A Geological Evaluation of the
Cinola (Specogna) Gold Deposit,
Queen Charlotte Islands, B.C.

By

Normand Champigny

A thesis submitted in partial fulfillment
of the requirements for the degree of
master of applied science

in

The Faculty of Graduate Studies
Department of Geological Sciences

We accept this thesis as conforming
to the required standard:

The University of British Columbia
April 1981

© Normand Champigny, 1981
In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Geological Sciences

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date April 10, 1981
Frontispiece - Areal view of the Cinola site, looking west. The deposit is the small hill with many cat roads in the foreground. In the background are rolling hills of the Skidegate Plateau, mainly formed of Tertiary volcanic rocks.
ABSTRACT

Cinola (Specogna) gold deposit in the northern Queen Charlotte Islands, British Columbia, was first discovered in 1970. It is now at the feasibility stage, with proven reserves of 45.4 million short tons averaging 0.054 oz. Au/s.t. The deposit is in a clastic sequence consisting of a lower shale unit (Haida Formation, Late Cretaceous) and an overlying conglomerate-sandstone sequence (Skonun Formation, Middle Miocene). Both sedimentary units are cut by a stock and dykes of rhyolite-porphyry. Two K-Ar model ages indicate mineralization and probably rhyolite-porphyry intrusion at about 14 Ma (Middle Miocene). The model ages, together with plant microfossil and fauna examination, revealed a 17-15 Ma age for the fluvialite Skonun sequence, in which the Cinola deposit occurs.

The deposit is the first Canadian Carlin-type deposit to be described in detail. Gold mineralization is widespread, and occurs as micron-size particles disseminated in the sedimentary host rocks and in quartz veins. Pyrite and marcasite are the main sulphides, and alteration type is dominantly argillic.

The Cinola deposit resulted from the development of a large geothermal system, the energy for which derived from the rhyolitic intrusion. Ore fluids originated from pore water in the fluvialite host rock, as indicated by fluid inclusion studies. Two temperature regimes centred on 160°C and 270°C existed during circulation of the ore fluids. Depth of mineralization
is estimated between 1.1 and 1.8 km.

A geostatistical evaluation of geochemical data from Cinola shows that Au, Ag, Hg, As, Sb, and W have systematic distribution patterns in either primary or secondary environments, and could be useful pathfinders for exploration for similar types of gold deposits. A geostatistical study of assay data has shown the deposit to be particularly amenable to reserve estimation by kriging of selection units.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>xii</td>
</tr>
<tr>
<td>CHAPTER 1: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER II: SPECOGNA GOLD DEPOSIT OF CONSOLIDATED CINOLA MINES LIMITED: AN EXAMPLE OF STRUCTURED PROPERTY EXPLORATION</td>
<td>5</td>
</tr>
<tr>
<td>CHAPTER III: CINOLA GOLD DEPOSIT, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA - A CANADIAN CARLIN-TYPE DEPOSIT</td>
<td>29</td>
</tr>
<tr>
<td>CHAPTER IV: FLUID INCLUSION AND SULPHUR ISOTOPE DATA IN RELATION TO GENESIS OF THE CINOLA GOLD DEPOSIT, QUEEN CHARLOTTE ISLANDS, B.C.</td>
<td>84</td>
</tr>
<tr>
<td>CHAPTER V: NEW EVIDENCE FOR THE AGE OF THE SKONUN FORMATION, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA</td>
<td>104</td>
</tr>
<tr>
<td>CHAPTER VI: CINOLA GOLD DEPOSIT, QUEEN CHARLOTTE ISLANDS, B.C. - A GEOCHEMICAL CASE HISTORY</td>
<td>119</td>
</tr>
<tr>
<td>CHAPTER VII: GEOSTATISTICAL STUDY OF THE CINOLA DEPOSIT, QUEEN CHARLOTTE ISLANDS, B.C.</td>
<td>161</td>
</tr>
<tr>
<td>CHAPTER VIII: CONCLUSIONS</td>
<td>190</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>193</td>
</tr>
</tbody>
</table>
LIST OF TABLES

CHAPTER II:

Table 1. General structure of an exploration program.
Table 2. Structure of property exploration program.
Table 3. Summary of exploration history of Specogna gold deposit.
Table 4. Approximate costs incurred during exploration of the Specogna deposit.

CHAPTER III:

Table 1. Table of Geologic Formations, Queen Charlotte Islands.
Table 2. Lithofacies and Sedimentary Structures Observed in the Skonun Sediments of the Cinola Gold Deposit and other Braided River Systems.
Table 3. Analytical Data and K/Ar model ages, Cinola gold deposit.
Table 4. Opaque Minerals and Their Relative Abundance, Cinola Gold Deposit. Trace amounts means less than 0.1%.

CHAPTER IV:

Table 1. $\delta^{34}\text{S}$ of pyrite sulphur at the Cinola deposit.
CHAPTER VI:

Table 1. Summary of means and standard deviations for raw and log-transformed (base 10) lithogeochemical data, Cinola deposit.

Table 2. Correlation matrix for log-transformed (base 10) lithogeochemical data, Cinola deposit.

Table 3. Means and standard deviations determined graphically for partitioned metal populations of lithogeochemical data, Cinola deposit.

Table 4. Summary of means and standard deviations for raw and log-transformed (base 10) soil geochemical data, Cinola deposit.

Table 5. Correlation matrix for log-transformed (base 10) soil geochemical data, Cinola deposit.

Table 6. Means and standard deviations determined graphically for partitioned metal populations of soil geochemical data, Cinola deposit.

Table 7. Summary of means and standard deviations for raw and log-transformed (base 10) silt geochemical data, Cinola deposit.
Table 8. Correlation matrix for log-transformed (base 10) silt geochemical data, Cinola deposit.

Table 9. Means and standard deviations determined graphically for partitioned metal populations of silt geochemical data, Cinola deposit.

CHAPTER VII:

Table 1. Data types used for geostatistical evaluation of the Cinola gold deposit.

Table 2. Summary of regularized spherical models calculated for down-hole assay data of "unaltered" and "altered" drill hole samples and horizontal data of "unaltered" bench composites, Cinola deposit.

Table 3. Summary of point spherical model calculated for down-hole data of "unaltered" drill hole samples, Cinola deposit.

Table 4. Summary of point spherical model for horizontal data of "unaltered" bench composites, Cinola deposit.
LIST OF FIGURES

CHAPTER II:

Figure 1. Location of Specogna gold deposit

Figure 2. Approximate variations in price of gold per troy ounce (U.S. dollars) to present.

Figure 3. Sequential option agreements relating to the Specogna deposit, and shown as a function of our estimates of the stage of exploration.

Figure 4. Arbitrary relative information measures to quantify information during successive years of exploration, Specogna deposit.

CHAPTER III:

Figure 1. Location map of the Cinola gold deposit, Queen Charlotte Islands, B.C.

Figure 2. Regional geology, Cinola gold deposit (after Sutherland Brown, 1968).

Figure 3. Property geology, Cinola gold deposit.

Figure 4. Cross-section AA'.
Figure 5. Cross-section BB'.

Figure 6. Gold-silver scatter diagram for "low grade" assays from drill core, based largely on 2 m core lengths.

Figure 7. Gold-silver scatter diagram for "high grade" assays (higher than 0.4 oz. Au/ton) based on 2 m core lengths.

Figure 8. Graphic log of diamond drill hole 78-6.

Figure 9. Paragenetic line diagram for the Cinola gold deposit opaque minerals.

Figure 10. Cross-section showing distribution of alteration minerals of the Cinola gold deposit.

Figure 11. Schematic sequence in development of the Cinola gold deposit.

CHAPTER IV:

Figure 1. Histogram of filling temperatures of fluid inclusions in quartz and calcite, Cinola deposit.

Figure 2. Histogram of freezing temperatures of fluid inclusions in quartz and calcite, Cinola deposit.
CHAPTER V:

Figure 1. Map showing the area underlain by the Skonun Formation (dashed line) and location of the Cinola deposit.

CHAPTER VI:

Figure 1. Location map of the Cinola gold deposit.

Figure 2. Procedural path in evaluating Cinola geochemical data.

Figure 3. Most significant correlations (at the 0.01 level) of logarithmically transformed (base 10) lithogeochemical data.

Figure 4. Lognormal probability plot for Sb lithogeochemical data partitioned into upper (A) and lower (B) populations.

Figure 5. Lognormal probability plot for Au lithogeochemical data partitioned into upper (A), median (A'), and lower (B) populations.

Figure 6. Au (ppm x 100) in rock.

Figure 7. Ag (ppm x 10) in rock.
Figure 8. Hg in rock (ppb).

Figure 9. Sb in rock (ppb).

Figure 10. W in rock (ppb).

Figure 11. Probability plot for Cu in soils, partitioned into upper (A) and lower (B) populations.

Figure 12. Au (ppm x 100) in soil.

Figure 13. Hg in B horizon (ppb).

Figure 14. Hg in peat (A horizon) (ppb).

Figure 15. Cu in soil (ppm).

Figure 16. Probability plot for Ag in silts, partitioned into upper (A) and lower (B) populations.

CHAPTER VII:

Figure 1. Location map of the Cinola deposit.

Figure 2. Geological cross-section of the Cinola deposit.

Figure 3. Probability plot for gold assays of 2 m samples from BX core.
Figure 4. Threshold values versus core sample length.

Figure 5. Average experimental down-hole semi-variograms (dashed lines), regularized spherical model (full line), curves for "unaltered" and "altered" data sets, and spherical point model curve for "unaltered" data (dots).

Figure 6. Locations of drill hole collars on the Cinola deposit.

Figure 7. Average experimental horizontal semi-variogram (dashed lines) for all "unaltered" drill hole samples, based on 10 m bench composites.

Figure 8. Kriged block mean grades for 30 x 30 x 10 m$^3$ blocks at the 110 m level.
ACKNOWLEDGMENTS

Special thanks are extended to Dr. A.J. Sinclair for providing guidance and encouragement throughout this study. The author appreciates the financial support and technical assistance of Consolidated Cinola Mines Ltd., in particular, that of K.G. Sanders, President, G. Sanders, Vice-President, S. Lacey and D. Bain, staff geologists, and A. MacKillop, camp manager. This study was also funded in part by a Canadian Natural and Engineering Science Council scholarship and a grant from B.C. Ministry of Energy, Mines, and Petroleum Resources.

Thanks are due to M.G. Cruson, consulting geologist, for numerous discussions on the genesis of the Cinola deposit. Asger Bentzen provided extensive assistance in obtaining computer output for the geostatistical study. His help was greatly appreciated. Charles Henderson completed the fossil identification and Dr. G.E. Rouse (U.B.C.) conducted the palynological analysis.

Fluid inclusion measurements were done by Shen Kun. The detail and accuracy of his work is gratefully acknowledged.

Model ages were calculated by J.E. Harakal. Most of the drawings were executed by John Newlands (U.B.C.). Thanks to Jan Ashdown, who typed the individual papers. The tremendous effort put forth by Roberta Crosby to type the final manuscript is greatly appreciated. John Gardiner provided technical assist-
ance in the field. A special mention goes to Nicole Barcelos for her personal encouragement.
CHAPTER 1

Introduction
Cinola (Specogna) gold deposit is located at longitude 132°13'W, latitude 53°32'N in central Graham Island, the northernmost of the Queen Charlotte Islands, B.C. The deposit was discovered in 1970, but it was not the first time that gold was found in the Queen Charlotte Islands. The first few ounces of gold produced by a lode mine in British Columbia were from the Early Bird Mine on Mitchell Inlet in 1852. Gold occurrences on the islands were all found by prospecting. This shows the pronounced effect of physiographic features such as elevation and vegetation on exploration methods.

The deposit went through several exploration stages during the early 1970's. Feasibility stage was reached in 1979 by the present operator, Consolidated Cinola Mines Ltd. Up to then no rigorous geological evaluation had been done, and there was very little understanding of possible ore controls of this high tonnage - low grade gold deposit.

The first step of a complete evaluation of the Cinola deposit, which is a collection of field data, was undertaken by the writer during the summer of 1979. Detailed drill core examination and surface mapping were completed and new information was checked on several subsequent visits to the property. This thesis is organized in the form of a series of papers that are an outgrowth of the writer's field work. The papers are arranged in a logical sequence, and each one forms a subsequent chapter in this thesis. A brief description of each follows.
Chapter Two shows the structured progression of exploration of this mineral deposit since discovery, and is an attempt to quantify progressive exploration of the property.

A rigorous geological description of the setting of the Cinola deposit is given in Chapter Three. In the concluding part of that chapter a genetic model is proposed.

In Chapter Four additional support to the proposed genetic model is given from fluid inclusions and sulphur isotope data.

K-Ar data combined with palynological and paleontological data from the Skonun Formation, which hosts the Cinola deposit, resulted in a revision of the age of this rock unit. Chapter Five details this age revision.

Chapters Six and Seven are devoted to a statistical analysis of exploration data. In Chapter Six rock, soil, and silt geochemical data from surveys undertaken in the early development of the deposit are re-evaluated using statistical methods. A formal geostatistical approach to ore reserve estimation is described in Chapter Seven. The total amount of drill hole assays were made available to the writer to do geostatistical estimations, including (1) data evaluation, (2) generation of experimental semi-variograms, (3) development of semi-variogram models, and (4) kriging. Geological parameters were also taken into account in this study.
General conclusions are summarized in Chapter Eight.
CHAPTER II

Specogna Gold Deposit of
Consolidated Cinola Mines Limited:
An Example of Structured Property Exploration
ABSTRACT

Specogna gold deposit of Consolidated Cinola Mines Ltd. has generated widespread interest since shortly after its discovery in 1980, when it was described as being of the "Carlin-type", and therefore was thought to have potential for a large tonnage low grade deposit. Exploration since discovery has been ongoing, and has followed a logical structured progression, with early emphasis on surficial measurement techniques and later dominance of subsurface probing by drilling. Property exploration phases include: (1) discovery, (2) preliminary surface evaluation, (3) detailed surface evaluation, (4) direct subsurface exploration, and (5) feasibility. Specogna is presently in the feasibility phase, and has yet to attain the development (6) and production (7) phases of exploration. The importance of various exploration methods, with time, can be monitored by a variety of empirical measures of "relative information gain", the most obvious of which is total drilling per unit time.
INTRODUCTION

Undiscovered ore deposits are hidden resources that commonly elude all but the most thorough search. Even when a mineral occurrence is known, a considerable amount of uncertainty clouds an appreciation of its ultimate worth.

A comprehensive exploration program can be divided into an orderly framework of stages, as illustrated in Table 1 (Fortesque, 1965). This classification is somewhat idealized, and assumes a far-reaching exploration program based on substantial financial resources, a situation that does not always prevail. Nevertheless, such a scheme is a useful conceptual framework for considering exploration for mineral deposits. The underlying principle of this ideal outline is that, as the scale of examination changes progressively from general to specific, more and more detailed information is obtained by which targets become better localized.

In considering a particular mineral property, however, the framework of Table 1 does not provide a realistic or comprehensive appreciation of the detailed and progressive nature of exploration, and a more detailed sequence of subdivisions is warranted. It is often said that "mines are made, not found", an expression that must not be taken too literally, but one that emphasizes the extraordinary insight, cost, and effort generally involved in defining an ore body for the purpose of exploration.
There is little question that the optimal exploration of any mineral property is unique in detail, but just as unique origins for mineral deposits can be grouped into a few principal categories, so can sequential exploration. Early stages in the exploration of many mineral properties depend mainly on the application of surficial evaluation techniques; that is, those methods that are limited to direct observation of surficial material or indirect measurements of the subsurface. In contrast, more advanced stages of an exploration program on a property commonly emphasize subsurface methods that provide direct observations of subsurface material. This orderly sequence derives mainly from the fact that surficial exploration methods provide rapid and cheap information relative to subsurface methods of investigation. Thus, in a staged exploration program, surface methods serve to clarify the precise character of a potential target such that the more costly subsurface investigation can be organized in an optimal manner. Of course, in practice there is overlap—limited drilling may be done early in an exploration project, or some aspects of surface work may be done late in the program.

In other cases, one can imagine that a particular level of exploration, dominant in the evaluation of one property, might be of negligible importance in evaluating another. For example, surface exploration procedures might be extremely important in exploring a deposit that crops out a surface, but such techniques may be unnecessary in exploring a deeply buried deposit located from existing underground workings.
Despite these problems, the concept of staged exploration at the property level is a useful means by which to plan and describe ongoing exploration. Three important levels serve as a basis for discussion: viz., surface exploration, subsurface exploration, and general ongoing exploration during exploitation. From this point of view, these can be viewed as a progression from youth to maturity, and eventually to old age. A detailed documentation of these stages of property exploration is given in Table 2.
Table I

GENERAL STRUCTURE OF AN EXPLORATION PROGRAM

(modified from Fortesque, 1965)

STAGE I: Regional Plan: General concept of an exploration program evolves and target areas for exploration outlined.

STAGE II: Definition of Objectives: A detailed approach to an exploration project is designed with a specific objective to each part of the project.

STAGE III: Detailed Project: This stage of an exploration program involves application of specific methods to the target area and commonly involves three principal levels of exploration.

(a) Regional Level: A broad examination of a regional target area selected in STAGE I. Purpose is to define sub-areas or local targets that appear to be anomalous or, in other words, appear to have a relatively high mineral content compared with the rest of the regional target area.

(b) Followup Level: Local target areas are evaluated by a variety of exploration methods to isolate those with greatest potential for the occurrence of mineral deposits.

(c) Detailed Level: Exploration is designed to test high priority local targets for the presence of mineral deposits with economic potential.

STAGE IV: Development Exploration: Detailed exploration to provide a thorough information base for evaluating the feasibility of mineral production at a profit. In practice it may be difficult to ascertain where STAGE III ends and STAGE IV begins.

