A GEOLOGICAL EVALUATION OF
WHITE RIVER COPPER DEPOSIT
OF
SILVER CITY MINES

by

062001

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Confidential
Given to I.N.A. by
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A GEOLOGICAL EVALUATION OF THE WHITE RIVER COPPER DEPOSIT OF SILVER CITY MINES LIMITED

INTRODUCTION

The White River property of Silver City Mines Ltd., is about 220 air miles northwest of Whitehorse, Yukon, and 6 1/2 miles east of the Alaska border on the east bank of the White River about 16 miles upriver from the point where the Alaska Highway crosses White River. The deposit has been mentioned in the literature since near the turn of the century (e.g. Cairnes, 1915), and has been touted as representative of a native Cu-basalt association that is recognized on a world-wide scale (Cornwall, 1956). The White River copper deposit is reknowned locally in Yukon by the fact that a 2590 pound slab of native Cu forming part of the original discovery has been erected for display near the local musuem in Whitehorse.

Most recent exploration activity on the property has been under the auspices of Silver City Mines Ltd. and various aspects of their work form the bases of numerous private reports mainly by Dr. W.V. Smitheringale. The writer became involved in a study of the deposit at the request of Mr. Cy Keyes, President of Silver City Mines, and with the encouragement of Mr. A. Oliver of the Department of Indian Affairs and Northern Development. Agreement was reached on a one-year research project in which the writer undertook a review of geological information on the property, the project to be underwritten financially by Silver City Mines Ltd. A copy of the original agreement forms Appendix I of this report.

The writer visited the property for 4 days in late June 1975 in the company of Mr. Cy Keyes, W.V. Smitheringale, A. Bentzen and D. Wriggett, to familiarize himself with the general features of the deposit, to obtain a realistic view of the scope of the proposed study, and to outline a 2-month field program. Messrs. Bentzen and Wriggett remained on the property until late August 1975 charged with, (a) field mapping near the mineralized showings, (b) relogging of nearly 15,000 feet of diamond drill core, and (c) sampling for purposes of assaying, petrologic and mineralographic examination and geochemical analyses. Mr. J.A. McLeod subsequently became involved in laboratory aspects of the study.

Three interim reports (McLeod, 1975a, 1975b; Bentzen, 1975) were prepared under the authors supervision and represent a series of progress reports for the project. The present report is a summary of previous work, adds results of further studies, and attempts to tie together available data, ending with a practical discussion dealing with implications of the study to exploration.

GENERAL GEOLOGY

General geology is described by Muller (1967). Rocks in the Kluane Ranges range in age from Devonian to Cenozoic, and all are folded and cut by southwesterly dipping thrust faults of regional extent. The White River property is in a small thrust slice of Permian and Triassic rocks bounded in plan on the east by the Duke River overthrust and on the west by an unnamed thrust surface. Both faults dip gently to the southwest.

Permian rocks in the general area include two units, one predominately volcanic and the other sedimentary. The volcanic unit is characterized by pyroclastic rocks with minor amounts of intercalated greywacke, argillite and limestone. The sedimentary unit consists of argillite, sandstone, conglomerate, limestone and chert (see Read and Monger, 1976). Triassic Nikolai volcanic rocks are characterized by the presence of amygdaloidal and/or porphyritic structure in basaltic rocks that range in colour from red-brown to dark green, and are commonly 1000 feet or more in thickness. Native copper-copper sulphide deposits in the region are confined to the Nikolai volcanic unit or immediately adjacent strata.

Elsewhere in the area small mafic and ultramafic intrusions of possible Triassic age have associated with them showings of Cu-Ni sulphides. Much of the area immediately to the east of the Silver City property is underlain by Cretaceous intrusive rocks of intermediate composition, but these intrusions appear to be unrelated to Cu deposits associated with Nikolai volcanic rocks.

No detailed account of the geology of the White River native copper deposit has been published to date. The most widely available description is a compilation of published literature and private reports summarized in a proprietary file, "Northern Cordilleran Mineral Industry" prepared by the consulting firm, Archer, Cathro and Associates Limited. Some early results of the present project were presented at a Geoscience Forum in Whitehorse during December 1975--an abstract of this presentation is appended (Appendix II).

Host for the White River copper deposit is the Upper Triassic Nikolai Greenstone, a unit long recognized for the number of native copper-copper sulphide occurrences located within or stratigraphically near it. Within the general area the unit ranges up to several thousand feet thick. In the White River thrust slice the true thickness is unknown but probably is much less than the value of 3000 feet quoted by Read and Monger (1976). Lithological variations are summarized in Table I. In general, all units of the Nikolai Greenstone are basaltic, the main mappable features being presence or absence of amygdules and/or phenocrysts (including glomerophorphs) and colour variations. These features are not necessarily uniform even in a single flow. For example, both top and bottom of a flow might be amygdaloidal but the interior need not be; a flow top might be extensively oxidized to a red-brown colour whereas the remainder of the flow could be dark green. Because of these variations considerable emphasis during mapping and core logging was placed on recognition and extrapolation of flow tops as a means of working out the structure of the volcanic sequence.

Five mappable units summarized in Table II are shown in the projected sections of Figures 1 and 2. Of these, units 3 and 5 are mostly indistinguishable in hand specimen but in the field are separated, structurally at least, by a recognizably different rock, unit 4. A brief de-

TABLE I

VOLCANIC ROCK CLASSIFICATION

MINERALOGICAL	TEXTURAL	COLOUR
Basalt	Amygdaloidal	Red
	Porphyritic	Green
	Glomeroporphyritic	(Other)
	"Gabbroic"	
	Greenstone	

scription of each unit follows. Note that units are comparable to those defined by Bentzen (1975) but names have been modified slightly for the sake of consistency with microscopic data (see McLeod, 1975a. 1975b).

Porphyritic Basalt (Unit 1): This unit is a sequence of undefined thickness at the base of the structural succession containing the mineralized zones. The rock is a fine-grained volcanic rock with plagioclase phenocrysts and many amygdaloidal sections. Colour is green, grey-green, or red-brown. Glomeroporphs are rare and smaller than in units 3 and 5.

Red and Green Amygdaloidal Basalt (Unit 2): This unit is fine-grained with no glomeroporphs and relatively few plagioclase phenocrysts. It consists of intercalated dark red-brown and dark green layers and is commonly very amygdaloidal (about 15 volume percent amygdules). Most amygdules consist of either chlorite, calcite or zeolites. Minimum thickness of the unit is 100 feet but it could be as thick as 200 feet.

Glomeroporphyritic Basalt No. 1 and No. 2 (Units 3 and 5): Glomeroporphyritic basalt is either green, grey-green or some shade of red-brown. It is porphyritic (about 10 percent plagioclase phenocrysts up to 4-5 mm. long) and characteristically contains widely spaced glomeroporphs in which stubby to lath-shaped phenocrysts are arranged in clusters with a crude radial or star-like form. Flow margins in the unit are amygdaloidal with chlorite the main mineral forming amygdules. Unit 3 has an apparent thickness through the main mineralized zone of 250 feet but appears to thin somewhat with depth. The minimum established of unit 5 is about 60 feet. It is certainly thicker but outcrops and drill data are too sparse to provide more information. Most of the known copper minerals are concentrated in Glomeroporphyritic Basalt No. 1 (Unit 3) although it should be pointed out that all units contain some native copper and/or copper sulphides.

"Grained" Basalt (Unit 4): This unit, referred to in the field as a "gabbro" is a volcanic rock with a high proportion of stubby phenocrysts and a correspondingly small amount of matrix. Hence, the megascopic appearance is that of a medium-grained phanerite. Amygdules are present, mainly formed of chlorite, or calcite but are not nearly as abundant as in other units. Apparent thickness of the unit is about 130 feet.

Greenstone: A greasy appearing volcanic rock termed greenstone in the field was recognized only as thin layers within other units, particularly Glomeroporphyritic Basalt No. 1 (Unit 3). On very close examination small phenocrysts and amygdules (up to 3 mm. in long dimension) can be seen, or relicts of phenocrysts and amygdules remain. Most specimens contain at least a few very small blebs of native copper and it is for this reason that the rock type has been considered of some importance in the past. Detailed examination has shown the rock to be an altered vitrophyre, the greasy lustre arising from alteration of volcanic glass. Apparent thicknesses of individual layers range from about 5 to 20 feet.

TABLE II

STRUCTURAL SUCCESSION OF UNITS, WHITE RIVER COPPER DEPOSIT

UNIT	SYMBOL	APPARENT THICKNESS (feet)
Glomeroporphyritic Basalt No. 2	GLB2	60 (min)
Grained Basalt	GRBS	130
Glomeroporphyritic Basalt No. 1	GLB1	250
Red and Green Amygdaloidal Basalt	AMYG	100 (min) 200 (max)
Porphyritic Basalt	PRBS	40 (min)

Structure and Volcanic Stratigraphy

Figure 1 is a "projected" vertical section through the 2900 adit. It is termed "projected" because all drill hole information within 150 feet of the plane of section has been projected along strike to the plane of section. The section was generated on the computer from a computerized data file of some drill hole information and was output using a Calcomp drum plotter. Programming was done by A. Bentzen. All drill holes have been coded such that a variety of cross sections can be produced at will, with tremendous saving of manpower.

