A GEOCHEMICAL CLASSIFICATION OF DIKES OF THE
GRANDE RONDE SWARM, COLUMBIA RIVER BASALT

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	iii
INTRODUCTION	1
AREA OF INVESTIGATION	2
METHOD OF INVESTIGATION	2
GEOCHEMICAL CLASSIFICATION OF DIKES OF THE GRANDE RONDE SWARM	3
PRESENTATION OF DATA	3
Class 1	3
Class 2	4
Class 3	4
Class 4	5
Class 5	5
Class 6	6
COMPARATIVE SUMMARY	6
DIKE-FLOW RELATIONS INDICATED BY GEOCHEMISTRY	7
RELATION OF DIKES TO PROXIMATE FLOWS	7
RELATION OF DIKES TO FLOWS OF THE PASCO BASIN .	7
REFERENCES CITED :	8
TABLES	10
FIGURES	25

ABSTRACT

Analysis of approximately 40 major Columbia River Basalt dikes of the Grande Ronde swarm, northeastern Oregon-southeastern Washington, revealed that these dikes can be divided into six chemical classes. The compositions of dikes of four of these classes are comparable with the Yakima, Umatilla, Lolo, and Frenchmen Springs chemical types of Wright and others (1973). The dikes of the remaining two classes have an average content of 47.4% SiO₂, 10.3% CaO, 1.7% TiO₂, 0.49% K₂O, and 7.9% MgO; and 51.5% SiO₂, 9.5% CaO, 1.4% TiO₂, 0.75% K₂O, and 5.8% MgO.

Analysis of Columbia River Basalt flows of the swarm area disclosed that lower Yakima flows (as defined by Wright and others, 1973) are chemically comparable to dikes of Yakima-type chemistry and that middle Yakima flows are chemically comparable to dikes of one of the remaining five classes. The dike-flow relations indicated by chemistry can be substantiated by field evidence.

The study revealed that several flows and related dikes of the Grande Ronde area are chemically equivalent to Pasco Basin flows characterized by the Atlantic Richfield Hanford Company. This observation supports the need to direct further work toward ascertaining the extent to which chemically similar flows in both areas can be correlated in the field. Such a study would afford a more adequate evaluation of the significance of the Grande Ronde dike swarm as a source area.

A GEOCHEMICAL CLASSIFICATION OF DIKES OF THE GRANDE RONDE SWARM, COLUMBIA RIVER BASALT

INTRODUCTION

In 1968 the Atlantic Richfield Hanford Company (ARHCO), in behalf of the United States Atomic Energy Commission, undertook a study to develop a detailed stratigraphic model of the Columbia River Basalt flows underlying the Pasco Basin. The ensuing effort was directed toward the drilling of five deep core wells and a comprehensive geochemical characterization of the basalt flows penetrated. The results of this work showed conclusively that certain flows exhibit unique chemical properties that do not vary significantly with distances of up to 40 km (Brown and Ledgerwood, 1973, p. 174) and underscored the feasibility of utilizing comparative geochemistry for long-distance correlation.

Possible source areas for many of the flows underlying the Pasco Basin are major denuded dike swarms bordering the margins of the Columbia Plateau. When a need was expressed by ARHCO to define the relation of distal swarms (Fig. 1) to flows of the Basin, an examination of the Grande Ronde dike swarm was initiated¹. The subsequent investigation was oriented toward determining the feasibility of utilizing comparative geochemistry to indicate dike-flow correlations.

This document is an account of the initial results of this investigation and is predominantly concerned with the

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geochemical classification of the dikes examined. The relation of the dikes to proximate Columbia River Basalt flows and to flows of the Pasco Basin will be discussed only briefly and will be covered in more detail in another publication now in preparation.

AREA OF INVESTIGATION

Flow-directional and petrographic studies (Waters, 1950, 1961; Schmincke, 1967; and Taubeneck, 1970) have indicated that many of the Columbia River Basalt flows of the central and eastern portions of the Plateau were sourced by dikes of the extensive Chief Joseph swarm (Taubeneck, 1970), formerly segregated by Waters (1961) into the Grande Ronde-Cornucopia swarms. Few dikes of the Chief Joseph swarm are as well exposed as those traversing the canyons cut by the Grande Ronde River and its tributaries in northeastern Oregon and southeastern Washington (Fig. 1). A reconnaissance map (Fig. 2) published in 1969 by Gibson reveals the presence of approximately 40 major dikes in this area. The geochemical classification of these dikes is the subject of this paper.

