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**CHEMICAL DISCRIMINATION OF THE WOLF RHYOLITES,  
CENTRAL BRITISH COLUMBIA: CONSERVED ELEMENT  
DIAGRAMS**

by

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## **ABSTRACT**

The Wolf epithermal precious metal vein prospect is hosted in rhyolites. The aim of this study is to determine whether the rhyolite samples collected are cogenetic or not. In order for the samples to be cogenetic, they must originate from the same magma batch. A magma batch may represent one flow, one eruption, numerous flows from the same eruption or numerous eruptions. Chemically, using conserved elements, we can determine whether the samples are derived from chemically indistinguishable magmas or not. Using Pearce element conserved constituent diagrams and conserved constituent scatterplots we can graphically test the cogenetic hypothesis. In total, seven separate magma batches are identified from fourteen samples tested in this manner.

## **CHAPTER 1: INTRODUCTION**

### 1.1 INTRODUCTION

This study focuses on the rhyolites which host the Wolf epithermal precious metal vein prospect, central British Columbia. The objective is to use chemical data to gain an improved understanding of the chemical diversity of the rhyolites, and in so doing, to chemically distinguish them from one another. Based on such chemical distinction, within the analytical error determined, the cogenetic hypothesis may be supported or rejected.

### 1.2 PROPERTY LOCATION AND ACCESS

The Wolf prospect is located approximately 185 km southwest of Prince George, in central British Columbia near latitude 53°12' north and longitude 125° 26' west (Fig. 1). Access is by helicopter, float plane or four-wheel drive road off kilometre 142 of the Kluskus-Ootsa logging road out of Vanderhoof.

### 1.3 HISTORY

In 1982, Rio Algom Exploration conducted a lake sediment survey in central British Columbia. Sediment related to the Wolf property was found to be anomalous in silver. Rio Algom worked on the property from 1982 to 1985 doing extensive trenching of silicified and brecciated zones, as well as diamond drilling totaling 593 metres in 6 holes. Presently, Minnova is leasing the property and in 1992 did more trenching and drilled approximately 17 more holes, totaling about 2500 metres.

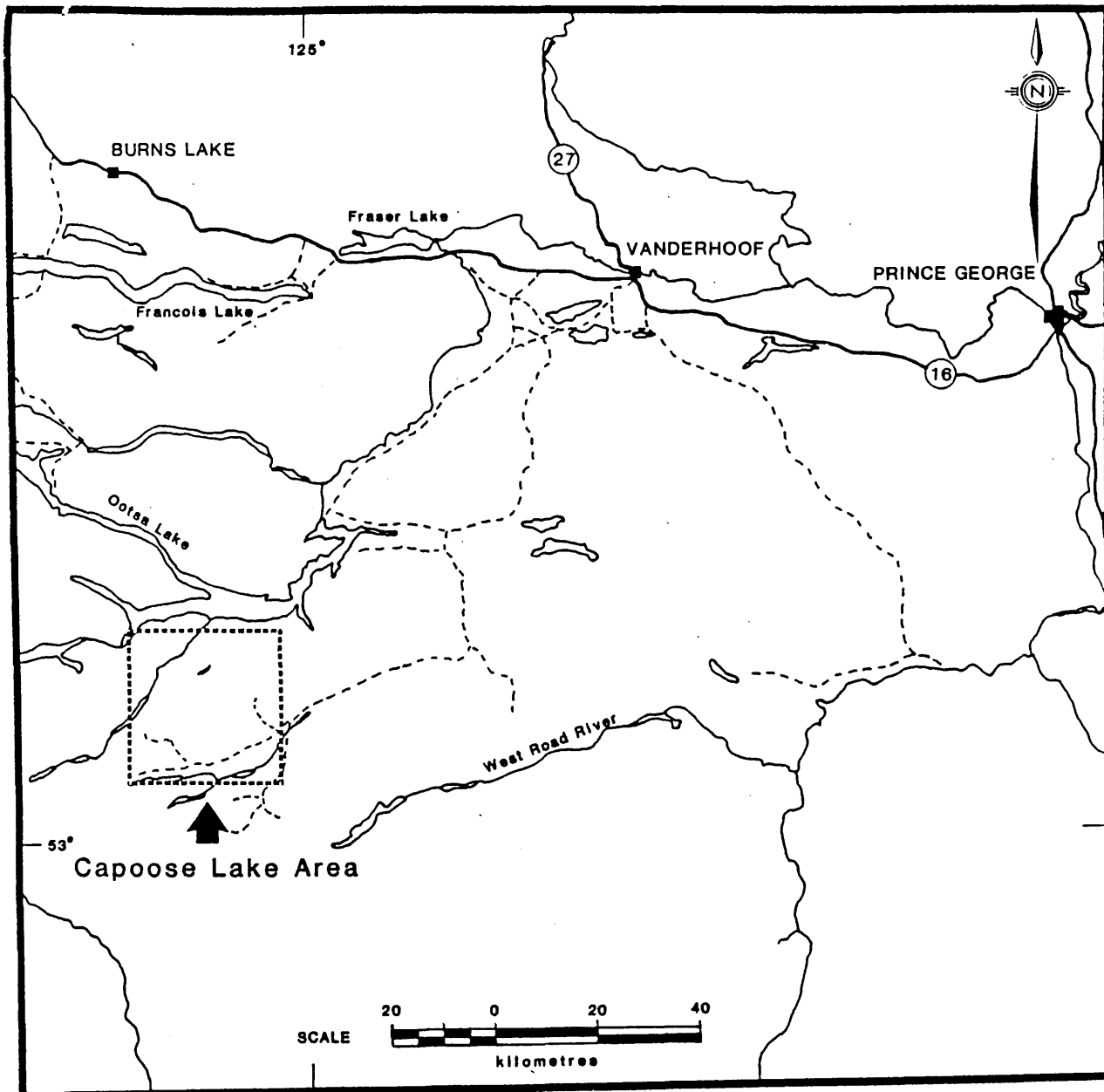


Figure 1: Location of the Wolf prospect of the Capoose Lake Area, Capoose Lake area, central British Columbia (after Andrew, 1988).

## 1.4 GENERAL GEOLOGY

The Wolf prospect is within the oceanic arc terrane of the Stikinia in the Intermontane Belt (Andrew, 1988). Wolf is in the Ootsa Lake Group volcanic rocks of Eocene age. The volcanic suite found at Wolf is predominately felsic volcanic rocks and is grouped in the rhyolite member of the Ootsa Lake Group. Intrusive into these are rhyolite domes with associated flows and breccias and also porphyritic plugs and dikes.

## **CHAPTER 2: FIELD WORK**

The samples analyzed in this study were collected during the 1992 field season in part by the author under the employment of Minnova Inc., and in part by other Minnova employees. At the time, the samples were not collected with the intended purpose of this study. As a result the geological descriptions of the samples are not too extensive. A very general description for each sample is listed in Table 1.

## **CHAPTER 3: METHODOLOGY**

Wolf volcanic rocks may be from one or more igneous processes and be part of one or more initial magma batches. A magma batch is a chemical system formed by partial melting of source rocks that left the source region as a chemical system, and can have undergone physical-chemical processes of such a nature that the system remained closed to some constituents during its evolution (Higman, 1990). Magmas related to each other through modification of an initial magma are

Sample	Geologic Field Description
TC1	probably a tuffaceous rhyolite or quartz feldspar porphyry
TC2	probably a tuffaceous rhyolite; is from a trench in the Black Fly Zone
TC3	probably a tuffaceous rhyolite; is from a trench in the Black Fly Zone
TC4	quartz feldspar porphyry tuff
TC5	silicified rhyolite; possibly a silicified tuff
TC6	silicified rhyolite; flow banded
TC7	quartz feldspar porphyry; from the East Zone (from a different mapsheet)
TC8	silicified rhyolite
TC9	quartz feldspar porphyry
TC10	quartz feldspar porphyry
TC11	rhyolite; brecciated
TC12	possible rhyolite; could be a vein sample
TC13	rhyolite; brecciated; from near the Black Fly Zone
TC14	rhyolite or quartz feldspar porphyry

Table 1: Geologic Field Description of Rhyolite Samples From Wolf Prospect, Central B.C.

said to be comagmatic, cogenetic, or share the same community or origin (Nicholls and Stout, 1988).

This study uses Pearce element ratio diagrams to discriminate between suites of rocks from different initial magmas. Pearce element ratios (Russell et al., 1990) are a means of portraying chemical variation within igneous rock suites and interpreting the causes of chemical diversity. Pearce element diagrams are more discriminating of rival petrologic hypotheses than other variation diagrams. With Pearce element ratio diagrams few hypotheses can be accepted whereas with other variation diagrams many petrologic hypotheses cannot be rejected (Russell and Nicholls, 1988).

Pearce element ratio conserved constituent diagrams and conserved constituent scatterplots have the ability to discriminate between rival hypotheses formulated to test whether members of a rock suite are comagmatic. Comagmatic rocks have constant ratios for elements conserved in the differentiation process. Thus by using conserved element ratios we can compensate for the effects of magmatic differentiation. Conserved constituent scatterplots plot two conserved elements against one another in ppm or percentage values. This results in a straight line distribution of comagmatic rocks as the nonconserved elements (present on the denominator of a percentage) change and the ratio of the conserved elements remains constant.

Additionally, conserved element ratio diagrams can illustrate the limitations of the analytical precision. This is critical since we cannot discriminate between magma batches if they are identical within experimental or analytical uncertainty. Given that we cannot reject a hypothesis of a comagmatic relationship between certain rock suites then the suites deserve further scrutiny.

## **CHAPTER 4: ANALYTICAL TECHNIQUES**



#### 4.1 X-RAY FLUORESCENCE ANALYSIS

The fourteen samples studied were received from Min-en Labs as powdered whole rock samples of a uniform grain size. The major element analyses were made using glass disks. The minor element analyses were made using pressed pellets.

The major glass disks procedure uses a six times dilution of 0.6 grams of sample to 3.6 grams of flux 105. This mixture is then put in a platinum crucible in a furnace at 1100°C for thirty minutes. The sample is brought up to its original weight with the addition of flux 100. The sample is then reheated with a "Meker" burner under a fume hood until it is red hot. The molten sample is poured onto a mould which is heated on a hot plate at 400°C. The molten sample is then quickly pressed. When the sample is cooled, it is trimmed, resulting in a thin, circular glass disk of approximately 1.5 inches in diameter.

The method of preparing powder pellets which are used to analyze for minor elements, is less labour intensive than the glass disks procedure. Approximately 3 grams of rock powder is mixed with a dilute polyvinylalcohol binder and pressed into pellets.