Note: Ground acquisition by claim staking, purchase, option agreement, or other method is normally initiated prior to or early in Stage III, but may continue intermittently as information is obtained from an exploration program.
<table>
<thead>
<tr>
<th>PHASE OF EXPLORATION</th>
<th>GENERAL DESCRIPTION OF WORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Discovery</td>
<td>Discovery may result from a staged exploration program, prospecting, wildcat investigations, or accident. This stage includes initial ground control by staking, option, etc.</td>
</tr>
<tr>
<td>2. Preliminary surface evaluation</td>
<td>Limited surficial examination, including conceptual geological appraisal, limited geochemical and/or geophysical responses are measured, sampling for assay and mineralogical studies, limited test pits, and stripping. This is the initial rapid appraisal or &quot;scouting&quot; stage of many major companies.</td>
</tr>
<tr>
<td>3. Detailed surface evaluation</td>
<td>This stage generally begins with the laying out of a regular grid on areas of interest, to serve as a base for detailed geochemical and geophysical surveys and geological mapping. Limited stripping, trenching, and drilling are common at this stage, as a guide to development of geological theories. Systematic sampling.</td>
</tr>
<tr>
<td>4. Subsurface evaluation</td>
<td>Subsurface evaluation involves various types of drilling, generally in a more-or-less systematic manner, and initially with a relatively wide spacing of holes. Other methods, such as sinking exploratory shafts or declines and driving adits and other workings, are less common now than in the past.</td>
</tr>
<tr>
<td>5. Feasibility</td>
<td>The feasibility level begins when a conscious decision is made to mount a detailed program to examine the possibility of economically viable production. Exploration at this stage involves delimiting a mineral deposit in some detail by an extensive regular grid of drill holes, bulk sampling procedures, and pilot plant milling tests. Several stages of feasibility studies may be involved, and will include a thorough evaluation of ore grade and tonnage.</td>
</tr>
<tr>
<td>6. Development</td>
<td>Normally represents a halt in exploration efforts while the deposit is pre-</td>
</tr>
</tbody>
</table>
pared for production.

7. Production An on-going exploration program is common during the productive life of a mineral property. Here both surface and subsurface techniques are used as needs arise. Work can be focussed on extending limits of known ore bodies or searching for new discrete ore zones.
<table>
<thead>
<tr>
<th>Year</th>
<th>(Description)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>Property optioned by Kennco Ltd. Twenty-seven claims and seven fractions added to original group. Four bulk samples (23 kg each) taken and assayed for Cu, Mo, Zn, Pb, Ni, Co, Au, Hg, Ag, As, and Sb. Fifteen hundred soil samples collected at 60 m intervals on claim boundaries. A-horizon samples analyzed for Hg and B-horizon for Cu, Mo, Zn, Pb, Ni, Co, Au, Hg, and Ag. Large Hg and Au anomalies located. Two packsack holes drilled (56 m), and core assayed for Au, Ag, and Hg. Property dropped at the end of 1971.</td>
</tr>
<tr>
<td>1972</td>
<td>Canex Aerial Exploration investigated property from January to May 1972 and conducted limited soil sampling (125 samples), with analysis for Au and Ag. Cominco Lt. took over in the summer of 1972. 6960 m of line were cut; 105 soil samples were analyzed for Au. Air photo interpretation revealing the Footwall fault. 26 trenches and 502 m of diamond drilling (9 vertical holes). Ore picture was 20 to 40 million tons of .035 oz Au/ton. Property dropped at the end of 1972.</td>
</tr>
<tr>
<td>1973</td>
<td>Silver Standard Mines Ltd. optioned the property. Very limited amount of surface work was done. Additional ground was staked. Marino Specogna found new showing with visible gold. A six-ton sample assayed from 2.7 to 16.5 oz Au/ton and 1.5 to 6.7 oz Ag/ton.</td>
</tr>
<tr>
<td>1974</td>
<td>Quintana Minerals Corp. assumed 90% of Silver Standard option contract on May 1, 1974. Two hundred and eighty-one 1.5 m chip samples weighing from 9 to 14 kg each taken from a cliff face .57 m of pack sack drilling (4 holes) and 604 m (18 drill holes) of percussion drilling were performed. Core assayed for Au. Ore reserves were established at 13 m.t. of .046 oz Au/ton, with a cut off of .025 oz Au/ton. Extensive nature of the mineralization verified.</td>
</tr>
<tr>
<td>1975</td>
<td>Quintana Minerals Corp. drilled 5 diamond holes (720 m, BQ size). Staking of 34 additional units. Two metallurgical tests were conducted. Assay discrepancies found in assays of Quintana and also previous assays by Kennco. Unacceptable gold recoveries (50%) and political climate forced the company to drop the prospect. Ore reserves gave 13.8 m.t. at .058 oz Au/ton using a .03 oz/ton cutoff and a depth of 30 m.</td>
</tr>
</tbody>
</table>
1976 No reported work.

1977 Consolidated Cinola Mines Ltd. optioned the property from E. Specogna (44 full claims and 7 fractions). Drilling started in July, using a 30 x 30 m grid. 697 m of diamond drilling (13 vertical holes) with BQ core. Core assayed for gold and part for silver.

1978 Eight vertical holes totalling 1253 m were drilled following a 40 m grid. Bottom of 78-6 hole assayed 0.86 oz/ton and re-assayed 1.15 oz Au/ton, with 0.43 Ag oz/ton over an interval of 24 m. This changed the picture as to mineral potential of the deposit. Aggressive drilling program was proposed for the next year. Cinola purchased the claims at the end of 1978.

1979 From January to August, 3041 m of diamond drilling (15 holes using BQ and NQ size) were performed by Cinola. Drilling extended the mineralization down depth (up to 315 m). Core assayed for gold and some for silver.

Start of joint venture with Energy Reserves Group in August 1979. From August to end of year, 5127 m of diamond drilling completed (33 holes). Initial metallurgical testing completed.

1980 First quarter diamond drilling of 32 holes totalled 3544 m. Additional 10,000 m of drilling planned, as is underground examination, bulk sampling, and a pilot mill program to process 10,000 short tons. Indicated reserves for the southern part of the mineralized system are 28.6 m.t., averaging 0.064 oz Au/ton.
SPECOGNA (BABE) DEPOSIT

Specogna deposit of Consolidated Cinola Mines Ltd. is an interesting example to examine as an exploration case history, because it was discovered relatively recently, and information concerning sequential exploration is readily available. The property is centrally located on Graham Island, the northern of the two largest Queen Charlotte Islands (Figure 1), and is accessible by about 18 km of good quality logging road south from the town of Port Clements.

The original showing, a prospecting discovery by E. Specogna and J. Trico, was staked in 1970 and subsequently was optioned successively to several major exploration companies. Interest was maintained in the showing because of an extensive silicified zone carrying low gold values, and exploration decisions during the decade the property has been examined have been affected by the dramatic variations in the price of gold (Figure 2).

Exploration methodology has been guided by physiographic features such as elevation, overburden, and vegetation cover. Specogna property lies in the border zone between the relatively low and flat Queen Charlotte Lowlands to the east and the higher, more rugged Skidegate Plateau to the west. These two physiographic provinces are separated by a major northwesterly trending fault zone, the Sandspit Fault, of regional extent, that underlies much of the property. A major splay of this
fault, striking 157° and dipping about 50°E, cuts the western part of the property and marks the footwall of the main mineralized zone. Outcrop is sparse on the property, and is concentrated mainly along the scarp of this Footwall fault. The original discovery site is an intensely silicified part of the footwall material along this scarp. Two small hills, with elevations 217 m and 180 m, are the main physiographic features of the property. Total relief is about 100 m.

A description of the geology of the property and reference to earlier works is given by Champigny and Sinclair (1980). In brief, the deposit has been classed as Carlin-type (Richards et al., 1976), and is characterized by a gold-bearing silicified zone at the contact between two host rocks, a Miocene rhyolite (14 Ma) and older coarse clastic sediments of the Miocene Skonun Formation. The silicified and mineralized zone is now known to underly an area of at least 1.3 km². Several stages of silicification are recognized, all of which have associated "micron" gold. Associated sulphides are mainly pyrite and marcasite, with very small amounts of sphalerite, chalcopyrite, pyrrhotite, and visible gold as much as trace amounts of other minerals, galena, cinnabar.

Most of the property is covered by glacial overburden, apparently till, with variable thickness, but commonly about 1.5 m thick. The vegetation cover is principally thick stands of relatively small second growth conifers, mainly sitka spruce, western hemlock, and red cedar. A major river, the Yakoun, lies
Figure 1. Location of Specogna gold deposit.
Figure 2. Approximate variations in price of gold per troy ounce (U.S. dollars) to present.
just to the south of the claims, and several streams drain the
property, flowing south into Yakoun River.

Exploration on the property has been ongoing since original
prospecting in 1970, with the exception of 1976, when little
active work was done. Until very recently, property work has
been confined mainly to summer exploration seasons, despite the
relatively mild, if rainy (average annual rainfall at nearby
Masset of 140 cm), climate compared to the more extreme climate
throughout much of British Columbia. A detailed summary of pro­
gressive exploration of the property is given in Table 3, and
indicates the continuing accumulation of information on which
successive exploration decisions were made. General sequence of
these major decisions is illustrated in Figure 3, where indivi­
dual blocks with company names are organized with respect to
year and our evaluation as to level of corresponding property
evaluation. Each company name implies existence of a formal
agreement to conduct exploration, with an option on eventual
purchase. These options were dropped successively until out­
right purchase of the property in 1978 by Consolidated Cinola
Mines Ltd.

The data of Table 3 indicate a predominance of surface mea­
urement techniques in the early years of exploration, with
drilling much more important in the latter years. Principal
surface work consisted of sampling surface showings for assay
and soil sampling. All companies involved in evaluating the
property rechecked previous sampling and assaying results.
Thus, the emphasis on surface exploration can be illustrated by examining these foregoing types of work.

A rough measure of the relative information obtained from various soil sampling projects must consider number of samples, number of elements analyzed for, and geographic area covered by a survey. Here we ignore the area aspect and adopt an arbitrary method of taking into account the number of samples and the number of elements determined for each sample as a means of indicating relative information obtained. Our procedure is to calculate a quantity \( I_Y = n \sum_{j=1}^{k} (1/j) \), where \( j \) is the element to a maximum of 6, \( n \) is the number of samples, and \( I_Y \) is the relative information gain for a given time period (one year, in our case). Therefore, for the 1500 soil samples taken in 1971 and analyzed for 11 elements, we calculate a relative information \( I_{71} \) of 1500 \( \times \left( \frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} + \frac{1}{6} \right) \) = 3675. The comparable figure for 1972 when 125 samples were analyzed for Au and Ag and 105 samples were analyzed for Au is 293. In an analogous manner, we estimate relative information gain for rock sampling as a function of total sample weight per year, multiplied by the number of claims from which samples were assayed. Relative information from drilling can be approximated by total length drilled per unit of time to provide a relative information measure of the later stages of exploration. These three relative information measures cannot be compared one to the other, but illustrate the changing emphasis with time to individual exploration procedures. Figure 4 shows the changing emphasis of principal evaluation techniques as exploration on the Specogna property pro-
Figure 3. Sequential option agreements relating to the Specogna deposit, and shown as a function of an estimation of the stage of exploration.
Figure 4. Arbitrary relative information measures to quantify information during successive years of exploration, Specogna deposit.

A: Relative information from soil sampling
B: Relative information from rock samples
C: Relative information from diamond drilling

See text for further explanation regarding relative information measures.
gressed.

Of course, in a general way a single parameter such as funds expended per unit time can be used to monitor the general intensity of exploration on a property. Consequently, we include here a summary of annual expenditures (Table 4) estimated by us from reports describing the nature of work performed; that is, the work summarized in Table 3. These costs do not involve office overhead, and are not standardized to a single reference year. Corrections for both overhead and inflation would serve only to further exaggerate the obvious trend of dramatically increasing expenditures as phase of property evaluation progresses.
Table 4. Approximate costs incurred during exploration of the Specogna deposit.

<table>
<thead>
<tr>
<th>Year</th>
<th>Exploration Expenditures ($)</th>
<th>Annual</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>1971</td>
<td>40,000</td>
<td>45,000</td>
<td>45,000</td>
</tr>
<tr>
<td>1972</td>
<td>50,000</td>
<td>95,000</td>
<td>95,000</td>
</tr>
<tr>
<td>1973</td>
<td>20,000</td>
<td>115,000</td>
<td>115,000</td>
</tr>
<tr>
<td>1974</td>
<td>60,000</td>
<td>175,000</td>
<td>175,000</td>
</tr>
<tr>
<td>1975</td>
<td>75,000</td>
<td>250,000</td>
<td>250,000</td>
</tr>
<tr>
<td>1976</td>
<td>0</td>
<td>250,000</td>
<td>250,000</td>
</tr>
<tr>
<td>1977</td>
<td>80,000</td>
<td>330,000</td>
<td>330,000</td>
</tr>
<tr>
<td>1978</td>
<td>750,000</td>
<td>1,080,000</td>
<td>1,080,000</td>
</tr>
<tr>
<td>1979</td>
<td>800,000</td>
<td>1,949,000</td>
<td>1,949,000</td>
</tr>
</tbody>
</table>
CONCLUSIONS

1. Exploration and evaluation of a mineral property can be divided conveniently into logical phases that describe the general framework of an evaluation program, viz. (a) discovery, (b) preliminary surface, (c) detailed surface, (d) subsurface, (e) feasibility, (f) development, and (g) production phases.

2. Early phases of property exploration are dominated by surficial techniques that incorporate direct examination of surficial material on the property and indirect examination of subsurface material.

3. Later phases of property exploration involve techniques that probe the subsurface direction, principally a variety of drilling procedures, but including exploratory underground workings.

4. Specogna deposit of Consolidated Cinola Mines Ltd. is an exemplary illustration of the structured aspect of property exploration and evaluation.

5. As exploration proceeds, the relative importance of a particular exploration method can be monitored approximately by arbitrary measures of information gained per unit time (commonly, per year). In the case of Specogna deposit, empirical methods are presented for measuring relative information
for both soil geochemical data and rock sample analyses. For soil samples, the number of samples, number of elements determined, and survey area are used to estimate relative information. For assayed samples, we consider number and size of samples and area sampled to be general indicators of relative information gain. In the case of drilling, total length of bedrock intersected is accepted as a rough estimate of information gained.

6. These estimates of "relative information" are obviously crude at best, but provide a useful means of monitoring the general importance of various exploration procedures through the course of ongoing property evaluation. Consequently, such selective measures provide a convenient basis for discussing exploration case histories, particularly if it is borne in mind that some flexibility is necessary in determining appropriate measures of relative information gain for a given property.
ACKNOWLEDGMENTS

Mr. A. McKillop has aided immeasurably in providing perspective on some of the early phases of exploration on the Specogna property. Discussion with G.G. Richards and W.K. Livingstone, who had considerable involvement with the property in the past, clarified some aspects of the early exploration.
REFERENCES


CHAPTER III

Cinola Gold Deposit,
Queen Charlotte Islands, British Columbia -
A Canadian Carlin-type Deposit
ABSTRACT

Cinola gold deposit in the northern Queen Charlotte Islands, British Columbia, is in a clastic sequence consisting of a lower shale unit (Haida Formation, Late Cretaceous) and an overlying interbedded sequence of pebble conglomerate and coarse grained sandstone (Skonun Formation, Middle Miocene). Both units are intruded by a stock and dykes of rhyolite-porphyry. Two K-Ar model ages indicate mineralization and probably rhyolite-porphyry intrusion at about 14 Ma (Middle Miocene). A splay of the Sandspit fault system constitutes the footwall on the west of the deposit and marks a sharp contact with adjacent rocks to the west, principally Haida shales.

The Cinola deposit can be classed as Carlin-type, based on features such as (1) small particle size for gold, (2) Tertiary age of mineralization, (3) geochemistry (e.g. high Hg), (4) alteration (dominantly argillic), (5) structural setting (association with major faults), (6) porosity of the host rock, and (7) spatial and possibly genetic association with felsic intrusions. Gold mineralization is widespread and occurs mainly as minute grains (<0.5 μ) in silicified sediments, and in quartz veins. Locally coarse (>100 μ) particles of native gold occur in quartz veins, especially in highly brecciated rhyolite-porphyry. Ore minerals are mainly pyrite and marcasite, but include small amounts of chalcopyrite, sphalerite, galena, pyrrhotite, cinnabar, tiemannite (HgSe), rutile, magnetite, hematite, and limonite, in addition to native gold and electrum. No silver min-
erals have been found, but silver was found in gold particles in amounts varying from 6.2 to 76.4 weight percent. Alteration products are sericite, illite, kaolinite, and chlorite, with abundant quartz of several stages.

Host rocks, specifically the Skonun Formation, formed as an alluvial plain facies in a braided river system discharging into a marine basin in early Middle Miocene time. During Middle Miocene this sequence was intruded by a rhyolitic stock. The highly porous and permeable Miocene clastic sequence apparently provided an optimum setting for development of a large geothermal system, the energy for which probably derived from the rhyolite stock. Mineral deposition followed a well-defined paragenesis, which from oldest to youngest is: (1) precipitation of iron sulphides, and early quartz, (2) several stages of quartz veins with deposition of sphalerite succeeded by galena, chalcopyrite, and visible gold. Micron-size gold was precipitated throughout these two stages of mineral deposition. Argillitization of the host rocks probably coincided in part with the mineralization and continued during cooling of the geothermal cell.

In situ reserves have been estimated at 45.4 million short tons, averaging 0.054 oz Au/s.t., using a cutoff of .025 oz Au/s.t.
Résumé d'auteur

Le gisement Cinola (Specogna) est localisé dans une séquence de mudstones (Formation Haida, Crétacé supérieur) et une séquence de conglomerats a cailloux interlité avec des grès grossiers (Formation Skonun, Miocène Moyen). Un stock de rhyolite porphyrique fait intrusion à travers les deux séquences. Deux datations par la méthode potassium-argon indiquent un âge d'intrusion et de minéralisation d'environ 14 Ma. (Miocène Moyen). Une faille parallèle à la faille régionale Sandspit constitue l'épouze ouest du gisement et marque un contact abrupte avec la séquence de mudstones.

Le gisement Cinola peut être classifié du type Carlin suivant les critères communs suivants: (1) petite taille des particules d'or, (2) âge de la minéralisation (Tertiaire), (3) géochimie (anomalie en mercure par exemple), (4) altération (surtout argillique), (5) contexte structural (association des failles majeures), (6) porosité des roches hôtes, (7) association spatiale et génétique avec des intrusions felsiques. La minéralisation aurifère est étendue et consiste en des particules sub-microscopiques (<0.5\(\mu\)) dans des sédiments silicifiés, et dans les veines de quartz. Localement des grains grossiers (>100\(\mu\)) d'or sont observés ans les veines de quartz spécialement dans les rhyolites porphyriques bréchiques. Les minéraux opaques observés sont presqu'exclusivement la pyrite et la marcasite. De faibles quantités de chalcopyrite, sphalerite, galène, pyrrhotite, cinnabar, tiemannite (HgSe), rutile, magné-
tite, hématite, et limonite sont aussi présentes en plus de l'or natif et de l'électrum. Aucun mineral d'argent a été identifié, de l'argent est contenu dans les particules d'or dans des proportions qui varient de 6.2 à 76.4 pourcentage poids. Les minéraux d'alteration sont la sérive, l'illite, la kaolinite, et la chlorite. Le quartz épithermal est très abondant.

