Province of
British Columbia

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Energy, Mines and
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May 31, 1990

To: R.W. Smyth, Chief Geologist
Geological Survey Branch

Subject: Joint GSC - BCGSB Sullivan proposal

With the recent notice of closure of the Sullivan mine and the resultant impact on the economy of southeastern B.C., the Geological Survey of Canada, hopefully in cooperation with the B.C. Geological Survey Branch, are proposing an integrated 5-year project to study the Sullivan deposit and its setting. The principals, John Lydon, Bob Turner and myself, have had a number of informal and formal meetings regarding this project - one that included Bill Wolf and John Hamilton of Cominco Ltd. and J.M Duke and R.J.F. Scoates of the GSC.

The attached is a draft of a proposal that we wish to submit to both the GSC and the GSB. Lydon and Turner hope that it can be passed on to Cominco Ltd. for their input in a week or two. They have also requested that I meet with them and some Cominco staff in the Sullivan area some time this summer with the intent of discussing the individual projects in more detail.

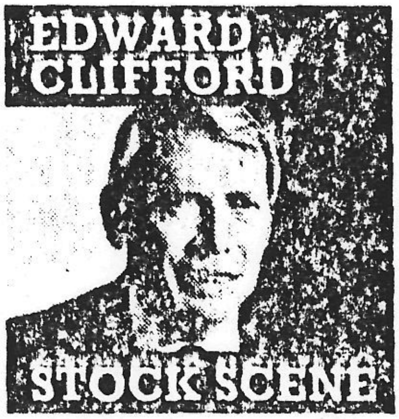
I see our role as primarily a coordinator and possibly a source for graduate student research. My own work would probably be minimal, unless it was incorporated in the proposed massive sulphide project. Because of our past committment to the Purcell project, the considerable expertise we have in the area, and the political importance of the Sullivan mine, I feel we should have some strong representation in the project.

Trygve Hoy

cc. W.J. McMillan

Trig, I support the project in principal. I believe you & GSC should proceed & get Cominco on side. Then I think a one day meeting (plus Univ?) of principal investigators & interested mgrs & funders be held and all of sub projects be tabled. I have some concerns re deep drilling / geophysics etc. Ron

Kimberley closing costs jobs, but Cominco doesn't hurt a bit



The interests of shareholders of a company and its employees sometimes run on parallel tracks. When the company is going great guns, everybody's happy; dividends flow and pay envelopes bulge.

When things aren't so hot, a corporation has to choose whom to disappoint. In the case of Cominco Ltd., on Wednesday it chose to announce the closing of its zinc mine at Kimberley, B.C., putting 700 people out of work for an indefinite period.

That seems to suggest that the interests of its 13,815 shareholders take precedence over those of the 700 miners. Cominco says it lost $2.2-million on the mine in November, and $2.6-million in December; a time when zinc prices were running at 68 cents (U.S.) a pound.

The company says the price has fallen to 57.1 cents a pound since then. If Kimberley was losing that much money at 68 cents a pound, it was losing even more after a 16 per cent price drop, the reasoning goes.

The company's huge Red Dog zinc mine in Alaska is expected to come into production this year, which will make Cominco one of the world's lowest-cost zinc producers. The "indefinite period" that Kimberley will be closed may be an understatement. Try "forever."

The fact that the company decided to eliminate a loser should have pleased investors as much as it displeased the displaced miners. Not at all; the share price rose only 12 cents (Canadian) after the announcement.

The company is the favorite of integrated mine analysts who like its wide product mix (zinc, lead, copper, fertilizers).

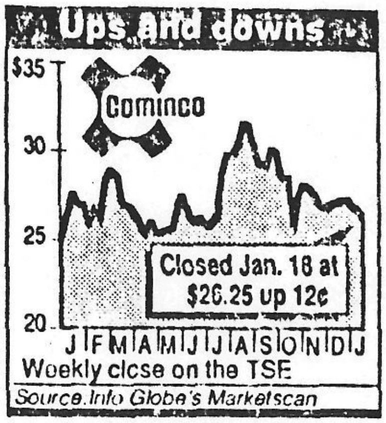
A typical comment was one by John Lydall of First Marathon Securities Ltd., who said Cominco "remains in the best financial shape of the senior integrated producers." Except for the Red Dog project loan, the company is essentially debt free.

"Although lower zinc and copper prices will reduce Cominco's earnings, with little scheduled capital spending other than Red Dog, 1990 should be a good year," he said. He noted that Teck Corp., which has a holding in Cominco of more than 40 per cent, continues to be an active buyer of its shares.

Raymond Goldie of Richardson Greenshields of Canada Ltd. rates the shares as a buy. He is expecting profit of $3.30 a share for 1989, rising to $3.95 in 1990.

He does not see the same downside potential for zinc prices that some others do — a low of 30 to 35 cents (U.S.) a pound — and pointed out that the price-inventory relationship for zinc jumped in 1989 to new and higher levels. "As a result, the new base level for zinc prices is around 55 cents. This jump and the support it can give to future prices has not been generally recognized by the stock market."

About 50 per cent of zinc, which accounts for one-third of Cominco's revenues, goes into the manufacture of galvanized steel, a product widely used in the automotive industry. If North American and West European consumption falls, the slack may well be taken up by Japan and the Pacific Rim countries, according to Harit Jolly, an analyst with Value Line Inc. of New York.



On the supply side, he said, Peru, the third-largest zinc producer in the West, "is still not very politically stable." A repeat of the 1988 miners' strike there could hamper supply and provide some price support. Prophetically, Mr. Jolly said "systematic capacity rationalization during steel's slow period will help limit excess supply and prevent major erosion in prices."

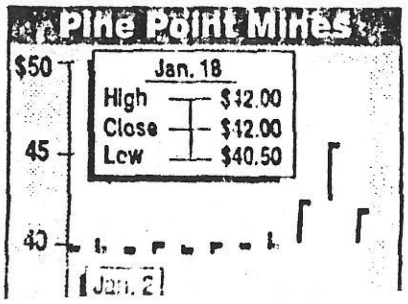
Mr. Jolly said Cominco's current investments in various projects are likely to help sustain healthy long-term profit momentum. Thanks to the strength of prices over the past two years, the company is in a good cash position. "Rather than just giving the money to shareholders in the form of increased dividends, Cominco is aggressively investing these funds to ensure steady growth."

These investments have included a 43 per cent stake in a copper deposit in Chile, a 50 per cent interest in a nickel smelter in Oregon, and an equity stake in Aur Resources Inc. of Toronto.

