Property Submission

822047

SUSTUT COPPER   94 D/10E

LOCATION

200 Km north of Smithers. Four miles west-northwest of Sustut Peak, on the west side of Sustut River, at approximately 6000 feet elevation. Discovered in August 1971.

OWNERSHIP

Falconbridge Nickel Mines Ltd.

GEOLOGY

The deposit occurs in gently dipping volcanic rocks of the Upper Triassic Takla Group, which outcrops as rugged mountains. The mineralized zone is approximately concordant with the strata over 100-200 feet of the Middle Formation succession. It lies just below the zone of transition from subaqueous to subaerial deposition in the top unit. Hematite, chalcocite, pyrite, bornite, chalcopyrite and native copper are dissemmated throughout all sizes of lithic fragments and matrix. Volcanic rocks are basaltic andesite in composition and form a grey to green succession that includes a few minor units of red-brown siltstone. Host rocks for mineralization are lahar, tuff breccia, and conglomerate beds that are within a 1,100 m thick volcaniclastic unit. The volcaniclastic unit overlies a succession of pillow lavas, basaltic tuff breccias, and marine siltstones.

RESERVES

30,000,000 Tons + 1% Cu

REFERENCES

1) CIM Bulletin - January 1977 - Paper by G. Harper. Pg. 97
2) Handbook of Stratabound and Stratiform Ore Deposits 1976 Pg 95
3) GEM 1973 Pg 417-432
4) GEM 1974 Pg 305-309.

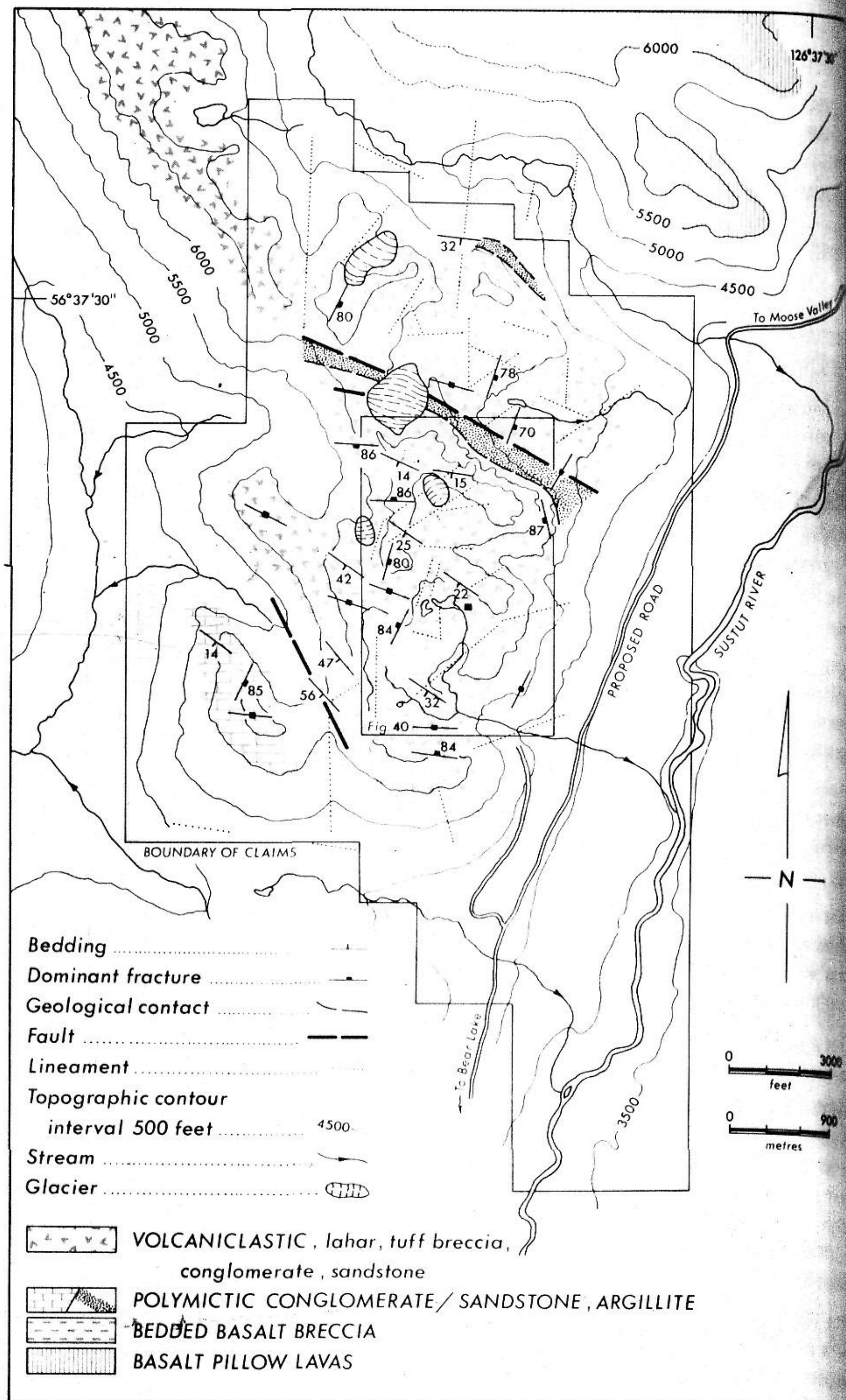

Figure 36. Geology of Sustut Copper.

rich and contain liquid, vapour and daughter minerals of halite, sylvite with or without calcite, hematite or an opaque phase. At Bell, the dominant inclusion type contains liquid, vapour and halite. Some vapour-rich inclusions are present in both deposits, which suggests that the fluids boiled at times. Inclusions at Granisle homogenize largely by vapour disappearance at temperatures between 240 and 1300 degrees C, with two maxima at 480 and 1050 degrees C. Inclusions at Bell homogenize largely by halite disappearance (after vapour disappearance) at temperatures from 310 to over 700 degrees C, with most filling at about 530 degrees C. The inclusion fluids at Granisle have salinities of up to 73% NaCl plus KCl, whereas those at Bell have salinities of 33 to 58% NaCl and less than 10% KCl. These observations indicate that Granisle mineralization took place at near-magmatic temperatures and that Bell mineralization took place at sub-magmatic temperatures from a solution saturated with halite and much more saline than the meteoric water which is thought to have formed the sericite overprint.

Paper No. 134 — 3:30 p.m.
Origin of the Sustut Copper Deposit, Central British Columbia.
D. H. WILTON and A. J. SINCLAIR, University of British Columbia, Vancouver, B.C.

The Sustut copper deposit is in central British Columbia, about 370 km northwest of Prince George. Copper concentrations are in the Upper Triassic Moosevale Formation, mainly in gently dipping tabular zones parallel to bedding and much less abundantly in cross-cutting veinlets that occur in local concentrations and with local preferred orientations. Copper-rich zones with economic potential appear to be restricted to a zone of about 200 m within the 700-m-thick, coarse-grained volcaniclastic host, although there are minor occurrences throughout. Copper minerals (chalcopyrite, bornite, chalcocite and native copper) and gangue (epidote, quartz and calcite) are common to both veins and tabular zones, although proportions of these minerals vary drastically from place to place. Some detailed textural features, especially bornite-chalcopyrite intergrowths, are also common to both veins and tabular zones. Veinlets are predominantly open space filling, whereas tabular zones are a combination of open space filling and replacement, commonly with replacement dominant.