The cross section is to all intents and purposes perpendicular to the trend of the volcanic flows on the property, and provides a fairly clear indication of the general disposition of individual volcanic units. Superficially the sequence is homoclinal, but such an interpretation is a gross oversimplification because in areas of outcrop to the north (along the shore of White River) part of the same volcanic succession can be seen cut by fault surfaces that are subparallel to the rough orientation of volcanic units. Comparable faults certainly exist in and near the mineralized zones, and, in fact, can be recognized in drill core and in adits. However, these faults cannot be projected with confidence, even over short distances; consequently, the extent to which they complicate the simple homoclinal structure indicated in Figure 1 cannot be ascertained. Field evidence indicates that the succession is rightside up.

Contacts in general dip steeply to moderately to the east. Irregularities apparent in the contacts could arise because of several causes; (a) data are projected over a total zone width of 300 feet and the section might not be perpendicular to local strikes over this short dis-

Figure 1: (in pocket) Computer-generated section through portal of 2900 level, White River property, Silver City Mines Ltd. Pole of section strikes 006° and is horizontal. Viewer is north-facing. All information within 150 feet of the section has been projected to the plane of section along the strike direction (006°).

Figure 2: (in pocket) Computer-generated plan of 2900 level, White River property, Silver City Mines Ltd. All information on principal rock units above and below the section has been projected to the 2900 level plane along the average dip (65°) of the apparent homoclinal section of Figure 1.

tance, (b) surveyed elevations are only approximate, (c) drill holes (unsurveyed) are assumed to be perfectly straight, and (d) local faulting may have produced real local irregularities in the "apparent" contacts. Despite these sources of uncertainty the accompanying section provides useful insight into the general structure of the mineralized zone and approximate orientation of individual units. The contact between the Red and Green Amygdaloidal Basalt and Glomeroporphyritic Basalt No. 1 is thought to be a fault, at least in part, based largely on the abundance of broken core observed during drill core logging.

Strikes and dips of some marker surfaces or units can be determined by solutions to 3-point problems where sufficient drill intersections are available. A number of such calculations done at various locations in and near the mineralized zone (Bentzen, 1975) where effects of faulting are thought to be minor show the strike to be essentially northerly. Dips are all to the east and range from moderate to steep. Precise dip values calculated from 3-point problems are not particularly significant because of the short distances over which they have been calculated and the approximate methods used to determine locations in space.

A projected plan is shown in Figure 2. This plan was computer-generated by projecting critical drill hole information in the average direction of the homoclinal sequence to the 2900 level. Thus, particular details of the plan can be slightly in error, but the distribution shown for mappable units is generally correct and the "projected" plan considered with the "projected" vertical section provide the first clear understanding of the general structure of the volcanic succession in the immediate vicinity of the White River copper deposit.

Petrography

All mappable units have many petrographic (as well as chemical) features in common, that seem to require a common genesis. Even the field units Grained Basalt and Greenstone were found to be simply textural modifications of porphyritic and/or amygdaloidal basalts. The Grained Basalt, for example, simply contains a high proportion of phenocrysts and a complementary low proportion of matrix, and superficially has the appearance of a phaneritic rock rather than a porphyry.

Perhaps a more significant point is that the Greenstone unit, an easily recognizable field unit with a greasy lustre, is simply a basalt in which phenocrysts and matrix are more altered than in other rock types, the phenocrysts being set in what was a glassy matrix, now devitrified. The devitrified glass is the cause of the greasy lustre, and the unit in the past was interpreted as a highly altered phase of other rock types.

Primary minerals recognized in these rocks are plagioclase, augite, magnetite, hematite and rare apatite. A few pseudomorphs of serpentine after olivine were recognized but no olivine remains. These primary minerals are commonly set in an ill-defined matrix that originally ranged through microcrystalline, cryptocrystalline to glassy, from place to place. This matrix has been altered to varying degrees. The red-brown colour of parts of the volcanic succession can be seen to derive from partial oxidation of abundant magnetite that is present in all units. However, even where a deep red-brown colour occurs only a fraction of the magnetite has been oxidized.

The extent of deuteric processes is unknown. It may be that the principal vestige of deuteric alteration is serpentine as pseudomorphs after olivine. However, the rock has been altered extensively by low grade regional metamorphism and any deuteric effects that might have existed are no longer obvious.

Approximate modes or presence of minerals are indicated for 22 speciments in Table III. A rapid perusal of this table, approximate though it be, shows that the primary minerals are in the relative proportions to be expected of basaltic rocks. Of particular interest though is the prevalence of alteration minerals in many of the specimens. The abundance of chlorite and calcite, and the somewhat more locallized occurrence of prehnite, pumpellyite, and analcime indicate that the rock has undergone substantial alteration. In fact, these minerals are indicative of the prehnite-pumpellyite facies of metamorphism.

Primary Minerals:

Plagioclase is the most abundant mineral in the rocks studied. It occurs as lath-shaped phenocrysts about 1 to 3 mm. long, locally arranged as glomeroporphs, and as an important component of the ground mass where it forms microlites. It commonly displays a subophitic texture with augite. Locally plagioclase is replaced extensively, although in many places it is relatively fresh. Sericite, chlorite and less abundant calcite or epidote commonly partly replace plagioclase. Where fresh, plagioclase phenocrysts are zoned normally with cores about An_{80} and rims about An_{60}. Plagioclase in a hornblende-bearing dyke(?) rock of limited occurrence has a composition of An_{54}.

Augite, the only pyroxene recognized, is present in highly variable amounts. It forms anhedral grains with either an interstertal or subophitic relation to plagioclase. Grains are normally in the range 0.2

TABLE III

Table of Approximate Modes or Indications of minerals present*

No.	Name	Plag.	Aug.	Mag.	Analc.	Prehn.	Sericite	Chlorite	Calcite	Pump.	Hematite	Cu	Qtz.	Cu	Sulphide	Ep	Serp.	Py	Glass	Hbde	Ap
40-1-1	Red Porph. Basalt	55	25	10				7									3				
40-4-1	Red Amgy. Porph. Basalt	x	x	x	x			x	x		x				?	x			x		
45-1-187	Red Amgy. Porph. Basalt	x	x	x		x		x	x		x						x		x		
45-1-256	Green Porph. Basalt	x	x	x	x	x		x	x							x	x				
87-2-50	Green Glom. Basalt	55	7	10				20	7				1					x			
89-1-60	Green Glom. Amyg. Basalt	55	7	5	5			15	5								8				
89-1-231	Green Glom. Amyg. Basalt	50	10	10			8	10									12	x			
104-1-12	Green Glom. Basalt	60	15	10		x	x	15	x							x					
104-1-45	Red Glom. Basalt	55	20	10		3		5									5				
104-4-82	Red Glom. Amyg. Basalt	x	x		x	x		x								x			x		
104-5-112	Red Glom. Basalt	x	x	x			x	x	x								x				
105-1-177	Red Amyg. Basalt	x	x	x	x	x		x									x		x		
105-1-189	Red Porph. Basalt	25	25	15				22	3								10				
109-4-125	Hbde dyke?	85	1	4				3	2											5	x
5-1-85	Red Amyg. Basalt	x	x	x	x		x	x	x	x						x	x				
1-89	Green Porph. Basalt	x	x	x				x	x								x				
2-83	Greenstone	x		x	x			x	x			x									
2-92	Green Glom. Basalt	x	x	x				x	x						x	x	x				
5-143	Red Glom. Basalt	60	20	5				15									Tr				
12-126	Red Amyg. Porph. Basalt	50	15	8	1			25													
3A-14	Greenstone	x		x			x	x	x			x	?				x		x		
7A-112	Red Glom. Basalt	50	x	x	x	x	x	x	x							x	x				

*x's indicate presence of a mineral in a rock too highly altered to permit extraction of meaningful modes.

to 0.6 mm. Augite is surprisingly fresh in most cases but locally is replaced by chlorite.

Magnetite is ubiquitous in Nicolai rocks as anhedral grains normally 0.2 to 0.4 mm. diameter. It is variably altered to hematite. Most magnetite is intersertal to plagioclase but locally if forms skeletal crystals.

The former presence of olivine is recognized by pseudomorphs of serpentine with well developed olivine crystal morphology now outlined by iddingsite. Olivine does not appear to have been abundant. Individual crystals were mostly in the range 0.5 to 1.0 mm. diameter.

Hornblende has been found in only a single rock unit located in two short drill hole intersections, both intersections presumably representing the same dyke(?). Crystals are phenocrysts up to 4.5 mm. long in a matrix of plagioclase microlites with trachytic texture.

