A study of selected igneous bodies of the Norris-Red Bluff area, Madison County, Montana
by John Arthur Kavanagh Yllarramendi

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN APPLIED SCIENCE With a Major In Geology
Montana State University

Abstract:
The igneous bodies studied crop out in the Norris Hills, between the upper and lower Madison Valley, southeast of the Tobacco Root Mountains and northwest of the Spanish Peaks, They appear to be intrusive plugs, with surface features obscured by Quaternary deposits. In average samples the silica 'content varies between 66 per cent and 78 per cent. Chemical and normative analyses indicate that the rocks with lower and intermediate silica content are dacites. Petrographic analysis indicates the richer silica rocks are rhyolites. One andesite body is also present. The sodium content of the dacites is unusually high.

The dacites at the northern end of the upper Madison Valley are aligned, generally northwest-southeast, and lie in a zone of intensive faulting. The igneous bodies east of Norris are flow-banded dacites and breccia pipes. Pyrite-gold mineralization is present in hydrothermal quartz veins peripheral to the dacites. This mineralization seems to have been controlled by the faulting in the area.

The dacites are microcrystalline with a few phenocrysts of plagioclcise (andesine) and quartz. Microlites of feldspar and anhedral quartz grains mixed with volcanic glass form most of the groundmass. The microlites are oriented in the direction of flow. The phenocrysts in the rhyolites are orthoclase, sanidine, plagioclase,.quartz, and biotite. The groundmass is also microcrystalline, with volcanic glass appearing either as paptially crystallized microlites or as inclusions in the phenocrysts. Sericitization is abundant.

Although the Tobacco Root batholith seems to have been emplaced during early Tertiary time the igneous bodies studied appear to "be younger, probably of Eocene age. It is improbable that they were comagmatic with the batholith.

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE IN APPLIED SCIENCE

With a Major In Geology

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Bozeman, Montana

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ABSTRACT

The igneous bodies studied crop out in the Norris Hills, between the upper and lower Madison Valley, southeast of the Tobacco Root Mountains and northwest of the Spanish Peaks. They appear to be intrusive plugs, with surface features obscured by Quaternary deposits. In average samples the silica content varies between 66 per cent and 78 per cent. Chemical and normative analyses indicate that the rocks with lower and intermediate silica content are dacites. Petrographic analysis indicates the richer silica rocks are rhyolites. One andesite body is also present. The sodium content of the dacites is unusually high.

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A STUDY OF SELECTED IGNEOUS BODIES
OF THE NORRIS-RED BLUFF AREA,
MADISON COUNTY, MONTANA

INTRODUCTION

Purpose of the paper

The main purpose of this paper is to present results of a comprehensive field and laboratory study of selected igneous bodies situated between the upper and lower Madison Valley, southeast of the Tobacco Root Mountains and northwest of the Spanish Peaks. Included are their description and classific-cation, the field relations between them and neighboring igneous bodies, plus special petrological considerations.

Previous work

A general reconnaissance of the Tobacco Root Mountains has been made by W. Tansley, P.A. Schafer and L.H. Hart (1933). Some of the igneous bodies treated here were described in the report, but no petrological nor detailed field work was in-volved. Rolland R. Reid (1957) wrote about the bedrock geology of the north end of the Tobacco Root Mountains. Although the igneous bodies studied in this paper were not treated in Reid's report, this work is valuable in the attempt to determine petrological and structural relationships between the Tobacco Root batholith and the igneous bodies that surround it. G.W. Berry (1943) studied the stratigraphy and structure in the vicinity of Three Forks, Montana; geomorphic studies of the area of the Madison Valley and Norris Hills have been done by Swanson (1950), and Montagne (1960).

GEOLOGICAL SETTING

The igneous bodies studied occur over an area of about 280 square miles. They are exposed southwest, east, and northeast of the town of Norris (Fig. 1). The basement rocks are pre-Belt gneisses and schists of the Cherry Creek and Pony series. The igneous bodies cut these basement rocks and are either covered by Quaternary glacial sediments or are in close relation to them. East of the general area, Cambrian and Devonian sedimentary rocks are exposed in a southeast-northwest trend (Fig. 2), intruded at places by Tertiary coarse-grained igneous bodies, mainly quartz monzonites, diorites and other related rocks. Undifferentiated Tertiary sediments cover large areas south and north of the Tobacco Root batholith which lies close to the center of the area. The Tobacco Root batholith crops out in an elliptical shape with its longest axis having a length of about 18 miles, and its shortest axis having a length of 6 miles on the average. Glacial Quaternary sediments are predominant toward the northern end of the Madison Valley, and several distinct Quaternary surfaces can be distinguished, ranging in age from pre-Wisconsin to Late Wisconsin. The present floodplain of the Madison River forms the most recent surface.

The igneous bodies studied have been identified with letters of the alphabet (Fig. 1). South of Norris, five igneous bodies are labelled as A, B, C, D, and E. East of Norris and south of Red Bluff, two more igneous bodies, F and G, are exposed, and igneous body H is located northeast of Red Bluff.

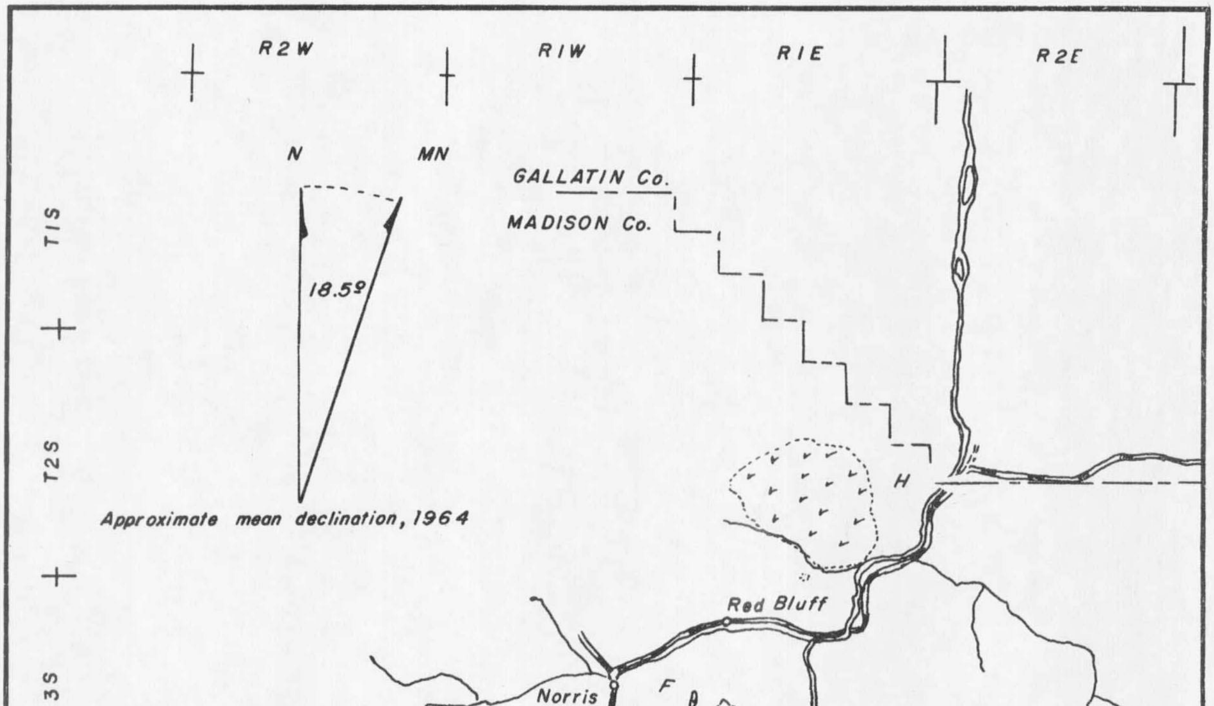
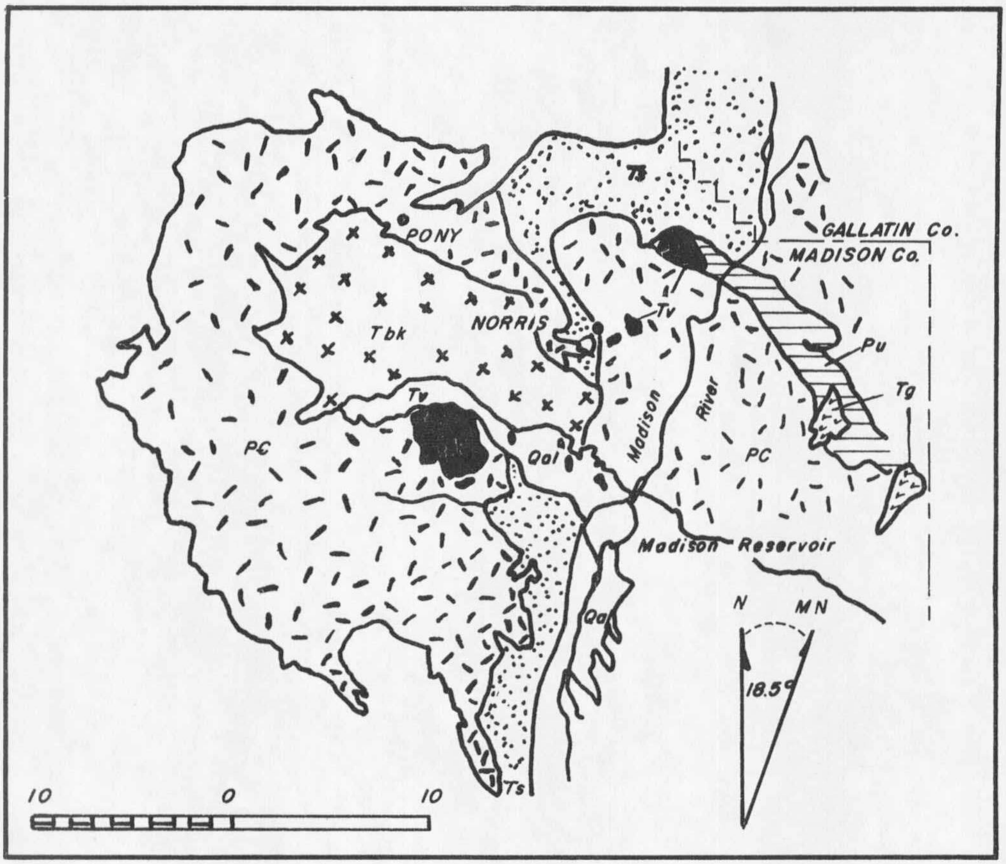


FIGURE 1. Index map of igneous bodies



Qal — Quaternary alluvium, glacial and fluvial sediments

Ts — Tertiary sediments, undifferentiated.

Tv — Tertiary volcanics, andesites, dacites and rhyolites

Tbk — Tertiary, Tobacco Root Batholith

Tg — Tertiary, intrusive coarse-grained rocks diorites, quartz monzonites and similar rocks

Pu — Paleozoic, undifferentiated

P€ — Precambrian, gneisses and schists

Modified from Geologic Map of Montana (1955), compiled by
C. P. Ross,
D. A. Andrews, and
I. J. Witkind.

