5894

STATISTICAL ANALYSIS OF GEOPHYSICAL DATA, ASHNOLA PORPHYRY PROSPECT

Osoyoos Mining Division

(Lat. 49° 07' N; Long. 120° 20' W)

for

PRISM RESOURCES LIMITED

by

Dr. A. J. Sinclair, P. Eng.

June 17, 1976

INDEX

TABLES

FIGURES

INTRODUCTION

The writer had participated in a detailed geochemical study of the Ashnola porphyry copper depost (Montgomery, Cochrane and Sinclair, 1975) in which he was responsible primarily for data analysis. Evaluation methods used involved probability plots, partitioning of constituent populations by graphical means, optimal choice of thresholds, and preparation of contoured maps using thresholds as contours. These maps were done to the same scale as a geological base map so that the two could be super-imposed to provide a sound basis for utilizing geological information in the interpretation of geochemical patterns. Details of the procedure are given by Sinclair (1974).

This geochemical study was particularly successful and led to a fairly refined morphological model being developed for the Ashnola porphyry system. Some generalizations regarding the model were known from earlier work but they have more recently been supplemented with hitherto undocumented microscope studies and a more thorough evaluation of hydrothermal effects (Sinclair, 1975). As a result of these early positive results of data analysis, and as part of a continuing study of the Ashnola porphyry system by Prism Resources Limited, the writer was requested by Mr. A. L. J. MacDonald, P. Eng.,