Apatite is a minor accessory mineral observed in several specimens in very small amounts as minute crystals.

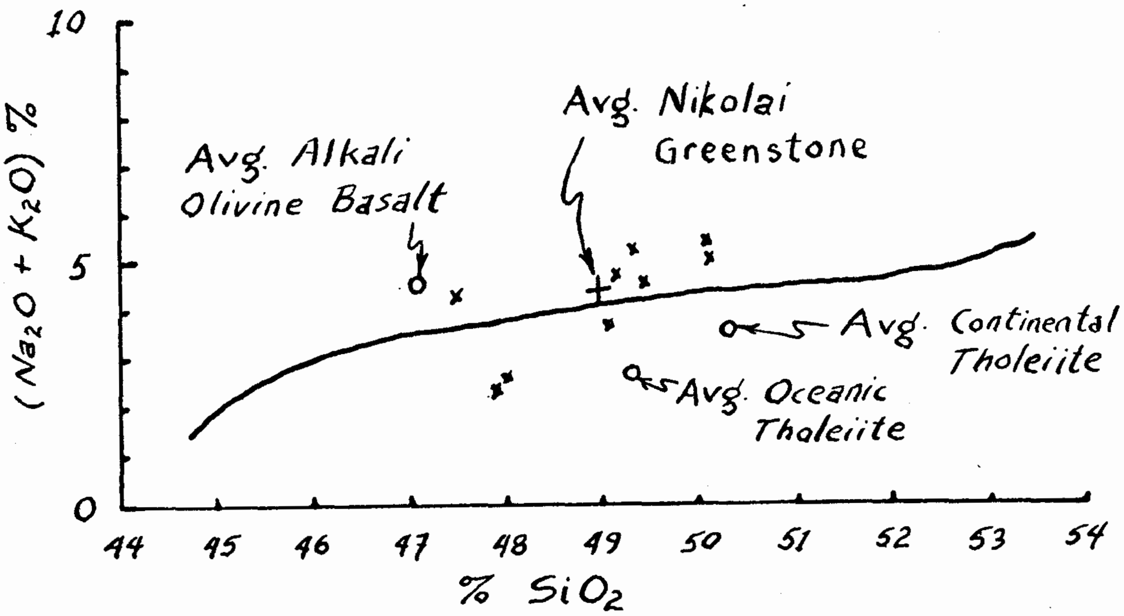
Hematite is a primary mineral that formed largely prior to complete consolidation of the rocks in which it occurs, by oxidation of magnetite. Hematite forms rims around magnetite and extends diffusely outward from magnetite cores into thin intergranular coatings that locally give rise to a deep red-brown colour, particularly in flow types. This oxidation appears to have occurred during consolidation of the flow.

Secondary Minerals:

Alteration minerals are present in all rocks examined, although their amounts vary as does the intensity of alteration of primary minerals. In many cases the bulk of alteration effects are noted as infilling of voids by chlorite, calcite, prehnite, epidote, etc. and related opaque minerals. The voids were vesicles, gas release tubes, small scale fractures, and more extensive planar openings (perhaps joints) some of which cross cut the trend of the volcanic strata. Any openings that existed at the time of alteration were potential sites for deposition.

In addition to open space fillings, alteration effects are particularly evident in glassy or very dense matrix material which is now generally completely devitrified and/or altered to chlorite most commonly. A more advanced stage of alteration involves replacement of primary minerals, principally plagioclase, mainly by chlorite and lesser amounts of epidote and calcite.

These alteration minerals are properly referred to as metamorphic minerals, and a most interesting aspect of them is the presence of native copper and copper sulphides as a natural and original part of the assemblage.



Avg. Alkali Olivine Basalt
Avg. Nikolai Greenstone
Avg. Continental Tholeiite
Avg. Oceanic Tholeiite
10
5
0
$(Na_2O + K_2O)$ %
44
45
46
47
48
49
50
51
52
53
54
% SiO_2

Chemical Analyses

All volcanic rocks investigated are basaltic in composition. Whole rock chemical analyses done on fresh, representative samples from drill core are listed in Table IV. Data were obtained by X-ray fluorimetry by J.A. McLeod. No precision estimates are given but 3 specimens were sampled and analyzed in duplicate (Nos. 34, 58 and 233) and the slight compositional variations shown between duplicates indicates a high quality of reproducibility in the analytical technique. Accuracy is presumed to be of equally good quality to reproducibility because of the high quality working curves that were obtained for standards of comparable composition.

Chemically the Nikolai analyses are intermediate between alkali olivine basalts and tholeiites (see Figure 3). The main basis for grouping analyses into these two categories is not chemical however, but is based on mineralogical characteristics. Important criteria such as (a) the high anorthite content of plagioclase, and (b) the rarity of olivine (although a few pseudomorphs of serpentine and iddingsite are present), indicate that the Nikolai Greenstone is tholeiitic, although it is relatively rich in alkalies and titanium in comparison with most tholeiitic basalts.

Trace Metal Content

Samples analyzed for major elements were also analyzed for Rb, Sr, Zn, Cu and Ni. Results are listed in Table V. No data are available regarding accuracy and precision of these particular analyses; however, the method routinely provides a counting precision of about 5 percent (two relative standard deviations).

The specimens do not seem particularly abnormal with respect to

TABLE IV

XRF ANALYSES OF NIKOLAI BASALTS

Sample	14	34	34A*	58	58A*	71	99	213	217	233	233A*	248
SiO_2	49.119	49.659	49.150	49.369	49.252	47.991	49.078	47.532	50.073	48.549	47.293	50.179
Al_2O_3	14.646	15.032	15.167	15.736	15.719	16.518	13.878	16.887	13.611	15.143	14.992	13.750
FeO	14.564	12.507	12.785	11.770	11.472	11.937	13.269	12.879	13.423	13.804	13.356	13.173
CaO	6.283	6.017	5.994	6.182	6.251	10.584	6.584	7.483	4.606	8.591	8.348	6.533
MgO	3.641	3.973	3.824	4.000	3.841	4.060	4.603	3.999	3.370	4.647	4.504	4.282
MnO	.164	.139	.139	.245	.247	.257	.185	.254	.184	.207	.201	.179
TiO_2	2.858	2.607	2.631	2.214	2.212	2.658	2.346	2.735	3.184	2.775	2.709	2.483
K_2O	1.191	.659	.647	1.531	1.558	.415	.254	1.470	.850	1.000	.999	1.549
Na_2O†	3.548	3.971	4.044	3.571	3.627	2.246	3.502	2.681	4.613	1.502	1.449	3.492
P_2O_5	.415	.432	.388	.385	.378	.446	.398	.426	.437	.437	.451	.427
H_2O	1.768	2.564	2.636	2.485	2.543	2.058	3.066	2.403	2.252	2.352	2.459	2.263
TOTAL	98.198	97.560	97.406	97.399	97.101	99.170	97.164	98.750	96.603	99.007	96.761	98.311

† analyzed on volatile sample

* a subscript indicates a duplicate sample

TABLE V

Trace Element XRF in ppm

Sample	Elements					
	Rb	Sr	Zn	Cu	Ni	Rb/Sr
14 Glomeroporphyry	15.33	258.78	90.0	94.5	95.0	.0592
34 Flow marg. Glomeroporphyry	8.04	206.42	91.5	61.5	88.0	.0389
58 Glomeroporphyry	22.80	220.23	126.5	217.5	86.0	.1035
71 Greenstone	3.74	232.54	138.0	97.5	83.0	.0160
99 Glomeroporphyry	3.57	90.79	95.0	173.0	79.0	.0393
213 Glomerporphyry	19.06	289.15	142.0	233.0	104.5	.0659
217 Glomerporphyry	5.32	80.63	177.0	177.0	89.0	.0659
233 Greenstone	6.06	196.50	118.0	185.0	89.0	.0309
248 Glomeroporphyry	16.76	207.74	161.5	88.0	79.5	.0807

trace elements presented here. One interesting aspect of the copper data arises in comparing it with assay data presented in a later section. Note that the average value of copper in the samples analyzed is 126 ppm or about 0.013%. Two 10-foot chip samples (see Table VI) produced assays of 0.005%--both samples contained minute amounts of visible copper. Despite the imprecision of the assay values (because they are near the detection limit of the assay method) an important implication of these results is that unmineralized rock can contain substantially more copper than does some mineralized rock.

ECONOMIC GEOLOGY

The native Cu-chalcocite assemblage occurs in several distinct settings, viz. (1) apparently disseminated, mainly in greenstone, (2) in amygdules, and (3) in veinlets. In all these associations Cu minerals are associated intimately with metamorphosed volcanic rock, and are believed to be a natural and primary part of a metamorphic mineral assemblage that includes prehnite, pumpellyite, chlorite, epidote, calcite and locally, apophyllite or analcime.