FIGURE 2. General geology of the area

GENERAL GEOLOGY OF IGNEOUS BODIES

Igneous bodies A and B

Igneous bodies A and B are acid igneous rock; megascopic, plus chemical and petrographic analysis (see Petrography) permit classification of these rocks as dacites. These intrusive dacites are exposed in the general region of Meadow Creek. Quaternary sediments and alluvium obscure border relationships with the host rock. The boundaries of the igneous bodies were determined by float, because contacts do not crop out. Cooling cracks are found throughout the dacites of this body, forming plates which range in thickness between 3 and 8 mm., according to the amount of exfoliation. The cooling cracks give the dacites a peculiar form in outcrops (Plate 1, Fig. 2), and there is microscopic evidence that these cracks are oriented parallel to the direction of flow. The tendency of the igneous bodies to form parallel plates aligned with the direction of flow will be referred to from now on as fissility. The structure of the bodies was determined by measuring attitudes of the flow, as indicated by this fissility. The general structure of igneous body A shows

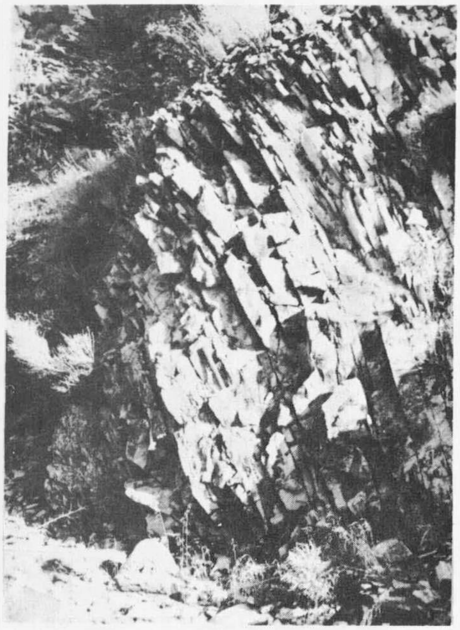


PLATE ONE

FIGURE 1. Igneous body C. Dacite intrusion.
Fissility conforms with the direction of flow.

FIGURE 2. Igneous body C. Dacite extrusion.
Arrow shows direction of flow.

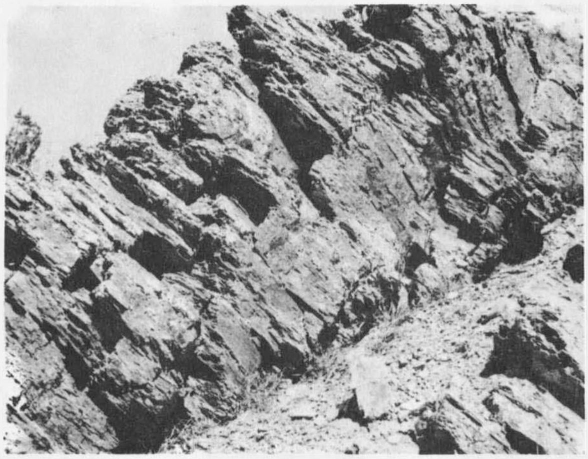
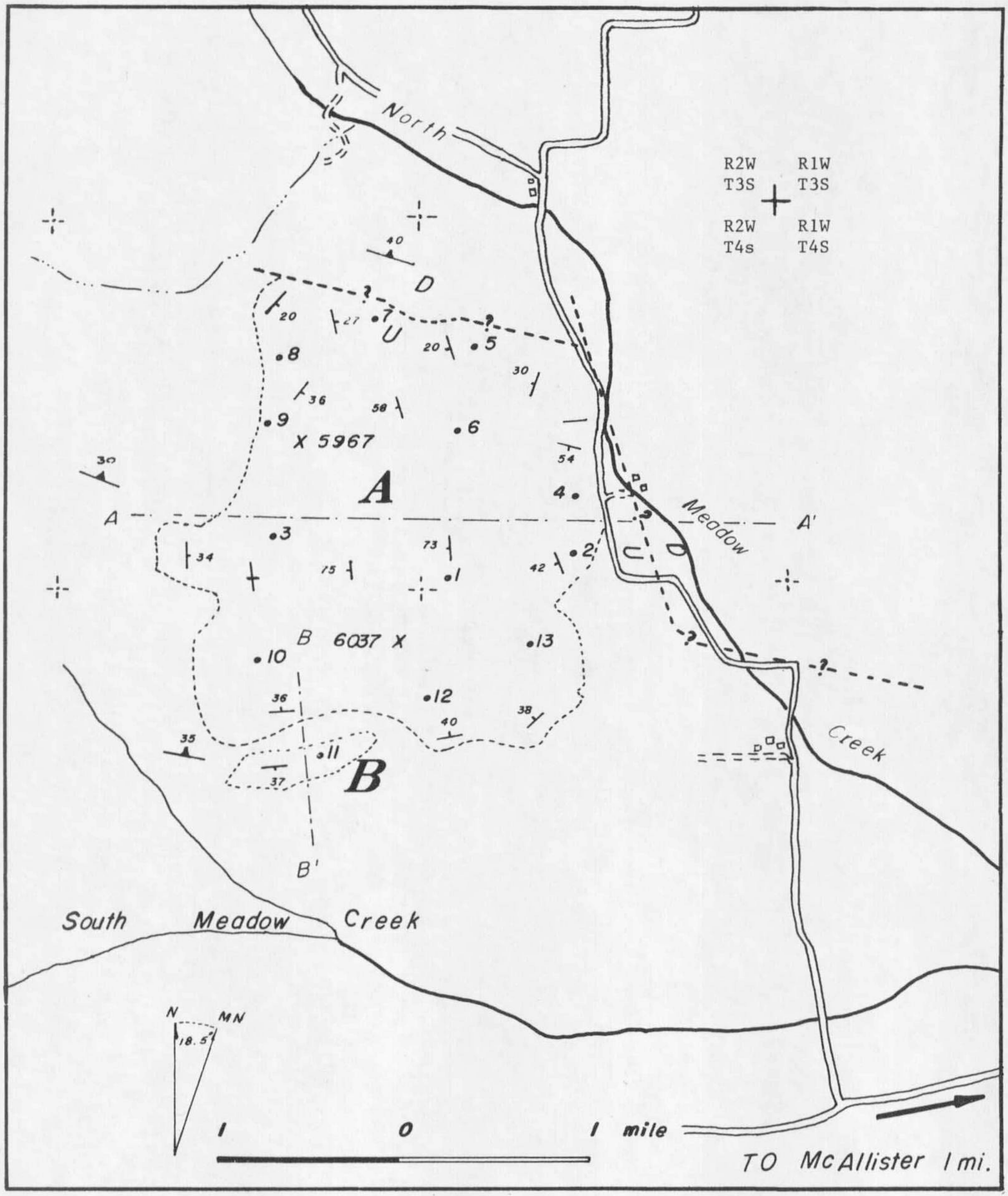


FIGURE 3.

Igneous body A.
Fissility in dacites. This fissility conforms with the last direction of flow.

two patterns; one at the southern end and another at the northern end of the area. At the southern end (Fig. 3) -if outcrop B is excluded- a distinguishable vent or plug structure appears, with the fissility of the dacites dipping concentrically inward and the dip also steepening inward, towards the southwest portion of the igneous body. The fissility of igneous body B does not conform with this pattern, dipping uniformly southward. This pattern suggests that the dacites of body B represent a separate intrusion and are not part of the main body. In the northern part of the main igneous body, fissility dips inward from the east and west but no inward dip is found along the northern boundary. At a lower topographic elevation and at the eastern boundary of the igneous body, a small exposure of highly fractured dacite is found. The fissility of this outcrop is obscured by another set of cracks at right angles to the cooling cracks. The overlying fissile dacite dips toward the south. Field evidence suggests two different intrusions: a small intrusion which produced the dacites of outcrop B and the underlying dacites of the northeastern part of the main body, and a later, more voluminous intrusion of later dacite, which partially covered the earlier intruded rocks.



Attitude of flow structure (dip showing where measurable)

Inferred fault

Attitude of gneiss foliation

Approximate boundary of igneous bodies

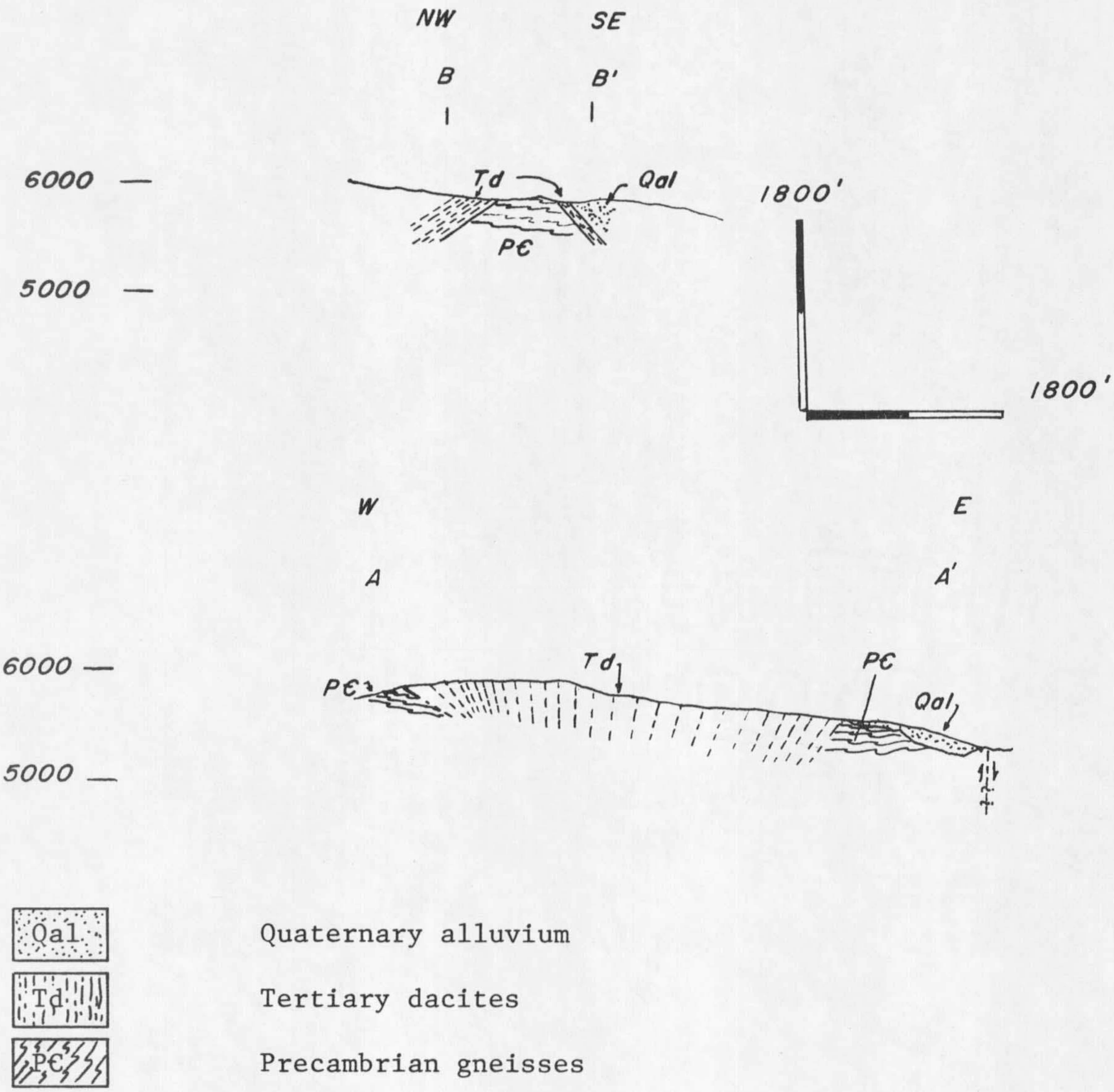
Sampling station

FIGURE 3. Geologic map of igneous bodies A and B

The attitude of the later dacite on the northeastern part of the igneous body could be attributed to surface rather than vent flow. Subsequent erosion has eliminated most of the surface flow farther away from the source. Faulting has probably occurred at two places: on the eastern side of the igneous body, where the so-called North Meadow Creek fault has been mapped (Shelden, 1960; p. 178-184) trending north-south on the eastern side of the igneous body and for which scant evidence exists, and another northwest-southeast fault evidenced by the sudden drop in slope of the igneous body, the disappearance of dacite and the interruption of the igneous body's structure. These faults are normal (?) with the upthrown block in the dacites, and accentuate the graben-like structure of Madison Valley (Montagne, personal communication). Two cross sections (Fig. 4) illustrate the structure. East-west cross section A - A' shows the vent structure and cross section B - B' shows the relationship between the dacite of the main body and the dacite of igneous body B.

