5-15-1951

Chemical Analysis of Igneous Rocks and Variation Diagrams of Petrographic Provinces of Montana

Frederick M. Hilpert

CHEMICAL ANALYSES OF IGNEOUS ROCKS AND VARIATION DIAGRAMS OF PETROGRAPHIC PROVINCES OF MONTANA

by
Frederick M. Hilpert

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
Butte, Montana
May 15, 1951

CHEMICAL ANALYSES OF IGNEOUS ROCKS AND VARIATION DIAGRAMS OF PETROGRAPHIC PROVINCES OF MONTANA

by
Frederick M. Hilpert

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
Butte, Montana
May 15, 1951

TABLE OF CONTENTS

CHEMICAL ANALYSES OF IGNEOUS ROCKS AND VARIATION DIAGRAMS OF PETROGRAPHIC PROVINCES OF MONTANA

by

Frederick M. Hilpert

INTRODUCTION

The two purposes of this paper are the collection under one cover of all the chemical analyses of igneous rocks for the state of Montana since 1913, and the comparison of the petrographic provinces of Montana by means of Larsen's variation diagrams. The writer, after an extensive perusal of the literature, has found 21 analyses that are not listed in the United States Geological Survey Professional Paper No. 99. Paper No. 99 includes 158 chemical analyses of igneous rocks for Montana prior to 1913.

The secondary purpose of this paper is to determine if any similarity exists between the various petrographic provinces of Montana. Larsen has presented a new type of diagram, in which he has plotted the acidic oxides, minus the basic oxides, against the basic oxides. These variation diagrams were used in the comparison of the petrographic provinces of Montana.

The writer, at this time, would like to express his gratitude and appreciation for the opportunity of pursuing this study at the Montana School of Mines, and for the cooperation and encouragement of the faculty and graduate students. Particularly are thanks due, and offered, to Dr. E. S. Perry and to Mr. F. S. Robertson, whose able guidence has been of inestimatable value in the investigation of this problem.

CHEMICAL ANALYSES OF IGNEOUS ROCKS OF MONTANA

A total of 179 chemical analyses of igneous rocks are available for the state of Montana, but these analyses do not cover the entire state in a satisfactory manner. There has been an emphasis on the central part of the state, and an almost complete lack of interest in the southern portion of Montana. This lack of interest is due in part to economic reasons, since economics to a large extent governs geologic exploration.

Professional Paper No. 99 of the United States Geological Survey has listed 158 analyses of igneous rocks of Montana made prior to 1913. These analyses have placed emphasis on nine localities, which are the Butte district, Elkhorn district, Bearpaw Mountains, Castle Mountains, Crazy Mountains, Haystack Stock, Highwood Mountains, Little Belt Mountains, and the Anaconda Range. Also included in Professional Paper No. 99, is a limited number of chemical analyses of igneous rocks other than those included in the above localities.

Since 1913, the igneous rocks of the Shonkin Sag, Big Belt Mountains, and the Beartooth Mountains have received a considerable amount of attention. This attention has taken the form of an investigation into the constituents of the igneous rocks, as well as an investigation of the structural features exhibited by the above areas. In addition to the chemical analyses of the igneous rocks of these three areas, a few miscellaneous chemical analyses are given on the following pages:

CHEMICAL ANALYSIS SINCE 1913

	33	87	88	89	90
SiO_2	66.22%	47.88%	45.77%	46.06%	49.88%
Al_2O_3	16.22%	12.10%	8.94%	11.05%	16.17%
Fe_2O_3	1.98%	3.53%	3.63%	3.04%	3.77%
FeO	0.16%	4.80%	7.13%	5.82%	3.42%
MgO	0.77%	8.64%	12.96%	8.03%	3.26%
CaO	1.32%	9.35%	11.56%	10.02%	5.00%
Na_2O	6.49%	2.94%	1.40%	2.50%	4.28%
K_2O	5.76%	5.61%	4.60%	6.25%	7.84%
H_2O +	0.08%	1.52%	0.95%	2.04%	2.64%
H_2O −	0.24%	0.70%	0.18%	0.16%	0.67%
P_2O_5	0.10%	1.11%	1.52%	1.21%	1.33%
TiO_2	0.22%	0.77%	0.76%	1.07%	0.42%
MnO	tr	0.15%	0.13%	0.30%	0.42%
CO_2		0.12%	0.00%	1.39%	0.35%
F	tr				
S					
BaO	0.29%	0.46%	0.26%	0.52%	0.60%
SrO	0.06%	0.13%	tr	0.08%	
Cl	0.04%	tr		tr	
Li_2O	tr				
Cr_2O_3		tr			
NiO		tr			
Total	99.97%	99.99%	99.79%	99.64%	100.05%

	128	129	130	131	132
SiO_2	48.96%	49.94%	50.18%	52.07%	47.76%
Al_2O_3	17.04%	17.02%	15.34%	18.18%	16.20%
Fe_2O_3	3.90%	6.05%	6.37%	4.17%	3.98%
FeO	5.02%	3.87%	4.44%	4.73%	6.45%
MgO	4.54%	4.25%	4.11%	3.33%	4.90%
CaO	8.56%	9.22%	8.62%	7.58%	8.60%
Na_2O	3.59%	2.81%	4.06%	3.57%	3.20%
K_2O	4.75%	2.41%	2.48%	2.87%	3.76%
H_2O +	1.97%	1.67%	2.01%	1.12%	3.06%
H_2O –	0.08%	1.11%	0.36%	0.65%	0.31%
P_2O_5	0.75%	0.41%	0.58%	0.64%	0.61%
TiO_2	0.61%	0.61%	0.89%	0.79%	0.58%
MnO	0.12%	0.13%	0.12%	0.09%	0.16%
CO_2	0.00%	0.00%	0.00%	0.00%	0.00%
F					
S	0.05%	0.14%	0.06%	0.03%	0.04%
BaO	0.17%	0.13%	0.17%	0.08%	0.15%
SrO	0.04%	0.00%	0.03%	0.02%	0.03%
Cl					
Li_2O					
Cr_2O_3					
NiO					
Total	100.15%	99.77%	99.82%	99.92%	99.79%

