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Preliminary Report on Geological Control to Ore Distribution in the Whitehorse Copper Belt, Yukon Territory

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SUMMARY AND RECOMMENDATIONS

The Whitehorse copper belt has traditionally been described as skarn-type occurrences developed in limestone by metasomatizing fluids derived and emanating from an adjacent batholith. Our preliminary examination of these and similar occurrences elsewhere suggests that the common denominator among the deposits is not necessarily a pluton of particular composition and form but rather the stratigraphic section within which the deposits are stratabound. This section is relatively thin bedded dolomitic, bioclastic and stomatolitic limestone in a predominately volcanic terrain. The carbonate rocks are comparable to present day intertidal evaporities which prograde algal mats and which in turn are succeeded by continental clastic rocks. The buried algal mat decays and becomes saturated with hydrogen sulphide. It is suggested that water rising through the volcanic and clastic rocks to the evaporite surface may leach small amounts of metal which may in turn be deposited in the reducing environment of rotting algae. Such primary concentration of metal may later be reconsituted by metamorphism accompanying intrusion in the waning stages of volcanism and uplife.

Our recommendations are as follows:

1. Petrography of the layered rocks should be continued in an examination of the reasonablness of the above suggestion.

2. If the importance of evaporite-type carbonate

rocks is substantiated for the distribution of copper deposits in the Whitehorse copper belt then the paleogeography of the Upper Triassic shoreline should be mapped if possible.

3. Detailed mineralogy of the skarn assemblages should be determined to study the effects of metamorphism on metal distribution.

4. Radiometric age determinations should be completed on the plutonic bodies of the belt to study their relationship to the volcanic rocks, the nature of the total igneous event, and its contribution to metal distribution.

5. Recommendations 1 through 5 can be completed, along with a field check of some sections by the end of this summer. This will provide definition of the problem for application to Indian and Northern Affairs for a full season in the field in 1975.

Table of Contents

List of Figures

List of Tables

List of Plates

INTRODUCTION

The Whitehorse copper belt, Yukon Territory, is 28 copper occurrences along 12 miles of intrusive contact between a batholith of quartz diorite and a layered sequence of andesite, greywacke, argillite, comglomerate, and limestone defined as the Lewes River Group of Upper Triassic age (Wheeler 1961). The batholith has been mapped as part of the Coast Range Intrusions of Cretaceous age. Copper occurs as chalcopyrite, bornite and chalcocite in calc-silicate and magnetite-bearing skarn. Mineralogy and distribution of occurrences suggest localization within particular limestone strata in contact with the batholith. Whitehorse Copper Mines Ltd. hold the known occurrences and operate the Little Chief Mine, central to the belt.

This report consolidates 1973 field and laboratory study of geological controls to copper deposition in the Whitehorse copper belt. Work was done under research agreement with the Department of Indian and Northern Affairs and the first season's objective was a preliminary examination of the layered rocks stratigraphically enclosing the copper occurrences, the attendant pluton and other geologic variables affecting metal distribution and of possible significance to exploration. We have drawn heavily on past work particularly that of J.O. Wheeler (1961), the staffs of Whitehorse Copper Mines Ltd. and of D.B. Craig, Resident geologist, Indian and Northern Affairs. C.G. Winder of the Department of Geology, University of Western Ontario helped with petrography of the carbonate rocks and W.A. Marchant provided interpretations of the magnetic expression of the plutonic rocks.

The Whitehorse copper belt is 3 miles west of the City of Whitehorse and the Alaska Highway (figure 1). It is accessable by road from MacRae to offices and plant site of Whitehorse Copper Mines Ltd. in the centre of the Belt, and by the Fish Lake road which leaves the Alaska Highway 3 miles north of Whitehorse, and by a mine haulage road which follows the length of the belt from the War Eagle pit in the north to the Black and Tan Cub occurrence in the south. Rocks of the Lewes River group beyond the confines of the belt can be reached in the north part of the map area by tote road from the Alaska Highway 4 miles south of Takhini thence westward to Jackson Creek and the Ibex River Valley. In the south part of the map area access is provided by the Klondike Highway to Carcross and the Annie Lake road from Robinson. East of the Yukon River a CN telecommunications is served by a road traversing rocks of the Lewes River group on Canyon Mountain.

REGIONAL GEOLOGY

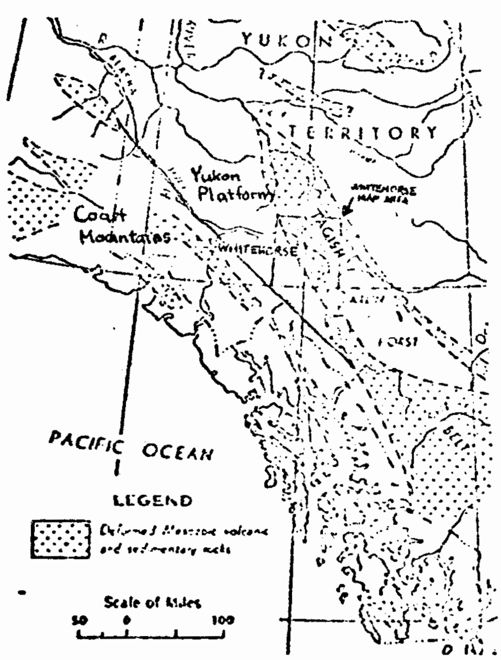
The Whitehorse map area (Wheeler, 1961) includes the north limit of the Coast Mountains and the west part of the Yukon Platform (figure 1). Exposed rocks are Precambrain to Pleistocene in age (Table 1, Wheeler, 1961, page 22). The former are Yukon group gnesisses and schists of metamorphosed quartz arenite, chert, limestone, and volcanic wacke. These rocks are unconformably overlain by Pennsylvanian and Permian limestone, chert, and greenstone including scoriaceous and

FIG.1 TECTONIC FEATURES AND GENERAL GEOLOGY OF THE WHITEHORSE MAP AREA

(after Wheeler, 1961)

Scale of Miles

10 0 10 20



LEGEND

UPPER JURASSIC ? AND LOWER CRETACEOUS

Tantalus formation (77-83)

LOWER JURASSIC AND ? LATER

Laberge group (29-74)

UPPER TRIASSIC

Lewes River group (1-22) Lewes River group or Laberge group (23-27)

TRIASSIC AND JURASSIC

Undifferentiated Lewes River group and Laberge group

PLUTONIC ROCKS

Pink quartz monzonite (1-4)

Leucocratic granite, biotite granite (5-13)

Granodiorite, quartz diorite (14-45)

YUKON GROUP

Metamorphic rocks (A-Z)(a-f)

amygdaloidal flows, pyroclastic rocks, and sills of the Taku group which in turn are unconformably succeded by Mesozoic eugeosynclinal strata of the Whitehorse trough, a segment of the Tagish belt (figure 1 inset).

The oldest Mesozoic rocks of the Whitehorse map area are basalts, andesites, pyroclastic rocks, and poorly sorted clastic sedimentary rocks of the Upper Triassic Lewes River group (Table 2, Wheeler, 1961, page 37). This eugeosynclinal assemblage gives way to coarse gravels and cobble conglomerate basal to the Laberge Group of Lower Jurassic age which signify rapid uplift and the start of an essentially continental non-marine succession of sedimentary rocks which constitute Middle and Upper Jurassic Laberge and Tantalus groups. Cretaceous and younger layered rocks are continental clastics and a continental volcanic suite of basalt and rhyolite. Layered rocks from Precambrian through Cretaceous age are intruded by batholiths of intermediate composition which have been mapped as Cretaceous (Wheeler,1961) but which by field relationships may be Upper Triassic to Cretaceous in age and comagmatic with the Triassic volcanism. Post Cretaceous intrusions are relatively small, of intermediate to felsic composition, and probably related to the Continental volcanism.

Rocks older than Cretaceous are in northwest trending folds with steeply dipping axial planes. Faults of undetermined displacement trend northwest and northeast and are steep dipping.

Table I

Table of Formations Exposed in the Whitehorse May Area (Wheeler, 1961)

Era	Period or Epoch	Formation (thickness in feet)	Lithology
Cenozoic	Pleistocene and Recent		Glacial drift, alluvium, loess, volcanic ash
			Basalt; minor pyroclastic rocks
	Unconformity		
	Tertiary		Granite porphyry, rhyolite
		Intrusive into lower part of Skukum group	
		Skukum group (4,000+)	Andesite, basalt, rhyolite, and trachyte breccias, tuffs, and flows; 'granitic agglomerate'
Unconformity			
Mesozoic	Late Lower or early Upper Cretaceous	Coast Intrusions	Pink granophyric quartz monzonite
			Intrusive contact with granodiorite
			Leucogranite, biotite granite, alaskite, kali-alaskite
			Intrusive contact
			Hornblende-biotite-oligoclase granodiorite, biotite-hornblende quartz diorite, biotite granite, hornblende diorite, gneissic porphyritic granodiorite, pegmatitic syenite
		Intrusive contact	
		Hutshi group (4,000+)	Basalt, andesite, porphyritic andesite, quartz latite, and rhyolite flows, breccias, and tuffs; minor greywacke and argillite; conglomerate locally at base
		Angular unconformity (granitic intrusion ?)	
			Peridotite, dunite, serpentine, and pyroxenite
	Relations unknown. Ultramafic rocks in contact with Laberge group		
	Upper Jurassic(?) and Lower Cretaceous	Tantalus formation (2,500)	Arkose, siltstone, conglomerate, argillite; coal
	Lower Jurassic and later	Laberge group (9,500+)	Conglomerate, greywacke, arkose, quartzite, siltstone, argillite, hornfels
	Disconformity (local conformity (?), local angular unconformity(?), local granitic intrusion(?))		
	Upper Triassic	Lewes River group (10,000)	Volcanic greywacke, siltstone, argillite, limestone, limestone breccia, conglomerate; volcanic breccia, agglomerate, tuff; andesite, porphyritic andesite, and basalt
Relations unknown			
Palæozoic	Pennsylvanian (?) and Permian	Taku group	Limestone, limestone breccia, chert; greenstone and (?) pyroclastic rocks
Relations unknown			
Precambrian and later		Yukon group	Quartz-mica, quartz-chlorite, and mica schists; quartzite; feldspathic hornblende gneiss, amphibolite, epidote-amphibolite, crystalline limestone; feldspathic gneiss, *lit-par-lit* gneiss; gneissic porphyritic granodiorite and quartz diorite

Table II

Ibex River Section of the Lewes River Group (Wheeler, 1961)

	Thickness (feet)
Laberge group	
Disconformity	
Dark green tuff	10+
Division E.	
Pale grey, massive limestone containing *Spondylospira lewesensis*	500
Division D.	
Green and dark purple volcanic greywacke, conglomerate with fragments up to a foot across mainly of volcanic, some granitic, rocks; subordinate volcanic breccia	1,000–1,500
Division C.	
Purple, grey, and green volcanic breccia containing blocks up to 2 feet across and a few rounded pebbles and boulders, volcanic greywacke; 60 feet of purple and grey amygdaloidal andesite and basalt flows about 700 feet above base; at base, purplish conglomerate 50 feet thick composed of purple basalt, greenstone, and limestone cobbles	1,500–1,000
Disconformity	
Division B.	
Pale grey and pale pink crystalline limestone in discontinuous lenses (10 feet)	75–100 (for this and the following five units)
Limestone breccia, with a few volcanic fragments 3 to 4 inches across (5 feet)	
Conglomerate, in lenses 10 feet thick, comprising rounded cobbles 2 to 3 inches across of purple volcanic rocks (10 feet in lenses)	
Limestone breccia, containing corals and brachiopods (5 to 10 feet)	
Conglomerate containing greenstone, purplish basalt, and feldspar porphyry cobbles	
Purplish limestone breccia and purplish greywacke grading upward into purple conglomerate	
Grey-green, limy greywacke, interbedded with siltstone and argillite, containing *Halobia*	100
Interbedded limy greywacke, in part gritty, and banded greyish green argillite, thin conglomerate beds containing pebbles of greenstone, greywacke, and limestone; some lenses of limestone about 10 feet thick	60
Interbedded grey-green, locally pebbly greywacke and banded argillite (lower part contains more argillite than greywacke)	100
(Division B thins northward and pinches out so that Division A merges upward with Division C)	
Division A.	
Greenstone, locally containing phenocrysts of chloritized hornblende and pyroxene, volcanic breccia of green fragments in a green or purplish matrix; minor conglomerate and siltstone	200
Base not exposed	

Precious metals occur in quartz veins within rocks of the Precambrian Yukon Group and some plutonic rocks and, continental volcanic rocks Cretaceous and younger in age. Copper appears to be confined to skarns in limestone of the upper part of the Lewes River group of Upper Triassic age where intruded by the Whitehorse batholith of intermediate composition.

GEOLOGY OF THE WHITEHORSE COPPER BELT

General Statement

Rocks of the Lewes River group strike northwest through the belt, are in open folds, and moderately well exposed on steep hill sides (Plate 1) and in pits on copper occurrences. Much of the Whitehorse batholith is drift covered (figure 1).

The Lewes River Group

Fossils of Upper Triassic age have been identified in sedimentary rocks intercalated with volcanic rocks which Wheeler (1961) describes as the Lewes River Group. The best exposures are along the east side of the Ibex River canyon west of Fish Lake, on Canyon Mountain immediately east of the City of Whitehorse, and on Needle Mountain south of the Copper Belt (figure 1). In general, western exposures of Lewes River group include volcanic rocks limy muds containing Halobia fauna, volcanoclastic rocks, and limestone with Spondylospira lewesensis fauna whereas central and eastern exposures within the map area are typically graded beds of mud, silt, sandstones, the Spondylospira-bearing limestone

Plate #1 View of the Copper Belt looking south from Haeckel Hill towards Golden Horn Mountain.

Plate #2 Algal structure in massive Halobia limestone exposed in the Ibex River Valley.

and minor volcanic rocks, indicating a decrease in volcanic influence eastward across the Belt. It appears from preliminary examination as if the copper occurrences of the Whitehorse copper Belt are associated with the Spondylospira-bearing limestone which is broadly divisible into a lower clayey argillaceous micritic unit, a middle bioclastic massive limestone, and an upper thin bedded and cherty limestone appears to thicken from west to east across the map area. Samples examined in thin section, peel section and by analyses for calcite and dolomite are listed in Table III. Most of these specimens are collected from the upper and lower parts of the limestone in an unsuccessful attempt to find conodonts for age determinations and hence are not wholly representative. The fine grain relative homogeneity, and lack of current structure indicates a low energy environment of deposition.

