded as the coarse ground flow portion of a pyroclastic flow, or closely related series of flows, in the Neoproterozoic. During the Paleozoic (probably in association with the Alleghanian Orogeny), the Fees experienced greenschist facies metamorphic conditions. The Fees exhibits considerable variation in the degree of metamorphic alteration. Plagioclase-bearing samples also contain abundant epidote, and have the highest levels of CaO. During metamorphism, Ca was removed from plagioclase and incorporated into epidote, resulting in residual albitic plagioclase phenocrysts. The Fees is a high-K rhyolite, and most samples have similar levels of most major and trace elements. The southwestern body of the Fees in the study area has the highest levels of Ba and Sr and the lowest levels of Nb and Ta. These differences are probably due to variations in phenocryst assemblages and proportions. Geochemical evidence suggests the possibility of a similar source for the Fees Rhyolite and rhyolites of the Pond Mountain volcanic center, but a stratigraphically meaningful correlation cannot be established on the basis of available data. A definitive correlation will require a complete geochemical characterization of the Pond Mountain rhyolites and the determination of isotopic ages for both units.

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APPENDIX A.
Microprobe Analyses of Plagioclase Phenocrysts

Microprobe analyses of plagioclase phenocrysts in sample FR - 14 were obtained with a JEOL JXA-8900 R microprobe at the Department of Mineral Sciences, Smithsonian Institution, Washington, D. C.

Beam specifications: 15kv, 10 nanoamps, 10 μ diameter

Standards: Ca, Si, Al - bytownite: Na, Fe, K, Mg, Ti, Ca - kakanui hornblende: Mn-manganite: also see albite standard analyzed as unknown. ZAF corrections were done.

Oxide	6-core	6-rim	1-core	1-rim	3-core	3-rim	5-core
SiO_2	67.37	68.52	67.49	66.66	67.58	68.06	69.17
Al_2O_3	19.37	20.26	19.19	19.46	20.60	19.93	19.58
FeO	0.01	0.27	0.01	0.19	0.62	0.17	0.00
MgO	0.00	0.06	0.02	0.05	0.07	0.06	0.03
CaO	0.07	0.05	0.10	0.11	0.12	0.14	0.13
Na_2O	11.32	10.96	11.61	10.75	10.80	11.19	11.14
K_2O	0.10	0.62	0.17	0.49	0.56	0.41	0.24
TiO_2	0.03	0.02	0.03	0.07	0.07	0.03	0.09
MnO	0.04	0.05	0.10	0.04	0.08	0.10	0.04
Total	98.32	100.81	98.71	97.82	100.48	100.10	100.40

Oxide	5-rim	5b-core	5b-rim	4-core	4-rim	2-core	2-rim
SiO_2	67.65	66.66	66.82	65.09	67.02	67.54	66.72
Al_2O_3	19.65	20.83	19.97	19.32	19.41	18.82	19.25
FeO	0.18	0.60	0.14	0.15	0.11	0.00	0.10
MgO	0.08	0.04	0.03	0.01	0.02	0.05	0.05
CaO	0.05	0.00	0.36	0.06	0.10	0.02	0.14
Na_2O	11.27	10.44	11.38	11.46	11.25	11.70	11.70
K_2O	0.43	1.24	0.29	0.42	0.19	0.14	0.12
TiO_2	0.02	0.00	0.05	0.04	0.01	0.01	0.03
MnO	0.10	0.00	0.00	0.00	0.00	0.04	0.00
Total	99.44	99.81	99.05	96.56	98.11	98.31	98.11

Oxide	Albite Standard as unknown	Albite Standard as unknown	Albite Standard as unknown	Albite Accepted Composition
SiO_2	67.84	68.44	69.06	68.27
Al_2O_3	19.48	19.59	19.25	19.59
FeO	0.09	0.09	0.01	0.17
MgO	0.04	0.04	0.04	0.00
CaO	0.00	0.03	0.04	0.44
Na_2O	11.35	11.30	11.81	11.80
K_2O	0.27	0.22	0.24	0.19
TiO_2	0.02	0.00	0.02	0.00
MnO	0.00	0.00	0.02	0.00
Total	99.08	99.70	100.49	100.46