Tabular zones and local sets of veinlets appear to have formed an interconnected system permeable to ore fluids, presumably derived from below. Comparable veins are reported in underlying Triassic lavas. Thus, veinlets form an integral part of the mineralizing system and become an important evaluation criterion in exploration. Age of mineralization is uncertain, but vertical mafic dykes that cut the Savage Mountain Formation stratigraphically above the main mineralized zones are pre-mineralization.

Logging of 10,000 feet of drill core representing several cross sections through the main copper-rich zones was done in a thorough and rigorous manner on a coding form designed for input into a computer. This procedure, combined with various forms of computer output, led to a rapid visual and quantitative evaluation of the data, particularly as regards internal stratigraphy of the volcaniclastic country rock, mineral zoning and the relationship of copper concentrations to wall rock with particular characteristics. In brief: (1) local internal stratigraphy is shown best by layers of sand-sized volcaniclastic rocks; (2) an ideal vertical zoning from margin to core in a tabular zone is pyrite-chalcopyrite-bornite-chalcocite - native copper, with much overlap of mineral zones and, in places, the absence of symmetry about the core; and (3) copper minerals statistically are much more prevalent in agglomeratic rocks that are dominantly green (i.e. iron in the reduced state) rather than red.

Paper No. 135 — 4:00 p.m.
Mineral Deposits in the Callaghan Creek Area, Southwestern B.C.
J. H. L. MILLER, A. J. SINCLAIR and D. WETHERELL, University of British Columbia, Vancouver, B.C., and A. H. MANIFOLD, British Columbia Institute of Technology, Burnaby, B.C.

Polymetallic sulphide deposits in the Callaghan Creek area of southwestern British Columbia occur in a roof pendant of pyroclastic rocks surrounded by various masses of the Coast Plutonic Complex. These coarse-grained pyroclastic rocks are divisible into five easily mappable units of rhyolitic to andesitic composition. The units dip steeply to the east, strike northerly or slightly west of northerly, and appear to form a homoclinal succession with tops to the east. The sequence has been correlated tentatively with the Gambier Group (Cretaceous) by others on the basis of general lithologic similarities with type sections of the Gambier rocks to the south. A crystal tuff unit in the sequence has been cut by what are thought to be genetically related hornblende-rich dykes for which a single K-Ar date on hornblende is 124 plus or minus 4 m.y.

Seven mineral occurrences are known, two of which, the Warman and Manifold zones, are in production by Northair Mines Ltd. Minor production has come from two of the more southerly occurrences, the "Millsite" and Silver Tunnel zones of Van Silver Explorations Ltd. (now defunct). Known occurrences are confined to the lowermost unit (acidic) and the uppermost unit (intermediate).

At least four of the known occurrences show various textural indications that a significant proportion of the sulphide might have concentrated prior to regional metamorphism (greenschist facies) and emplacement of Coast Plutonic rocks. An apparent stratigraphic control to some occurrences, their localization in a thick acidic to intermediate pyroclastic sequence and local intercalations with chemical sedimentary rocks (carbonate and chert) combine with textural and assay data to suggest that these occurrences are volcanogenic in origin, but have suffered considerable mobilization during subsequent metamorphism.

Some of the ore zones of Northair Mines are narrow and consist of several small veins filled mainly with quartz and/or calcite and small amounts of sulphides (mainly galena, sphalerite and pyrite), all of which are post-deformation in age. Similar, but non-sulphide-bearing, veins occur elsewhere on the property and presumably are related to metamorphism of the pyroclastic sequence and/or associated plutonism. We speculate that sulphides in such veinlets have been derived from nearby, pre-existing sulphides.

Consequently, small veinlets containing minor proportions of sulphides may well represent an important exploration parameter in this and other pendants within the Coast Plutonic Complex.

Paper No. 136 — 4:30 p.m.
Oil and Gas Potential of Canadian Frontiers.
C. R. EVANS, Imperial Oil Limited, Calgary, Alta.

Reconnaissance exploration of Canada's eastern and northern frontiers began some ten or twelve years ago. To date, significant gas discoveries have been made in three areas: the Beaufort Basin, the Sverdrup Basin and the Continental Shelf off the coast of Labrador. Oil has also been discovered in the Beaufort Sea and Arctic Islands, but in volumes of questionable economic size.

For a multitude of reasons, different segments of our society require estimates of what is there, what is economically recoverable and the timing of potential production. No single estimate of these three unknowns is or can be appropriate for the different types of decisions that must be made.

A probabilistic approach to these unknowns is less intellectually satisfying, but far more useful and meaningful, than a single number at this stage of frontier exploration.

(3) MECHANICAL-ELECTRICAL DIVISION, Mining Methods and Equipment, Hyatt Regency Plaza East, with D. PURDIE and E. MITCHELL, Session Chairmen.

Paper No. 137 — 2:30 p.m.
Retarding Systems for Electric-Drive Haulage Trucks.
B. J. TURLEY, General Electric Co., Erie, Pa.

The paper deals with the following topics:
What is Dynamic Retarding?;
Function of Dynamic Retarders;
Application Considerations;
Importance of Dynamic Response;
Recent Improvements in Retarder Systems.

Paper No. 138 — 3:00 p.m.
M/E Aspects of Kaiser Resources Limited's Newly Developed Underground-to-Surface Coal Slurry Pumping System.
A. W. GRIMLEY, N. PEASE and B. HART, Kaiser Resources Limited, Sparwood, B.C.

Hydraulic mining, the relatively new, extremely productive and safe mining system pioneered by Kaiser Resources Ltd. at their underground mines in British Columbia, is taking another step forward to help widen its applicability to varying conditions.

This joint paper gives up-to-date information on the new U/G dewatering and pumping complex, generally known as Panel 6, with emphasis on mechanical and electrical aspects.

Panel 6 is a completely new mine situated adjacent to earlier underground mines in the Sparwood Ridge area in general. It is designed to produce 1.3 million tons of coal per year for approximately 15 years starting in mid-1979, and will consist of basically a single-monitor operation together with its associated mining equipment, a diesel-powered monorail supply system, a highly efficient communications network and, last but not least, a specially designed and prototype underground dewatering and pumping system.

This system consists of 2 double-deck vibrating screens which dewater the minus 8- plus 3/8-in. material discharging into a 150-ton bin, from which a chain conveyor feeds onto a 36-inch conveyor transporting the coal to the surface.

