OTHER INVESTIGATIONS

A PRELIMINARY ASSESSMENT OF ZEBALLOS MINING CAMP
(92L)

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INTRODUCTION

This report updates and expands a preliminary report published last year on assessing resource potential of gold quartz veins in the Zeballos camp (Sinclair and Hansen, 1983). The Zeballos camp is located on the west coast of Vancouver Island (Fig. 85).
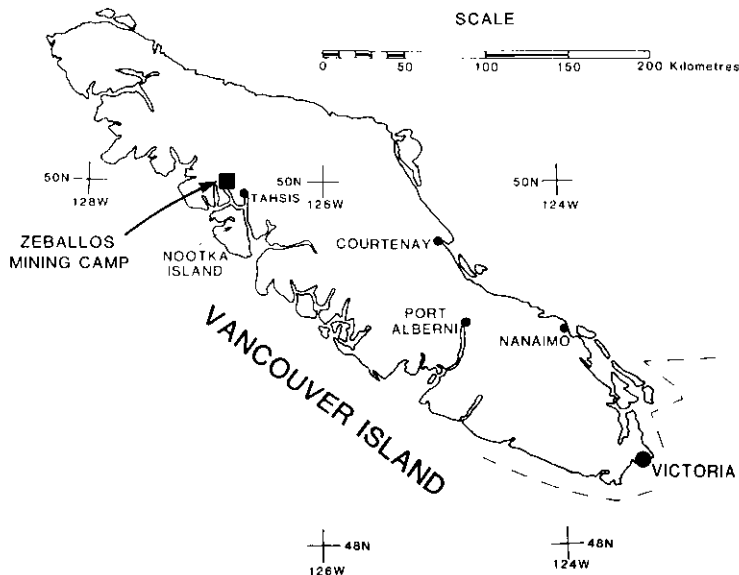

Figure 85. Location map of the Zeballos mining camp.

This evaluation was initially oriented toward a quantitative resource assessment following the approach of Sinclair (1979) and Orr and Sinclair (1971). To this end a data file was constructed (*see* Sinclair and Hansen, 1983, Table 1) to form a basis for quantitative evaluation.

Because of the scarcity of quantitative data the study was broadened to include a qualitative assessment of geological features, particularly structure. This was hampered to a certain extent by a lack of field observations.
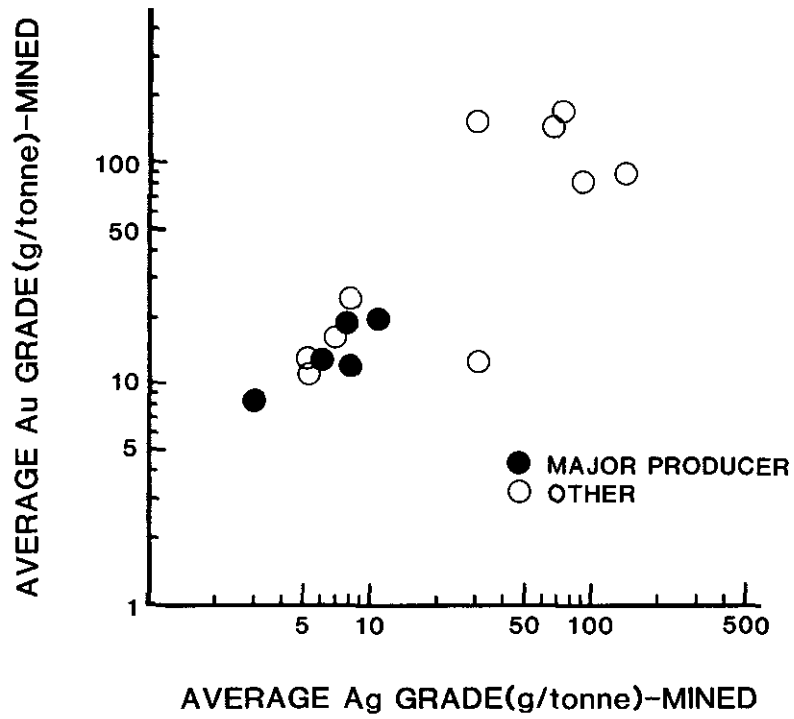
Figure 86. Plot of average gold grades (grams per tonne) versus average silver grades (grams per tonne) for Zeballos vein deposits.
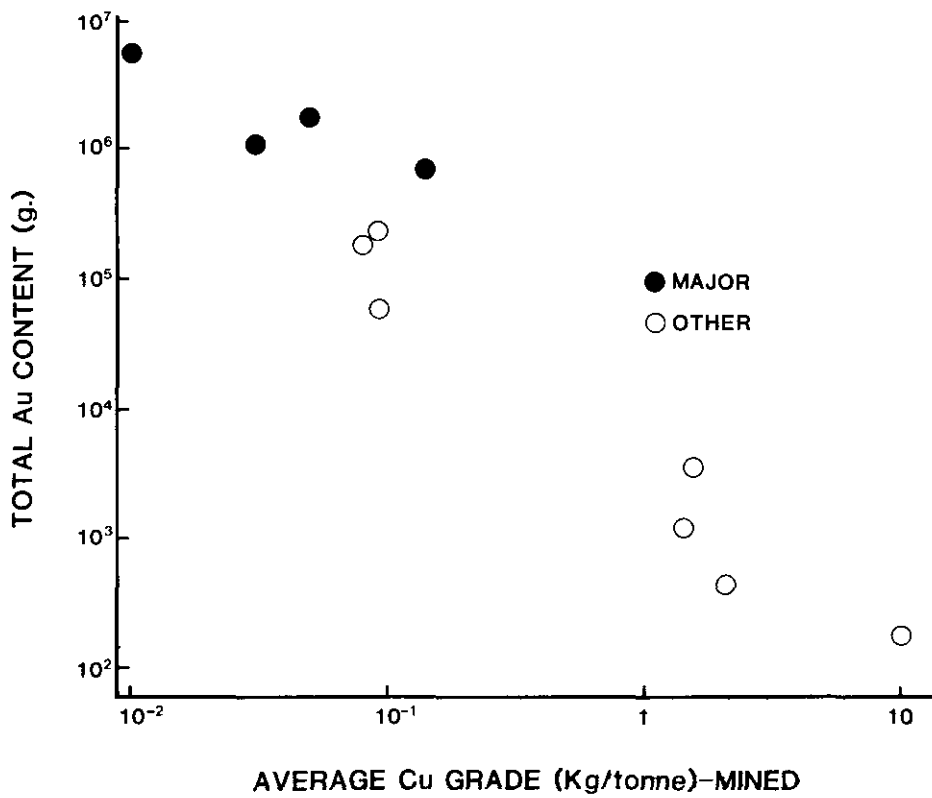