APPENDIX B

Sample Field Data

Sample	PM - 1
Date	6/15/98
Location	36°34'41"N, 81°35'37"W Ripshin Rd. 50m E of Miller complex driveway, Park Quad.
Rock Type	Rhyolite Porphyry (Zv2)
Foliation	none taken
Field Ref	SCJ - 1
Sample	PM - 2*
Date	6/15/98
Location	36°34'38"N, 81°35'44"W Ripshin Rd. 50m W of Miller complex driveway, Park Quad.
Rock Type	Rhyolite Porphyry (Zv2)
Foliation	none taken
Field Ref	SCJ - 1
Sample	PM - 3
Date	6/15/98
Location	36°34'38"N, 81°35'44"W Ripshin Rd. 50m W of Miller complex driveway, Park Quad.
Rock Type	Rhyolite porphyry (Zv2)
Foliation	none taken
Field Ref	SCJ - 1
Sample	PM - 4
Date	6/15/98
Location	36°35'10"N, 81°37'12"W Farmers Store Rd. 330m (0.2 mi) from State line, Park Quad.
Rock Type	Porphyritic rhyolite
Foliation	none taken
Field Ref	SCJ - 2
Sample	FR - 1
Date	6/15/98
Location	36°36'43"N, 81°28'53"W Entrance Rd. to Grayson Highlands State Park (GHSP) 1.1 km (0.68 mi) NE from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	047 37 SE
Field Ref	SCJ - 3

Sample	FR - 2*
Date	6/15/98
Location	36°36'39"N, 81°28'53"W Entrance Rd. to GHSP, 1 km (0.63 mi) NE from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 4
Sample	FR - 3
Date	6/15/98
Location	36°36'38"N, 81°29'03"W Entrance Rd. to GHSP 650m (0.4mi) NE from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Greenstone
Foliation	none taken
Field Ref	SCJ - 6
Sample	FR - 4*
Date	6/15/98
Location	36°37'04"N, 81°28'40"W Entrance Rd. to GHSP 1.9 km (1.2mi) NE from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 8
Sample	FR - 5
Date	6/16/98
Location	36°37'16"N, 81°28'25"W NE bank of Mill Creek, 300m NE of Mill Creek Ln., Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	055 44 SE
Field Ref	SCJ - 16
Sample	FR - 6*
Date	6/16/98
Location	36°37'12"N, 81°28'05"W Mill Creek Ln. 1.15km (0.7mi) N from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	010 39 SE
Field Ref	SCJ - 18

Sample	FR - 7*
Date	6/16/98
Location	36°37'19"N, 81°27'55"W Mill Creek Ln. 1.75km (1.1mi) N from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	048 57 SE
Field Ref	SCJ - 21

Sample	FR - 8
Date	6/16/98
Location	36°37'25"N, 81°27'57"W Mill Creek Ln. (unpaved) 2km (1.25mi) N from junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 24

Sample	FR - 9
Date	6/16/98
Location	36°35'07"N, 81°30'40"W Unpaved Rd. (Fees Branch Rd., NW off Rt. 746, 100m N of State line) 150m (.25mi) N of Kilby Cemetary, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	012 31 SE
Field Ref	SCJ - 29

Sample	FR - 10
Date	6/16/98
Location	36°35'22"N, 81°30'39"W Fees Branch Rd. 800m N of Kilby Cemetary, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	044 24 SE
Field Ref	SCJ - 30

Sample	FR - 11*
Date	6/16/98
Location	36°35'25"N, 81°30'42"W Fees Branch Rd. 1.1km N of Kilby Cemetary, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 32