The Ibex River Section

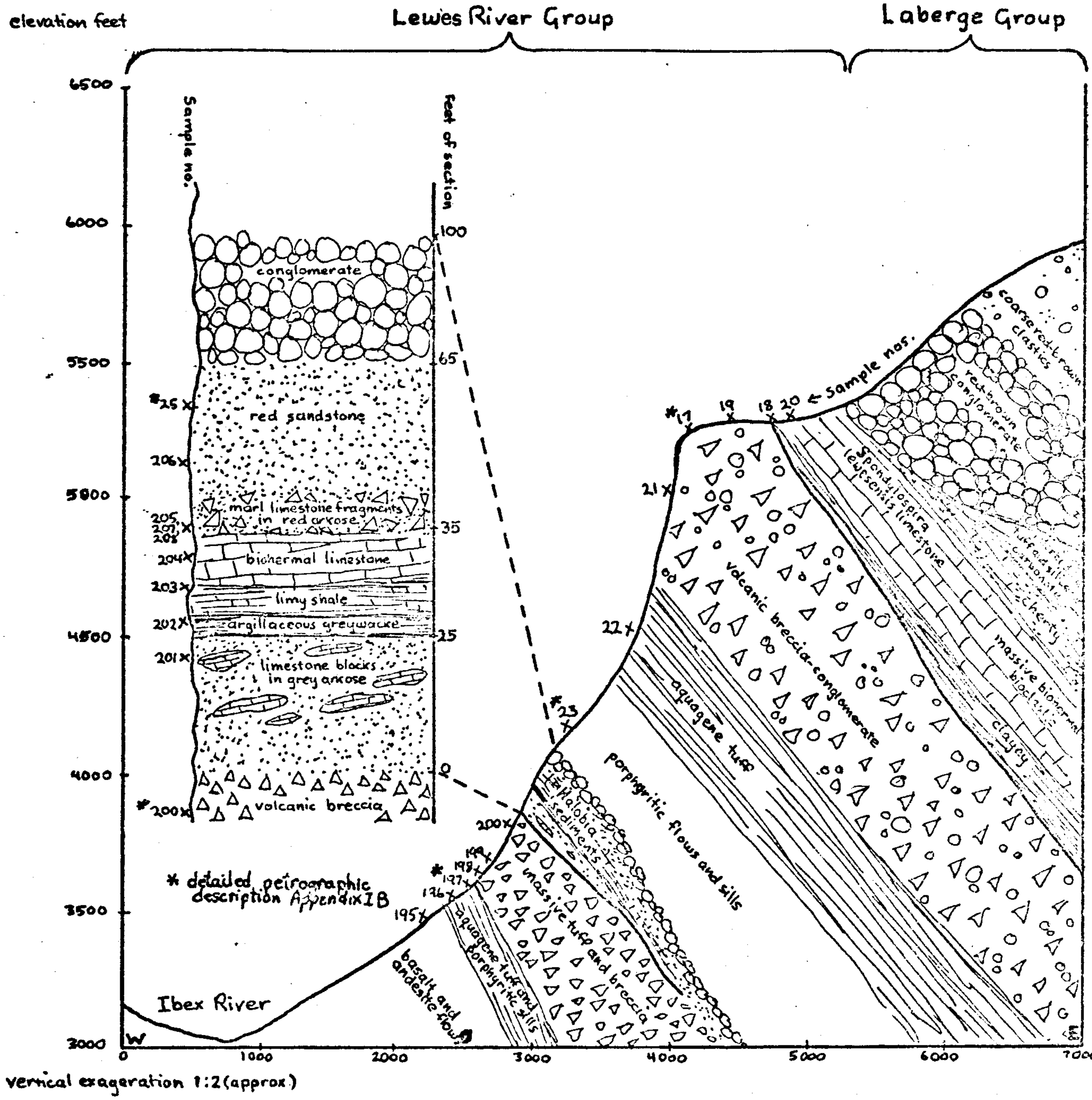
The most westerly section observed is along the east side of the Ibex River. It is described in Table 2 and Figure 2. The lower part is massive flows of basalt and andesite interbedded with fine-grained feldspathic wacke, argillite and tuff and volcanic breccia. Flows are commonly porphyritic with euhedral plagioclase, diopsidic-augite, and hornblende phenocrysts in a fine-grained matrix. Thin beds of feldspathic wacke and argillite commonly contain disseminated pyrite in a siliceous matrix. Clasts in the coarser argillite are feldspar, diopsidic-augite, hornblende, and fragments of mafic flows and tuff. The tuffs consist of

Table III

Selected Specimens of limestone from Spondylospira-bearing horizons

Sample#	Location	Remarks	Units SiO_2	C/D
WH 18	Ibex River	massive dolostone	3	.029
19	Ibex River	massive foss. mudstone	-	-
20	Ibex River	massive foss. packstone	10	-
20B	Ibex River	massive mudstone	7	.047
44	Needle Mt.	laminated mudstone	1	-
48	Needle Mt.	massive foss. limestone	-	-
49	Needle Mt.	massive mudstone	3	-
54	Carcross	massive mudstone	1	-
93A	Fish Lake	thin bedded oolitic dolostone	13	4.23
93B	Fish Lake	thin bedded siliceous mudstone	74	
96	Little Chief Mine	thin bedded dolomitic marble	-	.367
97	Little Chief Mine	thin bedded argillaceous	-	38.6
113	Wheelers foss. loc. 7	massive foss. dolostone	2	1.672
117	Wheelers foss. loc. 9	massive mudstone	-	.077
120	Wheelers foss. loc. 18	massive mudstone	1	-
126	Canyon Mt.	thin bedded argillaceous mudstone	-	-
130	Canyon Mt.		-	-

FIG.2 CROSS-SECTION OF THE LEWES RIVER GROUP EXPOSED ON THE EAST SIDE OF THE IBEX RIVER VALLEY



matrix-supported microlite and angular fragments of an unzoned plagioclase. Upward in the section these rocks are massive layers within volcanic breccia of alternating purple and green colour. Plagioclase is generally saussaritized and the mafic minerals slightly chloritized. The volcanic breccia becomes increasingly well bedded and fragments well rounded upward in the section. There are intercalated lenses of arkose, argillite, limy greywacke, limestone and conglomerate. The limestone is lense-like and contains the Halobia fauna (Plate 2) plus carbonaceous material, pyrite and siliceous material. Limestone is overlain by pink and green coloured marl, red sandstone and conglomerate with volcanic and limestone cobbles.

The upper part of the Ibex River section is repetative of the lower part and begins with flows and tuff overlain by volcanic breccia of purple, grey and green colour, volcanic wacke and ultimately limestone containing Spondylospira lewesensis and topped by chert, and tuff. The basal part of this upper limestone is a grey coloured, fine grained argillaceous dolostone with calcite crystals from 5 to 7mm in diameter and numerous subparallel calcite veinlets. The rock is homogeneous and micritic. This is succeeded by a light grey, bioclastic limestone (Plate 3) with a siliceous upper part. The rock has styllolitic bedding and is recrystallized. Contact with the overlying Laberge group is covered by drift in the Ibex-River area but a change in attitude of beds on either side of the contact suggests an unconformable

Plate #3 Massive biohermal Spondylospira lewesensis limestone composed of indeterminant colonial corals exposed north of Jackson Lakes.

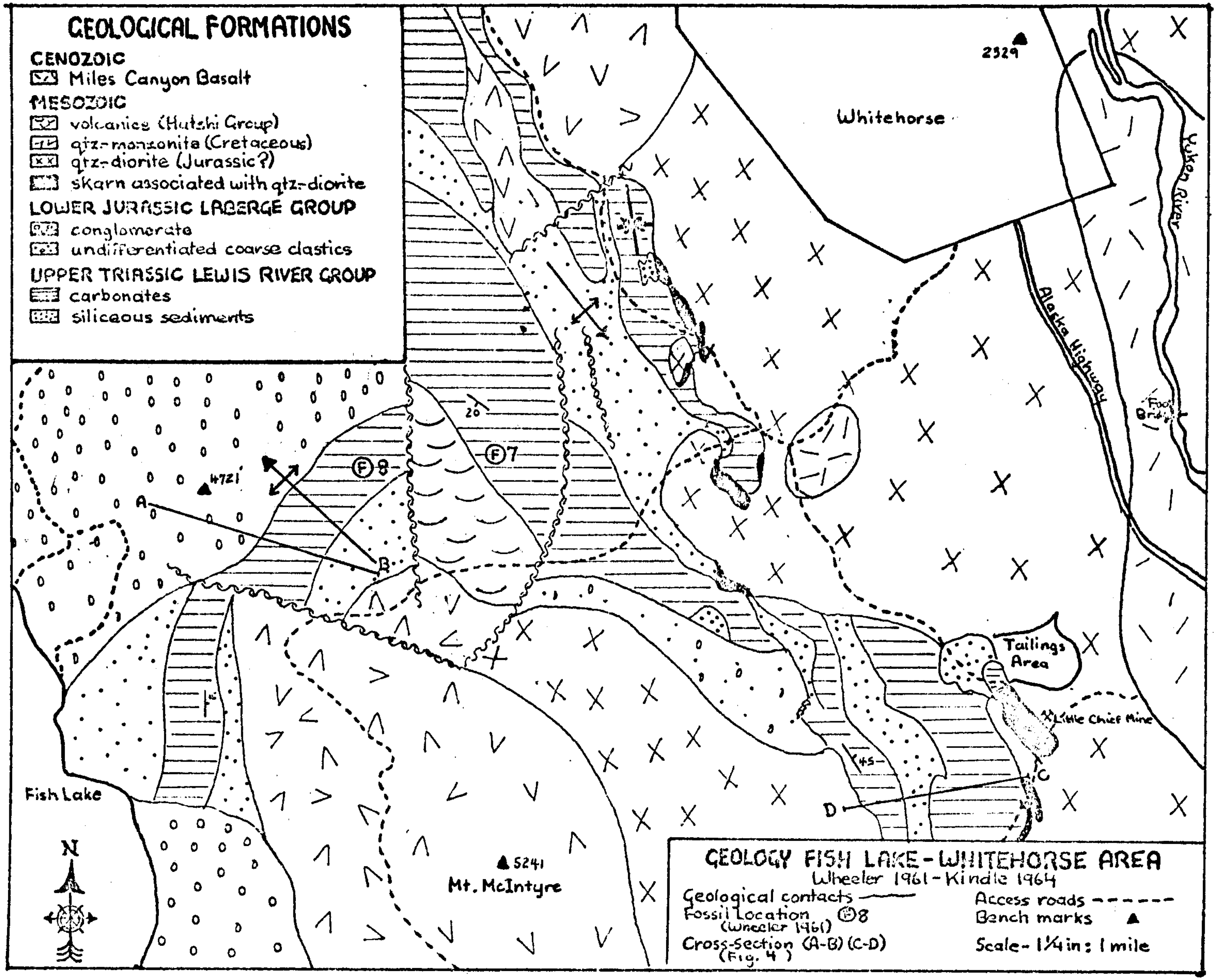
Plate #4 Laberge polymictic conglomerate observed northeast of Fish Lake.

relationship. Conglomerates of the Laberge group are polymictic, contain granitic cobbles and boulders to 4 feet in diameter (Plate 4) in a hematitic arkosic matrix.

The Fish Lake - Whitehorse Copper Belt Section

Rocks of the Lewes River group exposed in the Fish Lake area and within the Copper Belt were examined to determine which lithologies of the group contained copper sulphide minerals at the edge of the Whitehorse batholith (figure 3). From Fish Lake east through the Copper Belt rocks of the Lewes and Laberge groups are in open anticlines and synclines distributed by block faults. Individual units within the Lewes River group are difficult to follow through the sporadic outcrop of the copper belt but a tentative correlation from Fish Lake through the belt to the Little Chief mine of Whitehorse Copper Mines Ltd. is possible as illustrated in figure 4. At Fish Lake, conglomerate of the Laberge group appears to be conformable with oolitic limestone, pyritic quartzite, a limy clastic and limestone containing the Spondylospira lewesensis fauna and chert interbeds. This is underlain by and grades into a mottled wacke which is tuffaceous and consists of fresh and altered grains of feldspar and pyroxene in a granulate matrix of actinolite, chalcedony, calcite and hematite.

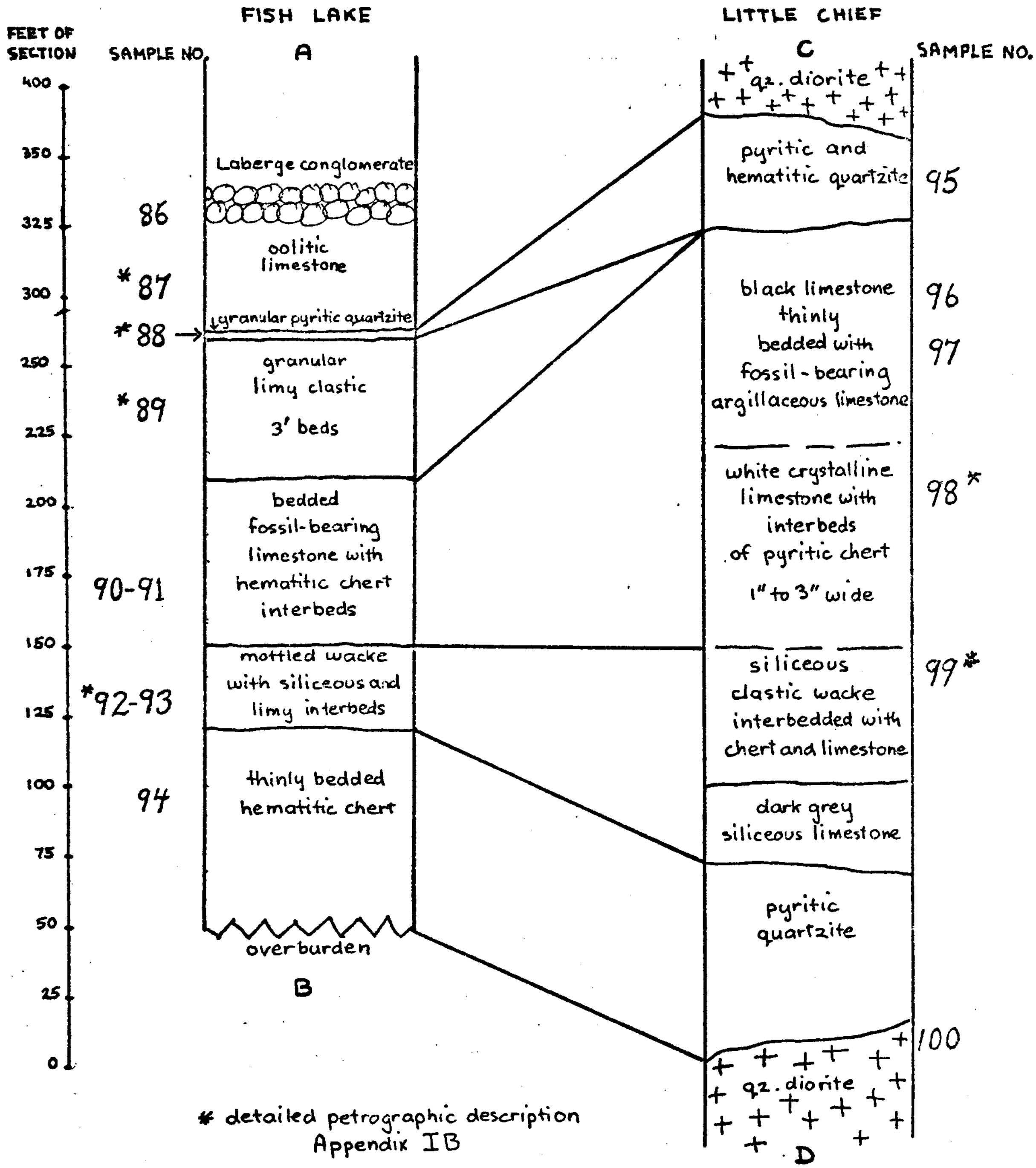
Immediately west of the Little Chief mine a thick sequence of limestone outcrops sporadically and has been described by Kindle (1964, page 5). Figure 4 illustrates this section which consists of pyritic and hematitic



GEOLOGICAL FORMATIONS
CENOZOIC
Miles Canyon Basalt
MESOZOIC
volcanics (Hutshi Group)
qtz-monzonite (Cretaceous)
qtz-diorite (Jurassic?)
skarn associated with qtz-diorite
LOWER JURASSIC LABERGE GROUP
conglomerate
undifferentiated coarse clastics
UPPER TRIASSIC LEWIS RIVER GROUP
carbonates
siliceous sediments
2329
Whitehorse
Yukon River
Alaska Highway
Foot Bridge
4721
A
B
F8
F7
20
Tailings Area
Little Chief Mine
C
D
45
Fish Lake
N
5241
Mt. McIntyre
GEOLOGY FISH LAKE-WHITEHORSE AREA
Wheeler 1961-Kindle 1964
Geological contacts
Fossil Location (Wheeler 1961) F8
Cross-Section (A-B) (C-D) (Fig. 4)
Access roads
Bench marks
Scale- 1¼ in : 1 mile

FIG. 3

FIG.4 STRATIGRAPHIC CORRELATION OF UPPER LEWES RIVER GROUP IN THE WHITEHORSE COPPER BELT



* detailed petrographic description Appendix IB

quartzite underlain by thin bedded black limestone with interbeds of dolomite siliceous, organic, fragmental, and argillaceous material. Stromatolitic structures are preserved in some dolomitic horizons (Plate 5). Pyrite is common in this section as are recrystallized calcite and quartz, sericite and actinolite in argillaceous seams. The clastic horizons appear to be tuffaceous with grains of plagioclase An_{30} and magnetite rather than the hematite characteristic elsewhere in the Fish Lake-Copper Belt area. Our tentative conclusion is that The Fish Lake-Copper Belt section can be correlated with the uppermost part of the Lewes River Group in the Ibex River section. These rocks probably formed in lagoonal and sabka-like evaporite environments during a period of regression leading to non-marine deposition of Lower Laberge group conglomerates.