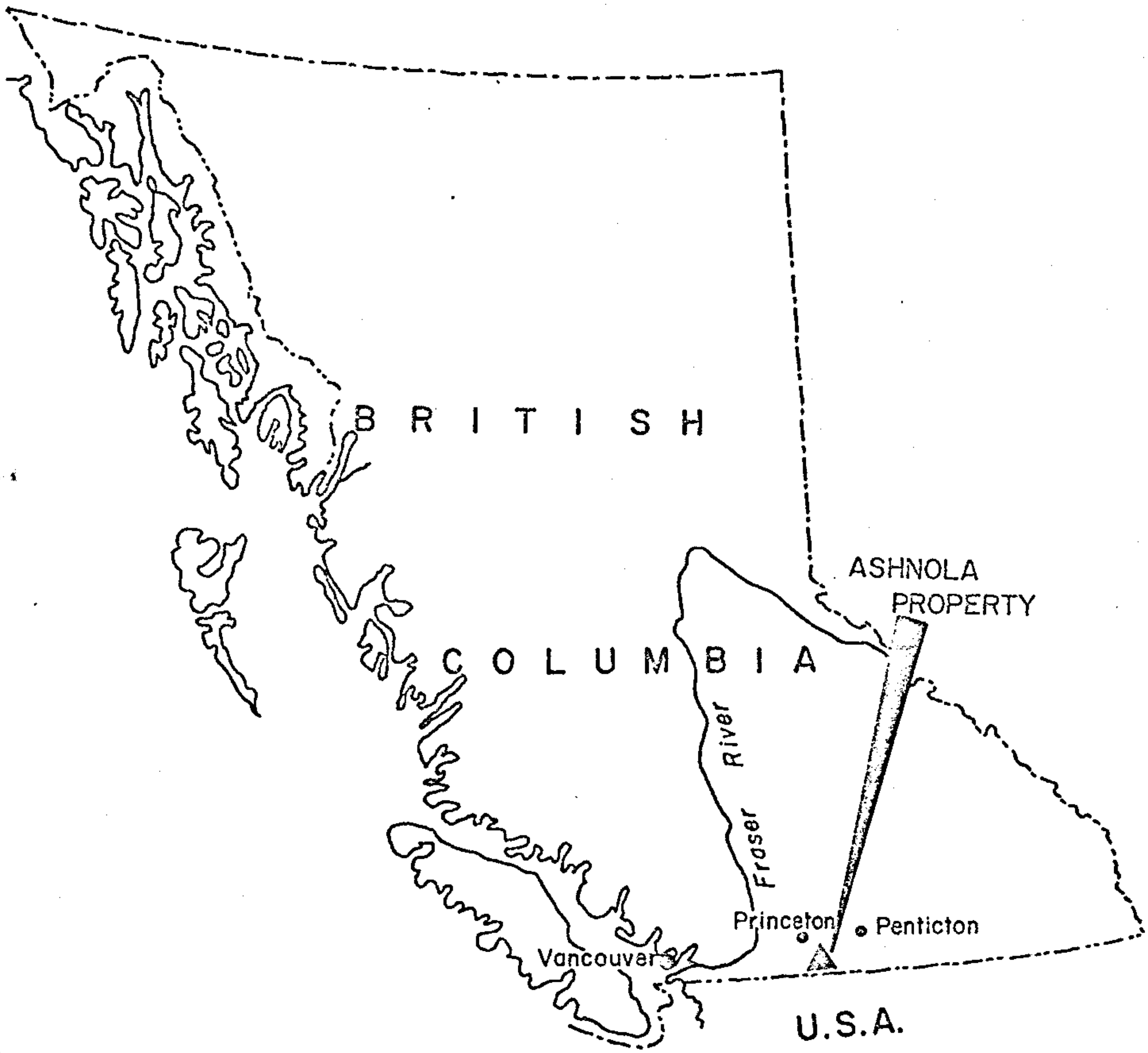


Figure 1: Location of Ashnola Property

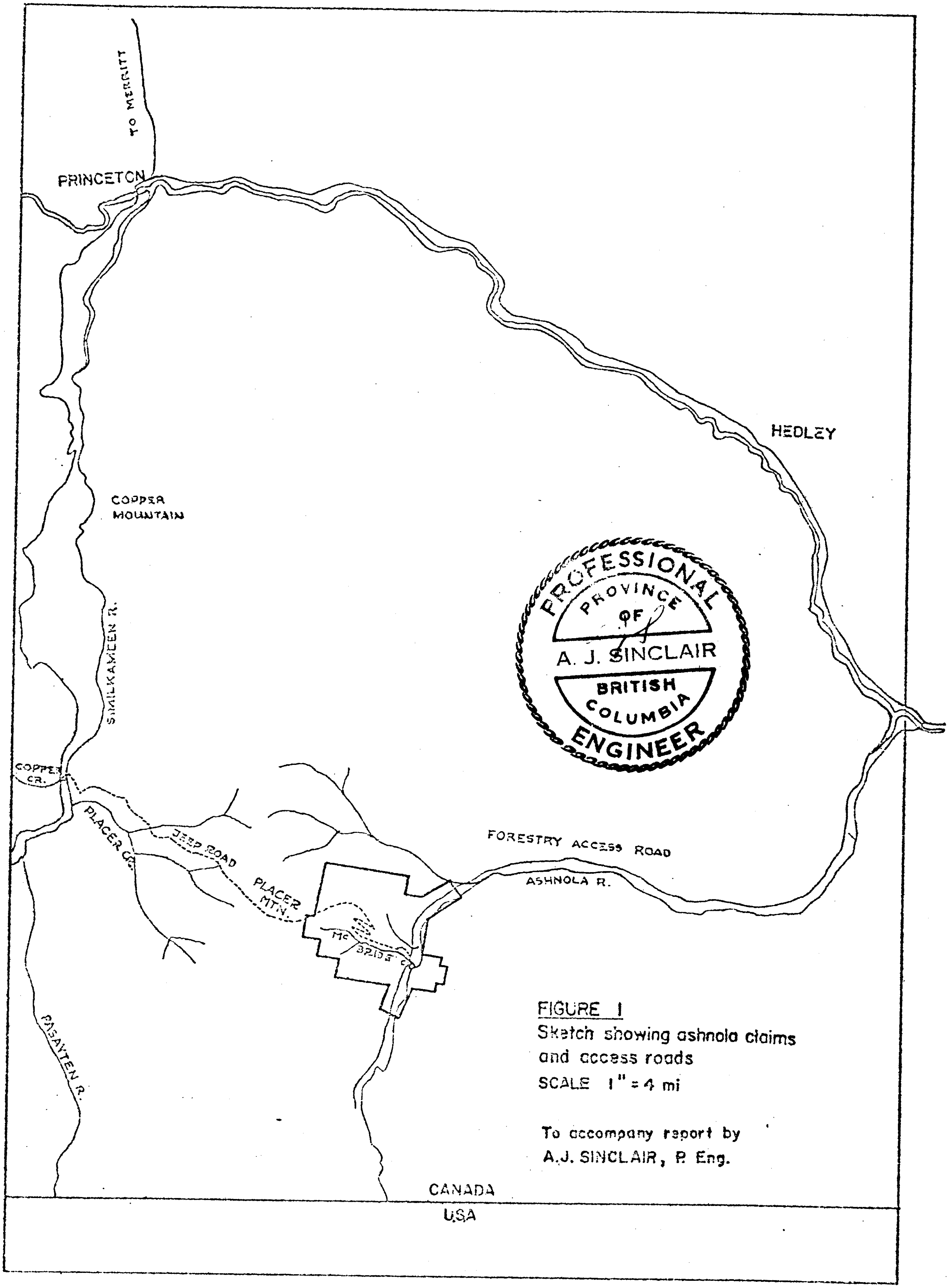


FIGURE 1
Sketch showing ashnola claims and access roads
SCALE 1" = 4 mi

To accompany report by
A.J. SINCLAIR, P. Eng.

President of Prism Resources Limited, to conduct a comparable study of available geophysical data. Earlier preliminary studies had suggested to the writer that such studies might be fruitful in further defining aspects of the porphyry system that might be useful in future exploration work or, at least, to add a further test of the model already presented (cf. Sinclair 1975.)

Geophysical work done to date over the entire property has been conducted by Cochrane Consultants and results have been described in a report submitted for assessment purposes (Cochrane, Giroux and Scott, 1970). Both ground magnetometer and induced polarization surveys were carried out. The I.P. survey included chargeability, apparent resistivity and self potential data.

ANALYSIS OF DATA

The initial step in data analysis was to examine the density distributions of each variable to determine whether normal and/or log-normal models or combinations of such models were appropriate to describe the observed variations. Histograms are shown in figure 2. It is apparent that these histograms are not well described by traditional and simple density distributions. However, Slichter (1955) indicates that a number of geophysical variables representing a single population show a close approach to lognormality. Where two

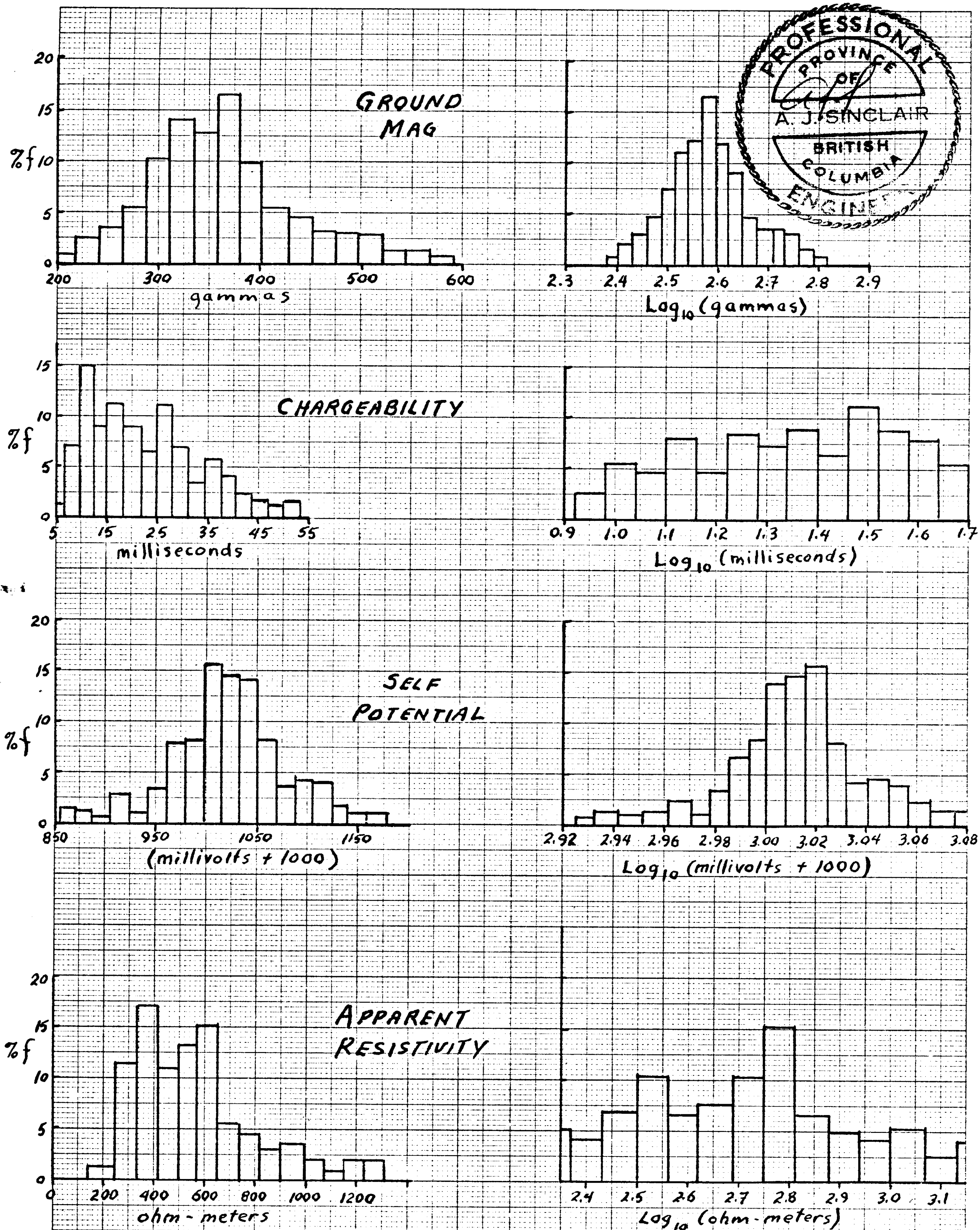


FIGURE 2

461510

TABLE I

Means and Standard Deviations of Arithmetic and Logged Exploration Data

Variable	N	Arithmetic		Logarithmic			units
		$\bar{x}$	s	$\bar{x}$	$\bar{x}$ - s	$\bar{x}$ + s	
CH (Chargeability)	722	23.44	12.46	20.3	11.7	35.2	milliseconds
MAG (gnd magnetometer)	773	369.5	94.1	359	279	461	gammas
RES (Apparent Resistivity)	708	535.2	328.6	452	252	809	ohm-meters

such populations are present in the same data set and the two have no significant overlap a non-intersecting bimodal lognormal model could easily be interpreted (cf. Sinclair, 1976). The interpretation becomes slightly masked if the two populations overlap significantly, but routine methods are now established to deal with this situation (Sinclair, 1976). The problem becomes more obscure as the number of populations increases in which case the sample size should be large and best results are obtained in cases where overlap of populations is least.

