GEOLOGICAL SETTING AND STRATIFORM LEAD-ZINC-BARITE MINERALIZATION TOM CLAIMS, MACMILLAN PASS, YUKON TERRITORY

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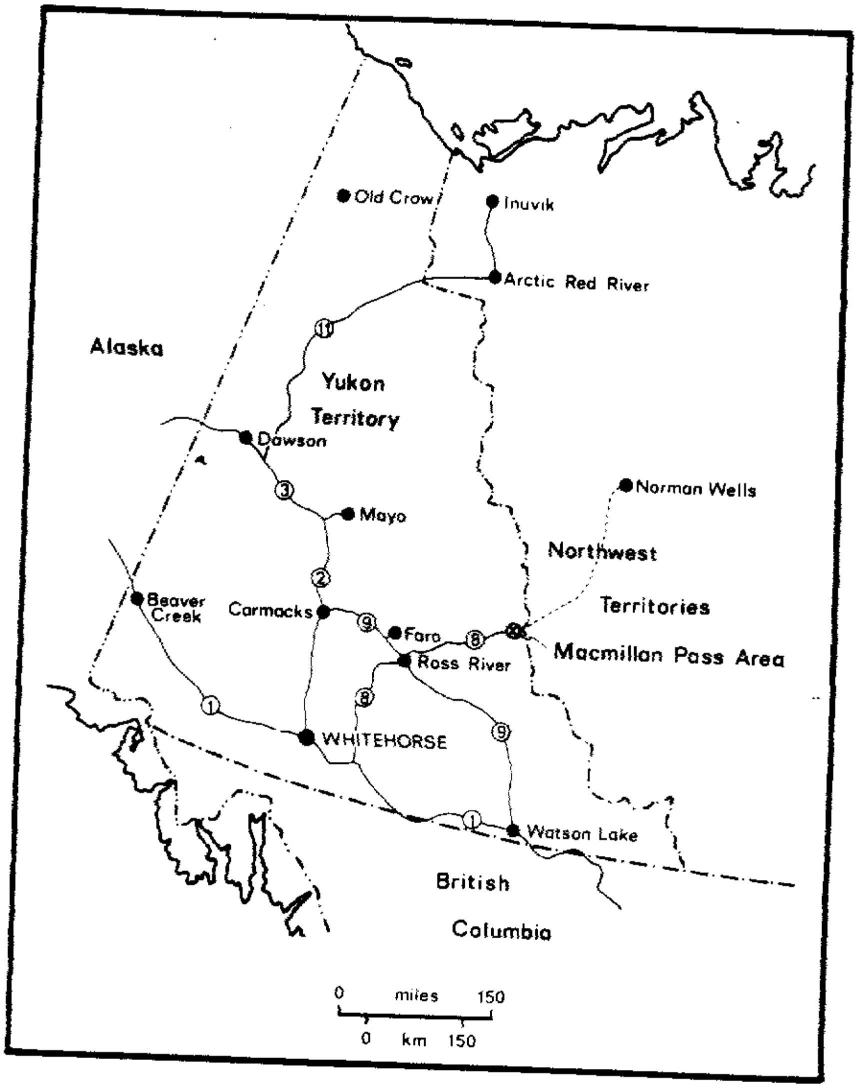

Figure 1. Map of Yukon Territory and Western District of Mackenzie showing location of Macmillan Pass area with respect to major settlements and highways.

GEOLOGIC SETTING AND STRATIFORM LEAD-ZINC-BARITE MINERALIZATION, TOM CLAIMS MACMILLAN PASS, YUKON TERRITORY

INTRODUCTION

The Macmillan Pass area, located along the North Canol Road near the Yukon-Northwest Territories border, has been of economic interest since the discovery of significant barite-lead-zinc-silver mineralization by Hudson Bay Exploration and Development prospectors in 1951. Interest in the area was recently renewed with the 1975 discovery of similar mineralization six km west of the original TOM showings. In addition to barite hosted mineralization of the Macmillan Pass area, the Upper Devonian to Lower Mississippian "Black Clastic" Unit and its correlative rocks in southeast Yukon and northeast British Columbia contain perhaps the worlds largest known accumulations of sedimentary barite. This report is based on field investigations carried out by the writer for the Department of Indian and Northern Affairs during 1976 and, in part, for Archer, Cathro and Associates during 1977. A more detailed account of the geology of the district is given in an MSc thesis by the author in preparation at the University of British Columbia.

Location and Access

The Macmillan Pass area[1] is located approximately nine km west of the Yukon-Northwest Territories border at about 63°10'N and 130°12'W (Figure 1). Vehicle access is by the North Canol Road which crosses both TOM and JASON claim groups. The road is not presently maintained during winter months (approximately October to April). A gravel surfaced, 600 metre airstrip which is located on the north part of the TOM property serves both camps. A permanent trailer camp on the TOM property is accessable by a 3 km gravel road leaving the Canol Road at Kilometre 440. The main showing area on the JASON property is served by a four-wheel-drive and bulldozer tote road that fords the Macmillan River. Ross River, about 160 km by road from the area, offers hotel accomodation, supplies and fuel.

[1]Following local convention, the area of the TOM and JASON claim groups is referred to in the present work as the "Macmillan Pass area".

General Character of the Area

Macmillan Pass lies within the Selwyn Mountains physiographic province (Bostock, 1948) and Selwyn Basin tectonic province (Gabrielse, 1967). Relief is moderate and elevations locally range from 1 160 m (3,800 ft.) to over 2 000 m (6,600 ft.). The most prominent physiographic feature is the Macmillan River valley which crosses the district in a northeast to southwest direction. Outcrop is generally scarce, with the exception of steep-sided ridges and peaks which are often craggy where underlain by resistant rock. Flat-topped ridges and hillsides are usually covered by talus and felsenmeer locally derived from frost riven bedrock. Valley bottoms are covered by a thick mantle of drift, colluvium and alluvium.

Although hunting in recent years has diminished populations of the larger mammals, moose, grizzly bear, caribou and wolves are still commonly seen in the region. Areas with elevations less than 1 500 m (5,000 ft.) support a dense vegetation cover, including alpine fir on well drained slopes and stunted black spruce, willow and arctic black birch on poorly drained valley bottoms.

Previous Geological Work

Earliest work by the Geological Survey in the region was by Kindle (1945), who carried out reconnaissance geological mapping during the summers of 1944 and 1945 along the route of the then recently completed Canol pipeline and road. Regional mapping by Blusson (1974), which includes the Macmillan Pass area, was released on Open File by the Geological Survey of Canada in 1974. Recent studies by Blusson (1976) have aided in defining the stratigraphic and tectonic settings of the TOM and JASON mineral deposits. This report draws heavily on unpublished diamond drill data kindly supplied by Hudson Bay Exploration and Development Company Limited. A preliminary account of the writer's field work during the summer of 1976 has been published (Carne, 1976).

Exploration History

Stratiform barite-lead-zinc mineralization on the TOM claims was discovered in 1951 by Hudson Bay Exploration and Development Company Limited prospectors working off the Canol Road. Development work by the company, primarily on the discovery or "West" zone during the period 1951 to 1953 consisted of geological mapping, sampling and trenching as well as 5 436 m of EX diamond drilling in 39 holes (Freberg, 1976). This operation is believed to be the first helicopter-supported diamond drilling program in the Yukon Territory (R.A. Freberg, pers. comm., 1976). Estimated reserves at this time were 10.47 million tons of material averaging 5% zinc and some lead (Green, 1965). Because of its remote location, the property lay idle until 1966 when a small crew resurveyed the original grid set up in 1951 and conducted geological mapping, geochemical soil surveys and a magnetometer survey (Freberg, 1976). Late in the 1967 season, an additional 1 675 m of BQ diamond drilling was carried out to evaluate a new soil geochemical anomaly discovered upslope and east of the discovery zone. The results of this work were encouraging and the company continued drilling in 1968 on the lead-rich new discovery or East zone as it became known. A total of 3 271 m of BQ diamond drilling in 16 holes was completed in conjunction with additional geochemical sampling and geological mapping. Reserves at this time were quoted at 5.1 million tons grading about 8% zinc, 8% lead and 2.7 oz/ton silver (Findlay, 1969).

During the summer of 1969, the company rebuilt the Canol Road from Ross River to the property and upgraded the existing airstrip (Craig and Laporte, 1970). A mining camp was established late in the season and an adit was collared west of, and downslope from the two showings (R.A. Freberg, pers. comm., 1976). During 1970 and 1971, the two mineralized zones were further delineated by a total of 1 887 m of underground development in conjunction with 2 363 m of underground diamond drilling. Additional AQ underground diamond drilling early in 1972 increased the total drilling on the property to 11 853 m (Archer, Cathro and Associates, 1972). Ore reserves are currently estimated at 9 million tons averaging 8.6% lead, 8.4% zinc and 2.8 oz/ton silver using an 8% combined lead and zinc cut off grade. Ten million tons of sub-ore grade material averaging 4.6% zinc, 0.9% lead and trace amounts of silver have been outlined (Archer, Cathro and Associates, 1972). Very little further physical work has been carried out on the property since culmination of the drilling program in 1972. A small crew was employed during August of 1976 to repair damage to the permanent trailer camp caused by an avalanche the previous spring. Additional soil sampling, trenching and geophysical surveys were carried out in the 1977 field season.

The JASON claims which adjoin the TOM property to the west (Figure 2) are owned by the Ogilvie Joint Venture (OJV)[1]. They were staked in August, 1974 and July 1975, following discovery of significant lead, zinc and barium soil geochemical anomalies. During June and July of 1975, geological mapping as well as geochemical and gravity surveys were conducted on the property. Zinc, lead and barium soil anomalies coincident with a gravity high led to definition of targets that were followed up by exploratory BQ diamond drilling in October, 1975. Seven holes were drilled totalling 640 m in length. Promising results and the intersection of stratiform barite-lead-zinc mineralization prompted an additional 2 163 m of BQ diamond drilling in 14 holes during the summer of 1976. Midway through the 1976 drilling program, diamond drill size was increased from BQ to NQ, and finally to HQ, in an effort to combat excess flattening of deep holes. Rotary drilling methods, using a small gas rig, which were employed during the summer of 1977, also proved unsatisfactory because of poor ground conditions. Controlled diamond drilling using HQ-size equipment with a Longyear 38 machine during the late summer and fall of 1977 resolved the flattening problems to the satisfaction of OJV geologists.

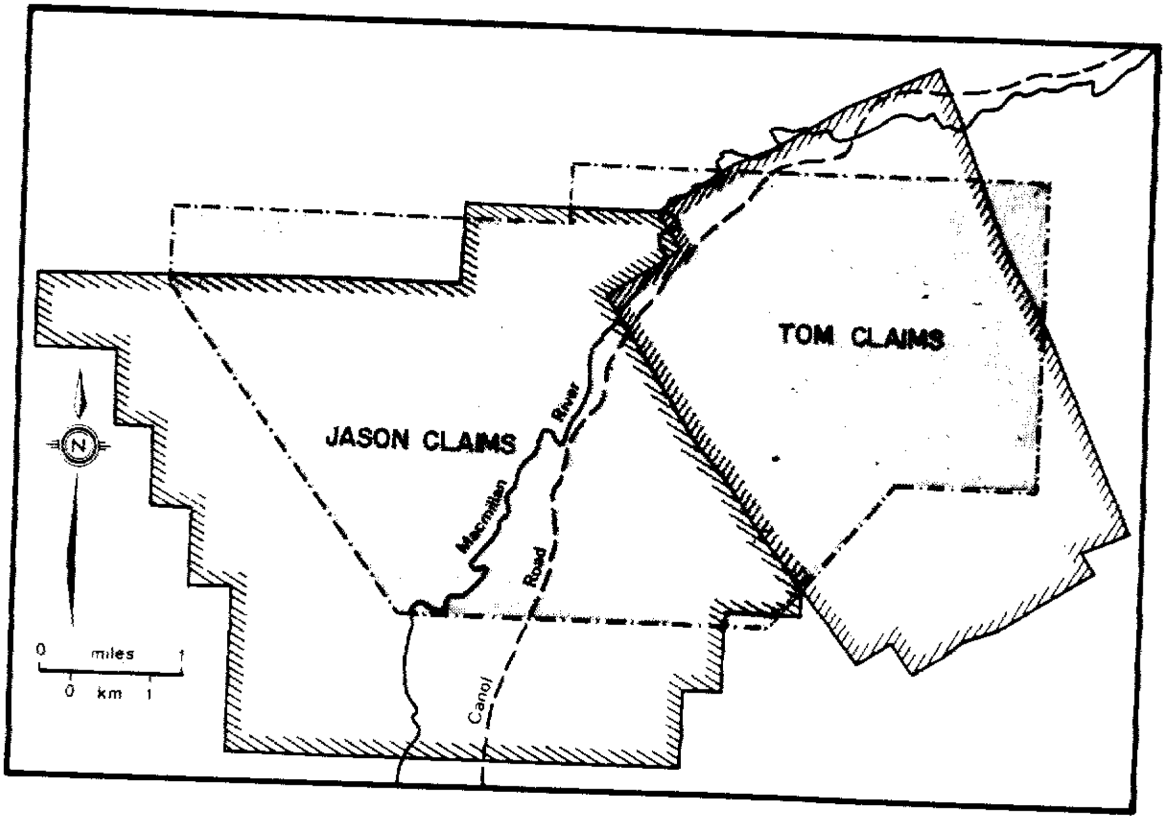

Figure 2. Location of area studied (shaded area) with respect to TOM and JASON claims.

Rumours of the discovery of "TOM-type" barite-lead-zinc mineralization on the JASON property precipitated a claim staking rush late in the summer of 1976 which covered most of the remaining favourable ground in the Macmillan Pass district.

[1]Ogilvie Joint Venture is a partnership consisting of C.L. Smith, Brinex, Ventures West Capital Ltd. and Mitsubishi Canada Ltd.