Figure 87. Total gold content (grams) versus average copper grades (percentage) for Zeballos vein deposits.

DATA BASE

The data have been compiled (Sinclair and Hansen, 1983) from two primary sources of information: a report and map by Stevenson (1950) and the MINFILE computer file of mineral deposits in British Columbia maintained by the British Columbia Ministry of Energy, Mines and Petroleum Resources. These tables are reproduced in updated form in an appendix. For comments on the terminology used, please refer to Sinclair and Hansen (1983).

STATISTICAL METHODS AND RESULTS

The following techniques all utilize the data as listed in Tables 1 to 5 in Sinclair and Hansen (1983). The small number of observations for which production data are available is a significant drawback which limits the potential of using multivariate techniques. Nonetheless, there are some interesting relationships and trends apparent, as described following. Those variables which do not display an approximately normal distribution, for example, all production data, are log normal and were invariably log transformed. No other transformations were considered necessary.

LINEAR REGRESSION

Selected plots of the more significant relationships are discussed, with the associated statistical values listed in Table 1. Precious metal contents (gold and silver) when plotted versus production (Sinclair and Hansen, 1983) showed good correlation between 'mined tonnage' and both gold and silver content, therefore production tonnage is an acceptable single measure of relative value of vein deposits of the Zeballos camp (compare, Sinclair, 1979). The corollary is that average grades among the larger producers are relatively constant. This would be of significant interest to any future producer at the camp. Average gold grade versus average silver grade is shown on Figure 86. Although the correlation is high (r = 0.815), the existence of two clusters suggests that this may be at least partly artificial. Nonetheless the cluster representing the larger producers is valid. It can be seen that gold grade is considerably higher than that of silver, the mean ratio is 2:3, with a standard deviation of 1:3; for the larger producers these values are 2:3 and 0:5 respectively.

TABLE 1. LINEAR REGRESSION DATA

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	NUMBER OF OBSERVATIONS	DEGREE OF FREEDOM	CORRELATION COEFFICIENT	RELEVANT FIGURE
LogMINE	LogTOAU	17	16	0.989	
REGRESSION EQUATION	LogMINE = 1.23·LogTOAU − 2.46				2.1
LogMINE	LogTOAG	15	14	0.975	
REGRESSION EQUATION	LogTOAG = 1.18·LogTOAG − 1.94				2.1
LogGRAU	LogGRAG	15	14	0.815	
REGRESSION EQUATION	LogGRAU = 0.75·LogGRAG = 0.59				2.2
LogTOAU	LogGRCU	11	10	−0.962	
REGRESSION EQUATION	LogTOAU = −1.62·LogGRCU + 3.61				2.3
LogTOAU	DSTC(+ve)	8	7	−0.637	
REGRESSION EQUATION	LogTOAU = −0.0019·DSTC + 6.38 (within stock)				2.4
LogTOAU	DSTV(−ve)	9	8	0.713	
REGRESSION EQUATION	LogTOAU = 0.0011·DSTC + 5.38 (in wallrock)				2.4

ABBREVIATIONS:
MINE = mined tonnage per deposit (tonne)
TOAU, TOAG = total grams gold per deposit, total grams silver per deposit
GRAU, GRAG, GRCU = grade of gold in grams per tonne, grade of silver in grams per tonne, grade of copper in kilograms per tonne
DSTC = distance from the Zeballos stock contact

On Figure 87, total grams of gold per deposit are plotted against average grade of copper. The good negative correlation over several orders of magnitude suggests copper grade may be an indicator of deposit relative value. However, this correlation may be partly artificial, as a result of selective up-grading of ore in the small deposits. This relationship is discussed further in the following section on multiple regression.

When a plot of deposit relative value (total grams of gold per deposit) was made against distance from the contact of the Zeballos stock (Sinclair and Hansen, 1983; Fig. 106), the graph showed a remarkably consistent pattern both in the stock and in the country rock. The equations describing these trends are given in Table 1. There is potential for this relationship to be used as a value estimate for any deposits remaining to be discovered. However, two assumptions are implicit in this relationship. First, the measure of distance from the contact is in the horizontal plane, potential influence of variation in the vertical plane is not considered. Second, the Zeballos stock is considered to be the only Tertiary intrusive in the vicinity; this may not be true.

MULTIPLE REGRESSION

The method used is called backward stepwise regression; in it, only the most significant variable(s) are retained in the equation at the final step. Although the potential of this method is severely limited by the small number of observations available, it has provided insight into which variables may reflect the mineralizing process.