	133	134	148	152	161
SiO_2	50.70%	47.40%	61.21%	39.19%	65.02%
Al_2O_3	18.32%	16.24%	15.20%	8.41%	14.16%
Fe_2O_3	4.62%	5.26%	2.49%	3.47%	8.44%
FeO	3.01%	4.73%	3.30%	5.51%	
MgO	4.09%	4.47%	4.12%	22.78%	0.05%
CaO	8.68%	8.16%	6.05%	8.90%	2.40%
Na_2O	3.33%	3.18%	3.32%	3.23%	5.39%
K_2O	3.16%	4.46%	2.31%	2.14%	2.72%
H_2O +	1.77%	4.27%	0.92%	3.66%	1.54%
H_2O -	0.60%		0.24%	0.56%	
P_2O_5	0.31%	0.69%		0.53%	0.19%
TiO_2	0.66%	0.58%	0.62%	0.40%	0.61%
MnO	0.09%	0.08%		0.24%	0.10%
CO_2	0.12%	0.00%		0.00%	
F					
S	0.28%	0.08%			
BaO	0.11%				0.15%
SrO	tr	0.04%			
Cl					
Li_2O					
Cr_2O_3				0.11%	
NiO					
SO_3				1.34%	
ZrO_2					0.10%
Total	99.83%	99.64%	99.78%	100.47%	100.77%

	164	172	173	174	175
SiO_2	64.17%	66.11%	70.82%	65.74%	65.94%
Al_2O_3	15.25%	15.44%	15.45%	16.49%	16.79%
Fe_2O_3	2.16%	1.30%	0.58%	0.66%	1.50%
FeO	2.98%	1.15%	0.65%	1.01%	0.25%
MgO	2.60%	0.97%	0.48%	0.83%	0.22%
CaO	4.24%	2.91%	1.53%	3.33%	2.25%
Na_2O	2.62%	3.76%	4.52%	4.37%	5.61%
K_2O	4.34%	3.01%	3.66%	2.35%	4.47%
H_2O +	0.65%	1.88%	0.99%	1.56%	0.57%
H_2O –	0.16%	0.47%	0.46%	0.56%	0.22%
P_2O_5		0.67%	0.04%	0.09%	0.06%
TiO_2	0.67%	0.27%	0.12%	0.17%	0.20%
MnO		0.06%	0.05%	0.07%	0.09%
CO_2		1.74%	0.55%	2.64%	1.65%
F					
S					
BaO			0.22%		
SrO					
Cl					
Li_2O					
Cr_2O_3					
NiO					
SO_3					
ZrO_2					
Total	99.84%	99.74%	100.12%	99.87%	99.82%

	176
SiO_2	62.27%
Al_2O_3	17.20%
Fe_2O_3	0.88%
FeO	0.49%
MgO	0.47%
CaO	1.91%
Na_2O	6.07%
K_2O	3.35%
H_2O +	0.63%
H_2O –	0.11%
P_2O_5	0.13%
TiO_2	0.19%
MnO	0.04%
CO_2	0.91%
F	
S	
BaO	0.09%
SrO	
Cl	
Li_2O	
Cr_2O_3	
NiO	
SO_3	
ZrO_2	
Total	99.74%

No. 33

Location: Gray Butte, Bearpaw Mountains, Montana

Analyst: H. N. Stokes

Reference: J. E. Blixt, Montana Bureau of Mines and Geology, Memoir 8, p. 9, 1933

Description: Quartz syenite porphyry

No. 87

Location: Shonkin Sag, Montana

Analyst: W. F. Hillebrand

Reference: F. F. Osbourne and E. J. Roberts, Am. Jor. Sci., 5 Ser., Vol. 22, p. 344, 1931

Description: Shonkinite

No. 88

Location: Shonkin Sag, Montana

Analyst: E. J. Roberts

Reference: F. F. Osbourne and E. J. Roberts, Am. Jor. Sci., 5 Ser., Vol. 22, p. 344, 1931

Description: Shonkinite

No. 89

Location: Shonkin Sag, Montana

Analyst: E. J. Roberts

Reference: F. F. Osbourne and E. J. Roberts, Am. Jor. Sci., 5 Ser., Vol. 22, p. 344, 1931

Description: Shonkinite

No. 90

Location: Shonkin Sag, Montana

Analyst: E. J. Roberts

Reference: F. F. Osbourne and E. J. Roberts, Am. Jor. Sci., 5 Ser., Vol. 22, p. 344, 1931

Description: Syenite medium grained

No. 128

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 466, 1944

Description: Not given

No. 129

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 445, 1944

Description: Not given

No. 130

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 445, 1944

Description: Not given

No. 131

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 445, 1944

Description: Not given

No. 132

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 445, 1944

Description: Not given

No. 132

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 445, 1944

Description: Not given

No. 134

Location: Big Belt Mountains, Montana

Analyst: F. A. Gonyer

Reference: J. B. Lyons, G. S. of A. B. 55, p. 445, 1944

Description: Not given

No. 148

Location: Bannack, Montana

Analyst: W. S. Yarwood

Reference: P. J. Shenan, Mont. Bur. of Mines and Geol., B. 6, p. 20, 1931

Description: Biotite hornblende granodiorite

No. 152

Location: Winnett, Fergus Co., Montana

Analyst: J. G. Fairchild

Reference: C. S. Ross, Am. Jor. Sci., Vol. 11, 5 Ser., p. 222, 1926

Description: Nephelite-bauynite alnoite

No. 161

Location: North Moccasin Mountains, Montana

Analyst: L. J. Hartzell

Reference: J. E. Blixt, Mont. Bur. of Mines and Geol., Mem. 8, p. 9, 1933

Description: Not given

No. 164

Location: Frohner Mine, Helena, Montana

Analyst: H. N. Stokes

Reference: P. J. Shenan, Mont. Bur. of Mines and Geol., B. 6, p. 20, 1931

Description: Quartz monzonite

No. 172

Location: Round Mountain, Nye Quadrangle, Beartooth Mountains, Montana

Analyst: T. Kameda

Reference: J. T. Rouse, H. H. Hess, J. S. Vhay and K. P. Wilson, J. G., Vol 45, No. 7, p. 732, 1937