Les sédiments minéralisés d'âge Miocene Moyen ont été déposés par un fleuve possédant un drainage tressé qui se déchargeait dans un bassin marin. L'intrusion du stock de rhyodiste porphyrique au Miocene Moyen a créé une immense cellule géothermale, l'énergie de celle-ci étant dérivée de l'INTRUSIF.

La minéralisation aurifère s'est produite suivant la paragenèse suivante (du plus vieux au plus jeune): (1) précipitation des sulfures de fer et d'une première génération de quartz; (2) plusieurs épisodes de veines de quartz accompagnés par la déposition de la sphalerite suivie par la galène, la chalcopyrite, et l'or visible. L'altération de type argilique a probablement débuté pendant la minéralisation et s'est continuée durant le refroidissement de la cellule géothermale. Le minerai prouvé a été estimé à 45.4 millions de tonnes avec une teneur moyen en or de .054 once Au/tonne courte en utilisant une teneur de coupure de .025 once Au/tonne courte.
INTRODUCTION

Cinola gold deposit, known also as Babe and Specogna deposit, is centrally located on Graham Island, the northern of the two largest Queen Charlotte Islands (Figure 1). It is accessible by about 18 km of logging road south from the town of Port Clements. Five companies optioned the property successively from 1971 to 1975 (Champigny et al., 1980). Consolidated Cinola Mines Ltd. acquired the claims by option in 1977 and purchased them in 1978. Since August 1979 Energy Reserves Group and Consolidated Cinola Mines Limited have undertaken a 50-50% joint evaluation venture on the property. Indicated open pit reserves are estimated at 45.4 million short tons grading .054 oz. Au/s.t., using a cutoff of .025 oz. Au/s. t. This includes 10% dilution from the walls of the orebody and from included waste. Silver grade is about the same as gold. Sutherland Brown and Schroeter (1975) were the first to describe the showings formally and produced a generalized geological cross-section of the deposit. Richards et al. (1976, 1979) classified the deposit as Carlin-type and published the first K-Ar age determination. Champigny and Sinclair (1980) published a more detailed description of the geology based on preliminary interpretation of surface and drill hole data obtained to the end of August 1979.

This account is based on geological examination of 5506 m of diamond drill core and limited surface exposure during the summer of 1979 followed by laboratory studies at the University
Figure 1. Location map of the Cinola gold deposit, Queen Charlotte Islands, B.C.
of British Columbia. Computer-oriented core logging techniques (GEOLOG System) were used as a basis for the field work (Blanchet and Godwin, 1972; Godwin, Henderson and Blanchet, 1977).
REGIONAL GEOLOGY

The Queen Charlotte Islands form part of the Insular Tectonic Belt of the Canadian Cordillera and are composed of rocks ranging in age from Late Triassic to Recent (Sutherland Brown, 1968) (Table 1). Three major periods of volcanism are recognized that separate four principal episodes of sedimentation. Plutonism seems to be confined to two main periods. Bodies of hornblende diorite to quartz diorite composition were emplaced in the Middle to Late Jurassic and a more varied sequence of quartz diorite to alkakine granitic rocks was intruded in the Early to Middle Tertiary. Crustal fracturing (mainly major northwesterly striking faults) has had a pronounced effect on volcanism, sedimentation, intrusion and secondary folding (Sutherland Brown, 1968).

The general area about the Cinola gold deposit is underlain by three main rock units, Haida Formation of Late Cretaceous age, Masset Formation of Early to Middle Tertiary age and Skonun Formation of Middle Miocene age (Figure 2). These rocks are cut by the Sandspit fault system of regional extent (Sutherland Brown, 1968). Sandspit fault system separates the two main physiographic provinces of the area, Queen Charlotte Lowlands on the east and the Skidegate Plateau to the west. The fault zone strikes about 143 degrees and seems to represent a large vertical movement. Southwest of the deposit the Haida Formation is mainly composed of shales. Skonun Formation overlies the Haida Formation unconformably and is composed of conglomerate with
coarse pebbles to small cobbles, coarse sandstone and minor siltstone or shale. West of the gold prospect volcanic rocks of the Masset Formation mark the beginning of the Skidegate Plateau. Near Cinola deposit Masset volcanic rocks are mainly olivine basalt.
PLEISTOCENE-RECENT  
glacial and interglacial sediments

LATE TERTIARY  
SKONUN FM: marine and non-marine sands

EARLY TO MIDDLE TERTIARY  
MASSET FM: alkali basalt floods and sodic rhyolite ash flows

LATE CRETACEOUS  
SKIDEGATE FM: marine sandstones and siltstones
HONNA FM: conglomerates
HAIDA FM: marine sandstones and shales

EARLY CRETACEOUS  
LONGARM FM: marine lithic wackes and calcareous siltstones

UPPER TRIASSIC TO LATE JURASSIC  
YAKOUN FM (M. JURASSIC): explosive andesitic volcanics
MAUDE FM (L. JURASSIC): marine shales and sandstones
KUNGA FM (L. JURASSIC AND UPPER TRIASSIC): limestones
KARMUTSEN FM (U. TRIASSIC): mafic volcanics

Table 1. Table of Geologic Formations, Queen Charlotte Islands.
Figure 2. Regional geology, Cinola gold deposit (after Sutherland Brown, 1968).
STRATIGRAPHY

The deposit underlies a small hill (210 m above sea level) in the transition zone between the Skidegate Plateau and the Queen Charlotte Lowlands. A shale unit (Haida Formation) and an overlying interbedded sequence of pebble conglomerate and coarse sandstone (Skonun Formation) are both intruded by an elongate stock of rhyolite-porphyry (Figure 3). A thin cover of glacial till and sand overlies the area and outcrops are scarce in the vicinity of the deposit.

Shale Sequence - (Haida Formation, Late Cretaceous)

This formation underlies an area from the Tertiary volcanics on the west side of the deposit to the overlying coarse clastic sequence to the east. Thickness of the shale sequence at the Cinola deposit is unknown - a maximum thickness of 34 m was penetrated in one drill hole. The unit is mainly dark grey to black, poorly consolidated and thinly bedded calcareous shale. Minor sandy layers are present. Near the contact with the rhyolite-porphyry, the shale sequence becomes an argillite or hornfels due mainly to intense silicification. On the basis of lithology this shale sequence appears to correlate with the upper member of the Haida Formation.
Figure 3. Property geology, Cinola gold deposit. Topographic contours in metres a.m.s.l. are shown only on the east side of the Footwall Fault which separates shale from the other two units AA' and BB' are locations of cross sections in Figures 4 and 5.
Conglomerate - Sandstone Sequence (Skonun Formation, Miocene)

A coarse-grained sedimentary sequence overlies the shale sequence and extends eastward to the Sandspit fault (Figure 3). The contact between the two units has not been observed clearly in drill core because of pervasive silicification and intrusion of the rhyolite-porphyry (Figures 3, 4 and 5). Thickness of the sequence throughout the drilled area varies from 0 to 300 m. Strike changes from northwesterly to northeasterly with most of the values around 015°. Strata consistently dip 15° to 25° to the east. Thickness of individual conglomerate, sandstone or siltstone layers range from 0.1 to 30 m, with a 2 m average. The sequence contains about 62 percent conglomerate, 26 percent coarse sandstone, 7 percent intercalated sandstone and siltstone with rare shale interbeds and 5 percent matrix supported conglomerate. Basal contacts of rock units are generally sharp but rare transitional contacts are also observed. Mafic volcanic, pebble-rich conglomerate, interbedded sandstone and shaley siltstone and some sandstone have been used successfully for stratigraphic correlation among drill holes as is apparent in Figures 4 and 5.

The principal rock type is a medium grey to pale brown polymictic conglomerate with well rounded to subangular large pebbles and small cobbles. Graded bedding and load cast structures are abundant. The coarse fraction totals 70 percent of the rock with an average fragment diameter of 3 cm. Particles are moderately sorted and sphericity is low to intermediate.
Most of the conglomerate units are pebble supported. Pebble and cobble lithologies are 60 percent felsic volcanic rock, 20 percent mafic volcanic rock, 10 percent granite, 5 percent argillite and shale and 5 percent conglomerate, sandstone, siltstone and chlorite schist. Acid volcanic clasts include massive and banded rhyolite, rhyolite-porphyry, quartz and rare pyroclastics, chert and hematitic rhyolite-porphyry. Mafic volcanic pebbles are mostly dark green porphyritic andesite with plagioclase and hornblende phenocrysts commonly altered to chlorite and epidote. Granitic fragments consist of a quartz-feldspar mosaic with about 10 percent disseminated biotite or chlorite. Rare wood fragments are intermixed with the coarse and fine fractions. The matrix of these conglomerates occupies 30 percent of the volume of the rock and consists of sand-sized particles of quartz and rock fragments. Distinguishing quartz cement from quartz clasts is difficult in most of the samples due to the poor definition of quartz clast boundaries. The mosaic and sutured contacts suggest that recrystallization during mineralization may have destroyed many original clast boundaries.

Sandstone units are medium grey to dark brown and medium to coarse grained with bedding and graded bedding commonly apparent. Quartz and volcanic rock fragments comprise most of the grains. Two to 15 percent wood fragments are present commonly aligned parallel to bedding. Leaves have been found in sandstone units. One small outcrop of sandstone contains abundant well preserved pelecypods. The shells are relatively thick and
Figure 4. Cross-section AA' - Location shown on figure 3. See figure 5 for legend.
Figure 5. Cross-section BB'.

CROSS-SECTION BB'
most of them are flat lying. One spheroidal concretion was observed in a sandstone bed.

Minor but persistent medium to pale grey interbedded sandstone and siltstone–shale units are found throughout the deposit. They show bedding, graded bedding, cross-bedding, ripple marks and rare convoluted bedding and flame structures.

Massive, matrix-supported conglomerate units are found locally. These units consist of angular fragments of sandstone and conglomerate in a matrix of silty mud.

Similar lithologies and types of clasts, abundance of carbonaceous material and regional stratigraphic setting suggest that this sedimentary sequence correlates with the basal part of the Skonun Formation of Middle Miocene age found in the lower part of the Tow Hill well (Sutherland Brown, 1968, p. 120) to the northeast. The designation of this coarse clastic sequence as pyroclastic material by previous geologists is misleading in the light of our detailed megascopic and microscopic studies. An epiclastic volcanic component does occur with other fragment types. No relict textures were seen which would indicate the presence of a pre-existing pumice or rhyolite as reported by Cruson and Limbach (personal communication, 1980).
ENVIRONMENT OF DEPOSITION AND AGE OF SKONUN SEDIMENTS

The coarse nature of the sediments, their polymictic character and erosional contacts between conglomerate and sandstone units strongly suggest a fluviatile environment of deposition for the Skonun sediments, either as meandering river deposits or braided river deposits (Blatt et al., 1972, p. 199). In sediments deposited by meandering rivers framework conglomerates are uncommon and occur only as localized lag concentrates. In contrast framework conglomerate dominate sediments deposited in modern braided rivers. Framework conglomerate is the dominant lithofacies at the Cinola deposit and according to Rust (1978) is evidence for deposition by a braided river system. Rust (1978), Miall (1978), and Vondra and Burggraff (1978) described distal braided rivers and alluvial plains sequences very similar to the Skonun sediments present at the Cinola deposit. Table 2 is a list of the lithofacies and sedimentary structures both observed at the Cinola deposit and in recognized distal braided rivers and alluvial plain deposits.

Conglomerate and sandstone units make up 85-90% of the total sediment volume, the remainder consisting of silty mudstone and minor shale. Conglomerate-sandstone units are interpreted as deposits of the active tract, whereas mudstone and plant fragments accumulated on inactive areas. The active tract migrated across the floodplain; the area eventually became inactive and accumulation of mud and support vegetation began, although minor channels still remained to transport sand during
flood periods.

Much of the detritus found in the fluviatile sequence is most likely to have been derived and transported eastward from the Early to Middle Tertiary volcanic rocks of the Masset Formation. The coarse clasts are mostly rhyolite, quartz-feldspar porphyry and porphyritic andesite all of which except porphyritic andesite, are very common in exposures of Masset Formation. Jurassic andesitic agglomerates, Upper Cretaceous shales and intrusions could be the sources for chloritized andesitic, argillite and granitic clasts respectively.

Rust (1972) found framework gravel 50 km from the river's source in a comparable fluviatile sequence. Occurrence of boulder-sized rock fragments, presence of some debris flow units and proximity of the probable source area suggest a distance of transport much shorter than 50 km, although most of the Skonun rocks appear distal.

A sample of carbonaceous siltstone with abundant pyrite was collected by the authors in the eastern part of the deposit (drill hole 79-14) and submitted for palynological analysis. In addition, three samples of shelly sandstone were collected on a surface trench. The plant microfossil assemblage and fauna reveal an early Middle Miocene age (17-15 Ma) for the deposition of the Skonun (Champigny, Henderson and Rouse, 1981). The suggested environment of deposition is that of near shore, possibly an estuarine environment which is in accord with the sedimento-
Table 2. Lithofacies and Sedimentary Structures Observed in the Skonun Sediments of the Cinola Gold Deposit and other Braided River Systems.

<table>
<thead>
<tr>
<th>APPROX. % TOT. SED. VOL</th>
<th>LITHOFACIES</th>
<th>SEDIMENTARY STRUCTURES OBSERVED</th>
<th>INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>62</td>
<td>MASSIVE OR CRUDELY BEDDED FRAMEWORK CONGLOMERATE</td>
<td>- GRADED BEDDING</td>
<td>CHANNEL DEPOSITS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- RARE HORIZONTAL BEDDING</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>SANDSTONE, MEDIUM TO VERY COARSE, MAY BE PEBBLY</td>
<td>- HORIZONTAL LAMINATION</td>
<td>CHANNEL DEPOSITS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- WOOD FRAGMENTS</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SAND, SILT, MUD</td>
<td>- FINE LAMINATION</td>
<td>OVERBANK OR WANING FLOOD DEPOSITS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- CROSS LAMINATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- RIPPLE MARKS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- PELECYPODS</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>MASSIVE MATRIX SUPPORTED CONGLOMERATE</td>
<td>NONE</td>
<td>DEBRIS FLOW DEPOSITS</td>
</tr>
</tbody>
</table>
logical interpretation proposed here.
RHYOLITE-PORPHYRY - MIDDLE MIOCENE

An elongate stock of rhyolite-porphyry and associated dykes crop out sparsely east and west of the Footwall fault. The intrusion cuts both the shale and conglomerate-sandstone sequence. Locally the contact with the coarse sedimentary rocks is sharp but in many places a transition zone exists. The contact zone is composed of a mixture of highly deformed conglomerate, sandstone and rhyolite fragments in an aphanitic white to bluish-grey siliceous matrix. The thickness of the rhyolite-porphyry mass decreases to the east (Figures 4 and 5). The rock is pale grey and contains 1 to 3 percent bluish-grey subrounded quartz-eyes 0.1 to 4 mm in diameter and 5 to 8 percent white subhedral to euhedral feldspar phenocrysts, 0.1 to 5 mm long.

Plagioclase phenocrysts (mainly albite) are more abundant than potassium feldspar phenocrysts. The rhyolite is brecciated in many places with angular fragments of rhyolite and shale contained in a very fine grained matrix of dark grey to black silicified shale. In the conglomerate units close to the intrusive mass, angular fragments representing broken pebbles are visible. These breccias are probably related to the intrusion of the rhyolite-porphyry.

Recent K-Ar data on the Tertiary volcanics (Masset Formation) compiled by Young and Chase (1976) resulted in a revision of their age. Sutherland Brown's (1968) interpretation and his single K-Ar analysis gave a Paleocene to Eocene age.
Nineteen recent whole rock K-Ar analyses provide ages ranging from 11 to 84 Ma. At least two interpretations are possible from these data: (1) there is more than one Tertiary volcanic cycle or (2) the younger dates are reset from Early Tertiary ages. If we accept the first interpretation then the rhyolite-porphyry intrusion could represent a plutonic phase associated with a Late Tertiary volcanic cycle. The Sandspit fault system probably also played an important role in the localization and form of the rhyolite-porphyry stock.
STRUCTURE

The major structural feature on the Cinola gold deposit is the Footwall fault which strikes 180 to 157 degrees and dips 53 degrees to the east (Figures 4 and 5). The Footwall fault parallels the Sandspit fault system and probably is a part of that system. In the drill core the Footwall fault is recognized by: (1) an abrupt change from silicified shale to soft, fresh shale and (2) slickensides in altered rhyolite-porphyry and silicified shale. In the northwestern part of the deposit, an outcrop called the Marino showing exposes the fault contact. Also on surface the fault is visible as a fault scarp near the southwest boundary of the deposit (Figure 3).

The rhyolite-porphyry is observed both beneath and above the Footwall fault. Thus, faulting occurred at least in part after intrusion of the rhyolite-porphyry. Absence of Middle Miocene sediments on the west side of the Footwall fault, and displaced geochemical anomalies and drainage patterns suggest a dextral fault with some relative downward movement of the east block. This is the same movement picture observed for the Sandspit fault system (Sutherland Brown, 1968, p. 153).