The -3/8-inch material and water report to a 186,000-gallon sump which is simply an excavation in the rock with a concrete dam at each end. From this point, there are two separate slurry pumping systems. Each system (or train) consists of 3 pumps connected in series and an installed spare. Once slurry flow is established, a nuclear density controller automatically maintains a pre-set specific gravity. Each train is capable of pumping 3240 gpm to the surface dewatering facility. Relief in case of emergencies or unscheduled shutdown of the underground dewatering system is provided for by a 300,000-gallon

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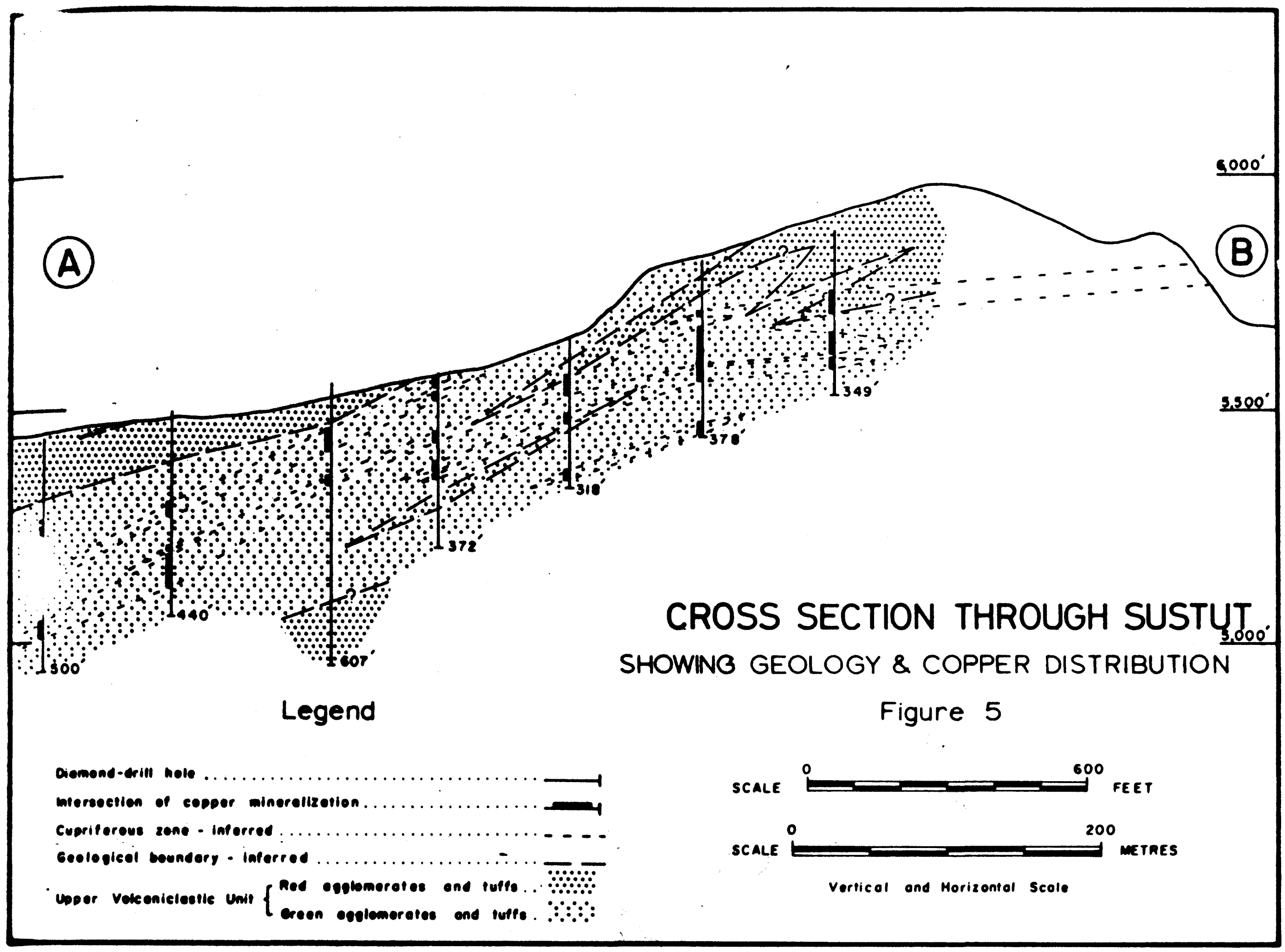


FIGURE 5 — Cross section through the Sustut deposit, showing geology and copper distribution.

Geology of the Sustut Copper Deposit In B.C.

G. Harper, Geologist,
Falconbridge Nickel Mines Ltd.,
Sudbury, Ontario

Abstract

The Sustut Copper deposit, 230 miles northwest of Prince George, B.C., was discovered in August of 1971. Subsequent exploration has included 56,417 feet of surface diamond drilling in 139 holes. The deposit occurs in gently dipping volcanic rocks of the Upper Triassic Takla Group, which outcrops as rugged mountains.

The general Mesozoic sequence comprises some 20,000 feet of green and red basaltic to andesitic rocks. The Lower Formation is characterized by subaqueous basalt, andesite and augite porphyry flows with interbedded breccias. They were rapidly deposited in tectonic depressions of limited extent and steep gradients. Facies changes are abundant. The Middle Formation consists of volcaniclastic rocks made up of fragments from the underlying formation. Two cycles are discernible, both with basal turbiditic, tuffaceous sandstone and shale units overlain by massive, volcanic conglomerates exhibiting graded and cross bedding. A broader, shallower-water basin is indicated. The top of the uppermost unit was subaerially deposited. The Upper Formation is a variable sequence of volcanic sedimentary rocks. Detritus was supplied from a wide source area and included multiple reworked fragments of the lower formations and material from other rock groups known in the region. Zeolite facies metamorphism is recognized throughout the entire sequence. Epidote is particularly abundant in the Middle Formation, demonstrating the results of metasomatism.

The mineralized zone is approximately concordant with the strata over 100-200 feet of the Middle Formation succession. It lies just below the zone of transition from subaqueous to subaerial deposition in the top unit. Hematite, chalcocite, pyrite, bornite, chalcopyrite and native copper are disseminated throughout all sizes of lithic fragments and matrix. Concentration into the specific zone is believed to be due to upward leaching of copper during low-grade metamorphic and metasomatic reaction. Precipitation occurred in the zone of hydration characterized by prehnite-pumpellyite below the oxidized subaerial rocks.

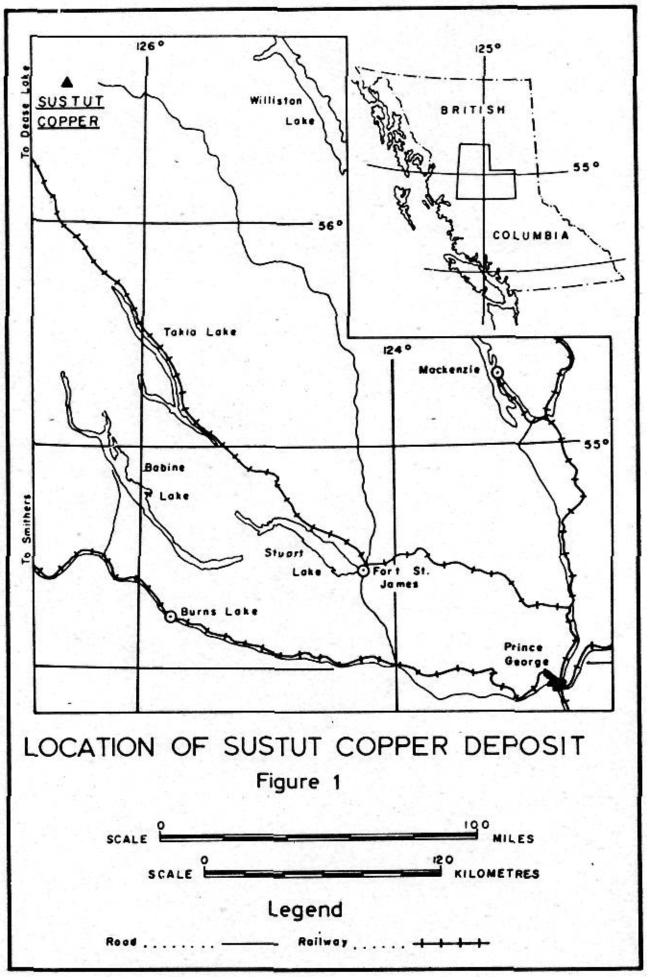


FIGURE 1 — Location map.