Description: Dacite porphyry

No. 173

Location: Round Mountain, Nye Quadrangle, Beartooth Mountains, Montana

Analyst: T. Kameda

Reference: J. T. Rouse, H. H. Hess, H. S. Vhay and K. P. Wilson, J. G., Vol 45, No. 7, p. 732, 1937

Description: Quartz-keratophyre porphyry

No. 174

Location: Timberline Creek, Beartooth Mountains, Montana

Analyst: R. B. Ellstad

Reference: J. T. Rouse, H. H. Hess, J. S. Vhay and K. P. Wilson, J. G., Vol 45, No. 7, p. 732, 1937

Description: Gray quartz-monzonite porphyry

No. 175

Location: Beartooth Plateau, Beartooth Mountains, Montana

Analyst: R. B. Ellstad

Reference: J. T. Rouse, H. H. Hess, J. S. Vhay and K. P. Wilson, J. G., Vol 45, No. 7, p. 732, 1937

Description: Brown quartz-monzonite porphyry

No. 176

Location: Rock Creek, Beartooth Mountains, Montana

Analyst: R. B. Ellstad

Reference: J. T. Rouse, H. H. Hess, J. S. Vhay and K. P. Wilson, J. G., Vol 45, No. 7, p. 732, 1937

Description: Gray quartz-monzonite porphyry

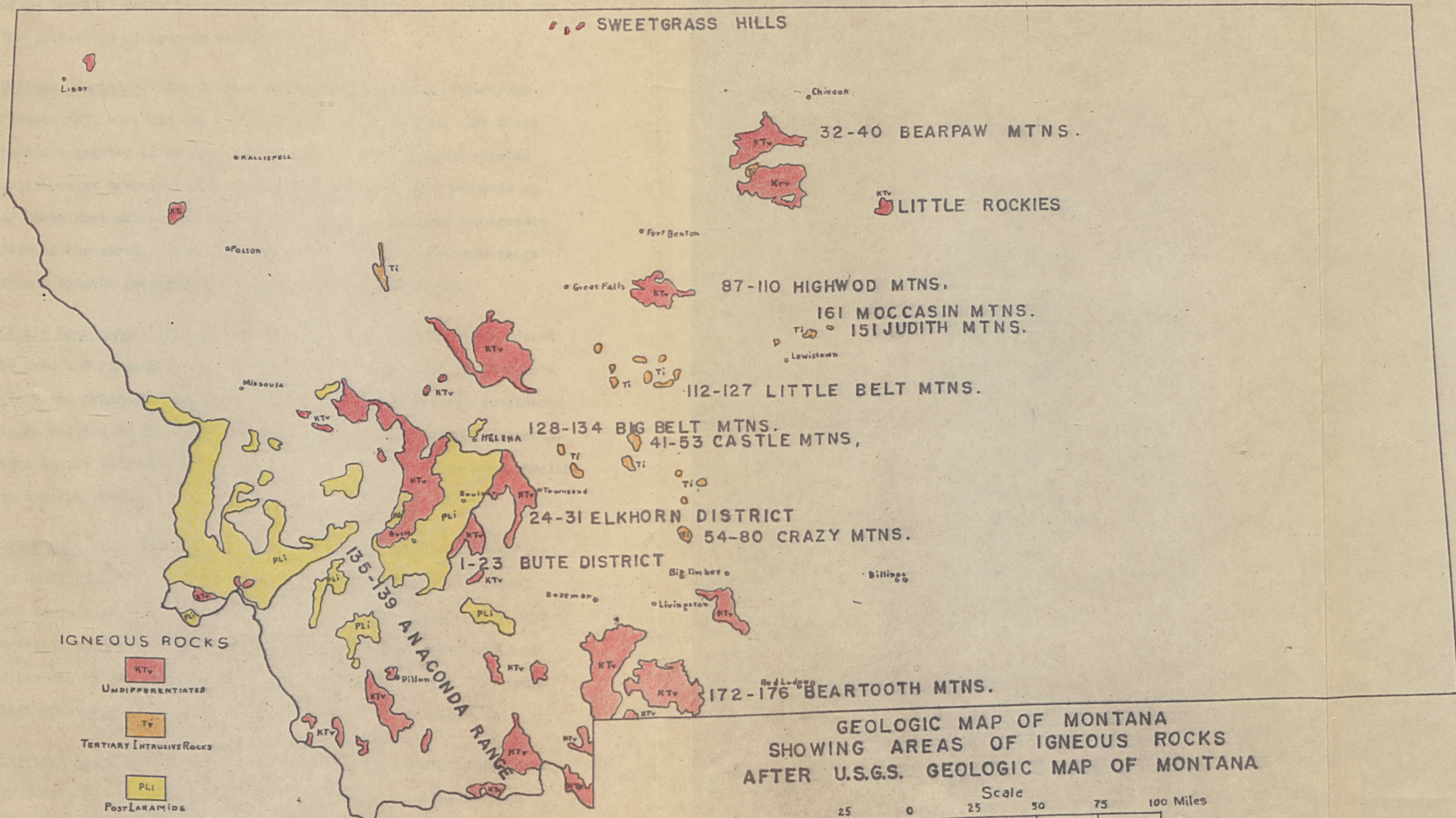
GENERAL DESCRIPTION OF MAJOR IGNEOUS AREAS

Analyses of igneous rocks sufficient for comparisons are available of seven igneous localities in Montana, therefore a brief description of the igneous rocks of these localities will follow:

Boulder Batholith: The Boulder batholith is divided into the Butte district, and the Elkhorn district. The Butte district, according to Weed (7), is in the southern part of the batholith, and is characterized by a change from the hornblende granite of the batholith to the local quartz monzonite. This monzonite at Butte is of a greenish color due to the greenish alterations of the feldspars present. There are two other types of rocks present; aplite, and fine-grained diorite, which is not present in the immediate vicinity of Butte.