K-alpha spectra were measured for the major and minor elements in the respectively prepared samples using an automated Philips PW1400 spectrometer at the Department of Oceanography, U.B.C. since the Department of Geological Sciences' manual X-ray fluorescence spectrometer was not in working order for the duration of the study. Raw peak and background counts were reduced to weight percent and ppm concentrations (Tables 2,3). Full mass absorption correction were employed and each element was calibrated using standard

		FE2O3	MNO	TIO2	CAO	K2O	SIO2	AL2O3	MGO	P2O5	NA2O
		%	%	%	%	%	%	%	%	%	%
JB2	93033018	14.42	0.21	1.23	9.81	0.41	53.98	14.72	4.57	0.07	1.78
TC1	93033018	1.02	0.02	0.22	0.12	3.87	90.58	7.26	0.01	0.01	0.52
TC2	93033018	0.67	0	0.1	0.11	2.71	93.73	5.68	-0.05	0	0.92
TC3	93033018	1.16	0.01	0.11	0.13	4.5	88.74	8.07	0.05	0	0.23
TC4	93033019	2.01	0.05	0.51	0.13	6.92	76.29	13.18	0	0.06	2.16
MRG-1	93033019	17.89	0.16	3.63	14.85	0.19	39.69	8.42	13.11	0.05	0.75
TC5	93033019	0.51	0.01	0.09	0.12	5.95	85.51	10.04	-0.03	-0.01	0.32
TC6	93033019	0.69	0.01	0.08	0.15	6.36	86.2	8.86	-0.08	0	0.39
TC7	93033020	1.07	0.01	0.37	0.14	4.03	83.57	9.7	-0.07	0.03	2.42
TC8	93033020	1.91	0.03	0.06	0.12	2.05	91.56	6.18	0.03	0	-0.01
TC9	93033020	0.71	0.02	0.15	0.12	3.08	93.95	5.24	-0.07	0	0.02
DRN	93033021	9.45	0.21	1.12	6.86	1.67	51.83	16.97	4.16	0.19	2.89
TC10	93033021	0.67	0.01	0.08	0.1	5.3	86.46	9.38	-0.07	-0.01	0.54
TC11	93033021	1.83	0.04	0.19	0.1	3.49	86.12	8.21	-0.09	0.01	1.49
TC12	93033021	1.15	0	0.13	0.12	4.83	85.52	9.62	-0.03	0	0
TC13	93033022	1.25	0	0.08	0.11	1.94	94.14	3.53	0.04	0	-0.16
TC14	93033022	1.36	0.02	0.08	0.11	5.1	87.68	8.17	-0.05	0.04	0.16

Table 2: Whole rock analyses of major elements

		Cp %	Nb ppm	Zr ppm	Y ppm	Sr ppm	Rb ppm	Pb ppm	Cu ppm	Ni ppm	Co ppm	Mn ppm	Ti %	V ppm	Cr ppm
GSP-1	93032919	5.6	21.5	488.1	33.6	224.2	241.6	57.5	29.4	7.4	4.5	261.8	6	55	10.5
TC1	93032921	7.1	8.4	183.2	26.4	20.3	130.2	0	-2.2	-0.1	3.1	197	2.3	-1.3	252.5
TC2	93032922	7.4	10.1	151.5	26.3	9.6	119.4	2.3	2.8	-0.5	1.4	20.7	1.1	-4.9	286.5
TC3	93032923	6.9	6.9	54.6	19.3	41.1	246.7	5.8	3.6	-2.3	2.8	61.5	1.2	5.4	200.8
TC4	93033001	6.3	13.3	344.7	46.9	30	224.8	11.3	3.6	5.8	3.4	455.3	4.8	14.7	160.1
MRG-1	93033002	3.2	21.5	104.9	11.4	267.1	4.9	13.3	130.7	177.6	98.5	1168.4	34.3	501.3	436.4
TC5	93033003	7	10.8	69.6	40	27	372.3	0.7	1.9	4.6	1.5	79.6	1.1	-5.6	234.9
TC6	93033005	6.9	10.9	60.8	32.1	55.5	383.8	10.6	4.9	4.3	2	36.9	1	-7.7	219.2
TC7	93033006	7.1	10	264	19.9	31.8	98.1	1.7	3.3	0.2	2.9	62.6	4.4	6.7	216.3
TC8	93033007	7.3	8.4	113	29.2	12.4	156	13.1	1.7	0.5	2.6	256.3	0.7	26.8	149.3
TC9	93033009	7.5	6	126.1	19.7	24	120.5	-1.5	2.6	-1.2	0.8	117.7	1.9	-2.4	268.6
BHVO-1	93033010	3.9	21.3	184.8	23.8	397.7	11	9.1	150.8	115.8	46.9	1256.7	23.7	306.1	271.9
TC10	93033012	7.1	11.1	57.7	32.3	19.4	267	2	0.5	3.1	1.6	55.3	1	-7.2	170.6
TC11	93033013	6.9	15.2	452	57.5	5.7	157.9	11.2	1.6	12	3.7	319.8	2	-1.3	226.7
TC12	93033014	7	15.1	242.2	51.6	19.3	255.7	20.2	4.4	10.9	2.7	18.2	1.4	4.4	321.8
TC13	93033016	7.5	8.6	115.6	21.8	29.4	106.7	10.7	6.5	2	3.7	70	1	-2.4	434.4
TC14	93033017	6.9	9.1	53.6	34.2	25.5	288.5	6.8	3.1	2.8	1.6	146.3	1	-3	205.3

	Ba ppm	Na %
GSP-1	1262.6	2.888
TC1	158.1	0.824
TC2	44	1.842
TC3	447.4	0.443
TC4	319.5	2.752
MRG-1	-23.3	0.657
TC5	89.2	0.563
TC6	91	0.679
TC7	335.3	3.273
TC8	58	0.129
TC9	140.5	0.297
BHVO-1	102.5	2.415
TC10	104.3	0.879
TC11	75.3	2.339
TC12	66.7	0.17
TC13	129.4	0.147
TC14	93.2	0.294

Table 3: Whole rock analyses of minor elements

compositions. Minor element data was most useful in this study since it was more likely to include elements which were incompatible with rhyolitic systems.

## 4.2 PRECISION AND ACCURACY

### 4.21 Introduction

Precision is the degree of uniformity of repeated measurements of a quantity. This is illustrated by the deviation of a set of measurements from their mean (Bates and Jackson, 1987). Accuracy is the degree of conformity between a measurement and an accepted standard (Bates and Jackson, 1987). Accuracy relates to the quality of a result in contrast to precision which relates to the quality of operation by which the result is obtained.

In this study precision is of particular importance since without excellent precision it is difficult to discriminate between data sets. Precision and accuracy arise from machine precision, sample preparation and sample inhomogeneity, which together comprise the total variance. Sample inhomogeneity reflects chemical variance due to geological uncertainty whereas analytical variance is a result of machine precision and sample preparation (Higman, 1990).

### 4.22 Determination of Analytical Variance

It is of the utmost importance in this study to precisely define the analytical uncertainty of our methods since we may fail to recognize geological difference if our analytical uncertainty is too large and we may infer geological differences where there are none if our analytical uncertainty is too small. Analytical

uncertainty is a reflection of machine precision and sample preparation and algebraically it is represented by:

$$S^2_A = S^2_{MP} + S^2_{SP} \quad (1)$$

where  $S^2_A$ ,  $S^2_{MP}$  and  $S^2_{SP}$  are the analytical, machine precision and sample preparation variances, respectively.

Higman (1990) uses the sample preparation techniques described above and analyses her samples in the same X-ray fluorescence PW1400 spectrometer that was used in this study. It is therefore reasonable to expect that the analytical uncertainty for Higman's samples is comparable to that of the samples in this study.

For each minor element, Higman calculates the analytical uncertainty according to:

$$S^2 = 1/(N-1)\Sigma(X_i - X)^2 \quad (2)$$

where  $S^2$  is the variance;  $N$  is the number of samples;  $X_i$  is the observation; and  $X$  is the overall average. Higman determines the machine variance by empirically evaluating the machine precision of the PW1400 by repeatedly measuring minor element concentrations for one pressed powder pellet. With  $S^2_{MP}$  defined, the uncertainty resulting from sample preparation is estimated by rewriting equation (1) to solve for  $S_{SP}$ :

$$S_{SP} = (S^2_A - S^2_{MP})^{1/2}$$

The analytical error is summarized for several trace minor elements in Table 4.

#### 4.23 Determination of Geological Variance

Geologic variance reflects the geological heterogeneity caused by geologic process which this study hopes to quantify in order to determine comagmatism. But observed variance also contains the effects of sampling. In this study the

ELEMENT	TOTAL ANALYTICAL ERROR		
	X	SA (N=5)	%
Nb	10.28	0.626	6.01
Zr	163.47	5.051	3.09
Y	32.66	1.623	4.97
Sr	25.07	0.629	2.51
Rb	228.2	47.53	20.83
Cu	2.74	0.421	15.39
Ni	3.01	0.196	6.52
Co	2.41	0.157	6.49
Ti	1.78	0.0059	0.33
Cr	239.07	2.797	1.17
Ba	153.71	9.099	5.92

Table 4: Computed sample preparation error from measured total analytical and machine precision errors (Higman, 1990). Minor elements are expressed in ppm. and percentages; X is the mean; SA is the analytical standard deviation; % is the percent total analytical error.

samples available were too variable to use to determine an estimate of sampling variance. As a result once the data in this study is corrected for analytical variance, the remaining observed variance is due to geologic process variances and sampling variances. It will be assumed in this study that sampling variances have a negligible effect on the variance of the data.

## **CHAPTER 5: CONSERVED ELEMENTS RATIO ANALYSIS**

### **5.1 INTRODUCTION**

Claiming that rocks of a suite are comagmatic is a scientific hypothesis. This claim can be disproven by a lack of similarities within the suite but it cannot be proven by the presence of common attributes.

An ideal comagmatic system is closed to at least one component, though it may be open to all other components. It is these components to which the system is closed that provide the common chemical attributes by which we postulate comagmatic rocks (Nicholls and Stout). If a rock suite is from a comagmatic system, then certain elements which are incompatible during early crystallization stages will be conserved. If the system remains closed with respect to some of these conserved elements then these elements can disprove a comagmatic hypothesis or they can be consistent with it.

### **5.2 DETERMINATION OF CONSERVED CONSTITUENTS**

Conserved constituents can be recognized with statistics; however the elements should be chosen based on the principles of petrology (Higman, 1990). Since Ti, Zr, Y and Nb are all elements with a high field strength (charge/radius

ratio) they are not usually transported in aqueous fluids and tend to remain unaffected in rocks which have suffered metasomatic alteration. The Zr/Nb ratio can be particularly informative since it is insensitive to variations in the degree of partial melting (Pearce and Norry, 1979). Zr is considered to be less mobile than either Ti or Y in hydrothermal regimes (Stanley and Madeisky, 1993).

In the Rio Tinto rhyolites Ti, Zr and Y are considered conserved (Stanley and Madeisky, 1993) which is consistent with the general phenocryst assemblage of rhyolites. Also, these trace minor elements are potentially more sensitive indicators of petrologic process than elements of larger relative concentrations but the interpretation of them is hindered by (i) the uncertain behavior of many trace elements in different chemical systems; and (ii) the large relative analytical uncertainties associated with their measurement (Higman, 1990).

### 5.3 GRAPHICAL TESTING OF THE COGENETIC HYPOTHESIS

#### 5.31 Introduction

The cogenetic hypothesis is actually a two-part logical statement: If the rocks are cogenetic *and* two constituents are conserved *then* the ratios of the two constituents will be equal (Stanley and Madeisky, 1993). Thus, if given that the constituent ratios are unequal then either the rocks are not cogenetic or the two elements are not conserved. But given that the constituent ratios are equal, the data is consistent with the cogenetic hypothesis and hence we fail to reject the cogenetic hypothesis.

We may graphically test whether constituent ratios are equal by using Pearce element ratio conserved constituent diagrams or conserved constituent scatterplots.



### 5.32 Pearce Element Ratio Conserved Constituent Diagrams

Pearce element ratios are defined as ratios with a denominator element which is conserved during physical-chemical processes (Russell and Stanley, 1990). Pearce element ratio conserved constituent diagrams are a type of Pearce element ratio diagram which plots two molar ratios with a common denominator where all three constituents are thought to be conserved (Stanley and Madeisky, 1993).