Location and Discovery

THE SUSTUT COPPER DEPOSIT is located in the Swannell Range of the Cassiar - Omineca Mountain Belt, in north-central British Columbia. Access to within 40 miles is available by rail, road or fixed-wing aircraft from Mackenzie, Prince Georges, Fort St. James and Smithers, all within 130-230 miles (Fig. 1). Final access is by helicopter. The claim area is cut by the Sustut River valley, which forms a major southwesterly break through the rugged northwest-trending mountains. Elevations range from 3,000 feet in the Sustut River valley to 7,000 feet on the peaks immediately to the north (Fig. 2). The treeline is at 4,500 feet, with alpine meadows extending up to 5,500 feet. Above this, bare rock, scree, felsenmeer and permanent snow are the essential elements. Most work to date has been above the treeline.

The copper mineralization was observed during a reconnaissance helicopter flight in August, 1971. It is a concordant band of malachite staining over widths of 100 feet extending intermittently for 2500 feet along the vertical cliff scarp. The prospect was staked and cursory prospecting and mapping done through an early snow cover. Since then, 56,417 feet of diamond drilling in 139 drill holes have been completed in a three-year exploration program to delineate the deposit.

Gerald Harper was born in Southampton, England in 1945. He was educated at the University of Rhodesia in Salisbury, where he received his B.Sc. in chemistry and geology in 1965 and his B.Sc. (Honours) degree in geology in 1966. After a brief period as a marine geologist in Cape Town, South Africa, he returned to Rhodesia as an Anglo American Corporation Research Fellow. He received his Ph.D. (1970) from the University of London, England for structural and stratigraphic studies of late Precambrian sediments in northwestern Rhodesia.

In 1970, Dr. Harper joined Falconbridge Nickel Mines Limited in Vancouver, B.C., where he has been concerned with exploration in the central part of the Province. He was transferred to the Sudbury area operations of the company in March of 1975.

Keywords: Sustut, Copper, British Columbia, Exploration, Volcanic succession, Folding, Faulting, Alteration, Stratabound deposits, Ore genesis.

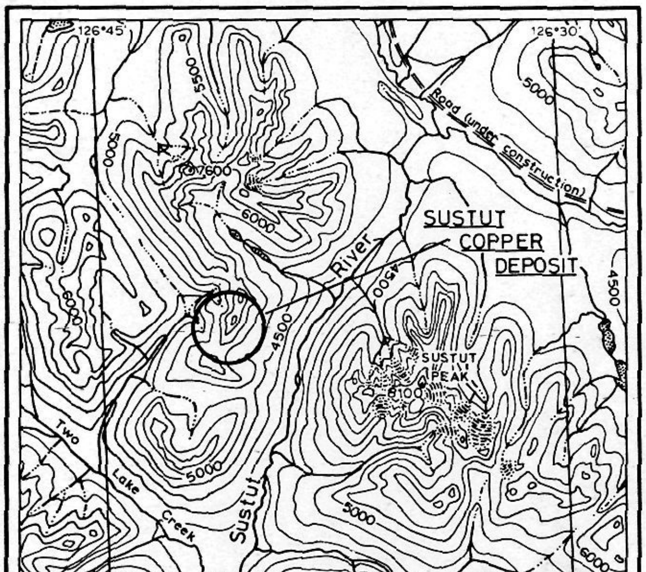
Regional Geology

The Sustut area lies near the east margin of the Intermontane Belt of the Canadian Cordillera (Sutherland Brown, *et al.*, 1971) within the McConnell Creek map sheet (NTS.94-D). Regional mapping was undertaken by C. S. Lord of the Geological Survey of Canada in the early 1940's (Lord, 1948). Subsequent work by J. Monger and G. Eisbacher of the Geological Survey of Canada, N. Church of the British Columbia Department of Mines, and Falconbridge staff geologists has modified, but not radically changed, Lord's interpretation.

The general geology comprises a sequence of northwesterly striking, southwesterly increasingly younger formations (Fig. 3). The oldest rocks are bands and inliers of Permo-Triassic sedimentary and volcanic rocks of the Asitka Group. Unconformably overlying these rocks, as outliers to the east and as a broad belt to the west, are the rocks of the Triassic-Jurassic Takla-Hazelton groups. This is a thick sequence of volcanic flows and volcaniclastics with minor non-volcanic sedimentary rocks. It is host to the Sustut Copper Deposit. In the extreme west, the Sustut Group of probable Cretaceous-Tertiary age overlies the Takla Group unconformably. The Sustut Group is made up of non-volcanic sedimentary rocks with minor tuffs (Eisbacher, 1971).

Stocks of diorite-granodiorite intrude the Takla Group rocks in the east. They form a northwesterly trending belt, probably related to the Omineca Intrusions of Lower Jurassic age, which outcrop farther southeast (Garnett, 1974). A few small stocks of apparently this same intrusive phase occur west of the main belt of Takla Group rocks. Minor basalt, andesite and porphyry dykes, sills and flows are found throughout the area of Takla Group rocks. Two groups are distinguished — an older, probably Jurassic and a younger Tertiary group.

Although the strata of the Takla Group are generally younger to the southwest, they do not dip uniformly in that direction. Broad U-shaped valleys along northwesterly and northeasterly trends have isolated mountainous blocks of the various rock successions. Within any one block, dips are generally fairly consistent, but are discordant between blocks. The linearity of these till-covered valleys may be due to underlying faults. Such faults could be responsible for block tilting. However, gentle folding may be, in part, the cause, as small-scale open folds are displayed to a minor extent within the blocks. A combination of both faulting and folding is likely to represent the true situation.



TOPOGRAPHY OF THE SUSTUT AREA

Figure 2

SCALE 0 — 10 MILES

SCALE 0 — 10 KILOMETRES

Creek, River, Lake — Glacier or Snowfield

Contour interval: 500 Feet

FIGURE 2 — Topographical map.

Stratigraphy of the Sustut Area

The immediate area of the Sustut Deposit has been mapped in detail (Fig. 4). From this, a picture of the local stratigraphy has been compiled (Table 1). The term "volcaniclastic" is used in this paper to describe clastic rocks with a dominant volcanic component regardless of the mode of origin (Fisher, 1961). The term "tuff" is used to indicate a fragment size of less than 4 mm; "agglomerate" and "breccia" contain fragments greater than 32 mm. These terms do not necessarily imply a pyroclastic origin.

Thicknesses of the Takla Group units vary considerably along strike, as facies changes are pronounced. However, the three fundamental stratigraphic subdivisions outlined in Table 1 persist, with their boundaries marking transition points in the sedimentary and tectonic evolution of the area.