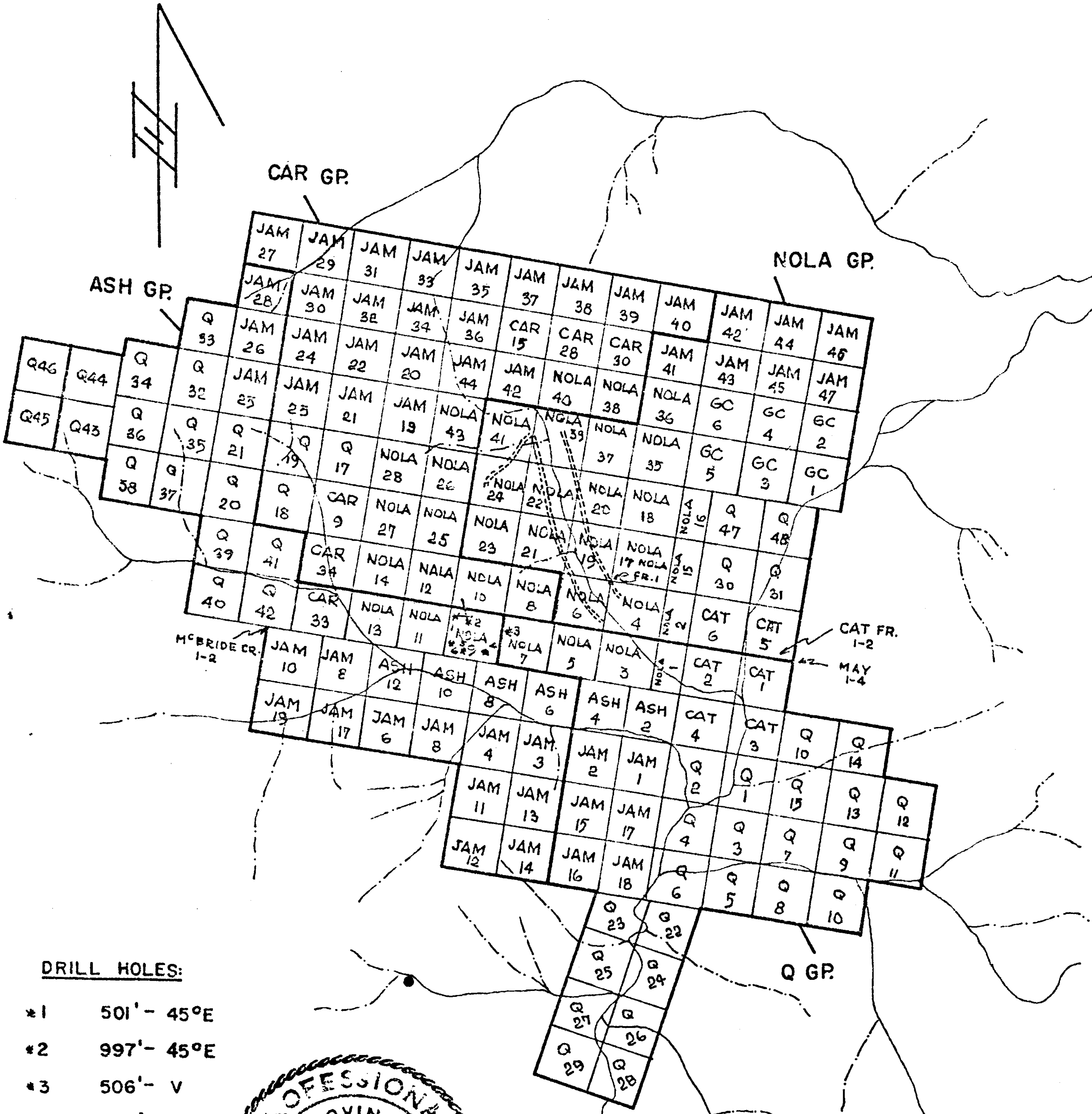
Despite the foregoing problems many geophysical variables measured routinely in mineral exploration can be dealt with successfully as probability plots by following the general procedures outlined for the earlier geochemical study. A word of caution must be entered here however, for some geophysical readings taken during a survey over an area characterized by a bimodal distribution,for example, are the summation of contributions from each population, and give rise to a third population.

Means and standard deviations of geophysical variables are listed in Table I. These data taken in comparison with the histograms show that combinations of populations are present in each of the variables to be evaluated. It seems reasonable to assume that these individual populations are lognormal on the basis of the general nature of many geophysical variables, an assumption which provides for reasonable geological interpretations as will be shown. Furthermore, it is apparent that evaluation of geophysical data using traditional threshold estimation techniques of geochemists ($\overline{X}$+2s) will not provide a useful or fundamental interpretation in this case.

INTER-RELATIONS AMONG VARIABLES

Two general procedures have been used to investigate inter-relations among geophysical variables (and geological and/or geochemical variables). The first approach is a standard rigorous evaluation of linear correlation co-efficients obtained for all pairs of appropriate variables for which adequate data are available. These results are shown in a correlation matrix in Table II. Note that because of their peculiar nature self potential data are not included in this analysis. Apparent resistivity and ground magnotometer data are strongly correlated and both are negatively correlated with chargeability. Furthermore, the only geochemical survey results that correlate with any geophysical variable is Cu in soil B horizon which is correlated with chargeability.

The second approach in comparing variables involves the procedure outlined in the introductory section for the earlier analysis of geochemical data. This method begins



DRILL HOLES:

*1	501' - 45°E	
*2	997' - 45°E	
*3	506' -	V
*4	408' -	V
*5	339' -	V
*6	200' -	V

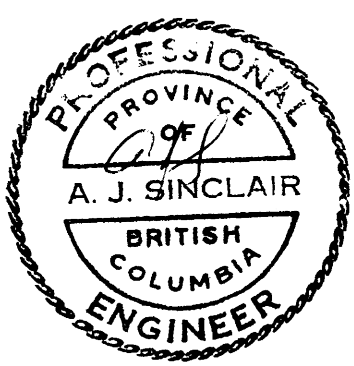


FIGURE 2

0 5000 10,000
feet (1:50,000

To accompany report by
A. J. SINCLAIR, P. Eng.