The Elkhorn district also is a part of the Boulder batholith, but associated igneous bodies are present. According to Barrell (1) the first of the igneous intrusions were dikes emanating from a syenitic magma. These dikes show an extreme differentiation from acidic to basic types. After the first intrusions, there followed eruptions from a dioritic and gabbroic magma forming stocks, laccoliths, and dikes. The next

PLATE I



GEOLOGIC MAP OF MONTANA
SHOWING AREAS OF IGNEOUS ROCKS
AFTER U.S.G.S. GEOLOGIC MAP OF MONTANA

intrusion was of a quartz diorite followed by the quartz monzonite of the Boulder batholith. Aplite dikes intruding the batholith was the last stage of igneous activity.

Bearpaw Mountains: The Bearpaw Mountains, according to Weed and Pirrson (8), have had two periods of igneous activity. The first period consisted of an extrusive stock, which in turn is related to extrusive breccias. The second period of activity was made up of dikes that cut and altered the sedimentary beds and the igneous rock of the stock. The intrusive igneous rocks of the area range from a syenite porphyry to mica-bearing basic pegmatite.

Castle Mountains: Igneous rocks in these mountains were considered by Weed and Pirsson (9) to be a dissected volcano that yielded lava flows and fragmental deposits. The igneous rocks are all considered to be related to the volcano source, and to result from differentiation in the original homogenous mass. These rocks range from rhyolite to a basic basalt.

Crazy Mountains: The igneous rocks of these mountains as described by Wolff (12), have formed stocks, laccoliths, sills, and dikes, and range from a granitite to a theralite. The basaltic rocks are coarsely grained and porphyritic when occurring in thin sheets or dikes due to the quicker cooling of the smaller bodies. The granitite probably comes from small dikes in a dioritic stock.

Haystack Stock: This stock near Cowles in Park County is described by Emmons (2) as having an irregular shape, and cutting through the pre-Cambrian schists, Cambrian sedimentary rocks, and early acid breccia. The stock itself is described as essentially a coarse-grained gabbro diorite with related rocks ranging from quartz monzonite to olivene gabbro. The related rocks are thought to be the result of differentiation in the original magma. The outcrop area of the igneous rocks is about two and a half square miles.

Highwood Mountains: The Highwood Mountains, also described by Weed and Pirsson (10), are a group of deeply eroded extinct volcanos, in which their central cores are now left as the main canals to large bodies of magma presumed to lie at depth. On the southeast of the mountains is a restricted area of intruded sheets and laccoliths. Also large masses of breccias occur mingled with the vent, which produced the lava flows. A series of radiating dikes surround the central cores. The igneous rocks of this area range from a syenite to a basic shonkinite.

Little Belt Mountains: The igneous rocks of the Little Belt Mountains, again described by Weed and Pirsson (11), are divided into four general groups. The first of these groups is a granular non-porphyritic granitic rock of plutonic origin, which occurs as stocks and a few of the dikes. The next group consists of acid feldspathic porphyries that are found in the laccoliths and a large number of the dikes and sills. The third group embraces the lamprophyres that are found in the dikes and sills only. The last group is the extrusive rocks, which are restricted to two occurrences of basalt.

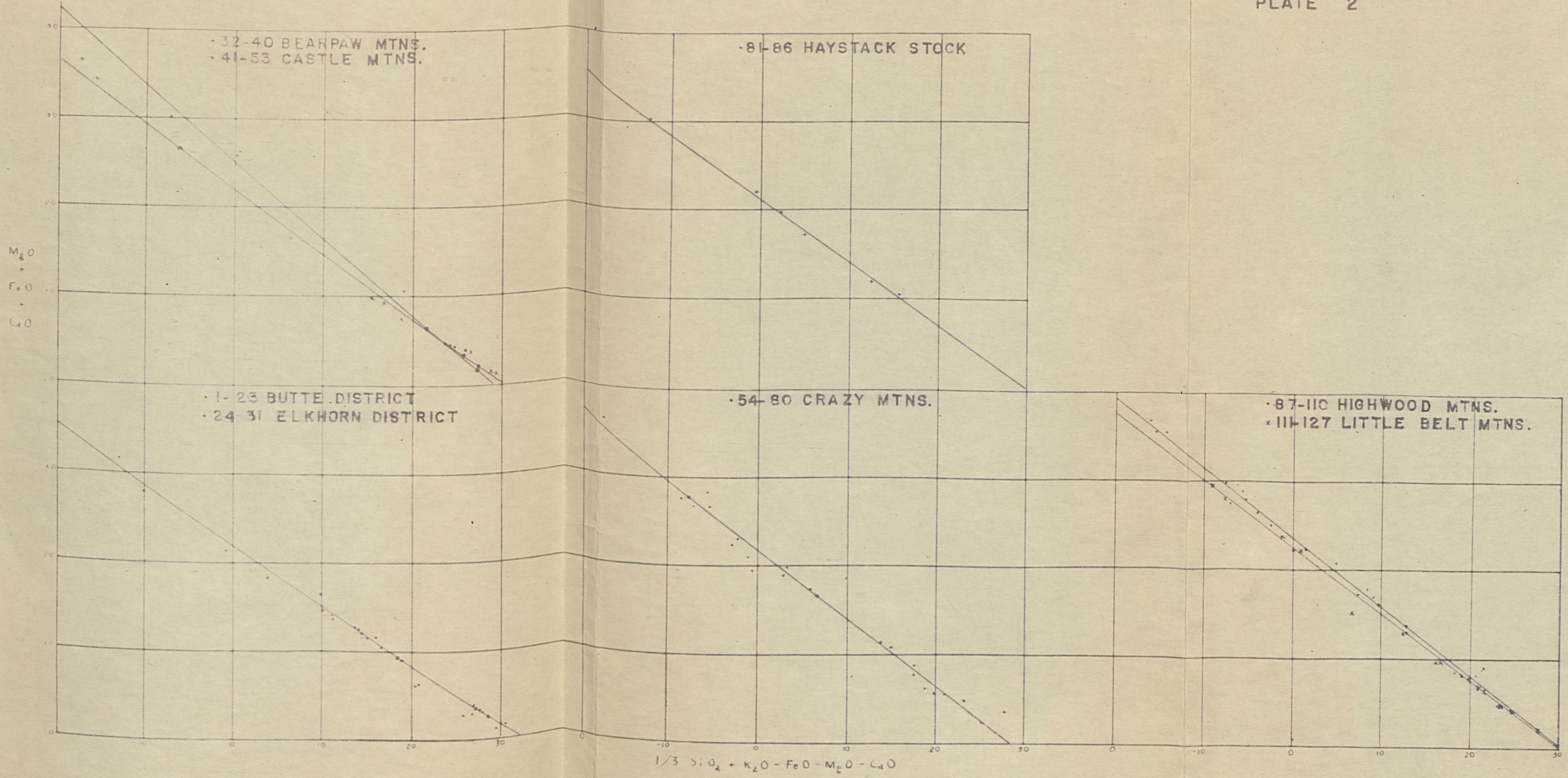
Big Belt Mountains: The Big Belt Mountains, described by Lyons (5), include a thick volcanic sequence of flow breccias and agglomerates folded along a northwesterly trending axis. The extrusive rocks are restricted to orthoclase basalts and analcime trachy basalts. The intrusive rocks range from gabbros to quartz monzonites. A swarm of dikes radiate from the Three Sisters composite stock, occasionally these bodies have changed their mode of occurrence and form laccoliths and sills.