METHOD OF INVESTIGATION

The major dikes mapped by Gibson (1969) were systematically sampled. To rapidly determine the degree to which the dikes could be chemically distinguished, all samples were analyzed for CaO, TiO₂, and Ba utilizing nondispersive X-ray fluorescence (NXRF). Analysis by NXRF indicated that a significant geochemical pattern was emerging, and subsequently composite samples of the dikes were analyzed by atomic absorption and by neutron activation to obtain a more complete chemical characterization. Thin-sections of

selected samples were also examined to determine the degree to which the chemical variability was reflected petrographically.

GEOCHEMICAL CLASSIFICATION OF DIKES OF THE GRANDE RONDE SWARM

PRESENTATION OF DATA

Chemically, the dikes can be divided into six classes.² Dikes belonging to four of these classes are closely comparable in composition to one of the 11 chemical types³ established by Wright and others (1973), and where applicable are designated as such. A discussion of the chemical and petrographic properties distinctive of each of the six classes follows, concluded by a comparative summary.

Class 1

Of the approximately 40 dikes sampled, the greatest number fall into the first chemical class. Chemically, members of this class (Fig. 3), with an average content of 54.0% SiO₂, 7.3% CaO, 1.9% TiO₂, 1.5% K₂O, and 3.8% MgO, correspond to the Yakima chemical type of Wright and others (1973). Major, minor, and selected trace element analyses of three dikes belonging to this class are listed in Table 1-A.

²The term "class" (Price, 1973a) refers to an informal chemical grouping of dikes and flows of the Grande Ronde area which may possibly be correlatable. Only the dikes of each class are discussed in this Section.

³The 11 chemical types of Wright and others (1973) represent the compositions of volumetrically important Columbia River Basalt flows or flow sequences. If chemically comparable, the types may be used to describe the composition of any dike (Wright and others, 1973, p. 381) or flow (Wright and others, 1973, p. 376) regardless of "stratigraphic" position.

Dikes of this class are indistinguishable petrographically. Hand-specimen samples are characteristically dense and fine-grained, rarely displaying phenocrysts. Samples in thin-section exhibit an intersertal texture with plagioclase and pyroxene microphenocrysts and microlites enclosed in a matrix of tachylite. A modal analysis of a dike petrographically representative of this class is presented in Table 1-B.

Class 2

Dikes belonging to the second chemical class are designated in Figure 3. Members of this class contain an average of 47.4% SiO_2 , 10.3% CaO , 1.7% TiO_2 , 0.49% K_2O , and 7.9% MgO . The average composition cannot be adequately described by any of the chemical types of Wright and others (1973). Major, minor, and selected trace element analyses of two members of this class are listed in Table 2-A.

Petrographically, members of this class are generally medium- to coarse-grained in hand specimen. Thin-section specimens are holocrystalline and generally exhibit a diabasic texture. Olivine and olivine alteration products are characteristically present. A modal analysis of a dike petrographically representative of this class is presented in Table 2-B.

Class 3

Dikes belonging to the third chemical class are located in Figure 3. Members of this class contain an average of 51.5% SiO_2 , 9.5% CaO , 1.4% TiO_2 , 0.75% K_2O , and 5.8% MgO . The average composition of dikes of this class cannot be adequately described by any of the chemical types of Wright and others (1973). Major, minor, and selected trace element analyses of two members of this class are listed in Table 3-A.

Members of this class are generally medium- to coarse-grained in handspecimen. Thin-section specimens are generally holocrystalline and exhibit an ophitic or subophitic texture. Olivine or alteration products derived from olivine are generally present. A modal analysis of a dike petrographically characteristic of this class is listed in Table 3-B.

Class 4

The fourth chemical class contains only one dike (Fig. 3) chemically characterized by 54.3% SiO_2 , 6.0% CaO , 2.5% TiO_2 , 2.6% K_2O , and 2.7% MgO . The chemistry of this dike, listed in Table 4-A, corresponds closely to the Umatilla chemical type of Wright and others (1973).