The Lower Formation is characterized by extrusions of dark green massive flows and pillow lavas. The flows range from augite porphyry basalt, with augite phenocrysts up to 8 mm in length, through feldspar porphyry and amygdaloidal feldspar porphyry to aphanitic basaltic andesite. Church (1973) has made preliminary studies of the chemical compositions, confirming their basaltic nature. Predominantly overlying, and to a minor extent interbedded with, the flows are massive breccia and bedded tuffs and breccias. The breccias consist of large blocks of the underlying and adjacent flows in a tuffaceous matrix of similar composition. Augite grains in the matrix still retain the sub-euhedral shape characteristic of their phenocryst origin. Fragments are poorly sorted in the massive breccias, but exhibit some grading in the bedded tuffs and breccias. Individual members are of limited lateral extent and vary rapidly in thickness. The Lower Formation is a subaqueous deposit developed essentially in an unstable, steep-sided basin environment, as indicated by breccia units terminated against faults. No specifically pyroclastic features were observed. Therefore, it is assumed that sedimentation was mainly by erosion from local sources rather than explosive volcanism.

The base of the Middle Formation is marked by a pause in volcanic activity when a thin layer of fine volcanic detritus accumulated. Karnian-age fossils have been found in these tuffaceous siltstones and sandstones. Some horizons display soft sediment deformation features, such as flame structures, slump,

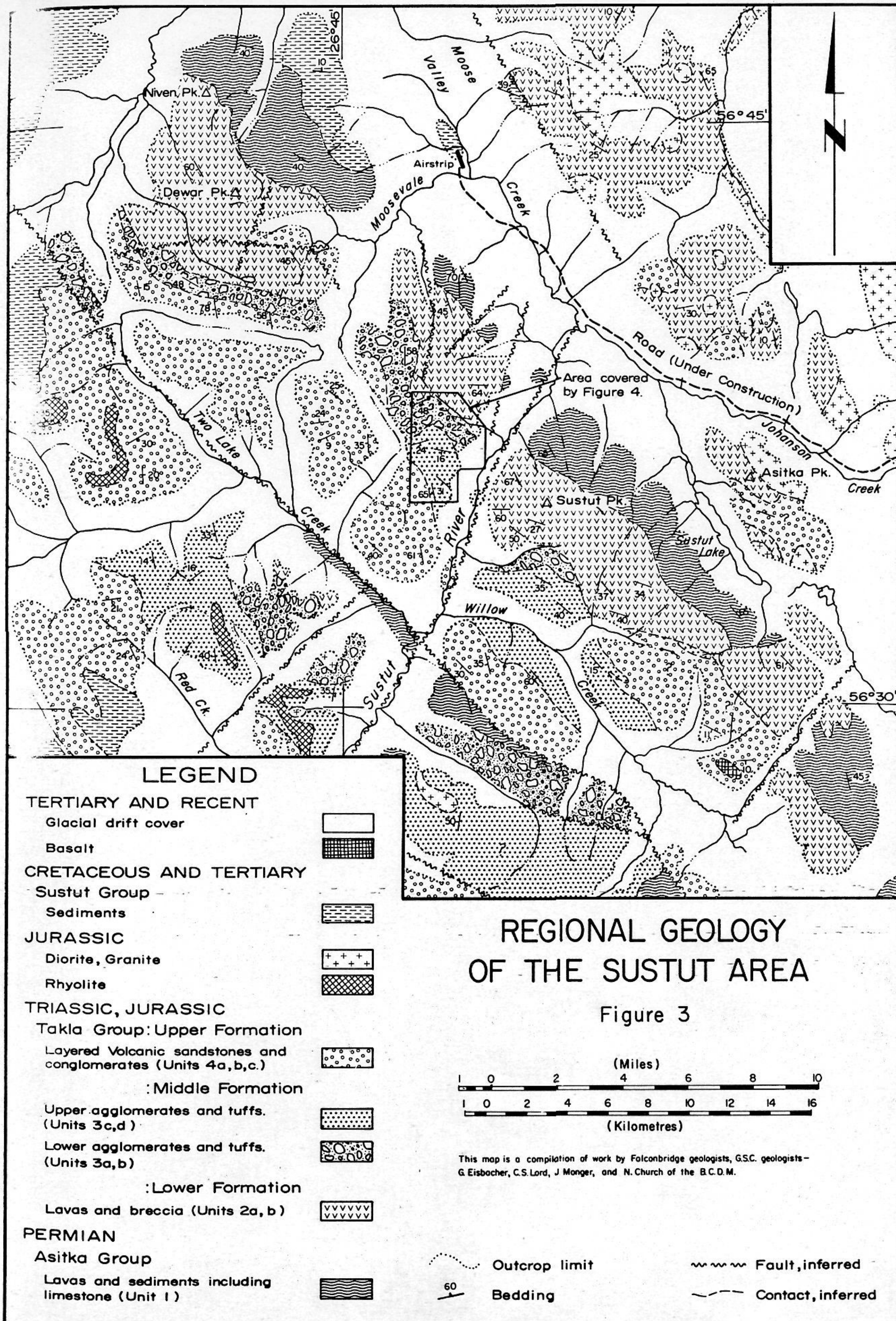


FIGURE 3 — Regional geology of the Sustut area.