Open pits in copper occurrences of the belt to the north and south of the Little Chief mine expose massive Skarn, crystalline limestone, clayey and argillaceous limestone, chert and quartzite as screens and inclusions within and at the contact of the Whitehorse batholith. Correlation between pits and outcrops west of the Little Chief mine is difficult but petrography and petrochemistry of some of the rocks described in appendicies A and B suggest most copper occurrences are in the thinnly bedded limestones and the immediately underlying more massive beds containing the Spondylospira lewesensis fauna described above. The thin bedded material is commonly replaced by a skarn assemblage and the more massive, more purely carbonate beds are

Plate #5 Preserved stromatolitic structure in dolomitic carbonates west of Little Chief Mine.

Plate #6 Massive outcropping of Spondylospira lewesensis limestone at White Hill near Needle Mt.

thoroughly recrystallized.

The Needle Mountain Section

Limestone with Spondylospira lewesensis fauna outcrops on Needle Mountain south of the Whitehorse Copper Belt and consists of 5 feet of limy grit, 2 feet of siliceous limestone with tuffaceous material, 15 feet of coarsely crystalline grey limestone, 15 feet of buff to grey coloured limestone in thin beds, and 10 feet of fossiliferous limestone. This section is overlain by a conglomerate of volcanic cobbles and cherty matrix. Plate 6 illustrates the largest outcrop of this limestone at White Hill on the east side of Needle Mountain.

The Canyon Mountain Section

On Canyon Mountain immediately east of the Yukon River and the City of Whitehorse limestone bearing Spondylospira lewesensis fauna is overlain and infolded with greywacke, argillite, and black slate containing ammonites which may be of Jurassic age (Wheeler, 1961, page 41). The limestone and clastic rocks appear to be conformable. The limestone is approximately 1500 feet thick at this locality, silceous and fissile with the more massive and cleaner beds in the upper part of the section with chert and quartzite intercalations. The lower part of the section has clay and micritic intercalations. The middle section is light grey and bioclastic.

Plutonic Rocks of the Whitehorse Copper Belt

Plutonic rocks of the Whitehorse Copper Belt can in general be divided into 3 major bodies (figure 5): the Whitehorse batholith, or Copper belt intrusion is an oval shaped body of quartz diorite underlying the Yukon River Valley in an area approximately 17 by 4 miles as interpreted from airborne magnetic data; (GSC Maps 3376G, 3377 G, 11341 G) the Mount McIntyre intrusion which includes Mount Granger and Golden Horn Mountain and which is roughly 11 miles in diameter as expressed by magnetic data and, the Northwestern intrusion which underlies Haekel Hill, the Jackson Creek area, and Mount Ingram. The magnetic data suggests that only northeast of Fish Lake and at Canyon Mountain is the sedimentary cover more than 3000 feet thick over the intrusions.

The copper occurrences are associated with the upper limestone of the Lewes River Group where it overlies, is enclosed within, and intruded by the west side of the Copper Belt intrusion or Whitehorse batholith (figure 5). The copper occurrences cluster into a northern group (Group 1) near the postulated junction of the Whitehorse batholith with the Northwestern intrusion, a central group (Group 2) near the contact between the Whitehorse batholith and the Mount McIntyre intrusion, and a Group 3 in the southern part of the Whitehorse batholith. All three groups at local magnetic highs (G.S.C. Maps 3376 G, 3377 G, 11341 G.)

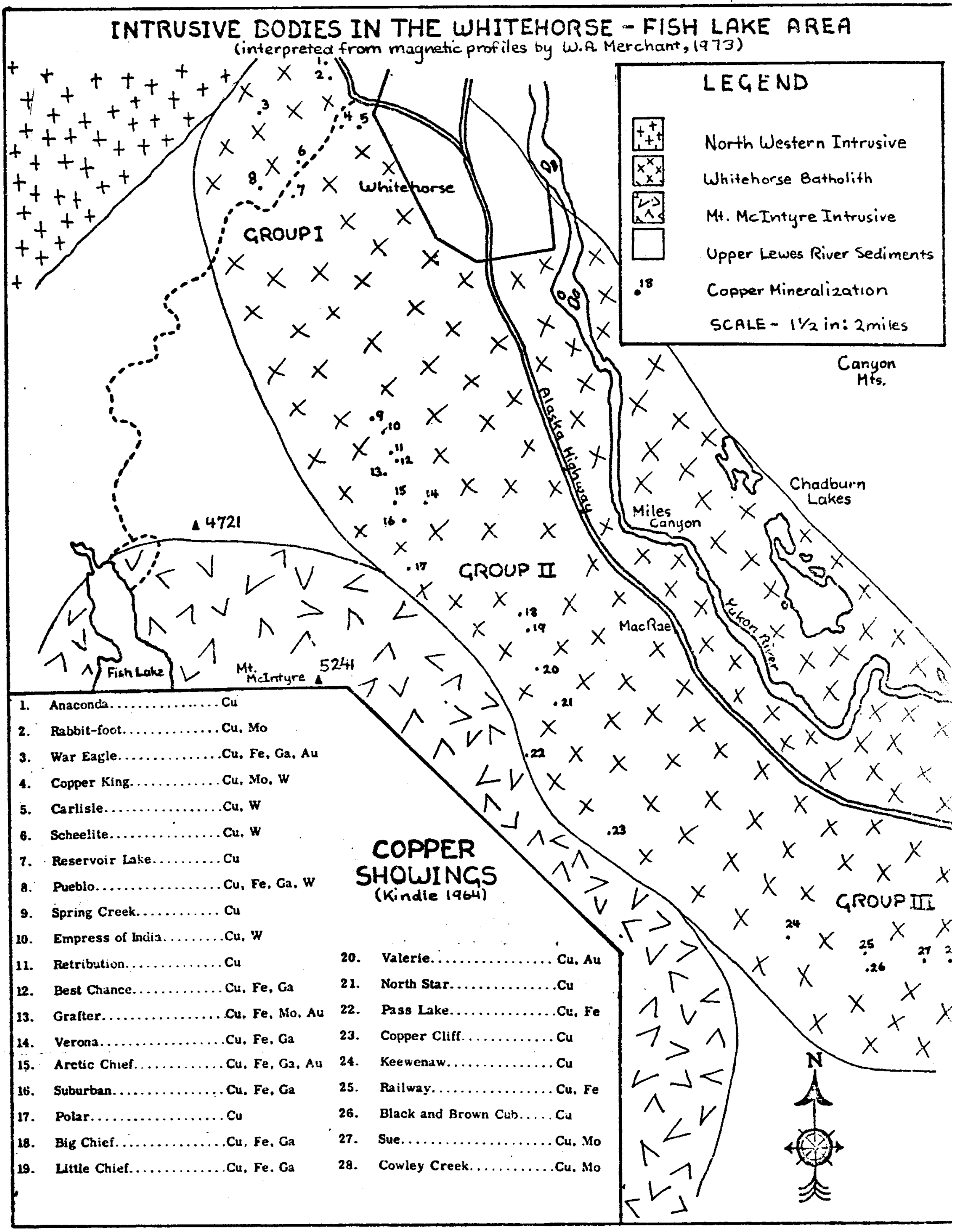

INTRUSIVE BODIES IN THE WHITEHORSE - FISH LAKE AREA
(interpreted from magnetic profiles by W.A. Merchant, 1973)
LEGEND
North Western Intrusive
Whitehorse Batholith
Mt. McIntyre Intrusive
Upper Lewes River Sediments
Copper Mineralization
SCALE - 1½ in: 2miles
Whitehorse
GROUP I
GROUP II
GROUP III
Alaska Highway
Yukon River
Miles Canyon
MacRae
Chadburn Lakes
Canyon Mts.
4721
5241
Mt. McIntyre
Fish Lake
N
COPPER SHOWINGS (Kindle 1964)
1. Anaconda.................Cu
2. Rabbit-foot.............Cu, Mo
3. War Eagle..............Cu, Fe, Ga, Au
4. Copper King............Cu, Mo, W
5. Carlisle.................Cu, W
6. Scheelite................Cu, W
7. Reservoir Lake..........Cu
8. Pueblo...................Cu, Fe, Ga, W
9. Spring Creek............Cu
10. Empress of India.........Cu, W
11. Retribution..............Cu
12. Best Chance.............Cu, Fe, Ga
13. Grafter..................Cu, Fe, Mo, Au
14. Verona...................Cu, Fe, Ga
15. Arctic Chief.............Cu, Fe, Ga, Au
16. Suburban.................Cu, Fe, Ga
17. Polar....................Cu
18. Big Chief................Cu, Fe, Ga
19. Little Chief.............Cu, Fe, Ga
20. Valerie..................Cu, Au
21. North Star...............Cu
22. Pass Lake................Cu, Fe
23. Copper Cliff.............Cu
24. Keewenaw.................Cu
25. Railway..................Cu, Fe
26. Black and Brown Cub.....Cu
27. Sue......................Cu, Mo
28. Cowley Creek.............Cu, Mo

FIG.5

Petrography

The Whitehorse batholith is essentially a quartz diorite in which hornblende predominates over biotite. The rock is massive, mesocratic and mottled with white and dark green coloured patches caused by aggregates of hornblende and plagioclase. The texture is hypidiomorphic inequigranular with anhedral grains of quartz, biotite, and sphene interstitial to interlocking subhedral grains of plagioclase and hornblende. Large plagioclases are zoned from andesine to oligocene. Small grains are unzoned and of similar composition and they coalesce into clots 1cm. in diameter. Hornblende occurs as solitary grains with green to brown pleochrism that are randomly oriented and evenly distribution throughout the rock. A few outcrops are porphyritic with coarse hornblende phenocrysts. Orthoclase may be a minor component and is frequently in myrmekitic intergrowth with quartz, it may be altered to sericite, epidote and clay minerals. Magnetite is the most abundant accessory mineral and is disseminated through the rock.

Variations are noted as in sample G-25h which is a hornblende diorite with relict augite and only 4% interstitial quartz. Specimen G-36 had 10% quartz and 10% hornblende. Trace element content does not vary appreciably however and fresh rock generally contains about 20 ppm Cu, 15 ppm Pb, and 45 ppm Zn. Fractures are commonly coated with potash feldspar and, chloritic and sericitic alteration along fractures is characteristic. Potash feldspar replaces plagioclase in antipertitic intergrowth (Specimen G-35) and in this instance the rock contains anomalously high copper and zinc values.

Age of the Whitehorse batholith is problematical until some radiometric determinations are completed. The rock has been mapped as Cretaceous and of Coast Range affinity (Wheeler, 1961). It could however be as old as Upper Triassic and co-magmatic with the volcanic rocks of the Lewes River group.

The Mount McIntyre intrusion is a distinctive red brown coloured quartz monzonite which is isotropic, homogeneous, and medium grained. The essential minerals are colourless and smoky quartz, perthitic potash feldspar slightly kaolinized, and a sodic plagioclase that is normally zoned. Actinolitic-hornblende, and epidote, are less abundant and magnetite and pyrite are accessories. Rock similar to the Mount McIntyre intrusion were observed by Wheeler crosscutting foliated granodiorite and Hutshi group volcanic rocks and he inferred a mid-Cretaceous age (Wheeler, 1961, p. 99).

The Northwest intrusion exposed on the south side of Haekel Hill and in the Mount Ingram area is typically a medium to coarse grained biotite granite but some phases are biotite granodiorite. Biotite predominates over hornblende and the rock may be either porphyritic or equigranular and foliated or non-foliated. Isotropic specimens have hypidiomorphic granular textures with euhedral and subhedral grains of plagioclase and mafic minerals and anhedral grains of quartz and potash feldspar. The plagioclase is commonly zoned and saussauritized and the potash feldspar is turbid with clay minerals. The mafic minerals are slightly chloritic. Accessory minerals include magnetite, zircon, leucoxene, sphene, apatite and locally allanite. The more lecocratic varieties may contain muscovite, smoky quartz and fluorite. Porphyritic specimens have potash feldspar phenocrysts randomly oriented in a medium to coarse grained hypidiomorphic granular matrix. Where a foliation is present it is defined by alignement of mafic minerals and small lenses of quartz.

Rocks of the Northwest intrusion are comparable to rocks described by Wheeler from a large area of granite in the west part of the Whitehorse map area (Wheeler, 1961), pages 92 & 100). A potassium-argon age determination of similar rock in this area gave 223 million years (Gabrielse, 1967, p. 286). Field relationships are not definitive as to age. Contacts between the intrusion and the volcanic rocks of the Lewes River group on the north side of the Ibex River across the valley from Mount Ingram are remarkably passive suggesting perhaps a rather close relationship between the outpouring of the volcanic rocks and emplacement of the batholith.