Handspecimen samples of this dike are fine- to medium-grained, exhibiting sparse phenocrysts of plagioclase up to 3 mm in length and blebs of chlorophaeite (Peacock and Fuller, 1928, p. 361) up to 2.5 cm in diameter. Thin-section samples display an intersertal texture with microphenocrysts and microlites of plagioclase and pyroxene, cross-cut by needles of apatite, surrounded by a matrix of tachylite. A modal analysis of a sample from this dike is presented in Table 4-B.

Class 5

Class 5 contains a single dike (Fig. 3) chemically characterized by 43.6% SiO_2 , 8.8% CaO , 2.9% TiO_2 , 0.96% K_2O , and 4.8% MgO . The chemistry of this dike most closely resembles the Lolo chemical type of Wright and others (1973). A more complete analysis of this dike is listed in Table 5-A.

Handspecimen samples of this dike are medium- to coarse-grained. Thin-section samples are holocrystalline, exhibiting a diabasic intergrowth of crystals of plagioclase, pyroxene, and altered olivine. A modal analysis of this dike is presented in Table 5-B.

Class 6

The sixth chemical class also contains only one member (Fig. 3). This dike averages 50.6% SiO_2 , 8.7% CaO , 3.0% TiO_2 , 1.3% K_2O , and 4.2% MgO , and most closely resembles in composition the Frenchmen Springs chemical type of Wright and others (1973). A more complete analysis of this dike is listed in Table 6-A.

The dike of this class is porphyritic in handspecimen containing 15 to 20% plagioclase phenocrysts averaging 5 mm in length. Thin-section samples exhibit an orthophyric texture with microphenocrysts and microlites of plagioclase and microlites of pyroxene surrounded by a tacylite matrix. A modal analysis of this dike is listed in Table 6-B.

COMPARATIVE SUMMARY

The distinctive chemical composition of each class is best illustrated graphically by SiO_2 - MgO , CaO - MgO , TiO_2 - MgO , and K_2O - MgO variation diagrams (Fig. 4). Each class, as illustrated in Table 7, also exhibits a characteristic range in content of selected trace elements. The referenced Figure and Table summarize most succinctly the intraclass and interclass chemical variations discussed in the text.

A summary of the petrographic properties distinctive of each class is presented in Table 8.

DIKE-FLOW RELATIONS INDICATED BY GEOCHEMISTRY

RELATION OF DIKES TO PROXIMATE FLOWS

Analysis of basalt flows comprising sections measured within the study area disclosed that the chemistry of the basalt pile varies in an orderly sequence. With reference to the informal stratigraphic classification of Wright and others (1973), the 1100-meter basalt section consists of approximately 80 meters of lower basalt, 900 meters of lower Yakima basalt, and 120 meters of section tentatively classified as middle Yakima basalt.

The chemistry of individual Yakima flows or flow sequences was found to be comparable to that of one of the six classes of dikes. Supplemental field work was oriented toward determining if chemically similar flows and dikes could also be related by field evidence. The subsequent examination revealed that dike-flow continuity is rarely preserved in the field and emphasized the value of utilizing comparative geochemistry to indicate dike-flow correlations (Price, 1973b). The relation of dikes of the six classes to proximate flows is summarized in Table 9.

RELATION OF DIKES TO FLOWS OF THE PASCO BASIN

A generalized stratigraphic column of the Columbia River basalt flows exposed around the margins of the Pasco Basin is presented in Figure 5. The unique flows identified by ARHCO in the deep core holes are essentially correlatable with members of this section (Ledgerwood, 1974, in press). The chemical composition of these flows can be described in general by 1 of the 11 chemical types of Wright and others (1973).

The data summarized in this document indicate that

several of the flows and related dikes of the Grande Ronde area are chemically equivalent to flows of the Pasco Basin (see Fig.5). This finding supports the need for directing further work toward ascertaining the extent to which certain flows in both areas (especially those of Umatilla-type chemistry) can be correlated in the field. Before such a study is conducted, a statement concerning the relation of dikes of the Grande Ronde swarm to flows of similar composition in the Pasco Basin would be premature.