These diagrams examine the ratios themselves and if the ratios are equal for both constituent pairs then the data will plot on a single point within analytical error. Such a result would require that all three elements are conserved elements and that the rocks are cogenetic. In such a case we would fail to reject the cogenetic hypothesis. In the case that the rocks are cogenetic but only two of the three elements are conserved then the data plots as a line. A horizontal or vertical line indicates that one of the numerator elements is not conserved. If the denominator element is not conserved, the data forms a straight line passing through the origin. The latter case is a type of the conserved constituent scatterplot which is discussed below.

The advantages of using Pearce element ratio conserved constituent diagrams to test for comagmatism are twofold: (i) two ratios may be examined simultaneously, providing more powerful evaluation; and (ii) suites of rocks exhibiting different ratios may be identified and discriminated. There are also disadvantages associated with using Pearce element ratio diagrams. Firstly, the amount of the error increases with the magnitude of the ratio. This causes the significance of the scatter of data points to vary across the diagram. Secondly, element concentrations cannot be examined or used to discriminate between

different cogenetic rock suites with this diagram as they can with conserved constituent scatterplots.

### 5.33 Conserved Constituent Scatterplots

In contrast to Pearce element ratio conserved constituent diagrams which plot three conserved elements, conserved constituent scatterplots plot two conserved constituents against each other (Stanley and Madeisky, 1993). Since the conserved elements are plotted as percents or as parts per million (ppm.) it is equivalent to plotting them as a ratio with a nonconserved element in the denominator. This reflects the fact that a percent or ppm value is essentially equivalent to dividing the given element by the remaining elements present in the rock which all together add to 100%. Cogenetic rocks will define a straight line with a zero intercept and a slope equal to the initial ratio of the two conserved constituents (Russell and Stanley, 1990). If all the data plot on a straight line within analytical error then we fail to reflect the cogenetic hypothesis.

The advantages associated with the use of conserved constituent scatterplots are numerous. Firstly, the error is constant across the diagram as long as the measurement error is constant. Secondly, rock suites with different conserved constituent ratios can be identified and differentiated on the same diagram. Thirdly, differences in constituent concentrations can be identified and used to discriminate between different cogenetic suites of rocks. Lastly, variation along lines passing through the origin reveal information about system size variation and material transfer within the system. The only major disadvantage associated with these diagrams is that one can only examine and evaluate one conserved constituent ratio at a time.

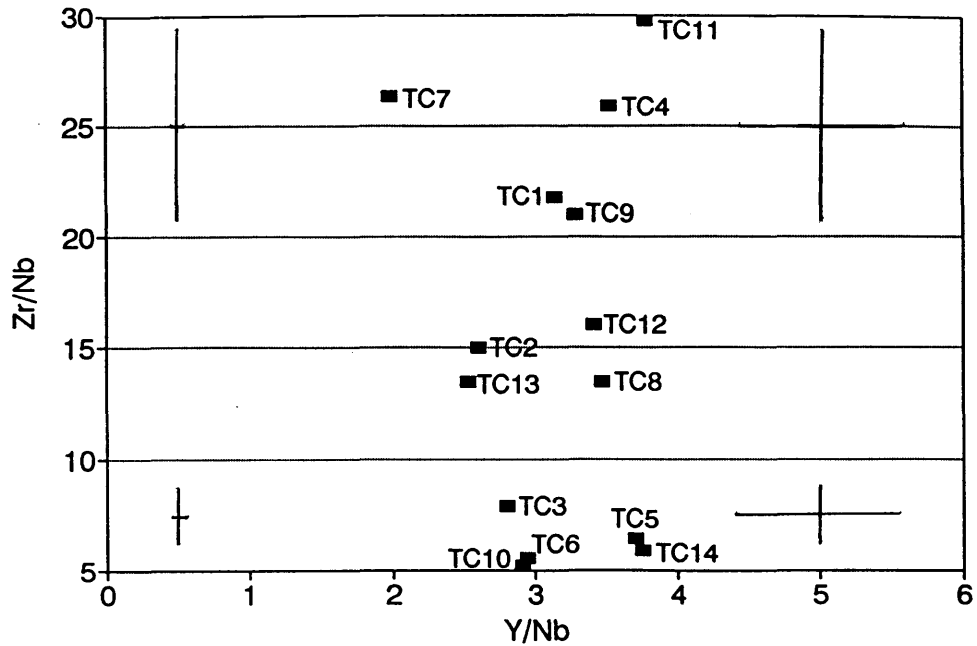


Figure 4: Pearce Element Ratio Conserved Constituent Diagram of Y/Nb and Zr/Nb. Bars show analytical error range. Clustering of samples within 2 Std. Dev. analytical error indicates consistency with the cogenetic hypothesis of those samples. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

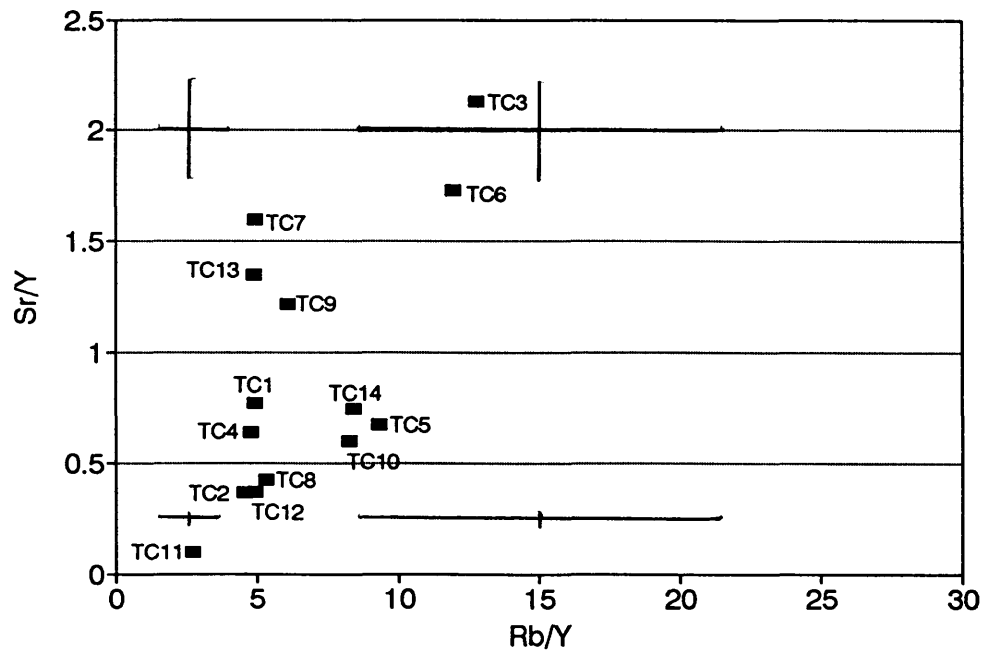


Figure 5: Pearce Element Ratio Conserved Constituent Diagram of Rb/Y and Sr/Y. Bars show analytical error range. Clustering of samples within 2 Std. Dev. analytical error indicates consistency with the cogenetic hypothesis of those samples. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

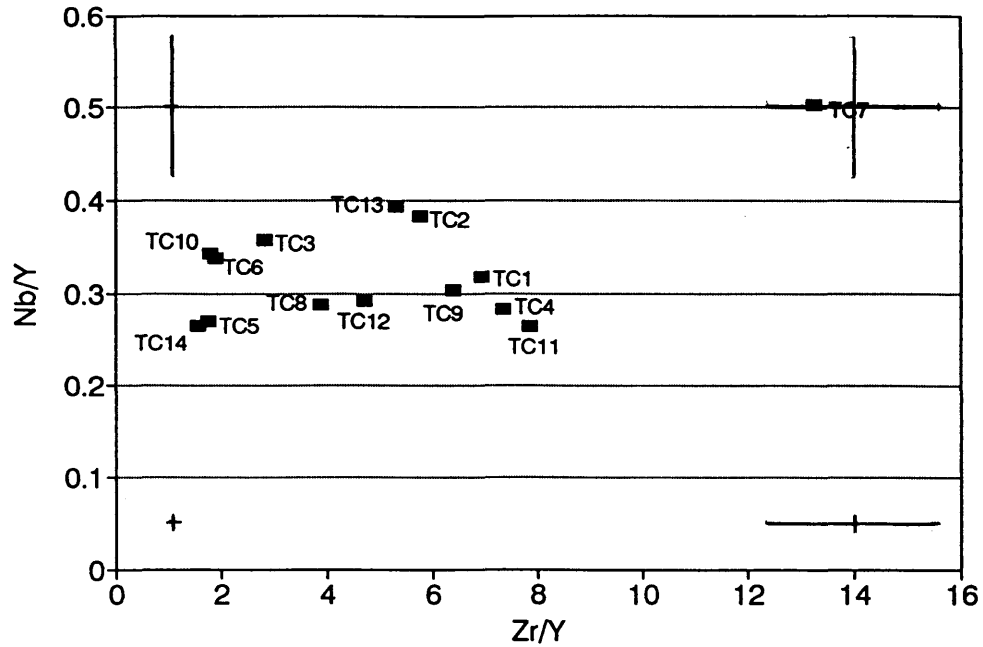


Figure 2: Pearce Element Ratio Conserved Constituent Diagram of Zr/Y and Nb/Y. Bars show analytical error range. Clustering of samples within 2 Std. Dev. analytical error indicates consistency with the cogenetic hypothesis of those samples. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

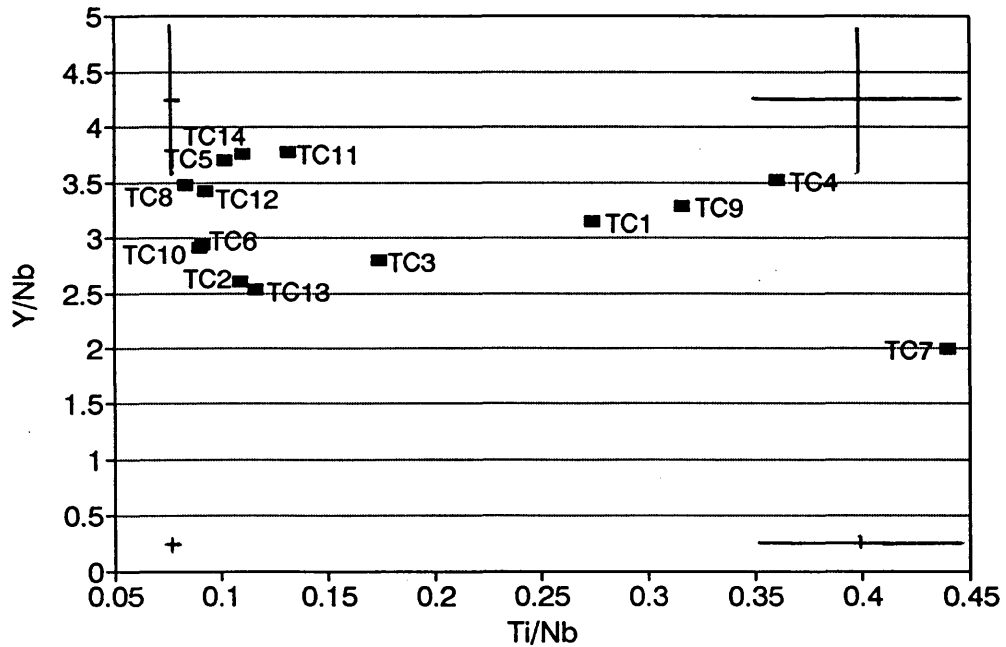


Figure 3: Pearce Element Ratio Conserved Constituent Diagram of Ti/Nb and Y/Nb. Bars show analytical error range. Clustering of samples within 2 Std. Dev. analytical error indicates consistency with the cogenetic hypothesis of those samples. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