Acknowledgments

The writer acknowledges the kind co-operation of the staff of Hudson Bay Exploration and Development Company Limited, in particular R.A. Freberg and R. MacIntosh who extended permission to examine and sample underground diamond drill core and who provided plans and diamond drill records for the TOM deposit. Ogilvie Joint Venture personnel aided in permitting examination of diamond drill core from the JASON property and by providing the writer with copies of a contoured orthophoto of the Macmillan Pass area on which mapping control for this study was based. In addition, C.L. Smith and L.K. Lu were most helpful in discussions on the stratigraphy of the district.

S.L. Blusson and K.M. Dawson of the Geological Survey of Canada offered constant encouragement and elucidated correlations with regional stratigraphy. Analysis of samples for microfossils and whole-rock geochemistry which were carried out by the Geological Survey were submitted to K.M. Dawson and D.F. Sangster respectively.

R.J. Cathro and W.R. Roberts are gratefully acknowledged for their help and advice with the section of this report which deals with exploration parameters for "TOM-type" mineralization.

The present report is based on post-graduate research carried out at UBC in 1976 and 1977 under the supervision of C.I. Godwin, A.J. Sinclair and W.R. Barnes. Analytical costs were borne by a grant from the Department of Indian and Northern Affairs. Their support and assistance is gratefully acknowledged.

GEOLOGICAL SETTING OF MACMILLAN PASS AREA

The Macmillan Pass area is located near the east edge of the Selwyn Basin tectonic province (Figure 3) in southern Selwyn Mountains. Generalized geology of the district, compiled from several sources, is shown in Figure 4. Sedimentary rocks, ranging in age from Hadrynian to Lower Mississippian (?) are divided into five major lithological packages. The sequence contains three unconformities, one of regional extent beneath the Ordovician to Middle Devonian succession, a local unconformity beneath Upper Devonian strata and a locally occurring unconformity beneath the Lower Mississippian succession. Paleozoic beds have an estimated aggregate thickness of over 3 000 m. Large stocks and dykes of Late Mesozoic granitic rocks intrude the sedimentary sequence. Minor Eocene basaltic sills and dykes occur locally. Lithological descriptions which follow are compiled from field work by Roddick and Green (1961), Blusson (1971), Gabrielse et al (1973), Gordey (1978) and from the writer's field work in the area during 1976 and 1977.

"Grit Unit" and "Phyllite Unit"

"Grit Unit" is an informal name coined by Roddick and Green (1961) to describe Hadrynian clastic rocks which consist mainly of gritty quartzite, black and dark green shale and slate, calcarenite, conglomerates and lesser limestone. Quartzites contain distinctive bluish, opalescent quartz grains which are typically fractured and, in many places, consist of a patchy mosaic of areas with slightly different extinction. Large (granule sized) quartz grains are generally well rounded while smaller grains usually have subangular outlines. Tourmaline, hornblende and zircon are minor constituents locally.

Gabrielse et al (1973) use the term "Phyllite Unit" for a succession of Late Proterozoic to Lower Cambrian fine-grained clastic rocks which conformably overlie the older "Grit Unit". Lithologies consist of greyish green, non-calcareous phyllitic slates with minor interbedded very fine-grained quartzite and limestone.

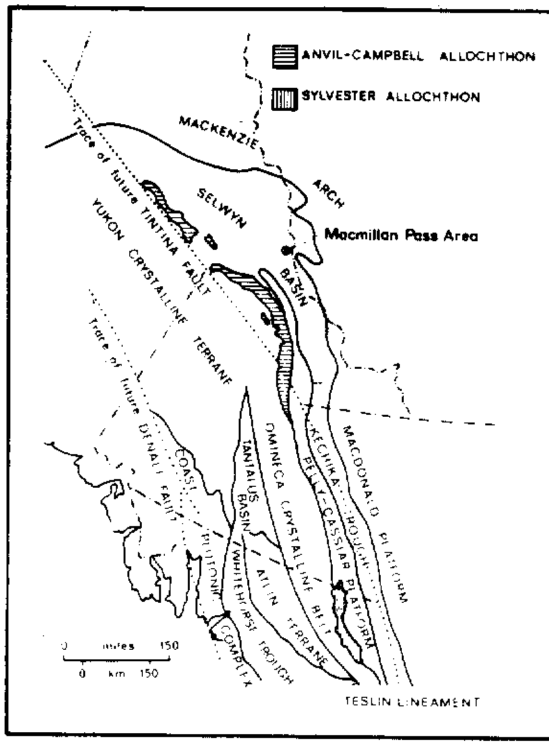

Figure 3. Tectonic elements of Yukon Territory before 450 km of right lateral movement on Tintina Fault (after Tempelman-Kluit, 1977 and Gordey, 1978).

Sekwi Formation

Lower Cambrian Sekwi Formation is characterized by an assemblage of brightly coloured, orange and yellow weathering dolomites, silty limestone and quartzite with interbedded dark recessive shale and argillaceous limestone (Gabrielse et al, 1973 and Gordey, 1978). Basic submarine volcanic flows and associated tuffaceous sedimentary rocks are an important component of the upper part of the formation in southernmost Selwyn Mountains. Platformal rocks of Sekwi Formation are probable time equivalents of parts of the "Phyllite Unit". The facies boundary between these rocks passes approximately through the centre of Figure 4 in a northwest-southeast direction. Both Sekwi Formation and the "Phyllite Unit" are eroded and, in places, entirely removed beneath a mid-Franconian (middle Upper Cambrian) unconformity of regional extent.

Road River Formation

Ordovician to Middle Devonian argillaceous and calcareous graptolitic rocks throughout northern Yukon, easternmost Alaska, Selwyn Basin and Kechika Trough are referred to as Road River Formation (Gabrielse, 1967). Lithologies consist largely of recessive, platy, thin bedded argillaceous limestone, calcareous shale and chert. In southern Selwyn Mountains, Road River calcareous shales and mudstones change facies eastwards to platformal carbonate rocks along a northwest-southeast trending belt which passes through the northeast corner of Figure 4. Southwest of Selwyn Mountains, Road River shales grade rapidly into sequences of varicoloured basinal cherts which underlie much of central Selwyn Basin (Blusson, 1971). In much of southern Selwyn Mountains, Road River lithologies lie unconformably on the Proterozoic "Grit Unit", Lower Cambrian "Phyllite Unit" and possible facies equivalents in Sekwi Formation (Gordey, 1978). To the east and southeast, where no significant hiatus is indicated, middle Paleozoic platformal carbonate rocks and basinal shales are conformable with silty limestones of underlying Upper Cambrian Rabbit Kettle Formation. Black, carbonaceous shales of Road River Formation host the large Howard's Pass stratiform zinc-lead deposit located about 100 km south of Macmillan Pass in Nahanni Map Area (105 I/6, 11, 12).

Canol Formation

The name Canol Formation was originally applied to black, siliceous, pyritic and non-fossiliferous Upper Devonian shales which occur near Norman Wells on the Mackenzie River (Basset, 1961). Rocks of the same age and similar lithology which occur in the Macmillan Pass area have been grouped with overlying coarser clastic rocks and informally referred to as the "Black Clastic Group". The lower silvery grey weathering black shale member of the "Black Clastic Group" has recently been tentatively assigned to the Canol Formation by Blusson (1976; cited in Dawson, 1977). Although this nomenclature has not achieved official recognition, it is applied here to facilitate discussion.

Shales and coarser clastic rocks of the "Black Clastic Group" blanket much of Selwyn Basin, Kechika Trough, Mackenzie Arch and northern Yukon. Canol Formation attains its greatest known thickness and lithological complexity in the Macmillan Pass area where it was deposited in an east-west trending, graben-like trough described by Blusson (1974 and 1976). Canol shales unconformably overlie Road River strata in Selwyn Mountains; however, no apparent unconformity of this age exists to the southeast in southern Mackenzie Mountains where the shales conformably overlie Middle Devonian carbonate strata of Nahanni and Headless Formations. According to Gabrielse (1967) and Tempelman-kluit and Blusson (1977), deposition of widespread Upper Devonian clastic rocks resulted from erosion of uplifted fault blocks within Selwyn Basin. The TOM and JASON stratiform barite-lead-zinc-silver deposits are contained within the Canol Formation, near its base and above a locally occurring, massive chert pebble conglomerate. Similar occurrences of barren bedded barite are present in numerous locations over a wide area extending from southern Kechika Trough to northern Mackenzie Mountains (Blusson, 1976 and R.J. Cathro, pers. comm., 1977). Barite deposits, which range in thickness from a few centimetres to 50 m or more, may attain a strike length of over 8 km.

Imperial Formation

Youngest sedimentary rocks exposed in southern Selwyn Mountains are the upper part of the "Black Clastic Group" which has been tentatively correlated with Imperial Formation (Hume and Link, 1945) of northern Mackenzie and Richardson Mountains (Blusson, 1976; cited in Dawson, 1977). In Selwyn Mountains, Lower Mississippian and (?) later Imperial Formation lithologies consist of resistant, massive siltstones, greywackes, conglomerates and shales. Basal members are separated from Canol Formation shales by a sharp lithological break which is locally an angular unconformity. Imperial Formation sediments are thought to have been derived, in part, from uplifted areas in the Barn and British Mountains near the Arctic Coast, but rapid, local facies changes in southern Selwyn Mountains are more indicative of complexly interfingered material derived from relatively local sources. Gordey (1978 and pers. comm., 1978) has mapped a fault near the Howards Pass area where Imperial Formation unconformably overlies juxtaposed Road River and Canol Formations.

Granitic Intrusive Rocks

Granitic stocks which occur in Selwyn Mountains are part of a belt of post-tectonic granitic intrusive rocks which fringe Selwyn Basin along its east and northeast edge. Dominantly granodioritic and quartz-monzonitic in composition, they are characterized by hornblende as the principal mafic mineral. Stocks generally lack foliation, have sharply defined contacts with few apophyses and are finer grained or, in part, porphyritic near contacts. Hornblende granodiorites of the Itsi Range (Figure 4) have been assigned a potassium-argon age of 96 million years (Baadsgaard et al, 1961) while biotite quartz-monzonites in southern Mackenzie Mountains (Flat River map-area, 95 E) yield a potassium-argon age of 110 million years (Leech et al, 1963).

Rusty weathering contact aureoles up to 600 m wide are most strikingly developed in fine grained clastic rocks. Pelitic hornfels consist primarily of sericite, muscovite, quartz and biotite with rare andalusite and graphite. Impure limestones are relatively unchanged in appearance by contact metamorphism except that differential weathering of silty banded limestones is accentuated by growth of new minerals. Highest grade mineral assemblages in these rocks consist of diopside, tremolite, idocrase, garnet, epidote, and rarely, potash feldspar, plagioclase, sphene and biotite. Sandy and silty dolomite and dolomitic sandstones are altered to mixtures of tremolite, diopside, quartz and carbonate minerals. The large Mactung tungsten deposit, located along the Yukon-Northwest Territories border (Figure 4), is contained within a skarn developed in Lower Cambrian limestone-shale breccias (Dawson and Dick, 1978).

Basaltic Intrusive Rocks

A minor occurrence of porphyritic, hornblende-biotite basalt sills is exposed near Kilometre 425 on the North Canol Road, about 10 km west of the Yukon-Northwest Territories border. Potassium argon analyses of biotite and hornblende separates from the rock indicate an Upper Eocene (40 my) age (Godwin et al, 1979).

Structural Geology

Northwesterly trending, northerly plunging open folds are the dominant structures developed in rocks of southern Selwyn Mountains. Isoclinal folding is more commonly developed in pelitic rocks of Selwyn Basin than in carbonate platformal equivalents to the northeast. Steeply dipping reverse faults which parallel the regional fold trend commonly die out in the cores of anticlines and are probably related in time to the regional deformation. Axial plane cleavage is best developed in pelitic rocks and, to a lesser degree, in carbonate rocks while only relatively competent sandstone and conglomerate beds lack cleavage. Steeply dipping, northeasterly trending normal faults cross-cut and displace earlier regional structures. Axial plane cleavage associated with regional deformation predates mid-Cretaceous granitic intrusions. Minor, small scale doming, folding and block faulting of country rock accompanied intrusion of the stocks.

A belt of east-west trending, isoclinal folds and vertical faults cross-cuts northwesterly trending structures of central Selwyn Mountains in the Macmillan Pass district (Figure 4). Fold axes and well developed axial plane cleavage are steeply dipping to slightly overturned. This structural belt is terminated at its eastern limit by northerly trending normal faults in a region located about 40 km east of the Macmillan Pass area. Although this deformation is likely post-Paleozoic in age, preliminary stratigraphic studies show that it may coincide with an Upper Devonian graben-like trough. Trend and location of these structures then, may be influenced by pre-existing structural anomalies.

GEOLOGY OF MACMILLAN PASS AREA

Stratigraphy

The Macmillan Pass area is underlain by clastic sedimentary rocks of the Upper Devonian to Mississippian and (?) later "Black Clastic Group". The lower part of the "Black Clastic Group" is correlative with Canol Formation black shales of the Norman Wells area, Northwest Territories, while the upper part is similar to Imperial Formation of northern Yukon Territory. Formation nomenclature, although not officially accepted for these rocks, are tentatively applied here on the basis of stratigraphy and spotty fossil evidence. Detailed geology of the Macmillan Pass area is shown in Figure 5. Stratigraphy is summarized in Figure 6. Units 1, 2, 3a and 3b of Figures 5 and 6 are assigned to Canol Formation while map units 4a and 4b are tentatively assigned to Imperial Formation. Paleozoic clastic sedimentary rocks are intruded by Cretaceous quartz-feldspar porphyry dykes genetically related to a large hornblende-biotite granodiorite stock which lies a few kilometres south of the detailed study area (Figure 4).