Cu minerals seem to be distributed erratically within the showing. Locally grades attain 2 to 3% Cu over distances of 25 to 50 feet but such occurrences are rare, in part because of the locallized nature of mineralized rock and in part because such occurrences, scattered in the first place, have been cut by faults, and further dispersed by related movement. Metallic Cu minerals are widely dispersed but the associated Cu grade generally is not high.

Both major Cu minerals occur in veinlets many of which cross-cut the general trend of volcanic rocks. In some places it seems that disseminated and amygdaloidal Cu minerals are concentrated near mineralized cross cutting veinlets. Whatever their origin, Cu minerals are unquestionably epigenetic in their present locale. As indicated above native Cu and Cu sulphides are intimately associated spatially and almost certainly genetically with a low grade metamorphic mineral assemblage of the prehnite-pumpelleyite facies.

Mineralography

A fully documented mineralographic report has been prepared by McLeod (1975a). His work has been reviewed and supplemented and is summarized below.

Opaque minerals recognized in the White River copper deposit are listed in Table VI with an indication of their approximate average amounts in specimens examined in detail. On the average, hand specimens used for the mineralographic study contained about 15 percent opaque minerals (by volume) which is substantially higher than through most of the deposit except for selected high grade zones.

Native copper is by far the most abundant ore mineral on the property and occurs mainly in veins, some of which are several inches wide at least locally and many of which are monomineralic over many feet or, conversely, contain a very small proportion of native copper. Calcite and epidote are common in veins. Prehnite is a fairly abundant vein-filling mineral and commonly shows a mammillary form along the two walls of the vein with local small openings (vugs) remaining intermittently along the length of the vein. In a number of cases small octahedral native copper crystals have been observed in vugs of this sort. The better mineralized zones contain numerous subparallel veinlets which widen locally to form "nuggets" that have irregular hackly extensions into the wallrock. In reality almost a complete gradation exists between veins with about 99 percent native copper and veins with about 99 percent gangue minerals although there is certainly a clustering towards the two extreme types.

A small proportion of native copper veinlets or seams contain an important amount of chalcocite, perhaps 10 percent. In virtually all such veins observed by the writer the margins are diffuse, with chalcocite concentrated along the margins followed by a gradational zone of intermixed chalcocite and native copper, with essentially pure native copper filling the central part of the vein. Because of the gradational margins thicknesses are difficult to measure accurately, but most veinlets do not exceed 5 mm.

Native copper also occurs in two other forms that in total account for a very small percentage of copper in the deposit. The most significant of these is as disseminated grains in Greenstone. Virtually all Greenstone (altered vitrophyre) contains at least some native copper as small disseminated grains in devitrified glass or less commonly as a replacement of plagioclase. It is interesting to note that chip samples taken over a distance of 10 feet of Greenstone containing visible but small amounts of native copper, assay substantially less than the normal geochemical abundance of copper in the Nicolai volcanic unit as a whole.

A third mode of occurrence of native copper of very minor importance quantitatively is in amygdules and gas release tubes where it is found only rarely and as a minor constituent of what are mainly calcite-chlorite and epidote-filled structures.

Chalcocite is the most abundant sulphide in the deposit and occurs in two principal mineral associations that are mutually exclusive; chalcocite-native copper described previously, and chalcocite-bornite. Bornite is commonly much more abundant than is apparent megascopically, principally because it is commonly intimately intergrown with chalcocite. Bornite has been observed only in association with chalcocite and chalcopyrite. The two minerals are most common in veinlets and as

TABLE VI

OPAQUE MINERALS AND THEIR RELATIVE ABUNDANCES
WHITE RIVER COPPER DEPOSIT

Native Copper	55
Chalcocite (incl. djurleite)	22
Bornite	9
Magnetite (in host)	8
Hematite	3
Pyrite	1
Digenite	1
Covellite	0.5
Chalcopyrite	0.5
Cuprite	tr
Malachite and Azurite	tr

an infilling to what appear to be very small crackle zones. Copper-bearing amygdules generally contain about 80 percent chalcocite and 20 percent bornite intergrown in vermicular fashion. Disseminated chalcocite is commonly adjacent to vienlets and is particularly abundant in zones near chalcocite-bearing amygdules. Bornite occurs in several samples with chalcopyrite, the two intergrown with crystallographic texture and consisting of about 8 percent chalcopyrite. Chalcopyrite is known in only one other type of occurrence on the property, in association with rare pyritic zones and as isolated blebs in a few amygdules. The association with pyrite has a somewhat unusual textural form in that fairly regular lamellae of chalcopyrite occur in pyrite crystals.

Digenite although widely dispersed throughout the specimens examined is present only in small amounts, partly as a reaction rim between chalcocite and bornite. In some cases digenite is obviously secondary, in other cases it might be primary. Covellite, on the other hand, is entirely secondary in origin, and occurs along grain margins of some chalcocite grains.

Pyrite is present in several specimens. It has been found in two short drill intersections and may represent a one to two foot layer that has potential as a marker unit. It has also been noted in nearby outcrop 50 feet south of the 2900 portal. In all cases it has associated with it small amounts of chalcopyrite. Very minor amounts of pyrite have been found in amygdules.

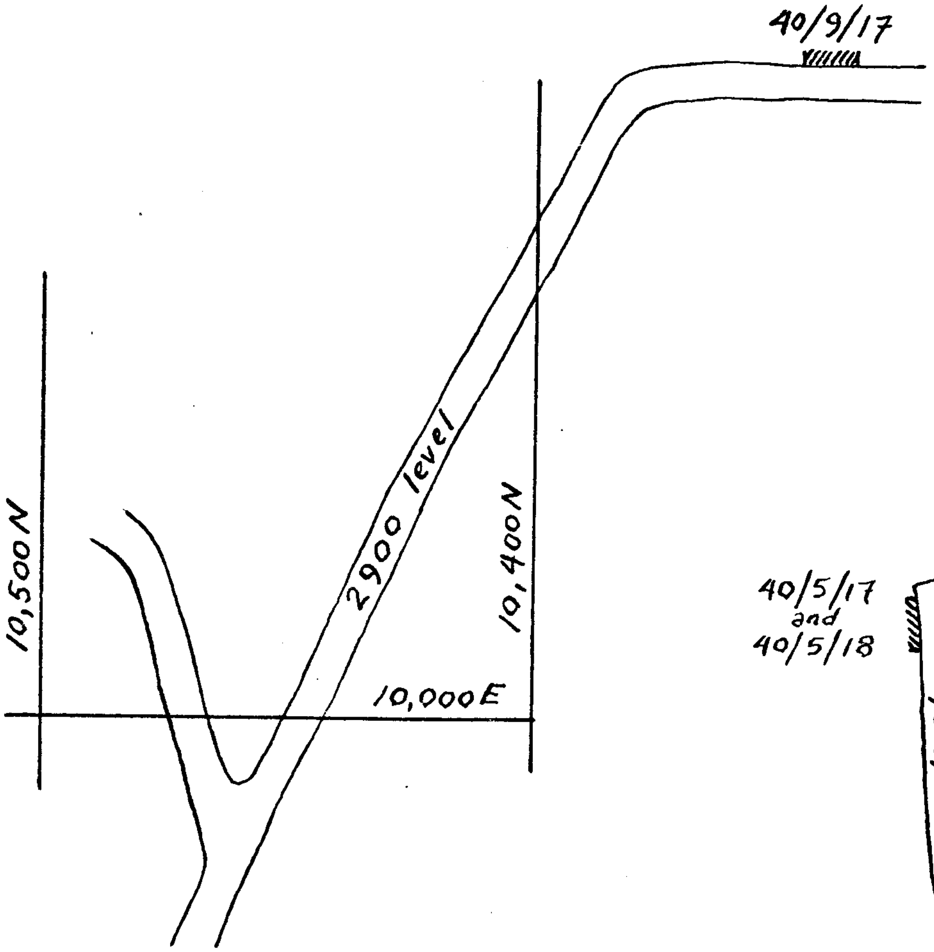
Both magnetite and hematite are primary minerals formed at the time the host crystallized. Magnetite is commonly intersertal, less commonly skeletal. It is the common iron oxide of green volcanic rocks. Even a small amount of oxidation to hematite imparts a distinctive red-brown colour to the rock. Most red-brown rocks investigated microscopically still retain a substantial portion of the original magnetite as cores to hematite patches. A few crystals of specularite have been noted associated with copper minerals. This specularite may simply represent hematite that has been recrystallized as a result of the later mineralizing process. Djurleite is suspected but not confirmed.