Anaconda Range: Igneous rocks occupy about half the area of the Anaconda and Flint Creek ranges, according to Emmons and Calkins (3). In general they occur in large irregular or domelike masses, and to a lesser extent as dikes and sills. These rocks, being more resistant to weathering, make up the high parts of the mountains along with the metamorphosed sediments. The large intrusives of the area range from diabase to a siliceous granitoid rock with muscovite and biotite.

LARSEN'S VARIATION DIAGRAMS

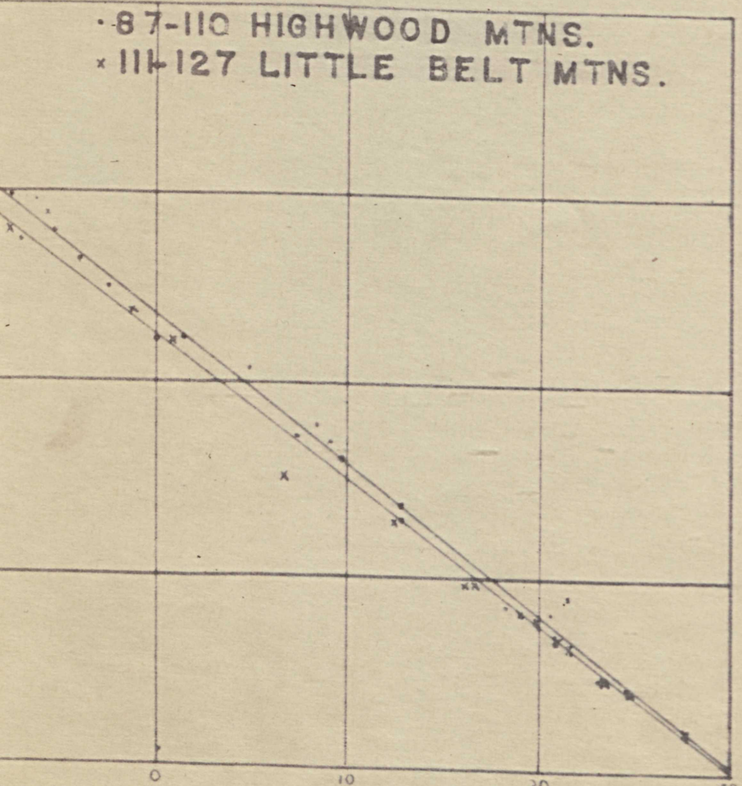
Larsen has this to say about his variation diagrams (4-506). "In petrographic provinces where the rocks range from basalt or gabbro to rhyolite or granite, the silica increases rather regularly, and in most batholiths the earliest intrusions were low in silica and later intrusions were progressively more siliceous. There is some justification, therefore, with such rocks for plotting the other oxides against silica. However, potash increases, and lime, total iron, and magnesia decrease about as regularly as silica changes. Moreover, it is about as likely that there is an analytical error in the determination of silica as of the other oxides, and magmas are as likely to be erratic in their silica content, through contamination or some other process, as in their other oxides."