TABLE II

Correlation coefficients for arithmetic data*

Variable**	CH	MAG	ACU	AZN	BCU	BZN	BMO	RES
CH	1.0							
MAG	*−0.279*	1.0						
ACU	0.105	−0.081	1.0					
AZN	−0.023	−0.039	0.582	1.0				
BCU	*0.183*	−0.138	*0.863*	*0.490*	1.0			
BZN	0.118	−0.142	*0.740*	*0.779*	*0.806*	1.0		
BMO	0.138	−0.170	*0.332*	0.083	*0.374*	0.132	1.0	
RES	*−0.583*	*0.558*	−0.066	0.082	−0.084	−0.018	−0.091	1.0

*Absolute values greater than 0.181 are significant at the 1% level and are italicized.
**CH = chargeability, MAG = ground magnetometer values, RES = apparent resistivity, ACU = A-horizon Cu, AZN = A-horizon Zn, BCU = B-horizon Cu, BZN = B-horizon Zn, BMO = B-horizon Mo.

with an analysis of the probability plot of a variable and ends with a map showing the distribution of various populations, that is used as a basis for interpretation. Each variable will be considered separately.

GROUND MAGNETOMETER

Ground magnetometer values were obtained for the most part at intervals of 400 feet along lines spaced at 800 feet. In a few local cases additional readings were taken between these general grid spacings. A total of 772 readings are summarized in the probability plot of figure 3. The general distribution of points plotted on this graph indicates the presence of more than one population. Three and possibly four populations seem reasonable based on subjective analysis of shape of the plot. The interpretation shown in figure 3 is based on the assumption that three populations are present (I-3%; II-95%; III-2%). In this case population II has been interpreted as a single log-normal population, although it may hide a small amount of a fourth lognormal population in the upper part of its range. If this fourth population exists, most of it lies in the range 417 to 550 gammas, a range that will be referred to as II-a in subsequent discussion.

Two of the three principal populations recognized are easily interpreted. The upper population (I) correlates reasonably well with magnetite-bearing intrusive rocks where these are exposed. Coincidence is not perfect because the spacing of readings is large compared with the narrow thickness of some dykes of magnetite-bearing intrusive rock.

Population II is a general background population for the most part. There is some suggestion, though, that II-a might be a recognizable population in its own right. Two major patterns exist for values in this range. The first is along and to the north of grid line 136N. We do not have abundant geological control in this area but it seems likely that the abnormally high gamma values in the extreme northwest corner of the grid which are flanked to the south and east by values in the II-a range, represent a primary lithologic control. The second form of II-a values is adjacent to population I values and in isolated clusters. This range appears to indicate nearby (i.e. covered) magnetite-bearing intrusive rock, and in the case of isolated clusters probably represents shallow but unexposed intrusive rocks. Such clusters are centred on:

85E, 98N	in pyrite halo
94E, 90N	in pyrite halo
134E, 74N	in pyrite halo
145E, 88N	on inner rim of pyrite halo

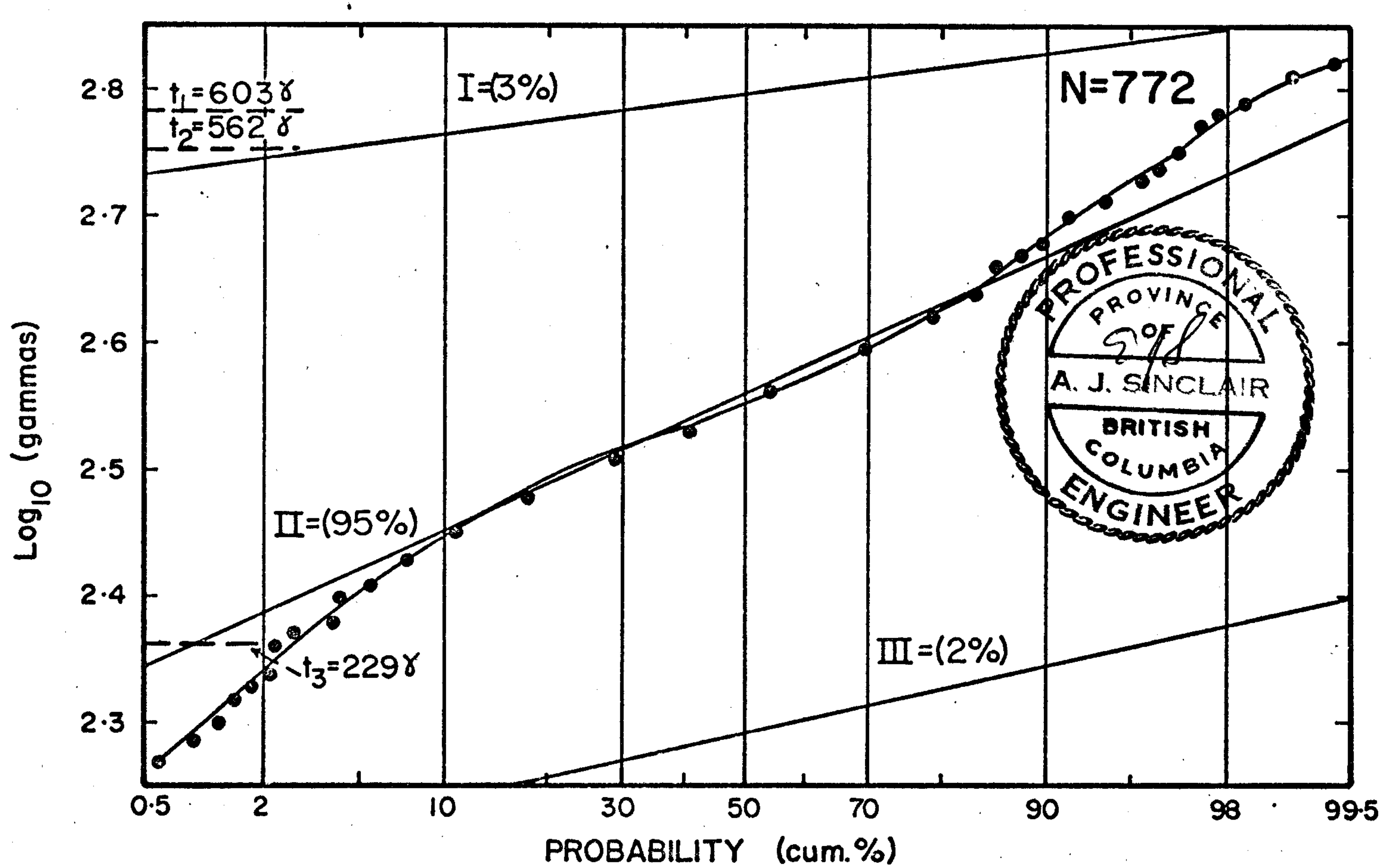


Figure 3: Probability plot of ground magnetometer data (gammas). Values plotted are Log_{10}(gammas). Original data are shown by black dots that are approximated by a smooth curve. Partitioned populations I, II and III are shown without construction points. Thresholds are indicated by t_i values along the left side of the graph.