Canol Formation

Unit 1

Relatively recessive lithologies mapped as Unit 1 are well exposed in steeply dipping beds which form the core of an anticline bordering the northwest edge of the detailed map area (Figure 5). Unit 1 is poorly exposed in uplifted fault blocks which occur in the southwestern part of the area and near the east edge of Figure 5 where the core of an anticline is cut by a cirque. Only the uppermost 45 m of Unit 1 were observed.

Lithologies consist primarily of grey weathering, black silty shales interbedded with grey sandy siltstones. Shale beds range from 1 cm to 4 cm thick and average about 2 cm. Sandy siltstone interbeds are much more variable in thickness, ranging from a few millimetres to accumulations over 5 cm thick. Overall shale-siltstone ratio of these rocks is about 5:1. This ratio decreases slightly toward the top of the unit due to an overall increase in thicknesses of the sandy siltstone component with respect to shale. Silty shales consist of a fine-grained mixture of clay minerals and opaque organic matter. A few silt-size clots of sericite are present as are scattered well rounded silt-size quartz grains. Framework of sandy siltstone beds is predominantly composed of subangular to subrounded quartz grains which range in size from less than 0.01 mm to 0.5 mm in long diameter. Subrounded to well rounded silt-sized argillaceous chert grains make up about 15% of the rock. Scattered masses of matted kaolinite and sericite with subequant to subrounded outlines may be alteration products of detrital feldspars. Nearly 40% of the rock is composed of a matrix of clay minerals and opaque organic matter which is poorly cemented by cryptocrystalline quartz. The amount of matrix material varies locally; in places, quartz and chert framework clasts are in point contact while, in the majority of cases, framework grains "float" in matrix material and cement.

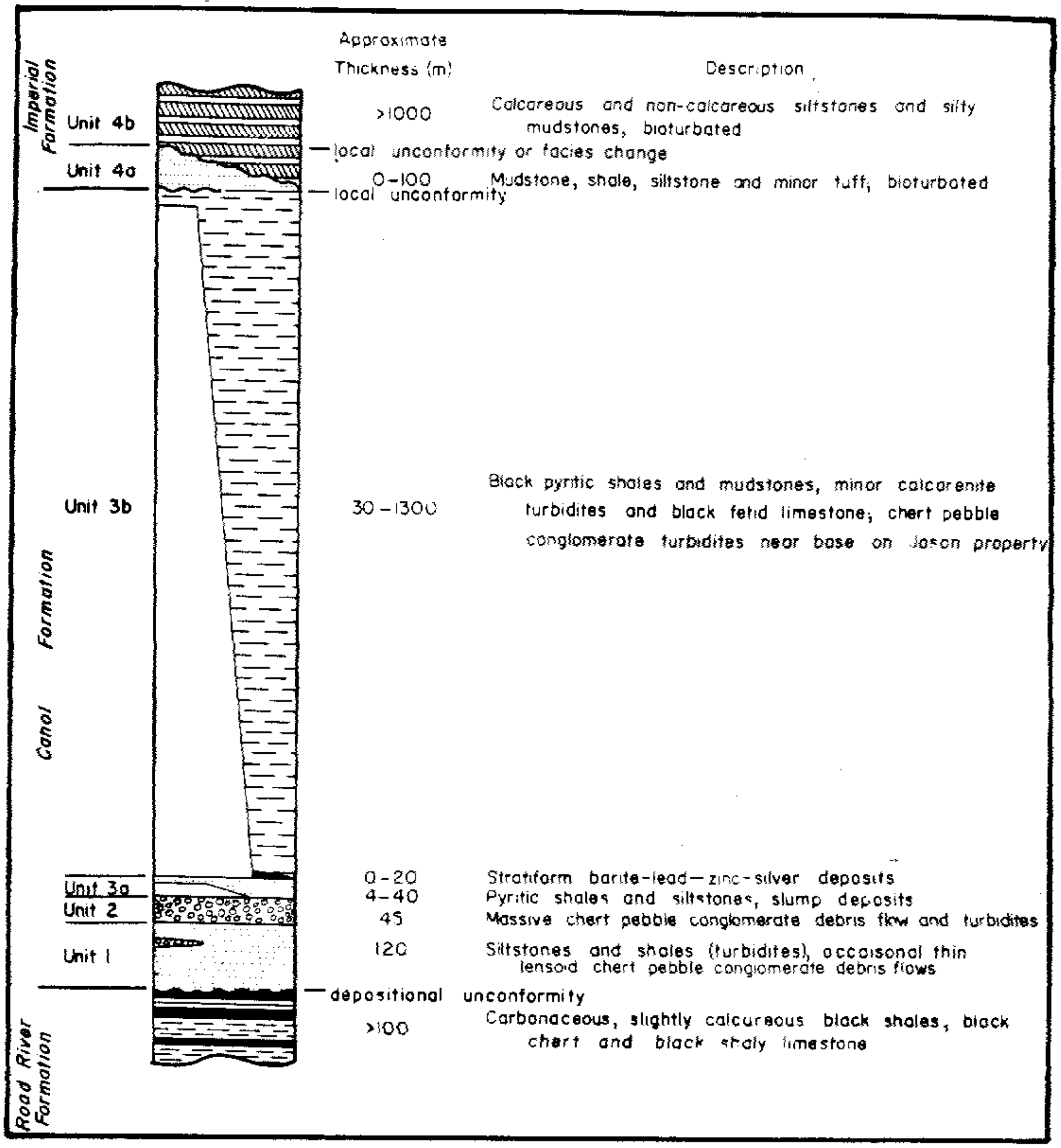

Figure 6. Generalized stratigraphy of Macmillan Pass area

Cubic pyrite crystal casts are common in sandy siltstone beds (Plate A). Limonitic staining of the rock, resulting rock oxidization of this pyrite, is conspicuous as brown bands aligned along bedding planes. Oxidation of pyrite does not appear to be merely a surface weathering effect since limonite and pyrite crystal casts are always present in diamond drill core of Unit 1, even when taken from considerable depths.

Sandy siltstones do not generally show well developed graded bedding although a general concentration of sand size grains is noted at bases of thickest units. Basal contacts are sharp and seldom show features indicative of erosive deposition although flute casts and sole markings are present on exposed bases of some of the thicker beds (Plate B). Load casting of sandy siltstones into underlying silty shales is common, grading into incipient ball and pillow structures with increasing thickness of sandy siltstone units. Parallel lamination is commonly well developed near the base of thicker beds while upper parts usually display well developed low angle cross-lamination. Upper surfaces of sandy siltstone beds are sharp and frequently rippled.

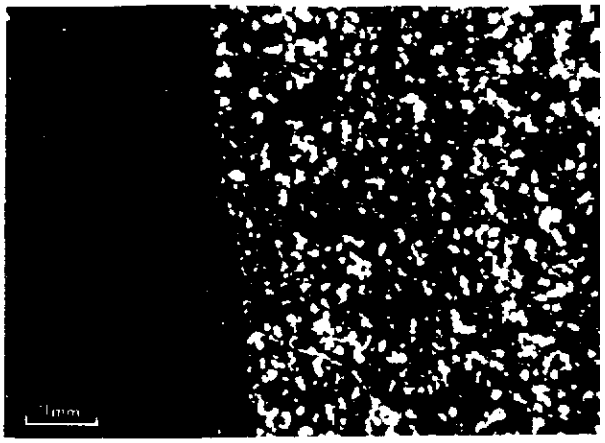

Plate A. Photomicrograph (crossed nicols) of basal contact of Unit 1 turbidite. Note the large pyrite crystal casts (black).

Plate B. Groove and flute casts on the basal surface of a Unit 1 turbidite.

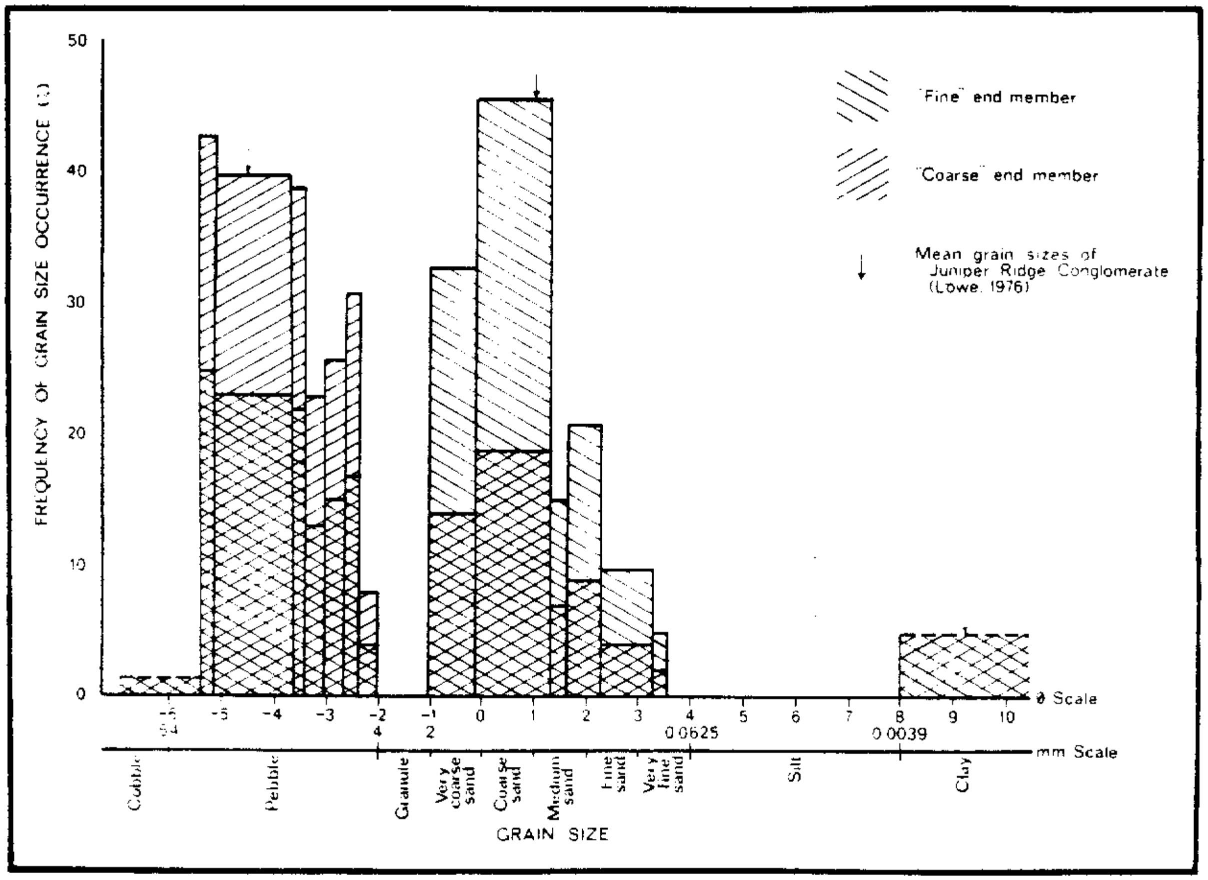

Figure 7. Frequency vs grain size for Unit 2 massive conglomerate.

Finely interbedded silty shales and sandy siltstones with sand:shale ratios of one or greater are characteristic of the deep water, distal turbidite facies as proposed by Walker and Mufti (1971). Load and flute casts are also common characteristics of turbidity current deposits (Davies and Williamson, 1976). However, the absence of well defined graded bedding and the presence of parallel lamination, small scale cross-lamination and abrupt, rippled tops in many thin sandy siltstone beds is more characteristic of distal turbidity current deposits which have been reworked by bottom-flowing currents. These deposits are termed contourites, as defined by Bouma (1973). Following these considerations, it is likely that normal pelite deposition was periodically interrupted with sand and silt influxes carried by turbidity currents. Reworking, redistribution and winnowing of coarse material was effected by contour-following bottom currents.

Contact relationships of Unit 1 with underlying calcareous shales of the Road River Formation were not determined in the Macmillan Pass area. Correlative rocks which occur at the base of Canol Formation near Howard's Pass overlie Road River lithologies along a sharp but apparently conformable contact.

No fossils or trace fossils were seen in rocks of Unit 1. An ammonite was collected in 1976 by J.A. Morin from a dense, black, non-calcareous mudstone which underlies beds of Unit 1 about 1 km east of the detailed study area (J.A. Morin, pers. comm., 1976). The fossil was subsequently identified as Ponticeras cf. P. tschernyschewi (Hozapfel) of Upper Devonian (Frasnian) age by W.W. Nassichuk at the Institute of Sedimentary and Petroleum Geology in Calgary. The species has previously been identified from above the Kee Scarp Formation on Carcajou Ridge, Norman Wells area, where it occurs in unnamed beds just below the Canol Formation (W.W. Nassichuk, pers. comm.; Report No. I-WWN-1977).

Unit 2

Relatively resistant chert pebble conglomerates of Unit 2 are well exposed on both the TOM and JASON properties, forming prominent ridges and scarps on rugged hillsides and low glaciated ridges and hills in lowlands of the Macmillan River valley. Lithologies consist of massive resistant chert pebble conglomerate with a thin capping sequence of less resistant, coarse-grained chert turbidites with interbedded, recessive, black silty shales. Although both the conglomerate and coarser members of the turbidite sequence are extremely well indurated, they are usually strongly jointed and are consequently very susceptable to frost heaving. All but the steepest exposures are covered with a variable thickness of locally derived felsenmeer. The massive conglomerate exhibits considerable variation in thickness, ranging locally from [illegible] m to 240 m. A complete section of the capping turbidites was only seen in exposures and diamond drill core from the TOM property where it measures about 6.4 m in thickness.