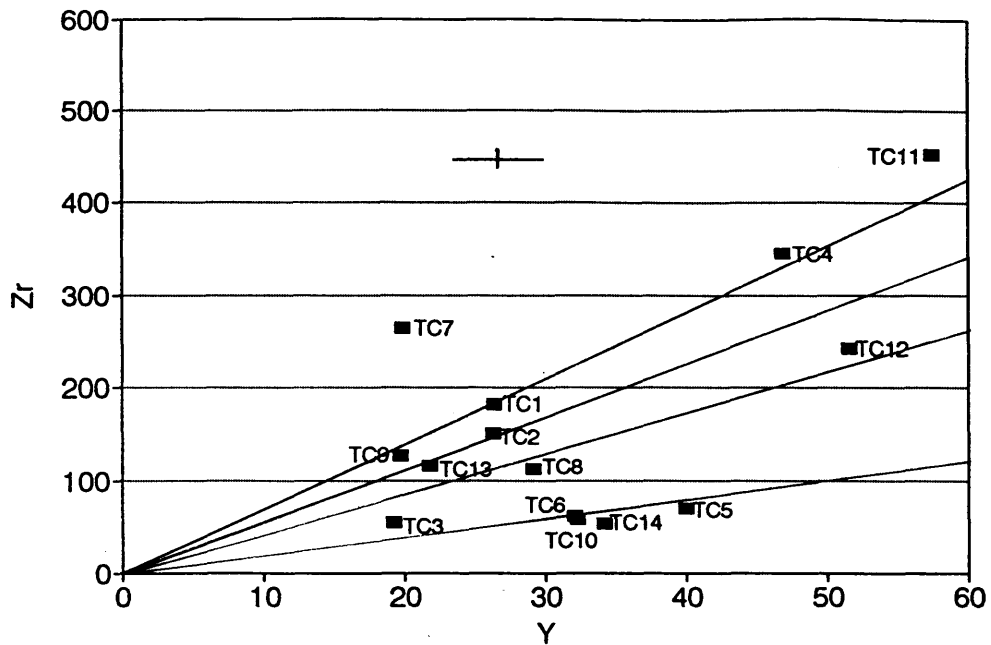


Figure 6: Conserved Constituent Scatterplot of Y and Zr. Bars show analytical error range. Samples are consistent with the cogenetic hypothesis if they follow a linear trend through the origin, within analytical error. Y and Zr values are in ppm. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

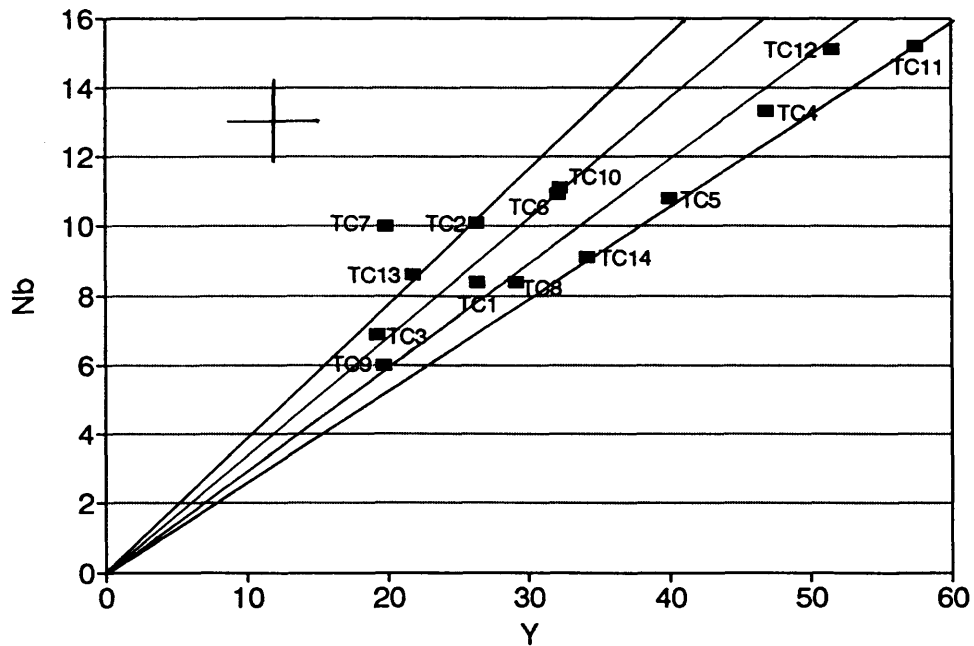


Figure 7: Conserved Constituent Scatterplot of Y and Nb. Bars show analytical error range. Samples are consistent with the cogenetic hypothesis if they follow a linear trend through the origin, within analytical error. Y and Nb values are in ppm. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

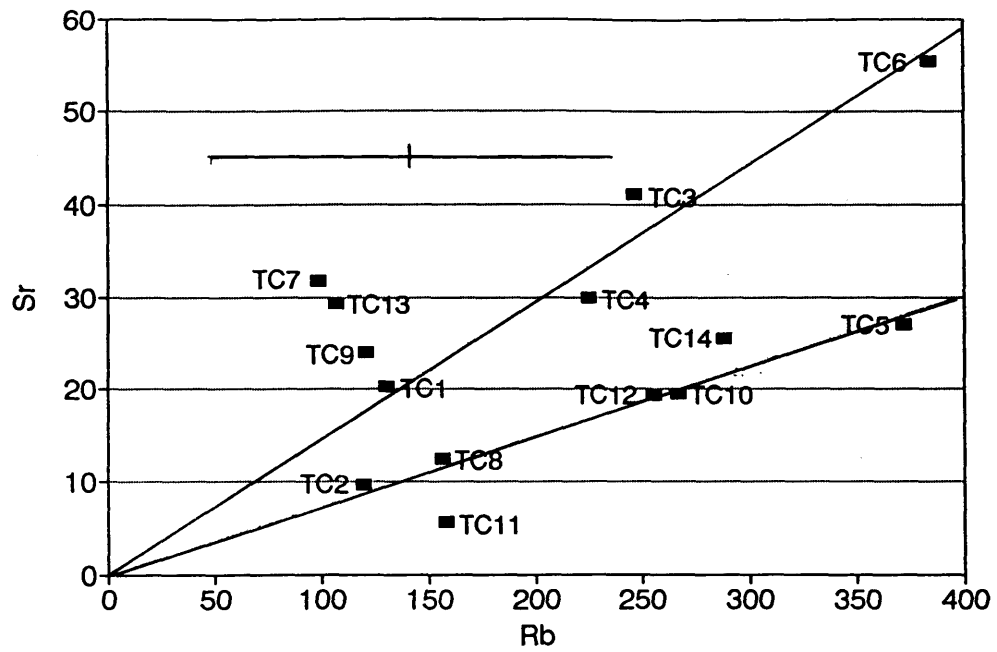


Figure 8: Conserved Constituent Scatterplot of Rb and Sr. Bars show analytical error range. Samples are consistent with the cogenetic hypothesis if they follow a linear trend through the origin, within analytical error. Rb and Sr values are in ppm. Samples TC1 through TC14 are of rhyolites from the Wolf prospect, central B.C.

Conserved Element Plot	Cogenetic Samples within Analytical Error
Zr/Y and Nb/Y	TC1, TC4, TC9, TC11 TC5, TC14 TC8, TC12 TC6, TC10, ≈TC3 TC2, TC13 TC7
Ti/Nb and Y/Nb	TC1, TC4, TC9 TC5, TC8, TC12, TC14, ≈TC11 TC6, TC10 TC2, TC13, ≈TC3 TC7
Y/Nb and Zr/Nb	TC1, TC4, TC9, TC11 TC5, TC14 TC2, TC8, TC12, TC13 TC3, TC6, TC10 TC7
Rb/Y and Sr/Y	TC1, TC4 TC5, TC10, TC14 TC2, TC8, TC12 TC3, TC6 TC6, TC7 TC7, TC9, TC13 TC11
Y and Zr	TC1, TC4, TC9 TC2, TC13 TC8, TC12, TC13 TC3, TC5, TC6, TC10, TC14 TC11 TC7
Y and Nb	TC2, TC3, TC13 TC1, TC3, TC6, TC10 TC1, TC4, TC9, TC8, TC12 TC5, TC11, TC14 TC7
Rb and Sr	TC1, TC3, TC4, TC6, TC9 TC2, TC5, TC8, TC10, TC12 TC7 TC9 TC11 TC13

Table 5: Samples which are consistent with the cogenetic hypothesis, within analytical error, on each conserved element plot.

INITIAL MAGMA BATCH	SAMPLE
A	TC1, TC4, TC9
B	TC5, TC14
C	TC8, TC12
D	TC6, TC10, ≈TC3
E	TC2, TC13
F	TC11
G	TC7

EVIDENCE:

As summarized in Table 5, the genetic hypotheses for magma batches A through G are supported by the correlations illustrated by the conserved element plots Zr/Y and Nb/Y, Ti/Nb and Y/Nb, Y/Nb and Zr/Nb, Y and Zr, Y and Nb (Figs. 2,3,4,6,7). The conserved element plots of Rb/Y and Sr/Y, Rb and Sr (Figs. 5,8) are rejected in this consideration of magma batches since these plots do not show sample correlations which are consistently seen in the other plots, namely those of magma batches A, D and E. The author interprets this rejection of the cogenetic hypotheses in these cases as a result of Rb and/or Sr not being conserved at least in magma batches A, D and E. It is indeed feasible that Rb and Sr may not be conserved in a rhyolitic system.

Table 6: Magma batches which are consistent with the cogenetic hypothesis and differentiated on the basis of Conserved Element Diagrams.



### 5.34 Analytical, Geological and Total Variance on the Conserved Element Diagrams

As discussed in Chapter 4, the total variance in element concentrations is a result of analytical and geological variance. The recognition of distinct chemical suites depends upon whether the total variance observed exceeds the analytical variance calculated. This difference represents the geological variance which in turn contains the effect of geologic process.

### 5.35 Identification of Initial Magma Batches

By plotting the error due to analytical variance at  $\pm$  two standard deviations on the conserved element diagrams, a visual estimate of the geological variance can immediately be made (Figs. 2-8). Table 5 lists each conserved element plot, and groups the samples which are consistent with the cogenetic hypothesis within analytical error. In order for the cogenetic hypothesis to be satisfied, the samples in question must plot in a cogenetic spatial relationship to each other in every conserved element plot. If they do not, the cogenetic hypothesis is rejected either because the rocks are not cogenetic or because the constituents are not conserved. Table 6 summarizes the conclusions drawn from the conserved element diagrams.

## **CHAPTER 6: CONCLUSIONS**

The analysis of the Wolf rhyolites using Pearce element ratio conserved constituent diagrams and conserved constituent scatterplots consistently grouped certain samples. These sample were chemically indistinguishable on the basis of conserved elements, within the calculated analytical error. As summarized in

Table 6, magma batches A, B, C, D, E, F, and G were chemically distinguished as originating from different initial magma batches.