TABLE III

ESTIMATED PARAMETERS OF PARTITIONED POPULATIONS OF GEOPHYSICAL VARIABLES

VARIABLE	N	POPULATION	b	$b + S_L$	$b - S_L$
Chargeability (milliseconds)	722	I	28	41	19
		II	10	17	6.1
Ground Mag (gammas)	772	I	628	666	593
		II	364	442	300
		III	197	216	179
Apparent Resistivity (ohm-metres)	708	I	1230	1360	1120
		II	780	930	675
		III	410	490	340
		IV	176	284	110
Self Potential (millivolts)	687	I	-157	-137	-175
		II	-5	37	-41
		III	89	108	74
		IV	164	194	135

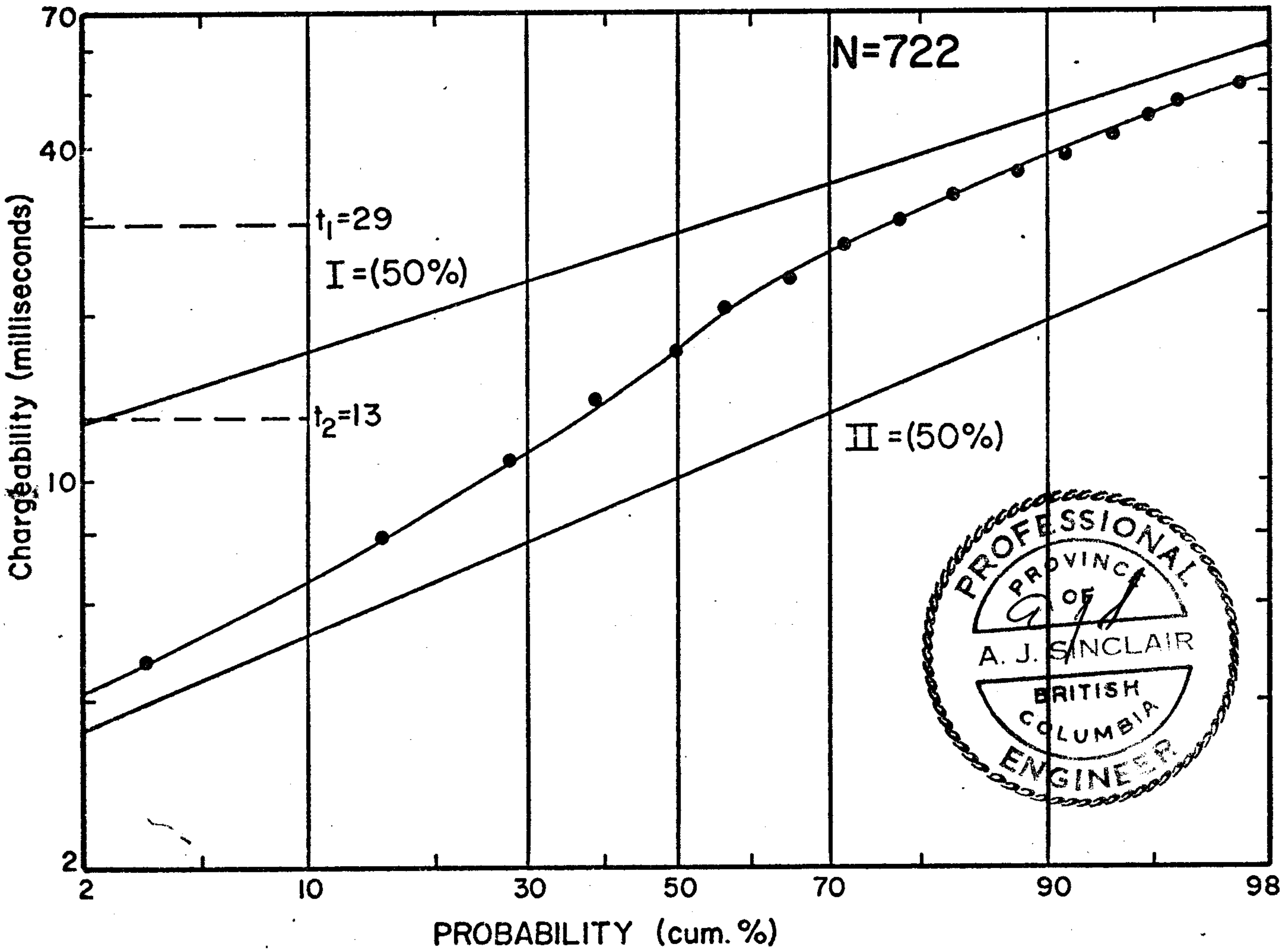


Figure 4: Log probability plot of chargeability data. Original data are shown as b lack dots that are approximated by a smooth curve resembling a bimodal model. Partitioned populations are shown as straight lines I and II. Thresholds are shown as t_i values on the left side of the graph.

TABLE IV

SUMMARY OF THRESHOLDS

Variable	Population	Threshold Valve	Threshold Units
Chargeability	I		
	----------	29	milliseconds
	----------	13	milliseconds
	II		
Ground Mag	I		
	-------	560	gammas
	II		
	-------	229	gammas
	III		
Self Potential	I		
	-----	-98	millivolts
	II		
	-----	64	millivolts
	III		
	-----	114	millivolts
	IV		
Apparent Resistivity	I		
	----	1000	ohm meters
	II		
	----	600	ohm meters
	III		
	----	280	ohm meters
	IV		

Scattered zone of II-a range also occurs in the South-eastern extreme of the grid, but these all lie on the outer finge of, or outside the pyrite halo.

Interpretation of the very low gamma values (population III) is difficult. They appear to be locallized in valleys, and thus, might represent, at least in part, areas of deep overburden. The location of a few of the low values is such that they probably represent an error in recording the 100's digit at some stage between field work and final map preparation.