Tow Hill well drilled on the eastern block of the Sandspit fault in the late 1950's shows the base of a conglomerate-sandstone sequence at 1800 m b.m.s.l. (Sutherland Brown, 1968). The Skonun sediments are exposed on the west side of the Sandspit fault system at the Cinola deposit at a minimum elevation near
-200m. Gravity measurements by Young and Chase (1976) give a dip for the Sandspit fault of 50 to 70 degrees east and a vertical displacement of approximately 1500 metres (east block down). This compares well with a vertical difference of 1600 metres between the Skonun sediments of the Cinola deposit and Tow Hill well. The Footwall fault on the Cinola gold deposit has been active after the intrusion of the rhyolite-porphyry, that is, after 14 Ma. Similar strike, dip and movement pictures of the Footwall fault and the Sandspit fault strongly suggest that the two result from the same stress pattern.
FORM AND SETTING OF CINOLA DEPOSIT

The Cinola deposit extending over an area of at least 1.3 K² appears to terminate abruptly against the Footwall fault on the west and disappears gradually to the north and east (Figure 3). Depth extent is unknown but is at least 350 m. In size and shape the mineralized system rivals small porphyry systems. The mineralizing system is characterized by a prominent zone of silicification with a few percent of pyrite and marcasite. Gold and silver values are widespread over the same area. Gold values range between .01 and 4.55 oz. Au/short ton. High grade gold values (i.e., higher than 0.20 oz. Au/short ton) are found in quartz veins sporadically throughout the deposit and in quartz veinlets at the contact zone between the rhyolite-porphyry and the Skonun conglomerates (Figure 8). The rocks are highly anomalous in mercury and arsenic and less anomalous in antimony and tungsten.

Intense silicification characterizes the host rocks. The degree of silicification increases in a general way towards the rhyolite-porphyry body. Several generations of veins and stringers cross-cut the host rock.

Large veins up to several metres width strike 020±20 degrees and dip 60° to 90° in either direction. Increasing spatial density of quartz veins near mineralized rhyolites has been measured quantitatively in most drill holes (Figure 8). Individual veins present clear accretionary features such as
crustification, chalcedonic quartz and development of well-formed quartz and calcite crystals reaching 2 cm in size with coxcomb texture in drusy cavities. Banding in the veins is common; several coloured bands of quartz show the different episodes of veining. Microveins and stringers commonly pervade wood fragments, producing a chess-board texture on a hand specimen scale. Cross-cutting relationships support the following sequence of veining in order of decreasing age: a) black to grey chalcedonic quartz, b) hematitic quartz, c) massive milky quartz d) clear euhedral quartz and e) calcite.

Wall rock silicification is common and in many places conglomerate clasts are brecciated and incorporated within a quartz vein. This is seen only with black and grey quartz veins. It is often difficult to distinguish between vein material and host rocks.
Figure 8. Graphic log of diamond drill hole 78-6. See Figure 5 for location and legend.
WALLROCK ALTERATION

Alteration minerals identified in the drill core and thin sections include in decreasing order of abundance; quartz, illite, kaolinite, sericite and chlorite. Iron hydroxides are also present near the surface.

Quartz is the predominant mineral and is present in two generations; (1) a first generation of cryptocrystalline quartz cement binding pebbles and smaller clasts of the original sediment and (2) a second generation of blocky clear crystals, 0.1 mm to 2 cm in diameter occurring as void fillings, vugs and veins. This latter generation corresponds to the sequence of mineralization described elsewhere in this account. This second generation of quartz is clearly related to gold mineralization. Thus, two periods of silicification have affected the original sediment.

Quartz cement has corroded parts of lithic clasts and produced quartz overgrowth. Cementation destroyed the clast boundaries which locally are reduced to an iron oxide rim. Quartz cement commonly rims pyrite grains and carbonaceous fragments.

In quartz veins, coxcomb structure is common. In numerous veins, thin selvages of quartz are coated with pyrite, which in turn is covered with drusy quartz crystals projecting to the interior of the vein where they are encased in pyrite crystals. This common texture shows that quartz deposition in part pre-
ceded formation of all opaque minerals and continued to some extent during deposition of opaque minerals. Plagioclase phenocrysts of the porphyritic rhyolite are replaced in many places by quartz.

Argillic alteration is extensive. Illite and kaolinite are the two clay minerals identified by X-ray diffraction. These clays seem to be the results of hydrothermal alteration based on their random orientation and fibrous habit in the mineralized rocks. Illite and kaolinite occur; (1) with quartz cement in the matrix of rhyolites, conglomerates, sandstones and siltstones (2) as void and vein filling, commonly coating quartz crystals and (3) as alteration of feldspar phenocrysts.

Clusters of idiomorphic pyrite crystals are found in clay-altered rocks. At the contact zone between the Miocene sediments and the rhyolite-porphyry argillically altered sediments are silicified with very fine grained quartz. This superimposed silicification on argillic alteration has been referred to as an advanced argillic alteration in porphyry-copper deposits by McMillan and Panteleyev (1980). These observations suggest that illitization and kaolinization took place during and after quartz and sulphide deposition. Taylor and Fryer (1980) observed that phyllic overprinting affected all primary minerals except quartz and pyrite which is also the case with the argillic alteration at Cinola.

A zone of argillic alteration (in which more than 30% of
the gold-bearing rock is composed of clays) constitutes the eastern boundary of the mineralization (Figure 10). This argillized zone dips steeply to the west and, in general, gold values are less than .01 oz. Au/short ton.

Sericitic alteration is found mainly as finely disseminated grains on feldspars phenocrysts of conglomerate pebbles and of the rhyolite-porphyry. Small amounts also occur in the matrix of rhyolites, conglomerates, fine grained sediments and in silicified shales. An earlier phyllic zone could have been present around the intrusion but the pervasive nature of the argillic alteration makes recognition of any early alteration stage very difficult if not impossible.

Except for alteration of phenocrysts in andesitic pebbles in conglomerate units, chlorite occurrences seem to be limited to the contact zone of the rhyolite-porphyry where the mineral is finely disseminated with quartz, illite and kaolinite. Chlorite might represent, (1) an alteration product of a glassy chilled margin of the rhyolite intrusion or (2) a mineral phase related to early hydrothermal alteration.

Iron hydroxides are present on surface exposures and up to 20 m in depth in drill holes. They form pale yellow to reddish-brown fine-grained earthy material filling and lining boxwork cavities and veinlets. They result from oxidation of pre-existing sulphides, principally pyrite and marcasite.
OVERBURDEN

SHALE

RHYOLITE PORPHYRY

ADV. ARGILLIC ALT’N.

SILICIFICATION ± SERICITIZATION

ARGILLIC ALT’N.

UNALTERED SEDIMENTS
Figure 10. Cross-section showing distribution of alteration minerals of the Cinola gold deposit. Argillic alteration indicates that the sediment is composed of more than 30% clays (illite and kaolinite). Grades in the argillic alteration zone are less than .01 oz. Au/ton. Advanced argillic alteration signifies that silification is superimposed on argillic alteration. The rhyolite-porphyry and the shale within a few metres of the fault contact are silicified, sericitized and gold-bearing.
ORE MINERALOGY

Opaque minerals recognized in the Cinola deposit are listed in Table 4 with an indication of their approximate abundances in 60 specimens examined in detail. Mineralized rock contained from 0.5 to 10 percent opaque minerals with an average of about 3% (by volume). Two general mineral associations are present in the deposit (Figure 9): pyrite-marcasite in silicified host rocks and pyrite-marcasite-sphalerite-chalcopyrite-galena-native gold in quartz veins.

Pyrite and marcasite are the most common metallic minerals. Four generations of pyrite are present. In order of decreasing age they are; (1) "raspberry-like" pyrite, rarely observed and possibly of sedimentary origin, (2) fine grained melnikovitic pyrite occurring as coatings and fissure fillings in pebbles of conglomerates, (3) well developed single crystals or crystal clusters in the coarse fraction and cement of the silicified sediments and (4) pyrite in quartz veins and vugs where it is disseminated or forms layers in cryptocrystalline quartz. Pyrite and marcasite occur individually or together. Individual grains range from .01 to 4 mm. Sulphide rims around pebbles in the conglomeratic host consist of disseminated pyrite grains (.001 to .05 mm). Marcasite commonly forms groups of small lath-shaped crystals and in places shows the characteristic coxcomb form. Quartz, pyrite and marcasite have filled spaces in wood fragments. Graphite was observed rarely with the organic matter. In conglomerate units pyrite and marcasite are distri-
buted through both the matrix and pebbles indicating a deposition subsequent to the formation of the sediment. No definite correlation can be obtained between sulphide content and gold values (Figure 8).

Inclusions of pyrrhotite, hematite and rarely magnetite and rutile were observed in pyrite grains. Five pyrite-marcasite grains were analyzed with the electron microprobe and in one grain 1.1 weight percent arsenic was measured. No arsenopyrite has been identified in the deposit and the high arsenic content can probably be attributed to solid solution of arsenic in pyrite and/or marcasite.

Rutile occurs as lath-shaped disseminated grains or aggregates. Grains are relatively small; around .02 mm. No other metallic minerals are in contact with rutile apart from abundant pyrite. Rutile could have been a primary mineral as it is not found in quartz veins.

Small amounts of pyrrhotite are found as inclusions from .01 to .03 mm in diameter in pyrite and marcasite. Hematite occurs as finely disseminated grains (<.005 mm) in quartz veins giving a brownish-red colour to the quartz. Trace amounts of hematite are found as inclusions (.01 to 0.1 mm) in pyrite or marcasite. Magnetite is very rare and was found as anhedral to euhedral grains from .02 to .3 mm in size included in pyrite and on one sample as an inclusion in cinnabar. Mercury minerals (cinnabar and tiemannite, HgSe) were observed in one quartz vein
<table>
<thead>
<tr>
<th>MINERAL</th>
<th>SILICIFIED HOST ROCK</th>
<th>QUARTZ VEINS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PYRITE</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>MARCASITE</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>RUTILE</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>PYRRHOTITE</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>HEMATITE</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>MAGNETITE</td>
<td>TR</td>
<td>TR</td>
</tr>
<tr>
<td>SPHALERITE</td>
<td>-</td>
<td>TR</td>
</tr>
<tr>
<td>CHALCOPYRITE</td>
<td>-</td>
<td>TR</td>
</tr>
<tr>
<td>GALENA</td>
<td>-</td>
<td>TR</td>
</tr>
<tr>
<td>GOLD</td>
<td>NOT VISIBLE</td>
<td>TR</td>
</tr>
<tr>
<td>CINNABAR</td>
<td>-</td>
<td>TR</td>
</tr>
<tr>
<td>TIEMMANITE</td>
<td>-</td>
<td>TR</td>
</tr>
</tbody>
</table>

Table 4. Opaque Minerals and Their Relative Abundance, Cinola Gold Deposit. Trace amounts means less than 0.1%.
Figure 9. Paragenetic line diagram for the Cinola gold deposit opaque minerals.
sample. Cinnabar is present as .01 to .05 mm disseminated patches in quartz. "Framboidal-like" pyrite is associated with cinnabar in several places.

Sphalerite is present only rarely but is the most abundant sulphide after pyrite and marcasite. It is encountered only in quartz veins generally in contact with pyrite, marcasite, chalcopyrite, galena and gold. Grains are generally irregular and their size vary from .01 to .02 mm. Sphalerite has been observed with inclusions of pyrite, chalcopyrite, galena and quartz, but many grains are clear of inclusions. Molecular percent FeS in sphalerite obtained from seven electron microprobe analyses range from 11 to 25 molecular percent indicating that sphalerite in the Cinola deposit is iron-rich. Chalcopyrite is less abundant than sphalerite and occurs closely associated with sphalerite either as inclusions in sphalerite or as simple composite sulphide grains or monominerallic grains. Grain size is comparable to sphalerite. All chalcopyrite grains are irregular. Thin veinlets of chalcopyrite were observed cross-cutting sphalerite grains. Rounded inclusions of native gold in chalcopyrite were observed in a few places. Galena is very rare and is observed in polymineralllic aggregates with sphalerite, chalcopyrite and gold, grains are .01 to 0.1 mm in size. One veinlet of galena cross-cutting a sphalerite grain was found. From 20 to 23 molecular percent Se was recorded in three electron microprobe analyses of galena grains, so the mineral is actually in the solid solution series galena-clausthalite. Native gold occurs in three principal ways (1) micron-gold (<0.5μ) in all
the rock types that have undergone silicification (quartz veins included), (2) as monominerallic grains in quartz veins and (3) included in chalcopyrite in quartz veins. The third association is only found locally. The visible gold grains (>10μ) are highly irregular with some as large as 500μ. Inclusions of gold in chalcopyrite are 10μ on average and are more-or-less rounded.

Eleven visible gold grains (>100μ) occurring in quartz veins were analyzed with the electron microprobe. All the gold contains silver ranging from 6.2 to 76.4 weight percent. Calculated Au/Ag ratios vary from 0.2 to 15.1 with an average and standard deviation of 6.3 and 4.9 respectively. These results contrast somewhat with gold-silver scatter diagrams for assays from drill core (Figures 6 and 7) which on average show about twice as much gold as silver. Nevertheless, we conclude that (1) virtually all the silver is tied up in solid solution with gold and (2) silver minerals other than gold-silver solid solution are unlikely to occur, none have been found to date. The trace amount of galena present may contain some silver. One gold analysis showed 9.8 weight percent Te in a grain abnormally enriched in silver (wt. % Ag = 76.4).
Figure 6. Gold-silver scatter diagram for "low grade" assays from drill core, based largely on 2 m core lengths.
Figure 7. Gold-silver scatter diagram for "high grade" assays (higher than 0.4 oz. Au/ton) based on 2 m core lengths.
AGE OF MINERALIZATION

Intrusion of rhyolite-porphyry and gold mineralization are closely related in space, time and perhaps genesis. Quartz veins of the mineralizing system cut the rhyolite-porphyry near its eastern margin indicating that at least some mineralization took place after the emplacement of the felsic plug.

Two samples of gold-bearing silicified porphyritic rhyolite and one sample of gold bearing silicified shale were dated by the K/Ar method and analytical data and model ages are given in Table 3. All three samples contained about 1% disseminated pyrite. A 17.4 Ma model age was obtained for silicified shale adjacent to the rhyolite-porphyry and represents a reset or partially reset age of the Late Cretaceous shale. Thus, the model age appears to be a maximum possible age of emplacement of the rhyolite-porphyry, a conclusion in accord with the early Middle Miocene age indicated by palynology for the Skonun Formation which is cut by the rhyolite-porphyry (Champigny, Henderson and Rouse, 1981). The two 14 Ma model ages for silicified and sericitized rhyolite-porphyry almost certainly represent the age of mineralization as well as minimum age of emplacement of the rhyolite-porphyry. These data indicate that both intrusive and mineralizing events were confined to a maximum interval of about 3 million years. We favour an interpretation in which 14 Ma represents the time of both intrusion and mineralization, and the 17.4 Ma model age was not completely reset by heat from the rhyolite-porphyry and/or the mineralizing fluids.
Table 3. Analytical data and model ages, Cinola gold deposit.

<table>
<thead>
<tr>
<th>Sample Identification</th>
<th>Rock Type</th>
<th>%K + b</th>
<th>40Ar (rad) / 40Ar (total)</th>
<th>40Ar (rad) (10^-7 cm^3 STP/g)</th>
<th>Apparent Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22065 Ma</td>
<td>Silicified Rhyolite Porphyry</td>
<td>1.19+0.04</td>
<td>.532</td>
<td>6.522</td>
<td>14.0+0.6</td>
</tr>
<tr>
<td>7906 D01</td>
<td>Silicified Rhyolite Porphyry</td>
<td>5.31-0.12</td>
<td>.440</td>
<td>29.22</td>
<td>14.1+0.6</td>
</tr>
<tr>
<td>7805 D01</td>
<td>Silicified Shale (Haida Formation)</td>
<td>2.91+0.04</td>
<td>.505</td>
<td>14.85</td>
<td>17.4+0.5</td>
</tr>
</tbody>
</table>

a Results provided courtesy of N.C. Carter and G.G. Richards
b error is one standard deviation (laboratory measurement error)
c constants used for model age calculations:  
\[ \lambda_a = 0.581 \times 10^{-10} \text{ year}^{-1} \]
\[ \lambda_\beta = 4.96 \times 10^{-10} \text{ year}^{-1} \]
\[ \frac{40K}{K} = 1.167 \times 10^{-4} \]
CLASSIFICATION OF THE CINOLA DEPOSIT

Richards et al. (1976) consider the deposit to be of the Carlin type, a conclusion supported by the authors' observations. Features in common with the gold deposits of north-central Nevada (Carlin, Cortez, Getchell and Gold Acres) are (1) small particle size for most of the gold (<0.5μm), (2) Tertiary age of mineralization (14 Ma in case of the Cinola deposit), (3) trace element geochemistry, in particular high Hg, As and Sb, (4) argillic alteration, (5) association with major high angle faults, (6) high porosity and permeability of the host rock (mostly un-cemented conglomerate and sandstone at Cinola), (7) close spatial association with felsic intrusions, and (8) low silver content.
GENETIC MODEL

A general model for the evolution of host rocks and genesis of the Cinola gold deposit includes three main events (Figure 11): (1) in the Middle Tertiary, extrusion of Masset volcanic rocks over Haida shales and activation of, or continuation of, movement along the Sandspit fault, (2) in the early Middle Miocene, uplift and erosion of Masset volcanic and older rocks and subsequent deposition of Skonun conglomerates, sandstones and siltstones, and (3) at 14 Ma, intrusion of the rhyolite-porphyry stock along the Footwall fault, followed by the development of a fracture system that provided structural control of mineralization and physical limits to the mineralizing system.

The pre-mineralization Skonun Formation is viewed as a permeable, water-saturated pile of clastic sediments. Initiation of faulting along the Footwall fault, a part of the Sandspit fault system, controlled emplacement of an elongate stock of rhyolite-porphyry at about 14 Ma. This event upset the pre-existing thermal regime, and initiated the development of convection cells in pore water in the Skonun Formation. As mineralization proceeded and filled channels, intermittent movement on the Footwall fault led to fracturing in adjoining rocks with resultant increases in permeability for ore fluids transport.