<u>Contact phenomena</u>

Skarn of lime-silicate materials, with or without magnetite, and copper sulphide minerals occur sporadically at the contact of the Whitehorse batholith with limestone of the Lewes River group bearing the Spondylospira lewesensis fauna. Plate 7 and figure 6 illustrate skarn development in the War Eagle pit, where a relatively thin bedded

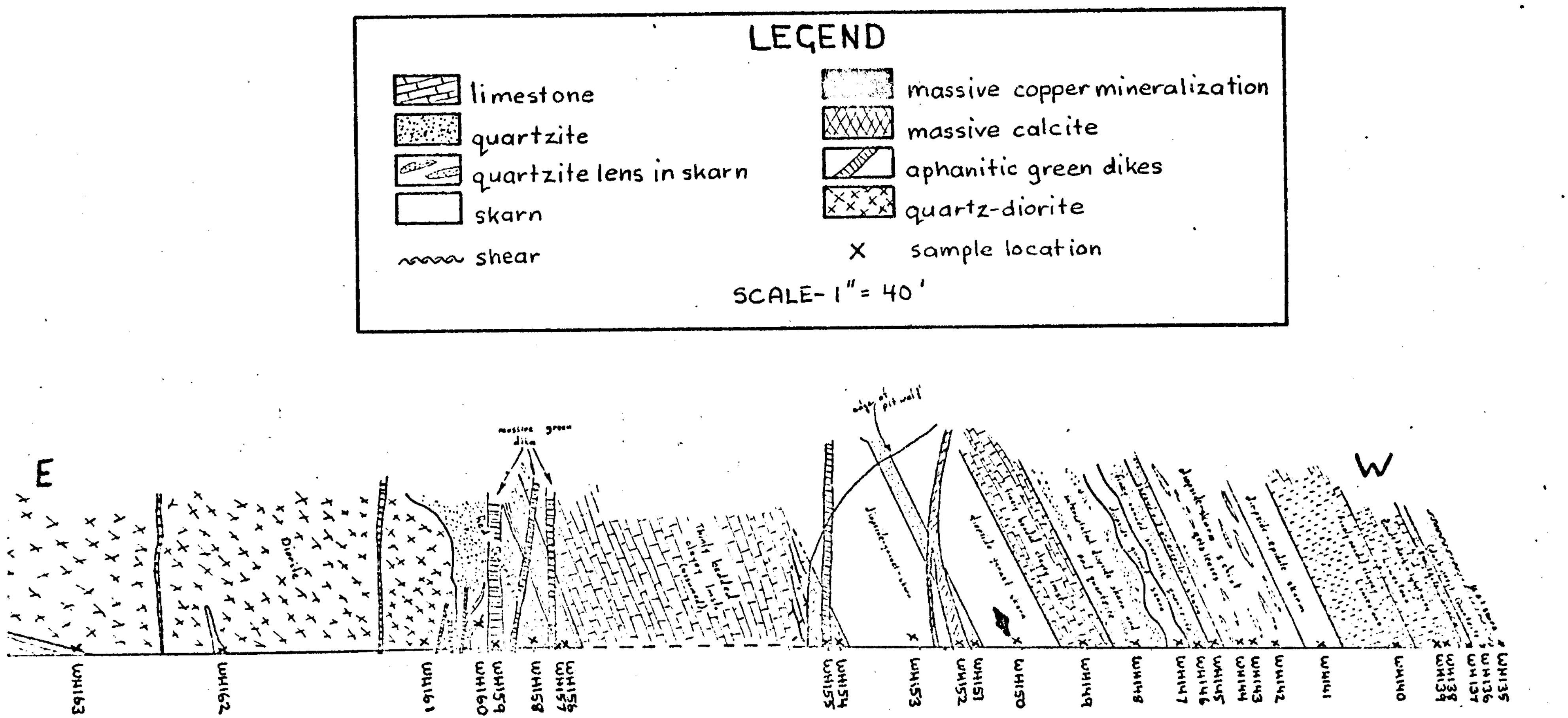


FIG. 6 DETAILED MAPPING OF THE SOUTH FACE OF WAR EAGLE PIT, WHITEHORSE COPPER BELT

sequence of quartzite and marble had been hornfelsed and selectively replaced by skarn minerals adjacent to the quartz diorite of the Whitehorse batholith. Apophyses of the batholith crosscut the layered sequence and the batholith includes zenoliths and rafts of the layered rocks. Andesite dykes crosscut both the layered rocks and the batholith near the contact. Marble and dolomitic marble contain minor tremolite, diopside, wollastonite and lesser magnesite and periclase. Where the carbonate rocks have been completely replaced the assemblage may be diopside-garnet, epidote-garnet, diopside-epidote, garnet-diopside-tremolite, and garnet-diopside-wollastonite. Massive skarn is often very inhomogeneous and contains irregular patches of monomineralic garnet, epidote, and diopside. Such rock often contains pyrite, chalcopyrite, bornite, chalcocite, and magnetite intergrown with quartz and calcite. The skarn may be fractured into a stockwork pattern and fractures coated with garnet-tremolite and quartz-calcite-epidote. Fractures may also contain sulphide minerals and magnetite. Quartzite members always contain disseminated pyrite and in some instances chalcopyrite.

In general through skarnification the carbonate rocks tend to become very coarse grained and characterized by large monomineralic masses of pyroxene, garnet, serpentine, magnetite and sulphide minerals. A tentative progression of skarn development in calcic (A) and dolomitic (B) strata is as follows:

Plate #7 Interbedded anhydrous skarn and carbonaceous sediments in the War Eagle pit.

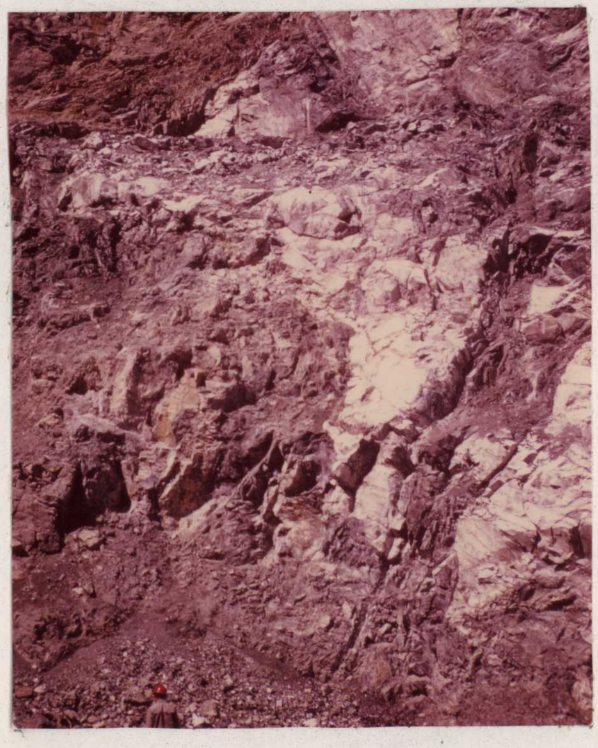


Plate #8 Hydrous skarn replacing limestone in the Little Chief pit.

(A)

marble → diopside ± vesuvianite → diopside + unzoned garnet

→ zoned garnet → zoned garnet + copper-iron min. → massive garnet + mineralization

(B)

dolomite marble → periclase, brucite, dolomite, calcite → serpentine, magnetite → magnetite, copper min.

Plate 8 illustrates the replacement of carbonate by massive serpentine skarn in the Little Chief Pit. Grabher (1973) describes the mineralogy and sequence of events for the Little Chief mine as follows:

> "Most of the massive skarn is believed to have resulted from a major bimetasomatic (after Korzinskii and others) event, caused by the differential migration of Mg, Fe, S, Cu, Si and Al into the limestone and the migration of Ca, K and Na outward. This caused the formation of a zoned skarn in the contact zone with the following sequence:
>
> Zoned Skarn Sequence
>
> 1) Marble ± pyroxene
> 2) Clinopyroxene + minor garnet and magnetite
> 3) Clinopyroxene + garnet (± garnet veins)
> 4) Clinopyroxene + zoisite ∓ garnet (± garnet veins)
> 5) K-spar + plagioclase + quartz ± magnetite and epidote
> 6) Granodiorite to diorite (± garnet and epidote veins)
>
> Boundaries between zones aren't always distinct, and in particular the K-spar zone is not continuous. Thin section evidence points to the presence of an early clinopyroxene (Di?) and Orthopyroxene being replaced by later, granular clinopyroxene (Hd?) and andradite garnet, indicating Mg skarn minerals being superceded by later Fe-rich skarn.

Ore minerals, from available evidence, were introduced in two stages. Present in magnetite concentrations near original limestone boundaries as inclusions are cpy and cpy-bor or cpy-digenite grains, generally quite small (.1 - .01 mm) in size. These are believed to be early grains with chalcocite-bor or bor-cpy intergrowths since altered to cpy and digenite, in part by later mineralization involving fresh eutectic-type intergrowths of bor-chalcocite, which are larger in size and replace early magnetite grains or are molded onto them, and are most abundant in the pyroxene-rich zones 2 and 3. A later mineralizing event is chosen to explain the massive and vein-type cpy, py and pyrrhotite mineralization cross-cutting or replacing other skarn phases and associated with the contact zones between granodiorite and skarn with garnet and epidote veins. Granodiorite and diorite near the contact also contains disseminated pyrite, with cpy in clots, while at more distant locations the granodiorite holds disseminated magnetite.

Both ore events are associated with a hydrous Fe alteration assemblage which includes actnolite, biotite, chlorite and especially epidote. Veins of bor-cpy are surrounded by a halo of epidote, and bor occurs with epidote crystals cutting pyroxene skarn along fractures. A few quartz-cpy-epidote veins with alteration halos of amphibole and chlorite also occur.

The final events in the contact zone were hydrous alteration of pre-existing skarn, possibly with the addition of Mg, to serpentine, talc, chlorite and spinel; also seemingly controlled by contact of skarn and granodiorite and associated with the formation of calcite veins which cut all units in pit. Occasionally ore minerals occur in these veins, but their contribution is minor.

Secondary replacement of original Cu-sulfides has occurred to a minor extent, with secondary cpy, chalcocite and digenite occurring in serpentinized areas, along with valleriite-pyrite. Valleriite surrounds bits of bor-cpy in serpentine, and where the whole rock has gone to serpentine, valleriite occurs with pyrite."

DISCUSSION

Copper occurrences of the Whitehorse copper belt and occurrences of similar character elsewhere, particularly in the Triassic of the Canadian Cordillera (Eastwood, 1965, Sangster 1969) are generally attributed to metasomatism of limestone by hydrothermal fluids emanating from an intruding magma. Metal, sulphur, and transporting fluids are believed derived from and concentrated in the magma during late stages of magmatic differentiation and crystallization. Deposition of sulphide minerals from the transporting fluids is in response to decreasing temperature and pressure and, chemical changes upon meeting the reactive limestone.

However, in the occurrences of the Whitehorse copper belt and others of this nature which we have examined, the immediately adjacent pluton may be quite variable in composition and form but the sulphide mineral deposit is invariably stratabound in relatively thin bedded, dolomitic, bioclastic and algal limestone with intercalated limy shale, and micritic mudstone. These strata are underlain and overlain by red volcanoclastic and clastic rocks isolated geographically and stratigraphically in a predominately volcanic terrain intruded by plutons which are probably comagmatic with the volcanic rocks. The carbonate rock enclosing the deposits is a common denomenator to these deposits and is comparable to present day sabka or subaerial evaporite mud flats. Forming along the edges of some regressive seas (Renfro, 1974). These merge seaward into intertidal mud flats and algal mats overlying an ooze of decaying algae in which hydrogen sulphide is generated. Interstitial brine, which can leach minor amounts of metal from the underlying volcanic and volcanoclastic rock, must rise through the reducing environment of decaying algae to reach the evaporation surface. Sulphide minerals may be deposited in strata-bound configuration within that reducing environment. Initial metal concentration may therefore be dependant upon sedimentation and lithification and secondarily on reconsitution through metamorphism by an intrusion which follows closely on the heels of the volcanism.

Perhaps the orthomagmatic model of genesis has been overemphasized in explaining distribution of skarn-type copper deposits and the time has come to consider the importance of the total geology to localization and hence, to exploration for additional deposits.

APPENDIX A

Volcanic Rocks in the
Ibex River, Fish Lake
and Little Chief Mine
Area.

Petrography by N.A. Duke

Sample - WH - 17   Andesitic Tuff

Petrography

A fine-grained yellow-green clastic. The matrix is quite cherty and supports fine saussauritized feldspar grains and black magnetite flecs. This material surrounds rounded and diffuse zenoliths of more porphyritic rock of similar composition. The test with HCl is negative.

In section the rock is composed of euhedral intermediate fledspar crystals and subhedral to subrounded pyroxene (diopsidic-augite) in a very fine crypto-crystalline quartzo-feldspathic matrix. Feldspars are zoned and are more or less altered to epidote and clay minerals. Zenoliths are vaguely outlined by an increase in epidote alteration and magnetite near their borders. They are commonly composed of euhedral feldspars in random orientation with intersticial quartz. Others contain fragmented hornblende and pyroxene phenocrysts which may show hematitic borders. Rarely quartz-calcite veins are observed crosscutting matrix and crystals.

Mode

feldspar	60%
quartz	20%
diopsidec-augite	10%
iron oxide	8%
hornblende	2%

Comments

The rock is of pyroclastic origin; possibly derived by sedimentary canabalism of crystal tuff horizons during weathering. Much of the material deposited was quite siliceous and gives rise to a fine impalpable matrix supporting larger zenolithic fragments of tuff and porphyry. The rock has been extensively hydrothermally altered with feldspars going to clay and epidote and the mafics show moderate chlorization.

Sample - WH - 23 Porphyritic Tuff (andesitic)

Petrography

A fine-grained red porphyritic rock in which irregular shades of red define an inhomogeneous matrix. Phenocrysts are small (2mm) euhedral feldspars and irregular zenolithic fragments are observed. The rock is non-magnetic and slightly calcareous.

In section the rock consists of a fine cryptocrystalline quartzitic or cherty matrix with inhomogeneously distributed hematite concentrations. In isolated areas hematite replaces quartz as matrix material. The phenocrysts are highly fragmented, zoned-feldspar altered to calcite and clay minerals. There is minor hornblende with chloritic alteration. Boundaries between matrix and zenoliths are distinct with acicular hornblende sometimes occuring along grain boundaries.

Mode

feldspar	55%
quartz	15%
hematite	10%
hornblende	10%
chlorite	5%
calcite	5%

Comments

The rock is a crystal tuff with evidence of crystal growth in situe (hornblende) and possibly formed by accumulation of crystals during ash fall into andesitic flow.

Sample - WH - 25 Hematitic Tuff

Petrography

Fine-grained red rock containing hematitic clasts. Isotropic and homogeneous with a few pyroxene crysts. Slightly magnetic and very slightly calcareous.

In section large (5mm) pyroxene grains show varying degrees of replacement to epidote and hematite. Often hematite rims remnant pyroxene (diopsidic-augite). The matrix consists of a fine fragmental to clastic intergrowth of angular feldspar shards somewhat altered to clay and calcite. Hematite occurs throughout the matrix however is concentrated near relict pyroxene.

Mode

quartz	10%
feldspar	50%
pyroxene	15%
hematite	15%
epidote	5%
calcite	5%

Comments

The rock is tuffaceous in origin - possibly an accummulation of ash in or oxidizing environment (emergent land mass). Zoned pyroxene and feldspar indicates changes in magma composition during crystallization. The rim replacement of pyroxene by hematite may signify circulating ground waters.

Sample - WH - 48 Crystal Tuff

Petrography

A fine-grained purple-red rock containing irregular patches of hematite. A few black crystal fragments are visible in hand specimen. Quite magnetic and very slightly calcareous.

In thin section the rock is composed of slightly oriented euhedral zoned-feldspar, generally kaolinized, and fresh euhedral pyroxene (diopsidic-augite) often twinned and showing hour glass structure. There is much evidence for large irregularly rounded cavities within this matrix (cryptocrystalline quartz-feldspar) which are now filled with hematite, chelcedony and chlorite (penninite).