Numerous runs were made using different dependent variables and combinations of all or some independent variables; in addition the numbers of observations used were varied.

Naturally the most significant dependent variables as value indicators are mined tonnage and total gold content per deposit. Elevation was used as a dependent variable in an attempt to define any zoning which may be present. The data are too sparse to allow any meaningful correlations.

The use of mined tonnage or total gold content as dependent variables restricts the number of observations to 18 and 17 respectively. If complete observations are desired the restrictions are even more severe, generally less than 10 or so observations. Where observations are incomplete, mean values are substituted for missing data. The results often do not appear significantly different in such cases.

The most significant independent variables, in approximate order of decreasing significance, are: grade of copper (GRCU), grade of gold (GRAU), bearing from the northwest nose of the Zeballos stock to the deposit (BRGN), distance to the contact (DSTC), average minimum vein width (MNVW), grade of silver (GRAG), grade of lead (GRPB), distance to the nose of the stock (DSTN), strike of the major vein(s) (STR1). This order varies depending on the nature of the other parameters. Of the nine variables only six are considered to be of geological significance. The variables DSTN and STR1 were dropped primarily because of their low rating in various statistical runs. In addition, the values for STR1 are averages and would be difficult to determine for a raw prospect.

The variable MNVW, although useful, was dropped for two reasons: it is an empirically determined value, and it is of no quantitative value when considering a prospect with limited vein exposure. The variables GRAG and GRPB were retained because they are quantitative production data and represent information which is relatively easy to obtain from a prospect. The variable BRGN was retained solely because of its significance in the regression analyses. It is difficult to explain geologically except insofar as it is presumably an indirect measure of other variables of significance, as discussed elsewhere (for example, position and orientation of shears).

Data resulting from the use of these six variables are presented in Table 2. The cases presented demonstrate the type of results obtained. Features of interest are: the high values for R^2 (that is, that fraction of total

variance explained by the relationship), the generally low standard error (around a half order of magnitude over five to seven orders of magnitude), and the persistence of GRCU as the retained independent variable. It appears that the grade of copper is of considerable, unexpected significance in terms of available data. This supports the conclusion in the previous section that grade of copper may well be useful as an indicator of potential value of a deposit.

TABLE 2. SELECTED RESULTS FROM MULTIPLE REGRESSION ANALYSES

DEPENDENT VARIABLE	MINE	TOAU	MINE	TOAU
INDEPENDENT VARIABLE	GRAU, GRAG, GRCU, GRPB	GRAU, GRAG, GRCU, GRPB	GRAU, GRCU, DSTC, BRGN	GRAU, GRCU, DSTC, BRGN
TOTAL NO OF OBSERVATIONS	18	17	12	12
TOTAL NO. OF COMPLETE OBSERVATIONS	9	9	11	11
DEGREES OF FREEDOM	11	11	11	11
FINAL STEP NUMBER	6	7	7	7
LAST VARIABLE REMOVED	GRAU	GRAG	BRGN	BRGN
RETAINED VARIABLE(S)	GRAG, GRCU	GRCU	GRAU, GRCU	GRCU
VALUE OF R²	0.97	0.93	0.97	0.93
STANDARD ERROR	0.41	0.50	0.40	0.48
REGRESSION EQUATION	LogMINE = −0.97·LogGRAG −1.67 LogGRCU +3.09	LogTOAU = −1.62·LogGRCU +3.09	LogMINE = −1.25·LogGRAU −1.53·LogGRCU +3.97	LogTOAU = −1.62·LogGRCU +3.60

NOTES: Abbreviations explained in text; all values are logged (as shown), except DSTC and BRGN.

CLUSTER ANALYSIS

Much of the data file consists of attributes, that is to say, measurements recorded on a nominal scale and having discrete values. Although such data may be evaluated empirically, it was considered that more significant results might be derived using a parametric statistical technique. It was desired to group the data from Associated Minerals using cluster analysis, after ensuring that it was valid to use such data in such a manner. The lower orders of clustering were meaningful, but did not provide information that could not be determined empirically. The higher orders of clustering did not appear to be geologically significant. It was presumed, therefore, that there is no practical grouping of observations within these data, other than what can be determined empirically.