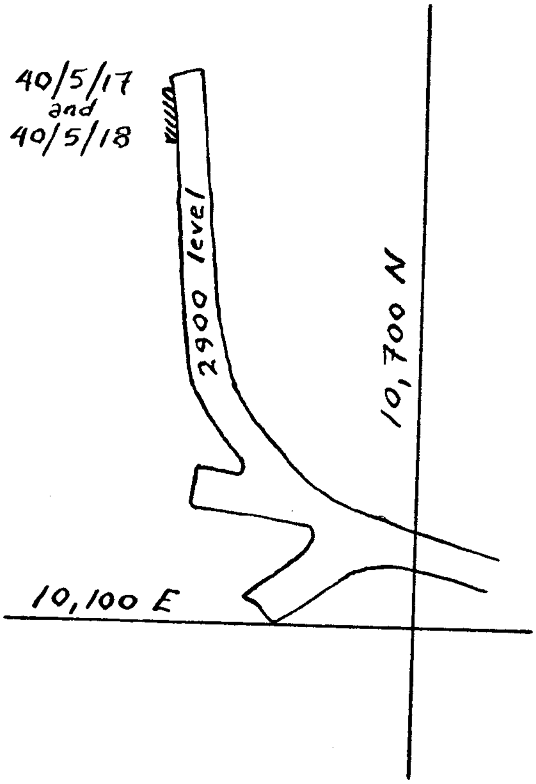
An unknown opaque mineral has been found associated with native copper. The mineral is in two anhedral grains within native copper, but of too small a size to identify even using the electron microprobe. The mineral is pale yellow, with moderate reflectivity and mutual boundaries with native copper.

Oxides identified in hand specimen and polished section are cuprite, malachite and azurite. These products are the result of oxidation of primary minerals and are confined to the near surface environment.

Assays

Four chip samples were taken at a height of 5 feet on the adit walls, each over distances of 10 feet, to test for average copper grades in and near several zones containing small amounts of megascopic Cu minerals. Each sample was crushed and divided into two parts for separate analyses. This procedure was used to provide a reasonable check on the possible biased sample preparation due to the presence of native Cu. Obvious potential sources of error are: (1) inability to crush individual grains of native Cu, (2) loss of native copper during crushing by plating onto crushing equipment. Sample preparation and analyses were done by Mr. P. Kemp, assayer in the Mineral Engineering Department,





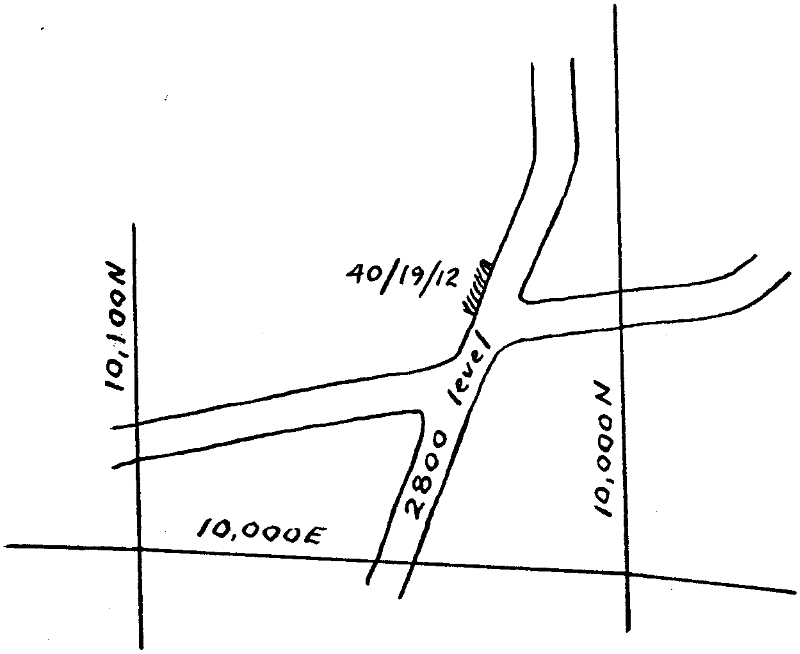


FIG. 4
Scale: 1" = 40'

U.B.C. using a fire assay method that measures total copper. Results are shown in Table VII. It is apparent from a visual examination of replicated data that no serious sampling problems exist after the initial crushing stage. Our data however, do not provide a check on possible loss of Cu during early crushing although this is thought to be minimal. It is of interest to note that two samples are near the detection limit of the assaying method used (0.005% Cu) and the quoted results are less than the geochemical abundances quoted for unmineralized rock.

Geothermometry

Several independent approaches to geothermometry of the White River copper deposit were investigated. Textural studies indicate that native copper, copper sulphides and the non-opaque minerals chlorite, calcite, epidote, prehnite, pumpellyite and apophyllite were all deposited in their present form during metamorphism of Nicolai basalts. Consequently, all these minerals must have formed under comparable conditions. The low grade metamorphic assemblage prehnite-pumpellyite is stable in the range 300°C. to 400°C. Several examples of this assemblage with native copper as a primary stable member have been observed in the White River deposit, particularly in drill hole no. 104. The stability field of this assemblage is not greatly dependent on pressure.

Several textures among the copper sulphides are interpreted as resulting from exsolution. In particular, a crystallographic texture of chalcopyrite blades in bornite has a minimum temperature of formation by exsolution of about 200°C. (Brett, 1963). The solvus, however, is very steep on the bornite-rich side of this minimum, and at 8 mole percent

TABLE VII

DUPLICATE ASSAY RESULTS OF CHIP SAMPLES TAKEN OVER 10 FEET

Sample No.	% Cu in Replicates	
	A	B
40/9/17	0.022	0.022
40/19/12	0.025	0.027
40/5/18	0.005	0.005
40/5/17	0.005	0.005

Analyst: Mr. P. Kemp, Mineral Eng. Dept., U.B.C.

chalcopyrite the temperature at which exsolution occurs (and therefore the minimum temperature of deposition) is about 400°C. In White River specimens the chalcopyrite content is close to 8 mole percent so that the minimum temperature of deposition of high bornite is substantially above 200°C. although we cannot specify a figure more precisely. A second texture that could also arise by exsolution is a vermicular intergrowth of bornite and chalcocite that is particularly common in some amygdules. If this vermicular texture originated by exsolution it indicates a minimum temperature of formation of 200°C.

We attempted fluid inclusion studies of several specimens of transparent minerals but found that most inclusions were either too small to work with or leaked on heating. However, one primary inclusion in calcite from a vein containing 85% calcite and 15% prehnite produced acceptable results (sample 40/2/3). The inclusion is small, about 0.02 mm. in longest dimension, and contained two phases, gas and liquid. The ratio of bubble equatorial area to maximum planar area of the inclusion is about 0.25. Slow warming from the frozen state produced beginning of melting at -13.0°C. with final dissappearance of ice at -4.9°C. These results could not be duplicated during cooling because of metastable retention of fluid to -54°C. Heating resulted in gradual decrease in bubble size and eventual disappearance between 270°C. and 275°C. These figures were reproducible over several trials. The uncertainty range is largely a function of bubble size rather than inherent in the equipment and procedures used.

Minute inclusions in apophyllite are abundant but are too small to deal with effectively.

The general implications of these geothermometric studies is that mineral deposition (metamorphism) took place at about 300°C. or somewhat higher, but no more than 400°C.

DISCUSSION AND CONCLUSIONS

A Conceptual Model For White River Copper Deposit

Mineralization at White River deposit took place during metamorphism and was in fact part of the metamorphic process. Temperatures were at least 300°C. but were less than 400°C. Copper appears to have been derived from Nikolai rocks, perhaps, in part, locally near the site of deposition, but in large part at some distance from the present site of deposition. Furthermore, we find no evidence for descending solutions contributing to anything but the development of secondary minerals such as cuprite, malachite, etc. Mineral deposition appears to have been a response to a change in oxidation-reduction conditions to which hot ascending solutions were subjected.

The foregoing requirements can be met by the model illustrated in Figure 5 and described below.

We envisage that a significant quantity of meteoric water was trapped in sediments underlying the Nikolai Greenstone and for which the Nikolai Greenstone subsequently formed a relatively impermeable caprock. With burial these waters became heated and perhaps charged with sulphate (numerous occurrences of gypsum are known in the area). These hot waters may have been available for reaction with Nikolai Greenstone at a zone of interaction at the base of the Greenstone pile, or even within permeable zones of the volcanic rocks themselves and in this way may have derived a significant copper content by extraction (leaching) from a part of the Nikolai succession.