In spite of the 135 per cent gain in the price of Cominco's shares during the past two years, "it should still be able to keep pace with the market over the pull to 1992-1994 . . . we are relatively confident that the company will be able to post steady earnings gains over the years due to the several new ventures it has recently undertaken."

Teck drops Pine Point offer plans

BY KAREN HOWLETT
The Globe and ...



Jannock bl...

BY BARRIE McKENNA
The Globe and Mail

MONTREAL

Plans by B.C. Sugar Refinery Ltd. ... ver to crack the eastern market by ... stake in Lantic Sugar Ltd. will have ...

A preliminary proposal for

AN Integrated Programme on

THE SULLIVAN DEPOSIT AND ITS GEOLOGICAL ENVIRONMENT.

PART 1 - CONTEXT AND BACKGROUND

SEDEX deposits are the most important single source for both zinc and lead. The majority of the largest and highest grade SEDEX deposits are of Proterozoic age. The Sullivan deposit is the only example of a world class Proterozoic SEDEX deposit in Canada. Because of its intact geological preservation and its relatively low degree of tectonic deformation and thermal metamorphism, the Sullivan deposit is acknowledged as the classic example of the SEDEX deposit type.

The future of the Sullivan mine is uncertain. In any event, depletion of known ore reserves means that the permanent closure of the mine within the foreseeable future is inevitable. The closure of the mine will have a major impact for two different concerns:

1. Socio-economic. After being a major employer in south-eastern British Columbia for such a long time, the loss of the Sullivan mine in the absence of substitute local opportunities for a specialized work force, will obviously lead to social destabilization and economic deprivation.
2. Scientific. Largely because of the contributions by Cominco staff to the scientific literature which has been exemplary for a mining company, basic documentation of the Sullivan deposit is good. However, this unique natural laboratory has the capacity to supply additional information important to the understanding of processes which control the formation and distribution of SEDEX deposits in general. This information is contained in the ores and host rocks of the Sullivan deposit itself; in the wealth of cores, samples, mining records and other documents made by Cominco over the mine's long history; and last, but by no means least, in the knowledge and experience of Cominco's mining and exploration staff. The closure of a mine usually results in such sources of information becoming inaccessible, lost or dispersed.

Although it is not within the means or mandate of the Geological Survey of Canada and the British Columbia Geological Survey to directly influence the socio-economic impact of a Sullivan closure, it is within their respective responsibilities to ensure that maximum scientific benefits have been derived from this unique Canadian natural asset before the opportunity to do is irretrievably lost.

This proposal outlines and explains the scope and rationale of the investigations that are appropriate.

PART 2 - MANAGERIAL AND ADMINISTRATIVE COMPONENT,

OBJECTIVES AND PURPOSE OF SULLIVAN PROJECT.

To provide as complete a documentation as possible of this classic Canadian ore deposit while it is still practicable to do so.

To provide new data and understanding of the geological environment of the Sullivan deposit, at both the local and regional scales.

To identify and document those geological factors which were essential to the ore-forming process and to quantify those geological, geochemical, or geophysical signatures that are diagnostic of the ore-forming environment.

To compare data on the Sullivan deposit to analogous modern seafloor hydrothermal vents, particularly those of Middle Valley, with the purpose of identifying and quantifying dynamic and kinetic factors in processes of hydrothermal precipitation, alteration and effluent dispersal.

PRODUCTS.

Annual workshop and display (poster and/or oral) at an appropriate geoscience event (e.g. Western Roundup, GAC annual meeting).

Annual progress reporting as GSC or BCGS Open Files, Papers.

Publication in scientific journals as appropriate.

Publication of final results of all projects within a single GSC or BCGS volume.

BENEFITS.

Permanent public record of the maximum amount of information that is obtainable on this important ore deposit.

Maximization of scientific returns by synchronous integration with studies of analogous modern ore-forming environments, with particular emphasis on the ODP drilling of Middle Valley.

New information for exploration models for SEDEX deposits, particularly in the Aldridge Formation of British Columbia.

Potential for socio-economic benefits that derive from new mineral exploration initiatives in south-eastern British Columbia that may be stimulated by the new data.

Integrated with synchronous studies at Middle Valley, provide new understanding of the interaction and effects of industrial-type pollution on the marine environment, and provide suggestions for toxic waste disposal that are in harmony with natural processes.

Potential for a high profile Federal-Provincial-Industrial-University collaborative programme.

TIMING AND DURATION.

The timing of the programme is to produce the results before the closing of Sullivan Mine and to take concurrent advantage of information emanating from the ODP drilling of Middle Valley. The proposed programme duration is:

1990-1. Feasibility study. Definition of main individual projects. Identification of principal investigators for individual projects. Commitments to support levels.

1991-4. Scientific investigations.

1994-5. Preparation of final manuscripts.

1995-6 Publication of Sullivan Volume.

PARTICIPANTS, COSTS AND RESOURCES

The organizations involved in the proposed Sullivan Project are :
Geological Survey of Canada.
B.C. Geological Survey.
Cominco.
Others - Universities, industry.

In order to achieve results to significantly enhance current knowledge and documentation of the Sullivan deposit and the Aldridge sedimentary basin, it is estimated that the following minimal costs and resources per annum of scientific investigation are necessary:

	PY	$1000.
GSC	2	100
BCGS	1	50
Cominco	0.5	5

The personnel resources will allow the participation of 5-6 GSC and 2-3 BCGS personnel devoting 20% to 50% of their time to the project. The financial resources are to cover field and travel, outside analytical contracts, outside scientific or services contracts. The estimate for Cominco is to cover a minimal participating, guiding or observing role and attendance at meetings. The profiling of expenditures will be:

1990-1	1991-2	1992-3	1993-4	1994-5	1995-6
$10K	$155K	$155K	$155K	$50K	$50K

The technical details of various proposals are appended to this proposal. What should and can be done will be decided by the collaborative parties at a working group field meeting in the fall of 1990 at which a first hand review and assessment of accessible data and sample sources.

INTEGRATION AND COORDINATION.