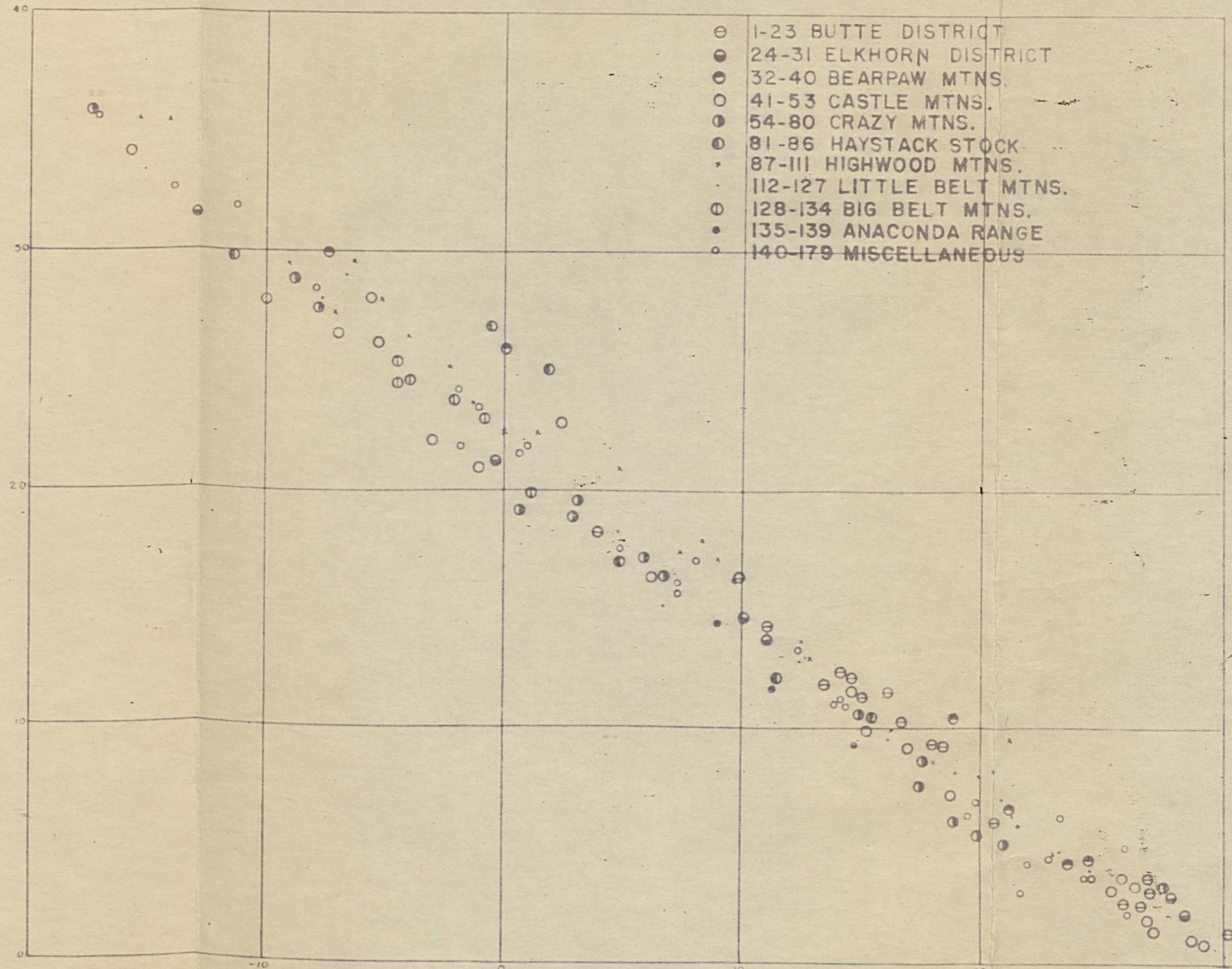
"After making many plots, it seems best to the author to determine the position of the rock on the basis of all its variable major constituents, which are SiO_2, CaO, MgO, total iron, and K_2O. Alumina is erratic and does not have a uniform slope; soda is nearly constant. The variation curves show that the range in percentages -from rhyolite to basalt-



·32-40 BEARPAW MTNS.
·41-53 CASTLE MTNS.
·81-86 HAYSTACK STOCK
·1-23 BUTTE DISTRICT
·24-31 ELKHORN DISTRICT
·54-80 CRAZY MTNS.
·87-110 HIGHWOOD MTNS.
×111-127 LITTLE BELT MTNS.
MgO + FeO + CaO
1/3 SiO2 + K2O - FeO - MgO - CaO

PLATE 2


·87-110 HIGHWOOD MTNS.
×111-127 LITTLE BELT MTNS.
0
10
20
30


1-23 BUTTE DISTRICT
24-31 ELKHORN DISTRICT
32-40 BEARPAW MTNS.
41-53 CASTLE MTNS.
54-80 CRAZY MTNS.
81-86 HAYSTACK STOCK
87-111 HIGHWOOD MTNS.
112-127 LITTLE BELT MTNS.
128-134 BIG BELT MTNS.
135-139 ANACONDA RANGE
140-179 MISCELLANEOUS
40
30
20
10
0
-10
0
10
20
30

for all the constituents except SiO_2 is about the same, and the latter has about three times this range. In the plots advocated in this paper, the position of the analysis is determined by the sum of one-third SiO_2 and K_2O minus the sum of the MgO, CaO, and total iron calculated as FeO."

Explanation of the Calculations: A sample calculation is shown on the following page for the purpose of explaining the method used in arriving at the position of the two axes. The first step in the calculations is the transcribing of the information from the source to the calculation form as shown in column 1. Since Fe_2O_3 must be converted to FeO, the Fe_2O_3 is multiplied by 0.9 and the MnO, if any, is added. This answer is then changed to the nearest tenth and added to the FeO and placed in column 2. The BaO and SrO, if any, are added to the CaO, again changed to the nearest tenth, as shown, and placed in column 2. The values from H_2O down are not included in the calculations. Column 2 is then added and adjusted to as close to 100% as possible. Upon completion of the primary calculations, 1/3 of the SiO_2, plus the K_2O, minus the FeO, minus the MgO, minus the CaO will constitute the horizontal axis. The MgO, plus the FeO, plus the CaO will determine the vertical axis.

DISCUSSION OF THE VARIATION DIAGRAMS

Since the discussion, from this point on, will deal primarily with petrographic provinces it would be best to give Pirrson's (6) definition of the term. "The igneous rocks of certain regions, regardless of mode of occurrence and general composition, have particular features that are more or less distinctive of all members of the group that occur there. This community of characters is shown by the presence in all the igneous rocks of particular varieties of

Sample No. 1

Location Nettie Mine, Butte, Montana

Analysist H. N. Stokes

Reference W. H. Weed, J. G., Vll, p. 739, 1899

Description Aplite

	1	2	3
SiO_2	76.87%	76.9%	77.7%
Al_2O_3	12.52%	12.5%	12.6%
Fe_2O_3	0.67%	%	%
FeO	0.00%	0.6%	0.6%
MgO	0.09%	0.1%	0.1%
CaO	0.49%	0.5%	0.5%
Na_2O	2.47%	2.5%	2.5%
K_2O	5.78%	5.8%	5.9%
H_2O +	0.52%		
H_2O -	0.25%		
P_2O_5	0.05%		
TiO_2	0.11%		
MnO	tr %		
CO_2	%		
F	%		
S	%		
BaO	0 %		
SrO	0 %		
Li_2O	tr %		
Cl	0 %		
	%		
	%		
Total	99.82%	98.9%	99.9%

$(Fe_2O_3 \times 0.9) + MnO =$ 0.6 %

$1/3\ SiO_2 + K_2O - FeO - MgO - CaO =$ 30.6

$MgO + FeO + CaO =$ 1.2

minerals, or by peculiarities of chemical composition and generally by a combination of these things."