Regardless of whether Cu was taken into solution in the foregoing manner, the hot solutions which may very well have been more-or-less stagnant, were released periodically and locally through conduits formed

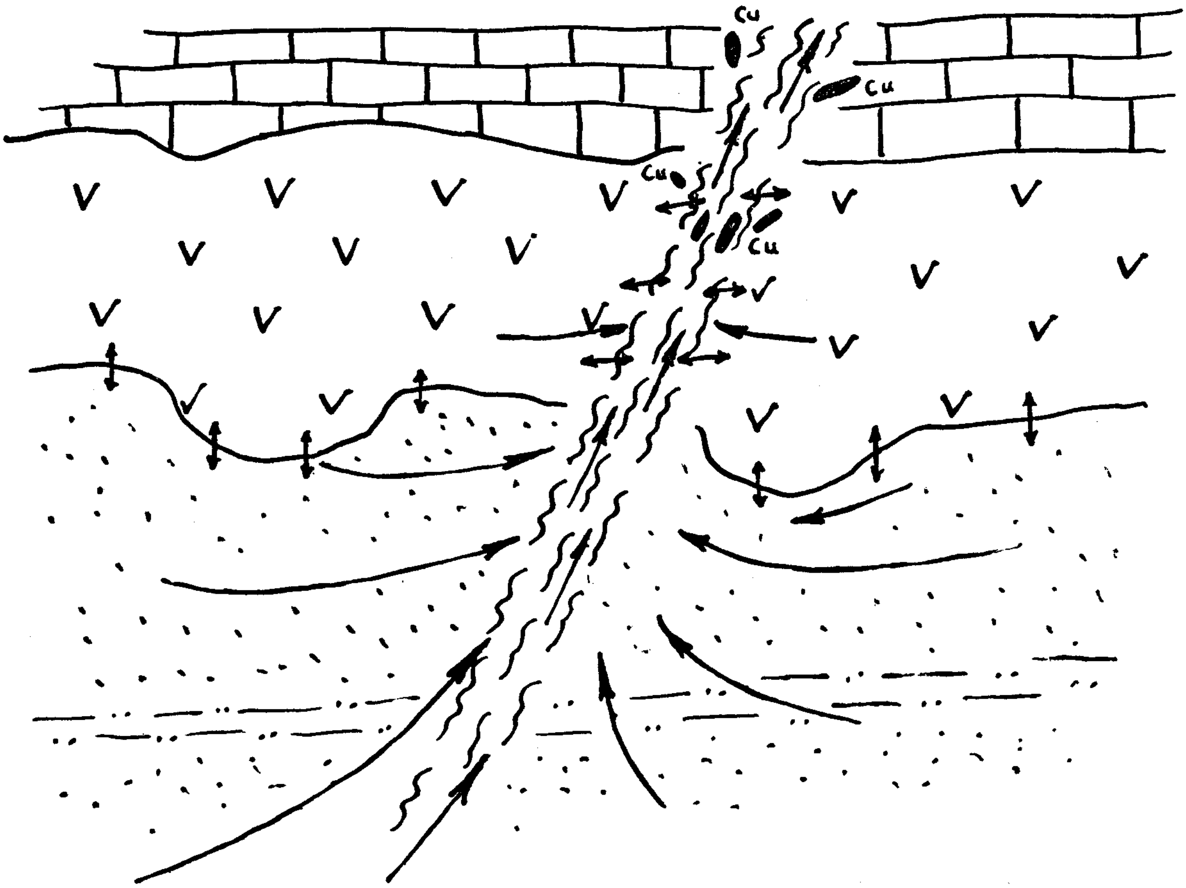


Figure 5: Conceptual model for development of copper deposits associated spatially with Nikolai Greenstone. Nikolai Greenstone (v) and overlying limestone form a caprock to Permian and earlier sedimentary and pyroclastic rocks that contain some evaporites. Interstitial water trapped by the volcanic caprock and depressed several kilometers below the surface is released periodically along conduits formed by local responses to tectonism and the hot fluids ascend and first extract copper from Nikolai rocks, then precipitate copper in the upper part of the Nikolai succession and perhaps in overlying limestone. Single-headed arrows indicate direction of flow of mineralizing fluids. Double-headed arrows indicate chemical exchange between rock and fluids. Sites of formation of copper deposits are shown as small solid ellipses marked Cu.

in response to local adjustments to tectonism. The hot fluids passed upward through the Nikolai succession, leaching copper during upward passage. Driving force for fluid flow was potential energy of the hot, contained fluids.

Extraction of copper might occur preferentially from certain types of volcanic rocks within the Nikolai succession. Note in particular that volcanic glasses might be very susceptible to alteration and transfer of elements as appears to be the case even locally for the Greenstone unit at the White River deposit. At some point relatively high in the Nikolai succession copper precipitated as native metal and/or various sulphides in response to local Eh conditions controlled by the amounts of magnetite and hematite present.

General Economic Considerations

1. Regional considerations suggest that copper deposits are related directly to Nikolai volcanic rocks but exactly how the two are connected can only be surmised as we have attempted in our proposed model.
2. Locally, Cu is found to be concentrated in a Glomeroporphyritic Basalt Unit no. 1 in the White River property, although native copper and copper sulphides are found in other units.
3. Copper minerals are epigenetic - most native copper is related to fractures that cross cut the general trend of volcanic units.
4. Cu of the White River deposit is a metamorphic mineral, forming part of the more common assemblages calcite-chlorite, prehnite-pumpellyite, etc. In this regard the occurrence is similar to much of the Cu related to amygdaloids in the Keweenaw Peninsula of the Lake

Superior district whose formation has been attributed to regional hydrothermal metamorphism (Stoiber and Davidson, 1959).

5. It is not certain whether Cu in deposits is of local or more regional provenance. We deduce from regional evidence that native and sulphide Cu are derived from Nikolai volcanic rocks through metamorphic processes. In all probability a certain amount is of local derivation. The limited minor element data that we have available indicate that most of the copper must have been derived from rocks that are a substantial distance (thousands of feet or more) from the site of copper deposition.
6. The model that we invoke to explain mineral deposition requires circulating hot waters at various times. In particular, fracturing, the result of intermittent tectonism, may provide conduits for escape of hot waters, that then react with the volcanic rock through which they pass; thus, perhaps a substantial section of Nikolai must be traversed from which Cu is leached prior to deposition. This zone of contact of ore fluid and Nikolai can be of great lateral extent, and need not be confined to a narrow zone. However, if fracturing is limited, the amount of Nikolai available to be leached is relatively small and only small Cu deposits can be expected.
7. Guides to exploration for new deposits include:
    a) recognition of major pre-metamorphism fracture zones that cut Nikolai volcanic strata, particularly transverse zones that crosscut all or most of the section. (According to our model, such zones represent potential leakage channels for trapped hot waters in underlying sediments) Our simple model would anticipate greatest potential for copper deposits in the zone of intersection

of fractures and the upper part of the Nikolai Greenstone, or possibly in overlying sedimentary rocks, especially carbonates.

b) prospecting for zones of extensive metamorphism of the prehnite-pumpellyite or zeolite facies. Common associated minerals that are relatively easy to recognize are chlorite, calcite and epidote. With limited experience prehnite is also easily recognized.

c) whole rock geochemistry may be a useful means of evaluating the distribution of Cu remaining in Nikolai rocks. Interpretation of such data is ambiguous, however, and it appears that an extensive geochemical orientation survey is warranted to evaluate how the distribution of Cu in Nikolai rocks relates to the distribution of known Cu occurrences. Furthermore, we have recognized small quantities of the mineral apophyllite, a fluorine-bearing mineral. It appears that the metamorphic (ore) fluids contained significant quantities of fluorine at least at some localities and fluorine geochemistry might therefore be an important aspect of any rock geochemical study.

Economic Aspects of Exploration of White River Copper Deposit

The White River deposit has been shown to be epigenetic, and to have developed during metamorphism at a significantly later date than deposition of the Nikolai Greenstone although it seems that Cu was derived (leached) from the Nikolai Greenstone during and possibly prior to metamorphism.

The principal requirements for a large Cu deposit appear to be an appropriate structural conduit that acts as a collector of ore fluids, a thick succession of Nikolai volcanic rocks from which to leach copper, and an adequate mechanism for precipitation of Cu either high in the Nikolai section or in overlying rocks.

The extent to which the foregoing requirements are met by the White River Copper zone is not readily apparent. Certainly the deposit is *relatively* large compared with other known showings in the Nikolai of Yukon Territory. Furthermore, the quantity of copper is such that it *could not* all have been derived insitu - consequently, a structural "collector" or conduit must exist, although the nature of this structure does not seem obvious from results of exploration to date. Furthermore, the stratigraphy of the Nikolai Greenstone is not known, and although we have established a local stratigraphy we are unable at present to express an opinion on where the deposit occurs within the total Nikolai succession.

Our observations show that in the White River deposit the great bulk of megascopic copper occurring as the native metal or sulphide is within a single, mappable unit, the Glomeroporphyritic Basalt No. 1, although much smaller quantities of Cu minerals are present in other units. Data are insufficient to show whether this unit differs appreciably from others within the Nikolai Greenstone although our impression is that the gross chemistry of all Nikolai units is remarkably uniform.

Many of the Cu-bearing structures appear to cross cut the general trend of the volcanic strata. We feel that further exploration should emphasize structural studies and should include (a) detailed evaluation of many individual Cu-bearing structures, especially within the two adits where orientations can be determined accurately, (b) general mapping in and around all Nikolai outcrops should be undertaken in the hope that an adequate evaluation of the effects of faulting could be made, at least in the immediate vicinity of the property, (c) surface exploration (trenching) might be undertaken to test for the nebulous structural conduit, (d) from an empirical point of view it would appear that the Glomeroporphyritic Basalt No. 1 warrants exploration at depth in the general vicinity of the main showings. Drilling should not be carried out, however, until detailed structural studies have provided the best possible information as a base for spotting drill holes, (e) some emphasis should be directed towards examining the limestone in contact with the Nikolai Greenstone on the White River property. If a structural conduit exists for known deposits and this conduit intersects the limestone unit, mineralizing fluids may have formed a replacement body in the limestone.