CHARGEABILITY

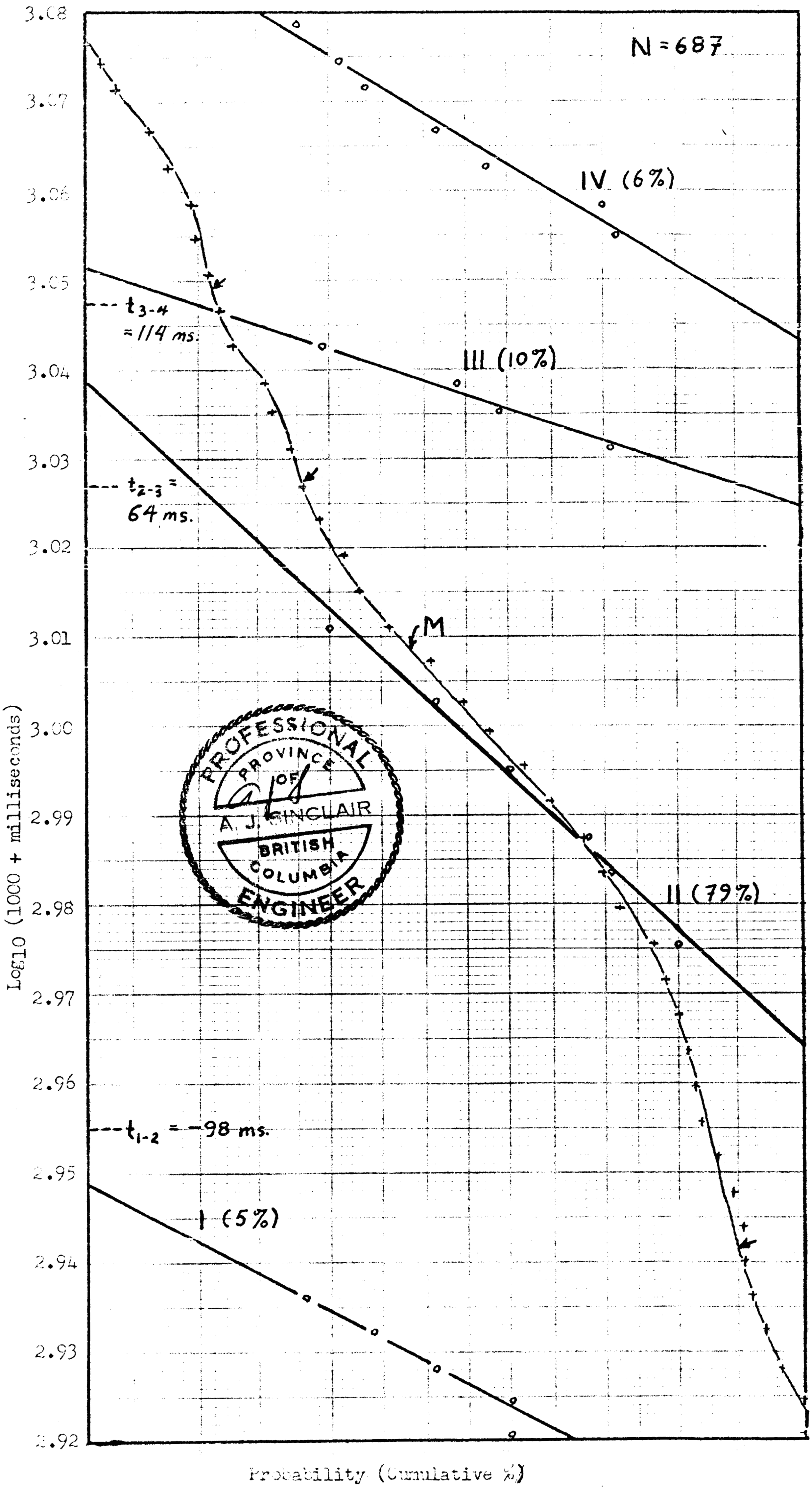
An Hew-100 pulse type induced polarization unit was used with a Werner electrode array and an "a" spacing of 600 feet. Readings were recorded midway between electrodes and thus did not coincide in location with sites for magnetometer and various geochemical data. Thus, a linear interpolation method was used to estimate readings at sites that did coincide with control points for other types of data. This slightly smoothed data base was then used for all statistical analyses including the correlation studies already referred to. A probability plot based on 772 values derived as indicated above is shown in figure 4. The graph is fairly obviously of the non-intersecting bimodal type and can be partitioned easily into populations I and II as indicated. Estimated parameters of these populations are given in Table III.

Thresholds were chosen using the procedure of Sinclair (1974) at 13 and 29 milliseconds respectively. These two values were used as contours to outline three categories of areas. Comparison with the geological map indicates that the high millisecond zone can be interpreted as the axial part of a pyrite-richzone, traditionally referred to as a pyrite halo. The intermediate zone represemts a gradual transition into background areas characterized by population II. The horseshoe-shaped nature of the pyrite zone is shown on figure 7 as the area with readings greater than 29 milli-seconds.

SELF POTENTIAL

Self potential values were determined routinely during the induced polarization survey. A total of 687 valves are summarized in the probability plot of figure 4. This graph has the appearance of a quadramodal lognormal model of non-intersecting populations and has been partitioned accordingly into the four populations indicated in figure 4 as straight lines. Thresholds were chosen using the method recommended by Sinclair (1974) and provide relatively efficient separators of the four assumed populations. Using these thresholds, values were colour-coded on a self potential base map produced originally by Cochrane, Giroux and Scott (1970). An evaluation of the patterns produced led to the following conclusions:

Figure 5: Probability plot of logarithms of values derived by the addition of 1000 to each self potential millivolt value. Purpose of this transform was to avoid negative values for the log transform. Crosses mark original data that has been approximated by a smooth curve that could be interpreted as a mixture of 4 normal populations. Four populations have been partitioned and construction points are shown as small open circles through which "best fit" straight lines have been constructed. Small arrowheads on the combined curve are inflection points used as a basis for partitioning. Thresholds are shown as t_i values on the left side of the graph.



N = 687
IV (6%)
III (10%)
II (79%)
I (5%)
M
t_{3-4} = 114 ms.
t_{2-3} = 64 ms.
t_{1-2} = −98 ms.
3.08
3.07
3.06
3.05
3.04
3.03
3.02
3.01
3.00
2.99
2.98
2.97
2.96
2.95
2.94
2.93
2.92
Log10 (1000 + milliseconds)
Probability (Cumulative %)
PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
A. J. SINCLAIR

1. Population I occurs as sporadic zones centred on the axial zone of chargeability highs (i.e. the pyrite-rich halo) with a couple of minor exceptions that are immediately adjacent to this zone.
2. Population IV is present in essentially the same proportion as population I and the two repreeent extreme polarity (electrical) conditions. Zones of the two populations are commonly adjacent to each other with population IV being either on the inner or outer side of the cylindrical pyrite halo. In brief, the two populations are paired with the very minor exception of two isolated values of population IV.
3. Population II is unquestionably a background population and characterizes virtually all the area outside the pyrite halo and most of the area inside the pyrite halo.
4. The significance of population III is somewhat in doubt. Some values are concentrated between zones characterized by populations I and IV respectively, and in this environment represent expected values on the steep gradient that exists between these two populations. Other values in population III are isolated within area of population II (background). In summary, two main interpretations can be applied to population III--(a) extreme members

of background, and (b) values on the steep gradient between populations I and IV.

There is little question that Self Potential results can be interpreted as indicative of natural electrical cells set up through oxidation of sulphides. These natural electrical systems are concentrated sporadically over known and inferred areas of pyrite concentrations and are indicated by paired zones of populations I and IV. The sporadic occurrence of these paired zones must relate in part to the vaguaries of local ground water systems and depth of overburden. It seems likely that where overburden is deep the "battery" effect would be appreciably less apparent, even masked, at surface, compared with areas of shallow overburden. This interpretation is entirely consistent with other geophysical and geochemical data (e.g. Montgomery et al, 1975) and the model suggested for the Ashnola porphyry system (Sinclair, 1975).

APPARENT RESISTIVITY

Seven hundred and eight apparent resistivity values derived from the Induced Polarization survey are summarized in the probability plot of figure 6. The sinuous smooth curve drawn through original data points appears to indicate that the curve is a mixture of four lognormal populations which have been partitioned accordingly and are shown as straight lines I, II, III and IV. Thresholds were chosen according to the method of Sinclair (1974) and used as contour values on a base map of resistivity values produced by Cochrane et al. (1970). Evaluation of this map led to the following conclusions:

Population IV is essentially coincident with high millisecond population of chargeability but is slightly more obscure in defining the pyrite halo. This relationship is consistent with and refines the interpretation of high negative correlation between apparent resistivity and chargeability (cf. Table II). Population III is localized in 2 main areas: (a) coincident with a quartz-sericite-pyrite alteration zone in the centre of the porphyry system, and (b) forming a transitional zone between low values over the axial zone of the pyrite halo and surrounding higher values.