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Ident	Date/Time	FE2O3	MNO	TIO2	CAO	K2O
		%	%	%	%	%
JB2	9303301801	14.42	0.21	1.23	9.81	0.41
TC1	9303301817	1.02	0.02	0.22	0.12	3.87
TC2	9303301834	0.67	0	0.1	0.11	2.71
TC3	930330185C	1.16	0.01	0.11	0.13	4.5
TC4	930330190E	2.01	0.05	0.51	0.13	6.92
MRG-1	930330192E	17.89	0.16	3.63	14.85	0.19
TC5	930330193E	0.51	0.01	0.09	0.12	5.95
TC6	930330195E	0.69	0.01	0.08	0.15	6.36
TC7	9303302012	1.07	0.01	0.37	0.14	4.03
TC8	930330202E	1.91	0.03	0.06	0.12	2.05
TC9	930330204E	0.71	0.02	0.15	0.12	3.08
DRN	9303302102	9.45	0.21	1.12	6.86	1.67
TC10	930330211E	0.67	0.01	0.08	0.1	5.3
TC11	930330213E	1.83	0.04	0.19	0.1	3.49
TC12	9303302151	1.15	0	0.13	0.12	4.83
TC13	930330220E	1.25	0	0.08	0.11	1.94
TC14	9303302224	1.36	0.02	0.08	0.11	5.1

SiO2 %	Al2O3 %	MgO %	P2O5 %	Na2O %
53.98	14.72	4.57	0.07	1.78
90.58	7.26	0.01	0.01	0.52
93.73	5.68	-0.05	0	0.92
88.74	8.07	0.05	0	0.23
76.29	13.18	0	0.06	2.16
39.69	8.42	13.11	0.05	0.75
85.51	10.04	-0.03	-0.01	0.32
86.2	8.86	-0.08	0	0.39
83.57	9.7	-0.07	0.03	2.42
91.56	6.18	0.03	0	-0.01
93.95	5.24	-0.07	0	0.02
51.83	16.97	4.16	0.19	2.89
86.46	9.38	-0.07	-0.01	0.54
86.12	8.21	-0.09	0.01	1.49
85.52	9.62	-0.03	0	0
94.14	3.53	0.04	0	-0.16
87.68	8.17	-0.05	0.04	0.16

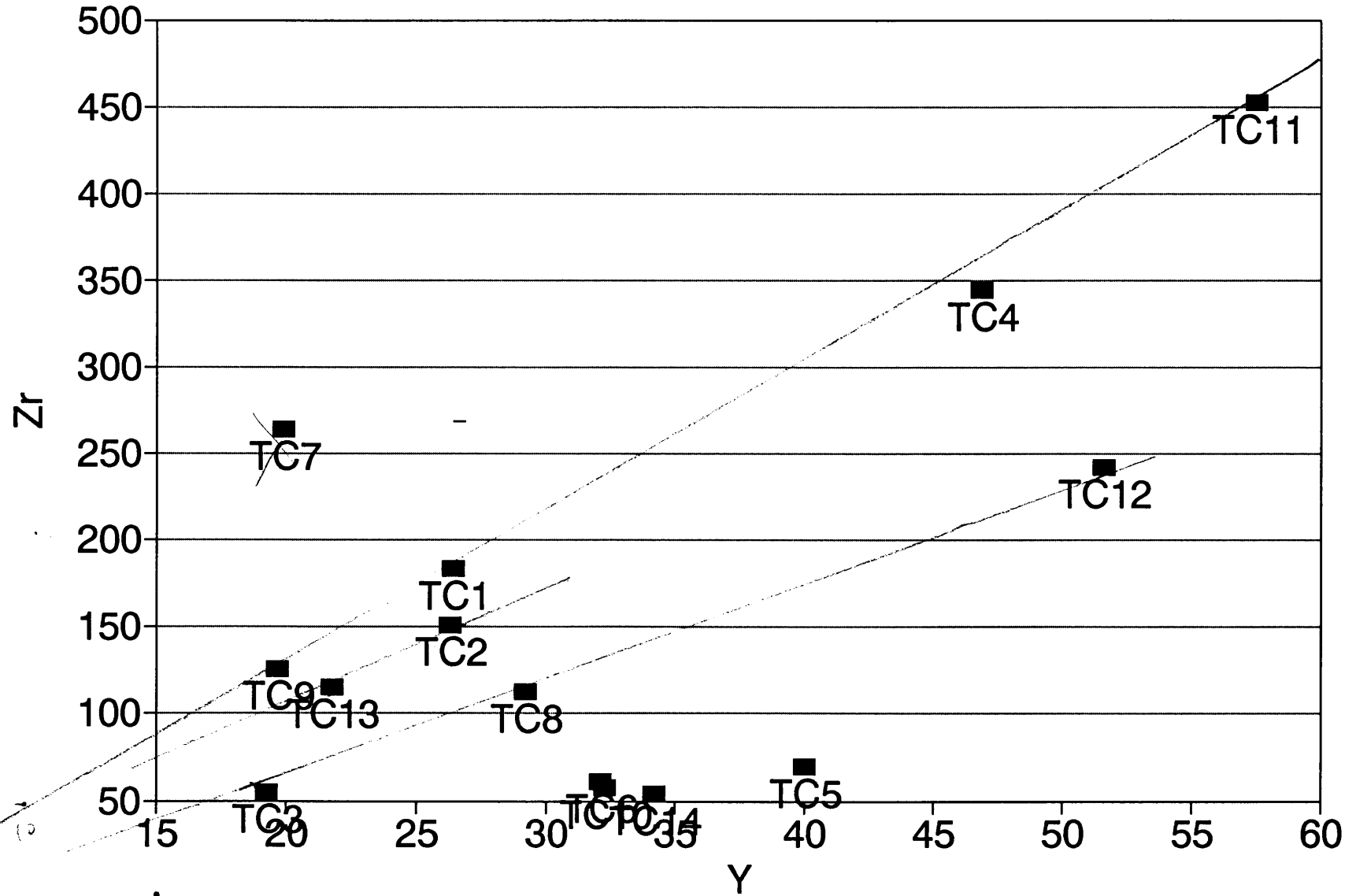
Ident	Date/Time	Cp %	Nb ppm	Zr ppm	Y ppm	Sr ppm
GSP-1	9303291942	5.6	21.5	488.1	33.6	224.2
TC1	9303292104	7.1	8.4	183.2	26.4	20.3
TC2	9303292226	7.4	10.1	151.5	26.3	9.6
TC3	9303292348	6.9	6.9	54.6	19.3	41.1
TC4	930330011C	6.3	13.3	344.7	46.9	30
MRG-1	9303300232	3.2	21.5	104.9	11.4	267.1
TC5	9303300354	7	10.8	69.6	40	27
TC6	930330051E	6.9	10.9	60.8	32.1	55.5
TC7	9303300637	7.1	10	264	19.9	31.8
TC8	930330075E	7.3	8.4	113	29.2	12.4
TC9	9303300921	7.5	6	126.1	19.7	24
BHVO-1	930330104E	3.9	21.3	184.8	23.8	397.7
TC10	930330120E	7.1	11.1	57.7	32.3	19.4
TC11	9303301327	6.9	15.2	452	57.5	5.7
TC12	930330144E	7	15.1	242.2	51.6	19.3
TC13	9303301611	7.5	8.6	115.6	21.8	29.4
TC14	930330173E	6.9	9.1	53.6	34.2	25.5

Ti %	V ppm	Cr ppm	Ba ppm	Na %
6	55	10.5	1262.6	2.888
2.3	-1.3	252.5	158.1	0.824
1.1	-4.9	286.5	44	1.842
1.2	5.4	200.8	447.4	0.443
4.8	14.7	160.1	319.5	2.752
34.3	501.3	436.4	-23.3	0.657
1.1	-5.6	234.9	89.2	0.563
1	-7.7	219.2	91	0.679
4.4	6.7	216.3	335.3	3.273
0.7	26.8	149.3	58	0.129
1.9	-2.4	268.6	140.5	0.297
23.7	306.1	271.9	102.5	2.415
1	-7.2	170.6	104.3	0.879
2	-1.3	226.7	75.3	2.339
1.4	4.4	321.8	66.7	0.17
1	-2.4	434.4	129.4	0.147
1	-3	205.3	93.2	0.294

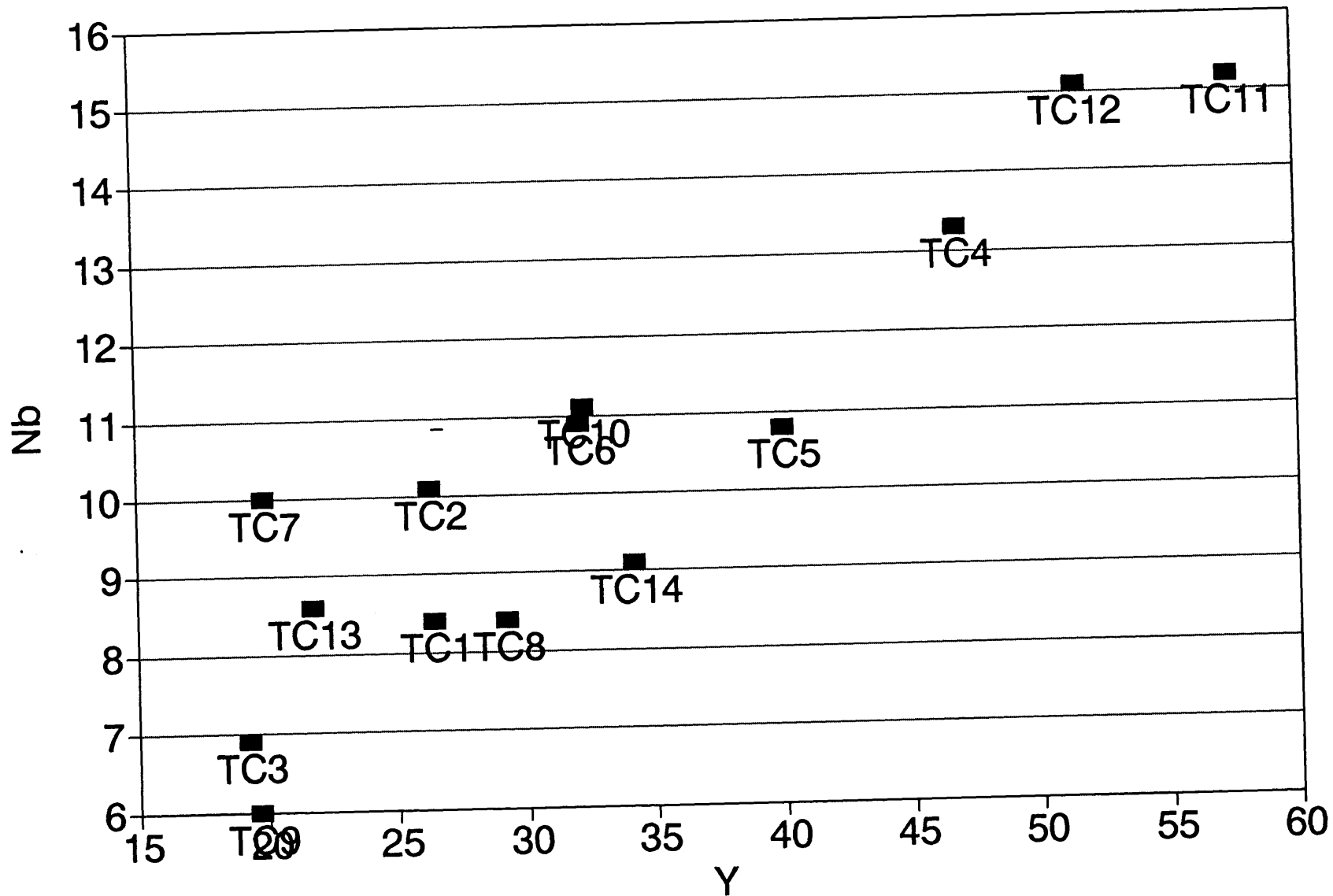
Rb ppm	Pb ppm	Zn ppm	Cu ppm	Ni ppm	Co ppm	Mn ppm
241.6	57.5	92.3	29.4	7.4	4.5	261.8
130.2	0	28.6	-2.2	-0.1	3.1	197
119.4	2.3	14.4	2.8	-0.5	1.4	20.7
246.7	5.8	29.5	3.6	-2.3	2.8	61.5
224.8	11.3	74.7	3.6	5.8	3.4	455.3
4.9	13.3	196.1	130.7	177.6	98.5	1168.4
372.3	0.7	16.1	1.9	4.6	1.5	79.6
383.8	10.6	15.3	4.9	4.3	2	36.9
98.1	1.7	23.5	3.3	0.2	2.9	62.6
156	13.1	51.4	1.7	0.5	2.6	256.3
120.5	-1.5	36.7	2.6	-1.2	0.8	117.7
11	9.1	112.7	150.8	115.8	46.9	1256.7
267	2	17.9	0.5	3.1	1.6	55.3
157.9	11.2	76.6	1.6	12	3.7	319.8
255.7	20.2	50.9	4.4	10.9	2.7	18.2
106.7	10.7	18.1	6.5	2	3.7	70
288.5	6.8	21.8	3.1	2.8	1.6	146.3