<u>Igneous body C</u>

Igneous body C is about one half-mile due east from igneous body A. It is noticeably smaller than A and B, and lies at a

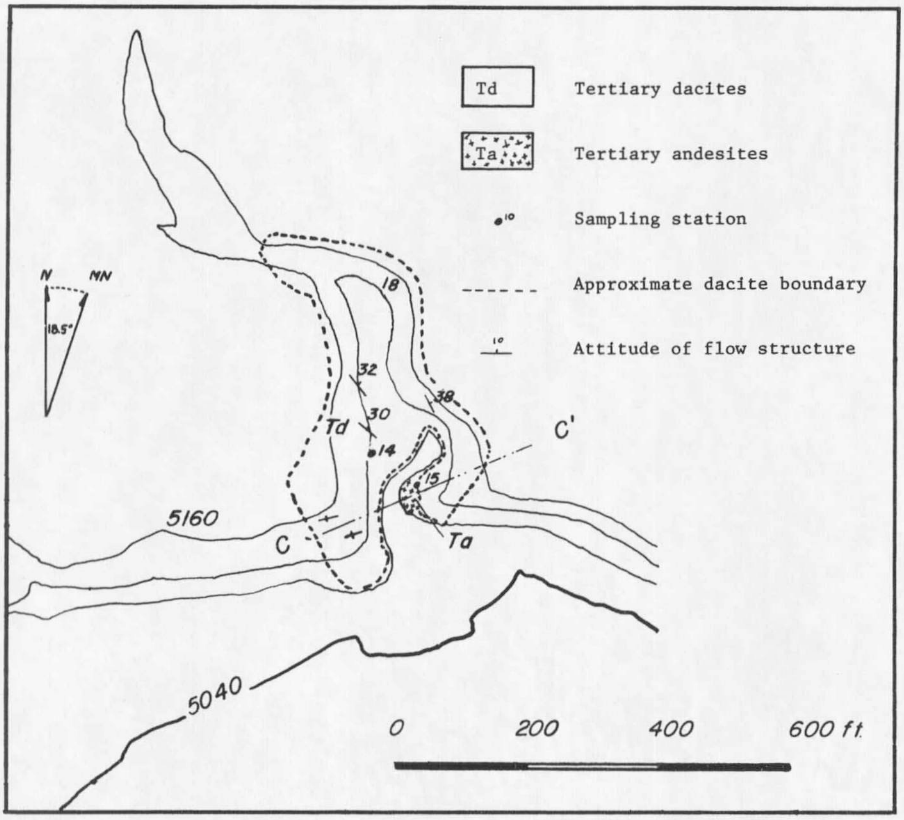


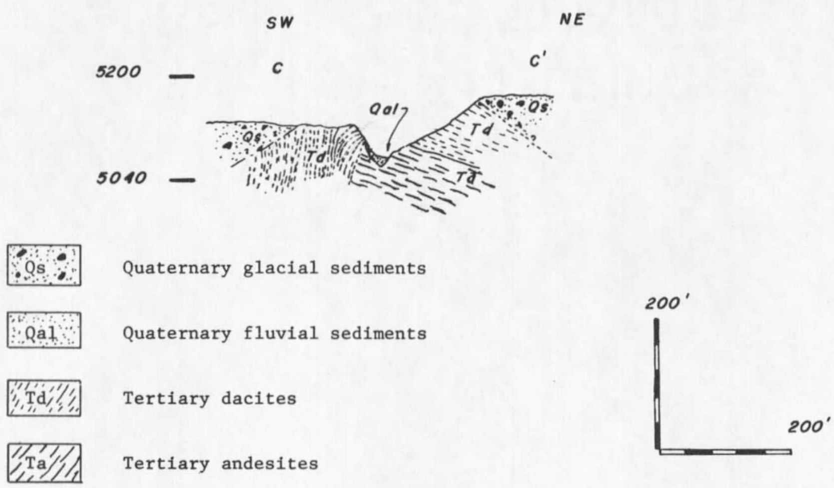
Dashed lines indicate flow direction in dacites

FIGURE 4. Cross section of igneous bodies A and B
Location of cross sections shown on FIGURE 3.

lower topographic elevation. Two distinct rock types are shown: an underlying andesite restricted in horizontal outcrop width to about forty feet, and an overlying dacite, which in places was intruded through the andesite and lies conformably on it in the rest of the outcrop. The andesites show the long axes of minerals plunging 16 degrees to the southeast. Fissility of the overlying dacite dips steeply in the southern part and 30 - 40 degrees northeastward in the rest of the body. The dacite is truncated by a pre-Wisconsin geomorphic surface.

The local structure (Fig. 5) suggests either an early andesitic extrusion, if the dip of the structure has not been disturbed, or an early andesite intrusion which has been tilted by later faulting. This andesite was later cut by the dacites on their way to the surface (Fig. 5, cross section C - C'). Once the dacites reached the surface, they extended horizontally over the paleosurface (Plate 1, Fig. 1, 2). Subsequent faulting could have tilted these dacites eastward. Glacial erosion and deposition on the pre-Wisconsin surface complete the picture.





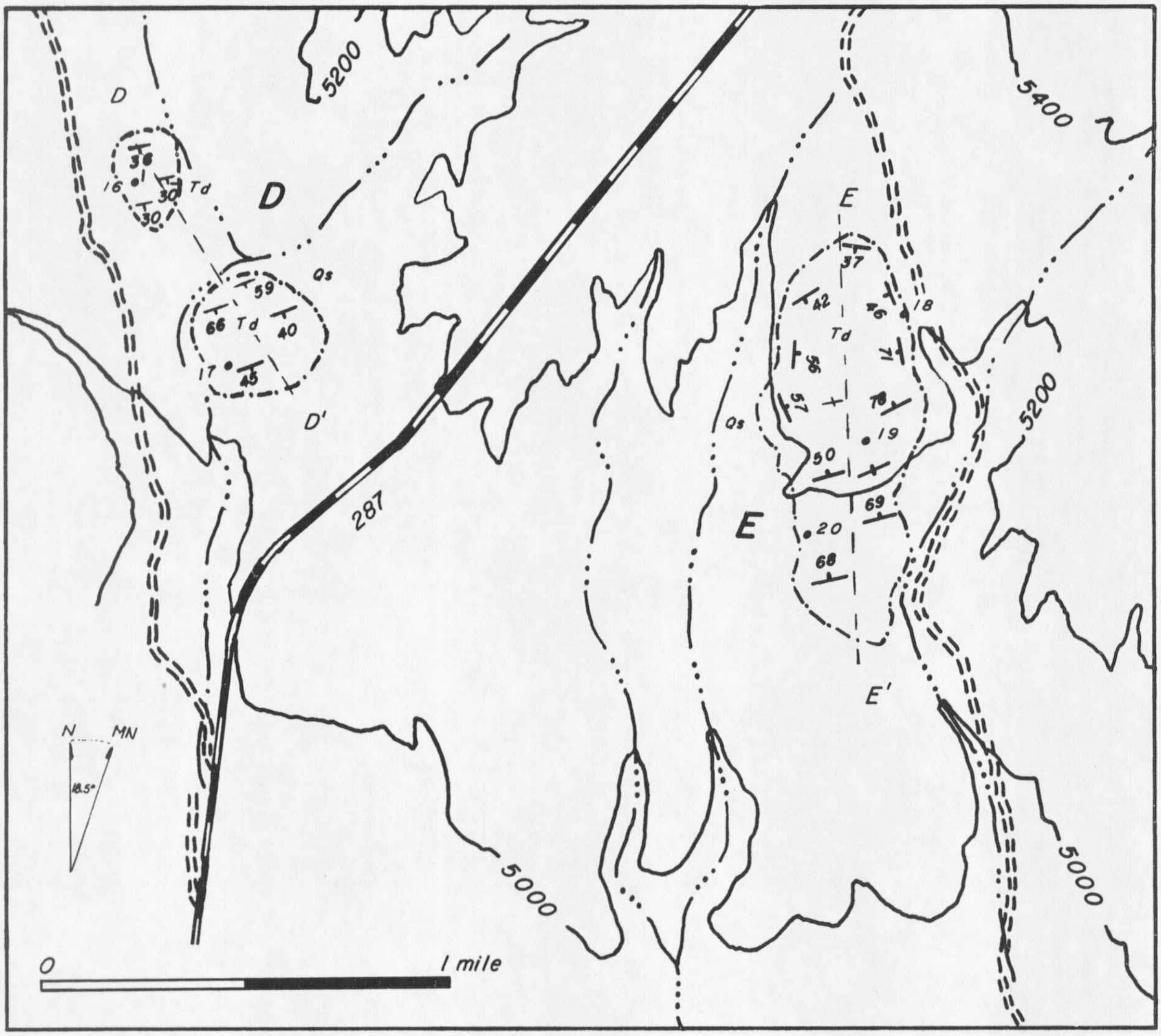
Dashed lines indicate direction of flow

FIGURE 5. Geologic map and cross section of igneous body C

T4S, R1W, Section 20

Igneous bodies D and E

North of the town of McAllister, igneous bodies D and E crop out. These outcrops are the most uniform from the petrological point of view (See Petrography). They exhibit fissility and are located at a lower elevation than the pre-Wisconsin surface which cuts the top of igneous body C. The sedimentary cover obscures the field relationships between the igneous bodies and the pre-Wisconsin glacial sediments. Nearby bedrock exposures are Precambrian gneisses. Igneous body D (Fig. 6) comprises two outcrops separated in space by fluvial sediments deposited between them by a local intermittent stream (Fig. 7, cross section D - D'). The strike of fissility of both outcrops is quite parallel, but the fissility dip of the northernmost exposure is not as steep as that of the southernmost one. Hand excavation was done by the writer in the alluvium between the two exposures, but no fresh rock was encountered. This indicates that either there is no connection between the two exposures or that fluvial sediments are deeper than the depth of excavation (about 4 ft.). The continuous pattern of the igneous body (Fig. 7, D - D') suggests the latter explanation. It is possible that both exposures belong to the