Populations I and II appear distinguishable on the probability plot of figure 6 but are not easily distinguished as to geological cause. One possible interpretation is that population I is true background (which is certainly true) for the area, and population II is a transitional zone between populations I and III (also true) that the writer speculates as representing a fringe of the hydrothermal

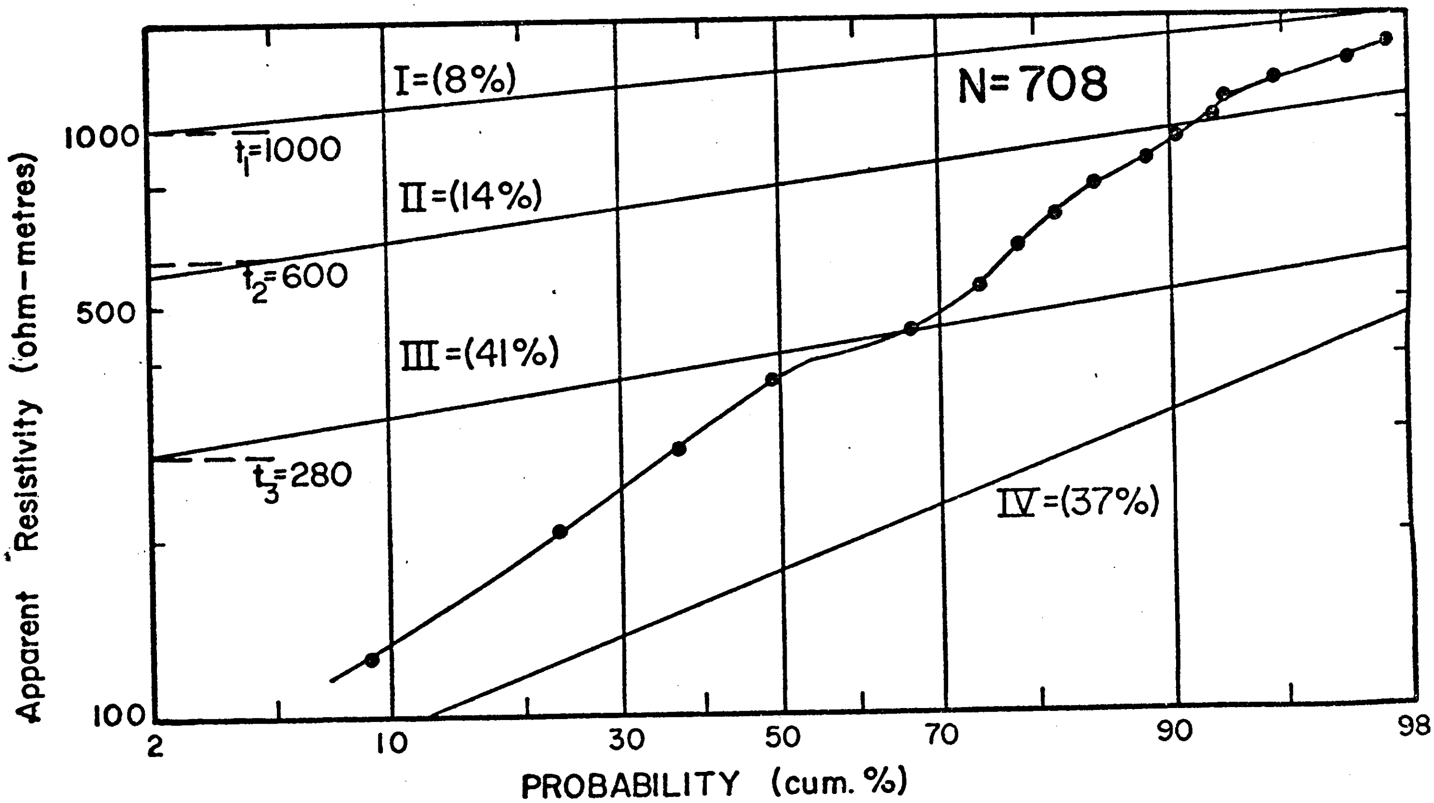


Figure 6: Log probability plot of apparent resistivity data. Original data are shown as black dots through which a smooth curve has been drawn. This curve has been partitioned into four populations shown as straight lines labelled I, II, III and IV. Thresholds are indicated by t_i values on the left side of the graph.

effects related to the Ashnola porphyry system.

SUMMARY AND EVALUATION

All geophysical variables proved amenable to analysis using an approach involving probability plots. Each of the four variables was shown to consist of two or more recognizable populations and, with minor exception, the populations were more easily interpretable than the simple correlation matrix or the less rigorous approach dealing with evaluation of contoured maps with arbitrary contour values and intervals, and ignoring the concept of combinations of populations. A summary of partitioned populations and their interpreted significance is given in Table V.

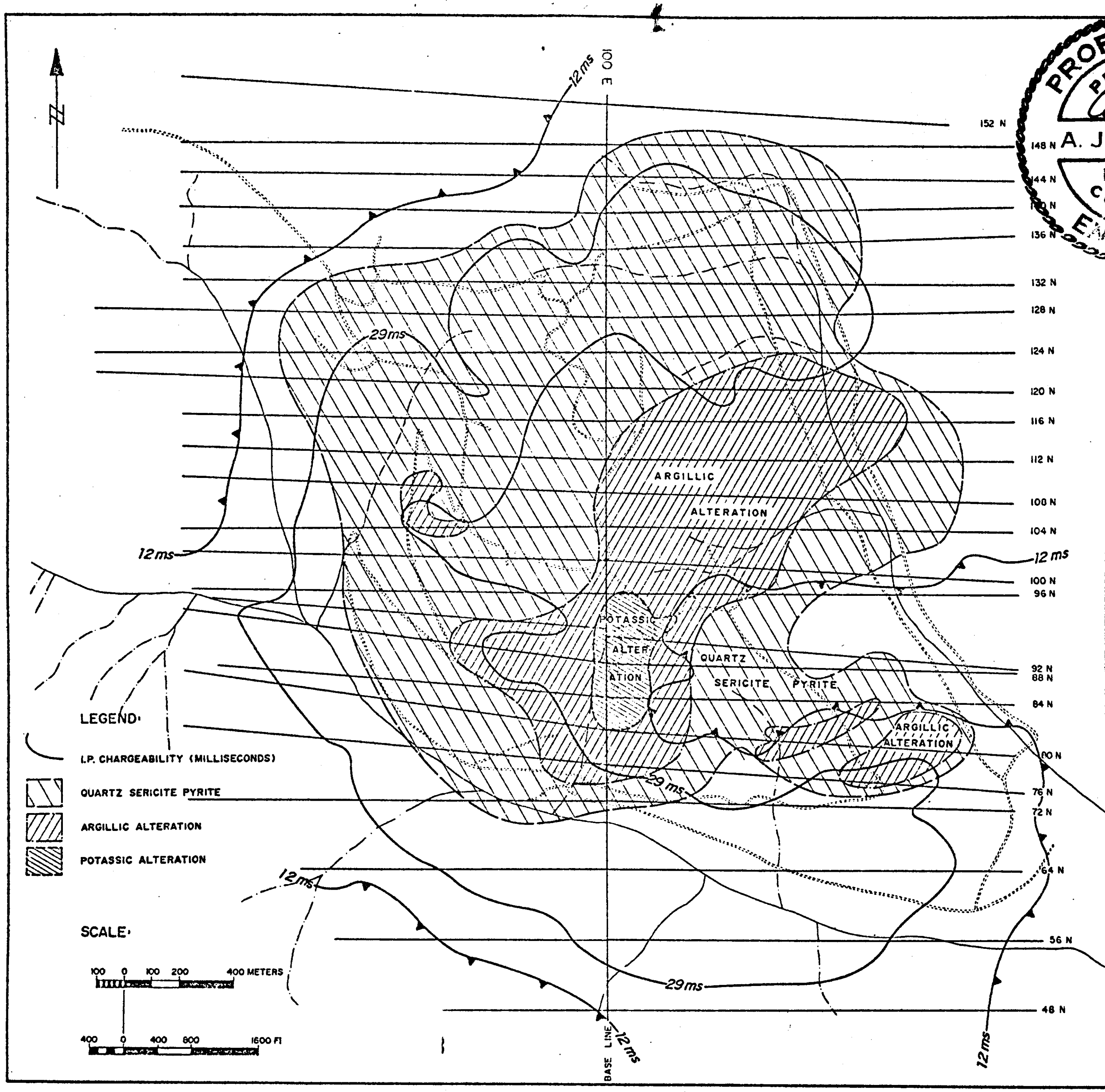
In particular, the success of the probability graph approach in dealing with apparent resistivity data was most gratifying. For the first time it was possible to attach geological significance to most ranges of measured values. It now seems clear that groundwater, overburden depth, and water table level do not seriously influence the lithological control on the readings obtained. Furthermore, the populations defined in the probability graph analysis could be interpreted easily and naturally in terms of the porphyry model, and, in fact, added to the earlier description of the model.