The proposed project involves a multi-disciplinary integration of different projects carried out locally on the Sullivan Mine, regionally on the Aldridge basin, and comparatively with the GSC and ODP programmes at Middle Valley. Scientific participants in the project will be drawn from the GSC, BCGS, Cominco, universities and possibly from other government departments and industry. To facilitate integration between different groups it is proposed that a coordination panel establish research priorities, recruit interested scientists, coordinate field and scientific activities, and generally facilitate progress and productivity of the project. Suggested co-coordinators are:

GSC (Ottawa)	-	John Lydon.
GSC (Vancouver)	-	Robert Turner.
BCGS (Victoria)	-	Trygve Hoy
Cominco	-	

Regional scale problems include:

The generation of metalliferous hydrothermal systems in a sedimentary basin, which involves two separate problems:
R.1. The source of the heat. Suggestions include: i) normal but anomalously high conductive heat flow. Aquifers which are both thermally insulated and hydrodynamically capped (usually by an argillaceous lithology) can attain temperatures equivalent to a thermal gradient of over 200°C per km. ii) local heating either directly by a cooling igneous intrusion or indirectly by convection cells driven by an igneous intrusion. The Moyie sills may have played a role for the Sullivan deposit that is similar to that suggested for sills and other intrusions for hydrothermal systems in the Guaymas Basin and Escanaba trough.
R.2. The source of high salinity. The salinity of a hydrothermal fluid must be at least as high as seawater to carry significant concentrations of metals. Suggestions include : connate marine formational waters; dissolution of evaporites; salt concentration by ion filtration during compaction of sediments. The high concentration of boron in the Sullivan feeder zone may suggest that the Sullivan ore fluids were derived from continental evaporites.

R.3. Spatial distribution of hydrothermal vents.
Flow from a hydrothermal reservoir to the sediment-water interface requires cross-stratal conduits. The most popular concept has been that cross-stratal permeability is provided by synsedimentary or growth faults that are related to the tectonic system controlling the sedimentary basin. Conventionally, the tectonic system has been assumed to be a major rift, and the growth faults part of and parallel to the main or ancillary graben structures. However, data from modern hydrothermal systems suggest that this conventional model may need to be modified from two perspectives. The first is that rhombochasms associated with transcurrent fault systems may be a more favourable setting for hydrothermal systems than pure rift systems, and that cross-faults are more important conduits for hydrothermal fluids than faults parallel to the main fault system. The second is that unconsolidated sedimentary sequences behave as a relatively homogenous permeable medium to buoyant hydrothermal fluids, which may rise as a diapiric plume through the sedimentary sequence independent of fault-controlled conduits. To prognosticate the full range of potential hydrothermal vent sites in the Aldridge basin, knowledge of regional synsedimentary tectonics and thermal perturbances are necessary.

assemblages is perhaps the most evident process. Understanding of the processes of precipitation enable a more realistic interpretation of chemical signatures, and a more reliable use of those signatures in exploration models.

D.3. Mechanisms of hydrothermal precipitation and accumulation at the surface.

Conventionally, SEDEX deposits have been regarded as the products of brine pool sedimentation. This concept automatically puts restrictions on the composition of the ore fluids (denser than seawater; contains all ore components including sulphur) and seafloor bathymmetry (need for a local basin to contain brine pool), which in turn sets criteria for exploration models (e.g. requirement for sub-basinal facies as ore host).

However, notwithstanding that the metalliferous sediments of the Red Sea brine pools provides undisputable evidence that the brine pool model has validity, the new knowledge from modern hydrothermal systems gives cause to re-evaluate the applicability of the brine pool model to all SEDEX deposits. The ascent of a hydrothermal diapir through unconsolidated sediment produces a column of hydrothermally altered and indurated sediment. Convection of heated mud at the top of this column in concert with differential compaction about the indurated column produces a topographic mound at the seafloor from which hydrothermal venting will preferentially take place. Coalescence, collapse, and replacement of hydrothermal chimneys and their talus in the vent complex to produce the vent complex lithologies, and mass wastage of this elevated complex via debris and turbidite flows combined with plume fall-out to produce a surrounding apron of bedded and laminated ores is an equally realistic way to produce the textural variants characteristic of SEDEX deposits.

Similarly, for sulphide sulphur at least, there is growing documentation that a substantial proportion of this essential ore component is derived from the depositional environment and not the hydrothermal fluid, emphasizing that hydrothermal discharge in itself may not be sufficient to form a SEDEX deposit in the absence of suitable environmental conditions. Whether the sulphide sulphur is most commonly derived by biogenic reduction of marine sulphate just below the sediment surface, by high temperature inorganic reduction in the vent complex, or existed as an integral component of an anoxic-bottomed stratified water column is still debatable. Whichever it is has ramifications for exploration models.

D.4. Post-ore environmental signatures and post-burial modifications to the deposit.

Information on why ore deposition ceased can provide as many clues as to the factors important for ore deposition as the processes that sustained ore deposition itself. For example, a gradual waning of hydrothermal temperatures might reflect collapse of the hydrothermal system because of heat source depletion; a sudden ventilation of bottom waters might suggest the integral factor of bottom water stagnation for sulphide accumulation; etc.

Comparison of chemical signatures immediately below and above the ore horizon can provide clues as to the impact of sustained toxic waste disposal on a submarine environment (remembering that the acidic, sulphurous, metalliferous, nutritional (PO_4, NO_3, NH_3), hydrocarbon-bearing hydrothermal effluent has many similarities to modern industrial waste).
Post-burial modifications to the ore are often mistaken for primary features. Comparison of diagenetic features in hanging wall rocks to those in the ores, especially those involving the redistribution of ore components, are helpful in subtracting post-burial overprints. Not the least in this regard are tectonic and metamorphic effects.

SCOPE AND CONTEXT OF INDIVIDUAL RESEARCH TOPICS COMPRISING THE SULLIVAN PROJECT.

Listed below are the main objectives of individual projects that will comprise the Sullivan Project. The projects are keyed to the thematic problems outlined above. Details of each research topic are attached in an appendix.

Most of the subprojects are dependant upon full co-operation by Cominco to provide sample material, data, mine access and general collaboration.

DEPOSIT SCALE TOPICS.

<u>Geology and geochemistry of the bedded ores.</u>
The fundamentals of this documentation has already been carried out by Cominco staff. What is needed is documentation of certain features in greater detail that will resolve different models of ore deposition, and to distinguish synsedimentary and post-burial effects. Work is already in progress (Lydon).
Scientific context: D.3.; D.4. ; R.4.
Requirements: Drill core ; underground samples.