Mode

quartz	5%
feldspar	65%
pyroxene	15%
hematite	10%
epidote	3%
chlorite	2%

Comments

A crystal tuff composed of feldspar and pyroxene which was rather loosely consolidated before quartz and hematite cemented the crysts and migrated into miarolitic cavities and causing breakdown of the feldspars.

Sample - WH - 87   Tuff

Petrography

A medium-grained mottled rock composed of euhedral feldspar crysts (1-2mm) interspersed with rounded dark-grey clasts. Quite granular in texture. The rock is slightly magnetic and effervesces moderately when tested with dilute HCl.

In section the rock exhibits fresh to completely altered feldspar and pyroxene in a granulated quartz-feldspar-chlorite matrix in which acicular actinolite, chalcedony, ragged calcite patches and hematite occur.

Mode

feldspar	35%
pyroxene	20%
matrix	30%
actinolite	5%
hematite	5%
quartz	5%
epidote-chlorite	5%

Comments

This rock is likely a tuff that was reworked through sedimentary processes and later subjected to thermal metamorphism.

Sample - WH - 88 Tuff

Petrography

A fine-grained brown-grey clastic showing small white crysts in an inhomogeneously coloured and fragmental matrix. There appears to be a concentration of hematite near the borders of fragments. The rock is non-magnetic and non-calcareous.

In section the rock consists of fragmented feldspar grains which are zoned and quite fresh. These are suspended in a green-yellow chloritic matrix containing granulated and highly altered hornblende with irregularly distributed hemolite.

Mode

quartz	2%
feldspar	70%
hornblende	10%
hematite	5%
chlorite	15%

Comments

The rock is a tuff with an interesting matrix. There is a slight suggestion of oolitic growth with chlorite as the predominant constituent. Perhaps a rock derived from winnowing out of the mafic constituents as very fine debris by oxygenated groundwaters during ash fall.

Sample - Wh - 89 Tuff

Petrography

Somewhat similar to WH-87. A light grey fine-grained rock composed of dark rounded clasts in a light grey matrix. The rock is non-magnetic and very calcareous.

In section this rock is similar to WH-87 with much sparry calcite growth. The fragmented feldspar fragments have extinction angles indicating a plagioclase content of An44.

Mode

quartz	10%
calcite	20%
hematite	5%
feldspar	50%
pyroxene	15%

Comments

This rock has a similar origin to WH-87. Likely a reworked andesitic tuff deposited in a chemical sedimentary environment and metamorphosed.

Sample - WH - 92 Reworked Tuff

Petrography

A yellow-grey mottled rock which is fine to medium-grained with rounded feldspar clasts (2-3mm) in a fine-grained grey matrix. The rock is isotropic, homogeneous, non-magnetic and slightly calcareous along fractures.

In section the rock is composed of large feldspathic zenoliths of crystal tuff (similar to WH-17). The matrix between rounded clasts are filled with sparry calcite, penninite (in radiating growths) and very fine cryptocrystalline quartz.

Mode

quartz	10%
feldspar	40%
pyroxene	10%
hornblende	10%
epidote	5%
chlorite	5%
hematite	acc.

Comments

This rock formed by sedimentary canabalism of unconsolidated tuffaceous material. Interstices and cavities were infilled by quartz (as chalcedony) and calcite precipitating out of percolating fluids which also caused hydrothermal alteration of the existing mineralogy. Metamorphism caused recrystallization and porphyroblastic grain growth.

Sample - WH - 98   Impure Pyritic Chert

Petrography

A very finely laminated rock showing development of sparry calcite. The rock is pale grey in colour, disseminated with pyrite, non-magnetic and non-calcareous except in areas showing sparry calcite growth.

In section the rock consists of cryptocrystalline brownish-coloured quartz disseminated by pyrite. Near sparry calcite large poikiloblasts of actinolitic-hornblende occur in random orientation. Pyrite may also show porphyroblastic tendencies and in places coalesce into ragged cubes. Laminations are discontinuous and defined by brown colouration and variation in pyrite content. Layers devoid of pyrite show sericite growth indicating the matrix is a very fine clay-quartz.

Mode

quartz	60%
clay	20%
pyrite	10%
calcite	5%
hornblende	5%

Comments

This rock is a calci-clay chert which originated under reducing conditions. It was later metamorphosed which caused recrystallization and porphyroblastic growth of pyrite and actinolitic-hornblende near areas of sparry calcite growth.

Sample - WH - 99 Impure Tuff

Petrography

A medium-grained, grey-white mottled rock composed of white feldspathic clasts in a dark grey matrix. Small fractures exhibit iron staining. The rock is non-magnetic and non-calcareous.

In section fragmented zoned feldspar grains occur in a fine quartz-clay matrix. The matrix material has undergone extensive porphyroblastic recrystallization to actinolitic-hornblende and the rock often appears with fragmented feldspars enclosed by amphibole. Twins in feldspar are often deformed and many grains are unzoned. Twin measurements indicate a plagioclase content of An30.

Mode

quartz	20%
clay	20%
feldspar	50%
actinolite	10%
opaques	acc.

Comments

This rock is a highly recrystallized quartzo-clay tuff as may be produced by winnowing of a very fine-grained ash fall. Metamorphic recrystallization is restricted to the matrix.

Sample - WH - 101   Myrmekitic Tuff

Petrography

A light reddish-brown fine to medium-grained rock showing light and dark coloured clasts in a fine-grained matrix. It is particularly isotropic and homogeneous in appearance. The specimen is quite magnetic and non-calcareous.

In section equant and euhedral zoned feldspar grains are suspended in myrmekitic quartz-feldspar intergrowth. Often the borders of the feldspar grains are scalloped with myrmekite. Actinolitic-hornblende also occurs as an interstical phase and sometimes as acicular porphyroblasts.

Mode

quartz	10%
feldspar	85%
actinolite	5%
magnetite	acc.

Comments

This rock could be a crystal tuff similar to WH-99 however consisted of closely packed feldspar grains and little matrix material. During metamorphism the quartzo-feldspathic components reacted to recrystallize as myrmekite. In areas of minor calcite actinolitic-hornblende grew as porphyroblasts. It is also possible the feldspars and myrmekite are igneous in origin and the rock is a sill or flow.

Sample - WH - 115 Quartz Hornblende Diorite

Petrography

A dark green and white mottled rock with inhomogeneous distribution of felsic and mafic constituents. It has a gabbroid texture where there is a concentration of feldspar. The mafic regions are quite fine-grained, very magnetic and has a positive reaction to HCl only along minute fractures.

In section the rock consists of medium and fine-grained areas of intergrown euhedral hornblende and subhedral to anhedral zoned feldspar and quartz. Amphibole is generally fresh and unaltered except where it is completely replaced by penninite and calcite. Feldspars are usually altered to calcite, epidote and clay.

Mode

feldspar	65%
hornblende	30%
quartz	5%
magnetite	acc.

Comments

The rock is a quartz, hornblende diorite showing what could be interpreted as effects of complete assimilation which result in the heterogeneous nature and varying texture.

Sample - WH - 197 Porphyritic Andesite

Petrography

A dark melanocratic porphyry with large (.5cm) phenocrysts of pyroxene occuring in a dark slate-grey matrix. The rock is non-magnetic.

In section large augite and, more rarely, hornblende crystals lie in a fine-grained matrix of interlocking subhedral plagioclase. The mafics sometimes occur in polycrystalline aggregates and are usually anhedral and rounded in shape. Borders of phenocrysts are ragged and show a concentration of epidote. Penninite often develops along fractures across the mafic grains and chlinochlore occurs in vesicules within the matrix.

Mode

quartz	2-3%
feldspar	80%
epidote	2-3%
augite	10%
hornblende	5%

Comments

The rock is a porphyritic andesite which shows characteristics which may be expected in a thick flow.

Sample 204 Porphyritic Tuff

Petrography

A mesocratic porphyry with light green phenocrysts (1 cm) and dark green crysts (.3 cm) occurring in a brown fine-grained matrix. The rock is quite magnetic and moderately calcareous.

In section large phenocrysts of fresh poikilitic diopside and smaller completely altered feldspar occur in a very fine quartzo-feldspathic matrix in which hematite and magnetite are disseminated. Borders on the pyroxene grains are sharp. Calcite and an emerald-green mineral, possibly a chlorite or an organic iron compound occur locally in the ground mass.

Mode

matrix	50%
pyroxene	20%
feldspar	20%
Iron oxide	10%

Comments

This rock is problematic in origin as it shows traits attributable to both intrusive and pyroclastic processes. The large unfractured diopside and feldspar grains suggest an igneous origin. The fine clastic nature to the matrix and the occurence of ground mass hematite indicates a tuffaceous origin.

APPENDIX B

Petrography and Chemical Analyses of Selected Specimens from the Whitehorse Copper Belt

Petrography by N.A. Duke

(Sample locations are plotted on map inside of back cover.)

Sample - G - 1 Quartz Diorite

Petrography

In hand specimen the rock is fine to coarse grained with large (.5cm) hornblende grains and smaller (.2cm) white feldspar crysts inhomogeneously distributed in a light grey quartzitic matrix. Garnet is an accessory observed in the hand specimen and occurs within the matrix material. The rock is quite magnetic and shows good chlorite alteration with disseminated pyrite along fractures.

In section the rock exhibits an allotriomorphic inequigranular texture. Plagioclase grains are normally zoned An40 - An20 with the more calcic cores commonly altered to clay minerals and sericite. The larger plagioclase grains tend to be subhedral in shape, however grain boundaries are seriate and polygonized. Hornblende occurs in large poikilitic grains and in polymineralic aggregates with biotite, sphene, magnetite, apatite and chlorite. The ground mass is composed of a polygonal aggregate of quartz, feldspar and biotite.

Mode		Description
plagioclase	50%	subhedral - anhedral
hornblende	25%	subhedral - anhedral
quartz	15%	intersticial ground mass
biotite	5%	anhedral in ground mass
chlorite	2%	alteration of hornblende
sphene	acc.	
apatite	acc.	associated with mafic aggregate in quartzitic ground mass
garnet	acc.	
magnetite	3%	
pyrite	acc.	

Comments

The rock is a quartz diorite that has likely been subject to contamination by assimilated wall rock. Its inequigranular nature and inhomogeneous mineral distribution is indicative of local variance in the composition of the melt from which it formed. Much of the quartz matrix may be attributed to metasomatic processes and on introduction the quartzitic material reacted with existing feldspar grains causing embayed borders. The alteration of the feldspars to clay and sericite plus the occurrence of chloritized fractures is likely hydrothermal.

Sample G-7 Dacite Porphyry

Bulk Chemical Analysis

SiO_2	70.50
Al_2O_3	13.87
TiO_2	.34
Fe_2O_3 Total	3.38
MnO	.01
MgO	1.40
CaO	2.80
Na_2O	3.40
K_2O	3.20
P_2O_5	.103
L.O.I.	.60
Total	99.63

Trace Elements

Cu	19
Pb	14
Zn	20
Ag	1
Au	.000

Petrography

A light grey, fine-grained porphyry consisting of chalky-white, euhedral feldspar phenocrysts and dark green, subhedral, chloritized amphibole phenocrysts in a quartzitic matrix. Small concentrations of chalcopyrite are observed associated with the chloritized amphibole. Moderately magnetic.

In thin section the rock consists essentially of quartz-feldspar; minor minerals include chlorite, hornblende, sphene, epidote, biotite, chalcopyrite, magnetite, sericite and clay minerals. The texture is porphyritic with zoned feldspar phenocrysts in an annealed quarzitic matrix.

Mode	Description
quartz	55% strained anhedral grains with sericite borders
feldspar	35% zoned phenocrysts, highly altered to kaolin and sericite. Twin measurements give An_{20}
chlorite	4% pale green chlinochlore, secondary after hornblend + feldspar
hornblende	3% green brown pleochroism - highly altered to chlorite
sphene	1% unaltered subhedral grain associate with magnetite
epidote	alteration product of feldspar
biotite	1% associated with chlorite alteration
chalcopyrite	anhedral grains associated with ferromagnesian minerals
magnetite	subhedral grains with sphene and anhedral grains with chloritic alteration

Comments

As indicated by both its chemical analysis and petrographic nature this rock is dacitic in composition. The specimen shows a great deal of alteration, probably due to hydrothermal alkali metasomatism causing breakdown of the normally zoned oligoclase to andesine phenocrysts to clay minerals, sericite mica epidote and chlorite. Much of the quartz matrix may also have been introduced metasomatically, in some cases reacting with the borders of the feldspars and developing a mortar texture between feldspar and recrystallised quartz. The anhedral altered aggregates of ferromagnesian minerals suggests these crystallized with quartz. Evidence suggest a late stage intrusion which has undergone hydrothermal alteration.

Sample G-8 Diopside-Garnet-Skarn

Bulk Chemical Analysis

SiO_2	37.34
Al_2O_3	7.82
TiO_2	.28
Fe_2O_3 Total	17.85
MnO	.21
MgO	1.90
CaO	32.20
Na_2O	3.30
K_2O	.98
P_2O_5	.106
L.O.I.	1.57
Total	100.95

Trace Elements

Cu	.33%
Pb	20
Zn	35
Ag	5
Au	.000

Petrography

In hand specimen this rock is buff-brownish-green and composed of large interlocking zoned garnets separating irregular phases that are garnet free and calcite rich. Commonly the garnet cores are a dark green-brown and this is surrounded by light buff brown zone which may be rimmed by dark brown outer zone. The rock is non-magnetic. Accessory amounts of valleriteand chalcopyrite occur interstitial to the zoned garnets.

Microscopic observation confirms the highly interlocking texture of the zoned garnets. Diopside pyroxene is liberally disseminated throughout with no indications of local concentrations. Calcite, the only other mineral observed in thin section occurs in irregular patches between intergrowths of zoned garnet. Accessory opaque minerals are associated with calcite.

Mode	Description
garnet (Andradite-Grossular)	85% zoned and anomalously birefringent
diopside	12% rounded anhedral grain
calcite	3% large optically continuous grains poikiolitically enclosing diopside and opaques
opaque	accessory

Comments

This rock is a diopside-garnet skarn with little evidence remaining which is suggestive of the parent rock. The nature of the rock would suggest a fairly homogeneous liquid of the composition as shown. Small (.5 mm) diopside grains crystallized and these were later poikiolitically included in large garnet, calcite grains. Local fluctuations in the chemistry of the metasomatic fluid caused zonation of the garnets.

Sample G-9

Bulk Chemical Analysis

SiO_2	43.08
Al_2O_3	9.50
TiO_2	0.38
Fe_2O_3 Total	3.68
MnO	2.20
MgO	.09
CaO	38.00
Na_2O	0.42
K_2O	0.38
P_2O_5	0.48
L.O.I.	1.85
Total	99.62

Trace Elements

Cu	.35%
Pb	22
Zn	48
Ag	5
Au	.000

Petrography

This rock is a very inhomogeneous, composed of light buff-grey and dark green-brown phases. The green-brown areas are essentially similar to sample G-8 however here the diopside garnet skarn contains large (1 cm.) bornite, chalcopyrite concentrations interstitial to zoned garnets. Contacts between the garnet rich skarn phases and the light buff grey areas are irregular with diopside garnet skarn projections into and apparently replacing the lighter rock.