Qs Quaternary glacial sediments

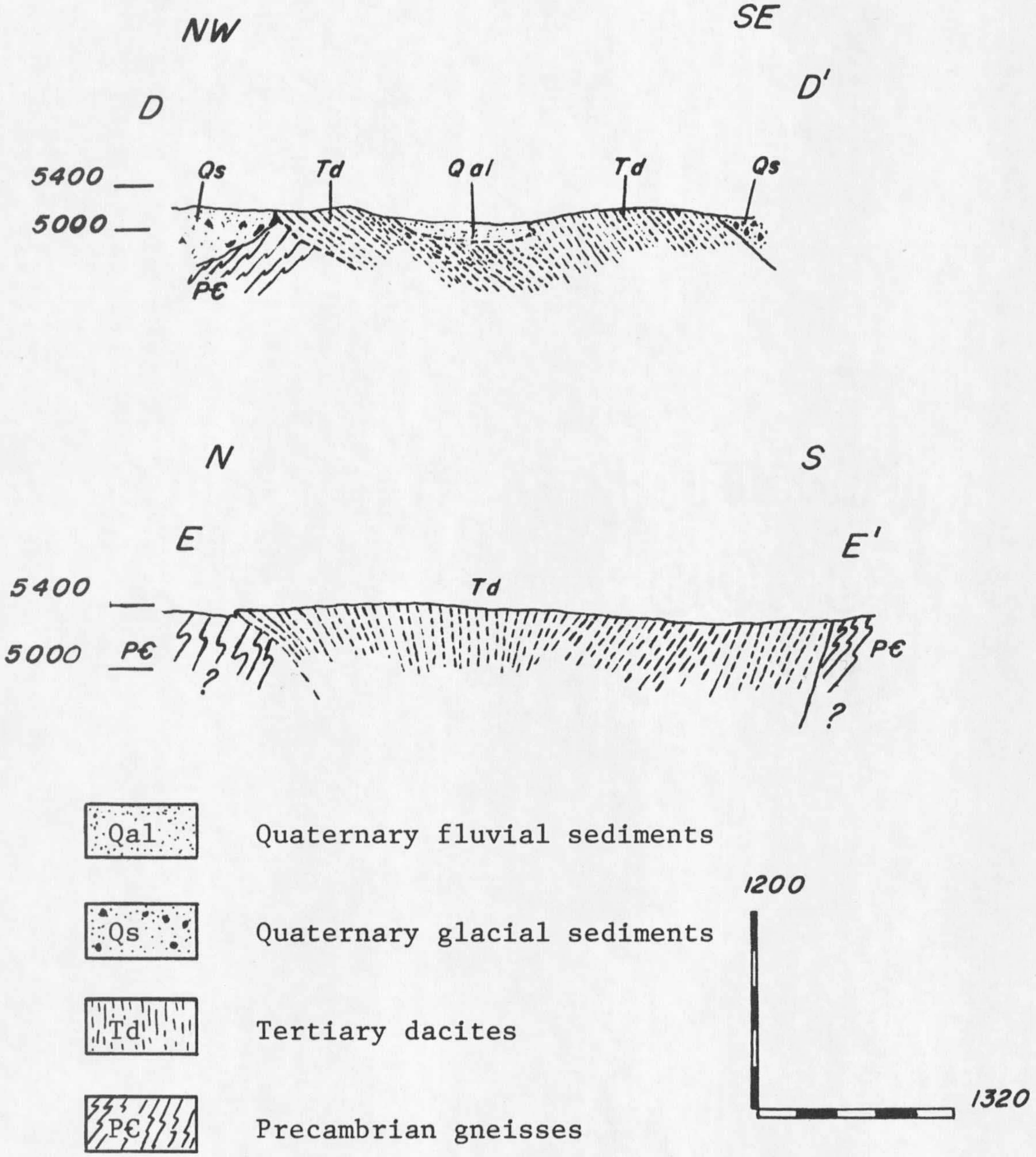
Td Tertiary dacites

Attitude of flow structure

Approximate dacite boundary

Sampling station

FIGURE 6. Geologic map of igneous bodies D and E T4S, R1W, Sections 21, 22, and 27



<u>Dashed lines indicate direction of flow</u>

FIGURE 7. Cross sections of igneous bodies D and E
Location of Cross sections shown in FIGURE 6

same plug. Glacial sediments surround this exposure, but the fact that the gneisses are exposed near the igneous body suggests that these dacites (see Petrography) were intruded into Precambrian basement rocks.

Igneous body E is located east of body D (Fig. 6), and it approximates in outline an ellipse with its long axis oriented almost north-south. The highest elevation of this body is 5391 ft., with the Quaternary sediments beginning at approximately 5200 ft. Fissility was also used here as a criterion for determination of flow direction. Although the northernmost end of the body shows vent characteristics, with the fissility of the dacites dipping concentrically toward the center of the igneous body, the southern end seems more indicative of a dike-like structure, with the closely spaced cracks dipping uniformly and steeply toward the north. It is assumed that the dacites cut through the Precambrian gneisses (Fig. 7, cross section E - E').

<u>Igneous body F</u>

South of Red Bluff and east of Norris (Fig. 1), there are two igneous bodies which show similarities in structure and petrology. Flow-banded dacites, breccias, and glassy flow-banded dacites are three distinctive lithologic units of these two outcrops (see Petrography). The westernmost igneous body has been labelled F. Prospect holes are found throughout the area in which the dacite is mapped. The prospect holes generally follow quartz veins, or try to intercept them at depth. Some of the quartz veins may be a product of metamorphism, and some may be hydrothermal veins, having pyrite-gold mineralization. The differentiation between the two kinds is rather difficult. Only the hydrothermal quartz veins are mineralized, whereas the quartz veins of metamorphic origin are barren of metallic minerals. Three lithological units are found in igneous body F (Fig. 8):

a. Flow banded dacite, light in color and showing a moderate degree of fissility, not as pronounced as that in the igneous bodies south of Norris.

b. Breccia, containing fragments of dacite, some of them flow banded, embedded in a glassy, microcrystalline matrix.

c. Faintly banded dacite, with characteristic perlitic cracks, darker-colored than the other units, and located near the contact with the Precambrian gneisses on the southern end of the igneous body.

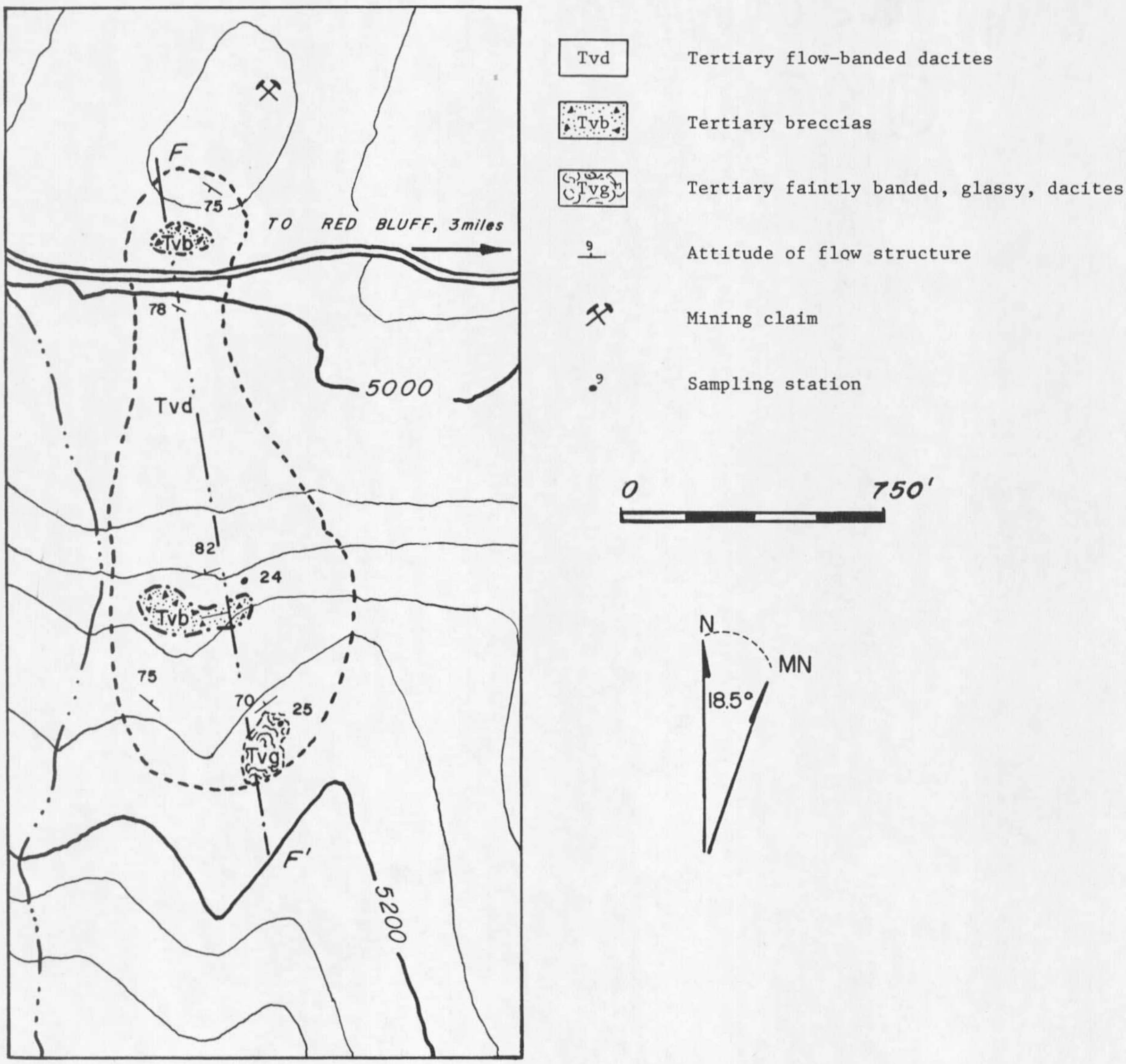
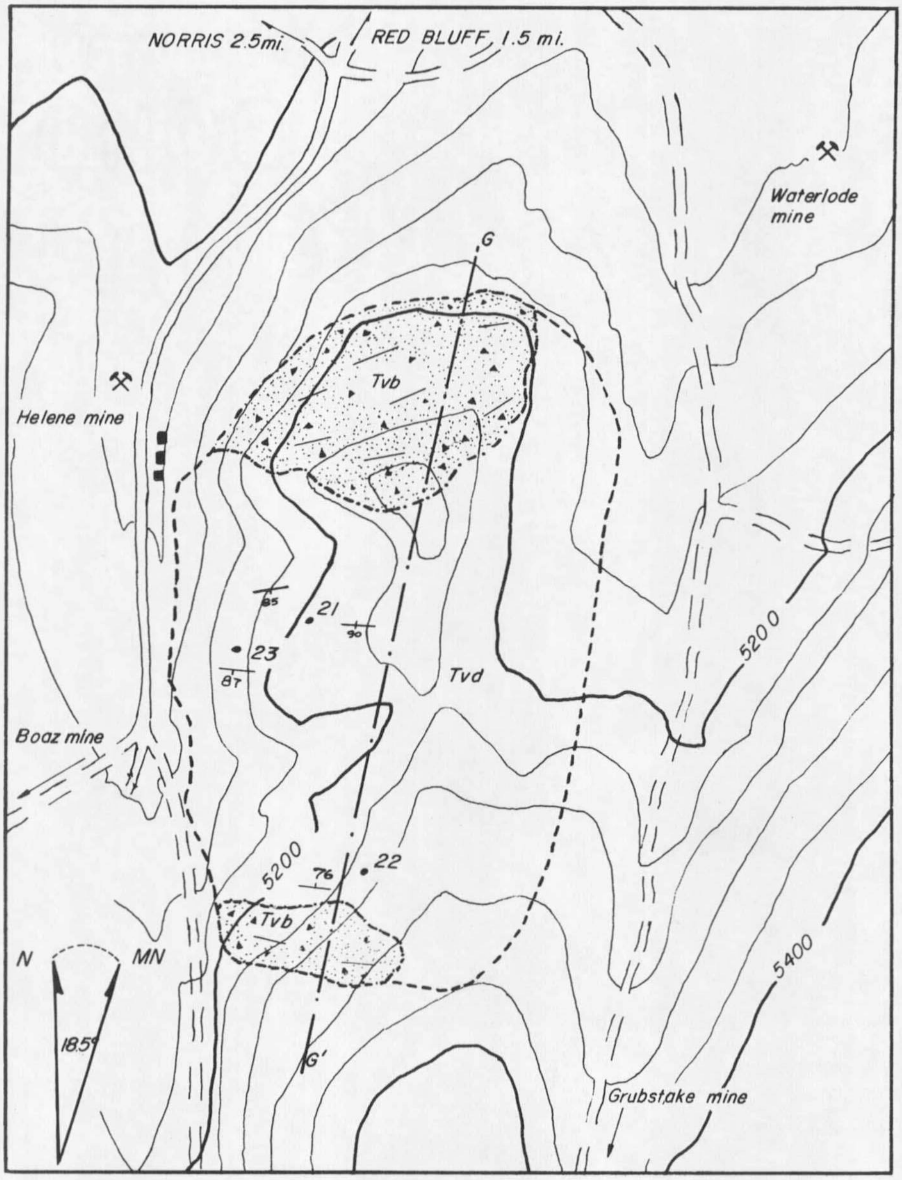


FIGURE 8. Geologic map of igneous body F T3S, R1E, Section 19, NE quarter.