A re-examination of results of an Induced Potential survey carried out on the ground suggests that the I.P. high response zone might be attributable to one or more of the gouge-bearing fault zones that are subparallel to layering in the volcanic succession. Our feeling is that any mineralized structure that exists cuts *across* the volcanic layering with, *very roughly*, an E-W orientation although we have insufficient data to specify the orientation of such a structural zone precisely.

Future Research

A. *Regional*

1. It is essential to determine stratigraphy within the Nikolai Greenstone.
2. Whole rock geochemical studies of the Nikolai Greenstone should be

undertaken as a primary exploration technique, and would serve the added purpose of providing a chemical data base to study metallogenesis in more detail.

3. Detailed studies of metamorphism of the Nikolai are warranted because a correlation between metamorphic facies and presence or absence of Cu showings might be expected. This argument is based on the assumption that higher temperature metamorphic fluids might have been relatively highly charged with copper compared with lower temperature fluids.
4. Age of metamorphism of Nikolai volcanic rocks should be determined by the whole rock potassium-argon method. This would establish a time of mineral deposition.
5. Sulphur isotope studies should be carried out to further refine (or change) the model of mineralization presented here.

B. Local

1. Suggestions for future exploration on the White River property are outlined in a previous section. Other Cu showings associated with the Nikolai Greenstone should now be investigated in comparable detail in light of the results of our studies. The writer's familiarity with the deposits at Kennicott Alaska is very limited, nevertheless, he believes that origin of these deposits should be re-examined in the light of the model presented here despite recent suggestion that they originate by deposition of Cu from groundwater in a sabkha environment.

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A RESEARCH PROJECT ON COPPER DEPOSITS OF SILVER CITY MINES AND RELATED VOLCANIC ROCKS, WHITE RIVER AREA, YUKON.

PROPOSAL

A research project is suggested that concerns a detailed study of Upper Triassic volcanic rocks on and near the White River, Yukon, property of Silver City Mines, and with special emphasis on Cu mineralization. The project will deal with:

(a) An attempt to outline stratigraphy within the Upper Triassic volcanic rocks of the area.

(b) Petrogenesis of the Upper Triassic volcanic rocks

(c) Detailed correlation problems on the Silver City Mines property

These general ends will require (1) detailed mapping on the property and of nearby Triassic volcanic sections, (2) relogging of drill core, (3) remapping of underground workings if possible, (4) construction of a 3-dimensional model of the surface, drill and underground information as an aid to solving structural and correlation problems, (5) sampling of volcanic rocks for whole rock analysis, and (c) laboratory investigation of hydrothermal effects using x-ray and microprobe equipment.

Results of the study could have considerable practical importance. It is apparent that any move towards describing a recognizable stratigraphy within the volcanic sequence will have an important bearing on exploration. Furthermore, the chemical nature of the Upper Triassic rocks will be important in integrating them into a plate tectonic model that relates mineral deposits to the new global tectonics. Specifically, it is hoped that the project will provide a base for more successful exploration on the property of Silver City Mines, particularly in tracing and extending the known native Cu-bearing volcanic rocks.

ESTIMATED BUDGET

Technical Assistance for laboratory work $500/mo x 12		6000.00
Thin sections, 200 @ $5.00		1000.00
Polished sections, 100 @ $5.00		500.00
Electron microprobe 50 hrs @ $20.00		1000.00
Whole rock chemical analysis 20 @ $150		3000.00
Shipment of specimens		300.00
Computer time		1200.00
Supervisor travel		600.00
	SubTotal	13,400.00
Miscellaneous and Contingency (materials for model, draughting, report preparation, etc.)		600.00
	TOTAL ESTIMATED EXPENDITURE	$14,000.00

It is understood that field expenses for a geologist and assistant, including salaries, are to be paid by Silver City Mines for a 3-month period of field work in the summer of 1975.

12-months after completion of the field work, a detailed completed report will be submitted to the Company. Progress reports will be submitted every 3 months.

A. J. Sinclair

A.J. Sinclair,
Professor.
March 14, 1975

APPENDIX II

MINERALOGRAPHY AND PETROGRAPHY OF THE NATIVE COPPER-BASALT ASSOCIATION, WHITE RIVER, YUKON*

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Dept. of Geological Sciences
University of British Columbia

ABSTRACT

A detailed mineralographic analysis of the native copper-chalcocite deposit of Silver City Mines in the White River area, Yukon, shows the presence of additional sulphides, some not previously recorded, including: pyrite, chalcopyrite, digenite and a suprisingly large proportion of bornite. The presence of djurleite is suspected but remains to be confirmed by X-ray analysis. In addition, specularite is relatively abundant. Associated gangue minerals (non-opague) include epidote, prehnite, pumpellyite, analcime, chlorite and calcite, an assemblage characteristic of relatively low temperatures of formation.

Host rocks are Triassic basalts characterized by the common presence of glomeroporphs of feldspar and/or amygdules containing some of the minerals noted above. Copper minerals are found in amygdules, gas release tubes and veinlets. Locally they are disseminated as small interstitial blebs. In places native copper and/or copper sulphides are found intimately associated with primary gangue assemblages and there is little doubt that the bulk of the Native copper is hypogene. It is equally apparent that copper mineralization is simply a specialized variety of the processes operative on a regional scale in filling vesicles, veinlets, etc. with more common minerals such as chlorite, calcite and analcime.

Some chalcocite-bornite intergrowths are suggestive of exsolution in which case mineral deposition may have been, in part at least, at temperatures somewhat higher than 250°C. The gangue associations recognized are consistent with the bulk of mineral deposition at temperatures of perhaps 200-300°C.

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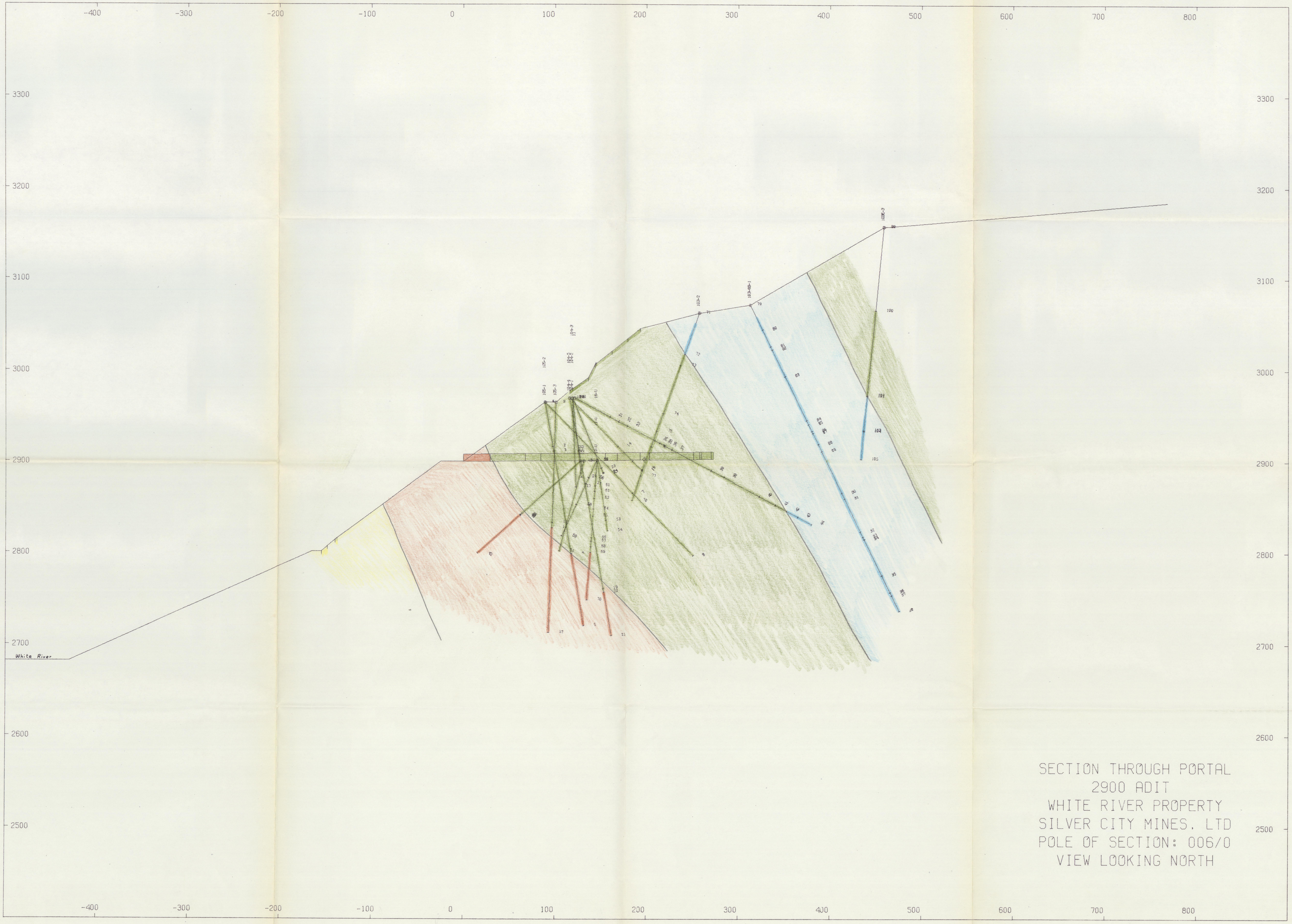
* Paper presented at the Geoscience Forum, Whitehorse, Yukon, December, 1975.