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	<u>J-15</u>	<u>G-2</u>	<u>G-8</u>
atomic absorption			
<u>%</u>			
SiO ₂	54.5	54.5	54.3
Al ₂ O ₃	13.7	13.7	13.4
FeO*	11.5	12.4	12.5
MgO	5.1	3.3	3.9
CaO	8.8	7.3	7.3
Na ₂ O	2.7	3.0	3.0
K ₂ O	1.0	1.6	1.6
MnO	0.19	0.21	0.25
TiO ₂	1.7	2.0	2.2
P ₂ O ₅	0.3	0.4	0.4
Volatility	0.9	1.2	1.2
Total	100.4	99.6	100.0
<u>ppm</u>			
Cr	50	17	8
Ba	591	822	639
neutron activation			
La	18	24	25
Sm	4.7	5.1	5.3
Yb	2.6	5.1	4.9
Eu	1.4	1.8	2.1
Co	37	38	40
Sc	33	33	37
Hf	4.0	6.2	5.7
Th	4.1	5.3	4.3
Tb	0.64	1.0	1.5
Ta	1.9	5.0	1.9

*All Fe reported as FeO.

Table 1-A Chemical analyses of selected dikes from Class 1
(see Fig. 3)

<u>Minerals</u>	<u>Vol%</u>
Plagioclase	42.6
Pyroxene	35.4
Opakes	8.3
Glass	8.1
Decomposition products	5.6
Total	100.0
Plagioclase/pyroxene ratio:	1.2
100-(glass+opakes)/pyroxene ratio:	2.4

Table 1-B Modal analysis of member (diike G-2) of Class 1.
Volume percentage of mineral constituents
determined from average of two sets of 500 point
counts

	<u>J-16</u>	<u>G-13</u>
atomic absorption		
<u>%</u>		
SiO ₂	48.6	48.1
Al ₂ O ₃	14.8	16.0
FeO*	10.9	10.8
MgO	7.8	7.8
CaO	10.7	10.1
Na ₂ O	2.4	2.3
K ₂ O	0.50	0.53
MnO	0.20	0.21
TiO ₂	1.6	1.8
P ₂ O ₅	0.4	0.4
Volatility	1.9	1.0
Total	99.8	99.0
<u>ppm</u>		
Cr	313	298
Ba	450	450
neutron activation		
La	21	20
Sm	4.8	4.3
Yb	4.0	3.6
Eu	1.5	1.6
Co	45	45
Sc	34	34
Hf	3.4	3.9
Th	1.9	1.2
Tb	0.86	0.86
Ta	2.3	3.8

*All Fe reported as FeO.

Table 2-A Chemical analyses of selected dikes from Class 2
(see Fig. 3)

<u>Minerals</u>	<u>Vol%</u>
Plagioclase	45.5
Pyroxene	25.2
Olivine	6.9
Opaques	5.4
Decomposition products	16.9
Total	99.9

Plagioclase/pyroxene ratio: 1.8

Table 2-B Modal analysis of member (dike J-16) of Class 2.
Volume percentage of mineral constituents
determined from average of two sets of 500 point
counts

	<u>J-37</u>	<u>G-7</u>
atomic absorption		
<u>%</u>		
SiO ₂	52.1	51.9
Al ₂ O ₃	14.8	14.8
FeO*	10.2	9.5
MgO	5.8	5.9
CaO	9.5	9.9
Na ₂ O	2.7	2.8
K ₂ O	0.71	0.90
MnO	0.20	0.21
TiO ₂	1.4	1.2
P ₂ O ₅	0.2	0.3
Volatility	1.9	2.4
Total	99.5	99.8
<u>ppm</u>		
Cr	207	101
Ba	445	575
neutron activation		
La	14	18
Sm	3.6	4.1
Yb	3.4	3.3
Eu	1.2	1.1
Co	37	35
Sc	42	40
Hf	3.7	3.5
Th	1.6	2.3
Tb	1.0	0.92
Ta	1.2	2.3

*All Fe reported as FeO.