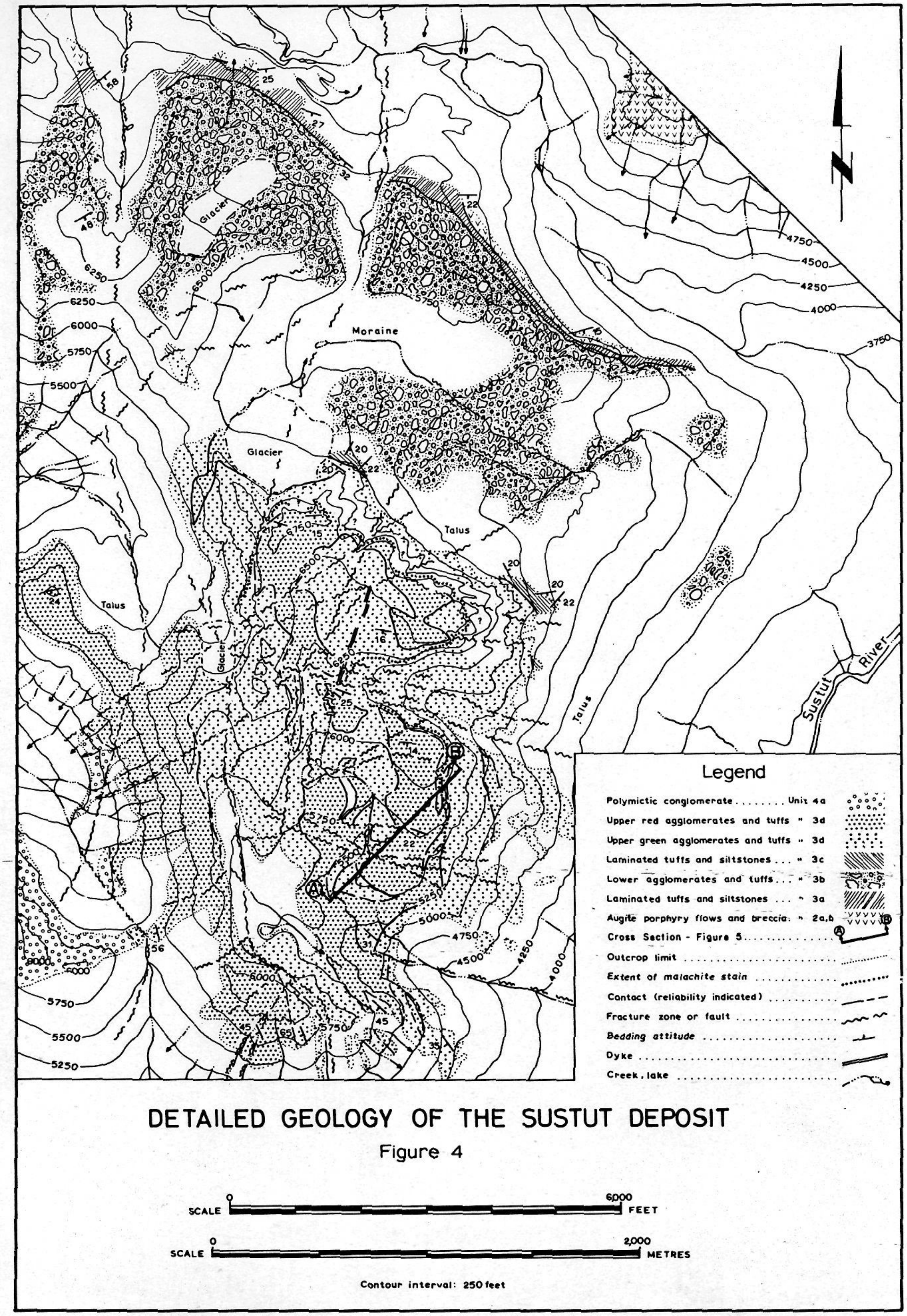


FIGURE 4 — Detailed geology of the Sustut deposit.

and boudinage, indicative of intermittent turbi-tivity. Overlying this is a major pile of volca-ics, which completes the lower cycle of the Formation.

upper cycle is a repetition of the lower, commencing with a thin tuffaceous siltstone and wacke-sandstone unit overlain by a thick pile of volcaniclastics. Similar fossils to those in the lower tuffaceous siltstone and sandstone are also found in the upper. The volcaniclastics are generally massive agglomerates, but locally display graded bedding, cross bedding and, high in the upper sequence, mud cracks and rare ripple marks. The clast content is substantially more heterogeneous than that in the Lower Formation volcanic breccia and increases in heterogeneity upwards. Notwithstanding, throughout the whole of the Middle Formation all detritus is apparently derived from the Lower Formation. The differing types of lava clast are drawn from a broader area of the Lower Takla than just the suite of flows visible immediately below. Within both volcaniclastic sequences there is a general trend upward from green to red. This transition is displayed in graded cycles, with fine tops characteristically red due to abundant hematite as grains and as a stain on other grains. The uppermost 1,200 feet of the Upper Volcaniclastic unit (3d) is entirely red. Just below this section, the banded red and green volcaniclastics feature a more lime-rich matrix than the volcanic tuff-grit matrix prevalent elsewhere.

Clasts throughout the volcaniclastic piles are poorly sorted, ranging in size from grit to blocks 12 feet (4 m) in diameter. The larger clasts tend to be subrounded or rounded, whereas the smaller (less than 32 mm) fraction is almost entirely angular to sub-angular. No genuine volcanic bombs or volcanic glass fragments were observed, but some very fine grained areas in the matrix are suspected of being palagonite.

The depositional environment envisaged is predominantly subaqueous, although becoming shallower through transgression-regression cycles. There was intermittent, but violent, explosive volcanic activity. The basin was of larger extent than that present for the Lower Formation. The source area was also of larger extent, but still confined essentially to the active trough. A few isolated limestone clasts (Asitka?) have been found near the top of the formation. The final phase of deposition was subaerial. Throughout the depositional cycle, changing basin form and a distinctly sloping depositionary surface caused recycling of detritus.

The Upper Formation is a highly heterogeneous assemblage of rocks. The upper part is characteristically a sequence of argillaceous and arenaceous clastic sedimentary rocks, largely of volcanic composition and predominantly red in colour. Bedding is abundantly developed, whereas cross and graded bedding are not. The lower part of the formation is more varied, with lenses of green and red volcanic conglomerate containing clasts of both the underlying Takla assemblage and foreign chert, limestone, rhyolite and jasper. These lower units are of limited extent, marked by rapid change in thickness and in composition. This implies that a broad source area provided rocks from several rock groups. Initial deposition was intermittently rapid in several small tectonic depressions. As tectonism waned, a broad shallow basin allowed the accumulation of recycled, finer-grained detritus in extensive layers. No direct volcanism is indicated during deposition of this Upper Formation.

TABLE 1 — Stratigraphic Column — Sustut Area

Era	Period	Group	Formation	Unit	Lithology	Thickness
				4c	Red and minor grey volcanic sandstones : ash flow tuffs, tuff breccia and derived volcanic siltstone, sandstone and conglomerate	4,000 ft
	(Norian)		Upper	4b	Volcanic conglomerate : red and green basaltic andesite, andesite and rhyolite-derived volcanic sediments.	3,700 ft
Mesozoic				4a	Polymictic conglomerate : with volcanic, chert and carbonate clasts.	1,700 ft
				3d	Upper volcaniclastic unit : green and red basaltic andesite tuff and agglomerate, volcanic breccia and derived volcanic sediments.	2,300 ft
				3c	Laminated to thinly bedded waterlain tuff, tuffaceous argillite, volcanic siltstone and sandstone.	200 ft
	Upper Triassic	Takla	Middle	3b	Lower volcaniclastic unit : green and red basaltic andesite tuff and agglomerate, volcanic breccia and derived volcanic sediments.	1,900 ft
	(Karnian)			3a	Laminated to thinly bedded waterlain tuff, tuffaceous argillite, volcanic siltstone and sandstone.	150 ft
				2b	Flow breccia.	1,200 ft
			Lower	2a	Flows : pillowed and massive augite porphyry basalt, augite-feldspar porphyry, amygdaloidal feldspar porphyry, bladed feldspar porphyry andesite and aphanitic basaltic andesite.	4,100 ft
	Unconformity					
Paleozoic	Lower Permian	Asitka		1	Rhyolitic flows, andesitic tuff, volcanic breccia, altered basalt, bedded chert and tuffaceous siltstone and limestone.	6,000 ft

Detailed Lithology of the Host Rocks

The Upper Volcaniclastic Unit (3d), which is host to the copper mineralization, is a highly variable sequence of volcaniclastic rocks ranging from augite porphyry basalt to andesite in composition. The sediments range from rocks composed of greater than 60% (by volume) of clasts, many of which are 2 feet or more in diameter, through abundant small clasts, a few large clasts and a few small clasts to an arenaceous grit which is similar to the matrix of the rudaceous rocks. Interbedded with the grits are argillaceous tuff bands.

Two colours predominate in the rocks — a dark green and a deep brownish red. They range from all-red clasts in a red matrix through any combination of red and green clasts and matrix to an entirely green rock. On the large scale, there is a tendency for green to predominate at the base and red rocks to increase in abundance upwards. The top 1,200 feet is almost exclusively red volcaniclastics.

Most of the sequence comprises massive, unsorted volcaniclastics. Interspersed, however, are sections displaying abundant graded bedding and cross bedding on several scales, suggestive of complex reworking and foreset-style deposition of material. Many examples were noted of a relationship between colour and grading. Coarse, basal material of a green colour grades upward through green and red grits to a fine-grained red tuff capping. Mud-cracked beds, as commonly found in the top grits, are red, but never green, in colour. In the massive volcaniclastics, gradational colour changes also occur. Here, however, there are no apparent sedimentary changes with which to relate them. Possible explanations in these cases include alteration as well as recycling during deposition.