Mineral deposition in the system followed a well defined paragenetic sequence with apparently sporadic abrupt decreases in temperature of the ore fluid. As deposition continued tem-
MIDDLE TERTIARY

EARLY MIocene

14 Ma (MIDDLE MIocene)

HAIDA
SKONUN
MASSET
RHYOLITE- PORPHYRY
Figure 11. Schematic sequence in development of the Cinola gold deposit. Erosion of the Haida shales during Early Miocene is speculative. Emplacement of rhyolite-porphyry is thought to have initiated thermal convection of pore water from the Skonun Formation and led to development of the mineralized system. See text for details.
Peratures ranged from 300°C to 130°C as indicated by preliminary fluid inclusion geothermometry data (Shen, Champigny and Sinclair, 1981). Inclusion data also indicate low salinities; thus the ore fluid is thought to have originated as pore water within the Skonun Formation. Metals are believed by the authors to have been derived from the Skonun Formation, in part by alteration of volcanic fragments and in part by dissolution of heavy minerals. It appears likely that precipitation of gold was to some extent promoted by the abundant organic material within the Skonun Formation.
ACKNOWLEDGMENTS

The financial support of Consolidated Cinola Mines Ltd. for our study has been gratifying. In particular the cooperation and assistance of K.G. Sanders, President and A. MacKillop, camp manager, is acknowledged with thanks. The laboratory work was funded in part by a N.S.E.R.C. Scholarship to Champigny and a grant from the B.C. Ministry of Energy, Mines and Petroleum Resources. H.J. Mah, P.H. Blanchet and T. Chen (International Geosystems Corp.) advised on the use of the GEOLOG system. Mr. John Gardiner provided technical assistance in the field. Discussions with Dr. A. Sutherland Brown and a visit with him to the type of locality of the Skonun Formation were extremely beneficial to this study.
REFERENCES

Blanchet, P.H., and Godwin, C.I., 1972, 'Geolog System' for computer and manual analysis of geologic data from porphyry and other deposits; Econ. Geol., v. 67, pp. 796-813.


Rust, B.R., 1972, Structure and process in a braided river; Sedimentology, v. 18, pp. 221-246.


CHAPTER IV

Fluid Inclusion and Sulphur Isotope Data
In Relation To Genesis of the Cinola Gold Deposit,
Queen Charlotte Islands, B.C.
ABSTRACT

Fluid inclusion studies from the Cinola deposit indicate low salinities and low CO₂ contents of the ore fluid. This supports a suggestion that the mineralizing fluids originated from pore water in the fluviatile host rock (mid-Miocene Skonun Formation). Bimodal distribution of filling temperatures suggests the existence of at least two temperature regimes centred on 160°C and 270°C during mineral deposition. Independent age and stratigraphic evidence indicate that depth of mineralization is between 1.1 and 1.8 k, corresponding to a hydrostatic load between 110 and 170 bars.
RÉSUMÉ D'AUTEUR

Les données sur les inclusions fluides du gisement Cinola indiquent de basses salinités et basses teneurs en CO₂. Ceci confirme que les fluides minéralisants ont été dérivés de l'eau interstitielle prise dans les sédiments fluviatiles hôtes. La distribution bimodale des températures d'homogénéisation implique l'existence de deux régimes de température concentrées vers 160°C et 270°C pendant la minéralisation. La profondeur à laquelle le gisement s'est formé est évaluée d'être 1.1 et 1.8 k à partir d'informations stratigraphiques indépendantes: ceci correspond à des pressions hydrostatiques de 110 à 170 bars.
INTRODUCTION

At the Cinola gold deposit, a shale sequence (Late Cretaceous) and a coarse clastic sequence of fluviatile origin (Middle Miocene) were intruded by a Middle Miocene stock of quartz-feldspar porphyry (Champigny and Sinclair, 1980b). The mineralized system consists of an intensively silicified zone with late stage veins and stockwork both superimposed on the rhyolitic intrusion and the adjacent sedimentary sequence. Thus, two periods of silicification have affected the host rocks. Silicified host rocks and veins contain about 3% disseminated pyrite and marcasite, with sub-microscopic gold and rare visible gold. Other ore minerals are sphalerite, chalcopyrite, galena, pyrrhotite, cinnabar, tiemmanite, rutile, hematite, and magnetite, but they are rarely observed. The veins are divided into four successive paragenetic events on the basis of form and cross-cutting relationships. These are, with decreasing age, black to grey chalcedonic quartz (earliest), hematitic quartz, massive milky quartz, clear euhedral quartz, and calcite (youngest). Quartz deposition in part preceded formation of all sulphides (mainly pyrite) and native gold, and continued during deposition of these opaque minerals. Veins at Cinola exhibit crustification, ribbon texture, and development of drusy vugs, and some calcite crystals attain 2 cm in length. Wall rock alteration is dominantly argillic and sericitic. The authors suggest that the rhyolite-porphyry intrusion initiated the development of a large geothermal system from which gold mineralization took place. Fluid inclusion studies of fracture-controlled,
gold bearing veins and sulphur isotope analyses of pyrite were performed to estimate the ore fluid composition and to better define a genetic model for the Cinola deposit. Samples for this study were collected from drill core during the summer of 1979.
FLUID INCLUSION DATA

Black, grey, hematitic, and cherty quartz are mostly too poorly crystallized for fluid inclusions studies. Consequently, attention was directed mainly to late stage milky quartz and rare occurrences of calcite. Six specimens of quartz and one of calcite were selected to provide preliminary insight into the application of fluid inclusion data to the development of a genetic model for the deposit. The specimens collected represent a large areal coverage of the Cinola mineralized system. Fluid inclusions range from 5 to 47 microns in their longest dimension, and all have two phases: a liquid phase and a vapour phase that totals from 1 to 15 volume percent but commonly is about 5 volume percent. The inclusions were found mostly along crystal growth zones, and in some cases from crystals developed in vugs or as crustiform layering with no evidence of deformation. Thus, we feel relatively confident that inclusions studied are primary.
HOMOGENIZATION DATA

Homogenization temperatures by vapour disappearance were recorded from 38 inclusions (Figure 1). They show a bimodal population with a low temperature mode between 150° and 160°C and a higher temperature mode between 270° and 280°C. These two populations of filling temperatures can be interpreted as at least two episodes of mineral deposition and mineralization within the late stage white quartz and calcite veins. From seven measurements above 275°C, five were from translucent quartz cement grains binding pebbles and matrix in a conglomerate unit. This is in accord with an early stage of deposition of quartz cement observed by Champigny and Sinclair (1980b). Our limited data for filling temperature for inclusions in calcite suggests that calcite deposition is part of the low temperature (160°C) mineralizing stage. This agrees with calcite's position in the paragenetic sequence (Champigny and Sinclair, 1980b).
Figure 1. Histogram of filling temperatures of fluid inclusions in quartz and calcite, Cinola deposit. Calcite measurements are shown in black. Hatched pattern is for (early) quartz cement.
FREEZING DATA

Most freezing temperatures measured from 4l inclusions are between 0.0 and -0.9°C (Figure 2). Recorded temperatures from 2.5 to 4.9°C are considered evidence for the presence of dissolved CO2 (clathrates) in the aqueous solution (Collins, 1979). Melting points of these clathrates range from 3.0 to 3.4°C and 2.5 to 4.9°C for the two samples where they were observed. Double freezing, a characteristic phenomenon of clathration, was very difficult to observe because of the small size of the inclusions and gas bubbles. Salinity estimates of the inclusion fluids were obtained using the formula of Potter et al. (1978). NaCl equivalent in solution varies from 0 to 1.5 weight percent, with an average of 0.5 weight percent. The presence of small amounts of CO2 in the trapped ore fluid is possible, but would not significantly change the estimated salinities (Collins, 1979, Figure 5).
Figure 2. Histogram of freezing temperatures of fluid inclusions in quartz and calcite, Cinola deposit. Calcite measurements are shown in black. Hatched pattern is for (early) quartz cement.
PRESSURE CORRECTIONS

The homogenization data are uncorrected for the effects of pressure. Host rocks at Cinola are mainly conglomerates which are correlated with the base of the Skonun Formation as found to the east (Tow Hill Well, Sutherland Brown, 1968). Skonun sediments are weakly cemented and highly porous where exposed at Skonun Point, 65 km to the northeast. This, combined with the extensive fracturing in the mineralized zone, suggested that pressure during deposition was hydrostatic. Average thickness of the Skonun sediments from five drilled wells is about 1200 m, and 1760 m of strata are present in Tow Hill. Hydrostatic pressures of approximately 117 and 172 bars correspond to these depths. From this, pressure corrections of $15^\circ$C or less, for a solution of 1 percent NaCl equivalent, could apply (Potter, 1977); that is, actual temperatures of deposition probably are no more than $15^\circ$C higher, on average, than the filling temperatures reported here.
SULPHUR ISOTOPE DATA

Sulphur isotope analyses were obtained for six samples of pyrite from Cinola deposit (Table 1). In all cases pyrite occurred as disseminated rains in silicified sediments. The sulphur is 'light', and the range is small, from -3.58 to -0.52%. The most negative (lightest) value is from dark brown melnikovitic pyrite, whereas the other $\delta^{34}S$ values are from pyrite-marcasteite grains containing small inclusions of pyrrhotite. A variety of origins of sulphur is consistent with these sulphur isotope data, including the genetic model presented by Champigny and Sinclair (1980a) and outlined in detail elsewhere in this volume.
Table 1 - $\delta^{34}$S of pyrite sulphur at the Cinola Deposit

<table>
<thead>
<tr>
<th>Drillhole No.</th>
<th>Depth (Metres)</th>
<th>$\delta^{34}$S</th>
</tr>
</thead>
<tbody>
<tr>
<td>78-2</td>
<td>95</td>
<td>-0.52</td>
</tr>
<tr>
<td>78-5</td>
<td>27</td>
<td>-3.58</td>
</tr>
<tr>
<td>79-6</td>
<td>123</td>
<td>-0.82</td>
</tr>
<tr>
<td>79-9</td>
<td>137</td>
<td>-0.73</td>
</tr>
<tr>
<td>79-10</td>
<td>130</td>
<td>-1.82</td>
</tr>
<tr>
<td>79-11</td>
<td>139</td>
<td>-1.28</td>
</tr>
</tbody>
</table>
DISCUSSION

From the homogenization and freezing data, it is apparent that mineralizing fluids at Cinola had a relatively low and only slightly variable salinity, containing very minor amounts of NaCl equivalent and CO₂. Low salinities such as estimated for the Cinola deposit are characteristic of gold quartz veins and Carlin-type deposits (Nash, 1972), and are consistent with a meteoric origin for the ore fluids. In the present case, heated pore waters of the Skonun sediments are a likely source of mineralizing fluids. The sedimentary host rocks at Cinola are of fluviatile origin, and therefore pore waters should have low NaCl and CO₂ contents, in agreement with the indications from freezing data for fluid inclusions.

Textures indicative of open space filling and the absence of coexisting vapour-dominated inclusions at Cinola suggest that boiling did not occur or that the boiling "top" of the system has been removed by erosion. For maximum filling temperatures of 300°C and a salinity of 0.5 percent NaCl equivalent solution, a hydrostatic pressure equivalent to a depth of 1100 m below surface is necessary to prevent the system from boiling (Haas, 1971).

This depth is considered a minimum for mineral deposition, in that part of the system available for study because of the absence of textural and other evidence indicative of boiling. The maximum possible depth of mineralization appears to be 1.8
k, based on the total maximum thickness of the overlying stratigraphic section to the east (Sutherland Brown, 1968).

Clathration, observed in two samples, indicates the presence of small amounts of CO$_2$, and it is possible that a very small amount of CO$_2$ does occur in inclusions where clathration was not recognized. The Skonun Formation is a plausible source for this CO$_2$.

Local shell-rich layers are a characteristic feature of the Skonun Formation and are well exposed at the type locality at Skonun Point, on the north shore of Graham Island (Sutherland Brown, 1968). Similar layers have been identified in drill core at the Cinola deposit (Champigny and Sinclair, 1980b). At the type of locality of the normally friable Skonun, sandstones and conglomerates are cemented by calcite for as much as 10-30 cm from shell-rich layers that are normally only a few centimeters wide.
CONCLUSIONS

Although the studies reported here are far from comprehensive, they provide important constraints on a genetic model for the Cinola deposit. The low salinities and low CO$_2$ contents of the ore fluid are consistent with the suggestion that the fluid derived from pore water in the fluviatile Skonun Formation. Filling temperatures and the absence of textures resulting from boiling suggest a minimum depth of formation of about 1.1 k, whereas stratigraphic information suggests a maximum depth of formation of about 1.8 k.

The two major peaks of filling temperatures suggest that two principal temperature regimes may have existed during the depositional history. These peaks indicate an early period of high temperature deposition and a late period of lower temperature deposition. Our very limited filling temperature data for paragenetically late calcite are comparable to the late quartz population, and indicate that calcite veins are probably an integral part of the mineralizing episode rather than a later unrelated and superimposed event.

Both the earliest and some of the latest quartz in the paragenetic sequence have fluid inclusion filling temperatures in the "high" temperature population of Figure 1. This may indicate that most deposition occurred under the high temperature regime, and that only the latest part of the youngest quartz and contemporaneous and younger calcite were deposited under the low
temperature regime.

Our preliminary sulphur isotope data are consistent with the views presented here, but are too sparse to provide evidence relating to a specific genetic model.
ACKNOWLEDGMENTS

Financial support for this study was provided by Consolidated Cinola Mines Ltd. and an N.S.E.R.C. scholarship to Champigny.
REFERENCES


Collins, P.L.F., 1979, Gas hydrates in CO₂-bearing fluid inclusions and the use of freezing data for the estimation of salinity; Econ. Geol., v. 74, pp. 1435-1444.

Haas, J.L. Jr., 1971, The effect of salinity on the maximum thermal gradient of a hydrothermal system at hydrostatic pressure; Econ. Geol., v. 66, pp. 940-946.


Potter, R.W., 1977, Pressure correction for fluid inclusion
homogenization temperatures based on the volumetric properties of the system NaCl-H₂O; J. of Research, U.S.G.S., v. 5, pp. 603-607.


CHAPTER V

New Evidence for the Age of the Skonun Formation,
Queen Charlotte Islands, British Columbia
ABSTRACT

Recent palynological, macrofaunal, and intrusive evidence from a low section of the Skonun Formation on the Cinola deposit on Graham Island indicates that it is of Middle Miocene age, that the whole formation is most probably of the same age, and that it correlates with several Middle Miocene series of the Pacific northwest.
RÉSUMÉ D'AUTEUR

Une étude récente des assemblages de palynomorphes et de mollusques combinée aux données radiométriques d'une section inférieure de la Formation Skonun sur le gisement Cinola (Graham Island) indique (1) un âge Miocène Moyen, (2) que toute la Formation Skonun est probablement du même âge, et (3) que la Formation Skonun peut être correlée avec plusieurs autres séries du Miocène Moyen sur la côte nord-ouest du Pacifique.
The Skonun Formation is a series of sandstones (marine and non-marine), shales, lignite stringers, and conglomerates underlying the Queen Charlotte Lowlands of eastern Graham Island (Figure 1). Named and described by MacKenzie (1916), the Skonun Formation was described most recently and thoroughly by Sutherland Brown (1968). Skonun sediments onlap volcanic rocks of the Masset Formation (Paleocene-Eocene?), and are cut by the Tow Hill sills of late Pliocene-early Pleistocene age (Sutherland Brown, 1968). Pleistocene marine drift, outwash deposits, and till overly the Skonun unconformably to conformably. Although exposures of Skonun sediments are very limited because of their friable nature and extensive erosion, a total thickness of the formation has been determined from drill holes from 107 to 1812 m. Quoting the palynological study by Martin and Rouse (1966), Sutherland Brown concluded that the Skonun sediments had accumulated in an estuarine-like basin, possibly controlled by the regional Sandspit fault system. Although they had no firm evidence at that time as to the age of the Skonun, Martin and Rouse (1966) suggested that deposition probably occurred between the late Miocene and early Pliocene. Based on assemblages of molluscs, Addicott (1978) indicated an early Late Miocene age and a shallow marine to brackish water depositional environment for the marine sands of the formation.

At the Cinola gold deposit on central Graham Island (Figure 1), conglomerate and coarse sandstone units comprise 85 to 90%
of the total Skonun Formation, with the remainder consisting of silty mudstone and minor shale. This clastic sequence appears to have been deposited by a braided river system discharging into a marine basin (Champigny and Sinclair, 1980, 1981). Detailed geological examination of drill core by Champigny, combined with K-Ar dates, palynological analysis, and molluscan fauna, have prompted us to revise the age of the Skonun formation over the previous estimates.
Figure 1. Map showing the area underlain by the Skonun Formation (dash lines) and location of the Cinola deposit.
RESULTS

**K-Ar Data:** A stock of porphyritic rhyolite and associated dykes cut the conglomerate-sandstone sequence at the Cinola gold deposit. Whole-rock K-Ar age determinations on two samples of rhyolite-porphyry indicated ages of 14.0 and 14.1 Ma. (Champigny and Sinclair, 1980, 1981). Hence, deposition of Skonun sediments occurred prior to 14 Ma, or Middle Miocene, according to Berggren and van Couvering (1974).

**Palynology:** A drill-core sample of carbonaceous siltstone with abundant pyrite, from the eastern part of the Cinola deposit, was collected for palynological analysis and processed using HCl, HF, acetolysis, bleach, and ZnBr. Palynomorph recovery and preservation were excellent, allowing for relatively good reconstructions.

The Cinola palynoassemblage is dominated by conifer pollen, particularly those of *Pinus* (pine), *Tsuga heterophyllites* (hemlock), *Picea grandivescipites* (spruce), *Pseudotsuga* (Douglas fir), *Sequoia* (redwood), and other taxodiaceous pollen. Other main elements are pollen of the Cyperaceae (sedges), *Quercus* sp. (oak), and *Fagus* (beech), and spores of *Osmunda*, *Laevigatosporites*, and *Polypodiaceae* (ferns). Other pollen occur in lesser amounts, *viz.* *Alnus* (alder), *Carya* (hickory), *Ilex* (holly), *Graminidites* (grass), and *Cedrus perialata* (cedar).
The palynoassemblage is similar to that reported by Martin and Rouse (1966) for stratigraphically higher strata of the Skonun Formation on Graham Island, northeast of the Cinola deposit. In the present assemblage, however, we found pollen of both *Nyssa* and *Liquidambar* previously unrecorded by Martin and Rouse (1966). In Alaska Wolfe and Leopold (1967) reported both *Nyssa* and *Liquidambar* in the younger of two Seldovian floras of early-mid Miocene age. These authors (p. 203) report that both genera are summer-temperature sensitive, and apparently became extinct in Alaska by the late Seldovian (Middle Miocene), in response to a rapid decline in summer temperatures. From this, we conclude that the Skonun assemblage from the Cinola site is no younger than the early part of the mid-Miocene, correlating closely with the younger Seldovian flora of Alaska, i.e. no younger than mid-Barstovian in the North American mammalian stage scale, or close to 15 Ma (Berggren and van Couvering, 1974).