Fissility dips steeply toward the center. The flow banding of the dacites is parallel to the plane of fissility (Fig. 10, cross section F - F'). Breccias are found within the igneous body proper, which helps explain the fact that only dacitic fragments are found. The attitude of breccias is rather obscure but the lack of local intensive disturbance in the dacites suggests that the breccias were emplaced along the same planes as the dacites (Fig. 10, cross section F - F'). However the possibility of vertical breccia pipes in which surface boundary features have been eroded, cannot be discarded. The dacite fragments comprising most of the breccia could have been obtained from a deeper zone, thereby suggesting autobrecciation. The glassy, faintly flow-banded dacites at the southern end of the igneous body also are found on the west side although not as distinctive outcrops but rather as float and with a varying degree of glassiness. They could have been emplaced either as a homogeneous viscous crystal mush which cooled rather rapidly, or as very viscous liquid that did not cool so rapidly; the perlite cracks could be due to contraction of the homogeneous material upon cooling (Harker, 1962, p. 137-172).



0 750' 1500'

Tvd Tertiary flow banded dacites

Tvb Tertiary breccias

Attitude of flow structure (dip showing where measurable)

Mining claims

Sampling stations

FIGURE 9. Geologic map of igneous body G T3S, R1E, Section 19

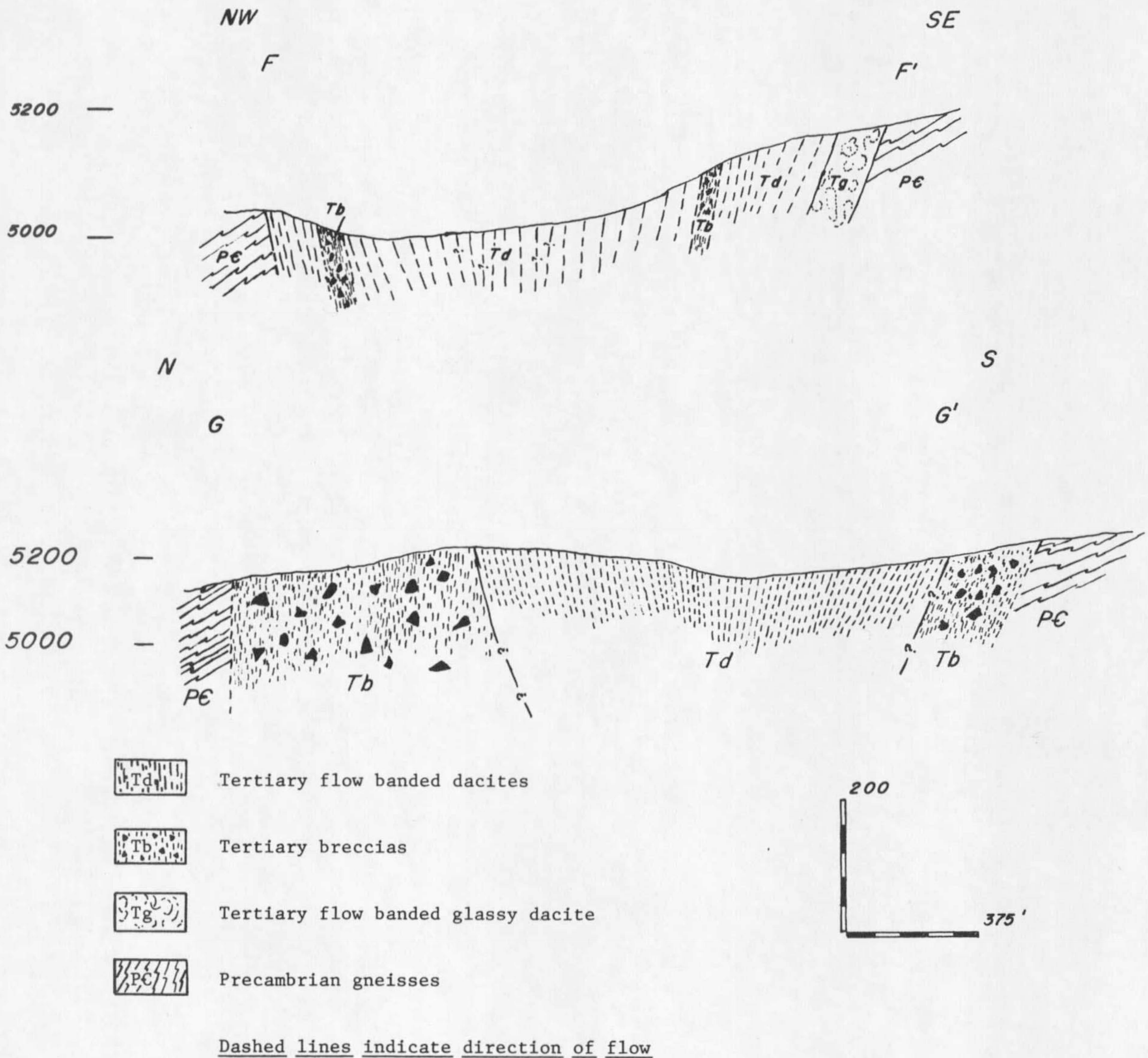


FIGURE 10. Cross sections of igneous bodies F and G
Location of cross sections shown on FIGURE 8 and FIGURE 9

Igneous body G

Two lithologic units comprise igneous body G (Fig. 9). The more voluminous unit, although not having the most distinctive outcrops, is a flow banded dacite, very similar to the one found in igneous body F. This dacite also has fissility aligned parallel to the flow banding. Most of the exposures were found at or near exploration holes dug by prospectors. The second lithologic unit is breccia, carrying angular to subangular dacite fragments embedded in a glassy matrix. The breccia outcrops are quite prominent and on the northern end of the igneous body the fissility appears to dip almost vertically. The flow banded dacites in the middle of the outcrop show steep dip toward the south, whereas in the southernmost exposures fissility dips toward the north. The east and west contacts could not be determined except by float, and thus structure is somewhat uncertain. A north northeast-south southwest cross section (Fig. 10, cross section G - G') suggests a vent. The uncertainty of attitudes on the western and southern boundaries of the igneous body limits an understanding of the structure; the structure illustrated is assumed. The breccias seem to be a product of late viscous liquids that were pushed outward by pressure away from the magmatic chamber. These liquids probably moved along the same weakness planes through which the dacites originally traveled, breaking and scraping the partially solidified dacites. Although the breccias are located near or at the contact between the igneous body and the surrounding Precambrian gneisses, they are monolithologic, with only dacite fragments. No gneissic material was seen in them. The fluid probably had too much viscosity to penetrate and rip off pieces of the metamorphic rocks. Steep contacts suggest intrusive breccias.

Igneous body H

Igneous body H is located near where the Madison River leaves the Madison Canyon (Figs. 1, 11) and it is known locally as Red Mountain. The lithological units present in this igneous body are:

a. Flow-banded rhyolite (see Petrography), light pink to reddish in color, showing alternate bands of light and red color, due to hematitic alteration.

b. Monolithologic breccia, containing fragments of rhyolite, with or without flow-banding, texturally very similar to the breccias described before.

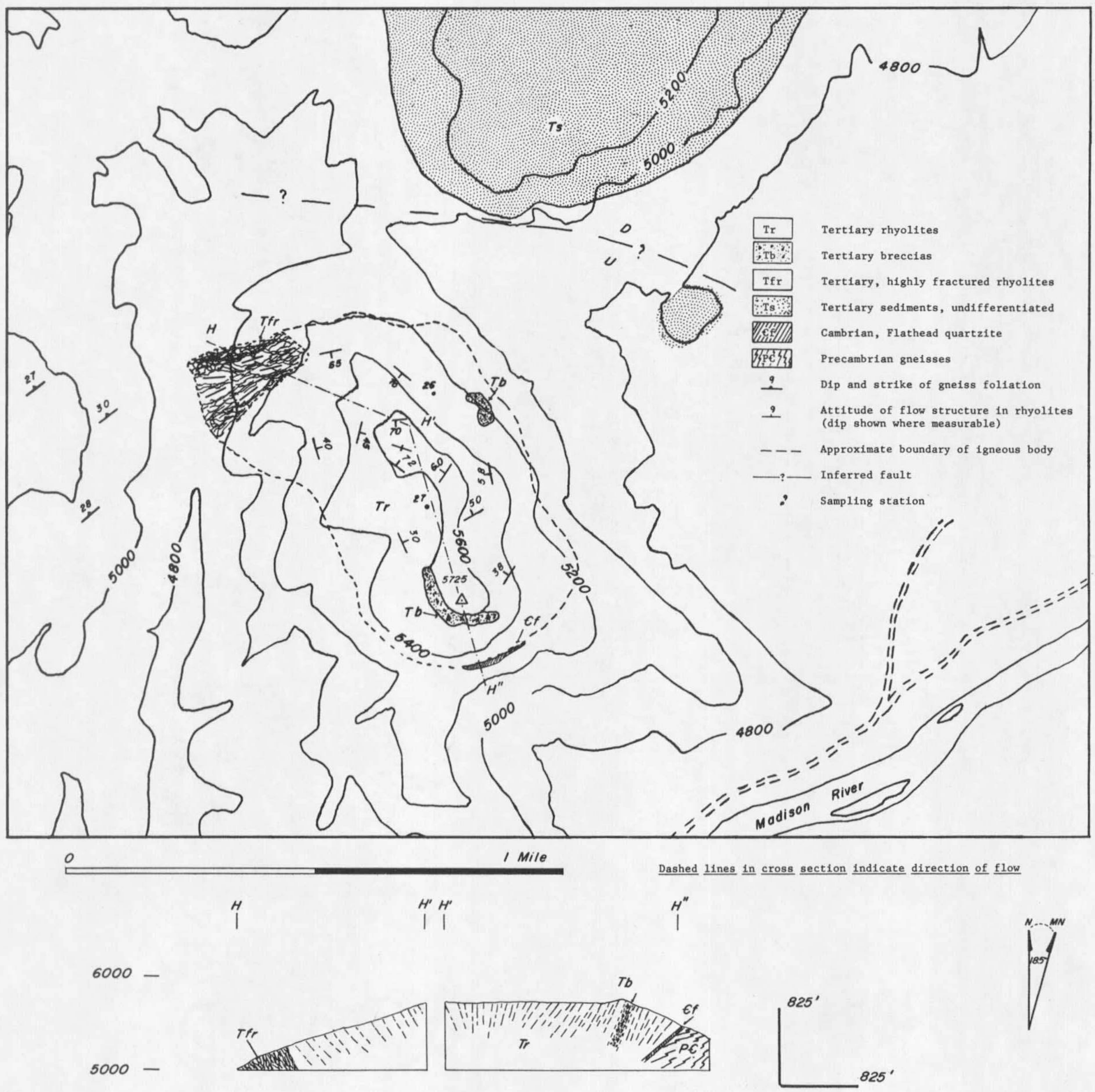


FIGURE 11. Geologic map and cross section of igneous body H

c. In-place breccia (Plate 2, Fig. 2) characterized by a number of small shear fractures. The breccia does not have large areal extent, but is rather localized in the northwestern end of the igneous body. The composition of the breccia is rhyolitic, and the original rocks have not been displaced far in space but have been broken and fractured throughout.

Fissility and flow banding are parallel in this igneous body, as they are in the other bodies showing both characteristics. A vent is suggested by the attitude of flow structure. A large fault lies near the eastern and northern part of the igneous body, and is quite evident owing to displacement of neighboring Tertiary strata. Faulting may have uplifted the block containing the rhyolite, and subsequent erosion probably has obliterated sediments that may have existed on the uplifted side.

PLATE TWO

FIGURE 1. Breccia-dacite contact zone, igneous body G.
T.3.S.,R.1.E.,S 19.