In this section the rock shows two stages of metasomatism. The later stage of diopside-zoned garnet skarn is replacing diopside-unzoned garnet-vesuvianite skarn with which slightly more calcite is associated. The mode of the latter is given below.

Mode	Description
garnet unzoned	60% many minute diopside, epidote, vesuvianit inclusions
diopside	25% generally small irregular shaped grains
vesuvianite	15% unzoned, low birefringence, small 2v. altered to diopside + garnet
quartz	acc. observed rimming opaques
opaques	acc. large anhedral grains

Comments

The relationships between different skarn assemblages are obscure however it would appear that the skarn having large zoned garnets and the copper mineralizatio is latest, or at least the most altered with respect to the parent rock which has been replaced. This would indicate the diopside-unzoned garnet-vesuvianite skarn reflects the original composition closer than the diopside zone-garnet-skarn and may indicate a clayey limestone as a source for metasomatic fluids (ie. such as could be originated from stoped and partially or wholely fused sedimentary rafts by the igneous intrusion.

Sample G-10 Grey Marble

Bulk Chemical Analysis

SiO_2	5.20
Al_2O_3	0.75
TiO_2	0.05
Fe_2O_3 Total	.50
MnO	.02
MgO	1.60
CaO	51.80
Na_2O	0.43
K_2O	0.20
P_2O_5	0.028
L.O.I.	40.12
Total	100.69

Trace Elements

Cu	7
Pb	36
Zn	16
Ag	3
Au	.000

Petrography

A slate-grey, crystalline, medium-grained rock composed of calcite. No relict structures are observed.

The texture is crystalline, with interlocking elongate crystals giving a dimensional preferred orientation (granoblastic-elongate texture). Individual grain boundaries are irregular to sinuous. Accessory minerals are disseminated throughout and consist of minute granules of diopside and possibly a few small grains of zoned vesuvianite. A minute veinlet of quartz crosscuts the preferred orientation of the calcite grains.

Mode		Description
calcite	98%	granoblastic-elongate
diopside	2%	small rounded grains
vesuvianite	acc	small grains of high relief and low birefringence

Comments

This rock probably formed by completely recrystallising a limestone with no addition or loss of material apart from a very late introduction of quartz along minute fractures. It is interesting that the rock should have a preferred orientation of the calcite grains. This may reflect a directed pressure variable during recrystallization or possibly original compositional inhomogeneities of the limestone controlled the recrystallization. i.e. the elongate calcites grew preferentially along bedding.

Sample G-11 Marble

Bulk Chemical Analysis

SiO_2	5.36
Al_2O_3	0.54
TiO_2	0.04
Fe_2O_3 Total	0.52
MnO	.01
MgO	1.08
CaO	50.92
Na_2O	1.66
K_2O	0.10
P_2O_5	0.059
L.O.I.	39.67
Total	99.96

Trace Elements

Cu	10
Pb	4
Zn	14
Ag	0
Au	.000

Petrography

A fine-grained, white, crystalline rock crosscut, into angular zones, by irregular grey phases and minute intersecting fractures. The rock is composed of calcite, is non-magnetic and has trace amounts of chalcopyrite (one small grains was observed).

Texturally the rock is similar to G-10 however the calcite grains do not show such a preferred orientation. Minute granules of epidote are disseminated throughout. Both the calcite twins and cleavage traces show minor deformation (bent) particularly near grain boundaries. Rarely faint lines of opaques are observed on minute intergranular fractures.

Mode

calcite	99
epidote	1

Comments

This marble possibly recrystallized from a more massive and slightly purer limeston than G-10. Evidence suggests that the opaque minerals are introduced into the rock as intergranular phases or perhaps were reconstituted as intergranular pore fluids during the recrystallization of the calcite.

Sample G-15

Bulk Chemical Analysis

SiO_2	67.50
Al_2O_3	15.90
TiO_2	.44
Fe_2O_3 Total	3.70
MnO	.05
MgO	2.15
CaO	4.60
K_2O	1.95
Na_2O	0.16
P_2O_5	.187
L.O.I.	0.72
Total	97.35

Trace Element

Cu	10
Pb	16
Zn	36
Ag	0
Au	.000

Petrography

In hand specimen the rock is medium to coarse grained, inequigranular. Large plagioclase grains have a tendency to coalesce forming aggregates up to 1 cm in diameter. Hornblende occurs as large solitary grains in random orientation and disseminated throughout the rock. Quartz and biotite occur interstitial to the plagioclase and hornblende grains. The rock shows slight chloritic alteration along fracture surfaces.

Microscopic observation confirms the hypidiomorphic inequigranular texture observed in hand specimen. Plagioclase grains are normally zoned An_{42} (core) An_{18} (rim). These grains, particularly core areas are altered to sericite and epidote. Subhedral hornblende grains may or may not be completely altered to chlorite. Quartz and biotite anhedra occur interstitial to the plagioclase and hornblende.

Mode		Description
plagioclase	70%	euhedral-subhedral
hornblende	8%	euhedral-subhedral
quartz	10%	anhedral
biotite	5%	anhedral
chlorite	5%	alteration
magnetite	2%	associated with all ferromagnesian silicate
sphene		accessory subhedral

Comments

This rock is a quartz-diorite exhibiting classic textures for this rock type (hypidiomorphic inequigranular). The high felsic and low ferromagnesian content plus the texture indicate a quite viscous magma of low ionic mobility - the grains tending to nucleate in clusters. This rock shows definite similarities to the quartzose porphyry G-7 which may represent a latter differentiate of the same magma. The alteration of the plagioclase and ferromagnesian is very likely deuteric.

Sample G-17 Aplitic quartz-diorite

Bulk Chemical Analysis

SiO_2	67.81
Al_2O_3	14.25
TiO_2	.44
Fe_2O_3 Total	3.85
MnO	.06
MgO	2.20
CaO	4.00
K_2O	3.75
Na_2O	3.80
P_2O_5	.153
L.O.I.	.41
Total	100.78

Trace Elements

Cu	21
Pb	8
Zn	19
Ag	.5
Au	.0017

Petrography

A fine-grained phanerite mottled by light and dark minerals. The dark to light mineral ratio is about 1:2. The rock is shot through by a stockwork of minute veinlets with associated pink colouration probably indicative of potassic metasomatism. Near these veinlets the ferromagnesian minerals appear to have been altered to chlorite and the feldspars are a chalky white in colour. The rock is quite magnetic and the veinlets show reaction to HCl. The rock is chloritized along fractures.

In thin section the rock is composed of interlocking anhedral grains giving the rock an allotramorphic granular or aplitic texture. The rock is essentially composed of plagioclase and hornblende. Minor minerals include quartz, magnetite, chlorite, sphene, epidote sericite.

Mode	Description
plagioclase	75% zoned oligoclase everywhere altered to sericite and epidote
hornblende	15% green to buff pleochroism generally fresh with little chloritization
chlorite	3% as alteration of hornblende and to a lesser extent of plagioclase
magnetite	2% subhedral to anhedral grains disseminated throughout rock
sphene	1% rare subhedral grains generally with opaque
epidote	acc. alt. of plagioclase
sericite	acc. alt. of plagioclase
quartz	4% small anhedral grains

Comments

Possibly a fine grained border zone or dike rock associated to quartz-diorite (G-15). Rock probably has undergone hydrothermal alteration near fractures - the hydrothermal fluids rich in potassium. The rock crystallized quickly with no well developed grain habits for any mineral species.

Sample G-18

Bulk Chemical Analysis

SiO_2	61.50
Al_2O_3	18.00*
TiO_2	.58
Fe_2O_3 Total	3.91
MnO	.05
MgO	1.25
CaO	3.80
Na_2O	5.30*
K_2O	1.55
P_2O_5	.202
L.O.I.	3.38
Total	99.25

Trace Elements

Cu	68
Pb	12
Zn	51
Ag	.5
Au	.0029

Petrography

This rock is similar in hand specimen to G-17. It is a massive fine grained phanerite, light-grey green in colour. The rock is non-magnetic and pyrite is disseminated throughout. There is well developed chlorite on fracture surfaces.

The rock is similarly textured to specimen G-17 however shows more pervasive alteration of both plagioclase and hornblende.

Mode	Description
plagioclase	80% highly altered to sericite, show prominent albite twinning
hornblende	5% as relict grains in chlorite
chlorite	10% alteration of plagioclase and hornblende
sericite	
opaques	1% disseminated
calcite	3% disseminated
sphene	acc. associated with ferromagnesian.

Comments

This rock is an altered variety of G-17 which has undergone intensive hydrothermal alteration. The feldspars are sericitized and albitized, the hornblende chloritized. The chemical analysis shows the rock increased in Al_2O_3 and Na_2O content while it dropped in SiO_2. The hydrothermal fluids were probably rich in alumina and soda and leached silica from the rock, precipitating out sulphides as the plagioclase and hornblende underwent hydration.

Sample G-19 Dolomitic Marble

Recommend Probing to identify minerals

Bulk Chemical Analysis

SiO_2	2.69
Al_2O_3	0.20
TiO_2	.04
Fe_2O_3	0.30
MnO	.07
MgO	21.30
CaO	30.80
Na_2O	0.10
K_2O	.08
P_2O_5	.112
L.O.I.	45.30
Total	100.99

Trace Elements

Cu	12
Pb	66
Zn	14
Ag	2.0
Au	.0035

Petrography

In hand specimen this rock is similar to G-10- light grey, crystalline, carbonate having a less violent reaction to dilute HCl. The hand specimen exhibits a planar structural feature defined by small parallel lenses and stringers of calcite. These are transected by minute calcite veinlets.

In thin section the rock exhibits a granoblastic polygonal texture with individual grains generally having sinusoidal to straight borders and in triple point junction with other grains - a near equilibrium texture. The specimen is composed essentially of calcite and dolomite with minor minerals including magnetite, brucite and diopside. Magnesite occurs as irregular phases intergrown with dolomite (where incipient alteration is intense these grains appear brownish), and as discreet grains. Brucite occurs as scaly aggregate which appear fibrous under cross nicols.

Mode	Description
calcite	60%
dolomite	30%
magnesite	9% untwinned high birefringence
brucite	acc. scaly aggregates
diopside	acc. small rounded grains

Comments

This rock is very likely a recrystallized dolomitic limestone. Compositional differences in the original rock give rise to 'boudinouged'? high calcite lenses and stringers which define a planar feature to the rock. The rock shows a variety of magnesium bearing minerals which nucleated during recrystallization of the dolomite.

Sample G-23 Magnetite Serpentine Skarn

Bulk Chemical Analyses

SiO_2	28.50
Al_2O_3	1.90
TiO_2	.12
Fe_2O_3 Total	28.30
MnO	.21
MgO	25.20
CaO	4.00
Na_2O	3.30
K_2O	.75
P_2O_5	.075
L.O.I.	6.45
Total	98.65

Trace Elements

Cu	1.40%
Pb	12
Zn	.17
Ag	16
Au	.0105

Petrography

A fine-grained, massive, yellow and black layered rock which is highly magnetic. It shows a moderate reaction to HCl. There is some antigornite plated out on fracture surfaces.

In thin section the rock shows a pronounced granular texture with rounded grains of serpentine (antigorite) occurring in a framework of interstitial magnetite and minor calcite and epidote. Dolomite occurs as rare remnant grains.

Mode

serpentine	60%
magnetite	30
calcite	5
epidote	3
dolomite	2

Comments

This rock possibly represents a metasomatised variety of G-19. During the metamorphic period calcite was nearly totally leached from the rock; silica + iron was introduced. The dolomte recrystallized under these circumstances as serpentine and the iron was deposited interstitially to serpentine and preferentially along zones high in calcite (where there was less dolomite to react to form serpentine). There is no apparent quartz associated with the magnetite suggesting there was abundant Mg present and all the silica was used in the recrystallization to serpentine. The remnant dolomite would suggest that not enough SiO_2 was introduced to totally react with the dolomite.

Sample G-25k Diorite Dyke

Bulk Chemical Analyses

SiO_2	53.67
Al_2O_3	15.10
TiO_2	1.70
Fe_2O_3 Total	9.00
MnO	.11
MgO	5.25
CaO	6.40
Na_2O	3.10
K_2O	1.95
P_2O_5	.607
L.O.I.	2.18
Total	99.14

Trace Elements

Cu	64
Pb	24
Zn	75
Ag	.65
Au	.000

Petrography

This drill core specimen is a grey green, very fine grained phanerite. Accessory amounts of sulphide, pyrite, possibly chalcopyrite is observed disseminated throughout the rock. The sample is non magnetic.

The texture of the rock is intergranular to subophitic with randomly oriented subhedral plagioclase and actinolitic hornblende. Minor minerals occurring interstitial to the plagioclase and hornblende are opaques (sulphide), epidote, chlorite, sphene, rutile, calcite and quartz. The major minerals are highly altered, plagioclase to sericite and epidote, hornblende to actonolitic hornblende and chlorite.

Mode	Description
plagioclase	65% zoned andesine
hornblende	30% pale green pleochroism - actinolite-slightly feathery
chlorite	alteration of hornblende
epidote	alteration of plagioclase and hornblende
sericite	alteration of hornblende
sphene	3% anhedral patches disseminated in interstitial areas
rutile	acc.-1% accicular needles
calcite	acc.
quartz	acc.
sulphides	acc.

Comments

This is probably a fine grained dioritic dike rock or crystalline andesite containing minor sulphide mineralization. The rock shows extensive hydrothermal alteration however there is little evidence for introduction or leaching of materials.

Sample G-25h Diorite

Bulk Chemical Analyses

SiO_2	53.20
Al_2O_3	16.08
TiO_2	.88
Fe_2O_3 Total	8.92
MnO	.13
MgO	4.90
CaO	9.90
Na_2O	3.40
K_2O	1.50
P_2O_5	.371
L.O.I.	1.76
Total	101.04

Trace Elements

Cu	18
Pb	14
Zn	57
Ag	.65
Au	.000

Petrography

A medium to coarse grained inequigranular/mottled rock white and dark green by aggregate concentration of hornblende and plagioclase. The rock is moderately magnetic.

In section the texture exhibited is hypidiomorphic inequigranular with anhedral grains of quartz and sphene interstitial to strongly interlocking aggregates of subhedral plagioclase and hornblende. The plagioclase grains are very cloudy due to incipient alteration to clay minerals and minor epidote. The hornblende, pleochroic from green to a buff brown may show relict zones of pyroxene (augite). Minor hornblende is altered to chlorite.

Mode	Description
plagioclase	60% zoned oligoclase - may be totally altered
hornblende	30% intergrown with augite and generally unaltered
pyroxene	2% augite in relict grains in hornblende
clay minerals	alteration of plagioclase
sericite	alteration of plagioclase
epidote	alteration of plagioclase
quartz	4% interstitial
sphene	1% interstitial
chlorite	2% alteration of hornblende
magnetite	1% associated with ferromagnesian minerals

Comments

This rock is of similar chemical composition and mineralogy as G-25k however is coarser grained and the mafics are less altered. Similar to sample G-15 the magmatic source was likely quite viscous causing the heterogeneous distribution of the felsics and mafics. All minerals observed appear primary except the alteration products.