Other closely correlative Miocene floras from the Pacific Northwest are the Mascall of Oregon (K-Ar - 15.4 Ma), the Rockville of Idaho (16.7 Ma), and the Fraser Bend Formation near Quesnel, B.C., estimated recently by Rouse and Mathews (1979) to be between 17 and 13.7 Ma. The Fraser Bend assemblage, however, lacks pollen of *Nyssa*, and hence may be slightly younger than the Cinola assembly. Alternatively, the absence of *Nyssa* might reflect a more inland and/or upland location relative to the other floras of similar agefloristic composition. Based on the collective evidence, a reasonable estimate of the age of the
Cinola-Skonun assemblage is between 17-15 Ma, early Middle Miocene, or early to mid Barstovian on the North American mammalian stage sequence (Berggren and van Couvering, 1974).

The presence of Nyssa and Liquidambar in the Cinola assemblage supports a conclusion that the conglomerate-sandstone sequence at Cinola is older than the other sections of the Skonun Formation to the north and east, and hence stratigraphically lower (Champigny and Sinclair, 1981). It also suggests that the higher sections of the Skonun, in outcrops to the north and east, are younger, but still within the Middle Miocene, judging by the presence of pollen of Fagus, Quercus, and Juglans, which became extinct in the late Seldovian (Middle Miocene) in Alaska (Wolfe and Leopold, 1967). This apparent range in age for the Skonun Formation on Graham Island could likely be confirmed by additional palynological and invertebrate studies of wells in eastern and northern Graham Island. In six wells drilled by Richfield (now Atlantic Richfield) Oil Corporation (Sutherland Brown, 1968, p. 123, figure 20), what appears to be Skonun equivalent varies from about 1760 m in the Tow Hill well to zero thickness in the Masset well. In the Tow Hill well, the lower 750 m is mainly conglomerate with some sandstone, resembling the lithology of the Cinola deposit. The facies of the upper part of Tow Hill well, by contrast, ranges from coal, shale, siltstone to sandstone, essentially the same as in the outcrops studied by Martin and Rouse (1966) and Addicott (1978).

To see if we could corroborate the suggested correlation,
five core samples from the Tow Hill well were analyzed for palynomorphs. The upper two samples, at 187 and 649 m, essentially contained assemblages identical to those of the outcrops reported by Martin and Rouse (1966); both lacked Liquidambar and Nyssa. However, the assemblage at 762 m contained one Liquidambar, but no Nyssa. The lower two samples from the coarse facies contained too few and relatively poorly preserved palynomorphs to be useful in correlation. Although the presence of a single grain of Liquidambar is insufficient evidence, it is tempting to speculate that it may represent the uppermost part of the lower coarse facies of the Skonun Formation.
FAUNAL EXAMINATION

Three samples of poorly sorted, coarse grained, silicified sandstone with abundant disarticulated bivalves were collected on a surface trench at the Cinola deposit. The pelecypods are preserved as internal and external molds without any trace of original shell material. The identified taxa include: *Spisula* (*Mactromeris*) sp. (Miocene-Recent in Western North America), *Chione* (*Securella*) sp. (Oligocene-Pliocene in Northwestern North America), and ? *Macoma* (Eocene-Recent). The specimen of the subgenus *Securella* bears a strong resemblance to *S. ensifera* (Dall) which, according to Moore (1963) (*fide* Etherington, 1931), did not occur beyond the Middle Miocene. However, the preservation (external mold) is not sufficient to make a definite specific identification.

This bivalve assemblage compares with other western North American Miocene fauna (Addicott, 1973), in particular those of the Miocene Clallam and Astoria Formations (Addicott, 1976; Moore, 1963). The assemblage, together with the immature character of the sandstone and the coquinoïd nature of the molds, suggests deposition in a beach to near-shore marine environment.
CONCLUSIONS

With the three independent lines of evidence, we conclude that most of the Skonun Formation was deposited during the early part of the mid-Miocene (17 to 15 Ma), probably coinciding with an interval during which the Sandspit fault system was very active (Sutherland Brown, 1968). The environment of deposition is mainly non-marine, but relatively close to sea, and includes estuary, swamp, and beach.

Additional evidence for the age of the Skonun has been provided by Shen et al. (1981) in a study of fluid inclusions at Cinola. They estimated a minimum sedimentary cover of 1100 m at the time of intrusion and associated mineralization, suggesting that all of the Skonun was deposited prior to 14 Ma.
ACKNOWLEDGMENTS

We thank Jane Shepperd (Geological Sciences, U.B.C.) for the palynological sample preparation. Financial support was provided by N.S.E.R.C. through a post-graduate scholarship (N.C.) and by Consolidated Cinola Mines Ltd.
REFERENCES


Addicott, W.O., 1978, Late Miocene molluscs from the Queen Charlotte Islands, British Columbia, Canada; Jour. Res. USGS, v. 6, no. 5, pp. 677-690.


Surv. Canada, Mem. 88.


CHAPTER VI

Cinola Gold Deposit, Queen Charlotte Islands, B.C. —
A Geochemical Case History
ABSTRACT

Cinola deposit, a large tonnage, low grade Carlin-type gold deposit on Graham Island (Queen Charlotte Islands), was subject to extensive geochemical exploration shortly after its discovery in 1970. We have reviewed the available rock, soil, and silt multi-element geochemical data from this early exploration stage in a rigorous, systematic manner, and in the light of substantial geological information about the deposit. Some specific conclusions from our study are:

1. Ag lithogeochemical data defines the known mineralized zone better than does Au. This is apparently due to a more continuous primary dispersion of Ag relative to gold.

2. Cu, Ni, Co, Pb, Zn, and Mo in rocks, soils, or silts do not provide clear cut patterns or high enough abundance levels for use in exploration.

3. Hg in soil and Hg in peat show a pronounced secondary dispersion pattern, apparently due to fluid transport eastward from the main centre of mineralization at the Cinola deposit.

4. Threshold selection using probability graphs is a useful practical approach to evaluate spatial distribution patterns of subpopulations in geochemical data sets.
INTRODUCTION

Cinola gold deposit, centrally located on Graham Island, off the west coast of British Columbia (Figure 1), has been described geologically by Champigny and Sinclair (1980a, 1981). The deposit is large, more than 45 million tons, with an average of .054 oz. Au/s.t, and has many of the characteristics of a Carlin-type deposit (Richards et al., 1976; Champigny and Sinclair, 1980b, 1981). Geological features characteristic of the deposit include (1) small particle size for gold (less than 0.5 μ), (2) mid-Miocene age of mineralization, (3) proximity with a major fault system, (4) argillic alteration, (5) porosity of the host rock, and (6) spatial and possibly genetic association with a rhyolite-porphyry intrusion. Surficial deposits are glacial tills ranging in thickness from 0 to 35 m, with an average of 3 m. Glacial movement followed a southwest-northeast direction in the area (Sutherland Brown, 1968). The area is heavily forested, due to a mild and rainy climate, and outcrops are absent except along fault scarps. Three continually flowing creeks and one river drain the mineralized zone.

This work forms part of a comprehensive study which emphasizes the application of geological studies for exploration and evaluation of the Cinola deposit. A systematic evaluation of exploration geochemical data was done to:

1. provide a rigorous evaluation of multi-element geochemical data for a Canadian "Carlin-type" gold deposit;
2. evaluate critically the primary and secondary dispersion haloes of elements represented in the various data sets available to us; and

3. illustrate the advantage of a rigorous but simple statistical approach as an evaluation procedure for geochemical data.
Figure 1. Location map of the Cinola deposit.
THE DATA

Multi-element geochemical data were available for rock, soil, and silt samples taken during routine exploration of the Cinola property in the early and middle 1970's (see Champigny, Sinclair, and Sanders, 1980). These data are available in assessment reports filed with the British Columbia government, but were provided to us by G.G. Richards of J.M.T. Services Corp. and R.W. Stevenson of Kennco Exploration Ltd. A brief description of the nature of each data type follows.

Lithogeochemical data: fifty-nine grab samples from limited surface exposures were analyzed for all or some of Au, Ag, Hg, As, Sb, and W. Gold content was measured by fire assay. Ag and Hg were determined by atomic absorption spectrophotometry. The As and W analyses were obtained by colorimetric methods. No information regarding analytical method was available for Sb.

Soil data: four hundred and eighty-six soil samples were taken more-or-less regularly over the Cinola property, mainly along claim lines. Most were B-horizon samples that were analyzed for Au, Ag, Hg, Mo, Cu, Pb, Zn, Ni, and Co. A-horizon samples were analyzed for Hg. A second soil survey over the mineralized zone added 158 more samples that were analyzed for gold. The -80 mesh fraction was used for all the analyses. Determination of all elements was by atomic absorption spectrophotometry.

Silt: Fifty-eight silt samples were collected from three creeks
and a river in the vicinity of the mineralized area. The samples were analyzed for all or some of Au, Ag, Mo, Cu, Pb, Zn, Ni, Co, and As, with the same analytical procedures as were used for the soil samples. As content was measured by a colorimetric method.
DATA EVALUATION PROCEDURE

Our general procedure (Figure 2) for creating each of the foregoing data groups involved (1) coding and editing, (2) production of correlation matrixes for raw and log-transformed data, (3) construction of a correlation diagram, (4) threshold selection from probability plots of individual elements, (5) drawing of machine-constructed maps showing distributions of various sub-populations for each element in each data group, and (6) integration of results for the three separate data sets, and interpretation in a geological context.

The method of threshold selection is that described by Sinclair (1974, 1976), in which multi-modal distributions are partitioned on probability graphs into two or more components, which in general appear to be lognormal in form.
Figure 2. Procedural path in evaluating Cinola geochemical data.

GEOCHEMICAL DATA

COMPUTER FILE
(SAMPLE LOCATION AND CHEMICAL ANALYSIS)

REARRANGED COMPUTER FILE
(LOG TRANSFORMED VALUES)

CORRELATION MATRIX
AND SCATTER Diagrams

CORRELATION Diagrams

PROBABILITY PLOTS

SELECTION OF THRESHOLDS

COMPUTER MAPS
OF VALUES ABOVE THRESHOLDS

INTERPRETATION
LITHOGEOCHEMISTRY

A summary of means and standard deviations for raw and log-transformed lithogeochemical data is given in Table 1, and a correlation matrix for log-transformed variables is given in Table 2. The critical features of the correlation matrix are summarized in the correlation diagram of Figure 3. These results are of interest because they demonstrate clearly that among the elements studied a simple, direct relationship involving gold exists with silver, arsenic, and antimony. Mercury and tungsten have significant inter-correlations, but do not correlate significantly with gold at the 0.01 level.

Probability graphs of all variables were examined in detail. Ag, Hg, Sb, and W can be interpreted without difficulty as combinations of two, and in the case of gold, three lognormal populations. Two of these graphs are reproduced in figures 4 and 5. Both illustrate the ease with which thresholds can be selected using the method of Sinclair (1974). Such thresholds have been used as a basis for contouring the data to separate geographic areas underlain by "high" and "low" valued populations so that their distributions could be examined in relation to the mineral deposit as outlined by extensive diamond drilling. Representative examples are shown in Figures 6, 7, 8, 9, and 10, and indicate:
1. the close spatial correlation of areas of certain "high" element concentrations and their relationship to the gold deposit;
Table 1. Summary of means and standard deviations for raw and log-transformed (base 10) lithogeochemical data, Cinola deposit. Arithmetic values are all in ppm except Hg which is in ppb.

<table>
<thead>
<tr>
<th>NAME</th>
<th>NO. OF VALUES</th>
<th>ARITHMETIC</th>
<th>LOGARITHMIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MEAN</td>
<td>STD.DEV.</td>
</tr>
<tr>
<td>Au</td>
<td>59</td>
<td>0.2954</td>
<td>0.6060</td>
</tr>
<tr>
<td>Hg</td>
<td>48</td>
<td>2158.</td>
<td>2572.</td>
</tr>
<tr>
<td>Ag</td>
<td>45</td>
<td>1.509</td>
<td>1.307</td>
</tr>
<tr>
<td>As</td>
<td>45</td>
<td>127.8</td>
<td>200.0</td>
</tr>
<tr>
<td>Sb</td>
<td>45</td>
<td>63.91</td>
<td>61.84</td>
</tr>
<tr>
<td>W</td>
<td>45</td>
<td>40.02</td>
<td>37.10</td>
</tr>
</tbody>
</table>
Table 2. Correlation matrix for log-transformed (base 10) lithogeochemical data, Cinola deposit.

<table>
<thead>
<tr>
<th></th>
<th>Au</th>
<th>Hg</th>
<th>Ag</th>
<th>As</th>
<th>Sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>.50</td>
<td>.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>.56</td>
<td>.63</td>
<td>.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>.50</td>
<td>.34</td>
<td>.36</td>
<td>.12</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>.40</td>
<td>.49</td>
<td>.07</td>
<td>.36</td>
<td>.49</td>
</tr>
</tbody>
</table>

The correlation coefficients are based on 45 paired observations between Hg, Ag, As, and Sb, 29 paired observations between Au and Ag, As, Sb, and W, and 31 paired observations between Au and Hg.

2. A high silver population that clearly defines the centre of the gold deposit.

Parameters of partitioned populations are given in Table 3. The geographic distribution of gold values above threshold is not surprising (Figure 6). Diamond drilling has indicated that gold mineralization decreases progressively to the north and east. Sporadic occurrences of Au highs probably arise from the widespread nature of mineralization combined with its local variability, a variability that would be enhanced by the small size of the lithogeochemical samples. Silver is about as abundant as gold at Cinola, and is known to be present in solid solution in gold particles (Champigny and Sinclair, 1980b, 1981). A low silver content in the bedrock produces a much lower geochemical contrast of silver relative to gold, and therefore a smaller area of silver "high" (Figure 7).

Cinnabar and tiemannite (HgSe) occur in the Cinola ore and are the obvious sources for mercury. Sphalerite, rarely ob-
served, is also a possible source of Hg. Fracture systems through the poorly lithified Skonun sediments east of the ore body probably contributed to the diffusion of mercury (Figure 8).

Disseminated pyrite occurs outside the limit of economic mineralization and electron microprobe analysis has shown locally a high As content (1.1%) in pyrite (Champigny and Sinclair, 1981). No arsenic and antimony minerals have been identified in the deposit. As and Sb lithogeochemical highs can probably be attributed to solid solution of arsenic and antimony in pyrite and/or marcasite, as reported in other gold deposits by Boyle (1979, p. 144-145).

The tungsten anomaly (Figure 10) may be caused by the presence of trace amounts of scheelite, which is not reported at Cinola but is a common trace mineral in gold deposits (Boyle, 1979, p. 195).
Table 3. Means and standard deviations determined graphically for partitioned metal populations of lithogeochemical data, Cinola deposit.

<table>
<thead>
<tr>
<th>Element</th>
<th>Conc. Unit.</th>
<th>A population</th>
<th>B population</th>
<th>Threshold(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% b b+SL b-SL</td>
<td>% b b+SL b-SL</td>
<td></td>
</tr>
<tr>
<td>Au</td>
<td>ppm</td>
<td>11 1.6 2.0 1.2</td>
<td>55 0.01 0.03 0.006</td>
<td>0.05 and 0.85 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34 0.13 0.30 0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>ppm</td>
<td>29 3.3 4.2 2.5</td>
<td>71 0.7 1.35 0.36</td>
<td>2.5</td>
</tr>
<tr>
<td>Hg</td>
<td>ppb</td>
<td>58 3630 5750 1950</td>
<td>42 178 355 85</td>
<td>800</td>
</tr>
<tr>
<td>As</td>
<td>ppm</td>
<td>100 36 260 4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>ppm</td>
<td>45 129 170 98</td>
<td>55 13 26 5.8</td>
<td>70</td>
</tr>
<tr>
<td>W</td>
<td>ppm</td>
<td>56 61 110 36</td>
<td>44 7.5 13.5 4.3</td>
<td>23</td>
</tr>
</tbody>
</table>

Graphs based on 59 values for Au, 48 values for Hg and 45 values for Ag, As, Sb and W cumulated individually.

b = antilog of mean of log transformed data

b+SL = antilog of mean plus one std. dev. of log transformed data

b-SL = antilog of mean minus one std. dev. of log transformed data
Figure 3. Most significant correlations (at the 0.01 level) of logarithmically transformed (base 10) lithogeochemical data.
Figure 4. Lognormal probability plot for Sb lithogeochemical data partitioned into upper (A) and lower (B) populations. Black dots are original data.
Figure 5. Lognormal probability plot for Au lithogeochemical data partitioned into upper (A), median (A') and lower (B) populations. Black dots are original data.
Figure 6. Au (ppm X 100) in rock. Triangles are high population; plus signs are low population. Hachured area represents relatively high grade zone of Cinola deposit. Principal faults are shown as follows: FF = Footwall Fault, SF = Sandspit Fault.
Figure 7. Ag (ppm X 10) in rock. See Figure 6 for explanation of symbols.
Figure 8. Hg in rock (ppb). See Figure 6 for explanation of symbols.
Figure 9. Sb in rock (ppb). See Figure 6 for explanation of symbols.
Figure 10. W in rock (ppb). See Figure 6 for explanation of symbols.
A similar method of data analysis was used for soil data as for lithogeochemical data. A summary of means and standard deviations is given in Table 4 and a correlation matrix of log-transformed values is provided in Table 5. The correlation matrix indicates the presence of three groups of elements. Group I (Au, Hg, Hg in peat, Ag) would appear to relate most directly to the mineralization process. Group II elements (Cu, Ni, Co, Zn, Pb) have high intragroup correlations, but correlate only in a limited manner with Group I elements. It would appear that these two groups are fundamentally different. Group III consists only of Mo, about which little can be said, because of the narrow range of values and poor analytical precision.

Probability graphs of all elements in groups I and II can be partitioned into two or three lognormal sub-populations and thresholds chosen with ease (Figure 11 and Table 6). As with lithogeochemical data, we produced contoured plots, using thresholds as the only contour values. Four examples are shown in Figures 12, 13, 14, and 15 for Au, Hg, Hg in peat, and Cu respectively. The example for copper clearly illustrates the sporadic distribution of high values throughout the property, a result that we found to be characteristic of all elements of Group II. These erratic soil geochemical highs are easily explained in the cases of zinc, copper, and lead, because of trace amounts of sphalerite, chalcopyrite, and galena occurring very sporadically in the Cinola deposit.
On the other hand, Group I elements, excepting silver, have appreciably more regular distribution patterns. Most regular are the comparable patterns shown by Hg in B-horizon and Hg in A-horizon soils. The pattern is pronouncedly arcuate, concave to the west but dramatically removed to the east of the Cinola deposit, in a manner suggestive of secondary easterly dispersion (Figures 13 and 14). This dispersion was probably chemical rather than physical, because gold which is intimately related in the deposit has soil highs in part directly over the Cinola deposit (Figure 12), suggesting relatively little secondary dispersion.