Sample	FR - 12
Date	6/16/98
Location	36°35'34"N, 81°30'40"W Fees Branch Rd. 100m S of Fees Ridge Cemetary, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	047 38 SE
Field Ref	SCJ - 33
Sample	FR - 13*
Date	6/16/98
Location	36°35'50"N, 81°30'18"W Trail to NE at end of Fees Branch Rd. to top of Fees Ridge, above tree farm, elevation 4040ft, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	060 39 SE
Field Ref	SCJ - 35
Sample	FR - 14*
Date	6/17/98
Location	36°35'12"N, 81°30'45"W 200m W of Fees Branch, elevation 3340ft, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 36
Sample	FR - 15
Date	6/17/98
Location	36°36'04"N, 81°29'47"W Rt. 797, 100m ESE of Spencer Branch, Grassy Creek Quad.
Rock Type	Metagraywacke (Zms)
Foliation	082 41 S
Bedding	086 26 S
Field Ref	SCJ - 39
Sample	FR - 16
Date	6/17/98
Location	36°36'03"N, 81°29'40"W Rt. 797, 250m ESE of Spencer Branch, Grassy Creek Quad.
Rock Type	Greenstone
Foliation	052 22 SE
Field Ref	SCJ - 40

Sample	FR - 17
Date	6/17/98
Location	36°37'39"N, 81°28'05"W Mill Creek Ln. (unpaved) 2.75km (1.7mi) N from junction with Rt. 58, Trout Dale Quad.
Rock Type	Phenocryst poor rhyolite (Zv2)
Foliation	none taken
Field Ref	CMB - 1
Sample	FR - 18*
Date	6/17/98
Location	36°37'21"N, 81°28'19"W 500 m NE of Mill Creek at top of hill, Grassy Creek Quad.
Rock Type	Phenocryst-poor rhyolite (Zv2)
Foliation	043 58 SE
Field Ref	CMB - 1
Sample	FR - 19*
Date	6/17/98
Location	36°37'29"N, 81°27'29"W St. Rt. 817 (Big Wilson Creek Rd.) 600m N of junction with Rt. 58, Grassy Creek Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 49
Sample	FR - 20*
Date	6/17/98
Location	36°37'38"N, 81°27'40"W St. Rt. 817, 1km N of junction with Rt. 58, Trout Dale Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 52
Sample	FR - 21
Date	6/18/98
Location	36°35'02"N, 81°30'50"W Logging Rd. west of Fees Ridge, Park Quad.
Rock Type	Greenstone
Foliation	039 30 SE
Field Ref	SCJ - 56

Sample	FR - 22
Date	6/18/98
Location	36°35'00"N, 81°31'05"W Tributary to Helton Creek (Bus Driver Creek) SW of Fees Ridge, 400m from Rt. 751, Park Quad.
Rock Type	Porphyritic rhyolite (Zfr)
Foliation	052 34 SE
Field Ref	SCJ - 60

Sample	FR - 23*
Date	6/19/98
Location	36°36'48"N, 81°28'53"W Entrance Rd. to GHSP, 20m S of Contact Station, W side of Rd., Grassy Creek Quad.
Rock Type	Porphyritic metarhyolite (Zfr)
Foliation	none taken
Field Ref	SCJ - 72

Sample	RR - 1*
Date	6/18/98
Location	36°40'00"N, 81°23'25"W Rt. 658, 25 N of bridge over Fox Creek 2.4km (1.5mi) from Grant, Trout Dale Quad.
Rock Type	Rhyolite prophry
Foliation	none taken
Field Ref	SCJ - 62

Sample	RR - 2
Date	6/18/98
Location	36°41'00"N, 81°23'30"W Rt. 677, 100m N of junction with Rt. 676, Trout Dale Quad.
Rock Type	Volcanic conglomerate
Foliation	none taken
Field Ref	SCJ - 63

Sample	RR - 3
Date	6/18/98
Location	36°41'17"N, 81°23'35"W Rt. 677, 800m (0.5mi) N of junction with Rt. 676, Trout Dale Quad.
Rock Type	Porphyritic rhyolite
Foliation	none taken
Field Ref	SCJ - 64