Although the massive conglomerate displays no suggestion of sedimentary fabric, such as bedding or imbrication, sorting or size grading of clasts, two extremes of grain size distribution are apparent: a "coarse" end member in which the majority of the rock is composed of pebble sized clasts (4 mm to 6 mm in maximum diameter); and a "fine" end member in which most of the clasts are sand sized (0.0625 mm to 2 mm in maximum diameter). Frequency histograms of clast size for each end member are shown in Figure 7. Although both end members exhibit a dramatic variability in grain size, each are overwhelmingly trimodal. Three grain size populations are present:

(a) gravel, consisting predominantly of pebbles with a modal maximum diameter of -4 on the phi scale (63 mm),
(b) sand, mainly coarse sand with a modal maximum diameter of approximately 1 on the phi scale (0.5 mm), and
(c) minor amounts (less than 5%) of clay sized material.

Both the granule classification, ranging in size from -1 to 2 phi (2 mm to 4 mm), and the silt sized fraction, ranging in phi from 8 to 4 (0.0039 mm to 0.0625 mm) are missing from the distributions. This phenomena may be due to bias introduced by grain size measurement procedures, presorting in the source area of the clasts or sorting and/or preferential abrasion of these grain sizes in transportation to the site of deposition of the conglomerate. Since measurement of maximum grain size was rigorously conducted it is unlikely that measurement bias is responsible for the trimodality of the distributions.

The coarse-grained nature of the conglomerate permits a detailed examination of its constituents. The rock is composed of at least eleven distinctive types of framework grains whose charcteristics are summarized below.

Clast Type I: well rounded, mottled light grey and dark grey chert grains which are predominantly composed of cryptocrystalline quartz (97%), microcrystalline clay minerals (less than 3%) and minor silt size detrital quartz grains are the most common framework grains in the conglomerate. Clay mineral particles are randomly oriented and uniform in size. The mottled appearance of the chert is due to patchy areas of recrystallized quartz.

Clast Type II: Dark grey chert grains with subangular, elongate outlines form about [illegible]% of the coarse material in the conglomerate. Twenty-five to thirty per cent of the chert is composed of spheroidal masses of interlocking microcrystalline quartz, probably recrystallized radiolaria. Bulk of the chert is predominately cryptocrystalline quartz and lesser clay mineral flakes and organic(?) matter.

Clast Type III: Dark grey to black chert grains with conspicuous light grey peripheral rims form about 15% of the framework clasts in the conglomerate. They are composed mainly of cryptocrystalline quartz (about 95%), up to 3% sub-opaque to opaque organic(?) matter and approximately 2% sericite or clay mineral flakes which have subparallel alignments. They are usually pyritic and rarely contain recrystallized radiolaria "ghosts". Light grey rims which range in width from 0.6 mm to 8.5 mm appear to be primarily due to leaching or oxidation of organic(?) matter and pyrite, perhaps in a subaerial environment (Plate C). Although their sizes range from 5 mm to 40 mm in maximum diameter, they are remarkably well rounded and almost entirely oblate in shape where more than one dimension was observed. Bedding(?) in clasts, represented by subparallel alignment of micaceous minerals, inevitably parallels the long axes of the clasts.

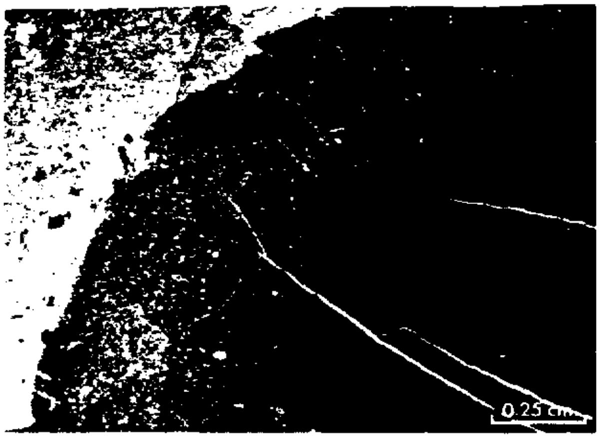

Plate C. Photomicrograph (plane light) showing detail of bleached and oxidized rim of an oblate, dark grey chert pebble (Clast Type III) in Unit 2 massive conglomerate.

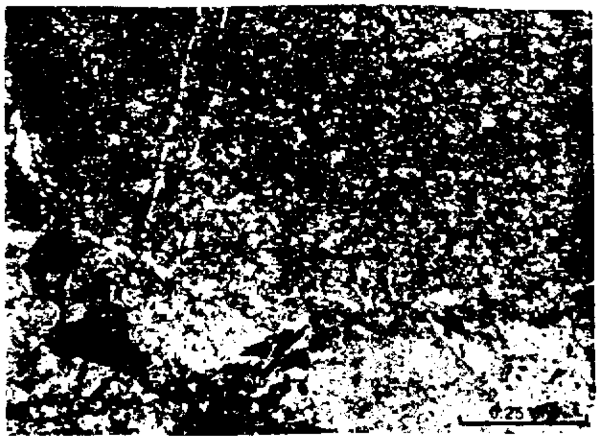

Plate D. Photomicrograph (plane light) of radiolarian chert pebble (Clast Type VI) in Unit 2 massive conglomerate. Note pressure solution of framework grains where they are in point contact.

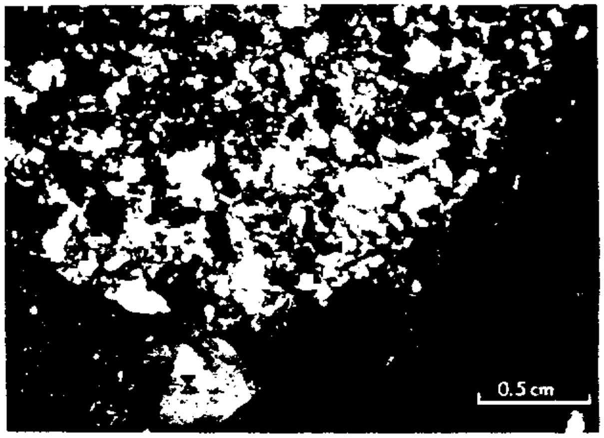

Plate E. Photomicrograph (crossed nicols) of Unit 2 massive conglomerate showing well rounded quartzite pebble (Clast Type VII) and polycrystalline quartz grain (Clast Type X).

Clast Type IV: Well rounded, white chert pebbles which are composed of a patchy mosaic of microcrystalline and cryptocrystalline quartz make up about 7% of the coarse framework grains in the conglomerate.

Clast Type V: Pyritic, carbonaceous and siliceous black shale fragments with elongate, angular outlines are often plastically deformed around other framework grains. They comprise less than 5% of the coarse fraction in the conglomerate. Their relatively angular outlines in conjunction with their apparently poorly lithified nature when deposited suggest that they may have been picked up as bed load from underlying sediments during transportation of the conglomerate.

Clast Type VI: Subangular, equant-shaped grains of banded, light grey chert are almost totally composed of "ghosts" of radiolaria (?) 0.06 mm to 0.3 mm in diameter (Plate D). Megascopic banding is due to the presence of a small amount of carbonaceous material concentrated in zones parallel to bedding(?) in the clasts. Light grey banded chert grains make up about 5% of the coarse fraction.

Clast Type VII: Less than 4% of the conglomerate is composed of very well rounded orthoquartzite pebbles (Plate E). Pebbles are dominantly composed of monocrystalline, sand-size quartz grains which usually show straight to slightly undulose extinction. Grain boundaries have been altered by the addition of quartz overgrowths in optical continuity with the grains, or by pressure solution along grain-to-grain contacts. Minor amounts of clay and carbonate minerals are present as matrix material. Silt sized detrital igneous minerals such as biotite, hornblende and zircon are present in trace amounts.

Clast Type VIII: Monocrystalline sand-size grains of very well rounded and subspherical clear quartz make up about 3 to 8 per cent of the conglomerate. In hand specimen, this quartz has a distinctive, opalescent blue colour. Majority of the grains show straight extinction, while the remainder show slightly undulose extinction.

Clast Type IX: White, monocrystalline quartz grains with subrounded outlines and very low to moderate sphericity comprise about 2% to 5% of the rock. Minute, fluid-filled inclusions are ubiquitous throughout, imparting a cloudiness or white colour to the quartz.

Clast Type X: Polycrystalline quartz grains with well rounded, subequant shapes and strongly undulose extinction make up about 2% of the rock (Plate E).

Clast Type XI: Miscellaneous igneous accessory minerals such as biotite, zircon and hornblende are found in trace amounts in the conglomerate.

Broadly speaking, constituents of the Unit 2 chert pebble conglomerate represent two different types of source lithologies. Bulk of the framework grains are moderately rounded to well rounded chert sand and pebbles of various types. Remainder of the framework clasts are composed of relatively mature quartz sand and minor quartzite pebbles.

Overall texture of the conglomerate does not vary appreciably. No preferred orientation of clasts, such as imbrication, is present. Size grading of clasts or indications of bedding are not present. The only sorting of grain size is an apparently random differentiation between a predominance of relatively coarse, pebble sized clasts and a predominance of sand sized framework grains. Coarse clasts "float" in a matrix of finer grains, a clay matrix and cryptocrystalline quartz cement. Sutured grain contacts are present only where packing of coarser clasts is sufficiently close enough to allow pressure solution of adjacent grains.

The massive Unit 2 conglomerate displays most of the characteristics peculiar to debris flow deposits. Debris flows are described as thick grain flows of gravel and sand sized material modified by the presence of interstitial plastic mud (Lowe, 1976). The Juniper Ridge conglomerate, a submarine debris flow of Upper Cretaceous age located in northern California, consists of gravel, sand and clay in the following proportions (Lowe, 1976):

	Mean diameter (mm)	Composition (%)
Gravel	18.5	65
Sand	0.05	23
Clay	0.002	3
Porosity		9

The mean diameters of clasts in the Unit 2 massive conglomerate are almost identical to the Juniper Ridge debris flow (Figure 7). Debris flow deposits generally lack internal bedding attributes and commonly show unsupported framework grains (Fisher, 1976). Experimental work and theoretical analyses suggest that clasts can comprise more than 35% of the debris volume and yet have essentially no influence on the gross strength of the mixture (Rodine and Johnson, 1976).

Erosional remnants of chert pebble conglomerate similar to the Macmillan Pass occurrence blanket much of Selwyn Basin (Blusson, 1976 and Gabrielse, 1977). However initial regional studies of the "Black Clastic Group" give no indication of the number or areal extent of individual debris flows involved or whether or not these conglomerates were formed by some other process, such as deposition by turbidity currents. No detailed paleocurrent determinations were made for the Unit 2 conglomerate because of its massive nature, but broad scours present along its basal contact indicate an east to southeasterly direction of transport. In addition, a westerly provenance may be inferred from constituents of the conglomerate. Source terrane for chert and cherty argillite clasts may have been Lower Paleozoic basinal cherts of the Road River Formation, while quartzite pebbles and relatively mature quartz sand may represent second generation material derived from erosion of underlying Proterozoic "Grit Unit" lithologies.

Relatively resistant, thick bedded turbidites which overlie the massive chert pebble conglomerate are best exposed near the southeastern corner of the detailed map area (Figure 5). Thickness of the turbidite section here is 6.4 m. Turbidite divisions A, B, C, D and E (Bouma, 1962) are generally present along with diagnostic sedimentary textures such as, load casts, groove casts, ripple cross-lamination and graded bedding. Sedimentary framework of divisions A, B and C is composed of various types of chert and quartz grains similar to those which form the bulk of the underlying massive conglomerate. In the turbidites however, sand size quartz grains, generally predominate over the usually larger clasts except at the base of the thickest turbidites where grain size is generally coarser.

Paleocurrent measurements for the turbidites based on assymetrical ripple mark and flute cast orientations locally indicate deposition from east to southeasterly flowing turbidity currents.

In a few localities within the Macmillan Pass area, the evenly bedded turbidite succession shows evidence of extreme soft sediment deformation by slumping and sliding. Intraformational conglomerates and large-scale recumbent isoclinal folds developed in these rocks are probably indicative of post-depositional instability developed by oversteepening. On the TOM claims in the east part of the district, where these features are best exposed, vergence of recumbent folds and imbrication of intraformational conglomerate clasts suggests a westerly sense of movement.

Unit 3a

Lithologies of Unit 3a are best exposed in the beds of westerly flowing creeks which drain the eastern part of the TOM property. Well exposed sections of the unit are present on the north limb of the large syncline on the JASON claims. Frost heaved felsenmeer and talus float are typical of most exposures in the area. Although Unit 3a commonly exhibits a high degree of lithological variability, it is best distinguished in the field from similar appearing lithologies of Unit 1 by its deep brown weathering colour and its very pyritic nature.

A section through Unit 3a which was measured in the bed of a creek flowing down a steep slope immediately west of the TOM West Zone stratiform mineralization is shown in Figure 4. At this locality, the majority of the map unit consists of finely interbedded, porous silty sandstone and faintly laminated black, pyritic shale. Silty sandstone beds range from a few millimetres to nearly one-half metre thick. Thickness of beds and laminae are locally variable, pinching and swelling along strike. Even deposition of thin beds was mildly erosive, as illustrated by the common occurrence of flute casts and scour marks. Silty sandstone beds do not generally exhibit size grading of clasts. Tops of these intervals are usually sharp and featureless. Sand and silt sized grains are predominantly composed of well rounded, abundant quartz and subordinate, moderately to well rounded chert. Matrix of the rock is composed of clay mineral particles, cement is cryptocrystalline quartz.