Sample G-26 Quartz Diorite

Bulk Chemical Analysis

SiO_2	62.34
Al_2O_3	17.00
TiO_2	.69
Fe_2O_3 Total	4.85
MnO	.06
MgO	2.45
CaO	5.50
Na_2O	4.66
K_2O	1.55
P_2O_5	.205
L.O.I.	0.99
Total	100.29

Trace Element

Cu	12
Pb	14
Zn	.41
Ag	.70
Au	.0006

A medium grained, white and green mottled rock similar in appearance to G-25H. The mafic constituents are more homogeneously distributed and this gives the rock a graphic or mortar texture appearance with the hornblende outlining the plagioclase concentrations. The rock is weakly magnetic. Near fracture surfaces feldspars are chalky white, fractures are chloritized.

In thin section the euhedral to subhedral feldspar grains butt up against one another in random orientation. Subhedral hornblende generally occurs intergrown with anhedral sphene and quartz interstitial to the feldspar. The texture is hypidiomorphic granular.

Mode	Description
plagioclase	60% zoned oligoclase - very cloudy to incipient clay alteration
hornblende	25% - may be completely altered to chlorite and epidote
chlorite	4% - alteration of hornblende
biotite	2%
quartz	8% interstitial to plagioclase and hornblende
sphene	1% interstitial to plagioclase and hornblende
epidote	alteration of plagioclase and hornblende
sericite	alteration of plagioclase and hornblende
magnetite	associated with highly altered hornblende

Comments

Crystallization of the hornblende was slightly later than the plagioclase but preceded quartz-sphene crystallization. The rock has undergone extensive hydrothermal alteration particularly near rock fractures. There is little difference either compositionally or texturally among G-15, G-25H and G-26.

Sample G-27 Quartz-diorite dike

Bulk Chemical Analysis

SiO_2	63.83
Al_2O_3	16.08
TiO_2	0.48
Fe_2O_3 Total	3.50
MnO	.04
MgO	1.45
CaO	4.00
Na_2O	4.30
K_2O	2.00
P_2O_5	.168
L.O.I.	4.65
Total	100.49

Petrography

A fine grained, light grey-green phanerite which is massive in appearance. The rock has a very weakly developed porphyritic or amygdoloidal appearance with bleb-like occurrences of epidotized feldspar interspersed in the mottled feldspar, quartz and mafic mineral groundmass. The rock is non-magnetic and shows a moderate reaction to HCl.

When observed in thin section all the minerals show extreme alteration; the feldspar to clay minerals and sericite, the mafics completely to chlorite and epidote. Quartz and calcite are the most common minerals observed in irregular patches interstitial to the altered plagioclase and hornblende however large aggregates of epidote, chlorite sphene and opaque mineral also occur.

Trace Elements

Cu	10
Pb	11
Zn	55
Ag	.50
Au	.0012

Mode	Description
plagioclase	45% altered to sericite
hornblende	completely altered to chlorite
chlorite	35% pale green, low birefringence
quartz	10%
calcite	5%
sericite	alteration of feldspar
epidote	5%
sphene	1%
opaque	1%

Comments

This is likely a dike rock which has been highly altered. The irregular occurrences of quartz-calcite and to some extent chlorite and opaques may suggest these minerals were introduced at the time of alteration.

Sample G-3i Dolomitic limestone

Bulk Chemical Analyses

SiO_2	1.00
Al_2O_3	1.50
TiO_2	.04
Fe_2O_3 Total	.25
MnO	.02
MgO	16.50
CaO	35.10
Na_2O	.01
K_2O	.08
P_2O_5	.036
L.O.I.	45.47
Total	99.70

Trace Elements

Cu	3
Pb	44
Zn	14
Ag	0
Au	.000

Petrography

A dark slate-grey / rock aphanitic in hand specimen. Small white stringer and blebs define a planar structure. The rock is non-magnetic and reacts to dilute HCl.

In thin section the rock is composed of interlocking grains of calcite and dolomite. Generally the rock is highly carbonaceous with carbon and rarely hematite flecs outlining small irregular grains of the carbonate minerals. Occasionally coarser grained phases of granoblastic polygonal dolomite and calcite free of carbon is observed.

Mode	Description
calcite	50% twinned
dolomite	40% generally untwinned
carbon	5-10%
hematite	trace

Comments

This rock is a carbonaceous dolomite limestone which has not been subject to intense thermal metamorphism or metasomatic activity. The few coarse phases of carbonate may be due one of these secondary effects however on the main the rock is unaltered.

Sample G-33 Dolomite Marble

Bulk Chemical Analysis

SiO_2	.90
Al_2O	.33
TiO_2	0.04
Fe_2O_3 Total	.20
MnO	0.02
MgO	20.95
CaO	31.00
Na_2O	0.02
K_2O	0.08
P_2O_5	0.21
L.O.I.	46.41
Total	100.21

Trace Elements

Cu	4
Pb	11
Zn	11
Ag	0
Au	.000

Petrography

In hand specimen the rock is a buff white colour and has a somewhat sugary texture. White blebs and stringers define a planar structure. Fractures parallel to the planar feature have associated rusty iron sulphide. The rock is non-magnetic and weakly responds to dilute HCl.

In thin section the rock is granoblastic polygonal, being composed on rounded equant grains of calcite and dolomite.

Mode

calcite	40
dolomite	60

Comments

This rock is a thermally metamorphosed variety of G-31 with the carbon content removed.

Sample G-35 Quartz Diorite

Bulk Chemical Analysis

SiO_2	64.00
Al_2O_3	17.10
TiO_2	0.59
Fe_2O_3 Total	4.35
MnO	0.07
MgO	2.00
CaO	5.00
Na_2O	4.66
K_2O	2.55
P_2O_5	.201
L.O.I.	0.61
Total	101.36

Trace Elements

Cu	26
Pb	23
Zn	51
Ag	0
Au	.000

Petrography

A white and black spotted coarse grained rock. Large, rounded, composite hornblende grains are randomly interspersed in medium grained feldspar, quartz and biotite giving the rock an inequigranular appearance. The rock is moderately magnetic.

In section the rock is hypidiomorphic granular with interlocking grains of subhedral feldspar and hornblende and subhedral to euhedral biotite. Quartz, sphene, biotite and magnetite occur interstitial to the feldspar and hornblende. The plagioclase shows minor incipient alteration to clay minerals. Hornblende shows all degrees of alteration to chlorite and in the event where it has totally gone to chlorite - this chlorite may be intergrown with biotite. Sphene is sometimes observed partly rimming hornblende grains. Orthoclase was observed in one location as a patch antiperthite in plagioclase where a chloritized hornblende grain crosscut the feldspar.

Mode

plagioclase	65% zoned oligoclase slightly altered a few grains of unaltered unzoned oligoclase
hornblende	16% green to buff brown pleochroism
biotite	5% deep brown to pale brown to neutral
quartz	10% interstitial
sphene	2%
chlorite	alteration after hornblende
magnetite	2% associated with ferromagnesian minerals
orthoclase	tr. metasomatic replacement

Comments

This rock is similar to other quartz diorites described however may represent a slightly later crystallizing phase as there is more abundant K_2O. The result of this is the occurrence of biotite which in some cases may be primary. Generally biotite is associated with chlorite and probably the result of a late deuteric alteration. The orthoclase would also fit into this secondary process of late alkali metasomatism possibly during the period of quartz crystallization.

Sample G-36 Quartz diorite - Granodiorite

Bulk Chemical Analyses

SiO_2	64.82
Al_2O_3	17.07
TiO_2	0.52
Fe_2O_3	4.21
MnO	0.06
MgO	2.08
CaO	5.00
Na_2O	4.90
K_2O	1.75
P_2O_5	.170
L.O.I.	.61
Total	101.27

Petrography

A fine to medium grained, black and buff spotted rock. There is a weak fabric defined by the distribution of felsic and mafic minerals. The rock is weak to moderately magnetic and there is accessory pyrite mineralization.

In thin section the rock is hypidiomorphic granular. The feldspar grains are not so well developed as in other coarse igneous rocks described. The plagioclase is zoned oligoclase generally, however unzoned oligoclase showing fine albite twinning is common. Twin measurements normal to (010) on unzoned varieties give An_{12}. Orthoclase is also a constituent and generally occurs as anhedral grains associated with quartz. Quartz occurs as small anhedral aggregates interstitial to plagioclase and hornblende. Biotite anhedra are also interstitial.

Trace Elements

Cu	26
Pb	16
Zn	48
Ag	1
Au	.000

Mode		Descriptions
plagioclase	65%	zoned and unzoned oligoclase
orthoclase	5%	
quartz	10%	
biotite	10%	dark brown to buff
hornblende	10%	fresh subhedral grains
apatite	acc.	
opaques	acc.	

Comments

Mineralogically this specimen is slightly different than the "more common quartz diorites" described. It is approaching granodiorite in composition. The foliar fabric observed in hand specimen may suggest it's near a border zone and they're more susceptible to contamination which may account for its textural and mineralogical differences from other rocks.

Sample G-37 Quartz-monzonite

Bulk Chemical Analysis

SiO_2		64.67
Al_2O_3		16.66
TiO_2		.51
Fe_2O_3	Total	4.27
MnO		.06
MgO		1.41
CaO		4.20
Na_2O		4.66
K_2O		2.80
P_2O_5		.217
L.O.I.		.61
Total		100.06

Petrography

A medium to coarse grained inequigranular rock composed of white euhedral plagioclase, dark green anhedral hornblende grains and interstitial quartz biotite and orthoclase. The plagioclase shows a tendency to form composite aggregates causing an uneven distribution of the earlier formed and later formed minerals. The rock is moderately magnetic.

In section two types of plagioclase are observed: (1) highly altered zone oligoclase and oligoclase showing fine albite twin lamellae generally unaltered. The texture is hypidiomorphic granular with quartz and biotite and perthite interstitial to the plagioclase and hornblende. The hornblende is somewhat altered to actinolitic hornblende and chlorite. Spene sometimes occurs as blebs in chlorite or is associated with magnetite.

Trace Elements

Cu	7
Pb	20
Zn	34
Ag	0
Au	.000

Mode		Description
plagioclase	45%	(20% unzoned oligoclase)
orthoclase (perthite)	15%	
quartz	20%	
hornblende	10%	
biotite	5%	
chlorite	5%	
sphene	acc.	
magnetite	acc.	

Comments

The amount of late differentiate, quartz and perthitic orthoclase and the increasing amount of unzoned alkali feldspar would suggest this rock represents a more acidic phase of quartz diorite. The early formed minerals, zoned plagioclase and hornblende were probably altered during the crystallization of the interstitial material to a mineralogical composition which is now present. (Little evidence of a late hydrothermal alteration).

Sample G-38 Quartz-diorite

Bulk Chemical Analysis

SiO_2	64.83
Al_2O_3	13.58
TiO_2	1.40
Fe_2O_3	6.20
MnO	.12
MgO	2.67
CaO	6.40
Na_2O	4.48
K_2O	2.30
P_2O_5	.520
L.O.I.	1.56
Total	100.92

Trace Elements

Cu	65
Pb	14
Zn	48
Ag	1.5
Au	.000

Petrography

A medium grained, green-white mottled rock composed essentially of hornblende and plagioclase. The hornblende sometimes occurs as large (.8 cm.) grains giving the rock an inequigranular texture. The rock is quite magnetic and has a clayey odour due to breakdown of the feldspars.

In thin section the texture is hypidiomorphic inequigranular. Large subhedral grains of plagioclase are completely altered to clay minerals and sericite and large subhedral grains of hornblende are now altered to epidote and chlorite. These grains are scattered and locally concentrated in a mass of medium size grains of partially altered,well-twinned oligoclase of subhedral shape. Quartz and biotite occur interstitial to these grains. Sphene is partially associated with opaque in the interstitial material or with opaque in altered hornblende grains. Sphene was also observed mantling hornblende. Epidote is a product of altered hornblende.

Mode	Description
plagioclase	(1) altered grains 25%
	(2) twinned oligoclase 35%
hornblende	30% altered to chlorite
chlorite	
quartz	1%
sphene	3%
epidote	2%
biotite	1%
magnetite	1%
apatite	acc.

Comments:

This rock is an altered quartz-diorite that possibly had an interruption of its crystallization causing inequigranularity, the differing types of plagioclase grains and very likely the high degree of alteration of the first crystallized minerals.

Sample G-46 Quartz-Hornblende-Diorite

Bulk Chemical Analysis

SiO_2	65.00
Al_2O_3	11.83
TiO_2	.72
Fe_2O_3	8.33
MnO	
MgO	2.45
CaO	6.53
Na_2O	4.33
K_2O	.70
P_2O_5	.249
L.O.I.	1.30
Total	101.60

Trace Elements

Cu	171
Pb	28
Zn	94
Ag	1.5
Au	.0023

Petrography

An inhomogeneous, fine/ to medium grained rock composed chiefly of hornblende. The inhomogeneous nature is caused by local concentration into irregular shaped phases of the felsic and ferromagnesian constituents. The rock is non-magnetic. There is one large hornblende of 1.2 cm in diameter.

In section the texture is hypidiomorphic granular with intergrown subhedral feldspar and hornblende grains. Quartz occurs interstitial to these minerals. Chlorite and epidote are alteration products of hornblende, opaques(sulphide) are sometimes associated with these intergrowths. The cores of the plagioclase is generally altered to clay minerals, sericite and epidote.

Mode		Description
hornblende	65%	altered to chlorite and epidote
plagioclase	15%	altered to sericite and clay minerals
quartz	20%	
chlorite		
epidote		
apatite	acc.	

Comments

This rock may represent a contaminated quartz diorite or a mafic rich differentiate with a high quartz content. The occurrence of segregated mafic and felsic rich phases and large individual grain indicates that the chemical and physical conditions of crystallization was not uniform. There is no evidence to suggest later metasomatic activity. That the rock should be so mafic rich but does not contain any magnetite is interesting. It is however enriched in Cu over other samples of diorite.

Sample G-50 Crystalline Limestone

Bulk Chemical Analysis

SiO_2	0.13
Al_2O_3	.33
TiO_2	.03
Fe_2O_3 Total	.75
MnO	.01
MgO	1.40
CaO	55.8
Na_2O	0.03
K_2O	.01
P_2O_5	.049
L.O.I.	42.35
Total	100.91

Trace Elements

Cu	49
Pb	4
Zn	5
Ag	0
Au	.0017

Petrography

This hand specimen is a dark grey, fine grained finely laminated rock. The laminations are defined by minute stringers and blebs of lighter colouration as well as slight changes in composition of wider banding (up to one cm.). The rock is non-magnetic and reacts violently to dilute HCl.

In thin section the rock is composed of calcite and has a granoblastic elongate texture, giving rise to a well developed foliation. Much carbonaceous material occurs along the grain boundaries. A few grains of dolomite occur and do not appear to be concentrated in a particular band.

Mode

calcite	95
dolomite	2
carbon	2

Comments

The banding observed in hand specimen is probably due to variation in carbon content of the original limestone. The rock has undergone recrystallization and the diversion of the calcite grains was controlled by the original bedding.

Sample G-82 Diorite-porphyry

Bulk Chemical Analysis

SiO_2	56.50
Al_2O_3	16.41
TiO_2	1.00
Fe_2O_3 Total	6.67
MnO	.11
MgO	5.29
CaO	6.40
Na_2O	3.67
K_2O	.55
P_2O_5	.086
L.O.I.	1.56
Total	98.17

Trace Elements

Cu	21
Pb	10
Zn	43
Ag	1
Au	.0012

Petrography

A green-white, medium-grained mottled rock with large (2 cm) poikilitic phenocrysts of hornblende. The rock is quite magnetic. The phenocrysts appear to have very diffuse outlines and grade into a normally textured intergrowth of feldspar and hornblende.