Since almost all the geographical restricted areas, for which a sufficient number of analyses are available, exhibit a wide variety of rocks, an excellent curve can be plotted from the chemical analyses. Seven mountain ranges or districts have sufficient number of analyses to attempt separate curves for possible correlation purposes. The other areas of Montana for which a limited number of analyses are available are plotted on the composite diagram. Also included in the composite diagram are analyses, which cannot be located from the description given in the sources.

The Butte district was combined with the Elkhorn district because of their association with the Boulder batholith. A very good curve has resulted from the plots of the combined districts, since the Butte area is primarily acidic in nature, while the Elkhorn district has a complete range in differentiation. This range in differentiation is due to the emanations of basic type rocks followed by the intrusion of the Boulder batholith. If the point on the x axis and y axis where the curve intersects, is used as a reference point, then it is seen that the combination of the Butte and Elkhorn districts intersect the x axis at 31.6, and the y axis intersection is 35.4. These figures will be used for correlation with the other variation diagrams.

Both the Bearpaw Mountains and the Castle Mountains show a range of rock types, and therefore make a good representative variation diagram. As shown by the diagram, there is a wide difference between the two mountain ranges on the basic end, and a closer agreement on the acidic end. The Bearpaw Mountains are more acidic and likewise more basic than the Castle Mountains. The intersections of the Bearpaw and Castle Mountains are, respectively, 29 x and 42.2 y, and 30 x and 36.5 y.

The Crazy Mountains also have a wide range from the acidic to the basic rocks. The points on this diagram do not exhibit the same uniformity as the other diagrams, which is due to the analyses of some of the semi-basic and basic rocks. A representative curve is still possible with the wide range in rock types. The intersepts of the x and y axes are 28 and 37.

Only five analyses of the Haystack stock are available, but the range in rocks from acidic to basic is very good, henceforth the curve is justifiable. The curve for the Haystack stock intersects the x axis at 30 and the y axis at 35.

The Highwood and Little Belt Mountains also have a large number of analyses, which show a wide range in rock types. The curves drawn for these two areas are almost parallel, although there is a general trend to come closer together at the acidic end of the diagram. The intersepts for the Highwood Mountains are 30.4 x and 39.3 y. The Little Belt Mountains intersects the x axis at 30.4 and the y axis at 37.7.

The composite diagram was made to include all the above areas and the miscellaneous analyses available of the state. The miscellaneous items include areas for which a suitable number of analyses were not available to construct single diagrams. In addition to these areas, analyses were given of the state for which exact locations are missing, and which also were included in the miscellaneous. The composite variation diagram does not show the two general trends that are discernable in the single diagrams, since the plots appear as one rather broad curve.

There are two general trends in the variation diagrams, which can be correlated by their geographic location. The Highwood and Bearpaw Mountains, which lie in the north central part of the state have the highest y interseptions of the areas investigated. These interseptions are 39.3 and 42.2 respectively. The x axis interseptions are 30.4 and 29 respectively. These two areas could be considered as one general trend.

The second major division is made up of the Little Belt Mountains, Haystack stock, Crazy Mountains, Castle Mountains, and the Butte and Elkhorn districts. The maximum range in interseptions of the x axis is 30 to 31.6, while the range in the y axis is 35.4 to 37.7. These districts are south of the Highwood and Bearpaw Mountains, which lumps the western end of the state and the north central end into two general petrographic provinces and also into two general geographic areas.

CONCLUSIONS

The primary purpose of this paper is the collection, under one cover, of the chemical analyses of Montana's igneous rocks made since 1913. The United States Geological Survey has done an admirable piece of work in the gathering of all the analyses prior to 1913 in professional Paper No. 99, but that paper is not as up to date as one might desire. The writer hopes that, in the future, someone may be able to use the analyses listed in this paper.

The secondary purpose of this paper is the discussion of Larsen's variation diagrams in regard to the rocks of Montana. The two general trends that appear as the result of the investigation of this problem are: that the Highwood Mountains and the Bearpaw Mountains could be grouped into one general petrographic province; and that the Little Belt Mountains, Crazy Mountains, Castle Mountains, Haystack stock, Butte district, and the Elkhorn district lie in a second general petrographic province. These two provinces, as shown by the enclosed map of Montana, have a general geographic division into two areas.

In the secondary phase of this paper, it is very difficult to arrive at any conclusive answer. Very little is known of the application of variation diagrams in correlating petrographic provinces. Questions, such as how exact must the lines on the variation diagrams coincide, have not as yet been answered in a satisfactory manner. Therefore, any conclusions derived from the variation diagrams in this study are approximate and cannot be stated as accomplished facts.

ANALYSIS BIBLIOGRAPHY

Butte, Montana

6, 21, 22; Knopf, A., U. S. G. S. Rec. Lab.

3; Weed, W. H., U. S. G. S. B. 168; p. 119; 1900.

2, 4, 5, 7, 8, 9, 10, 11, 12, 13, 17, 18, 19, 20, 23; Weed, W. H., U. S. G. S. P. P. 74; p. 33, 41, 44, 45, 88; 1912.

1, 14, 16; Weed, W. H., J. G., Vll; p. 739; 1899.

15; Weed and Towers, U. S. G. S. B. 228; p. 134; 1904.

Elkhorn District, Montana

24, 25, 26, 28, 29, 30; Barrell, J. S., U. S. G. S. A. R. 22, (11); p. 514, 525, 529, 536, 540; 1901.