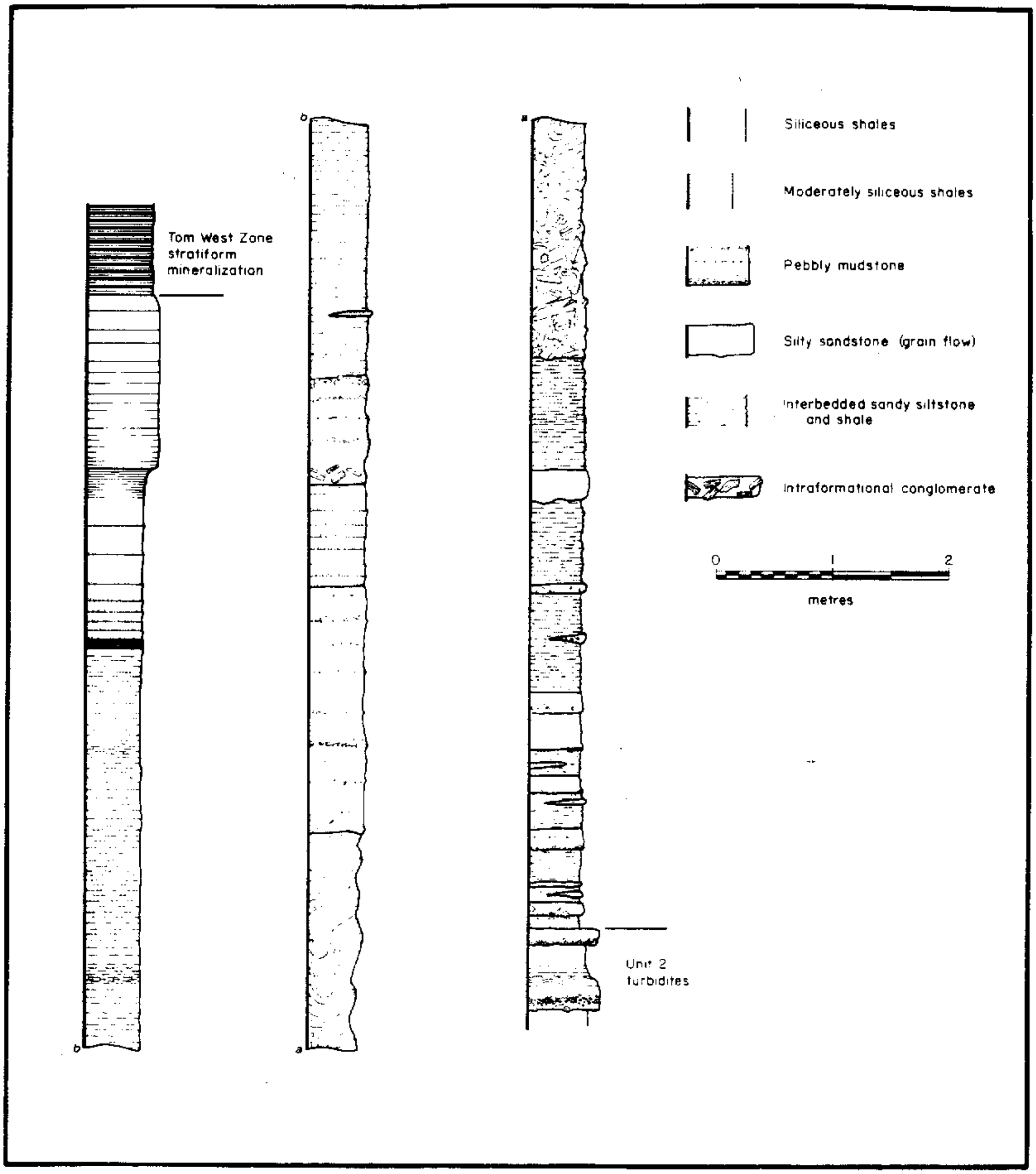

Figure 8. Detailed stratigraphy of Unit 3a in an area immediately underlying TOM West Zone stratiform barite-lead-zinc mineralization.

A thick sequence of contorted, interbedded silty sandstone and shale is present in the lower half of the observed section of Unit 3a. Bedding near the base of this sequence is extremely contorted and disrupted (Plate F). A similar occurrence of convolute bedding is located approximately 300 m north of the described section. At this locality, convolute bedding is contained within an elongate body with a lenticular cross section and a maximum thickness of about 10 m.

Two relatively thick sequences of pebbly mudstone lie above the convolute bedding in the former location. Pebble and sand sized framework grains are imbedded in a very fine grained, carbonaceous mudstone matrix (Plate G). Upward fining of framework clasts is well developed with reverse grading occasionally present. Pebbles are composed of well rounded chert of several types, all of which are present in underlying Unit 2 conglomerate and turbidites. Finer clasts are predominantly moderately well rounded quartz grains while well rounded sand size chert grains are present in lesser amount. Bases of both pebbly mudstone sequences are marked by beds of intraformational conglomerate.

Aside from pebbly mudstone and intraformational conglomerate intervals, overall grain size and siltstone/shale ratio of Unit 3a decrease to the top of the measured section, where the footwall to the overlying TOM West Zone stratiform mineralization is composed of evenly fine grained pelitic rocks.

Sections of Unit 3a observed elsewhere in the Macmillan Pass area are more lithologically and texturally uniform. For example, a section measured in a creek bed about 400 m south of the previously described location contains very few contorted beds and no intraformational conglomerate or pebbly mudstone. In the northwest corner of Figure 5, Unit 3a consists of evenly bedded thin siltstone and shale. On the north limb of the large syncline in the northwest part of Figure 6, Unit 3a consists of finely interlaminated siltstone and shale in what is best described as a "pinstripe" texture. Siltstone laminae rarely exceed 5 mm in thickness, while average thickness of shale interbeds is about 3 cm. Moving southward from this location, siltstone laminae rapidly increase in relative thickness and a few thin intraformational conglomerate and pebbly mudstone intervals are present.

Inspection of drill core from rocks which stratigraphically underlie the JASON barite-lead-zinc horizon reveals that lithologies of Unit 3a are radically different in this area. Pebbly mudstone, chaotic intraformational conglomerates and breccias, and chert pebble conglomerate beds up to 2 m thick dominate the section. In places, muddy matrix material of the conglomerates and breccias makes up over 50% of the rock volume; more commonly, matrix is subordinate in proportion to well rounded chert of angular lithic clasts. According to detailed studies by OJV geologists of diamond drill core from the JASON claims, both the average thickness of these beds and the modal grain size of their constitutents locally decrease rapidly to the northeast (C.L. Smith, pers. comm., 1977). In contrast, thickness of Unit 3a on the TOM claims, as measured from diamond drill sections, increases systematically to the north and west accompanied by a general decrease in overall grain size.

Beds of Unit 1 and Unit 2 clastic rocks are relatively constant in thickness, texture and lithology throughout the Macmillan Pass area. Their lateral continuity and uniformity is inferred to be a consequence of the more regional uniformity of their depositional setting. In contrast, characteristics of overlying Unit 3a lithologies are highly variable. Correlation between exposures is difficult to make and would be virtually impossible if not for the distinctive dark brown weathering colour of the map unit coupled with its well defined stratigraphic position.

Plate F. A 25 cm thick poorly sorted slump debris deposit which occurs near the base of Unit 3a on the TOM claims. Contorted siltstone intraclasts are outlined.

Plate G. Photomicrograph (plane light) of pebbly mudstone (Unit 3a).

Chaotic accumulations of pebbly mudstones and intraformational conglomerates and breccias with interbedded finer grained clastic rocks are often referred to as olistostromes (Abbato et al, 1970; Hsu, 1974). In the strictest sense, however, true olistostrome deposits are more regional in extent than the scattered slump and slide debris present in the Macmillan Pass area, although a similar depositional setting may be inferred. Instability of sediments caused by local tectonic activity such as rapid differential subsidence of the seafloor accompanied by earthquake shocks may be responsible for the high local variability and disrupted nature of Unit 3a. The likely derivation of coarse clastic material from Unit 2 sediments and its subsequent incorporation into pebbly mudstones of Unit 3a is critical in this context. In addition, indicated directions of transport for this material are diametrically opposed to those determined for underlying beds of Unit 2, suggesting a rapid change in depositional regimes.

Unit 3b

Distinctive silvery grey weathering, pyritic black shales and associated coarse clastic rocks of Unit 3b underlie most of the Macmillan Pass area. Lithologies weather recessively and outcrop is generally limited to siliceous members (Plate H). Non-siliceous shales are exposed as small, and usually slumped, outcrops along the sides of creeks and avalanche gullies or, most commonly, as small talus fragments and felsenmeer. Base of the unit is best seen in creeks draining the TOM property and in diamond drill core from both TOM and JASON claims. Unfortunately, because of the structural compelexity of rocks in the area immediately adjacent to the JASON mineralization, direct correlation of lithologies is difficult at this stage and will not be attempted for the present study. Detailed examination of diamond drill core from this area has, however, provided insight into the general nature of the stratigraphy of otherwise poorly exposed sections of Unit 3b.

Plate H. Typical exposure of recessive, silvery grey weathering black shale (Unit 3b), JASON claims.

Lowermost 400 m of Unit 3b are best observed in core from JASON Diamond Drill Hole 8 (JDDH 8), collared approximately 100 m south of the Canol Road near the TOM-JASON property boundary (Figure 5). Here, the lowermost section of Unit 3b is composed of a fining upward sequence of gritty black pyritic shale interbedded with poorly sorted debris flow deposits and coarse turbidites with well developed A-E Bouma divisions. Coarse framework grains of debris flow deposits and turbidites are moderately well rounded to very well rounded chert pebbles similar to those which form the bulk of framework grains in Unit 2 and coarse clastic members of Unit 3a. Finer framework grains are subangular to well rounded quartz with subordinate amounts of well rounded chert sand. Thickness of individual coarse clastic beds ranges from a few centimetres to several metres, usually separated by varying thicknesses of gritty to uniformly fine grained black pyritic shale. A general thinning and upward fining of coarse clastic beds is present. Similar horizons are not present in exposures of lower Unit 3b on the TOM property, a few kilometres to the east. Minor intraformational conglomerates interbedded with gritty black shale on the north JASON claims are probably correlative.

The overlying 250 m of Unit 3b, as seen in JDDH 8, consists largely of evenly fine grained black pyritic shale interbedded with pyritic calcarenites. Coarse clastic beds are thin and frequently grouped in clusters with thickest beds at the base of each cluster, thinning and fining upsection through successive clusters. These turbidites, in contrast to underlying coarse clastic rocks, consist primarily of Bouma divisions C and D (ripped or wavy laminae and upper parallel laminae). Framework clasts consist of detrital pyrite, micrite, shale fragments, quartz grains and organic debris including calcisphere and radiolaria fragments.

The lower 400 m of Unit 3b are well exposed in creek beds draining the southeast part of the TOM property. The unit here, on the whole, consists of uniformly fine grained, carbonaceous black shales. Shale beds vary in thickness from thin and platy (less than 2 cm) to very thick and massive (as much as 1 m). Thickest beds tend to be very carbonaceous and non-siliceous, as demonstrated in the field by their soft and "sooty" nature. Thinner beds are generally harder to the knife blade, perhaps indicative of a higher degree of silica cementation. A sequence of very porous and siliceous rock was observed in the bed of a creek draining the south part of the TOM property, near the portal and about 320 m stratigraphically above the base of Unit 3b. These beds outcrop over a strike length of at least 1 200 m while thickness of the whole sequence ranges from 0.3 m to 1.2 m. Individual beds are composed of upward fining, silt to granule sized angular black shale fragments. Minor moderately well rounded detrital quartz grains and trace amounts of recrystallized radiolaria(?) are also present. Basal parts of the beds are heavily stained with iron oxides. Approximately 40% of the total rock volume is pore space. Voids are roughly equant with angular outlines. They appear near the base of each bed and "fine" upward, increasing in frequency of occurrence until the beds take on the appearance of pumice. Porous beds on the TOM property likely represent the surface weathered equivalents of pyritic, calcareous turbidites seen in core from JASON Diamond Drill Hole 8. Void space is likely from surface leaching of carbonate clasts dissolved by acidic groundwaters released by the oxidation of detrital pyrite in the rock.

Plate I. Photomicrograph (crossed nicols) of Unit 3b *black fetid limestone. Note undulatory* extinction and curved cleavages of calcite.

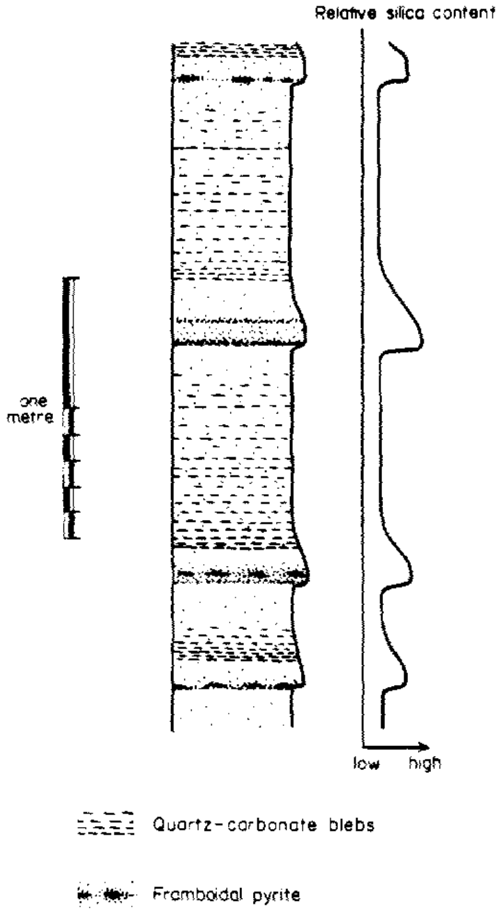

Figure 9. Typical section of framboidal pyritic and "blebby" shale, Unit 3b.

At least four distinct beds of black weathering, dark grey, fetid limestone lie within the lower half of Unit 3b. Bed thickness ranges from 10 cm to about 35 cm. The limestone is almost pure calcium carbonate. Microcrystalline quartz and very finely disseminated euhedral pyrite are present in trace amounts. Calcite occurs as irregularly shaped, monocrystalline masses with grain sizes ranging up to 3 mm in diameter. Individual crystals have undulose extinction and unusually curved cleavage traces (Plate I). Since cleavage directions and undulose extinction are randomly oriented, it is unlikely that these phenomena are inherited from strain induced recrystallization of the limestone.