Some ambiguities arose, for example, in the possible presence of a fourth population in the ground magnetometer data. The advantage of the probability graph approach in

TABLE V

SUMMARY INTERPRETATION OF PARTITIONED POPULATIONS OF GEOPHYSICAL VARIABLES

Chargeability	I	50	Pyrite halo
	II	50	Core and fringe to pyrite halo
Ground Gamma	I	3	Magnetite-bearing intrusion
	II	95	Acid extrusive rock
	III	2	Thick overburden?
Self Potential	I	5	Sulphides-redox reaction
	II	79	Background, gradients between I and IV
	III	10	Background, gradients between I and IV
	IV	6	Sulphides-redox reaction
Apparent Resistivity	I	8	Background
	II	14	Fringe of Ashnola hydrothermal system
	III	41	(a) Quartz-sericite-pyrite alteration core (b) Transition between II and IV
	IV	37	Pyrite halo



PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
A. J. SINCLAIR

this case is that it points to the possibility of such alternate interpretations; thus allowing both to be considered. In this case it seems likely that the 4 populations do exist and a means is thereby indicated for locating buried but shallow, magnetite-bearing intrusive bodies.

Self potential data pose a problem in normal correlation studies. However, the procedures used in this study were particularly successful. In fact, the probability graph approach presented here is shown to be a powerful procedure for analyzing self potential data and the particular interpretation is likely to be a common one in many exploration situations.

Chargeability data and its interpretation are self evident. Comparison with geology shows that one population coincides with a pyrite-rich zone or halo that is well defined by the 29 ms. threshold contour value. These results are shown in figure 7 overlain on a general map of alteration types. This map forms a useful reference for the interpretation of chargeability, resistivity and self potential data in particular. Perhaps one of the more useful although somewhat speculative results of the study is the use of apparent resistivity data to define limits to the total hydrothermal system!

REFERENCES

Cochrane, D. R., G.H. Giroux and A. Scott, 1970, Geophysical and geochemical reporton Prism Resources' Ashnola property; Private report to Prism Resources Limited, submitted for assessment work, dated Oct. 5, 1970.

Lowell, J.D., and G.M. Guilbert, 1970, Lateral and vertical alteration-mineralization zoning in porphyry ore deposits; Econ. Geol, vol. 65, p. 373-408.

Montgomery, J.H., D.R. Cochrane and A.J. Sinclair, 1975, Discovery and exploration of Ashnola porphyry copper deposit near Keremeos, B.C.: A geochemical case history; in Geochemical Exploration 1974, Elsevier Schientific Pub. Co., p. 85-100.

Sinclair, A.J., 1974, Selection of threshold values in geochemical data using probability graphs; Jour. Geochem. Explor., vol. 3, p. 129-149.

Sinclair, A.J. 1975, The relationship between sulphides and wallrock alteration, and its importance to explorat-ion, Ashnola property; private report for Prism Resources Ltd., submitted for assessment work, dated Sept. 22, 1975.

Sinclair, A.J., 1976, Applications of probability graphs in mineral exploration; Assoc. Explor. Geochem., Spec. Vol. 4, 95 p.

Slichter, L.B., 1955, Geophysics applied to prospecting for ores; Econ. Geol., 50th Anniv. Vol, Part II, p. 885-969.

CERTIFICATE

I, Alastair J. Sinclair, of the City of Vancouver, Province of British Columbia, hereby certify:

1. That I am a Geological Engineer residing at 2972 W. 44th Ave., Vancouver, British Columbia.

2. That I obtained a B.A. Sc. degree in Applied Geology from the University of Toronto in 1957, an M.A. Sc. degree in Geological Engineering from the University of Toronto in 1958, and a Ph. D. in Geology from the University of British Columbia in 1964.

3. That I am a registered Professional Engineer in the Province of Ontario in the Mining Division, and in the Province of British Columbia in the Geology Division.

4. That I have practiced my profession for nineteen years.

5. That I have no interest directly or indirectly, nor do I expect to have any direct or indirect interest in the properties or securities of Prism Resources Limited.

6. That the accompanying report is based upon my studies of various reports on previous exploration work done on the Ashnola property, visits to the property, and examination of drill core.

Dated at Vancouver in the Province of British Columbia, this 17th day of June, 1976.

PROFESSIONAL PROVINCE OF A. J. SINCLAIR BRITISH COLUMBIA ENGINEER

A. J. Sinclair, P. Eng.

APPENDIX I

NATURE OF CHARGES

A. J. Sinclair, P. Eng., Professional services for statistical analysis. Feb. 4, 6, 7, 8, 9, 12, Mar. 2, 4, 6, 7, 8, and 14. $11\frac{1}{2}$ days at $175.00	2012.50
Draughting and reproduction of diagrams	205.00
Report Preparation A. J. Sinclair, June 8, 15, 16, 17, 1976 $2\frac{3}{4}$ days at $175.00	481.25
Xeroxing and typing	65.00
TOTAL EXPENDITURES	$2763.75

PROFESSIONAL
PROVINCE OF
A. J. SINCLAIR
BRITISH COLUMBIA
ENGIN