<u>Geology and geochemistry of transition zone ores.</u>
The transition zone occupies the contact between the bedded ores and the massive pyrrhotitic core of the vent complex. Study of this part of the stratiform ore is important to determine whether it is dominantly a replacement front proceeding outwards from the vent complex or a disconformity between autochtonous sulphide mound and sedimented hydrothermal products. Whatever its significance, understanding its nature and origin will provide fundamental evidence as to the major process responsible for the accumulation of the sulphide ores. Documentation of mineral paragenesis and geochemistry will provide information fundamental to process of subsurface mineral precipitation and replacement, and processes of subsurface replacement and zone refinement. A proposal for this subproject. has already been submitted to the GSC and Cominco (Turner).
Scientific context: D2 ; D.3. ; D.4.
Requirements: Drill core ; underground samples.

Geology and geochemistry of the pyrrhotite core.
Presumably the pyrrhotite core was the locus of recurrent hydrothermal flow throughout ore deposition. Like the footwall stockwork zone it should therefore preserve a record of the evolution of the hydrothermal fluid. However, because of the great difference in mineralogical composition between the two, the pyrrhotite core will be sensitive to different chemical parametres than the footwall rocks.
Scientific context: D2 ; D4.
Requirements: Drill core ; underground samples.

Geology and geochemistry of the hanging wall.
The hanging wall alteration zone is evidence that hydrothermal fluids continued to flow after the sulphide deposit was buried by normal sedimentation. Whether this represents a direct continuation of discharge from the ore-forming hydrothermal system or a secondary effect such as pore fluid expulsion from the sulphide body by compaction remains to be determined.
The hanging wall to the main sulphide zone contains anomalous stratigraphic units, including sulphidic units. These are restricted to the mine area and therefore indicate the continuation of anomalous sedimentary processes after the main stage of sulphide deposition. The interrelationship between hanging wall alteration, hanging wall sedimentation, and post-burial modification to the sulphide body needs to be investigated.
Scientific context: D1 ; D4
Requirements : Drill core ; underground samples.

Hydrothermal alteration of the footwall feeder zone, Sullivan deposit.
A study has already been carried out (D.M. Shaw) but the results have not been documented. Several types of hydrothermal alteration assemblages have been recognized, occurring in the following sequence: i) tourmaline; ii) chlorite ; iii) muscovite ; iv) chlorite-pyrrhotite ; v) albite-chlorite-pyrite. The purpose of this subproject is to document the nature and evolution of the hydrothermal fluids that upflowed through the vent zone. Data derived by petrography, chemistry, stable isotopes, fluid inclusions.
Scientific context: D.1. ; D.2 ; D.4
Requirements : Compilation ?; Drill core ; underground samples.

GIS computer analysis of drill hole data base.
GIS type analysis of the chemical and geometric data of the mine exploration drill hole grid is important to clearly understanding the three dimensional architecture of the Sullivan deposit. For example, planar projections of single ore bands can reveal chemical zoning patterns that directly comment on the mechanism of deposition of each band e.g. debris flow or chemical precipitate; stacked slices through the pyrrhotite core can

reveal intimate details of its internal structure.
Scientific context: D2 ; D3
Requirements : Drill hole data, assay data.

MINE STUDIES WITH A REGIONAL COMPONENT

Comparison of barren tourmalinite pipes to the Sullivan feeder zone.

Tourmalinite is the most conspicuous hydrothermal alteration product in the feeder zone of the Sullivan deposit, but tourmalinite alteration zones elsewhere in the Aldridge have no associated base metal mineralization. The purpose of the study is to determine the significance of the tourmalinite pipes to the hydrodynamics of the Aldridge basin, their relationship, if any, to metalliferous hydrothermal fluids, and any differences in the environment of venting or fluid evolution that may have effected suppression of base metal mineralization.
Scientific context: R.2. ; R.3. ; D.1
Requirements : Drill core; underground/surface samples.

Stable isotope chemistry of hydrothermal alteration in the Aldridge basin.

A start has already been made on this work at the Sullivan deposit (Nesbitt, Campbell and coworkers). Stable isotope data can be very useful in distinguishing different types of hydrothermal fluids and detecting the flow paths of the fluids.
Scientific context: R.2. ; D.1.
Requirements : Drill core; underground/surface samples.

Evidence for subsurface hydrothermal plumes in the Aldridge basin.

Perhaps the major difference of practical importance between fracture controlled hydrothermal conduits and diapiric hydrothermal plumes are the different exploration criteria that they imply. The subproject would compare chemical, mineralogical, textural and isotopic signatures (O, S, C, Sr) of footwall rocks around the Sullivan deposits, to stratigraphically equivalent rocks elsewhere. For example, the potassic metasomatism of the micaceous alteration type and/or the pyrrhotite-enriched footwall rocks may be indicators of such a plume.
Scientific context: R.3. ; D.1.
Requirements : Drill core; underground/surface samples.

REGIONAL STUDIES

Geochronology of thermal events in the Aldridge Formation.
There is limited reliable geochronological data on thermal events that are, or could be misinterpreted as, synchronous with Aldridge sedimentation. Additional U/Pb data on zircons from the Moyie sills could provide data on the spatial migration of contemporaneous igneous activity, and U/Pb data on rutile formed by hydrothermal alteration could provide analogous information for hydrothermal events.
Scientific context: R.1. ; R.3.
Requirements : Surface/underground samples.

Stratigraphic geochemistry of the Aldridge Formation.
Stratigraphic geochemistry (including S, O, C, Sr isotopes) can provide information on changing environmental conditions, hydrothermal effluent dispersal, and stratigraphic correlation. Stratigraphic geological correlation within the Aldridge Formation is difficult and is heavily dependant on Cominco's proprietary "marker" information.
Scientific context: R.4. ; D.3.
Requirements : Drill core ; surface samples.

Geophysical stratigraphy of the Aldridge Formation.
Geophysical signatures can provide an alternate or complimentary tool to the problem of stratigraphic correlation.
Scientific context: R.3.
Requirements : Deep drill holes.

Sedimentology of the Aldridge Formation.
The important information from this subproject is data on seafloor topography, sediment transport and water current directions, sedimentation rates, and contemporaneous tectonic dislocations (e.g. growth faults). Perhaps all field work that is possible has already been carried out, and all that is required is compilation and synthesis.
Scientific context: R.3.
Requirements : Compilation ; surface access/samples.

MOYIE SILLS - A MIDDLE PROTEROZOIC MAGMATIC EVENT DURING DEPOSITION OF THE ALDRIDGE FORMATION AND SULLIVAN DEPOSIT

Initiator: T. Hoy
Principal researcher: T. Hoy
Additional researchers: R. Turner; G. Goles (University of Oregon)

Introduction

Considerable preliminary work on the Moyie sills, an extensive suite of basaltic rocks in the Middle Proterozoic Purcell Supergroup rocks, indicates that they intruded, in part, during deposition of the Aldridge and Fort Steele formations (Hoy, 1989). The sills are spatially restricted to these formations in the lower part of the Purcell succession and are distinct from a suite of mafic sills higher in the succession. They may comprise up to 30 percent of a typical sequence but generally decrease in volume up-section as the abundance of thick-bedded A-E turbidites decreases. A number of the sills have textures and contact relationships that suggest they intruded unconsolidated or partly consolidated wet sediments.