JASON Diamond Drill Hole 8 intersected a 240 m section of black, pyritic and very siliceous shale which contains conspicuous "blebs" or flattened nodules of quartz-carbonate composition. An additional 220 m of similar "blebby" shale is exposed upsection in sporadic outcrop directly south of the drill hole collar. Composition of the blebs is uniformly about 80% microcrystalline calcite, the remainder being composed of microcrystalline quartz. A few large blebs contained trace amounts of pyrite, galena and sphalerite. Quartz-calcite blebs are flattened along bedding planes, averaging 4 mm across and 0.6 mm thick. The blebs occur in "cycles" with pyritic siliceous shale laminae. The base of each cycle is marked by a very siliceous and pyritic horizon (Figure 9). Pyrite occurs as framboids in diffuse and often non-continuous laminae ranging in thickness from the width of a few framboids to accumulations of over 3 cm. Cryptocrystalline quartz cementation is pervasive, enveloping the pyrite laminae and extending above them for a distance of a few centimetres. Radiolaria are very abundant in the siliceous zones, forming as much as 30% of the rock and decreasing rapidly in concentration towards the top of each cycle. Appearance of quartz-carbonate blebs is abrupt, usually about 2 to 10 cm above the pyrite accumulations. Framboidal pyrite is usually very finely disseminated throughout the "blebby" shales. Individual cycles range in thickness from 0.6 m to 1.5 m and repetitively occur in 4 to 8 m thick successions of five or more cycles. Five such successions or zones are present in the 480 m section of Unit 3b observed in JDDH 8 and immediately overlying surface exposures. Similar and probably correlative lithologies are present in Unit 3b exposures on the TOM property and on the north JASON claims. At all three locations, individual zones can be traced along strike for distances exceeding 3 000 m.

Overlying rocks, which comprise the upper three-fourths of Unit 3b, consist of uniformly fine grained and very carbonaceous black shales. Radiolaria are present in trace amounts only. The uppermost 150 m of these rocks consists of rhythmic alternations of very siliceous black mudstone and non-siliceous gritty black shale. Cherty mudstone beds, which range in thickness from 2 cm to over 40 cm, are distinguished by their massive, non-fissile nature and by their blocky, subchonchoidal fracture. In thin section, they are uniformly very fine grained and carbonaceous. No radiolaria or other siliceous microfossils are present. Silica presumably occurs as abundant cryptocrystalline quartz cement. Bases of cherty mudstone beds are smooth and featureless while basal surfaces of non-siliceous gritty shales are commonly load casted into underlying mudstone beds. This phenomenon may be due to much higher depositional rates for shales than for the mudstones. Shales are much too friable to be examined petrographically but their gritty nature is probably indicative of a fairly high content of silt-sized material.

No identifiable diagnostic fossils were observed either during field investigations or during petrographic examination of Unit 3b rocks. Fragments of carbonized material seen in some specimens of silvery grey weathering shale on the TOM property are probably similar to "younger than Devonian" fossilized woody plant fragments collected from the same rocks by Sangster (1971 and pers. comm., 1976). Samples of the fossiliferous limestone were dissolved and analyzed for microfossils by the Geological Survey of Canada but proved to be unfossiliferous. Radiolaria can be reliably used for dating purposes if their external morphology is preserved. The recrystallized nature of radiolaria in Unit 3b rocks as well as the commonly lacking or poorly preserved nature of spines prohibits this type of study. Calcispheres are common in sedimentary rocks ranging in age from Silurian to Recent. Specimens from rocks of Unit 3a and 3b are very similar to Radiosphaera described by Stanton (1963). On the basis of limited data, he indicated that this type of calcisphere is restricted to Upper Devonian sediments in North America although its range extends through to Lower Carboniferous in eastern Asia. Brachiopod and conodont collections from the TEA barite deposit, located 20 km west of the Macmillan Pass area, give an Upper Devonian age for the bedded barite. Barite at this location occupies the same stratigraphic position as the TOM and JASON barite-lead-zinc horizons (Carne, 1976, and Dawson, 1977).

Unit 3b is thin or locally missing along the eastern margin of the area shown in Figure 6. Because of poor outcrop character, it is difficult to tell whether rocks mapped as Unit 3a in this area are not, in fact, interbedded clastic rocks and shales of the type commonly seen elsewhere near the base of Unit 3b. In any case, the maximum thickness of Unit 3b along the eastern margin map area is less than 30 m. Thickness of the unit undergoes a dramatic increase from the east central part of the Macmillan Pass area to its central parts where it attains a minimum thickness of at least 1 430 m. This thickening of Unit 3b is illustrated in cross section ABC shown on Figure 5.

Tentative correlation of four fetid limestone marker horizons observed in JDDH 8 and in overlying Unit 3b shales with similar limestone beds on the TOM property suggests that rapid differential subsidence of the central Macmillan Pass area accompanied deposition of Unit 3b (Figure 10). Unit 4a lies uncon-

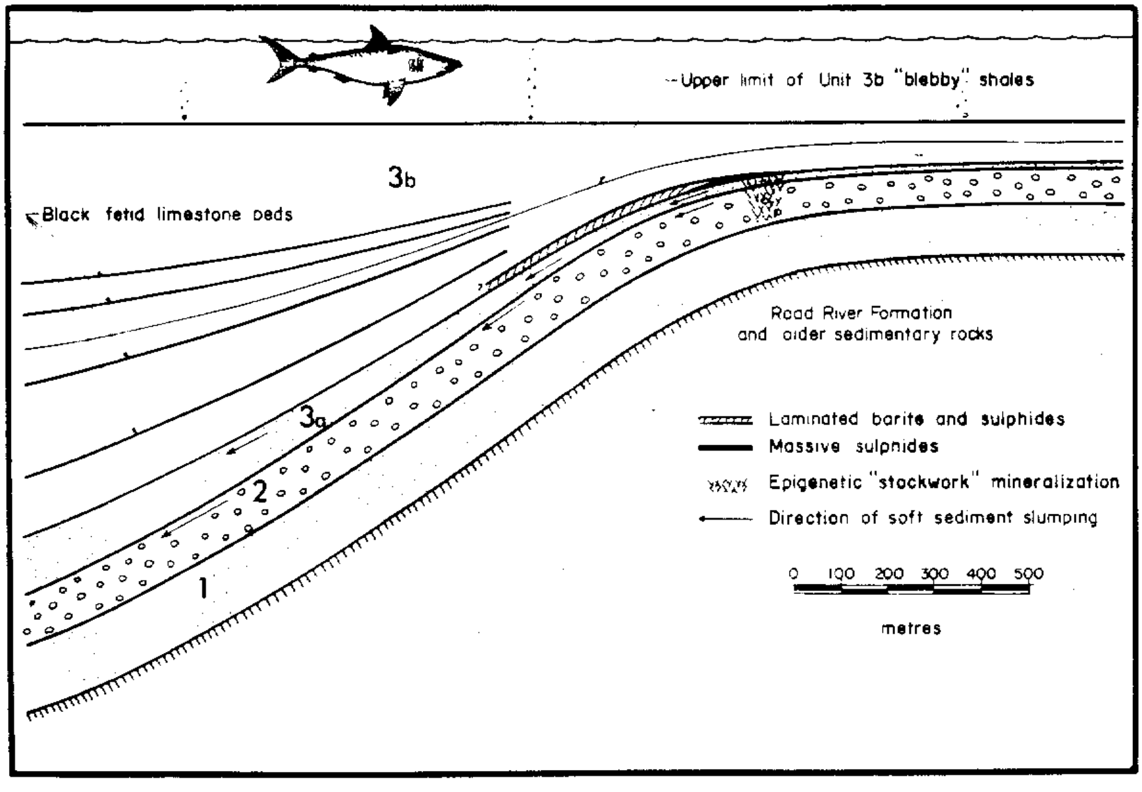

Figure 10. Reconstructed cross-section (looking north) through the TOM deposit at the close of Unit 3b (Canol Formation) time. The reconstructed section is located approximately along section line A-B of Figure 5.

formably upon Unit 3b along the eastern margin of the map area while the contact between Units 3b and 4a in the central map area is apparently conformable. Uplift and erosion of part of upper Canol Formation lithologies may have occurred prior to, and possibly concurrent with, deposition of basal lithologies of Imperial Formation east of the thrust fault shown on Figure 5. Timing and mechanism of thrust faulting and uplift is discussed in more detail in the following section dealing with structural geology. Rapid thickening of Unit 3b in the Macmillan Pass area is then probably due to a combination of initial deposition in a subsiding basin with further erosion of the basin margins after tectonic uplift and exposure. Delineation of the limits of the proposed Macmillan Pass basin on north, west and south sides is hampered by lack of complete sections from base of Unit 3b to overlying cover rock of Imperial Formation. Further detailed mapping in the area in conjunction with stratigraphy outlined from the results of ongoing diamond drilling in the area will hopefully resolve this problem.

IMPERIAL FORMATION

Unit 4a

Strata of Unit 4a are well exposed as talus and felsenmeer along ridge tops and scree slopes in eastern and southeastern parts of Figure 5. Although exposure is excellent, the relatively recessive and poorly indurated nature of most lithologies contribute to their poor outcrop characteristics. Although most lithological components of Unit 4a exhibit considerable lateral variation in thickness and extent, their distinctive lithologies and weathering characteristics serve to identify them in the field. Unit 4a consists of cyclic alternations of reddish brown and grey coloured, shallow water clastic sedimentary rocks. Their distinctive overall buff-brown weathering colour distinguishes them from underlying silvery grey weathering shales of Unit 3b and from overlying dark brown weathering muddy siltstones of Unit 4b. Total thickness of the package varies from areas where it is not present to accumulations over 100 m thick.

Lowest member of Unit 4a consists of a succession of interbedded very fine grained black mudstones and black shales which varies in thickness from 1 m to 2.5 m. Two cm to 5 cm thick massive mudstone beds are separated by 25 cm to 60 cm thicknesses of very carbonaceous, non-pyritic black shale. Mudstone beds contain distinctive spherical anhydrite-barite nodules which range from a few millimetres to over two centimetres in diameter. Central parts of the nodules consist of prismatic anhydrite crystals in an argillaceous matrix which is cemented by microcrystalline quartz. Barite occurs as prismatic crystals within a similar matrix and cement along the outer rims of the nodules. Both barite and anhydrite crystals either show random or radiating textures. Crystallographic orientation of both minerals appears to vary from nodule to nodule with no systematic relationship to size or location of the nodules. Gradual zonation between barite in the rims of nodules and anhydrite in the cores suggests that barite may be progressively replacing anhydrite nodules in a manner proposed by Laznicka (1976) for barite nodules which occur in correlative platformal carbonate rocks and shales of Mackenzie Arch.

Variable thicknesses of soft, grey silty shale overlie nodule-bearing black mudstone and shales in most exposures of Unit 4a. Matted masses and individual particles of clay minerals make up ten to twenty per cent of the rock. Matrix and cementing material are too fine grained to determine microscopically but the very earthy odour of wetted specimens of grey shale indicates that kaolinite may make up a major part of the clay mineral content of the rock.

Siltstone, mudstones and shales of Unit 4a generally exhibit marked cyclic colouration where grey and black fine grained rocks alternate with coarser red-brown siltstones. Reddish colouration is due to thin iron-oxide coatings on grains. Iron-oxides occur less frequently as a cementing agent in coarsest siltstone. Because silica cementation and silica overgrowths on quartz grains are secondary to iron-oxide coatings and cement, it is likely that iron-oxide formation proceeded very early in the diagenetic history of the sediments in an oxidizing environment. Furthermore, the presence of grey shales is usually taken to be indicative of very well aerated depositional environments where oxygen reaches bottom muds and bacterial degradation of organic matter is facilitated. Thin and infrequent carbonaceous black mudstone horizons may reflect periodic accumulation of organic-rich sediments in localized stagnant tidal ponds or lagoons.

Evidence of diagenetic evaporite mineral formation is present in most Unit 4a lithologies. In addition to anhydrite-barite nodules in lower black mudstones, distinctive bladed gypsum crystal casts make up about 30% of the total rock volume of finely interbedded grey silty mudstones and shales which occur near the middle part of the Unit 4a section. Casts of euhedral gypsum crystals are occasionally filled or partially filled with coarsely crystalline anhydrite. Vacant casts are rimmed by a thin layer of fibrous chalcedony which is unusual in its optically length-slow character. Secondary nodular, pore filling or replacement gypsum and anhydrite usually indicative of shallow marine, intertidal and supratidal environments (Lucia, 1969) while length-slow chalcedony is only associated with evaporite minerals (Folk and Pittman, 1971).

A reddish brown flat pebble conglomerate bed, which varies in thickness from a few centimetres to over one metre, forms a distinctive marker horizon near the top of Unit 4a. "Pebbles" are irregularly shaped, plate-like, thin fragments of hematitic, siliceous siltstone which are laterally separated by thin, vertically oriented bodies of poorly cemented mixtures of silty clay and lithic shale fragments. The pebbles are vertically separated by elongate, flattened bodies of fibrous, length-slow chalcedony which is oriented with crystal long axes perpendicular to bedding in the rock. Roughly polygonal outlines of the plate-like "pebbles" in plan view suggests that their lateral separation by thin bodies of poorly sorted sediment may have resulted from infilling of dehydration cracks. Flat pebble conglomerates of this type may have resulted from lithification of intertidal sediments into thin crusts which are subsequently broken by dehydration and wave action.

All lithologies of Unit 4a show evidence of bioturbation. Biologic activity is reflected in numerous feeding tunnels of burrowing organisms which are commonly filled with porous sandstone and siltstone partially cemented by iron-oxides and silica. Small, semi-opaque and structureless spherical bodies in most burrow fillings may be fecal pellets.