The erratic spatial distribution of silver highs probably results from the low abundance level in soils in combination with poor analytical precision. It is also possible that no background correction was applied during spectrophotometric analysis.
Table 4. Summary of means and standard deviations for raw and log-transformed (base 10) soil geochemical data, Cinola deposit. Arithmetic values are all in ppm except Hg and Hg in peat (HgP) which are in ppb.

<table>
<thead>
<tr>
<th>NAME</th>
<th>NO. OF VALUES</th>
<th>ARITHMETIC</th>
<th>LOGARITHMIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MEAN</td>
<td>STD.DEV.</td>
</tr>
<tr>
<td>Au</td>
<td>644</td>
<td>0.3781E-01</td>
<td>0.8178E-01</td>
</tr>
<tr>
<td>Hg</td>
<td>474</td>
<td>590.0</td>
<td>1227.</td>
</tr>
<tr>
<td>Ag</td>
<td>486</td>
<td>0.6926</td>
<td>0.5865</td>
</tr>
<tr>
<td>Mo</td>
<td>480</td>
<td>1.077</td>
<td>0.3484</td>
</tr>
<tr>
<td>Pb</td>
<td>484</td>
<td>10.18</td>
<td>3.629</td>
</tr>
<tr>
<td>Zn</td>
<td>483</td>
<td>29.74</td>
<td>19.46</td>
</tr>
<tr>
<td>Ni</td>
<td>483</td>
<td>9.673</td>
<td>18.66</td>
</tr>
<tr>
<td>Co</td>
<td>483</td>
<td>7.077</td>
<td>5.184</td>
</tr>
<tr>
<td>HgP</td>
<td>457</td>
<td>675.3</td>
<td>1248.</td>
</tr>
</tbody>
</table>
Table 5. Correlation matrix for log-transformed (base 10) soil geochemical data, Cinola deposit. Dash lines represent correlation coefficients that are not significant at the 1% level.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>ELEMENT</th>
<th>Au</th>
<th>Hg peat</th>
<th>Hg</th>
<th>Ag</th>
<th>Cu</th>
<th>Ni</th>
<th>Co</th>
<th>Zn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Hg peat</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Hg</td>
<td>.24</td>
<td>.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Ag</td>
<td>.19</td>
<td></td>
<td></td>
<td>.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Cu</td>
<td></td>
<td></td>
<td></td>
<td>.29</td>
<td>.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Ni</td>
<td></td>
<td></td>
<td></td>
<td>.14</td>
<td>.63</td>
<td>.72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Co</td>
<td></td>
<td></td>
<td></td>
<td>.17</td>
<td>.73</td>
<td>.78</td>
<td>.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Zn</td>
<td></td>
<td></td>
<td></td>
<td>.69</td>
<td>.78</td>
<td>.82</td>
<td>.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Pb</td>
<td></td>
<td></td>
<td></td>
<td>.38</td>
<td>.26</td>
<td>.35</td>
<td>.30</td>
<td>.38</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Mo</td>
<td></td>
<td></td>
<td></td>
<td>.15</td>
<td>.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The correlation coefficients are based on about 480 paired observations between all elements excepting pairs with Au and Hg in peat which are based on 438 and 340 paired observations respectively.
Table 6. Means and standard deviations determined graphically for partitioned metal populations of soil geochemical data, Cinola deposit.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>CONC. UNIT</th>
<th>A population</th>
<th>B population</th>
<th>Thresholds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>b</td>
<td>b+SL</td>
</tr>
<tr>
<td>Au</td>
<td>ppm</td>
<td>4</td>
<td>0.26</td>
<td>0.29</td>
</tr>
<tr>
<td>Ag</td>
<td>ppm</td>
<td>5</td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Hg</td>
<td>ppb</td>
<td>10</td>
<td>2.0100</td>
<td>3600</td>
</tr>
<tr>
<td>Hg peat</td>
<td>ppb</td>
<td>7</td>
<td>3200</td>
<td>4700</td>
</tr>
<tr>
<td>Mo</td>
<td>ppm</td>
<td>100</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Cu</td>
<td>ppm</td>
<td>65</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Pb</td>
<td>ppm</td>
<td>96</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Zn</td>
<td>ppm</td>
<td>70</td>
<td>35</td>
<td>54</td>
</tr>
<tr>
<td>Ni</td>
<td>ppm</td>
<td>15</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Co</td>
<td>ppm</td>
<td>70</td>
<td>8.4</td>
<td>13</td>
</tr>
</tbody>
</table>

Graphs based on 644 values for Au, 486 values for Ag, 484 values for Pb, 483 values for Zn, Ni and Co, 480 values for Mo, 474 values for Hg and 457 values for Hg in peat.

Symbols used are the same as Table 3.
Figure 11. Probability plot for Cu in soils partitioned into upper (A) and lower (B) populations.
Figure 12. Au (ppm X 100) in soil. Symbols as in Figure 6. Sampling grid mostly follows claim boundaries.
Figure 13. Hg in B horizon (ppb). Symbols as in Figure 6.
Figure 14. Hg in peat (A horizon) (ppb). Symbols as in Figure 6.
Figure 15. Cu in soil (ppm). Symbols as in Figure 6.
SILT GEOCHEMISTRY

An identical statistical analysis was done for stream sediment data as for the rock and soil data. Plotting and contouring of the data were not done in this case, because the silt survey covered only a very small portion of the property. Table 7 contains the means and standard deviations of the nine elements that were analyzed. Groupings of elements from the correlation matrix for silt data (Table 8) are very similar to groups defined from the correlation matrix for soil data. Group I for silt samples include Au, As, and Ag. Group II elements (Cu, Ni, Co, Zn, and Pb) elements are highly intercorrelated, especially Zn, Ni, and Co, which have correlation coefficients higher than 0.8. Correlations of Group II to Group I elements are restricted to Ag and As; no significant correlation of Group II elements exists with gold. Mo has a very narrow range of values, and is the only variable included in Group III.

For both soil and silt correlation matrixes, Group I and Group II are easily distinguished. Group I is certainly related to mineralization, but such a relationship is not apparent for Group II.

Bimodal lognormal distributions were observed for most variables of Groups I and II of the silt data. Selection of thresholds was done without difficulty. Partitioning of upper and lower populations is shown for Ag in Figure 16 and summarized for all variables in Table 9. Arsenic and copper data
seem to represent single lognormal distributions.
Table 7. Summary of means and standard deviations for raw and log-transformed (base 10) silt geochemical data, Cinola deposit. Arithmetic values are all in ppm.

<table>
<thead>
<tr>
<th>NAME</th>
<th>NO. OF VALUES</th>
<th>ARITHMETIC</th>
<th>LOGARITHMIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MEAN</td>
<td>STD.DEV.</td>
</tr>
<tr>
<td>Au</td>
<td>58</td>
<td>0.1845E-01</td>
<td>0.1412E-01</td>
</tr>
<tr>
<td>Ag</td>
<td>58</td>
<td>0.7293</td>
<td>0.2728</td>
</tr>
<tr>
<td>Mo</td>
<td>58</td>
<td>0.7241</td>
<td>1.121</td>
</tr>
<tr>
<td>Cu</td>
<td>58</td>
<td>9.138</td>
<td>3.390</td>
</tr>
<tr>
<td>Zn</td>
<td>58</td>
<td>70.90</td>
<td>48.98</td>
</tr>
<tr>
<td>Pb</td>
<td>58</td>
<td>10.48</td>
<td>3.803</td>
</tr>
<tr>
<td>Ni</td>
<td>58</td>
<td>14.53</td>
<td>5.823</td>
</tr>
<tr>
<td>Co</td>
<td>58</td>
<td>35.50</td>
<td>60.55</td>
</tr>
<tr>
<td>As</td>
<td>57</td>
<td>141.9</td>
<td>191.3</td>
</tr>
</tbody>
</table>
Table 8. Correlation matrix for log-transformed (base 10) silt geochemical data, Cinola deposit. Dash lines represent correlation coefficients that are not significant at the 1% level.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>ELEMENT</th>
<th>Au</th>
<th>Ag</th>
<th>As</th>
<th>Cu</th>
<th>Ni</th>
<th>Co</th>
<th>Zn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Ag</td>
<td>.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>As</td>
<td>.45</td>
<td>.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td></td>
<td>.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td></td>
<td>.65</td>
<td>.60</td>
<td>.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Co</td>
<td></td>
<td>.60</td>
<td>.52</td>
<td>.57</td>
<td>.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zn</td>
<td></td>
<td>.54</td>
<td>.54</td>
<td>.54</td>
<td>.94</td>
<td>.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td></td>
<td>.48</td>
<td></td>
<td>.63</td>
<td>.63</td>
<td>.61</td>
<td>.54</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Mo</td>
<td></td>
<td></td>
<td>.50</td>
<td></td>
<td>.45</td>
<td></td>
<td>.45</td>
<td></td>
</tr>
</tbody>
</table>

Correlation coefficients based on 58 paired observations.
Table 9. Means and standard deviations determined graphically for partitioned metal populations of silt geochemical data, Cinola deposit.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>CONC. UNIT</th>
<th>A population</th>
<th>B population</th>
<th>Threshold(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>b</td>
<td>b+t</td>
</tr>
<tr>
<td>Au</td>
<td>ppm</td>
<td>30</td>
<td>.037</td>
<td>.048</td>
</tr>
<tr>
<td>Ag</td>
<td>ppm</td>
<td>83</td>
<td>0.80</td>
<td>1.00</td>
</tr>
<tr>
<td>As</td>
<td>ppm</td>
<td>100</td>
<td>63</td>
<td>250</td>
</tr>
<tr>
<td>Cu</td>
<td>ppm</td>
<td>100</td>
<td>8.4</td>
<td>11.6</td>
</tr>
<tr>
<td>Zn</td>
<td>ppm</td>
<td>20</td>
<td>125</td>
<td>180</td>
</tr>
<tr>
<td>Pb</td>
<td>ppm</td>
<td>30</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Ni</td>
<td>ppm</td>
<td>71</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Co</td>
<td>ppm</td>
<td>6</td>
<td>133</td>
<td>174</td>
</tr>
<tr>
<td>Mo</td>
<td>ppm</td>
<td>100</td>
<td>0.72</td>
<td>1.84</td>
</tr>
</tbody>
</table>

Graphs based on 58 values for all elements apart from As which is based on 57 values.

Symbols used are the same as Table 3.
Figure 16. Probability plot for Ag in silts partitioned into upper (A) and lower (B) populations.
CONCLUSIONS

This simple statistical evaluation of geochemical data from the Cinola deposit has led to the following conclusions:

1. Significant but moderate correlation coefficients between Au on the one hand and Hg, Ag, As, Sb, and W on the other hand indicate that all were part of the primary mineralizing process at Cinola.

2. Spatial correlation of sub-populations determined by partitioning probability graphs of each variable is a more useful method for evaluating lithogeochemical data than is a matrix of single linear correlation coefficients.

3. A high silver lithogeochemical population defines the Cinola deposit better from an exploration viewpoint than does a high gold population. High populations of Hg, Sb, and W in rocks are as much dispersed as is gold.

4. A correlation matrix for multi-element soil data leads to recognition of two groups of elements. Group I elements (Au, Hg, and Ag) are shown to have more-or-less systematic dispersion patterns in soils relative to the Cinola ore body. Group II (Cu, Ni, Co, Zn, and Pb) are very erratically dispersed in soils, and the absence of a systematic pattern makes them less useful in an exploration sense.
5. Groups of elements from the correlation matrix for silt data are very similar to the groups for the soil data. This suggests that Group I elements in silt (Au, Ag, As) can be considered as good indicators of the proximity of Cinola-type gold concentrations.

6. Significant correlations between (1) Au and (2) Ag, Hg, and As and comparable distributions of these elements in rock, soil, and silt are a feature of the Cinola data. Thus Au, Ag, Hg, and As are potential elements to be analyzed for in geochemical exploration for similar large tonnage, low grade Carlin-type gold deposits. Insufficient data were available to fully evaluate the exploration potential for Sb and W, although high lithogeochemical populations of each of these two elements showed systematic distribution patterns.

In contrast, the more abundant elements, such as Cu, Pb, and Zn, are shown to be much less useful because their sporadic occurrence in geochemical samples seems to reflect their minor and sporadic occurrence in the mineralized system comprising the Cinola deposit. Similarly, Mo, Co, and Ni are of little practical use, in this case because of their very low levels of abundance.
ACKNOWLEDGMENTS

Various maps and reports supplied to us by G.G. Richards and R.W. Stevenson made the job of data compilation easier than it otherwise would have been. Mrs. Zofia Radlowski assisted cheerfully in the tedious task of data coding. We appreciate the rapidity with which an abundance of computer output was obtained for us by Mr. Asger Bentzen. Cost of the study was borne by an N.S.E.R.C. grant to A.J. Sinclair and funds supplied by Consolidated Cinola Mines Ltd.
REFERENCES

Boyle, R.W., 1979, The geochemistry of gold and its deposits; Geol. Surv. of Canada, Bull. 280.


CHAPTER VII

Geostatistical Study of the Cinola Deposit,
Queen Charlotte Islands, B.C.
ABSTRACT

The Cinola gold deposit, owned by Consolidated Cinola Mines Ltd., is at the feasibility stage of evaluation. Ore reserve estimation by a geostatistical approach outlined here is based on drill hole assays from a grid of vertical diamond drill holes spaced at intervals of approximately 40 m. Separate geostatistical models are developed for unaltered ore and extensively argillically altered ground. The detailed model for "unaltered" gold concentration is used to illustrate the practical application of geostatistics in producing grade and error estimates. Blocks (selection units) that were estimated are measuring 30 x 30 x 10 m$^3$ where 10 m is the expected bench level of open pit mining.

One of the most striking results of this study has been the recognition of unusual uniformity of gold grade distribution compared with many other gold deposits. The results show that a geostatistical approach to ore reserve estimation is a viable and useful procedure.
INTRODUCTION

Ore reserve estimation of gold deposits is probably one of the most difficult problems faced by geologists and engineers. The apparently erratic distribution of gold in many ore bodies is the main reason for the tremendous difficulty in making confident estimations of mean grades for selection units (mining blocks). This paper documents a rigorous geostatistical approach to grade estimation at the Cinola gold deposit, based on a relatively uniform and dense distribution of sampled diamond drill holes. The mathematical concepts used in this analysis have been described in numerous publications, such as Clark (1980), Journel and Huijbregts (1978), and David (1977).

Cinola deposit is a large tonnage, low grade gold deposit in central Graham Island, Queen Charlotte Islands, B.C. (Figure 1). About 50 million tons of low grade material were inferred on the basis of limited drill information early in the exploration history of the occurrence (Richards et al., 1976). It was not until 1980 that the present operator, Consolidated Cinola Mines Ltd., proved by diamond drilling 45.4 million tons at an average grade of .054 oz. Au/s.t., using a cutoff of .025 oz. Au/s.t.

The gold deposit is contained in a coarse-grained, clastic, sedimentary sequence of Middle Miocene age which is cut by a rhyolite-porphyry body (Figure 2) (Champigny and Sinclair, 1980, 1981). The sequence is composed of interbedded conglomerate and
Figure 1. Location map of the Cinola deposit.
Figure 2. Geological cross-section of the Cinola deposit. The mineralized zone is localized at the margin and to the east of the rhyolite-porphyry.
sandstone units dipping gently (15°) to the east. Upper Cretaceous shales are in fault contact with the rhyolite intrusion on the west and constitute the footwall of the deposit. These three units are cut by several generations of quartz veins that locally contain high grade values (higher than 0.20 oz. Au/s.t.). Gold is also disseminated through the silicified coarse-grained sediments, to a lesser extent in the rhyolite-porphyry and rarely in the shales. Pyrite and marcasite are the most abundant sulphides, and gold particles are mainly of sub-microscopic size. A steeply clipping envelope of argillic alteration abruptly truncates the economic mineralization on the east.

The ultimate goal of this study was to calculate mean grade and error for blocks measuring 30 x 30 x 10 m^3 where 10 m is the bench height proposed for open-pit mining. An important product of the geostatistical approach includes testing whether the drill hole spacing, commonly about 40 m at Cinola, is close enough to provide reasonable estimates for 30 x 30 x 10 m^3 blocks. To answer these questions we proceeded in four stages as follows: (1) data evaluation, (2) generation of experimental semi-variograms, (3) development of semi-variogram models, and (4) kriging.

Over 20,000 m of assayed drill core form the data set for this study. Calculation involving this quantity of data must be done in the computer. In addition, extensive care must be taken in editing data so that errors are not built into subsequent
expensive computer runs.

**Data Control**

Borehole gold assays obtained during all exploration phases of the deposit since discovery were made available by Consolidated Cinola Mines Ltd. Several data types make up the data set and are listed in Table 1. Nearly all holes are vertical, and the core was analyzed in continuous sample lengths of 1.5, 2, or 3 m. Check assays from at least one other analytical laboratory were provided for the five categories of data. No assay discrepancies were recognized.

<table>
<thead>
<tr>
<th>Core size</th>
<th>Sample length (m)</th>
<th>% of total data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percussion</td>
<td>3.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Diamond</td>
<td>AX 1.5</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>BX 1.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>BX 2.0</td>
<td>40.5</td>
</tr>
<tr>
<td></td>
<td>BX 3.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>NX 3.0</td>
<td>49.3</td>
</tr>
</tbody>
</table>

Geological description by the writers of most of the drill core, combined with observations of other geologists on the remainder of the drill core, allowed us to settle on a simple one-letter coding system for host rock of each sample assayed for gold. The three principal host rock categories are; (1)
conglomerate-sandstone, (2) rhyolite-porphyry, and (3) shale.

Early in the study it appeared that all rock types could not be taken into account because of the small proportion of both rhyolite-porphyry and shale. All assays of shale are below the .025 oz. Au/s.t. cutoff, and are excluded from the study.

Probability graphs were constructed for assays for each of three different core lengths, 1.5, 2, and 3 m. An example, for sample length of 2 m, is shown on Figure 3. Two lognormal populations are apparent in each case, and a threshold separating them was selected using the partitioning procedure described by Sinclair (1976). The thresholds represent optimum separation of a high-grade population from a low-grade population. A linear relationship is apparent between the threshold values and the core sample length, and is illustrated in Figure 4. Longer and therefore bigger core samples are less variable in their gold values than are shorter samples.