GEOLOGY AND MINERALIZATION

GENERAL

The geology of Zeballos camp, as shown on Figure 88, consists of a northwest-striking, southwest-dipping sequence of Mesozoic volcanic and sedimentary rocks cut by Jurassic and Tertiary intrusions. The general structure represents the southwestern limb of a northwesterly trending anticline (Hoadley, 1953), considerably disrupted by faults and intrusions. The area to the north of the Zeballos stock and to the east of the North Fork of the Zeballos River is tightly folded. The Lower Jurassic Bonanza Group is a typical island arc sequence, largely consisting of basaltic to rhyolitic volcanic rocks. This unit is underlain conformably by limestone of the Quatsino Formation. These two units are now thought to be separated by the Parson Bay Formation as elsewhere on Vancouver Island; this is described in detail following. Tholeiitic basalts of the Upper Triassic Karmutsen Formation form the base of the sequence in this area. These bedded rocks are cut by Jurassic plutons of the Island Intrusions, mainly diorite to granodiorite in composition. The Zeballos stock with its spatially related gold-quartz veins is a quartz diorite phase of the Catface intrusions of Eocene age.
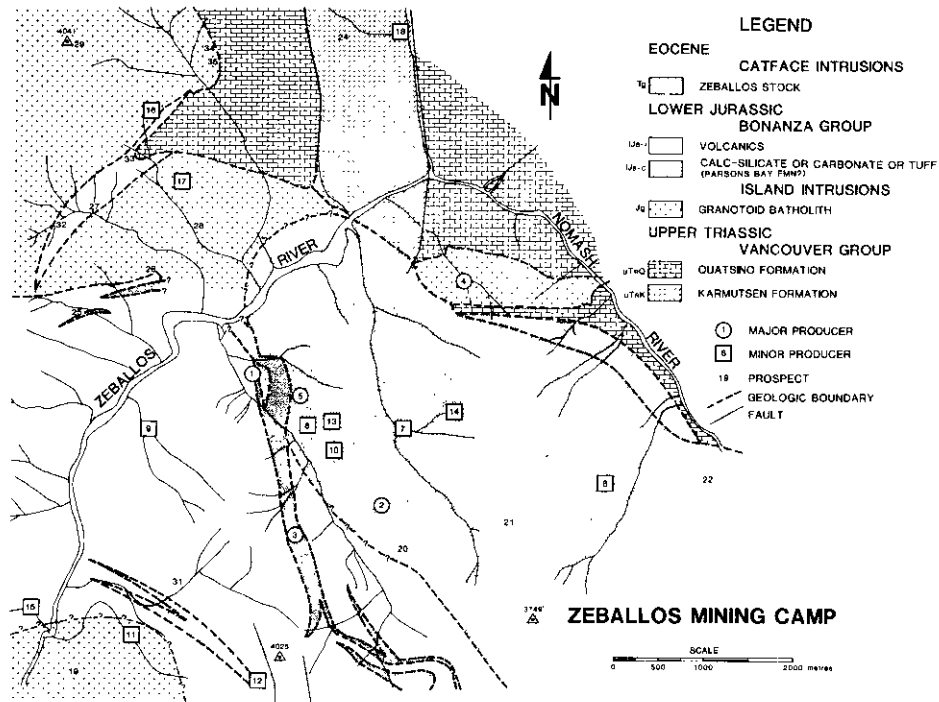
223

Figure 88. General geology of the Zeballos mining camp (modified from Stevenson, 1950).
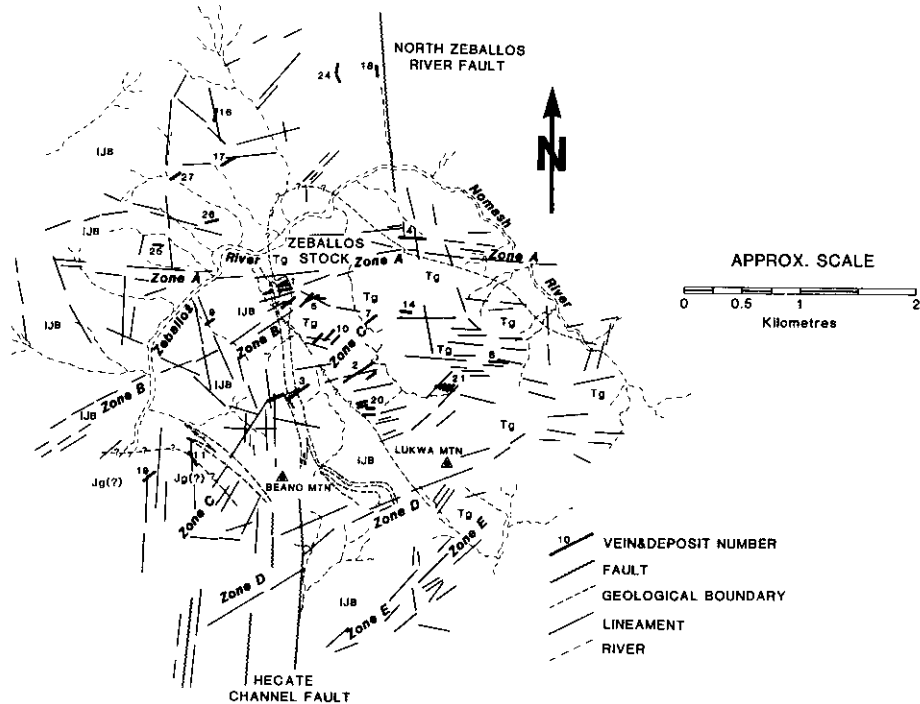

Figure 89. Fracture trace diagram from Zeballos mining camp as interpreted from aerial photographs. Scale is approximate because aerial photographs were used as a base. Several geological features are included as an aid to correlating this figure with Figure 88.

224

STRATIGRAPHY

On Figure 88 the Bonanza Group is shown to contain units of carbonate, calc-silicate, and tuff. According to Dr. J. E. Muller (personal communication, 1982), these units almost certainly represent the Parson Bay Formation; that is, these units would represent the northwest continuation of the formation as shown on the 1:250 000 map of Nootka Sound (*Geol. Surv., Canada,* Map 1537A, 1981). The contact between Parsons Bay Formation and Bonanza Group is known to be gradational, as it would appear to be here. The Bonanza Group elsewhere on Vancouver Island is not known to contain any carbonate horizons, although sedimentary units do occur. The calc-silicate rocks adjacent to the Zeballos stock presumably represent contact metamorphosed carbonate or carbonate-rich sediment. If indeed these units are Parson Bay Formation, the implication is of a more complex structure than was previously thought to exist. The two horizons of Parson Bay Formation to the west of the stock seem to be a structural repetition. This would suggest either a tight, doubly plunging syncline or fault-controlled repetition. The latter explanation is favoured because there is no evidence of folding, in terms of the attitude of the bedding or of repetition of the underlying Vancouver Group.