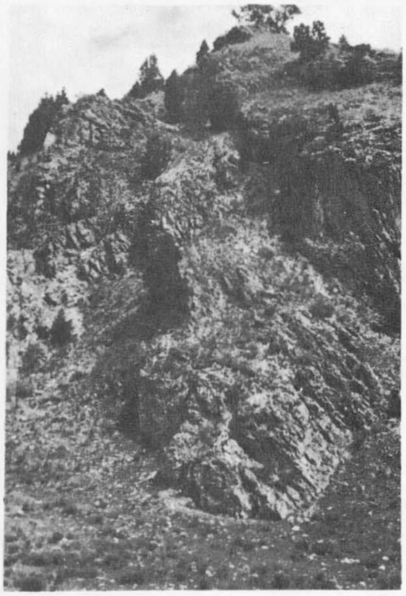


FIGURE 2. Highly fractured rhyolite, igneous body H
T.2.S.,R.1.E.,S 34.

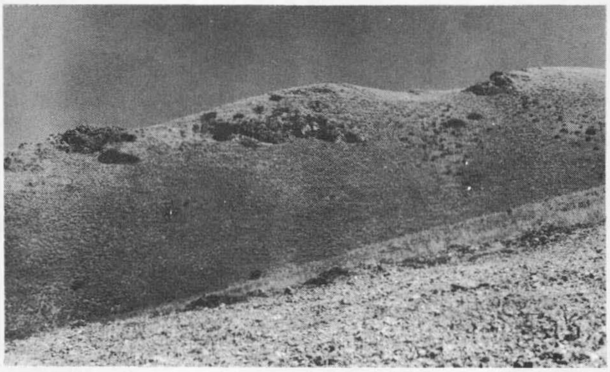


FIGURE 3. Same location as FIGURE 1, igneous body G.
Flow-banded dacite float in foreground,
breccia outcrop in background.

CHEMICAL ANALYSIS OF SAMPLES

Sampling

Each igneous body was sampled thoroughly, and several specimens were taken from each available outcrop. Selected samples were then analyzed for silica content, either by the writer or by Technical Services Laboratories, of Ontario, Canada. Comparison of the author's results with those obtained from the Laboratories shows that, on the average, silica content in the author's analyses was higher by 3 to 5 per cent, probably due to the fact that the author was measuring all insoluble material rather than only silica. Consequently, all the results obtained by the author have been corrected downward by an average of 4 per cent.

All sampling stations have been pinpointed by number on the maps of their respective igneous bodies.

Silica Analysis

The following table gives a summary of all silica analyses made:

TABLE I SILICA ANALYSIS OF SAMPLES

Sample No.	Igneous Body	Location	Silica Per Cent
1	A	Fig. 3	66.0 *
2	A	Fig. 3	68.1 *
3	A	Fig. 3	70.0 **
4	A	Fig. 3	66.2 **
5	A	Fig. 3	66.0 **
7	A	Fig. 3	66.0 **
9	A	Fig. 3	68.6 **
11	B	Fig. 3	72.2 **
13	A	Fig. 3	67.1 **
14	C	Fig. 5	67.2 *
15	C	Fig. 5	60.1 *
16	D	Fig. 6	66.0 *
17	D	Fig. 6	68.0 **
18	E	Fig. 6	66.4 *
19	E	Fig. 6	67.1 **
20	E	Fig. 6	66.3 **
21	G	Fig. 9	72.9 *
22	G	Fig. 9	72.0 **
23	G	Fig. 9	70.3 **
24	F	Fig. 8	73.3 *
25	F	Fig. 8	77.6 *
26	H	Fig. 11	78.6 *
27	H	Fig. 11	76.6 *

(*) Analysis done by Technical Services Laboratory, Ontario, Canada.

(**) Analysis done by the author. Corrected downward by 4 per cent.

Oxide Analysis

Two samples were selected in order to determine complete oxides, one of a low-silica sample, and one of an intermediate-silica sample. The low-silica sample is from igneous body A, and the intermediate silica was collected at igneous body G. The complete analysis were done by Warren Laboratories, Cresson, Pa.

Table two gives the results.

TABLE II OXIDE ANALYSIS OF SELECTED SAMPLES

	Igneous body A	Igneous body G
$Si\ O_2$	66.0	72.5
Al_2O_3	19.0	17.7
Fe_2O_3	1.9	0.8
FeO	0.4	0.1
MgO	0.4	0.2
CaO	2.7	0.9
Na_2O	6.3	4.3
K_2O	2.9	3.2

(In percentages of total)

Comparison of sampled rocks with similar igneous bodies

A comparison of the author's samples with Travis' (1955) average chemical composition of dacites indicates a remarkably high sodium oxide content for the rocks of this area. Otherwise they compare quite well. Even if we take into consideration that the average chemical composition of Travis' dacites is no more than an average of dacites from the North American continent, and consequently limited in value, it seems that the sodium content is unusually high. It would probably be better if these analyses could be compared with other rocks which belong to the same regional or petrological setting.

Rittmann (1962), has derived an empirical equation to determine the "suite" to which a rock belongs. According to him, the three extrusive suits of rocks (Mediterranean, Atlantic and Pacific) offer similarities in chemical and mineral composition. Rittmann's equation is:

$$\sigma = \frac{(Na_2O + K_2O)^2}{SiO_2 - 43}$$ (weight percentages in the analysis)

The value of σ is almost constant for any one volcanic suite, and Rittmann proposed to call this value the "suite index". The indexes of the different suite types can be seen on Table 3.

TABLE III INDEXES OF DIFFERENT SUITE TYPES

σ - value	Weight % alkalis	Suite type
Less than 4	$Na_2O \gtrless K_2O$	Pacific (Calc-alkaline)
Between 4 and 6	$Na_2O > K_2O$	Atlantic (Sodic)
Larger than 6 and negative	$Na_2O < K_2O$	Mediterranean (Potassic)

On determining the suite indexes of the two completely analyzed samples from the map area, we find that the suite index of igneous body A is 3.74 (Weak Pacific), and the one of igneous body G is 1.99 (Average Pacific).

Chemical analyses in Table 4 have been included here for comparison with those of the local area. These samples were selected from the Pacific suite and range from andesites to rhyolites.

TABLE IV OXIDE ANALYSIS OF SOME PACIFIC SUITE ROCKS

No	16	17	18	19	20
SiO_2	55.7	61.8	68.4	72.3	74.7
Al_2O_3	18.7	16.8	14.9	12.5	12.7
FeO	7.7	6.1	3.6	2.4	1.4
MgO	3.6	2.7	1.0	0.1	0.1
CaO	8.4	6.2	3.1	1.4	0.5
Na_2O	3.9	3.8	5.6	3.3	3.9
K_2O	0.7	1.5	1.8	3.6	4.9
TiO_2	0.8	0.8	0.7	0.1	0.1
P_2O_5	0.1	tr	0.2	0.3	tr
MnO	0.2	0.1	0.1	tr	tr
H_2O	0.6	0.5	1.0	3.5	1.0
suite index	1.7	1.5	2.2	1.6	2.4

16. Andesite, Galunggung volcano, Java
17. Dacite, Guntur volcano, Java
18. Dacite, eruption of 1883, Krakatoa, Sunda Islands
19. Rhyolite (ignimbrite), Owharoa, New Zealand
20. Rhyolite, Lipari, Aeolian Islands, Sicily

Comparing Tables 2 and 4, the sodium content of both rocks of the local area are noticeably higher than that for most of the rocks which Rittmann considers typical of the Pacific volcanic suite. This anomalously high sodium content seems to be quite uniform throughout the area, not only around the Madison Valley, but as far east as the dacites of Squaw Creek and Moose Creek in the Gallatin Range (McMannis and Chadwick, 1964, p. 25-29). It seems that this area is part of a sodium rich petrological province.

Rock Classification

The rock classification of the low and intermediate-silica rocks was done by normative mineral content as calculated from the chemical data, by CIPW system.

TABLE V NORMATIVE MINERALS OF SELECTED SAMPLES

	Igneous body A	Igneous body G
Albite	53.4	36.7
Orthoclase	17.2	19.4
Anorthite	13.3	4.4
Enstatite	0.5	0.6
Magnetite	1.3	0.4
Hematite	0.9	0.4
Quartz	11.8	32.4
Corundum	0.5	5.3

(In percentages of total)

Igneous body A which is representative of those igneous bodies located south of Norris, shows:

Total Feldpar = 84 per cent of the rock

Potash Feldspar = 21 per cent of total feldspar

Quartz = 12 per cent of rock

The texture is microcrystalline, and the sample can be classified as a dacite.

The sample taken at igneous body G, representative of igneous bodies F and G, that is, the flow banded rocks, shows:

Total Feldspar = 67 per cent of rock

Potash Feldspar = 30 per cent of total feldspar

Quartz = 32 per cent of rock

The texture is also microcrystalline, and the sample is also classified as a dacite. It would possibly be more accurate to restrict this classification by referring to the rock as a "border line" dacite. The relatively high silica content of some of these rocks would be more typical of a quartz latite or rhyolite. It may be that some of the rock of igneous bodies F and G is quartz latite or rhyolite. Petrographic analyses were made to classify the rock of igneous body H and igneous body C (sample No. 15 of Table 1). As it will be seen later, igneous body H is mainly rhyolite, whereas igneous body C falls in the andesite group.

PETROGRAPHY

Although sample classification was done by means of normative mineral content as calculated from chemical data, a detailed petrographic study was also made in order to search for evidence which would establish genesis of igneous rocks. The evidence encountered suggests intrusions of dacitic and rhyolitic material emplaced either as rapidly cooling viscous liquid or as slowly cooling homogeneous crystal mush, also highly viscous. Flow-banding indicates mineral separation in preferential zones while in the magmatic chamber, with texture retained during intrusion due to the high viscosity of the magmatic material. Breccias have been formed after dacitic and rhyolitic intrusions, although in terms of geologic time they can be considered contemporaneous.

Petrographic description

Dacites (Plate 3, Fig. 1) which are exposed in the area south of Norris (Igneous bodies A - E) are microcrystalline with few phenocrysts. Phenocrysts which are present do not

PLATE THREE

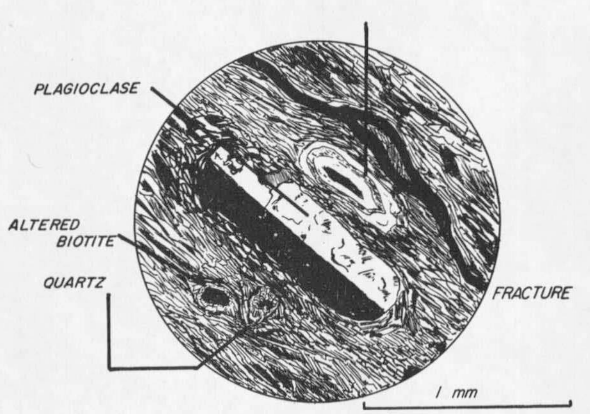


FIG. 1 Composite figure showing outstanding features of samples from igneous bodies A, B, C, D, and E.

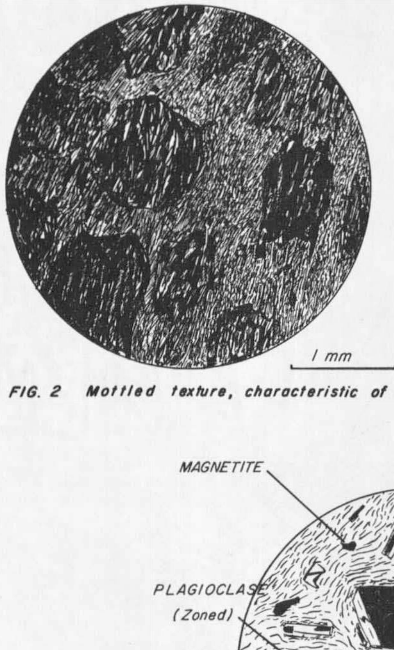


FIG. 2 Mottled texture, characteristic of igneous bodies D and E.