Sample	RR - 4
Date	6/18/98
Location	36°42'46"N, 81°21'08"W Rt. 601, 1.9km (1.2 mi) SE from junction with Rt. 677, Middle Fox Creek Quad.
Rock Type	Rhyolite porphyry
Foliation	none taken
Field Ref	SCJ - 66

Sample	RR - 5
Date	6/18/98
Location	36°41'12"N, 81°19'03"W Rt. 672, 100m N from junction with Rt. 658/672, Middle Fox Creek Quad.
Rock Type	Granite
Foliation	none taken
Field Ref	SCJ - 68

Sample	RR - 6
Date	6/18/98
Location	36°43'02"N, 81°20'12"W Rt. 675, 1.6km (1mi) from junction with Rt. 601, Middle Fox Creek Quad.
Rock Type	Porphyritic rhyolite
Foliation	none taken
Field Ref	SCJ - 69

Sample	RR - 7
Date	6/18/98
Location	36°44'48"N, 81°18'28"W Newlands Ridge Rd. (unpaved), near BM 19 M, elevation 4176ft, Middle Fox Creek Quad.
Rock Type	Greenstone (?)
Foliation	none taken
Field Ref	SCJ - 70

Sample	RR - 8*
Date	6/18/98
Location	36°43'03"N, 81°22'01"W Rt. 601 (Flat Ridge Rd.) 50m NE of junction with Rt. 603
Rock Type	Porphyritic rhyolite?, Volcanic conglomerate?
Foliation	none taken
Field Ref	SCJ - 71