The clasts throughout the sequence include red and green aphanitic andesites, green augite porphyry, augite-feldspar porphyry, grey and green amygdaloidal feldspar porphyry, grey bladed feldspar porphyry and red and green tuff and tuff breccia. Toward the base of the succession, the aphanitic andesite and augite porphyry clasts increase in proportion to the total clast assemblage. These are the two predominant flow types of the Lower Formation in the immediate vicinity. A contrasting example is the bladed feldspar porphyry, which proportionately becomes more abundant toward the top of the sequence. The nearest mapped outcrop of these flows is 6 miles northwest.

Igneous Intrusions

There is little evidence of intrusive activity in the immediate vicinity of Sustut. Two miles southwest of the deposit, quartz-feldspar porphyry sills and dykes have been mapped as intrusive into the upper (Unit 4c) volcanic siltstones and sandstones. On the Sustut copper property, intrusives are restricted to two suites of dykes. Narrow erratic lenses, rarely longer than 100 feet and wider than 5 feet, are apparently randomly oriented. They are comprised of subvolcanic andesite to dolerite.

A single dyke up to 10 feet wide follows a north-northeasterly trending, steeply dipping fracture. It is a fine-grained dark green andesitic rock, with augite phenocrysts up to 2 mm long, and commonly contains 5% or more of fine opaque minerals. In both these dyke types, chilled margins are absent. This, and the similarity of composition with the volcaniclastics, suggests that intrusion of both dykes was coeval with continuing Takla Group volcaniclastic deposition.

Folding and Faulting

At least two recognizable directions of folding are apparent. Both are broad open concentric folds with resultant domes and basins. In the less-competent, fine-grained, volcanic siltstones and sandstones of the Upper Formation, wavelengths of the order of a half mile, with dips up to 30 degrees, are typical. In contrast, in the highly competent, coarse agglomerates of the Middle and Lower Formations, warps of 2-3-mile wavelengths are typical. In the Sustut Prospect, area dips steepen from 10 degrees to as much as 55 to 60 degrees southwesterly. Church of the B.C. Department of Mines (1973) was able to show a specific fold axis of 167°, pl. 14° S.E., responsible for the Sustut prospect area warping. Although this is the dominant structural feature of the Sustut Prospect, on a regional scale the following sequence is envisaged.

F_3 — Minor warping or tilting; maybe fault associated. Axial planar strike 130-170°.
F_2 — Broad open asymetric synclines and anticlines. Fold axis 020°, pl. 27° N.E., measured north of Sustut.
F_1 — Gentle folds with axial planes striking 110-130°. Possibly coeval faults strike 110-130° also.

Two problems arise in the interpretation of folding; namely, initial dips and the influence of faulting. In the major volcaniclastic piles, abundant cross bedding makes it difficult to find true bedding, as top-set beds were eroded and subsequent fore-set beds deposited.

Faulting along north-northwesterly and northeasterly trends is of major proportions. The Omineca Fault, along Two Lake Creek, has a vertical displacement of several thousand feet. The lack of stratigraphic markers makes quantitative evaluation of many other possible fault lineaments difficult, although changes of dip across some of these lineaments suggests the occurrence of fault-induced rotation. In several areas, the stratigraphic development of the Lower and Middle formations is best explained by periodic fault movement during deposition causing local tectonic basins.

Alteration

Burns (1973) has shown that regional metamorphism throughout the Takla Group rocks is of the zeolite facies. Metamorphic grade increases northeastward from laumontite subfacies in the Upper Formation through prehnite-pumpellyite subfacies in the Middle and Lower formations to actinolite-pumpellyite (probably of greenschist facies) in the Asitka Group rocks. Burns concludes that the increasing metamorphic grade with age is dependent on increasing pressure and temperature in burial regionally rather than local effects from a point source. Metamorphic minerals recognized in the Takla Group rocks and used in arriving at this conclusion include laumontite, potassium feldspar, quartz, prehnite, pumpellyite, calcite, chlorite, epidote, white mica (sericite) and sphene. They occur as alteration products of plagioclase feldspar and clinopyroxene as well as in open-space fillings, amygdules, veins and fractures.

Green rocks of the Middle Formation and to a lesser extent of the Lower and Upper formations are characterized by an unusual abundance of chlorite and epidote. The greatest concentrations of epidote are found in the Upper Volcaniclastic Unit (3d). Here, epidote, chlorite, quartz and calcite are common in fracture fillings as well as in open-space and amygdule fillings and replacing minerals. Finer-grained sequences are present, composed of 50% epidote. Unit 3d was the