27, 31; Weed, W. H., U. S. G. S. B. 419; p. 93; 1910.

Bearpaw Mountains, Montana

32, 34-40; Weed and Pirsson, A. J. S., 11; p. 147, 192, 196, 295, 354, 360; 1896.

Castle Mountains, Montana

41-53; Weed and Pirsson, U. S. G. S. B. 139; p. 84, 88, 90, 96, 99, 101, 103, 106, 112, 115, 120, 125, 128, 130; 1896.

Crazy Mountains, Montana

78; Weed and Pirsson, U. S. G. S. B. 139; p. 115; 1896.

23, 28; Wolff, J. E., N. Transcont. Surv., Sep.; p. 10, 11; 1885.

54-57, 61, 63-69, 71, 73, 74, 76, 77; Wolff, J. E., U. S. G. S. B. 148; p. 142, 143, 144, 146; 1897.

70, 72, 79; Wolff, J. E., U. S. G. S. B. 150; p. 201; 1898.

58, 59, 60, 62; Wolff and Tarr, B. Mus. Comp. Zool., XVl; p. 232; 1893.

Haystack Stock, Park County, Montana

81-86; Emmons, W. H., J. G., XVl; p. 207, 210, 212, 214, 216, 218; 1908.

Highwood Mountains, Montana

93; Lindgren and Melville, A. J. S., XLV; p. 296; 1893.

92, 94-100, 102, 104, 105, 107, 108, 110; Pirsson, L. V., U. S. G. S. B. 237; p. 74, 79, 92, 109, 123, 128, 134, 139, 145, 156, 164, 168; 1905.

103; Weed and Pirsson, B. G. J. A., Vl; p. 414; 1895.

91; Weed and Pirsson, A. J. S., l; p. 295; 1896.

106; Weed and Pirsson, A. J. S., ll; p. 321; 1896.

101, 109; Weed and Pirsson, A. J. S., Xll; p. 14; 1901.

Little Belt Mountains, Montana

112-118, 121-123, 125-127, Pirsson, L. V., U. S. G. S. A. R. 20, 111; p. 466, 490, 497, 499, 509, 511, 514, 517, 519, 523, 531, 545, 548; 1900.

119, 120, 124; Weed and Pirsson, A. J. S. L.; p. 471, 473, 474; 1895.

Anaconda Range, Montana

135-139; Emmons and Calkins, U. S. G. S. P. P. 78; p. 96, 106, 109, 124; 1913.

Little Rocky Mountains, Montana

153, Weed and Pirsson, J. G., lV, p. 414, 1896.

Clancy, Montana

154, 155; A. Knopf, U. S. G. S. Rec. Lab.

Red Bluff, Montana

166, 167; G. P. Merill, Pr. U. S. Nat. Mus, XVll; p. 651, 1895.

Keating Mine, Radersburg, Montana

156, 157, 158, 168; A. N. Winchell, U. S. G. S. Rec. Lab.

Marysville District, Montana

149, 150; J. S. Burrell, U. S. G. S. P. P. 57; p. 55; 1907.

Zosel District, Montana

159; W. H. Weed, U. S. G. S. B. 168; p. 119; 1900.

Judith Mountains, Montana

151; Weed and Pirsson, A. J. S., 11; p. 192; 1896.

Bald Mountain, Montana

162; J. P. Iddings, U. S. G. S. B. 148; p. 129; 1897.

Bald Butte, Montana

165; J. S. Barrell, U. S. G. S. P. P. 57; p. 45; 1907.

Gallatin County, Montana

143; A. C. Peale, U. S. G. S. B. 148; p. 141; 1893.

140; J. P. Iddings, U. S. G. S. B. 150; p. 147; 1898.

141, 142; G. P. Merrill, Pr. U. S. Nat. Mus., XV11, p. 640, 645; 1895.

Libby, Montana

145, 146; E. S. Larsen, U. S. G. S. Rec. Lab.

Bitterroot Range, Montana

147; W. Lindgren, U. S. G. S. P. P. 27; p. 18; 1904.

Red Mountains, Montana

144; H. W. Weed, J. G., V11; p. 739; 1899.

BIBLIOGRAPHY

1. Barrell, J. S., "Microscopic Petrography of the Elkhorn Mining District, Jefferson County, Montana", U. S. G. S. A. R. 22, (11), p. 511-549, 1901.

2. Emmons, W. H., "Geology of the Haystack Stock, Cowles, Park County, Montana", J. G., XV1, p. 193-229, 1908.

3. Emmons, W. H., Calkins, G. H., "Geology and Ore Deposits of the Phillipsburg Quadrangle, Montana", U. S. G. S. P. P. 78, 1913

4. Larsen, E. S., "Some New Variation Diagrams for Groups of Igneous Rocks", Journal of Geology, No. 3, Vol. XLV1, p. 505-520, May 1938

5. Lyons, J. B., "Igneous Rocks of the Northern Big Belt Range, Montana", G. S. of A. B. 55, Part 1, p. 445-472, 1944

6. Pirrson, L. V., Knopf, A., "Rocks and Rock Minerals", John Wiley and Sons, Inc., p. 143, 1949

7. Weed, W. H., "Granite Rocks of Butte, Montana and Vicinity", Journal of Geology, V11, p. 737-750, 1899

8. Weed, W. H., Pirsson, L. V., "The Bearpaw Mountains of Montana, Second Paper (Part 11)", A. J. S., 11, 1896

9. Weed, W. H., Pirsson, L. V., "Geology of the Castle Mountain Mining District, Montana", U. S. G. S. B. 139, 1896

10. Weed, W. H., Pirsson, L. V., "The Bearpaw Mountains", A. J. S., 1, p. 283-301, 1896

11. Weed, W. H., Pirsson, L. V., "Igneous Rocks of Yogo Peak, Montana", A. J. S., L, p. 467-479, 1895

12. Wolff, J. E., "Theralite (From Gordons Butte, Crazy Mountains, Meagher County, Montana", U. S. G. S. B. 150, p. 197-201, 1898