*Thin Sections Made

Appendix B
Sample Location Map

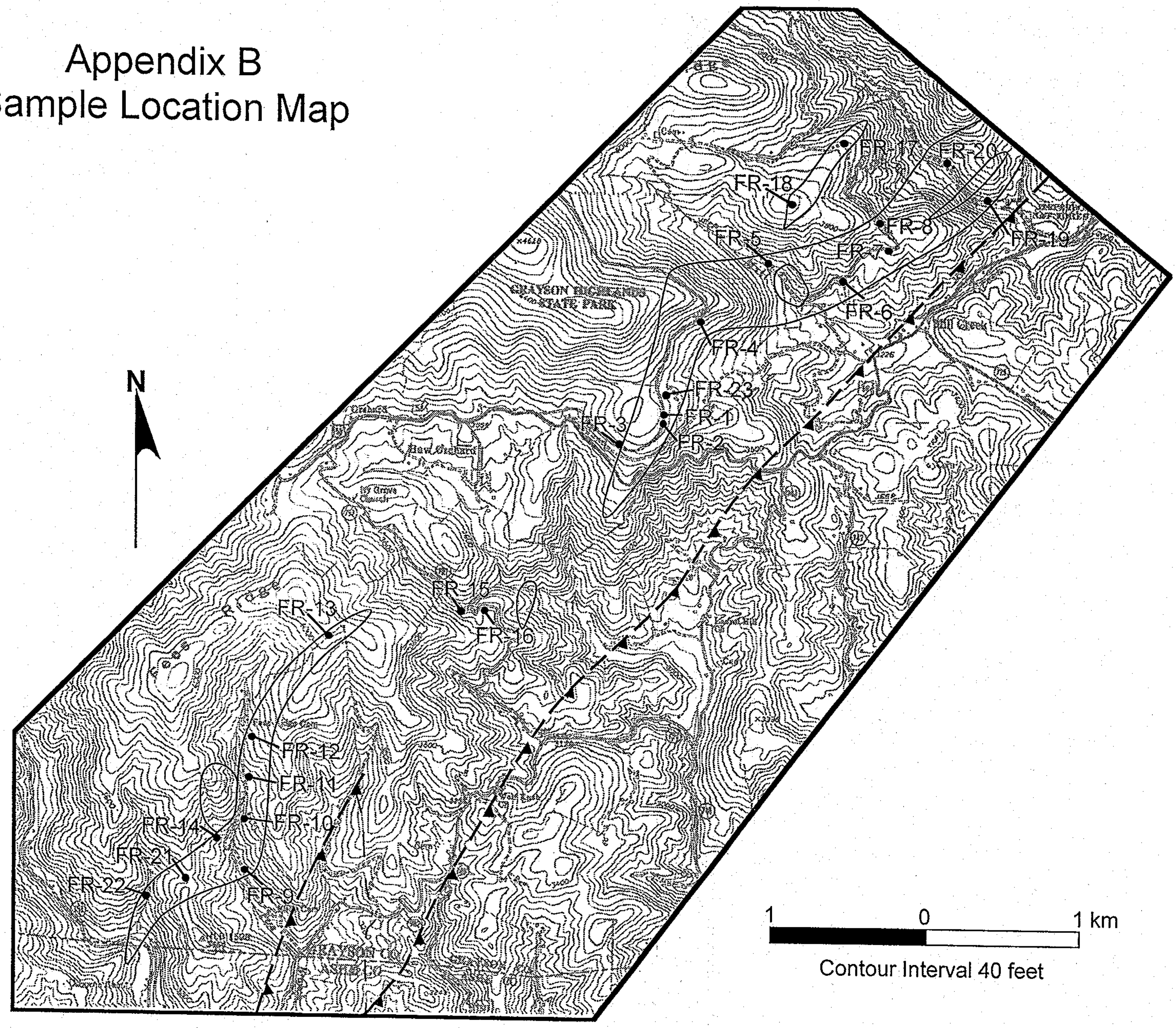
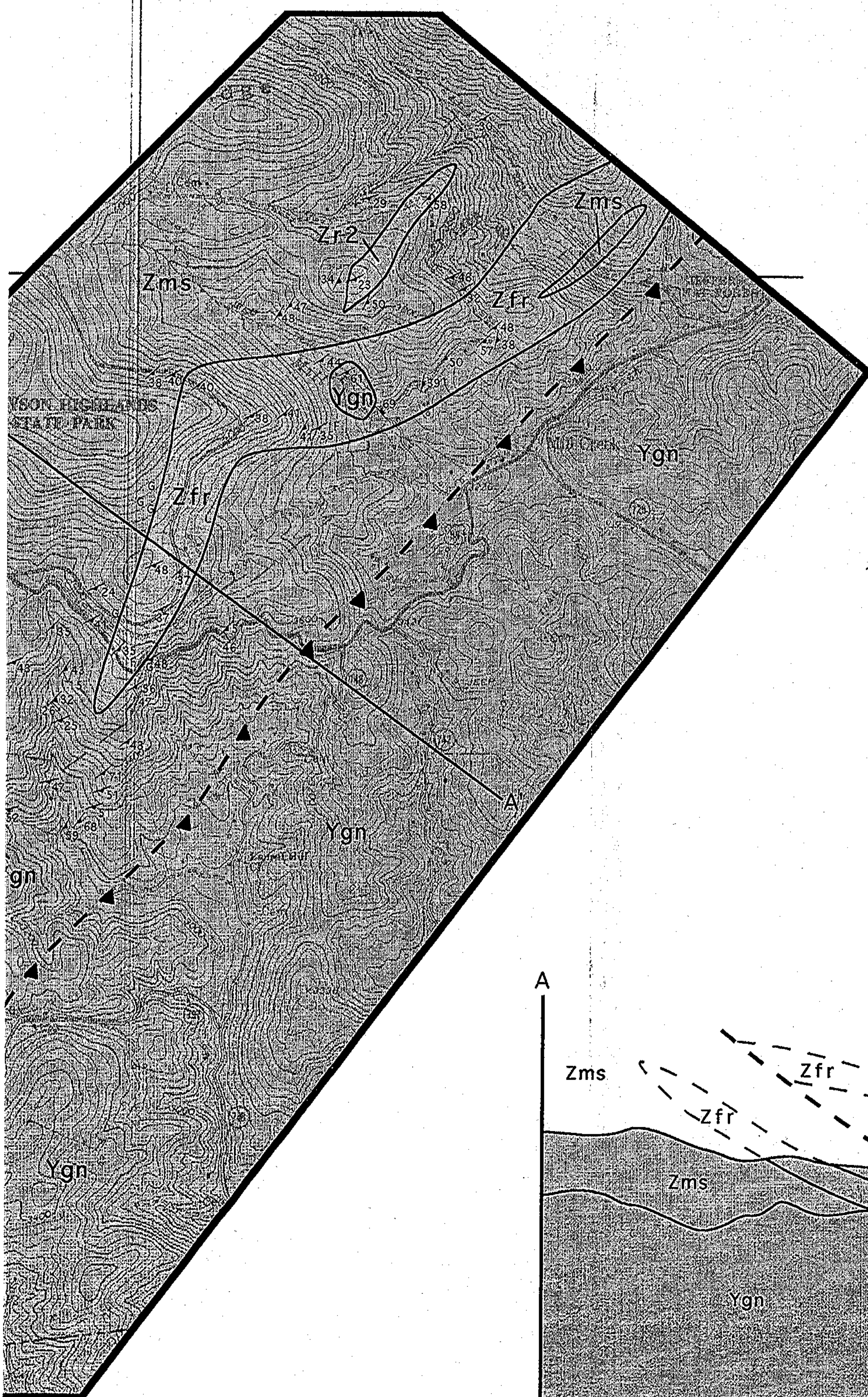
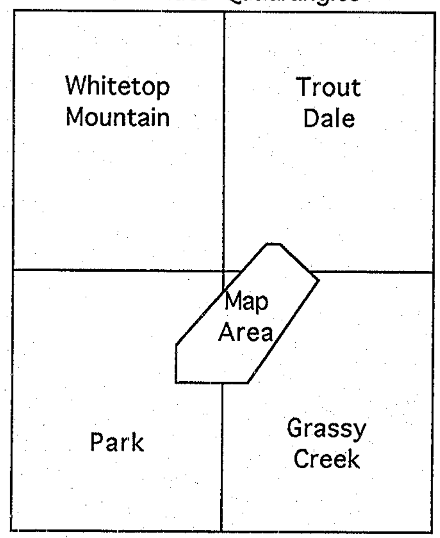