We have recognized two populations in the drill core assays; a "high-grade" population which totals 3.5 percent of the data and is assumed to be distributed randomly throughout the deposit, and a "low-grade" population which comprises the bulk of the data and whose distribution is more continuous. The values above thresholds, that is, the "high-grade" population, were deleted for mathematical modelling of the "low-grade" population.
Figure 3. Probability plot for gold assays of 2 m samples from BX core. Full circles are cumulated frequencies of raw data. Open circles are partitioning points using a method described by Sinclair (1976).
Figure 4. Threshold values versus core sample length. Thresholds were determined from probability graphs.
Relative Semi-Variograms

The semi-variogram \( \gamma(h) \) is a measure of the difference between the grades of samples separated by a distance \( h \). An experimental semi-variogram is calculated using the equation:

\[
\gamma(h) = \frac{1}{2n} \sum [g(x) - g(x+h)]^2
\]

where \( g \) is the grade, \( x \) indicates the location of one sample in the pair, and \( x+h \) indicates the location of the other. The total number of pairs for each spacing, \( h \), is given by \( n \). \( \gamma(h) \) has units of grade squared, that is, \((\text{oz. Au/s.t.})^2\) in our case, and is calculated for a maximum number of different values of \( h \). Relative semi-variograms are obtained by dividing \( \gamma(h) \) values by the squared mean grade of all samples used in calculating the semi-variogram. All the semi-variograms reproduced here are relative semi-variograms.

Construction of "down-hole" relative semi-variograms is simple in the case of drill holes, since we have one long line of regularly spaced samples, generally with no gaps. At Cinola these one dimensional semi-variograms define the structure of grades in a vertical direction. Structure is examined horizontally by constructing experimental semi-variograms in four directions in a horizontal field—for example, using bench level composites from a single bench or from all benches.
Down-Hole Semi-Variograms

Down-hole semi-variograms were generated by computer separately for each drill hole, and average semi-variograms were produced for each data support (Table 1). The purpose of generating these is to compare the variability of gold values from the different categories of data. Such a comparison may lead to: (1) grouping certain data types with similar variability, and (2) recognizing data supports that have distinctly different levels of variability.

Experimental semi-variograms from very limited data sets for AX and percussion drill holes are markedly different from those for other data types, and these two data types were excluded from the study because of the likelihood of a large sampling-type error.

All the semi-variograms for BX drill holes are very similar regardless of the sample lengths (1.5 m, 2m, and 3 m) (Figure 5). Similar curves based on NX drill holes are divided into two groups: one group has semi-variograms comparable to those for BX core samples, whereas a second NX data set has a much higher nugget effect. This second group of semi-variograms was calculated from drill holes located in zones of extensive argillic alteration, whereas those with a lower level of variability, as well as all the semi-variograms based on BX core, derive from the relatively unaltered part of the Cinola deposit (Figure 6).
Figure 5. Average experimental down-hole semi-variograms (dashed lines), regularized spherical model (full line) curves for "unaltered" and "altered" data sets and spherical point model curve for "unaltered" data (dots). "Unaltered" variogram curves are for BX 1.5 (2), 2 (4) and 3m (3) and some NX 2m (5) drill holes. "Altered" variogram curves are for some of the NX 2 m drill holes (1).
Consequently, the following two simple geological groups are defined for geostatistical purposes, "unaltered" samples including BX and NX drill holes and "altered" samples comprising only part of the NX drill holes.

From this we conclude that alteration, as opposed to core size, dictates the behaviour of experimental down-hole semi-variograms at Cinola. Unaltered rocks constitute the main mineralized zone. Altered rocks have grades less than .025 oz. Au/s.t. Figure 6 illustrated the mapped distribution of extensive argillic alteration in drill holes. The remainder of our study is confined to a geostatistical evaluation of the "unaltered" group of sample data.

**Horizontal Semi-Variograms**

Drill core assays from the unaltered holes were averaged into 10 m composites, 10 m being the proposed bench height at Cinola. For each bench level, horizontal semi-variograms were generated for four directions; north-south, east-west, northwest-southeast, and southwest-northeast. In addition, an average isotopic semi-variogram for each level and a weighted average isotropic semi-variogram for all levels were produced. Experimental semi-variograms for the four directions were similar for a given level and were also similar to the grand average semi-variograms for all levels, as reproduced in Figure 7. This implies isotropy in the distribution of gold assays in a horizontal plane.
Figure 6. Locations of drill hole collars on the Cinola deposit. The principal gold concentration extends from the Footwall fault (FF) to the AA' line. Drill holes within the orebody are grouped in the "unaltered" data set. A steeply dipping zone of argillic alteration extends east of the AA' line and carries no economic mineralization. Drill holes in the alteration zone are grouped in the "altered" data set.
Figure 7. Average experimental horizontal semi-variogram (dashed line) for all "unaltered" drill hole samples based on 10 m bench composites. The regularized spherical model curve (full line) and point spherical model curve (dots) are also shown.
Modelling

Experimental semi-variograms shown in Figures 5 and 7 are saw-tooth curves that can be approximated by smooth mathematical models. The most common model that applies to experimental semi-variograms is the spherical model defined as follows:

\[ \gamma(h) = C_0 + C_1 \left( \frac{3}{2} \frac{h}{a} - \frac{1}{2} \left( \frac{h}{a} \right)^3 \right) \quad \text{for } h < a \]

\[ \gamma(h) = C_0 + C_1 \quad \text{for } h \geq a \]

where \( C_0 \) is the nugget effect, \( C_1 \) is the sill of the spherical model, \( a \) is the range, and \( h \) is any sample separation. The range of influence of a sample (\( a \)) is the distance at which samples become independent. The sill, \( C_1 \), represents the structured part of the variability, whereas the nugget effect is a random component and indicates the presence of one or more smaller scale structural components (i.e. smaller than the momentum sample spacing of about 30 m), each with its own sill and range.

The experimental down-hole semi-variograms for unaltered and altered drill holes were each fitted with a spherical model curve. A fairly good fit was obtained, as shown in Figure 5. Parameters for these models are summarized in Table 2. Both data sets have a relatively short range (22 and 18 m), and the spherical model for altered data has a sill 1.8 times higher than the sill of unaltered data. A spherical model was also fitted to bench composites to provide an isotropic model in
horizontal directions (Figure 7).

Experimental down-hole semi-variograms are based on 1.5, 2, and 3 m core sample lengths, whereas horizontal semi-variograms are based on sample lengths of 10 m. The down-hole models are said to have "regularized" over 1.5, 2, and 3 m, and the horizontal model is regularized over 10 m. We cannot reasonably expect the grade smoothed over 2 m of core to have the same behaviour as the grade smoothed over 10 m of core. In order to compare horizontal and down-hole models, one must calculate the respective punctual spherical models. The mathematical manipulations involved in determining the punctual spherical model are described by Huijbregts (1971), David (1977, p. 130), and Clark (1980, chapter 3). Tables 3 and 4 summarize the point spherical models calculated for horizontal and down-hole data sets. The horizontal data have been approximated with a mixture of two spherical models (Figure 7). The first component is the down-hole point spherical model \((a = 16 \text{ m})\), to which is added a second component with a long range (240 m). The nugget effect is the same for both down-hole and horizontal data if calculated for the same sample length. The long range structure may be present on down-hole variograms, but drill lengths are too short to be certain. It is possible that the geostatistical structure is isotropic in three dimensions.

The long range of 240 m defined by the horizontal point spherical model makes drill spacing of vertical holes less critical. A spacing of 40 m is certainly acceptable at the present
Table 2. Summary of regularized spherical models calculated for down-hole assay data of "unaltered" and "altered" drill hole samples and horizontal data of "unaltered" bench composites, Cinola deposit.

<table>
<thead>
<tr>
<th></th>
<th>$C_0$</th>
<th>$C_1$</th>
<th>$A_1$(m)</th>
<th>$C_2$</th>
<th>$A_2$(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down-hole</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(regularized over 2 m samples)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>altered</td>
<td>.54</td>
<td>.37</td>
<td>22</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>unaltered</td>
<td>.30</td>
<td>.20</td>
<td>18</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(regularized over 10 m composites)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unaltered</td>
<td>.06</td>
<td>.20</td>
<td>18</td>
<td>.12</td>
<td>250</td>
</tr>
</tbody>
</table>

Table 3. Summary of point spherical model calculated for down-hole data of "unaltered" drill hole samples, Cinola deposit.

<table>
<thead>
<tr>
<th>$h^a$(m)</th>
<th>$h^a/\lambda$</th>
<th>$(1/C_1)^{h}(h)$</th>
<th>$b$</th>
<th>$C_0+\gamma\lambda(h)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.31</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>.31</td>
<td>.38</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>.63</td>
<td>.44</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>.75</td>
<td>.47</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>.95</td>
<td>.51</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>.95</td>
<td>.51</td>
<td></td>
</tr>
</tbody>
</table>

a $h$ is sample spacing; $\lambda$ is length over which grades are averaged

b value obtained from Huijbregts (1971).
Table 4. Summary of point spherical model for horizontal data of "unaltered" bench composites, Cinola deposit.

<table>
<thead>
<tr>
<th>$h^a$ (m)</th>
<th>$h/\ell$</th>
<th>$(1/C_1)^b \gamma(h)$</th>
<th>$C_0 + \gamma(h)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.06</td>
</tr>
<tr>
<td>25</td>
<td>2.5</td>
<td>.16</td>
<td>.28</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
<td>.31</td>
<td>.30</td>
</tr>
<tr>
<td>75</td>
<td>7.5</td>
<td>.45</td>
<td>.33</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
<td>.59</td>
<td>.35</td>
</tr>
<tr>
<td>150</td>
<td>15</td>
<td>.82</td>
<td>.38</td>
</tr>
<tr>
<td>200</td>
<td>20</td>
<td>.96</td>
<td>.40</td>
</tr>
<tr>
<td>250</td>
<td>25</td>
<td>.98</td>
<td>.41</td>
</tr>
</tbody>
</table>

a  $h$ is sample spacing; $\ell$ is length over which grades are averaged

b  value obtained from Huijbregts (1971).
level of exploration, as it will become clearer from kriging estimates that are considered in a subsequent section.

Kriging

Kriging is a weighted average procedure for estimating local mean grade, and is optimal in the sense that the estimation variance is minimized. Procedures are summarized by various authors, and will not be outlined here. The low sill level and long range for the horizontal semi-variograms at Cinola suggest that two-dimensional kriging with a point isotropic model fitted to the experimental data will provide reasonable block estimation for blocks of $30 \times 30 \times 10m^3$. Because the effect of the short range structure will be minimal, the model adopted for two-dimensional kriging is a simple spherical model fitted to the experimental semi-variogram of Figure 7 and having the following parameters:

$$C_0 = .24$$
$$C_1 = .38$$
$$a = 250 \text{ m}$$

For the 110 m level we attempted to krige 352 blocks arranged in a rectangular array measuring 22 blocks by 16 blocks. Individual blocks are kriged only if: (1) four or more assays (bench height composites) are found within the search radius of 80 m from the center of the square to be kriged, or (2) there is one or more bench composite within the block to be kriged. These restrictions give estimates for only one aureole of blocks
beyond the limit of available drill data. Kriged grades for the 100 m level are shown on Figure 8. These estimated grades consist of two components combined in a manner developed by Giroux and Sinclair (personal communications, 1981). Each block estimate consists of a kriged component and a total random component. The two components are present in the proportion of 96.5 and 3.5 percent for the low grade and high grade proportions respectively. For each block the estimated grade is determined as follows:

\[ m = (1-p) m + pm \]

\[ m = .965 m + .035 m \]

The high grade random component has a mean value of 0.235 oz. Au/s.t., or a contribution of 0.008 oz. Au/s.t. for each block.

Error estimates on mean grades of individual blocks range from 15 percent relative error to 56 percent, with a large number near 20 percent. Such values are remarkably low for gold deposits and reflect the continuity of mineralization at Cinola.

Conclusions

This study has provided a systematic procedure for geostatistical ore reserve estimation of a large tonnage, low grade gold deposit. The procedure includes:

1. careful editing of the data,
2. construction of probability plots to partitioned "high" grade and "low" grade populations,
110 LEVEL - Au (oz/s.t.)
Figure 8. Kriged block mean grades for $30 \times 30 \times 10m^3$ blocks at the 110 m level. The approximate trace of the Footwall fault (FF) at the 110 m level and the AA' line mark the extent of the principal gold concentration. East of AA' the rocks are severely altered. Blocks that were kriged west of the Footwall fault were excluded because of the abrupt termination of mineralization on the Footwall fault.
3. generation of experimental down-hole and horizontal relative semi-variograms and development of a three-dimensional point model, and omission of unreliable subsets of data, and
4. block kriging.

Although not considered here, a logical extension of the study would be to produce grade/tonnage curves. Specific results for the Cinola gold deposit are summarized as follows:
1. Core size (NX, BX) and core length from 1.5 to 3 m do not appreciably change the behaviour of experimental semi-variograms.
2. Argillic alteration has a pronounced effect on the behaviour of experimental semi-variograms, by increasing the relative variability.
3. A remarkable homogeneity in the distribution of gold values at Cinola is shown by the two-dimensional isotropic nature of the assay data and relatively low errors of kriged block means. Consequently, a drill spacing of 40 m is reasonable for evaluation of ore grades and tonnages at the present feasibility stage.

Acknowledgments

The assistance of Asger Bentzen and G.H. Giroux in obtaining computer output for this study is acknowledged with thanks. Financial support was obtained from Consolidated Cinola Mines Ltd. and the Natural Sciences and Engineering Research Council of Canada (N.S.E.R.C.).
REFERENCES


Huijbergts, C., 1971, Reconstitution du variogramme ponctuel a partir d'un variogramme experimental regularise; Report N-244, Centre de Morphologie Mathematique, Fontainebleau, 22 p. and three graphs.


CHAPTER VIII

Conclusions
Exploration data for Cinola deposit have been organized in a manner that clearly illustrates the changing emphasis in exploration method as the occurrence evolved from a raw prospect to a deposit of potential economic worth undergoing a thorough feasibility study. Early exploration emphasized soil and silt geochemical methods, followed by a greater weight on rock geochemistry. Diamond drilling became progressively more important as exploration continued to the feasibility stage.

Detailed geological mapping was confined largely to core logging by a rigorous computer based system (GEOLOG). Field data and mineralogical studies led to development of a genetic model for the deposit. A Middle Tertiary (17-15 Ma) coarse grained clastic sequence, the Skonun Formation is the principal mineralized unit, and is cut by a 14 Ma rhyolite-porphyry. This intrusion is thought to represent a heat source that set up a relatively near surface circulating geothermal system that derived its fluid from interstitial or pore fluid of the Skonun sediments. As mineralization proceeded and filled channels, intermittent movement on the Footwall fault led to fracturing in adjoining rocks, with resultant increases in permeability for ore fluid transport.

Fluid inclusion studies support the genetic model and showed that (1) the mineralizing fluids were probably derived from pore water of the fluviatile host rock, and (2) mineral deposition occurred at temperatures ranging from 300°C to 130°C and at a depth between 1.1 and 1.8 k.
A 17 to 15 Ma age for the Skonun Formation is proposed from three independent sources of evidence: K-Ar data, palynological analysis, and fauna examination of specifically collected samples at Cinola.

Primary and secondary dispersion haloes of Au, Ag, Hg, As, and W are evident from statistical analysis of rock, soil, and silt geochemical data. Ag in rock best defined the areal extent of the Cinola orebody. On the other end, base metals (Cu, Pb, and Zn), with Ni, Co, and Mo in addition, have low values and show an erratic distribution.

The uniform distribution of gold at Cinola is remarkable for a gold deposit. This is shown by the two-dimensional isotropic nature of drill hole assay data and relatively low error estimates on mean grades of kriged blocks.
REFERENCES


Blanchet, P.H. and Godwin, C.I., 1972, 'Geolog System' for computer and manual analysis of geologic data from porphyry and other deposits; Econ. Geol., v. 67, pp. 796-813.


Boyle, R.W., 1979, The geochemistry of gold and its deposits; Geol. Surv. of Canada, Bull. 280.


Collins, P.L.F., 1979, Gas hydrates in CO₂-bearing fluid inclusions and the use of freezing data for the estimation of salinity; Econ. Geol., v. 74, pp. 1435-1444.


Haas, J.L. Jr., 1971, The effect of salinity on the maximum thermal gradient of a hydrothermal system at hydrostatic pressure; Econ. Geol., v. 66, pp. 940-946.

Huijberchts, C., 1971, Reconstitution du variogramme ponctuel a partir d'un variogramme experimental regularise; Report N-244, Centre de Morphologie Mathematique, Fontainebleau, 22 p. and three graphs.


Richards, G.G., Christie, J.S., and Livingstone, K.W., 1979,
Some gold deposits of the Queen Charlotte Islands
(abstract); Can. Inst. Min. Metall. Bull., v. 72, n. 809,
pp. 64.

Rouse, G.E., and Mathews, W.H., 1979, Tertiary geology and pa-
lynology of the Quesnel area, British Columbia; Bull. Can.

Rust, B.R., 1972, Structure and process in a braided river;
Sedimentology, v. 18, pp. 221-245.

Rust, B.R., 1978, Depositional models for braided alluvium; in
A.D. Miall (Editor), Can. Soc. Petroleum Geol., Memoir 5,
Fluvial sedimentology, pp. 605-625.

Shen, K., Champigny, N., and Sinclair, A.J., 1981, Genetic im-
plications of fluid inclusion studies, Cinola gold deposit,
Queen Charlotte Islands, B.C.; B.C. Ministry of Mines and

Sinclair, A.J., 1974, Selection of thresholds in geochemical
data using probability graphs; Jour. Geochem. Expl., v. 3,
p. 129-149.

Sinclair, A.J., 1976, Applications of probability graphs in min-
eral exploration; Assoc. Explor. Geochemists, Spec. Vol. 4,
95 p.


Taylor, R.P., and Fryer, B.J., 1980, Multiple stage hydrothermal alteration in porphyry copper systems in northern Turkey: the temporal interplay of potassic, propylitic, and phyllic fluids; Can. J. Earth Sc., v. 17, n. 7, pp. 901-926.