In the extreme southwest of the map-area (Fig. 88) Stevenson (1950) has mapped a body of gabbro which contains the Answer and Golden Portal deposits. This gabbro contains fragments and boulders of un-replaced and partially altered volcanic rocks and is cut by diorite and granodiorite dykes which also cut the Zeballos stock and perhaps the Island Intrusions. Compositionally it is distinct from the hornblende diorite of the Island Intrusions in that it contains "...labradorite instead of andesine, and considerable augite with only a minor amount of primary hornblende" (Stevenson, 1950). The presence of pyroxene rather than hornblende suggests the possibility that this may be a feeder dyke (that is, subsurface equivalent) to the Bonanza volcanic rocks, or to higher level Tertiary volcanic rocks which have since been eroded. It is of interest to note that there are three gold producers in the immediate vicinity (Tagore, Golden Portal, Beano). It is generally accepted that gold-quartz vein mineralization is intimately related to Tertiary intrusions (for example, Carson, 1968) on Vancouver Island, yet the Zeballos stock is 2 to 3 kilometres away. In addition, a replacement deposit such as the Beano could be expected to lie quite near the source of mineralization. Thus it is at least possible that this gabbro is of Tertiary age.

There appears to be a close relationship between young dykes of a particular composition and the gold-quartz veins. Dykes which are the last phase of, or younger than, the Zeballos stock intrusion are of particular significance. Feldspar porphyries are intimately asssociated with the veins; a stock of feldspar porphyry occurs within the Mount Zeballos mine area. Orthoclase-rich granodiorite dykes are associated with mineralization at the Privateer and Central Zeballos deposits.

FAULTING

Faulting in this and surrounding areas seems to have been the major structural response to deformation (Muller, Northcote, and Carlisle, 1974). With this in mind a fracture trace diagram, reproduced here as Figure 89, was compiled from 1:20 000-scale black and white aerial photographs, taken in August 1980. Because of the empirical nature of such data and the limited time available, only the major or obvious lineaments have been shown. In addition, the compilation has not been corrected for distortion. Our inability to check the features on the ground is a significant drawback to our interpretation of lineaments. Figure 90 is a rose diagram of all lineaments whereas Figure 91 shows only those lineaments greater than approximately 600 metres in length. This division was chosen by examining a histogram of all lineaments. Lengths up to about 600 metres define a normal population; lengths greater than 600 metres are a pronounced 'tail' to this 'normal' population.

The distinct concentration in both figures at azimuths of 150 to 190 degrees is thought to represent the continuation of the pre-Tertiary Hecate Channel fault of Muller, Cameron, and Northcote (1981). This fault has been mapped on Bingo and Friend Creeks by Hoadley (1953). The lineaments continue north
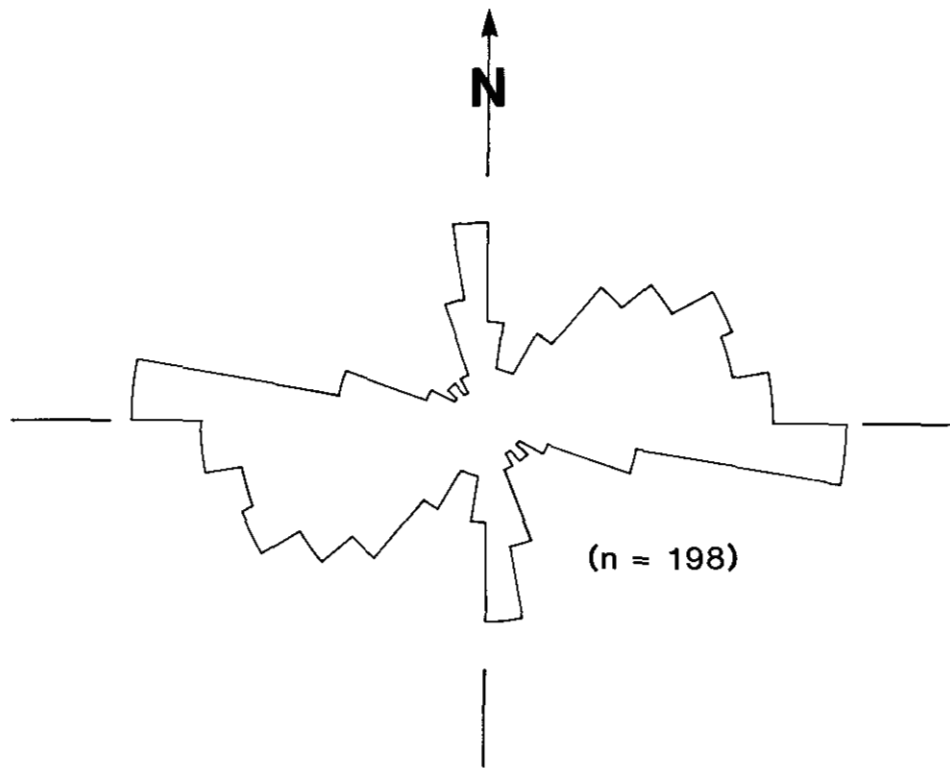
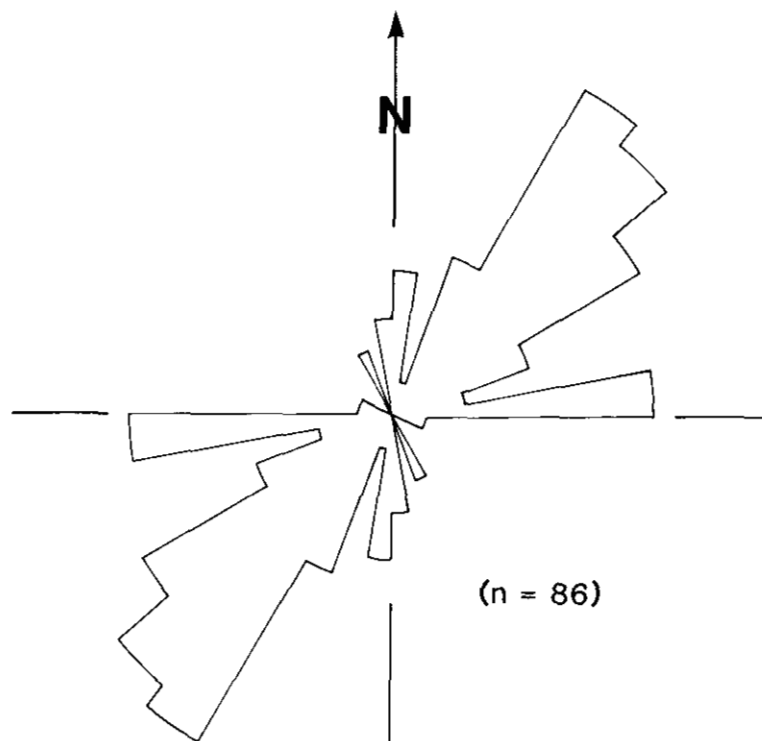Figure 90. Rose diagram of all fracture traces shown on Figure 89.