Table 3-A Chemical analyses of selected dikes from Class 3
(see Fig. 3)

<u>Minerals</u>	<u>Vol%</u>
Plagioclase	48.1
Pyroxene	31.0
Olivine	1.6
Opakes	6.2
Glass + decomposition products	13.0
• Total	99.9
Plagioclase/pyroxene ratio:	1.5

Table 3-B Modal analysis of member (dike G-7) of Class 3.
Volume percentage of mineral constituents
determined from average of two sets of 500 point
counts

%

G-17

atomic absorption

SiO ₂	54.3
Al ₂ O ₃	13.0
FeO*	12.1
MgO	2.7
CaO	6.0
Na ₂ O	3.2
K ₂ O	2.6
MnO	0.21
TiO ₂	2.5
P ₂ O ₅	0.9
Volatility	1.9
Total	99.4

ppm

Cr	3
Ba	3403

neutron activation

La	58
Sm	10.5
Yb	7.6
Eu	3.7
Co	24
Sc	24
Hf	12
Th	8.0
Tb	1.6
Ta	3.4

*All Fe reported as FeO.

Table 4-A Chemical analysis of single member of Class 4
(see Fig. 3)

<u>Mineral</u>	<u>Vol%</u>
Plagioclase	41.3
Pyroxene	10.2
Olivine	1.5
Opakes	7.2
Apatite	1.9
Glass	29.3
Chlorophaeite	4.8
Decomposition products	4.1
Total	100.3
Plagioclase/pyroxene ratio:	4.0
100-(glass+opakes)/pyroxene ratio:	6.2

Table 4-B Modal analysis of single dike (dike G-17) of Class 4. Volume percentage of mineral constituents determined from average of two sets of 500 point counts

J-6

<u>%</u>	
atomic absorption	
SiO ₂	48.6
Al ₂ O ₃	13.8
FeO*	14.6
MgO	4.8
CaO	8.8
Na ₂ O	2.8
K ₂ O	0.96
MnO	0.20
TiO ₂	2.9
P ₂ O ₅	0.6
Volatility	2.1

Total	100.2
-------	-------

<u>ppm</u>	
Cr	30
Ba	675

neutron activation	
La	37
Sm	7.3
Yb	6.7
Eu	2.4
Co	43
Sc	39
Hf	7.1
Th	3.7
Tb	1.4
Ta	3.2

*All Fe reported as FeO.

Table 5-A Chemical analysis of single member of Class 5
(see Fig. 3)

<u>Mineral</u>	<u>Vol%</u>
Plagioclase	50.0
Pyroxene	26.7
Olivine	
Unaltered	2.4
Altered	4.2
Opagues	6.9
Apatite	Trace
Decomposition products + devitrified glass	9.2
Total	99.4
Plagioclase/pyroxene ratio:	1.9

Table 5-B Modal analysis of single member (dike J-6) of Class 5. Volume percentage of mineral constituents determined from two sets of 500 point counts

G-5

<u>%</u>	
atomic absorption	
SiO ₂	50.6
Al ₂ O ₃	13.4
FeO*	14.6
MgO	4.2
CaO	8.7
Na ₂ O	2.7
K ₂ O	1.3
MnO	0.21
TiO ₂	3.0
P ₂ O ₅	0.6
Volatility	2.5
Total	101.8
<u>ppm</u>	
Cr	50
Ba	700
neutron activation	
La	28
Sm	7.1
Yb	5.7
Eu	2.3
Co	39
Sc	37
Hf	6.1
Th	3.6
Tb	1.5
Ta	2.5

*All Fe reported as FeO.

Table 6-A Chemical analysis of single member of Class 6
(see Fig. 3)

<u>Minerals</u>	<u>Vol%</u>
Plagioclase	
Phenocrysts	2.0
Microphenocrysts	2.6
Microlites	31.2
Pyroxene	30.6
Olivine	1.0
Glass + opaques	32.5
Total	99.9
Plagioclase/pyroxene ratio:	1.2
100-(glass + opaques)/pyroxene ratio:	2.2

Table 6-B Modal analysis of single member (dike G-5) of Class 6. Volume percentage of mineral constituents determined from average of two sets of 500 point counts.