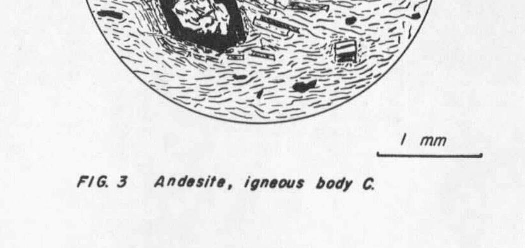


FIG. 3 Andesite, igneous body C.

exceed more than one per cent of the rock. They consist of corroded plagioclase, zoned plagioclase, highly fractured and partially corroded quartz and altered biotite. By measuring extinction angles of phenocrysts using the Michel Levy method (Moorhouse, 1959, p. 55-60) the plagioclase composition was determined to be in the andesine range. The groundmass is formed by innumerable microlites of undetermined composition, highly sericitized. These microlites are elongated parallel to each other, forming a mass which has aggregate polarization upon rotation of the stage. Fissility cracks conform in direction to the orientation of the lath-shaped microlites, giving evidence of being oriented in the same direction as the last flow. Biotite in the groundmass is either hexagonal in outline or in flakes and is almost always affected by corrosion which is shown by the partial rounding and the formation of a dark opaque border. In plain light the biotite is strongly pleochroic. Sericite in the groundmass appears as highly birefringent fine-grained needles, with parallel extinction. The quartz content in the groundmass is variable, but not high. Magnetite is present as small, anhedral grains, either totally or partially altered to hematite.

Igneous bodies D and E show a characteristic "mottled" texture, with small rounded areas appearing darker in color. This texture is seen under plain and polarized light, although it is less noticeable under polarized light with aggregate polarization of the groundmass microlites. No mineralogical difference could be detected between the lighter and darker areas of the dacite. This texture seems to be a result of selective deuteric leaching, accomplished by escaping late volatiles (Plate 3, Fig. 2).

Andesite, which is exposed at the base of igneous body C, contains about 35 per cent phenocrysts and 65 per cent groundmass (Plate 3, Fig. 3). Soda-lime feldspars are the predominant components among those plagioclase phenocrysts present. Oligoclase and andesine form most of the plagioclase, with andesine predominant. Zoned plagioclase is present, although secondary in volume to the unzoned kind. Brown, strongly pleochroic biotite, rimmed with an opaque alteration and showing remnant hexagonal outline, is commonly found; sericitization is not as abundant as it is in the dacites.

"Border-line" dacites, which are exposed in igneous bodies F and G, are either reddish or gray flow-banded rocks, and in thin section show differentiation in the mineral content of the bands. Phenocrysts form about 30 to 40 per cent of the rock, and consist of quartz, biotite, and feldspar. Quartz phenocrysts are either highly fractured or euhedral hexagonal, with biotite inclusions (Plate 4, Figs. 1, 2). Andesine-oligoclase phenocrysts are relatively common, comprising about 50 to 60 per cent of the phenocrysts. Biotite is strongly pleochroic, with extinction sometimes sufficiently oblique to show lamellar twinning parallel to the base. The groundmass of these dacites is a composite of microlites of feldspar, biotite, and highly crushed anhedral quartz. The microlites have a preferred orientation parallel to the banding and approximately parallel to the fissility of the sample. This is another line of evidence showing that the fissility is oriented in the same direction as the last flow. Banding in this dacite is due to concentration of some minerals, especially quartz, in selected parallel zones. Microlites of undetermined composition are also concentrated in zones, whereas the rest of the sample is composed of sparser microlites and glass. Since the microlites are oriented parallel to the banding and where in contact with the phenocrysts flow around them, an early

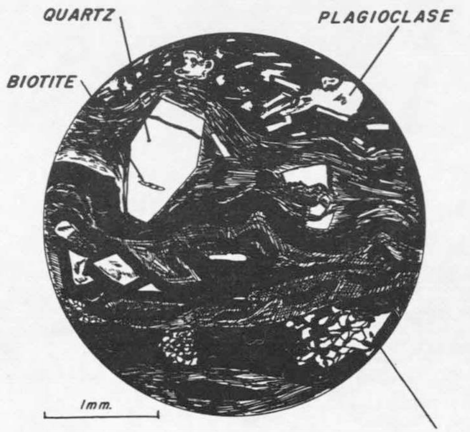


FIG. 1 Composite figure showing outstanding features of flow banded, "border line" dacites. Polarized light. Igneous bodies G and F.

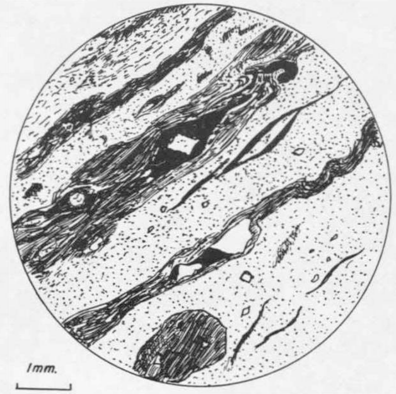


FIG. 2. "BORDER LINE" dacite, composite figure. Plain light.

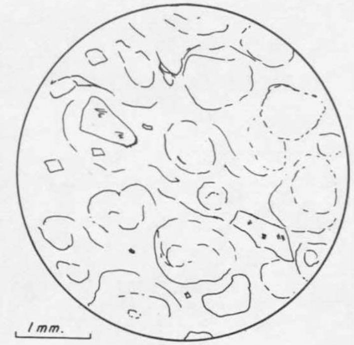


FIG. 3 Perlite cracks in faintly banded, glassy dacite. Igneous body F.

FIG. 4 Rock fragments in glassy matrix. Monolithological breccia. Polarized light. Igneous bodies F, G, and H.

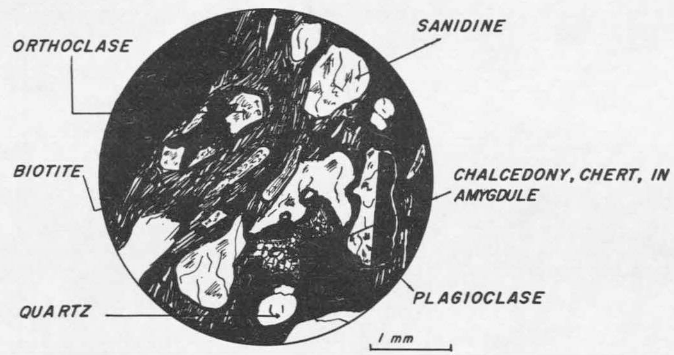


FIG. 5 Composite figure showing outstanding features of flow banded rhyolite. Polarized light. Igneous body H.

PLATE FOUR

differentiation of crystals is suggested; perhaps in the magmatic chamber, with the phenocrysts already crystallized. As the magma left the chamber, the high viscosity of the melt helped preserve the separation of the minerals in bands or zones, rather than mixing them thoroughly, for it is known (Shaw, 1965) that acid magmas increase their viscosity with decrease of water content, and decrease of temperature of the melt. Newtonian liquid behaviour can be expected of nearly all silicate magmas where the temperature has not reached the transformation range. In this way, flow of an emerging viscous melt, essentially homogeneous, will approximate laminar flow. Separation of minerals in selected bands will be preserved because of the viscosity of the melt and the slowness of effusion. Fissility will appear upon cooling as thermal cracks preferentially oriented in the direction of flow, and parallel to the microlite orientation.

The glassy, faintly banded dacite found at the southern boundary of igneous body F (Plate 4, Fig. 3), shows all the characteristics described above for the "border line" dacites, but the glass content is higher, and it shows perlite cracks. The estimation of glass content in the groundmass is based upon the absence of aggregate polarization upon stage rotation. The perlite cracks can be attributed to contraction of the homogeneous material upon rapid cooling (Harker, 1962; Turner and Verhoogen, 1960, p. 64). Emplacement of these glassy rocks seems to post date the flow banded, "border line" dacites, which do not show the perlite texture.

Breccias, (Plate 4, Fig. 4) which are found in igneous bodies F, G, and H, are characteristically monolithologic, and show angular to subangular dacite fragments, never exceeding 3 mm. across and embedded in a glassy matrix that contains some feldspar microlites in preferred orientation approximately parallel to each other. The fragments are dacitic, each one showing microlites which are parallel to each other, within the fragment. Some exhibit flow banding, with the same features as the ones described previously for the dacites. The breccias may be either vertical pipes near the boundaries of the igneous bodies or may be conformable with the surrounding structure within the dacites or rhyolites. The could be friction autobreccias produced during flowage of partly solidified magma either along the borders of the magma chamber, or within the solidified, previously intruded dacites or rhyolites (Fisher, 1960).

They could also be a product of magmatic material passing through thermal contraction fractures and on its way up, reworking previously intruded rocks (Kents, 1964). The fact that the breccias are not found discordant with the general structure of the igneous bodies or cutting through the general attitude of flow banding suggests that they were emplaced as friction autobreccias, rather than in thermal contraction fractures.

Rhyolites (Plate 4, Fig. 5) are exposed at igneous body H (Red Mountain), show flow banding and fissility, a microcrystalline groundmass and about 25 per cent phenocrysts. The phenocrysts are orthoclase, sanidine, oligoclase, quartz, and biotite. The orthoclase, which forms 60 per cent of the phenocrysts is highly fractured, anhedral, with a large axial angle in the interference figure. Twenty per cent of the phenocrysts are sanidine, which has a form much like the orthoclase, but can be recognized by its small optic angle. Oligoclase forms about 5 per cent of the phenocrysts, in tabular, corroded or altered crystals, without zoning. Quartz appears either as well rounded crystals or in dihexahedral outline. It is generally fractured, commonly corroded, and comprises about five per cent of the phenocrysts. Biotite appears either as phenocrysts or in the groundmass. It is easily recognizable by its light to dark brown pleochroism and bird's eye texture close to extinction. It is ellipsoidal in outline, and occasionally contains zircon inclusions. It forms about 10 per cent of the phenocrysts. The groundmass shows the largest amount of alteration with abundant sericite, chloritized biotite, and hematite. Feldspar microlites are intermixed with anhedral quartz grains. The non-ellipsoidal vesicles which are found in the groundmass are rimmed with fibrous chalcedony oriented perpendicular to the walls of the vesicles. The centers of the vesicles are completely filled with mosaic-textured chalcedony. Alteration of the groundmass is abundant in those rhyolites showing a more intense red color in hand specimen. The groundmass comprises 75 per cent of the rock.

PETROGENESIS

Dacites and rhyolites

In petrographic provinces there is a wide variation of chemical composition among associated rocks. This variation tends to be regular, rather than random. When, in a petrographic province, a series of chemical analyses are plotted in such a way as to compare the silica weight percentages with the different oxide weight percentages, a variation diagram is obtained (Harker, 1909, p. 88-109). Variation diagrams are not necessarily a comparison of silica vs. other oxides in a straight one-to-one proportion, but other proportions can be diagrammed in order to give smooth curves (Larsen, 1938, p. 505 - 520). It has been suggested (Bowen, 1915, p. 1-17; 1956, p. 125-132) that variation diagrams are valid only for fine-grained or glassy rocks because their composition has not been determined by crystal accumulation. The idea behind variation diagrams in a petrographic province is that silica weight percentages are an index of the stage of evolution attained in a magmatic sequence. The basalt-andesite-dacite-rhyolite sequence of rocks represent a line of evolution radically difference from that responsible for differentiation observed in tholeiitic magmas where the sequence has been considered as tholeiitic lavas-diabase-granophyre. The expected variation diagrams do not correspond, so it has been suggested (Turner and Verhoogen, 1960, p. 272-288) that the basalt-andesite-dacite-rhyolite sequence of rocks is a result of differential fusion of crustal rocks. A more complete explanation involves initial recrystallization of the component minerals into more stable forms at high temperature and pressure, followed by complete melting of the crustal rock at depth. This process is known as anatexis (Rittmann, 1962, pp. 80-100), and has been related to large tectonic movements. If we consider the basement rock of the Rocky Mountain province, we find a large preponderance of granite and gneiss in comparison to the more basic rocks such as amphibolite and diorite. If some of the magmas of this region have been formed by anatexis, the secondary magmas produced from them will be predominantly rhyolitic to dacitic in character. The "corroded" nature of the quartz and feldspar phenocrysts in the rhyolites and dacites of the area could be explained several ways. Reactions could be due to a late liquid phase (Tuttle and Bowen, 1958), which would produce reactions between the hot glassy or cryptocrystalline groundmass and the phenocrysts, perhaps through the medium of an intergranular film (Foster, 1960, p. 892-894). It could also be due to an increase in temperature after formation of phenocrysts, as happens in progressive anatexis (Rittman, 1962,

p. 88-100). If we accept anatexis as a predominant factor in the formation of rhyolites and dacites, the corroded phenocrysts of these rocks may not be magmatic precipitates but partly melted crystalloblasts.