Figure 91. Rose diagram of fracture traces longer than 600 metres as they appear on Figure 89.

226

from these creeks and from the east side of the lower reaches of the Zeballos River. It is thought that Hecate Channel fault continues, offset, on the north side of the Zeballos stock as the north Zeballos River fault. These faults and the accompanying lineaments are considered pre-Tertiary as the faults are offset across the Zeballos stock and north/south lineaments are rare within the stock. This conclusion is in agreement with Muller, *et al.* (1981).

Some of the lineaments representing Hecate Channel fault pass between the two horizons of Parson Bay Formation. Gunning (1932) considers the north Zeballos River fault has been downthrown to the east. The same sense of movement on the fault to the southwest of the stock (that is, continuation of the Hecate Channel fault) would explain the repetition of the Parson Bay Formation.

Most of the lineaments fall within a large, rather poorly defined population between 030 and 100 degrees, as shown on Figure 90. Part of this population probably represents second order faults related to the previously discussed north-trending faults. Numerous east/west trending, generally short, lineaments occur within the Zeballos stock; these might be related in part at least to cooling of the stock. A well-developed fracture pattern in outcrop is diagnostic of the Catface intrusions (Muller, personal communication, 1982). It is possible that such fractures may correlate, in part, with the aforementioned set of east/west lineaments for the Zeballos stock. If such a correlation was found to be general throughout the area fracture trace analysis could well prove a fast and accurate method of determining 'age' of particular intrusions.

Of the remaining lineaments, many fall within relatively well-defined zones, shown as zones A to E on Figure 89. Zone A, passing through the Privateer and central Zeballos deposits, appears to represent a fault zone which has offset the north part of the Zeballos stock to the west. Zone A corresponds with a concentration of east/west-striking granodiorite dykes at central Zeballos. Lineaments in Zone A are well defined on the photographs, however there is no mention of such a fault by workers in the area. Zones B to D define four groups of lineaments striking 40 to 60 degrees and located to the west of the stock. They may offset the Hecate Channel-North Zeballos River faults. In any event lineaments of Zones A to E appear to all represent the same age of faulting or shearing and may all correlate with Eocene or later faulting, that is, syn- (or post-) intrusive.

VEIN ORIENTATION

The strain ellipsoid of Figure 92 is modified after Stevenson (1950). On the basis of two major shears at Zeballos Pacific (035 degrees) and Big Star (090 degrees), along with some supporting data, he has concluded that planes of major shearing are oriented 035 degrees vertical and 090 degrees vertical. He derives
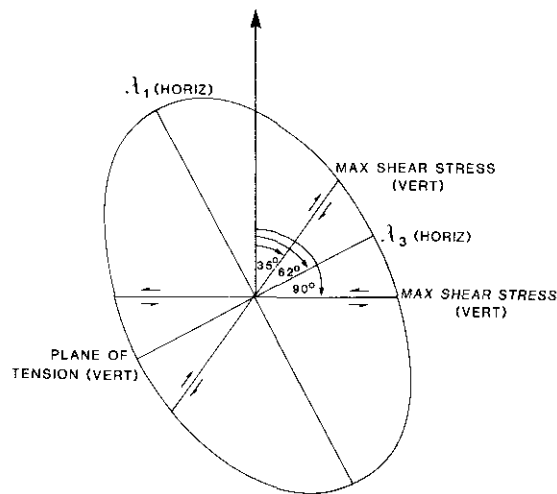

Figure 92. Strain ellipsoid for Zeballos mining camp.