Dike Class Number	1	2	3	4	5	6
	ppm					
Cr*	25	303	134	3	30	50
Ba*	684	464	508	3403	675	700
La	22	20	16	58	37	28
Sm	5.0	4.6	3.9	10.5	7.3	7.1
Yb	4.2	3.6	3.9	7.6	6.7	5.7
Eu	1.8	1.5	1.3	3.7	2.4	2.3
Co	38	45	38	24	43	39
Sc	34	34	41	24	39	37
Hf	5.3	3.5	3.7	12	7.1	6.1
Th	4.6	1.7	1.9	8.0	3.7	3.6
Tb	1.0	0.84	1.0	1.6	1.4	1.5
Ta	2.9	2.4	1.5	3.4	3.2	2.5

*Cr and Ba values determined by atomic absorption analysis;
remaining analyses by neutron activation.

Table 7 Average values of trace element analyses of
selected dikes of each class

Class	Texture		Mineral Assemblage					
			Handspecimen			Thin-Section		
			Phenocryst Percentage			100--(Glass+Opakes)		
	Handspecimen	Thin-Section	Plagioclase	Pyroxene	Olivine	Plagioclase/Pyroxene	Pyroxene	% Olivine
1	Fine-grained	Intersertal	Trace	Trace	Trace	~1.2	~2.4	<1
2	Coarse grained, granular	Holocrystalline, diabasic	<10	Trace	~10	~1.8		~6
3	Medium- to coarse-grained, granular	Hypo- to holo-crystalline, ophitic	<10	Trace	<10	~1.5		~1.5
4	Fine- to medium-grained	Intersertal	Trace	Trace	Trace	~4.0	~6.2	~1.5
5	Medium-grained, granular	Holocrystalline, diabasic	<10	Trace	~10	~1.9		~6
6	Porphyritic, fine-grained matrix	Orthophyric	>15	Trace	Trace	~1.2	~2.2	~1

Table 8 Comparison of general petrographic properties of six classes of dikes

Class	Basis of Correlation	Position of Flows in Relation To Formation Contacts*
6	Chemically and petrographically similar to flows comprising Big Butte (Fig. 3). Direct field evidence.	
5	Chemically and petrographically similar to youngest flows capping Shumaker Creek section (Fig. 3) and proximate to Anatone, Washington. Tenable field evidence.	
4	Chemically and petrographically comparable to flow between two major interbeds near top of Buford Creek section (Fig. 3) and to flows comprising Puffer Butte (Fig. 3). Direct field evidence.	Flows lying above lower Yakima-middle Yakima contact (Classes 2-6)
3	Chemically and petrographically similar to porphyritic/diabasic flow or flow sequence capping lower Yakima flows, Buford Creek section (Fig. 3). Tenable field evidence.	
2	Chemically and petrographically similar to porphyritic/diabasic flow or flow sequence capping lower Yakima flows, Shumaker Creek section (Fig. 3). Tenable field evidence.	
1	Chemically and petrographically comparable to lower Yakima flows. Direct field evidence.	Flows lying above lower basalt-lower Yakima contact
	All dikes sampled cross-cut lower basalt formation and appear to be younger.	Flows lying below lower basalt-lower Yakima contact

*Flows described above lower Yakima-middle Yakima contact not necessarily listed in stratigraphic order.

Table 9 Relation of dikes of six classes to proximate flows. Field evidence described as "direct" indicates dike(s) of class could be traced to or near point of contact with flow(s). Field evidence rated as "tenable" indicates field evidence supportive of dike-flow relations but could not be utilized as sole evidence of correlation.

Figure 1 Areal extent of the Columbia River Basalt Group, Columbia Plateau

Figure 2 Map of dikes of the Grande Ronde swarm prepared by Gibson (1969, p. 423)

Figure 3 Geochemical classification of dikes of the Grande Ronde swarm
(Number adjacent to dike indicates sample designation)

Figure 4 SiO₂-MgO, K₂O-MgO, TiO₂-MgO, CaO-MgO variation diagrams for six classes of dikes

Figure 5 Type section of Yakima Basalt flows exposed in the region surrounding the Pasco Basin (Brown and Ledgerwood, 1973, p. 178). Numbers adjacent to members designate chemically similar classes of dikes of the Grande Ronde swarm.