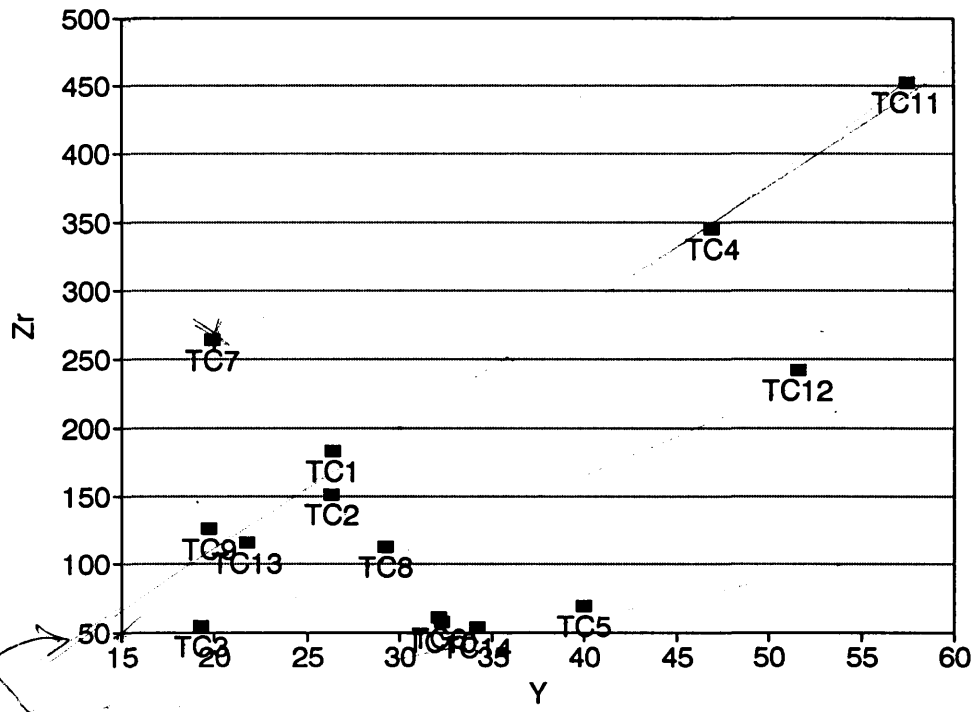


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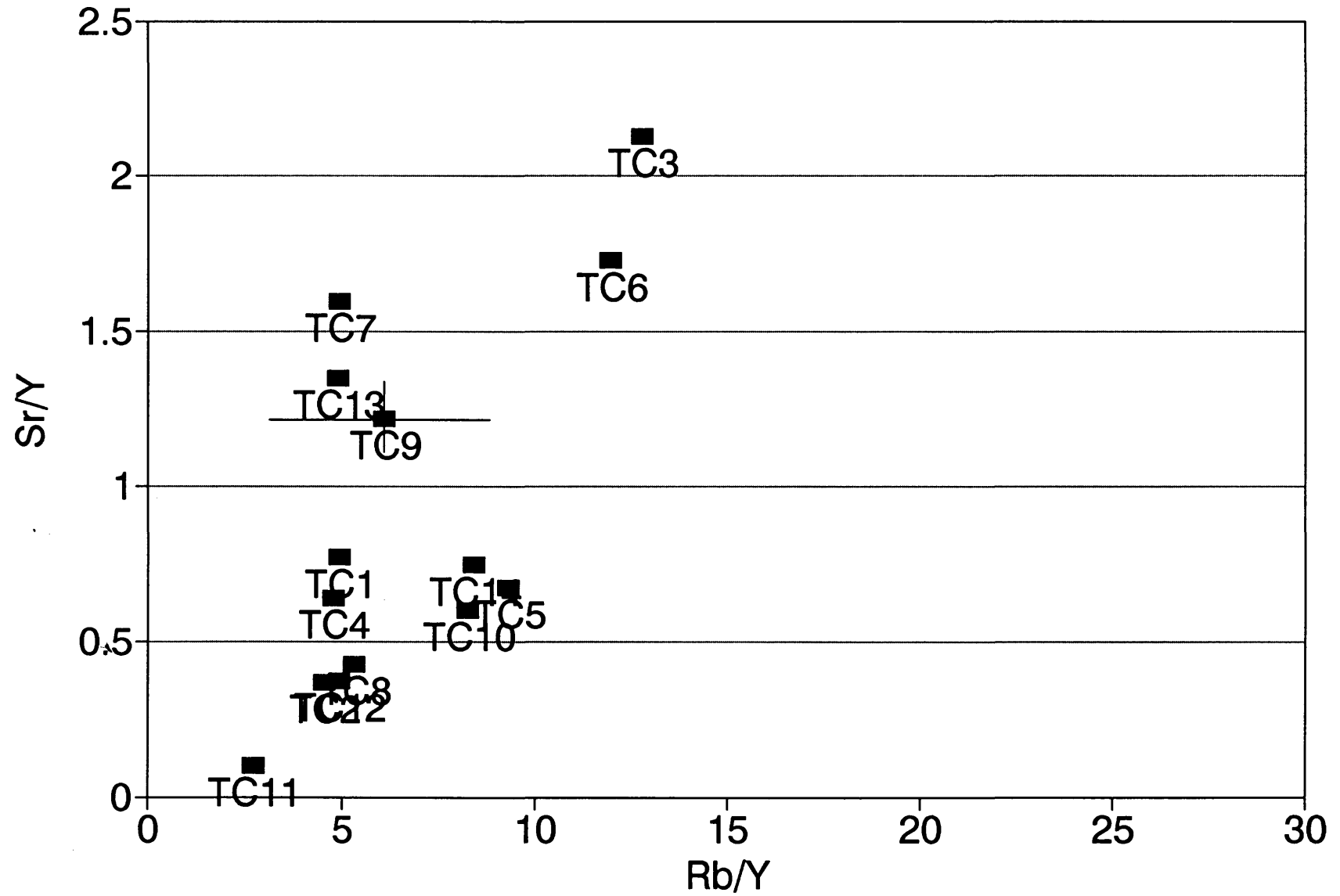


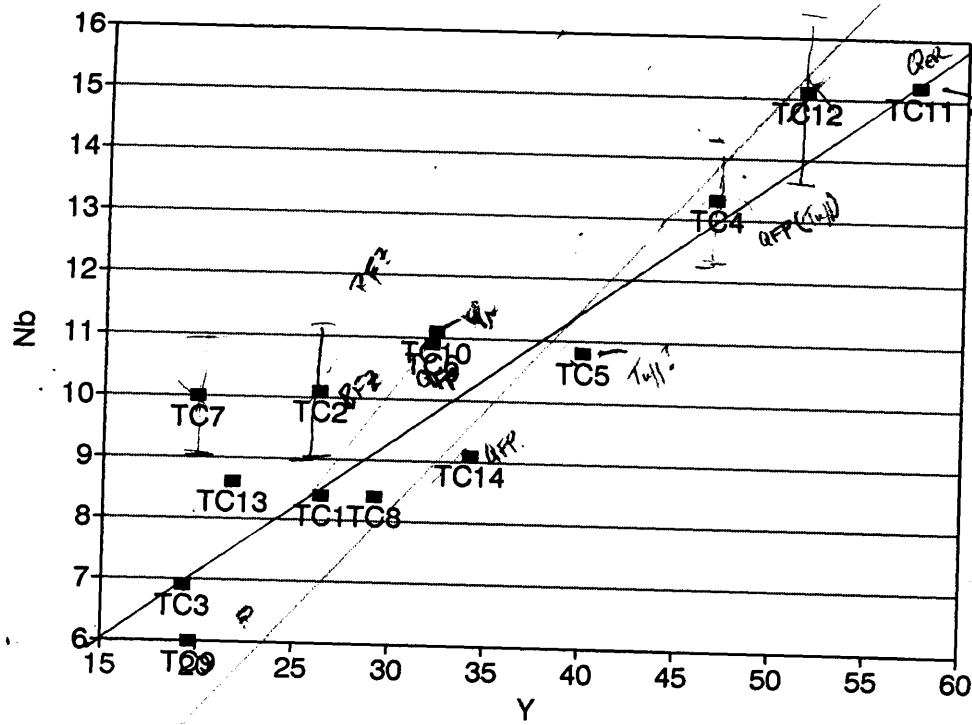
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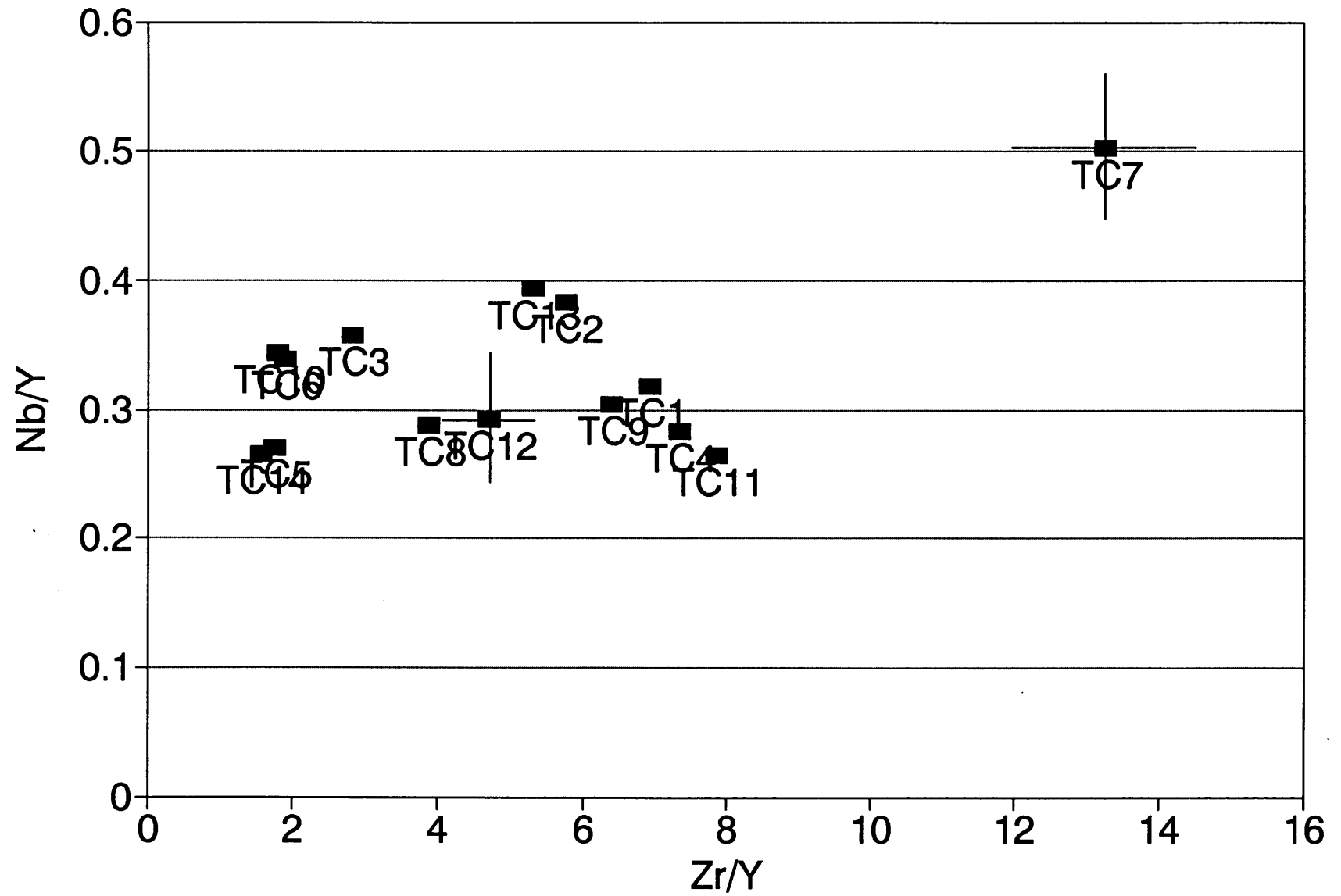