062 degrees vertical to the plane of tension. He concludes that this latter orientation is most important with respect to vein orientation and mineralization, "fractures and consequently veins formed under tension are the most favourable for ore ..." (80 to 90 degrees) correlating well with Zones A to E of Figure 89 (040 to 060 degrees, 80 to 100 degrees). An example of rotational strain, using a shear direction of 085 degrees is illustrated on Figure 93. This example may be related directly to Zone A of Figure 89 and No. 1 and No. 2 veins of the Privateer deposit. Brecciation and shattering can be expected under low confining pressures, as is indeed the case at the camp. In other areas, the conjugate shear is more prominent (namely, Zones B to E of Figure 89).
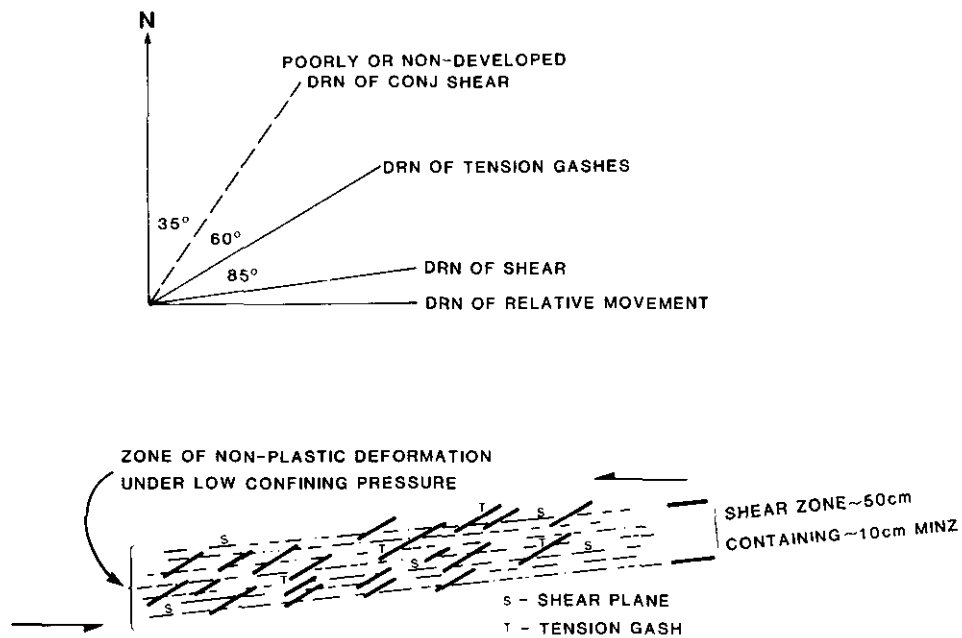

Figure 93.   Conceptual model for development of veins and related structural features, Zeballos mining camp.

NOSE OF STOCK

There is a strong correlation between the northwest nose of the Zeballos stock and mineralization. In a general way the greater the distance from the nose, the fewer the deposits and the less productive they have been. This is presumed to be a result of the extensive faulting and shearing in the vicinity of the nose providing the best pathways for ascending metal-bearing solution. Naturally there are other relationships which obscure the picture to a certain extent, such as that between metal content and distance to the intrusive contact. A complicating factor may be the gabbro in the southwestern part of the map-area, if this is Tertiary in age.

VEIN WIDTH

Most productinve veins show a wide range in width (for example 1 to 100 centimetres), but the bulk of such veins usually shows considerably less variation (for example, 10 to 30 centimetres). The latter variation is described, rather arbitrarily, as typical minimum and typical maximum vein width. Typical minimum vein width is of considerable empirical significance. In general terms, productive veins can be expected to have a typical minimum width of around 1 to 5 centimetres along with a relatively small variation in width. There does not seem to be a correlation between vein width and width of the enclosing shear zone.

228

HOST ROCK

Host rock to the veins includes all rock types in the area. Particular host rock type appears to have no influence on localization of veins, except insofar as the physical properties of the rock determine how it will react to deformation. Flexures appear to be favourable sites for mineralization, particularly in what is inferred to be Parson Bay Formation (for example, at Privateer and Mount Zeballos). Elsewhere on Vancouver Island the Parson Bay Formation is seen to be complexly folded, presumably because it reacts in an incompetent manner to deformation. The Bonanza volcanic rocks could be expected to react in a more brittle manner to deformation, thus more readily providing pathways and sites of deposition for migrating hydrothermal solutions. The presence of sharp bends or curves in the margins of the stock are also likely loci of deposition, as are areas of shattering and brecciation.

ASSOCIATED MINERALS

The sulphide assemblage characteristic of gold-quartz vein occurrences on Vancouver Island (for example, Bancroft, 1937; Muller and Carson, 1969; Carson, 1968) is pyrite, sphalerite, galena, and chalcopyrite. Arsenopyrite may be present and pyrrhotite is relatively uncommon. There is a strong negative correlation between chalcopyrite (GRCU) and total gold among the producers as discussed earlier. Arsenopyrite, alone, does not seem to be related to gold content, however if present in measurable quantity along with sphalerite, galena, and chalcopyrite there generally is associated high-grade (150 to 3 000 grams per tonne) gold. Quartz is ubiquitous, calcite locally accompanies mineralization, and ankerite is rare.

EXPLORATION PARAMETERS

The following parameters are intended to be applied to known vein(s) under investigation at Zeballos camp. However, it would not be unreasonable to extrapolate the use of some parameters to similar veins elsewhere on Vancouver Island. It should not be assumed that these are the only factors influencing economic mineralization or that the interpretation of these observations is necessarily unique.

(1) Spatial association of gold-quartz veins with the Eocene Catface intrusions is of primary importance. The best economic potential seems to be within 500 to 1 000 metres of the contact of intrusive bodies greater than 2 000 metres in diameter.

(2) Brecciation of the intrusive and/or host rock, along with pre-existing or contemporaneous faulting, aids in establishing pathways for the hydrothermal fluids.

(3) Close association with late or post-Catface intrusion dykes is a favourable feature, in particular, (quartz) feldspar porphyry dykes and stocks.

(4) Host rock type is important insofar as its physical properties determine its response to deformation. For example, fracturing on fold crests may, in association with other factors, provide a suitable locus of deposition.

(5) A folded or convoluted margin to the intrusion, or apophyses, might be expected to aid in the localization of mineralization.