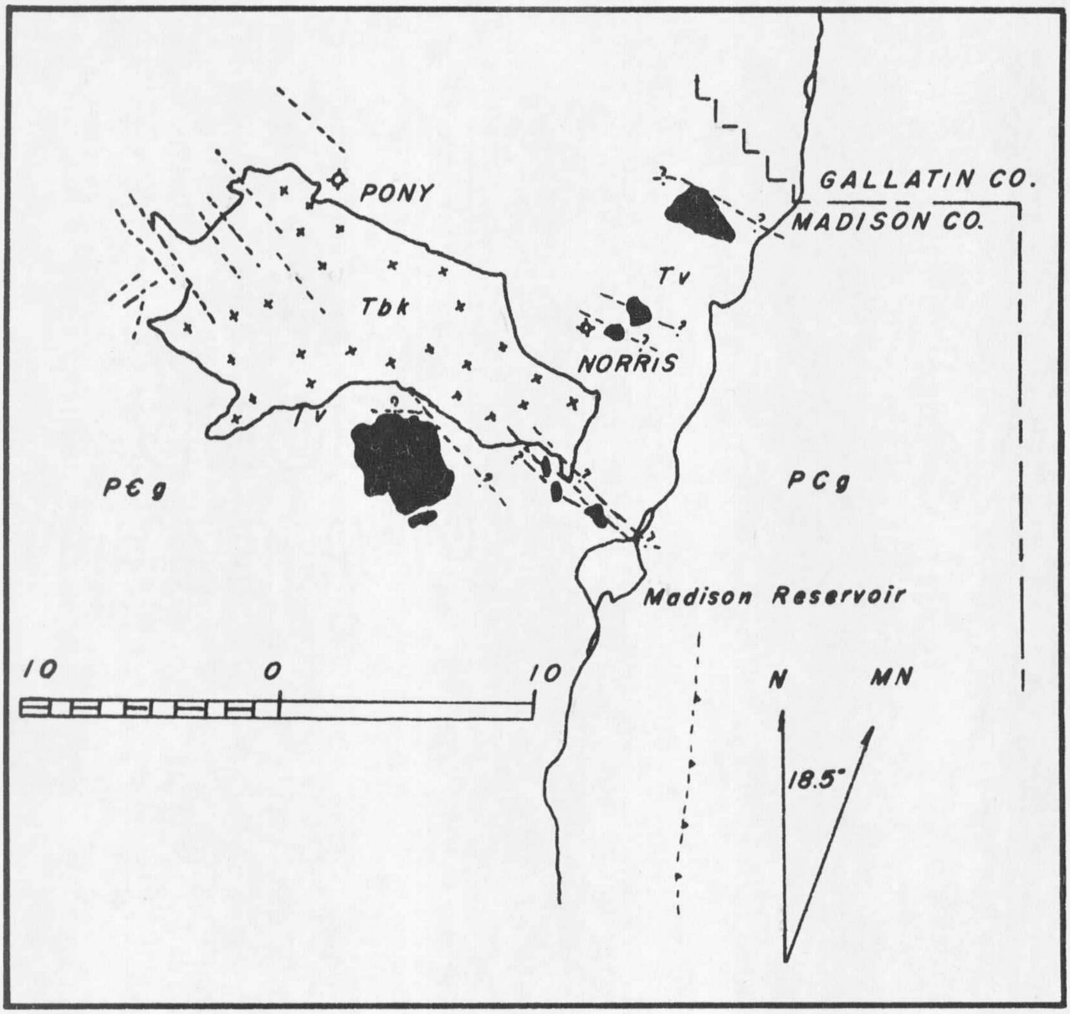
Regardless of the manner in which the original magma was formed, it seems reasonable to connect the large Tobacco Root batholith with the acid volcanics located peripheral to it, with faulting playing an important part in their emplacement. As it will be seen later (see General Relationships: Faulting) there is a regional trend of northwest-southeast faulting in this area; if we are to consider the dacites and rhyolites as comagmatic with the Tobacco Root batholith and products of magmatic differentiation, some assumption must be made. The batholith crops out about 3000 feet higher than the dacites from igneous bodies A to G. If all bodies were at one time comagmatic, the dacites probably occupied the upper parts of the magmatic chamber. This suggests that the batholith must extend underneath the actual exposures of dacitic material which means a vertical distance of at least 3000 feet and a horizontal extension which averages eight miles. Erosion may have helped produce the large differences in elevation between the batholith and the peripheral igneous bodies. The dacites located south of Norris (Igneous bodies A - E) have been subjected to glacial erosion. The erosional pattern is not so clear south of Red Bluff (Igneous bodies G - F), where the cover is composed of fluvial sediments derived from the Tobacco Root batholith proper and where there is little evidence of previous intensive erosion (Montagne, personal communication). If the acid igneous bodies and the Tobacco Root batholith are not comagmatic but the result of different and unrelated igneous activity, it seems plausible that the dacites and rhyolites are a product of magmatic differentiation and chemically representative of a sodium-rich magma which has crystallized at depth.

GENERAL RELATIONSHIPS

Faulting

South of Norris, the Norris Hills area has been separated geomorphically from the Madison Valley proper by an east-west-trending fault. This fault has uplifted the Norris Hills block and has affected the course of the ancient Madison River (Montagne, 1960). On the eastern flank of the Madison Valley, a north-south trending thrust fault marks the contact between

Paleozoic and Tertiary sediments. Northwest-striking faults paralleling the structural trends of the Precambrian gneisses have been mapped (Berry, 1943), in the northern Tobacco Root Mountains. The same fracture trend is found within the Tobacco Root batholith as shown by the Pony, Mammoth, Bismark and B & H faults (Reid, 1957, p. 17-20). Northeast-southwest-trending faults are also found (Fig. 12) cutting the Tobacco Root batholith on its western boundary. This pattern of faults, used in conjunction with regional north-south folds and thrust trends, indicates a main compressive force acting approximately east-west. Faulting appears to have occurred during Precambrian time with renewed movement along the fault planes during the Laramide orogeny; this movement along fault planes seems to have continued until Recent times, as shown by tilting of recent gravel sediments in the area (C.C. Bradley, personal communication). The igneous bodies located at the northern end of the Madison Valley are aligned in an approximate northwest-southeast direction, suggesting structural relationships between the bodies and the main trend of faulting in the area. The bodies are directly in line with the Spanish Peaks fault, suggesting faulting in the direction of the igneous bodies' alignment.



Tbk	Tertiary, Tobacco Root Batholith
Tv	Tertiary volcanics
P€	Precambrian gneisses and schists
------	Fault, approximately located (R.R.Reid, 1956)
-?---?-	Inferred fault

FIGURE 12. Fault relationships of the area

Obliteration of bedrock exposures by Quaternary glaciation obscures evidence supporting this theory. Inconclusive evidence is supplied by similar trending faults in the Three Forks quadrangle which have been dated as Pre-Oligocene (Berry, op. cit., p. 28-30). The more southerly faults were formed at approximately the same time and by the same mountain building processes. This trend in the strike of the faults is quite general for southern Montana.

This author considers some of the fault movement in the "Red Mountain" area to be post-emplacement of the dacitic and rhyolitic magmas (see General Geology: Igneous body H).

Mineralization

Mineralization in the area (Fig. 1) is concentrated near igneous bodies F and G. Mining has been done in the past, and the region is saturated with mining claims and prospect holes. The most renowned of the mines in the area are the Boaz, the Helene, the Waterlode, and the Grubstake. Mining was done along two important, parallel, gold-rich veins which strike N 40 W, and dip 60 degrees to the north. All the mines have been abandoned due to the high cost of producing the gold and to ground water flooding of underground workings. The commercial productions came from an oxidized zone extending to a depth of more than 100 feet. The vents which comprise igneous bodies F and G are located at a distance of about 200 to 300 feet from the mineralized veins, that is, they are in close space relationship. The mineralized veins, which are called the Boaz and the Golden Treasure veins, have the same trend as the faults cutting the northern end of the Tobacco Root batholith (Fig. 12); these latter faults appear to have exercised control over the formation of ore deposits in most of the north end of the Tobacco Root range (Reid, 1957, p. 21). The fact that the faults in the area seem to have been active since Laramide time offers several possibilities.

The dacites could have been emplaced before, after, or contemporaneous with the Tobacco Root batholith. Mineralization at the Boaz-Golden Treasure veins could have occurred before, after, or contemporaneous with the mineralization at the batholith. The Tobacco Root batholith would not be a variable because the fact that it is displaced by faulting indicates its emplacement prior to fault movement. When all the variables are combined, nine possibilities suggest themselves. The distance separating the acid igneous bodies from the Tobacco

Root batholith, the close space relationships between the Boaz-Golden Treasure mineralized veins, prompts this author to favor the theory that the dacite emplacement and the mineralization at the Boaz-Golden Treasure veins were contemporaneous and that both were later than the Tobacco Root batholith. The emplacement of the Tobacco Root batholith must have occurred prior to the faulting which apparently controlled mineralization and dacite intrusion in the region. Therefore, the Tobacco Root batholith and the dacite intrusion are probably not comagmatic.

Age of igneous bodies

The Tobacco Root batholith has been dated by H.W. Jaffe of the U.S. Geological Survey (Reid, 1957, p. 11) as being 66 million years old (Lead-alpha age determination on zircon), indicating that the batholith was intruded in Late Cretaceous or early Tertiary (Paleocene) time. If the igneous bodies studied are comagmatic with the Tobacco Root batholith, they would be the same age as the batholith. If the faulting displacing the batholith served as a control for the emplacement of the igneous bodies, the bodies would be younger than the batholith, although, this in itself would not deny the possibility that they are comagmatic. Similar acid rocks in the Mill Creek area, with closely similar chemical composition, and with a northwest trending zone controlling emplacement have been dated as being 49 million years old (R.A. Chadwick, personal communication) which would make them Eocene. In the belief that the igneous bodies are not comagmatic with the Tobacco Root batholith, this author prefers to ascribe to them an Eocene age. The igneous body of the Red Mountain area could possibly be displaced by northwest trending faults which also cut Tertiary strata. Due to the fact that movement along the fault planes was in several stages, the age of this igneous body is uncertain.

SUMMARY AND CONCLUSIONS

The selected igneous bodies are mostly dacites and rhyolites along with some related breccias. They are intrusive plugs. The extrusive rocks have been obliterated by glacial and/or fluvial erosion and subsequent deposition. The intrusive rocks are probably younger than the Tobacco Root batholith, and have been emplaced along zones of intensive faulting; the fault relationships of the Red Mountain area are not quite clear, making the dating of the body uncertain. Brecciation occurred during or shortly after emplacement of the igneous bodies, and appears to be autobrecciation produced by friction along planes and subsequent intrustion of viscous liquid along the fractured planes. Mineralization near igneous bodies F and G appears to have been controlled by northwest-southeast trending faults, in the same manner as mineralization on the northern end of the Tobacco Root batholith. The age of the dacite bodies is probably Eocene.

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