In section the rock is composed of euhedral to subhedral plagioclase An_{32} that is highly altered to clay minerals and epidote. The plagioclase is intergrown with subhedral hornblende or may be poikilitically included in irregular areas of optically continuous hornblende. Rarely augite pyroxene is also observed in the same fabric relationship as plagioclase quartz occurs as angular anhedra interstitial to the other minerals.

Mode		Description
plagioclase	40%	altered andesine
hornblende	50%	
pyroxene	5%	
chlorite		alteration of ferromagnesian
epidote		alteration of plagioclase
quartz	5%	
sphene	acc.	

Comments

This rock may represent an older differentiate of the diorite. It is comparatively lower in quartz and higher in ferromagnesian content. The plagioclase is slightly more calcic than usual. That the hornblende nucleated in large irregular grains does not in this case represent an earlier crystallization or change in rate of cooling but only that in some cases hornblende grew from one nucleation center instead of several as was the case with the large composite aggregates of other samples (for example 25-H).

Sample G-85 Augite-Ca-plagioclase porphyry or porphyritic diabase

Bulk Chemical Analysis

SiO_2	59.67
Al_2O_3	13.50
TiO_2	1.40
Fe_2O_3 Total	8.30
MnO	.12
MgO	2.67
CaO	6.40
Na_2O	4.48
K_2O	2.30
P_2O_5	.520
L.O.I.	1.56
Total	100.92

Trace Elements

Cu	40
Pb	20
Zn	80
Ag	1
Au	.000

This rock is an augite feldspar porphyry with large (.6 cm) plagioclase grains and rare augite phenocrysts set in a grey, fine-grained matrix. The phenocrysts are euhedral to subhedral and randomly oriented. The rock is moderately magnetic.

In thin section the large feldspar phenocrysts are observed to be completely altered to clay minerals sericite, calcite and epidote. The large augite grains are essentially unaltered (a few minute chlorite inclusions) and commonly twinned. The matrix material has an intergranular texture developed among subhedral grains of zoned and untwinned plagioclase, uralized pyroxene, magnetite, and sphene and anhedral grains of quartz-chlorite-epidote. Apatite is an ubiquitous accessory mineral.

Mode		Description
plagioclase	15%	phenocrysts
	45%	groundmass
pyroxene (augite)	5%	phenocrysts
	3%	groundmass
magnetite	3%	
sphene	2%	
epidote	5%	
quartz	5%	interstitial granophyre
apatite	2%	
chlorite	5%	

Comments

This is an augite-Ca-plagioclase porphyry showing no affinities to the quartz-diorite rocks. It is gabbroic in composition but has quartz-granophyre as an interstitial constituent, i.e. shows affinities to porphyritic diabase.

Sample G-87 Diopside skarn

Bulk Chemical Analysis

SiO_2	57.16
Al_2O_3	.33
TiO_2	.03
Fe_2O_3 Total	3.87
MnO	.09
MgO	14.41
CaO	22.60
Na_2O	.02
K_2O	.000
P_2O_5	.099
L.O.I.	2.08
Total	100.70

Trace Elements

Cu	12
Pb	14
Zn	31
Ag	1
Au	.000

A massive, fine-grained, light green phanerite. The rock is homogeneous and crosscut by a parallel set of fine dark stringers. The specimen has a high specific gravity, is non-magnetic and shows a weak reaction to HCl.

In thin section the rock exhibits a decusate polygonal texture with subhedral,elongate diopside + wollastonite? randomly oriented in rounded diopside granules. Rarely the granular diopside gives way to irregular masses of finely intergrown tremolite, quartz and calcite.

Mode		Description
diopside	80%	
wollastonite	10%	low birefringence biaxial neg. many cleavages
tremolite	5%	
calcite	3%	
quartz	2%	

Comments

This rock is a metasomatic skarn with possibly no evidence of its original nature (the black stringers in the hand specimen may be controlled by the original compositional bedding??). The wollastonite is only tentatively identified and should be probed or x-rayed for positive identification. The tremolite,calcite and quartz appear to be trapped or segregated phases in the metasomatic fluid or possibly represent small areas that has not totally reacted with the skarn material.

Sample G-117 Quartz-Diorite

Bulk Chemical Analyses

SiO_2	67.50
Al_2O_3	14.67
TiO_2	.50
Fe_2O_3 Total	4.46
MnO	.07
MgO	2.01
CaO	4.30
Na_2O	5.29
K_2O	1.45
P_2O_5	.187
L.O.I.	.56
Total	100.99

Trace Elements

Cu	17
Pb	12
Zn	.41
Ag	.65
Au	.000

Petrography

In hand specimen a medium-grained white-black mottled rock. It is slightly inequigranular with larger (.4 cm) hornblende and plagioclase in a finer grained (.2-.3 cm) mass. The rock is moderately magnetic.

In section the texture is hypidiomorphic granular with subhedral plagioclase and hornblende randomly oriented. Biotite quartz and sphene form anhedral grains interstitial to the plagioclase and hornblende. The plagioclase is zoned and generally fresh with only a few of the calcic centers showing clay mineral and sericite development. The hornblende is generally altered to actinotlitic-hornblende and chlorite. The biotite appears fresh and unaltered. Sphene and magnetite are associated with both hornblende and biotite.

Mode		Description
plagioclase	65%	zoned oligoclase generally fresh
hornblende	10%	altered to chlorite
biotite	8%	
quartz	12%	
sphene	2%	
magnetite	3%	

Comments

This rock is similar to other diorite samples mineralogically and texturally. It appears to have a simple cooling history with oligoclase and hornblende followed by quartz and biotite. The interstitial minerals show a slightly higher proportion in this specimen.

Sample G-120 Magnetite Skarn

Bulk Chemical Analysis

SiO_2	8.50
Al_2O_3	1.67
TiO_2	.01
Fe_2O_3 Total	84.00
MnO	.23
MgO	4.51
CaO	.10
Na_2O	1.69
K_2O	.40
P_2O_5	.017
L.O.I.	.10
Total	101.22

Trace Elements

Cu	1.28%
Pb	22
Zn	.35%
Ag	16
Au	.0233

A hand sample of fine grained magnetite ore containing chalcopyrite bornite and valerite copper mineralization. Along fracture surface some of the copper mineralization has been oxidized to malachite.

In section the rock is composed of finely intergrown magnetite grains and muscovite and quartz aggregates. The copper mineralization occurs as blebs and stringers in the magnetite or may be spacially associated with the silicate gangue (i.e. bordering silicate inclusions).

Mode	Description
magnetite	80%
quartz	4%
muscovite-sericite	6%
chalcopyrite	3%
bornite	2%
valerite	1%
malcachite	alteration

Comments

This rock is composed of a metallic skarn assemblage that includes a little silicate material. The occurrence of muscovite is unusual - the chemical analysis suggests it has a high paragonite content. The copper mineralization appears to be concentrated in blebs and stringers within the skarn.

Sample G-128 Quartz-Diorite

Bulk Chemical Analysis

SiO_2	65.75
Al_2O_3	14.37
TiO_2	.43
Fe_2O_3 Total	1.20
MnO	.07
MgO	2.15
CaO	5.00
Na_2O	5.17
K_2O	1.02
P_2O_5	.182
L.O.I.	3.64
Total	100.78

Trace Elements

Cu	21
Pb	14
Zn	41
Ag	.5
Au	.000

A medium-grained rock with coalesing mafic and felsic aggregates which imports a mottled-inequigranular appearance. The rock is weakly magnetic.

In section the rock is composed of large (.3 cm) zoned and untwinned plagioclase that is highly altered to clay minerals and sericite and twinned and zoned plagioclase (andesine) which is also commonly altered. The twinned plagioclase is of subhedral habit and of smaller grain size (.1 cm). The subhedral hornblende grains shows all degrees of alteration to chlorite and biotite. Quartz and sphene occur interstitially. Magnetite is generally anhedral and is associated with the ferromagnesian minerals.

Mode		Description
plagioclase	60%	zoned andesine - twinned oligoclase
hornblende	10	
chlorite	15	
biotite	5	
quartz	10	
sphene	acc.	
magnetite	acc.	

Comments

A typical quartz diorite whose history of crystallization is best told by the plagioclase grains: normal differentiation with interrupted cooling.

Sample G-140 Calc-silicate Skarn

Bulk Chemical Analysis

SiO_2	61.73
Al_2O_3	15.58
TiO_2	0.70
Fe_2O_3 Total	6.25
MnO	.09
MgO	2.25
CaO	6.20
Na_2O	4.58
K_2O	1.15
P_2O_5	.222
L.O.I.	1.23
Total	99.99

Trace Elements

Cu	65
Pb	8
Zn	47
Ag	0
Au	.000

A brown-green fine to coarse grained rock showing a heterogeneous mineral distribution. Calcite occurs in large pegmatitic grains and along minute stringers. Brown garnet, epidote and green diopside are intimately intergrown with calcite to give the typical skarn assemblage. Pyrite, chalcopyrite and magnetite form segregations interspersed throughout the rock.

In thin section large garnet grains poikolitically enclose calcite, epidote, diopside and quartz. Large epidote grains may have this same occcurence. The diopside grains are generally small and included in garnet. The occurrence of quartz and calcite in garnet is commonly crystallographically controlled. The opaque minerals occur similarly to the silicates. Large irregular patches poikolitically enclose the silicate minerals or the opaques may be caught up in gangue minerals. Often the opaques distribution in garnet is crystallographically controlled is was the calcite and quartz. Chalcopyrite and magnetite are intimately associated with islands of one mineral occurring in the other.

Mode

garnet	45%	unzoned
epidote	15%	
diopside	9%	
calcite	15%	
quartz	10%	
chalcopyrite	4%	
magnetite	2%	

Comments

Copper mineralization in a skarn assemblage which shows no evidence of the replaced rock.

Sample G-151 Quartz-diorite or porphyritic quartz andesite?

Bulk Chemical Analysis

SiO_2	61.13
Al_2O_3	14.76
TiO_2	.69
Fe_2O_3 Total	6.33
MnO	.09
MgO	2.25
CaO	8.20
Na_2O	4.70
K_2O	.93
P_2O_5	.252
L.O.I.	1.40
Total	100.79

Trace Elements

Cu	199
Pb	12
Zn	93
Ag	0
Au	.000

In hand specimen this rock is a light grey green aphanite. It has rounded white blebs interspersed throughout. The rock is weakly magnetic and shows a moderately vigorous reaction to HCl. The sample has a distinct clay odour.

In thin section the rock proves to be highly altered. Intergrown subhedral to anhedral feldspar laths are altered to sericite and epidote. Anhedral grains and aggregates of quartz, calcite, chlorite and sphene make up the rest of the ground mass where they occur interstitial to the feldspar where it shows crystal form. In these instances the texture is intergranular but more usually the texture is allotriomorphic. Large (1-2 mm) grains of plagioclase (andesine) whose borders are strongly corroded and altered to calcite and epidote are rare. Banded grains of quartz (.5-1 mm) also occur.

Mode

plagioclase	40%
calcite	15%
chlorite	15%
quartz	18%
sphene	5%
epidote	5%
magnetite	3%

Comments

A very unusual rock type, quartz diorite in composition however has volcanic characteristics. Perhaps tuffaceous (crystal fragments), possibly a fine-grained border zone of a dike however its hard to explain the occurrence of rounded quartz grains unless remnants preserved by quick cooling.

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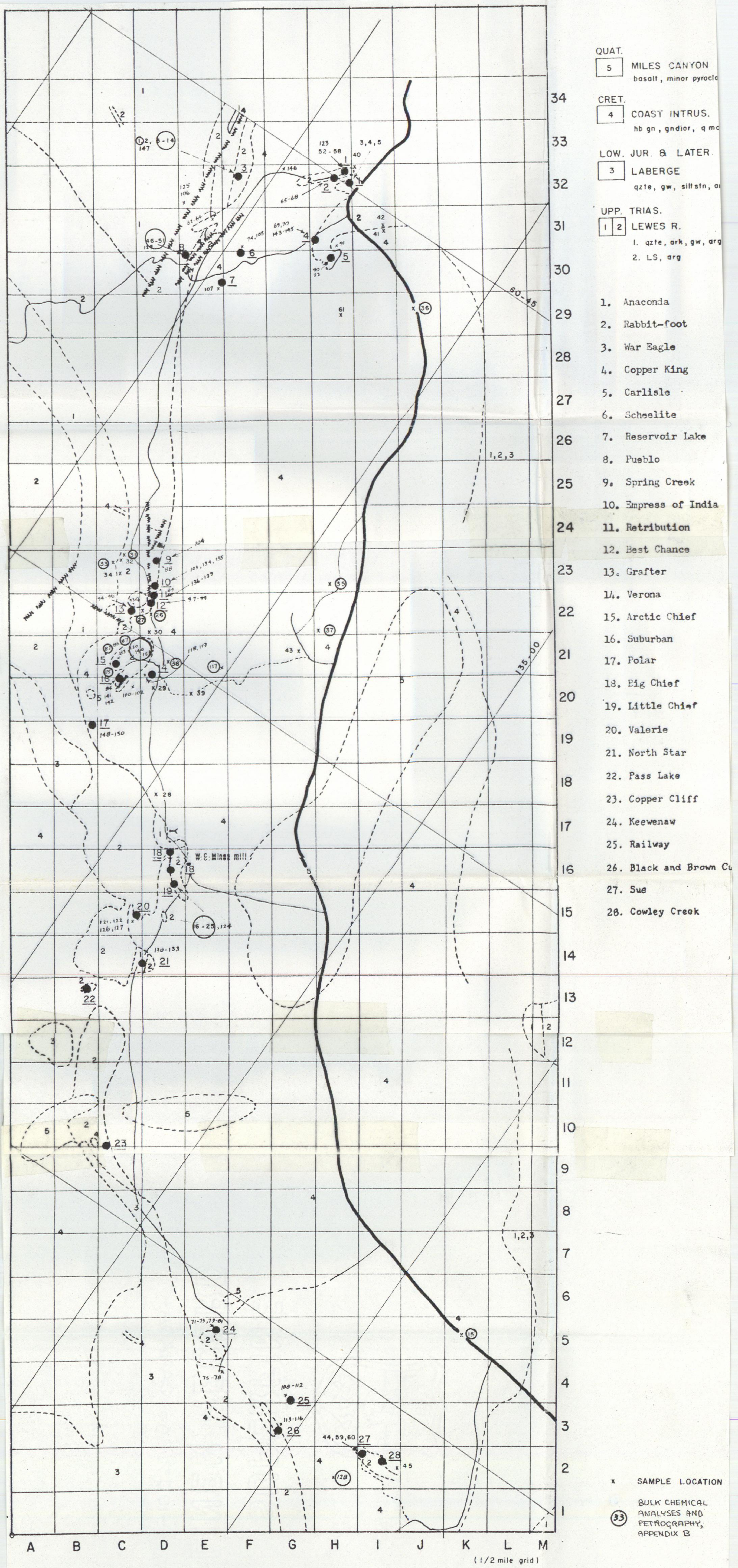

WHITEHORSE COPPER BELT

SCALE : 1 : 50,000

GEOLOGY OVERLAY

(KINDLE 1961)

FIG. 1