Thickness of Unit 4a varies from a maximum of over 100 m to areas where it is not present. Thickness decreases in a general manner from a maximum in the northeast TOM claims to absence in the south-central part of Figure 5. Variable thickness of the unit, as a whole may simply reflect partial removal before deposition of Unit 4b sediments. The lateral lithological and thickness variability of Unit 4a, in conjunction with its presumed shallow water environment of deposition, suggests that it may represent a relict shoreline deposit. In this case, the thinning and eventual disappearance of these rocks may be due to an unrecognized facies change to deeper water equivalents south of the Macmillan Pass area.

Unit 4b

Within the Macmillan Pass area, Unit 4b generally consists of a monotonous assemblage of resistant, cliff-forming, brown weathering silty mudstones and muddy siltstones with thin shaly mudstone intervals. Well developed, small-scale, climbing cross ripple lamination of most rock types indicates a southerly direction of transport. Over 70% of siltstone framework grains are dominately silt-size or finer, subangular to subrounded, well sorted quartz grains with slightly undulose extinction. Carbonaceous material, detrital muscovite-sericite clasts and opaque minerals make up the remainder of the framework grains. Silica cementation is generally poorly developed while higher in the section, south of the Macmillan Pass area, calcium carbonate is the most common cementing agent. Here Unit 4a consists of thick to massive bedded, well laminated, calcareous quartzose siltstones and arenites with lesser interbedded calcareous shales and thick bedded, cross-laminated calcareous and non-calcareous quartzites.

Quartz-Feldspar Porphyry Dykes

Distinctive, light grey to buff-orange weathering quartz-feldspar porphyry dykes cut sedimentary rocks of Canol and Imperial Formations in the south central Macmillan Pass area. Microscopic examination of these rocks shows that their composition, although highly variable, consists of approximately equal amounts of subhedral quartz, euhedral potash feldspar and lesser euhedral biotite phenocyrsts in an aphanitic groundmass. Strong surface alteration has completely kaolinized feldspar phenocrysts and, to a lesser extent, fine grained matrix of the rock. Chill margins of dykes are commonly thin and show evidence of flow banding. Thin contact aureoles of hornfels in intruded pelitic rocks are generally less than one metre wide. Dykes are nearly vertical or steeply dipping and are oriented in an approximately radial fashion about a hornblende-biotite granodiorite stock which lies about 1 km to the south (Figure 4).

An area of weakly developed hornfels in shales, mudstones and siltstones of Units 3b, 4a and 4b occurs in the southeast part of the map area (Figure 5). Incipient contact metamorphism of pelitic rocks has resulted in rusty weathering, resistant slates. Contact metamorphism in this area is not directly spatially related to the stock nor to dyke intrusion, and may be due to an unroofed apophysis of the stock.

Structural Geology

Four independent tectonic events have shaped the Middle Paleozoic to Upper Mesozoic structural evolution of the Macmillan Pass area.

Rapid localized differential subsidence within the Macmillan Pass area followed deposition of Unit 2 massive chert pebble conglomerate debris flow and proximal to intermediate facies turbidites. Slumping of Unit 2 unconsolidated sediments and deposition of chaotic debris and olistostrome deposits of Unit 3a into a localized basin reflect the high degree of tectonic and sediment instability at this time. Stable depositional regimes returned to the east part of the Macmillan Pass area by the end of Unit 3a time. Depositional instability in the southwest part of the area continued through to early Unit 3b time, as shown by the accumulation of thick, chaotic, intraformational and debris fan conglomerates. Passive differential subsidence continued through Unit 3b deposition as indicated by "fanning" of fetid limestone marker horizons (Figure 10). Subsidence in the east half of the area might have been "hinged" along an approximately north-south trending zone of flexure.

At the end of Unit 3b time, easterly directed compressional forces resulted in local crustal shortening through thrust faulting and folding of strata along the eastern basin margin. A plate of middle and upper Canol Formation sediments, riding on a decollement surface beneath massive Unit 2 chert pebble conglomerate, over-rode Canol sediments to the east while, during the same event, overthrust sediments were deformed into easterly verging, open slightly recumbent folds. Overthrusting was, in places, accomplished by imbricate thrust faulting (Figure 5). Mylonitized and brecciated zones marking decollement surfaces were seen in drill core recovered from surface diamond drilling on the TOM claims. Rocks of Units 1 and 3a within the zone of detachment and imbricate faulting are very strongly sheared. Shear planes, which are outlined by alignment of platy minerals and lamellar concentrations of graphite carbonaceous material, commonly cross-cut bedding at low angles in the drill core. Micro-folds and the rapid alternation of upright and overturned graded beds in the footwall of the thrust fault suggest that shearing and tight isoclinal folding locally accompanied fault movement. In this zone, finer grained pelitic sediments are commonly injected plastically along shear planes into more competent, well cemented coarse clastic rocks (Plate J). Foliation in pelitic rocks does not cut detrital quartz grains nor does it cut earlier formed quartz overgrowths on these grains. Coarse, well cemented siltstones do not display foliation, or at best, foliation is very poorly developed.

These features suggest that this deformation occured prior to complete lithification of the sediments, but after the formation of diagenetic silica overgrowths on quartz grains. Erosion of uplifted and folded sediments before deposition of Unit 4a places an upper time limit on initial deformation. Mild folding of the unconformity between Units 3b and 4a suggests that this deformation may have continued or reactivated at a later time (see cross section ABC of Figure 5).

Plate J. Photomicrograph (plane light) of sheared turbidite (Unit 1) beneath the decollement surface of the thrust fault in the east part of the study area. Note injection of fine grained sediments into and around more competent siltstones.

The Macmillan Pass area is located along the southern margin of a structurally anomalous belt 20 km wide which extends at least 100 km to the west and approximately 30 km to the east (see Figure 4 and Blusson, 1971 and 1974). Within this belt, Paleozoic and earlier sedimentary and volcanic strata generally are deformed into tight , slightly overturned, isoclinal, east-west trending folds. Northerly to northwesterly trending, open, upright folds are regionally the most common structures in the Mackenzie Mountains (Gabrielse et al, 1973). Since overprinting of the two contrasting structural fabrics does not appear to occur, the two structural styles might have resulted from the same orogenic event. According to Gabrielse et al (1973), northerly to northwesterly trending structures in Mackenzie Mountains have a pre mid-Cretaceous age because of cross-cutting relationships of Middle and Late Cretaceous granitic plutons.

East-west trending structures in the Macmillan Pass area are represented by the easterly plunging syncline and anticline pair in the west and by vertical to steeply dipping cleavage in rocks which are south of the Macmillan River (Figure 5). Arching of earlier northerly trending folds and thrust faults along the eastern margin of the area might be related to east-west anticlinal folding while bedding attitudes of rocks in the central part of the area suggest that cleavage is related to a southerly facing monocline.

Minor open folds with crescentic axial trends are present in the south-central map area (Figure 5). These folds have amplitudes of less than 10 m and dips on fold limbs are commonly gentle. Regional mapping in the Macmillan Pass area has shown that these fold axes are concentric about a granitic stock which lies about 1 200 m south of the map area (C.L. Smith, pers. comm., 1976). These structures are related to mild doming and deformation of country rock by intrusion of the granitic body.

Major faults may parallel valleys which form conspicuous topographic lineaments along the southwest edge of the map area and along the Macmillan River. Southeasterly and easterly trending faults which cut the south limb of the large syncline on the JASON claims might be related to either of these proposed fault systems although no concrete evidence for the existence of major faults is seen in the immediate area.

ECONOMIC GEOLOGY OF MACMILLAN PASS AREA

TOM West Zone, TOM East Zone and JASON mineral deposits are syngenetic, stratiform accumulations principally composed of finely interlaminated barite, black siliceous argillite, sphalerite, galena and pyrite. The three deposits occur at approximately the same stratigraphic interval, marking the sedimentary transition between locally derived slump and slide debris deposits of Unit 3a with finer grained black shales and minor conglomerates of Unit 3b. Due to the preliminary status and confidential nature of geological investigations into the mode and tenor of the JASON mineralization, present discussion is limited to the TOM deposits.

Stratiform, barite-lead-zinc-silver mineralization on the TOM claims occurs in two tabular bodies (Figure 5). The East Zone is 160 m long, 3 m to 20 m thick and dips steeply west. The West Zone, a much larger body with a length of about 1 200 m and a thickness of 3 m to 60 m, dips 50° to 70° west. East Zone mineralization has been explored in its entirety to a depth of about 350 m by surface and underground diamond drilling. Only the relatively high grade south half of the West Zone has been explored in detail by underground diamond drilling where ore grade material has been outlined to a depth of 260 m. Mineralization continues down dip beyond this depth but difficulties encountered in drilling deep holes have precluded further exploration of the West Zone to the present time. The two TOM deposits together total nine million tons of ore grade material averaging 8.6% Pb, 8.4% Zn and 2.8 oz/ton Ag using an 8% combined lead and zinc cut-off grade. Ten million tons of sub-ore grade material which averages 4.6% Zn, 0.9% Pb and trace amounts of silver have been outlined by surface drilling in the north half of the West Zone. The remote location of the deposits, poor zinc prices and lack of power development in the area have held back further exploration of the deposit.

Detailed study of East Zone ore textures and metal zonation is inhibited by the highly tectonized nature of the deposit. Stratiform mineralization and enclosing rocks have been severely disrupted by the action of shear stresses associated with post-ore faulting, resulting in massive recrystallization of ore minerals and obliteration of primary textures by shearing, micro-faulting and small scale isoclinal folding. In contrast, primary textures and other depositional features of the West Zone mineralization are largely unaffected by this and later events.

TOM West Zone Mineralization

South half of the TOM West Zone mineralization was selected for detailed study. Following its discovery in 1951 by Hudson Bay Exploration and Development Company Limited prospectors, the deposit was delineated by surface prospecting, trenching and diamond drilling during the periods 1951 to 1953 and 1966 to 1968. From 1969 to 1972, the extent of mineralization was further defined by a total of 1 997 m of underground workings in conjunction with over 4 762 m of underground AQ diamond drilling. Much of the core from underground drilling was stored at the company's facilities in Whitehorse until 1976 when it was donated to the H.S. Bostock Core Library in Whitehorse, operated by the Department of Indian and Northern Affairs. Accompanying assay records were kindly provided for the writer's use by the company. Surface diamond drill core which is stored on the property has since succumbed to the ravages of time and specimen collections. Underground workings were unfortunately unavailable for inspection by the writer because of bad air and the possibility of caving. Study of the West Zone mineralization was primarily accomplished through data collected by detailed logging of 525 m of underground AQ diamond drill core. For expediency, only those holes which were drilled along a horizontal plane at adit level and at approximately right angles to the strike of the mineralization were logged.

In order to best utilize textural, assay and mineralogical data, information derived from the diamond drill core logs was used to reconstruct the south half of the West Zone as it would have appeared at the culmination of ore deposition. This was accomplished by assignation of the top of stratiform mineralization as an arbitrary horizontal datum plane. Measured bedding attitudes of laminated ore in drill core were rotated to horizontal. Distances measured from the collar of the hole were adjusted accordingly and converted to metric units.

A structurally restored, true stratigraphic section of the south half of the TOM West Zone orebody is shown in Figure 11. Ore stratigraphy is derived from detailed logging of diamond drill core and from petrographic determinations on over 50 polished sections and 25 thin sections. Seven distinct styles of stratiform mineralization are recognized (Horizons A to G). Lateral ore horizon contacts shown on Figure 11 are extrapolated between diamond drill holes where possible, but in most cases they are arbitrarily located. Vertical contacts seen in core are remarkably consistent in their occurrences when plotted on the reconstructed section.

Massive, poorly laminated galena, sphalerite, pyrite, siderite, minor barite and quartz of ore Horizon A form the highest grade of mineralization yet discovered in the MacMillan Pass area. Assays range as high as 31% Pb, 14% Zn and 11 oz/ton Ag. Sulphide and sulphosalt minerals which occur in minor amounts include chalcopyrite, boulangerite, bournonite and tetrahedrite.

Lower part of Horizon A is primarily composed of bedded pyrite and siderite. Coarsely crystalline pyrite, which occassionaly contains very small irregular siderite masses, occurs in laminations or beds up to 2 cm thick. Crystalline quartz fills the interstices between pyrite grains. Interlaminated siderite is coarsely crystalline and relatively uncontaminated by the inclusion of other minerals . Galena and sphalerite occur in minor amounts subsidiary to pyrite, siderite and quartz. Chalcopyrite, boulangerite, bournonite and tetrahedrite are often found as minute blebs along pyrite grain boundaries. Barite is not present here. Pyrite content decreases abruptly towards the top of Horizon A where siderite is present in only trace amounts. Here galena and sphalerite are the most common minerals, making up over 70% of the rock. A general increase in zinc content with respect to lead occurs near the top and towards the northern lateral limit of the massive sulphide zone. A corresponding decrease in the occurrence of copper and silver bearing species as well as an increase in barite content of the ore accompanies the zonation from lead to zinc enrichment. Chalcopyrite in middle and upper parts of horizon A occurs as small, rounded exsolution (?) blebs in dark brown sphalerite.

At the top of and in northernmost parts of Horizon A, vaguely interlaminated tan coloured sphalerite and light grey barite gangue are the dominant mineral species. Barite grains have almost euhedral outlines and commonly enclose minute galena masses and blebs in fractures and along cleavage planes. Minor discrete bodies of finely crystalline galena also occur in sphalerite laminae. Chalcopyrite and sulphosalt minerals are not present in appreciable quantities. Pyrite occurrence is limited to minor amounts of finely disseminated framboids in sphalerite. Angular, silicified fragments of footwall Unit 3b silty shale and siltstone which "float" in a massive sulphide matrix occur throughout Horizon A. Footwall breccia fragments range from silt to cobble size.

Horizon B, which forms the lowermost part of most of the West Zone (Figure 11), consists of evenly laminated black cherty argillite, dark grey chert and lesser barite with interlaminated and disseminated very finely crystalline sphalerite, galena and pyrite. Strata of Horizon B are likely facies or time equivalents of Horizon A massive sulphides.