(6) The orientation of the vein and its enclosing shear, if present, along with intersecting shear zones, is of considerable importance. At Zeballos rotational strain apparently produced shears orientated at 035 to 060 degrees and 080 to 090 degrees (Fig. 94). When allied with tensional cavities and gash veins, they may have provided suitable sites for deposition of economic mineralization (Fig. 95).

(7) The sulphide assemblage should include pyrite, galena, chalcopyrite, and sphalerite with or without arsenopyrite.

(8) Average copper grade may be used as an aid in predicting potential total gold present. If substantial sample data are available a multivariate linear model relating size to copper, lead, silver, and gold grades can be applied.
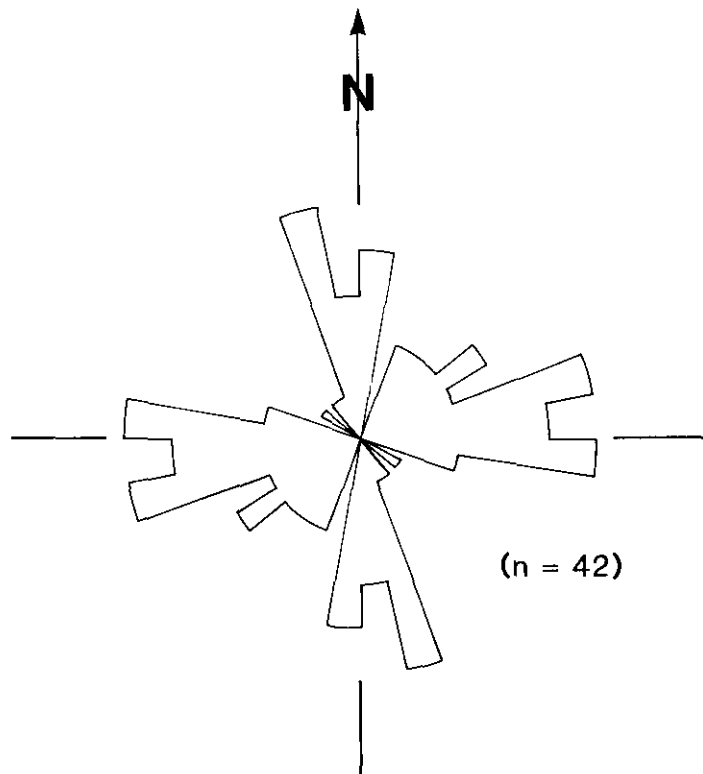
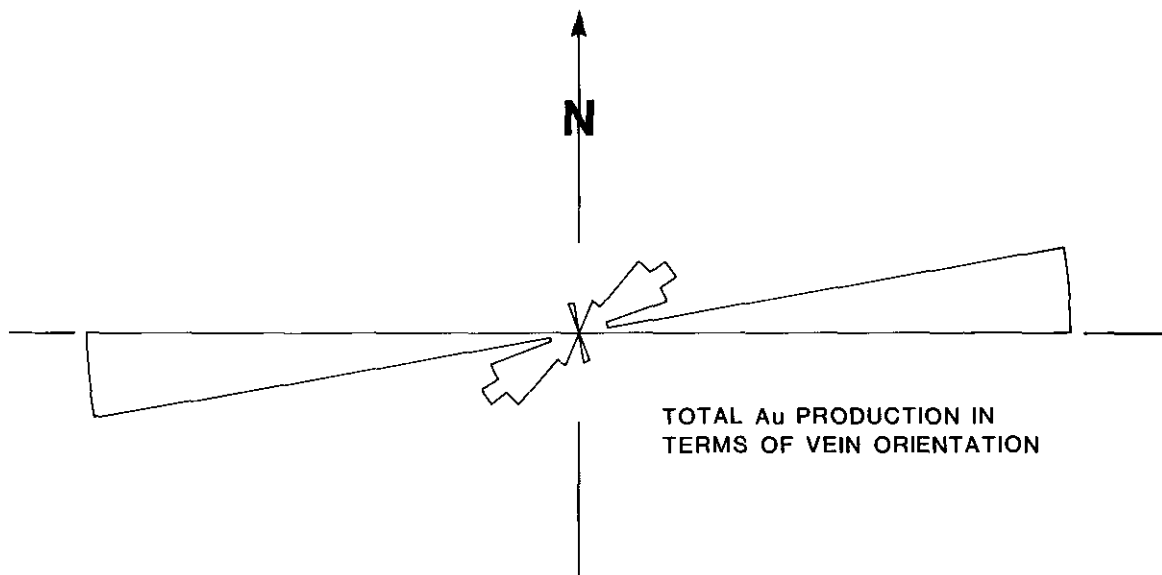Figure 94. Rose diagram of vein orientations, Zeballos mining camp.

Figure 95. Rose diagram of total gold production as a function of vein orientation, Zeballos mining camp.

The area of Zeballos camp is roughly 5 000 hectares and it might be thought that all veins in such a restricted area already have been discovered and exploited. However, aside from the possibility of a concealed mineralization, the rugged topography of the area, heavy vegetation, superficial cover on bedrock and the small size of the target may have prevented discovery of veins containing potentially economic minerals. In reference to the search for the White Star veins, Bancroft (1940) says "Half a dozen prospectors searched the slopes for 4 months before finding the quartz in place .... 500 or 600 feet above the bed of the creek". This was after having found "...rich gold quartz float with granitic rock attached..." in Spud Creek almost directly below the veins. It would seem that even today there exists opportunity for new vein discoveries.

Alternatively, it may be that past producers have not been exploited fully, or non-productive prospects may have the potential to become producers; our work is somewhat negative in this regard. Finally, it is important to mention that we have considered gold in quartz veins only. Other deposit forms (skarn, replacement) may have potential in the Zeballos camp.

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