Plate I
ieneralized Geologic Map of Fees Rhyolite Member, lount Rogers Formation, Virginia and North Carolina





Scale 1:24 000

1 0 1 km

Contour Interval 40 feet

Bedding Foliation Joint

Mineral Stretching Lineation

G Greenstone

Stratigraphic Contact, approximate

Reverse Fault, inferred

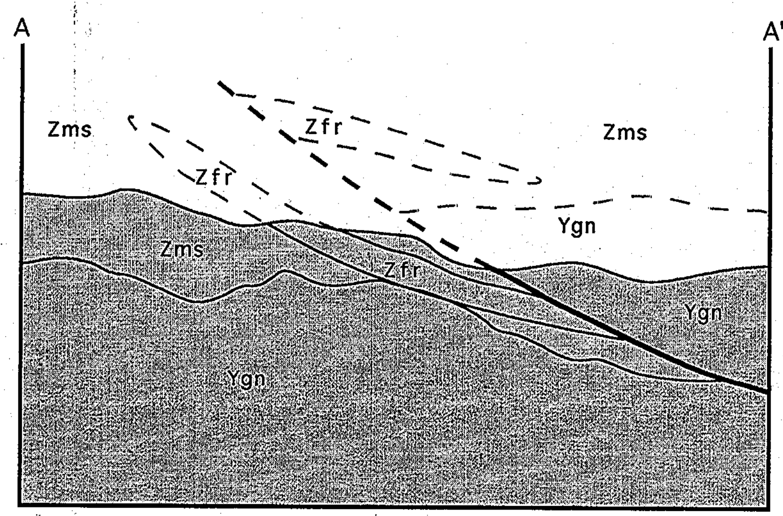


Plate I
Generalized Geologic Map of Fees Rhyolite
Mount Rogers Formation, Virginia and North