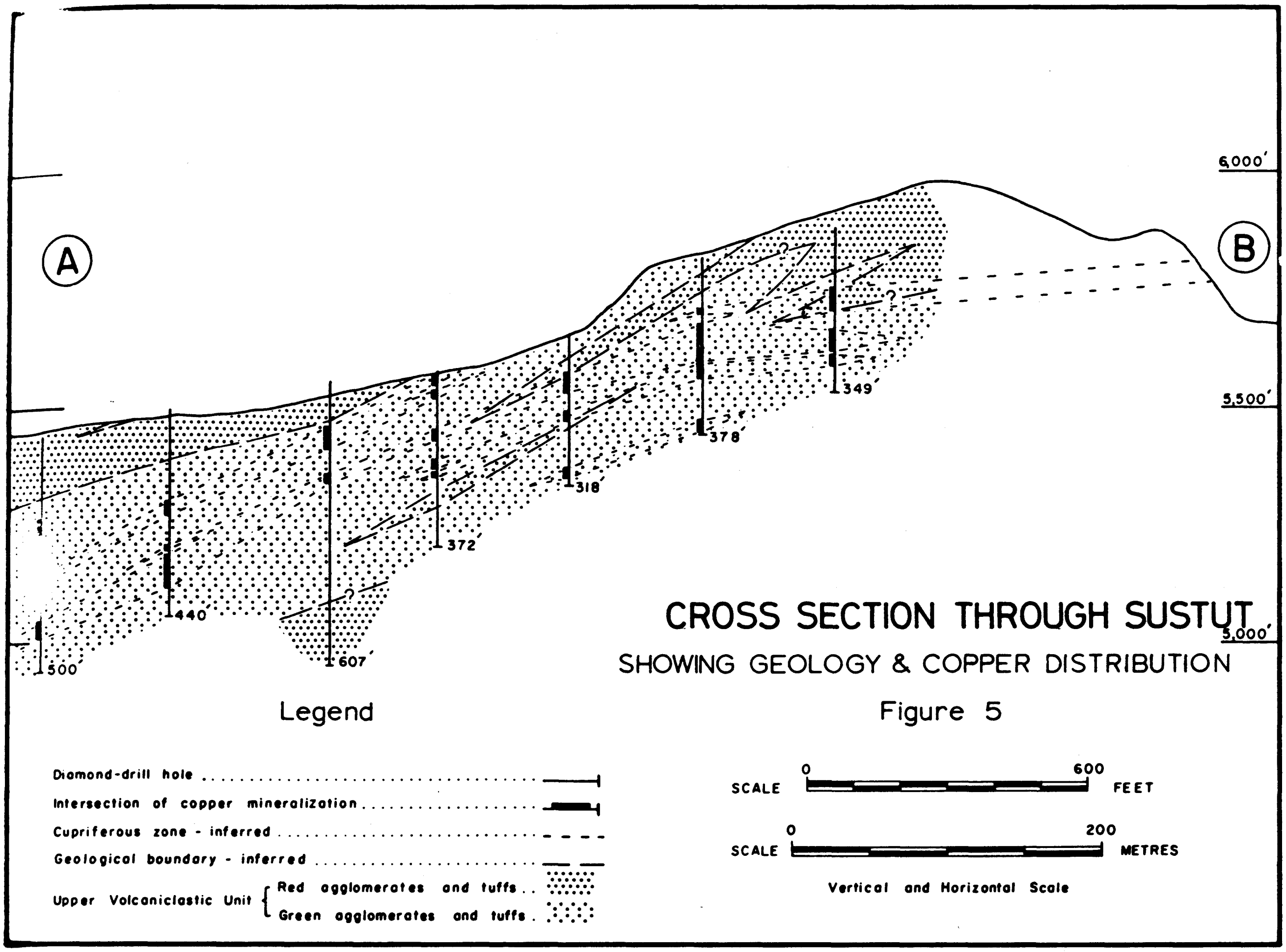


FIGURE 5 — Cross section through the Sustut deposit, showing geology and copper distribution.

l of important hydrothermal activity accompanied by metasomatism. The copper mineralization in this unit is not specifically associated with the greatest epidote concentrations, but is definitely within the broad epidote envelope.

Copper Mineralization

The copper mineralization discovered on the Sustut Property occurs in a sulphide-rich sheetlike zone up to 250 feet thick in the Upper Volcaniclastic Unit (3d) of the Middle Formation. Where exposed on cliffs on the northeast side, it is conformable with the average attitude of the bedding. This location places the base of the zone some 900 feet above the top of the siltstone-sandstone unit (3c) in the northern part of the property. Half a mile to the south, a deep drill hole had n intersected Unit 3c 1700 feet below the mineralized zone. This discordance is best explained by assuming that Unit 3c pinches out.

Down dip, the zone becomes increasingly irregular, but generally steepens slightly more rapidly than the bedding. Thus, its general morphology is only approximately stratabound.

The zone is composed essentially of hematite, pyrite, chalcocite, bornite, chalcopyrite and native copper in decreasing order of abundance. All occur as very fine grains disseminated through both matrix and clasts of the volcaniclastic. Increased mineral concentrations occur in the finer-grained tuff and tuffaceous matrix fractions. Hematite is ubiquitous throughout the zone; pyrite tends to form an incomplete envelope around the cupriferous lenses. Figure 5 is an idealized dip section through the deposit. The northern mountainous block is characterized by a uniform, closely stratabound, continuous zone of copper mineralization. It is 50-80 feet thick and has little pyrite associated. Copper minerals are essentially chalcocite and lesser native copper. Separating the north and south blocks is a deep cirque following a fracture zone.

In the eastern part of the southern area, copper mineralization is again fairly continuous and up to 150 feet thick. Chalcocite and bornite are the dominant minerals, with sporadic fringes above and below showing a gradation through chalcopyrite to pyrite. Down dip, the copper mineralization breaks up into a series of erratic lenses separated laterally and vertically by pyrite. Chalcocite is still the dominant copper mineral. Farther down dip, as the lenses steepen to become apparently transgressive to bedding, the mineralogy changes gradually to bornite and chalcopyrite. In the up-dip portion of the southern block, a clear vertical zoning sequence from pyrite fringes through chalcopyrite to bornite and to a chalcocite core is apparent. Elsewhere, vertical zoning is not apparent, and lateral zoning is insufficiently documented to be proven. All copper mineralization limits, with the exception of the cliffs, are gradational assay limits. The footwall limit is commonly fairly abrupt over 1-2 feet. The mineralized zone transgresses coarse- and fine-grained rocks with no discontinuity, but with a concentration variation as noted above. Pyrite has not been observed in proximity to native copper or chalcocite. Malachite development is insignificant away from the cliff face.

Lensing veins of massive bornite, chalcocite and native copper up to 6 inches wide are found in some epidote-, quartz- and calcite-filled fractures. They are most abundant in the southwest on fractures trending 110°-150°. It is not known whether this mineralization extends through and beneath the sheet-like zone.

The iron and copper mineralized zone covers an area of 1500 by 2300 feet in the north and 1800 by 2800 feet in the south. The zone limits have not yet been defined in the southwest.

Origin of the Copper Mineralization

A wide range of theories have been proposed by Falconbridge geologists. The absence of specific strata control, the zonal, vertical symmetry of sulphides and the sulphide distribution through clasts and matrix indicate that it is not syngenetic. Likewise, the absence of specific strata control, the distribution of sulphides through clasts and matrix and an apparent lack of feeders argue against a conventional hydrothermal "plumbing system" epigenesis. However, whether there is an enrichment or depletion occurring in the vicinity of intersections of mineralized fracture zones with the sheet-like zone is not yet known. Lateral zoning, if in fact present, would suggest some form of replacement system.

The theory favoured by the writer, in the light of present knowledge, is one of metasomatic mobilization. The observed low-grade metamorphism of the volcanic pile required substantial ionic migration. Water would be one of the most abundant molecules involved in the process as dehydration of the deeper rocks took place. Copper expelled from all highly altered rocks in permeable zones is removed by the aqueous, metamorphic fluids and carried upward to favourable precipitation environments. The more widespread distribution of iron sulphides than copper sulphides suggests that pyrite may pre-date the copper minerals. It could, therefore, have been the catalyst for the precipitation of copper.

The general parameters for, and feasibility of, movement of metal ions in low-grade metamorphic systems have been investigated by Jolly (1974), Fyfe (1974) and Brown (1974). Jolly has related the native copper deposits of the Keweenawan Peninsula in Michigan to a low-grade metamorphic system of this nature. He is now studying samples from the Sustut area. Jolly suggests that the zone of oxidation in the rock sequence would constitute the environment for precipitation of copper. Hopefully, his work will show whether or not the Michigan-based theory is applicable in detail at Sustut.

Conclusions

The Upper Triassic Takla Group rocks of north-central British Columbia are host to an unusual type of copper deposit. Locally, the Takla sequence consists of 20,000 feet of rapidly deposited andesitic to basaltic volcanic rocks. At the base flows predominate, but the upper 80% of the sequence is essentially volcaniclastic. These volcaniclastics display increasing evidence of re-working upward, in a depositional environment that evolved from a deep subaqueous trough to a broad shallow basin, variably subaqueous and subaerial. The sequence can be related to a model of eugeosynclinal deposition in an island-arc environment. Such a model has been proposed by staff of the Geological Survey of Canada, Cordilleran Section. Zeolite-facies metamorphism is recognized throughout the volcanic pile.

The copper deposit consists of an approximately stratabound sheet of fine-grained, disseminated chalcocite, bornite, chalcopyrite and native copper. It does not have any specific strata association, but lies wholly within the much thicker, massive volcaniclastic sequence of the Middle Formation, just below the transition from green upward to red rocks. In addition, lenses of the same copper minerals are found in fractures outcropping above the zone. The copper in the sheet-like zone is suggested to have been derived by "metasomatic" fluid leaching of the underlying altered rocks. Direct relationship of the fracture mineralization is not confirmed, but is possible as fractures provide more efficient channelways than does pore space in permeable rocks.

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