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2900 ADIT
WHITE RIVER PROPERTY
SILVER CITY MINES, LTD
POLE OF SECTION: 006/0
VIEW LOOKING NORTH

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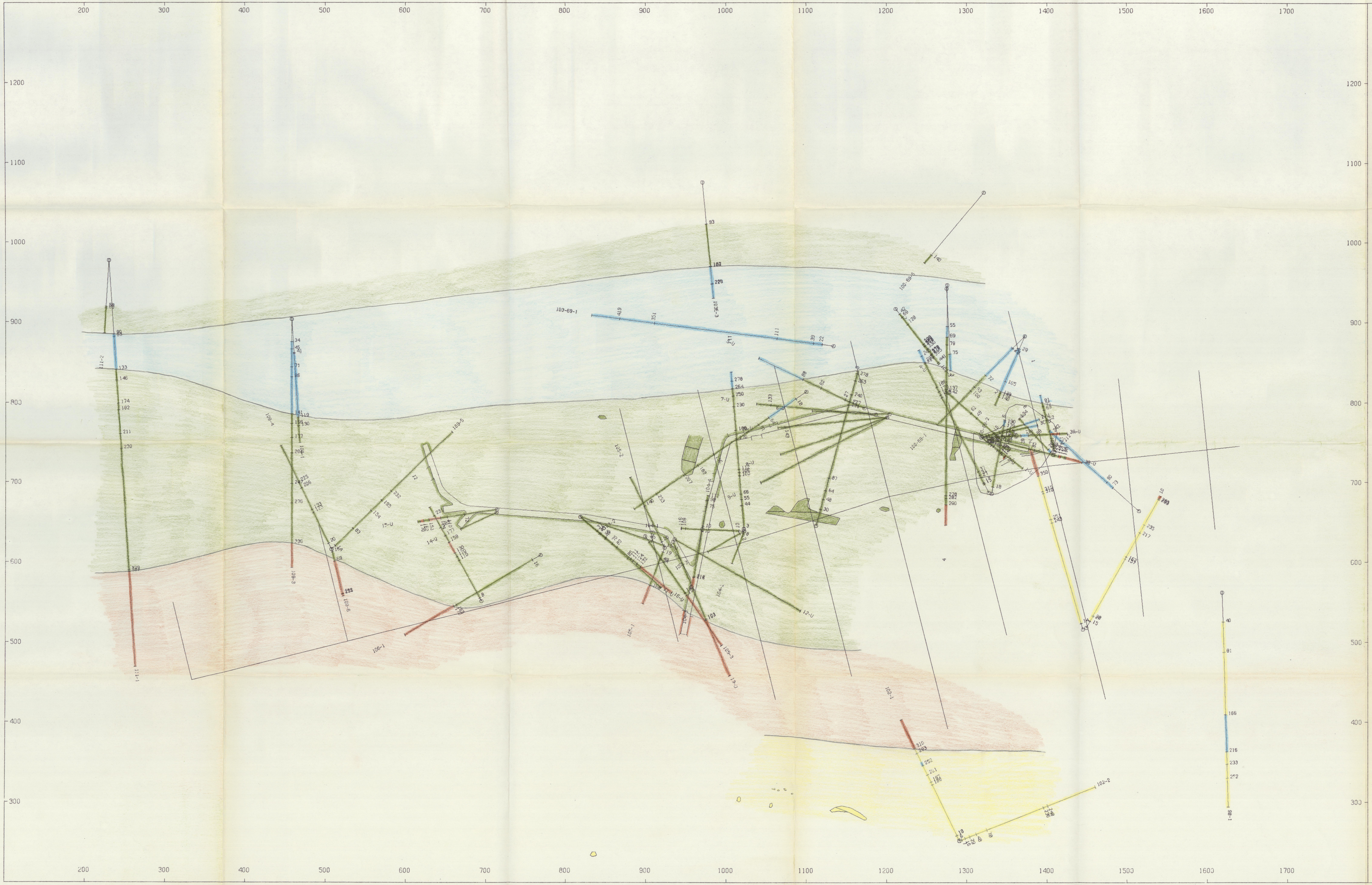

PLAN PROJECTED TO
2900 FOOT LEVEL
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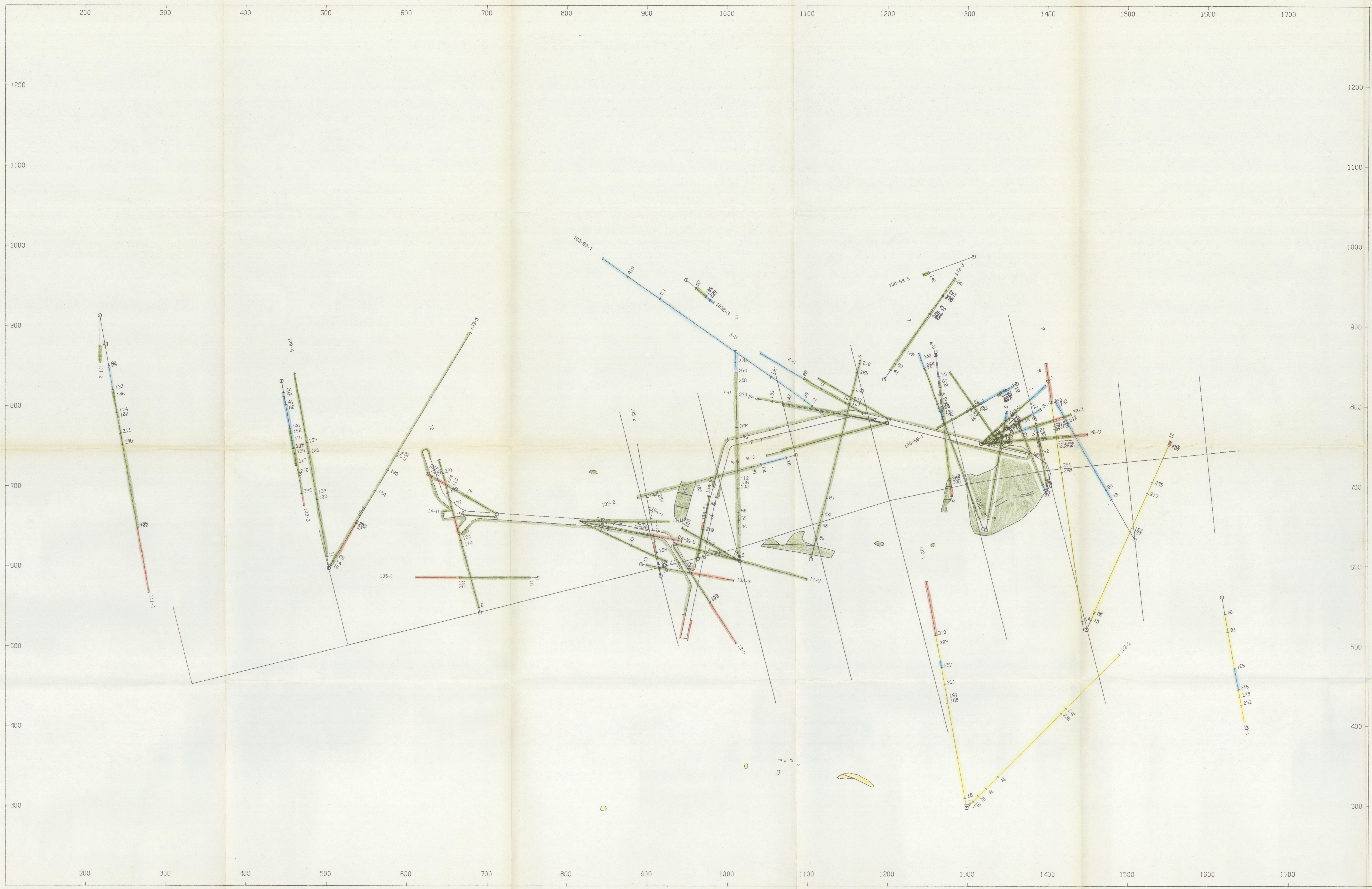

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