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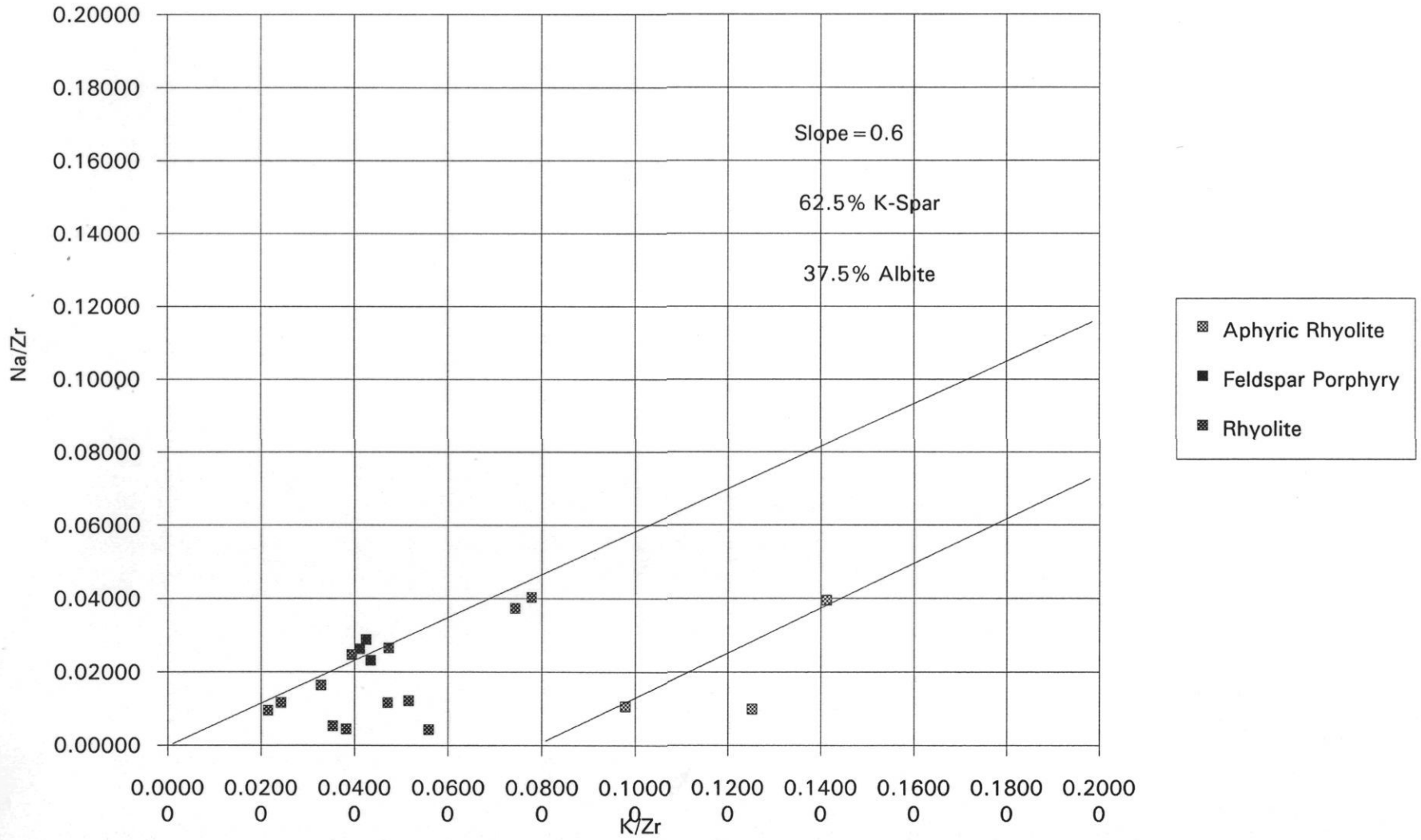
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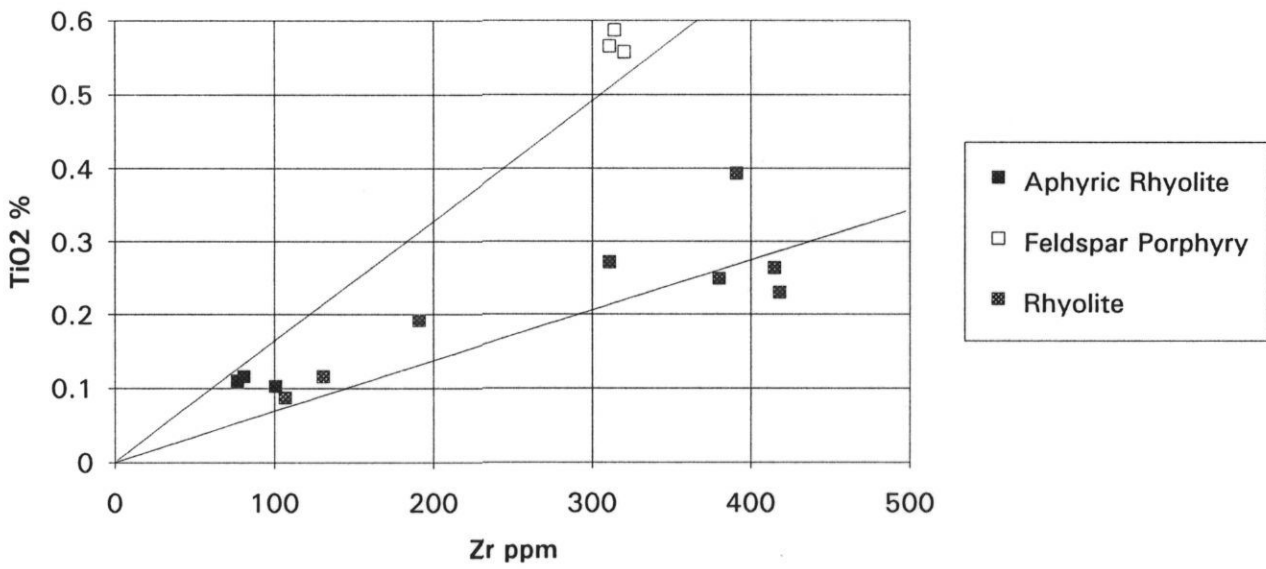


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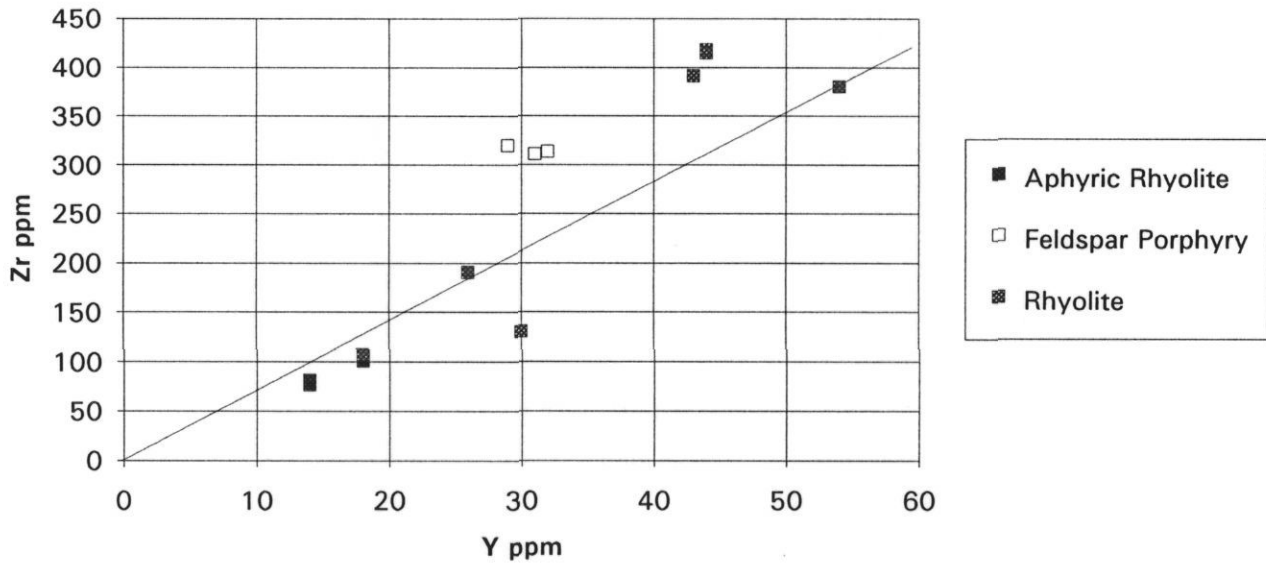