A U-Pb zircon Middle Proterozoic date of 1445 Ma from a coarse-grained sill is interpreted to be the minimum age of emplacement (Hoy, 1989). Because the sills are penecontemporaneous with Aldridge sedimentation, this date defines the minimum age of deposition of lower and basal middle Aldridge rocks.

Two distinct compositions of Moyie sills are recognized. Most are subalkaline, high iron tholeiitic basalts, whereas others are alkaline basalts. The two different chemical trends are typical of volcanism in an incipient rift environment or in the early stages of continental rifting. This supports a model for deposition of Belt-Purcell rocks in a large subsiding intracratonic basin formed by Middle Proterozoic rifting.

Proposal

The purpose of this project is to study in more detail the setting, characteristics, geochemistry and geochronology of the Moyie sills and to attempt to relate the sills to the evolution of the Purcell basin and the formation of stratiform sulphide deposits. In particular, little is known regarding any vertical or lateral variations in sill mineralogy or composition, regional variations from the edges to the centre of the Purcell basin, or evolutionary trends.

Undoubtably, some sills consolidated at depths, and hence comparisons between sills intruded at various levels may be possible.

Finally, the hydrothermal systems that are generated in sills that have intruded wet sediments, and are recognized in the host rocks of some Moyie sills; these warrant further investigation. They may have implications regarding fluid migration and accompanying metal transport beneath stratiform sulphide deposits and in vein deposits.

In summary, the project would include detailed mapping of Moyie sills and the immediate host rocks, better documentation of the effects of wet sediment intrusion, and analyses of the generated hydrothermal systems. The purpose of this work would be to better understand the setting of the Purcell basin and the evolution of hydrothermal systems.

Methodology

(1) Detailed field mapping of Moyie sills

(2) Chemical analyses, including trace element and LREE analyses

(3) isotope (C/O) analyses of both sills and host sediments

(4) Petrography

(5) Geochronology

(5) Research and write-up

Reference

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BUDGET ESTIMATE May 30/90
TECTONIC EVOLUTION OF THE PURCELL BASIN

1) Fieldwork (2 YR)

Vehicle operation/maintenance.......................8 000
Accommodation.(summer) 2 @ $350/mo.* 6mo............4 200
Per dium (summer) 2 @ $900/mo. * 6mo...............10 800
Film + processing..................................600

Total..23 600

2) Thin/polished-section preparation

Thin section @ $8/sample *50.......................400

Total..400

5) write-up

Printing supplies and expenses.....................500
Office supplies....................................400

Total..900

BUDGET TOTAL.......................................$24 900

REGIONAL FOOTWALL ALTERATION - SULLIVAN CAMP

Initiator: T. Hoy
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Introduction:

Well-defined stockwork feeder zones are recognised beneath many massive sulphide deposits, including the Sullivan deposit. These cross-cutting zones are generally assumed to represent the feeder zones for overlying stratiform sulphides. They provide important information regarding the nature and timing of formation of the sulphide deposits and, from a practical point of view, increase the size of a target during regional and camp exploration.

Large semi-conformable alteration zones have also recently been recognized beneath some volcanogenic massive sulphide deposits (Morton and Franklin, 1987). Their nature reflects many features critical to the understanding of the deposit, including the nature and extent of the hydrothermal fluids, variations in host rock lithologies, depth of water and dynamics of fluid migration. The recognition of a similar zone beneath the Sullivan Camp (Hoy, 1983) may have profound implications regarding the formation of sedex deposits and, as well, has considerable exploration potential.

Regional Footwall Geology

Deposits in the Sullivan camp include the Sullivan deposit, near the transition from lower-energy turbidites of the lower Aldridge into AE turbidites of the middle Aldridge, and a number of deposits on North Star Hill, including North Star and Stemwinder and showings on the Dean and All Over claims. They are within a large zone of intense alteration in lower Aldridge siltstone and quartz wacke (Hoy, 1983, in preparation). The zone is approximately 6000 metres in length and 1500 to 2000 metres in width and trends south-southeast from Sullivan. It has been extrapolated to a depth of 1500 metres beneath Sullivan (Hamilton, 1984) and has been intersected in drill holes to depths exceeding 200 metres on North Star Hill (D.H. Olson, personal communication, 1983).

The alteration zone appears to be restricted to lower Aldridge rocks; that is, rocks that stratigraphically under lie the Sullivan deposit. The zone is characterized by:

- A marked increase in the abundance of disseminated and irregularly laminated pyrrhotite and, to a lesser extent, pyrite. Surface exposures are typically highly oxidized.
- An increase in the number of pyrite, galena and sphalerite-bearing veins.
- An increase in the number of small massive sulphide

occurrences.

- Zones of pervasive tourmalinized and silicified rock, similar to those in the footwall of the Sullivan deposit. These are commonly irregular in outline with either sharp or gradational contacts; they cross lithologic boundaries. Locally, thin tourmaline-rich laminations occur in siltstone. The tourmalinite is a dark, hard siliceous rock that breaks with a conchoidal fracture.
- Irregular zones of breccia or "conglomerate". The conglomerate is generally a diamictite with subrounded siltite clasts up to 2 centimetres in diameter supported by a siltite matrix. Pyrite and pyrrhotite with minor amounts of sphalerite and galena typically occur in the matrix. The conglomerate often grades into massive (lacking bedding) siltsone or quartzite. The conglomerates may define beds but also form clastic dykes. Similar rocks in the footwall of the Sullivan orebody, termed "fragmental", are interpreted to have formed by injection and local surface extrusion, rather than by collapse of fault scarps (Hamilton, op. cit).
- Obliteration of bedding by intense sulphide alteration, tourmalinization, silicification, or development of "conglomerate".

Many of these features extend beyond the limits of the intense alteration zone. For example, thin laminations of tourmalinite occur 3 to 4 kilometres south of the North Star Hill (A. Hagen, personal communication, 1983). As well, anomalous numbers of sulphide laminae occur at the lower-middle Aldridge transition (the Sullivan horizon) on Concentrator Hill, which is 5 kilometres east of Sullivan.