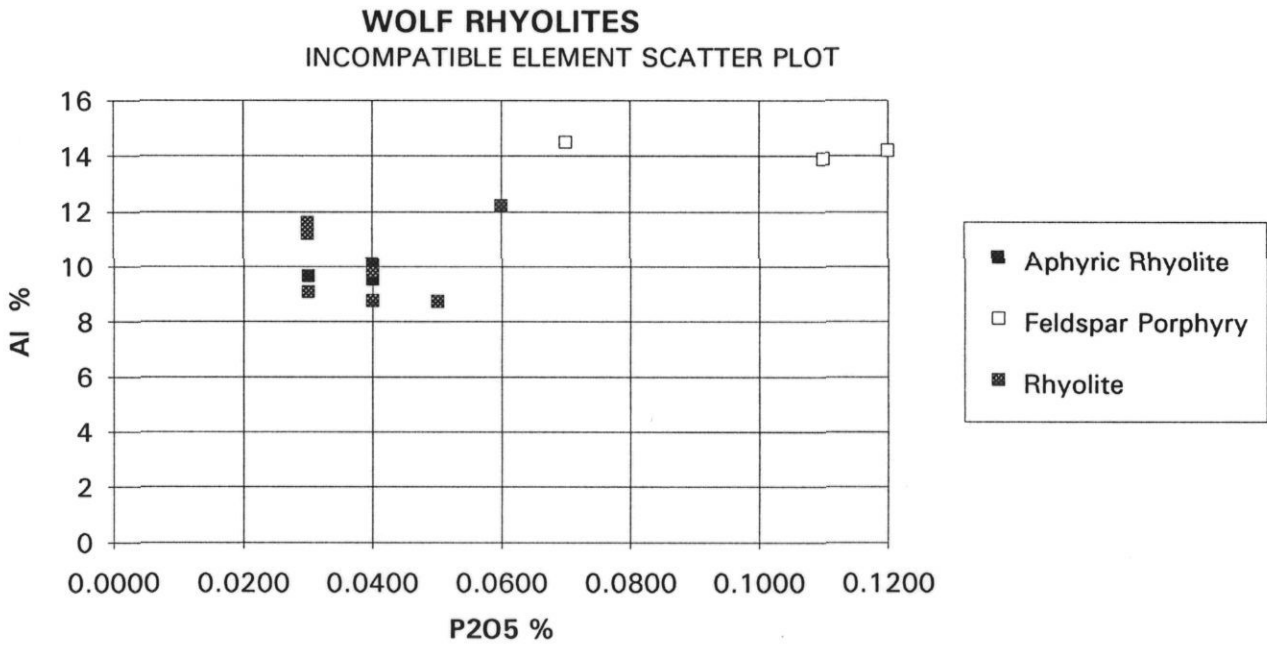
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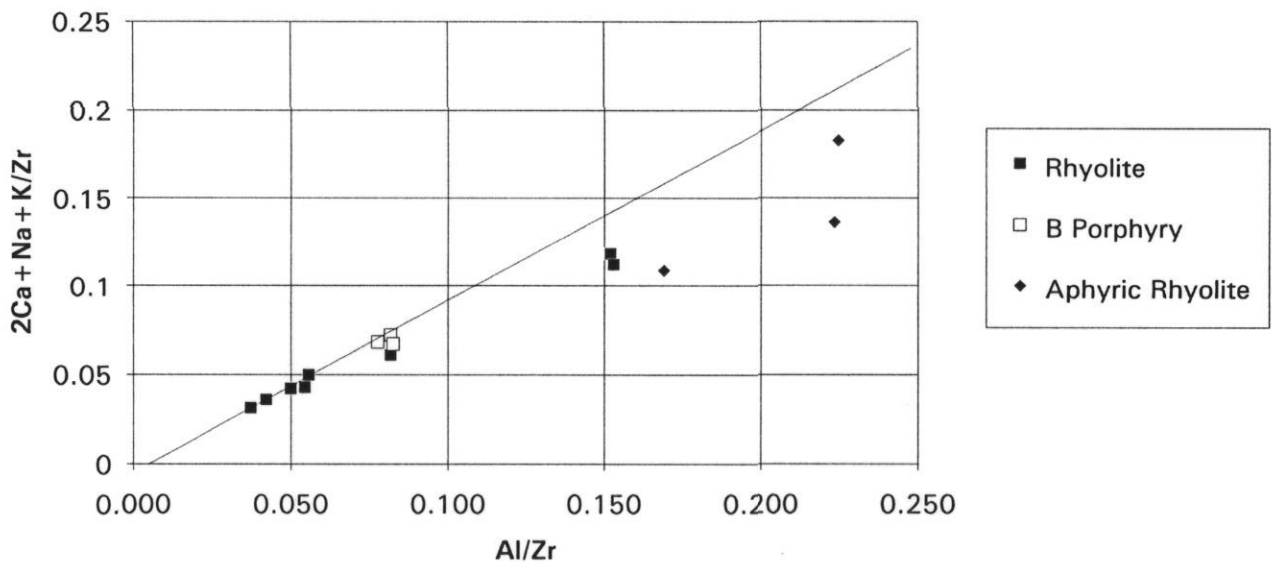


**WOLF RHYOLITES**  
INCOMPATIBLE ELEMENT SCATTER PLOT

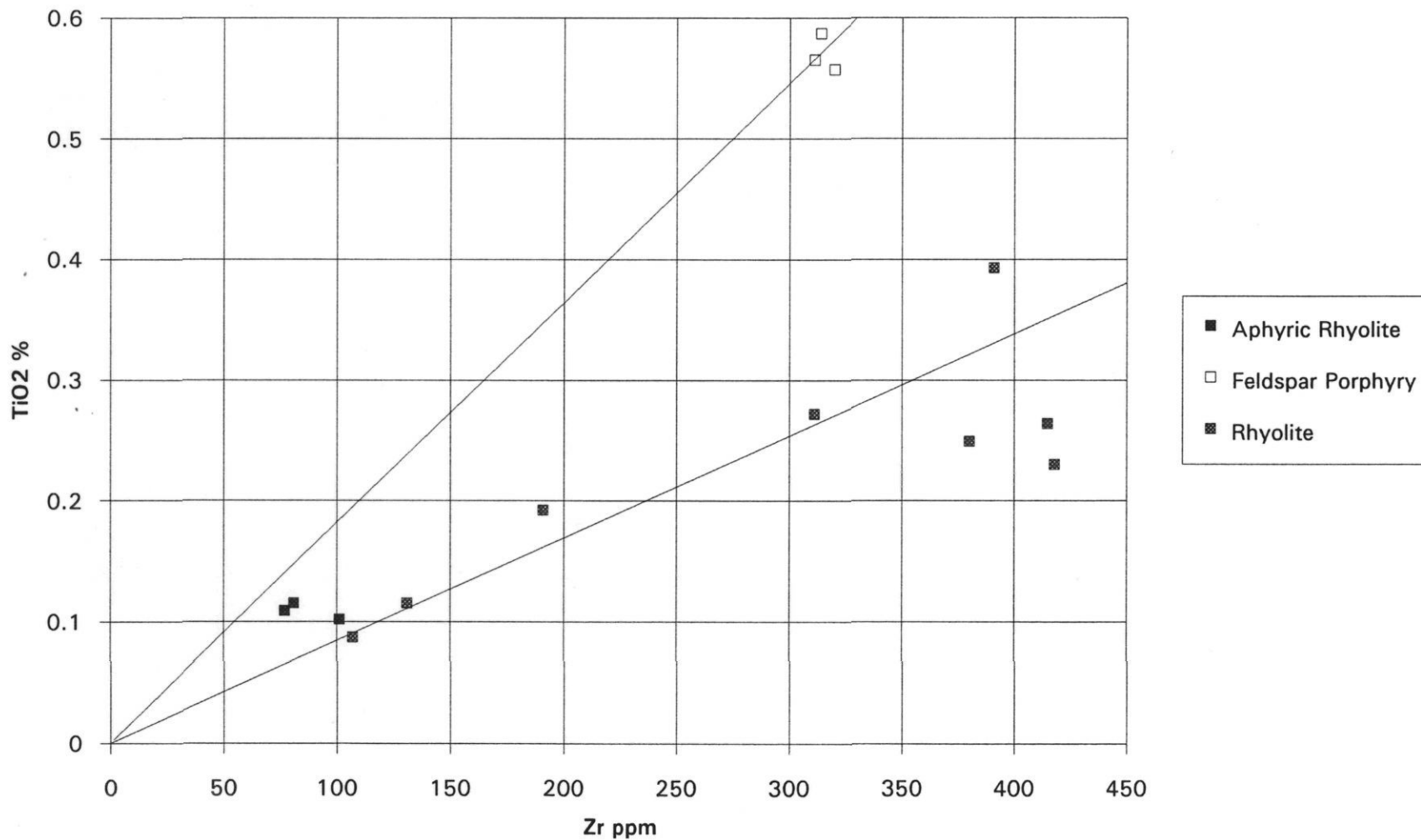




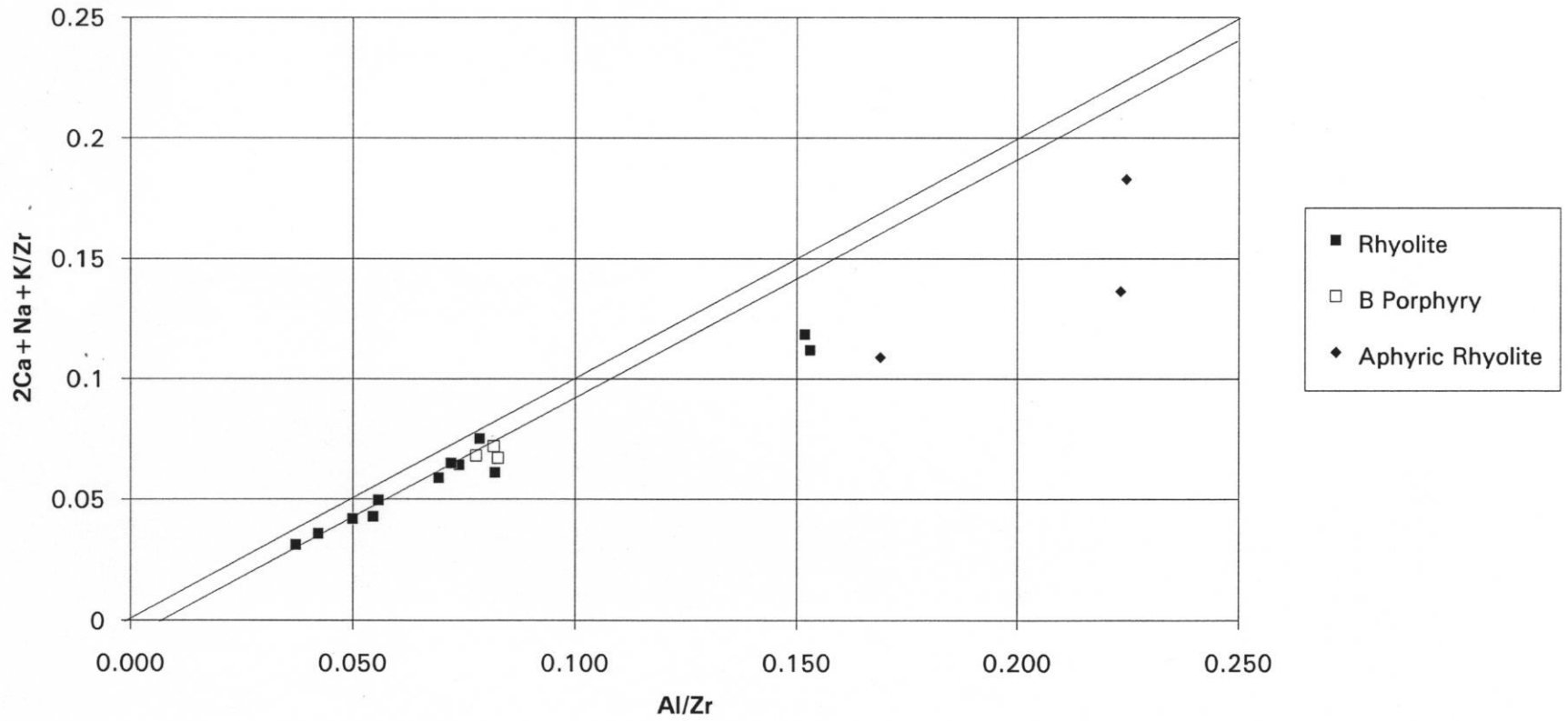
**WOLF PROPERTY**  
**Feldspar Fractionation Model**



### WOLF RHYOLITES INCOMPATIBLE ELEMENT SCATTER PLOT



**WOLF PROPERTY**  
**Feldspar Fractionation Model**



**WOLF PROPERTY**  
ALKALI FELDSPAR DISCRIMINATION DIAGRAM