Proposal

The purpose of this subproject is to more clearly document the nature and extent of this regional alteration zone. Its recognition is based on limited (1:20,000 - scale) regional mapping in the vicinity of these deposits. It has not been backed up by geochemistry, isotope investigations, detailed mapping, fluid inclusion work or petrography. Furthermore, no attempt has been made to tie its distribution and extent to structures.

The subproject therefore involves detailed surficial mapping and sampling, hopefully examinaiton of drill core, and follow-up lab work and research.

Results:

Recognition and documentation of this alteration zone can provide valuable information regarding the formation of sedex deposits. It is possible that it records a wide, diffuse zone of hydrothermal venting in late lower Aldridge time and that this discharge was focused, perhaps in response to development of more limited structural conduits, at Sullivan time. The nature of the focusing mechanism and the early evolution of the hydrothermal system may be recorded in the alteration zone.

Methodology:

(1) Detailed field mapping and core logging (2-3 months)
(2) Contract chemical analyses
(3) Contract stable and radiogenic isotope analyses
(4) Thin section preparation and study
(5) Research and write-up

This project may be suitable for a sponsored MSc candidate.

References

Hamilton, J.M. (1984): The Sullivan Deposit, Kimberley, British Columbia - a Magmatic Component to Genesis? (abstract), in The Belt, Belt symposium II, Montana Bureau of Mines and Geology, Special Publication 90, pages 58-60.

Hamilton, J.M., Bishop, D.T., Morris, H.C., Owens, O.E. (1982): Geology of the Sullivan Orebody, Kimberley, B.C., Canada, in Precambrian Sulphide Deposits, H.S. Robinson Memorial Volume; R.W. Hutchinson, C.D. Spence, and J.M. Franklin, editors, Geological Association of Canada, Special Paper 25, pages 597-665.

Hoy, T. (1983): Geology in the Vicinity of the Sullivan Deposit, Kimberley, British Columbia, Geological Fieldwork 1982, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1983-1, pages 9-17.

Hoy, T., in preparation, Geology of the Middle Proterozoic Purcell Supergroup in the Fernie west-half map area, Southeastern British Columbia, B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 76.

Morton, R.L and Franklin, J.M., 1987, Two-fold Classification of Archean Volcanic-Associated Massive Sulfide deposits, Economic Geology, Volume 82, pages 1057-1063.

BUDGET ESTIMATE May 30/90
REGIONAL FOOTWALL ALTERATION - SULLIVAN CAMP

1) Fieldwork (1 YR)

Vehicle operation/maintenance.......................4 000
Accommodation.(summer) 2 @ $350/mo.* 3mo............2 100
Per dium (summer) 2 @ $900/mo. * 3mo................5 400
Film + processing...................................300

Total...11 800

2) Chemical analyses

Whole rock analyses.@ $25/sample * 25.................625
Multi-element analyses @ $11/sample * 25..............275

Total...900

3) Geochronology

U-Pb zircon 1 @ $1 600..............................1 600
K-Ar 3 @ $750.......................................2 250
Pb-Pb zircon 1 @ $1 600.............................1 600
O-isotope analyses 20 @ $200........................4 000
H-isotope analyses 10 @ $1000.......................2 000
S-isotope analyses 5 @ $200.........................1 000
C-isotope andlyses 10 @ $200........................2 000

Total...14 350

4) Thin/polished-section preparation

Thin section @ $8/sample *25..........................200
Polished section @ $20/sample *25.....................500
Polished probe section @ $22/sample *25...............550

Total...1 250

5) write-up

Printing supplies and expenses........................500
Office supplies.......................................400

Total...900

BUDGET TOTAL......................................$29 200

RELATIONSHIP OF ZN-PB MINERALIZATION, SEDIMENTARY BRECCIAS AND ALTERATION WITHIN THE SULLIVAN-NORTHSTAR-STEMWINDER BELT

Principal Investigator Robert J. W. Turner

Additional Research Trygve Hoy.

Scientific context

Formation of sedex deposits reflects cross-stratal flow of hydrothermal fluids from a deep reservoir upwards to the seabottom. This sub project is concerned with the character of the structural control of the Sullivan vent site, looked at both from a mine scale and local mine area scale (i.e. including North Star and Stemwinder deposits). For example, current research on the Jason stratiform Zn-Pb deposit suggests formation adjacent to a syndepositional cross fault (Turner, 1990) within a pull-apart basin associated with strike-slip faulting (Abbott and Turner, 1990). The syndepositional fault is an altered and mineralized zone of ductile and brittle strain with an adjacent wedge of diamictite.

At the Sullivan mine, the breccia pipe and the overlying pyrrhotite body of the Sullivan deposit represents a vent complex and hydrothermal upflow zone during formation of the bedded ores. the Sullivan breccia pipe is sited on a north-trending syn-ore fault structure: (1) the Stemwinder and North Star Zn-Pb deposits and Sullivan breccia body define a north-trending linear; and (2) the Sullivan breccia pipe is a composite of north-trending breccia lenses; and (3) a gabbro sill underlying the Sullivan deposit cuts up-section vertically coincident with the west side of the breccia body suggesting intrusion up a steeply-dipping fault plane. It is possible that this structure was an east-side-down normal fault given that: (1) the Sullivan deposit is assymmetric in an east-west cross-section, with the sulphide body thinning rapidly west of the breccia body (Hamilton et. al., 1982) suggesting deposition on a structurally elevated block; and (2) the footwall conglomerate is wedge-shaped in cross-section, thickens towards the breccia pipe, and is absent west of the breccia pipe.

Exploration context

This subproject would address the following questions of exploration relavance.
(1) What are the characteristics of the structures that controlled the Sullivan deposit.
(2) What stratigraphic and sedimentological criteria can be used to define proximity to this syndepositional structure.

Scientific content

Sullivan mine studies

(1) Document distribution and character of footwall conglomerate.
(2) Document character of sedimentary breccias within Sullivan mine including textural character, contact relationships with bedded sediments and footwall conglomerate.
(3) Document the stratigraphic setting of the Sullivan deposit west of the breccia body.

Sullivan-Stemwinder-Northstar trend (see detailed proposal "Breccia footwall alteration - Sullivan (map).

(1) Document the distribution of breccias and conglomeratic rocks; compare to those within Sullivan mine.
(2) Document character of rock alteration associated with Stemwinder-Northstar trend.
(3) Document the stratigraphic setting of the Sullivan sulphide zone intersected by recent deep drilling north of the Sullivan deposit.

Methodology

(1) detailed core logging
(2) underground mapping of breccias and footwall conglomerate

Sample/Material requirements
(1) Access to Sullivan mine drill core through footwall conglomerate, breccias and western Sullivan ore body.
(2) Access to company reports with detailed underground mapping of breccias and footwall conglomerate (as these exposures are no longer accessible).
(3) Access to drill core from North Star- Stemwinder trend area.
(2) Access to core from deep drilling north of Kimberley fault.

Budget

3 months field work

Polished/thin sections	$1,000.00
Photographic supplies and services	$1,000.00
Contract chemical analyses	$1,000.00
Contract student lab and office assistance	$5,000.00
Field travel and expenses	(covered under transition zone sub-project)
Office and lab supplies	$1,000.00
TOTAL (over 3 years)	$9,000.00

References

Abbott, J. G. and Turner, R. J. W., Paleotectonic setting of Devonian stratiform Zn-Pb-barite deposits, MacMillan Fold Belt, Yukon in Abbott, J. G. and Turner, R. J. W., eds., Mineral deposits of the northern Canadian Cordillera: I. A. G. O. D. Field Guide # 14 (in press).

Hamilton, J.M., Bishop, D.T., Morris, H.C., and Owens, O.E., 1982, Geology of the Sullivan orebody, Canada, in Precambrian sulphide deposits (H.S. Robinson Memorial Volume): Hutchinson, R.W., Spence, C.D., and Franklin, J.M., eds., Geological Association of Canada, Special Paper 25, p.597-665.

Ransom, P.W., Delaney, G.D., and McMurdo, D., 1985, The Sullivan orebody, in Field guides to geology and mineral deposits in the southern Canadian cordillera: D. Tempelman-Kluit, ed., p. 11-20 to 11-32.

Turner, R.J.W., 1990, Geological setting, hydrothermal facies and genesis of the Jason South/Main stratiform Zn-Pb-barite deposit, Selwyn Basin, Canada, in Abbott, J. G. and Turner, R. J. W., eds., Mineral deposits of the northern Canadian Cordillera: I. A. G. O. D. Field Guide # 14 (in press).

(2) Document the distribution of trace elements within the different mineral assemblages. Why is the transition zone an area of trace element enrichment? Enrichment may reflect processes active during formation of the Sullivan orebody (i.e. remobilization and zone refining of Ag, Sb, Hg, Tl, Au, Sn), or remobilization into veins and faults within this structurally complex zone during younger deformation.

Comparison with transition zones of other exhalative deposits

The Jason and Tom stratiform lead-zinc deposits are both characterized by a massive vent proximal zone that has replaced distal bedded sulphides. Textures, mineralogy and chemistry of these transition zones can be compared with that of Sullivan. Comparison with current information about the transition between massive mound sulphides and flanking resedimented sulphide beds at the Middle Valley hydrothermal system will provide insight based on modern processes.

Methodology

(1) Detailed mapping and sampling of the best exposed underground transects across the transition zone.
(2) Logging and sampling of drill hole transects across the transition zone.
(3) Integration of transect studies with mine-scale data collected by Cominco (e.g. plan maps, cross-sections of ore horizon, metal distribution maps).
(4) Detailed study of samples collected: hand specimen textures, polished sectionn study, X-ray diffraction for mineral identification, ICP for bulk whole rock chemistry, microprobe analysis for mineralogy and mineral chemistry, and isotope geochemistry ($\partial^{34}S$ of sulphides; $^{87}Sr/^{86}Sr$, $\partial^{13}C$, $\partial^{18}O$ of carbonates).

Sample/Material Requirements

In order of importance,
(1) Access to stopes within the transition zone for purposes of mapping and sampling.
(2) Access to drill core through the transition zone for logging and sampling.
(3) Access to assay data for drill holes and underground sampling throughout the transition zone.

Budget (Turner and Leitch)

Polished thin sections (200)	$4,000.00
Photographic supplies and services	$2,000.00
Contract isotopic analyses	$4,000.00
Contract chemical analyses	$10,000.00
Contract student office assistance (total 6 months)	$15,000.00
Field travel and expenses	$15,000.00
Office/lab supplies	$4,000.00
TOTAL (Over 3 years)	$54,000.00

References

Goodfellow, W.D. and Rhodes, 1990, Geology and geochemistry of the Tom stratiform Zn-Pb-barite deposit, MacMillan Pass, Yukon, in Abbott, J. G. and Turner, R. J. W., eds., Mineral deposits of the northern Canadian Cordillera: I. A. G. O. D. Field Guide # 14 (in press).

SEDIMENTOLOGICAL AND CHEMICAL EVOLUTION OF THE ALDRIDGE FORMATION

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Other Participants:

Cominco Limited Geologists
Bob Turner
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Scientific Context

The formation of SEDEX deposits in rift-controlled sedimentary basins at particular times in the earth's history is not fortuitous but reflects the differentiation and stabilization of the crust and water column conditions which were conducive to sulphide precipitation and preservation. Although there is ongoing debate regarding mechanisms of metalliferous fluid generation in sedimentary basins, there is clear evidence that these fluids were derived from sediments of continental origin and discharged into sedimentary basins. It is not surprising therefore that the appearance of SEDEX deposits coincided with the establishment of a thicker, sialic and more rigid crust which when rifted formed depressions.

Crustal evolution is also important because of the important control this exerts on the composition of sediments with which hydrothermal fluids equilibrate. Sialic minerals tend to buffer the pH at neutral to weakly acidic values, thereby favoring metal chloride over metal bisulphide complexes. Furthermore, because of the difficulty of transporting high contents of metals in the presence of reduced sulphur at neutral pH and temperatures $<300^{\circ}C$, metalliferous fluids generated in sedimentary basins tend to be sulphide-poor. It follows therefore that for these fluids to form a SEDEX deposit, they must mix at the site of deposition with a second fluid carrying sufficient contents of reduced sulphur.

From studies of Paleozoic SEDEX deposits, two possible sources have been identified. These are: 1) the ambient water column stratified with reduced, sulphidic bottom waters; and 2) sedimentary barite sulphate reduced to sulphide in the vent complex by reaction with organic compounds. The ambient water column, probably the most important source of reduced sulphur in SEDEX deposits, may also account for the limited temporal distribution of SEDEX deposits.

During the Proterozoic, most of the Paleozoic and for geologically brief intervals in the Mesozoic, the earth's climate was stable with low temperature gradients from pole to pole. These climatic conditions were conducive to the establishment of stratified oceans with stagnant bottom waters and the buildup of bacteriogenic reduced sulphur, an essential component in the precipitation of metals and the formation of SEDEX deposits. Because

Red Sea rift whereas the latter process is less well understood. The large range of salinities fluids formed in modern and ancient sedimentary basins indicates that the source of saline fluids varies from between basins as a function of sedimentary environment and burial history.

2) Density and chemistry of ambient bottom waters, which have varied with time. Modern oceans are well oxygenated and weakly stratified with cold and therefore slightly more dense bottom waters. Ancient oceans, by contrast, were stratified with saline and anoxic waters for prolonged intervals during the Proterozoic and Paleozoic, and for brief episodes in the Mesozoic.

3) Hydrothermal brine pools (e.g., Atlantis II Deep, Red Sea) above vents with densities considerably greater than mean ocean water will influence the behavior of hydrothermal fluids discharged at the seafloor.

4) Hydrostatic pressure (i.e., water depth) which determines whether a hydrothermal fluid boils at the seafloor .

If the fluid forms a buoyant plume upon discharge, it will rise in the water column until neutrally buoyant, diffuse outward from the core of the plume and migrate in the prevailing current direction. Minerals precipitated in the plume will be zoned away from the vent site as a function of decreasing grain size and specific gravity. As the plume cools, it becomes more dense and sinks slowly to the seafloor unless it is continuously replenished.

The size of dispersion halos surrounding hydrothermal centers is controlled by the height of the plume, the hydrothermal flux rate and bottom water current velocities. The presence of a prevalent bottom current will tend to generate fan-shaped plume deposits.

The sedimentology, mineralogy and chemical composition of plume sediments is controlled by: i) hydrothermal fluid pulse frequencies and fluxes, and chemical evolutionary history of the hydrothermal system; ii) distance from the vent sites which relates to grain size and specific gravity; iii) the composition of the hydrothermal fluid; iv) the composition of the ambient water column; and v) mineral precipitation and dissolution kinetics.

<u>Scientific Content</u>

The objective of this sub-project is to determine how minerals and elements are temporally and spatially zoned about the Sullivan hydrothermal vent. To achieve this objective, the following strategies will be pursued.

(1) Document the sedimentology, thickness changes, mineralogy, mineral chemistry and bulk and isotope chemistry as a function of time within cores and with respect to distance between cores.

(2) Use the above data to determine the morphology of distal

are consistent with an ambient water column sulphur source, and preliminary isotope data from the Middle Proterozoic Jiashengpan Zn-Pb deposit indicate most of the sulphur originated from an ambient, reduced water column. The source of sulphur has one very important implication as to mineral exploration. If an anoxic water column enriched in reduced sulphur is essential to the formation of SEDEX deposits, then the exploration for this deposit-type should focus on those periods in the earth's history characterized by stagnant bottom water conditions.

Stable isotopes of carbon will be used to (1) substantiate periods of anoxia defined using sulphur isotopes because of the coupling of carbon and sulphur cycles, (2) give a measure of the relative biomass (organic productivity) through time and (3) provide clues on the level of exchange of water between the Aldridge Basin and open oceans.

(4) Determine secular variations in the bulk composition of sedimentary rocks of the Aldridge Formation. The whole rock major element data will provide a quantitative measure of the major components, whereas the trace elements will be used to identify hydrothermal pulses (including a major pulse during Sullivan time).

(5) Detailed mineralogy and chemistry will also be used to identify zones of widespread alteration formed by the upflow and lateral migration of hydrothermal fluids.

Methodology

(1) Megascopic description of drill hole core from a fence of drill holes representing the different sedimentary facies and spanning the time interval represented by the Sullivan deposit.

(2) Megascopic description of surface sections for areas well exposed but lacking drill hole coverage.

(3) Systematic sampling of megascopically identifiable units for the purpose of petrography, mineralogy, mineral chemistry, and isotope and bulk chemistry.

Sample Material, Map and DDH Log Requirements

(1) Maps, cross-sections and reports from Cominco Limited showing geological relationships and drill hole locations.

(2) Drill hole logs from Cominco Limited.

(3) Core from regional drill holes intersecting the Sullivan host rocks.

(4) Well controlled and exposed stratigraphic sections of the Aldridge Formation in areas lacking drill hole control.

Budget

(1) Field travel and expenses	$ 6,000
(2) Student assistant (3 months)	$ 8,000
(3) 100 polished thin sections	$ 3,000
(4) Photographic supplies and services	$ 1,000
(5) Contract isotopic analyses	$ 6,000
(6) Contract chemical analyses	$ 2,000
Total (over 3 years)	$ 25,000

hydrothermal sediments, to correlate hydrothermal events, to determine whether the Sullivan hydrothermal fluids behaved as buoyant plumes or bottom-hugging brines, and to assess the role of the ambient water column in precipitating metals and other hydrothermal elements.

(3) Attempt to correlate distal hydrothermal sediments with the more proximal bedded ores examined in detail by J.W. Lydon (refer to proposal by J.W. Lydon).

Methodology

(1) Detailed logging and sampling of drill holes (and of surface sections if available) intersecting distal hydrothermal sediments.

(2) Prepare polished slabs of representative structures and textures (estimated at 100) for megascopic observation and documentation of sedimentary, hydrothermal and diagenetic textures.

(3) Prepare polished thin sections (estimated at 100) for petrography, mineralogy and mineral chemistry.

(4) Determine representative samples for major, minor and trace elements using XRF, ICP-ES and AAS methods. The mineral chemistry will be determined by microprobe and energy dispersive methods coupled with an electron microscope.

(5) Sulphides and sulphate will be determined for delta^{34}S values and silicates for delta^{18}O values in an effort to determine hydrothermal fluid-seawater mixing ratios, to map paleotemperatures and to determine sulphur sources.

Sample Material, Map and Log Requirements

(1) Access to Cominco Limited maps and/or cross-sections showing geology and drill hole locations.

(2) Access to Cominco Limited logs and any reports describing cores from drill holes intersecting distal hydrothermal sedimentary rocks.

(3) Access to drill core for logging and sampling purposes.

(4) Access to assay data for the drill holes selected.

Budget

Field expense (including travel costs)........	$ 6,000
Polished thin sections (100)..................	$ 2,000
Student assistant (3 months)..................	$ 8,000
Contract isotopic analyses....................	$ 10,000
Contract chemical analyses....................	$ 6,000
Photographic and office supplies..............	$ 6,000
TOTAL (over three years)...	$ 38,000