Sulphide mineral, barite, siliceous argillite and chert laminae or beds of Horizon B display a high degree of both vertical and lateral thickness variation. In general, thicknesses of black cherty argillite and dark grey chert laminae vary from less than 1 mm to about 2 cm while sulphide and barite laminae range from less than 1 mm to about 5 mm thick. Sulphide laminae are usually monomineralic; that is, sphalerite laminae contain very little or no included pyrite and galena, and vice versa. Lesser amounts of galena and sphalerite occur as minute disseminations in black cherty argillite laminae. Pyrite is usually present as monomineralic, stratified concentrations of framboids or nearly idiomorphic recrystallized framboids. Minor amounts of framboidal pyrite are also scattered throughout cherty argillite laminae or beds.

Assay values of Horizon B are erratic, ranging from trace amounts of lead, zinc and silver to 22% Zn, 26% Pb and 10 oz/ton Ag. An overall northward decrease in the combined lead-zinc grade, with increasing distance from massive sulphide mineralization of Horizon A, is accompanied by a general increase in the Zn/Pb ratio of the ore. Lead/silver ratios increase from about 2:1 (2% Pb to 1 oz/ton Ag) to about 4:1 in a like manner. Sub-microscopic inclusions of silver-bearing minerals in galena may carry the bulk of silver present since no discrete silver-bearing sulphide or sulphosalt minerals were identified in polished section examination of drill core samples. No copper-bearing species were seen in specimens of Horizon B.

Horizon C, contained within a small body with a lense-shaped cross-section, is located at the south end of the West Zone where it concordantly overlies massive sulphide mineralization of Horizon A (Figure

11). Interlaminated sulphide minerals, barite and cherty argillite are similar in appearance to mineralization of Horizon B. Horizon C, however, contains significantly higher amounts of barite while mineral lamination is generally much more contorted and disrupted.

Sulphide mineral laminae range from less than 1 mm to over 1 cm thick while thicknesses of argillite laminae are much more variable, ranging up to 2 cm. Barite laminae are generally about 2 mm thick. Metal content of Horizon C is generally much lower than that of the underlying massive sulphide body, but higher than similar mineralization of Horizon B. Grades range up to 7% Pb, 20% Zn and 1 to 2 oz/ton Ag. Galena and honey coloured sphalerite occur in separate, almost monomineralic laminae. Sphalerite laminae are generally thicker and more common than galena laminae. Discrete barite laminations are composed of roughly euhedral barite crystals which are cemented by a matrix of galena and sphalerite. Trace amounts of very small, elongate chalcopyrite exsolution grains are concentrated along sphalerite grain boundaries and cleavage planes. Chalcopyrite also occurs as discrete mineral segregations interstitial to galena and barite grains. Euhedral pyrite crystals are present in trace amounts in sulphide mineral and barite laminae. Massive concentrations of framboidal pyrite are very common in siliceous black argillite laminae and beds. No identifiable silver minerals were seen.

Most specimens of Horizon C observed in drill core were at least mildly deformed. Brecciation and contortion of laminated ores appears to have occurred before their complete lithification as demonstrated by the "soft-sediment" nature of the deformation. Angular, silt to pebble sized grains of black, silty shale are scattered throughout Horizon C. Shale clasts are silicified, often carbonatized and commonly contain a variety of sulphosalt minerals which are foreign to surrounding banded sulphides, barite and argillite.

Horizon C displays well developed vertical metal zonation. At the base of the unit, zinc and lead occur in approximately equal amounts. Relative zinc enrichment towards the top of the horizon increases the zinc to lead ratio to almost 3:1. Similarly, the lead to silver ratio increases rapidly upward from about 1:1 (1% Pb per 1 oz/ton Ag) to about 6:1 at the top.

Horizon D, which contains the bulk of West Zone tonnage, appears to grade laterally from Horizon C (Figure 11). Gangue consists principally of finely laminated, light grey to white barite and lesser siliceous black argillite with minor dark grey chert. Grade varies from 1% to 9% Pb and 3.5% to 10% Zn. Only trace amounts of silver are present. Thickness of barite laminae range from about 0.5 mm to 1 cm while averaging about 2mm. They attain their greatest thickness at the northern limit of the West Zone cross section shown in Figure 11. Barite in Horizon D occurs as cryptocrystalline, massive bedded concentrations in contrast to Horizon A and C where barite is generally present as roughly lamellar occurrences of nearly euhedral crystals embedded in a matrix of galena and sphalerite. Black, cherty argillite laminations range from 0.1 mm to 1 cm thick, averaging about 6 mm. Minor dark grey chert laminae, which average about 6 mm in thickness, are scattered throughout the section. Argillite and chert laminae appear to have little lateral thickness variability although both exhibit marked variation in vertical thickness and frequency of occurrence. Both Horizons C and D are capped by a 2 cm to 4 cm thickness of massive, grey pyritic chert which serves as a distinctive marker horizon.

Honey coloured sphalerite and galena of Horizon D occur in discrete laminae as disseminations along grain boundaries in the barite. Sulphide mineral laminae are essentially monomineralic; that is, sphalerite laminations contain little or no galena and vice versa. Framboidal pyrite is disseminated throughout chert and siliceous argillite laminae while it is present in trace amounts only in barite, sphalerite and galena laminae.

Chert and argillite laminae, as well as the occasional barite lamination, contain no sphalerite or galena. Both barren barite laminae and sulphide-bearing barite laminae as well as chert laminae contain subangular, silt to granule sized clasts of black silty shale. Shale clasts appear to "float" in a matrix of barite and sulphides or chert. Slight depression of underlying laminae in conjunction with the onlapping and concordant nature of adjacent and overlying mineral laminations suggests that shale clasts were dropped into the ore during its deposition. Rapid deposition of the relatively thick, metal deficient barite laminae is indicated by the common occurrence of load casts into underlying metalliferous barite.

Horizon D is zinc rich. Highest zinc values with respect to lead occur near the top and northernmost parts of the section shown in Figure 11. Relative zinc enrichment however, parallels an overall decrease in combined lead-zinc grade. The horizon is characterized by an almost complete lack of soft sediment deformation except in diamond drill sections 18/19 and 55/56 (Figure 11) where intense small scale folding and faulting are commonly seen, especially near the top of the unit.

Lateral limits of Horizon E as shown on Figure 11 are, for the most part, arbitrary. Distinctive lithologies of this horizon were seen in core from only one diamond drill hole where it consists of contorted and disrupted laminae of black cherty argillite, witherite and/or baritocalcite, barite and sulphide minerals. Assay values are erratic, ranging up to 12% Zn, 2% Pb and 0.15 oz/ton Ag while averaging about 8% Zn, 1.2% Pb and trace amounts of silver. Silver values display no obvious correlation with lead assays. Sulphide mineral laminations, which range in thickness from 0.2 mm to 1.2 mm, are predominantly composed of dark brown sphalerite with lesser pyrite, galena and very minor amounts of chalcopyrite. Idiomorphic pyrite grains are scattered througnout the sphalerite while galena intergrowths are interstitial to sphalerite grains. Framboidal pyrite occurrences are limited to black siliceous argillite laminae. Elongate chalcopyrite blebs are present only at sphalerite grain boundaries. Quartz lined fractures which commonly cross-cut contorted lamination are filled with coarsely crystalline brown sphalerite and minor interstitial galena. Large, elongate cavities lined with euhedral barite crystals may have resulted from partial dissolution of adjacent and enclosing barium carbonate laminae. Contortion of laminae, small scale folding and microfaulting are best developed at the base of Horizon E, diminishing in frequency of occurrences and degree of development toward the top of the unit.

Mineralization of Horizon F is laterally equivalent to that of Horizon E. It concordantly overlies Horizon D stratiform mineralization, occupying an elongate body with a saucer shaped cross section (Figure 11). Interlaminated barite, sulphide minerals, black siliceous argillite and minor grey chert are indistinguishable in outward appearance and grade from mineralization of Horizon D. Metal values are surprisingly consistent throughout the unit, averaging 6% Zn, 1.5% Pb and trace amounts of Ag. Galena and sphalerite do not often occur together. Wispy, discontinuous lamellar concentrations of galena occur with idiomorphic pyrite crystals in siliceous argillite. Sphalerite occurs in three modes: as large, irregular clots in barite laminae; as disseminations and small blebs in siliceous argillite laminae; and as coarsely crystalline fracture fillings with quartz and barite. Mineralized fractures may be related to early dehydration of cherty argillite since they are irregularly spaced, do not cut adjacent barite laminae and may be partially filled with sags or injections of overlying laminae. Cherty argillite laminations also contain small, euhedral pyrite cubes and large framboids which range up to 0.12 mm in diameter. Assay values within the horizon are erratic and no systematic mineral zonation appears to be present, either vertically or laterally.

Much of the West Zone is capped by a thin layer of finely and evenly laminated dark brown sphalerite and siliceous black argillite (Horizon G) which is very similar in outward appearance to stratiform mineralization of Horizon B (Figure 11). Sphalerite laminae average less than 1 mm in thickness while argillite laminae vary from 0.4 mm to 6 mm thick. Sphalerite, galena and framboidal pyrite are disseminated throughout argillite laminae. Metal values do not display much variation throughout the horizon, averaging 0.8% Pb, 7% Zn and trace amounts of silver. No systematic metal zoning is present other than a general vertical increase in zinc content with respect to lead.

A zone of intensely silicified and pyritized silty black shale which ranges in thickness from about one metre to two metres forms the immediate footwall to stratiform ore of the West Zone (Figure 11). Pyrite framboids ranging up to 0.01 mm in diameter form 2 mm to 5 mm thick discontinuous laminae. Massive concentrations of framboids are partially recrystallized to idiomorphic pyrite which retains ghost outlines of framboidal textures when etched. Large euhedral pyrite grains are rimmed by tangentially arrayed, fibrous chalcedonic quartz. Silica enrichment, qualitatively determined by relative rock hardness, roughly parallels the overall concentration of pyrite. Silica, too fine grained to determine petrographically, probably occurs as cryptocrystalline quartz cement. Base of the pyrite and silica enrichment zone is sharply defined. Content of both pyrite and silica within this interval increases gradually toward the contact with stratiform barite-lead-zinc mineralization of Horizon B. Scattered quartz-siderite veins are weakly mineralized with sphalerite and galena.

A similar but less siliceous and less pyritic zone appears in the immediate hanging wall shales of the West Zone (Figure 11). No lead-zinc mineralization, either as disseminations or veins, was seen in these rocks. Upper contact of hanging wall silicified shales with more typical shales of Unit 3b is gradational. Contacts between stratiform mineralization and both hanging wall and footwall are abrupt.

A relatively large area of brecciated rock, approximately funnel shaped in cross-section, underlies massive sulphide ore of Horizon A (Figure 11). Breccia fragments are silicified, pyritized and sideritized. Pyrite, galena, sphalerite, chalcopyrite, chalcocite and a variety of sulphosalt minerals including bournonite, boulangerite, tetrahedrite, proustite and pyrargyrite occur with quartz and siderite as breccia matrix, veins and disseminations in breccia fragments. Base metal values range up to 2% Cu (estimated), 17% Zn and 6% Pb. Silver, present in amounts as high as 11 oz/ton, displays no obvious correlation with lead. Several generations of mineralization are recognized. Footwall clasts in the south part of the funnel-shaped breccia body are extensively sheared as are galena and sphalerite disseminated within the clasts. Sheared clasts are, in turn, brecciated and cemented by mineralized quartz-siderite mosaics which are not deformed. Breccia matrix and clasts are both cut by later undeformed, mineralized quartz-siderite veins.

Sulphide and sulphosalt minerals occur in a variety of textures. Sphalerite, the most common ore mineral, usually contains inclusions of chalcopyrite-chalcocite, bournonite and tetrahedrite. Massive sphalerite occurs in veins, fracture fillings and in the breccia matrix. Disseminated sphalerite in breccia fragments is present along clast margins and adjacent to veins. Large, idiomorphic pyrite crystals occur in breccia clasts as well as matrix. Matrix pyrite may be intergrown with bournonite and chalcopyrite. Matrix pyrite also commonly contains inclusions of galena and sphalerite. Chalcopyrite, chalcocite, sphalerite, tetrahedrite and boulangerite form complex intergrowths within euhedral bournonite crystals in the breccia matrix. Galena and chalcopyrite are usually intergrown with sphalerite in breccia matrix, in quartz-siderite veins, as fracture fillings and as disseminations along clast boundaries. Sulphide veins are often mineralogically zoned across their widths, although zonation does not appear to be consistent from vein to vein. Chalcopyrite of all types commonly contains minute inclusions of chalcocite. Small blebs of proustite, pyrargyrite and tetrahedrite (var. freibergite?) are observed in vein galena. Calcispheres in breccia fragments are nearly always replaced by metallic minerals, commonly pyrite but occasionally tetrahedrite, sphalerite and chalcopyrite. Framboidal tetrahedrite and chalcopyrite in the clasts may be replacements of pre-existing pyrite framboids. Tetrahedrite is occasionally seen rimming pyrite framboids. Trace amounts of chalcopyrite, tennantite, tetrahedrite, boulangerite, pyrargyrite and proustite form micron sized discrete minerals in quartz-siderite breccia matrix and veins.

Breccia clasts are sheared and deformed along a 2 m to 10 m wide zone which defines the southern limit of the funnel-shaped breccia body (Figure 11). Remainder of the breccia clasts are rotated and weakly deformed. Normal faulting of poorly lithified footwall sediments may have initially controlled the development of brecciation and epigenetic mineralization. All breccia clasts are intensely silicified, pyritized and weakly sideritized. Rims of most clasts are altered and replaced by very fine, irregular intergrowths of siderite and quartz. Matrix of the breccia is predominately coarsely crystalline quartz with lesser plumose siderite, sulphide minerals, barite and barium carbonate.

Drill core from the epigenetic breccia mineralization was not assayed rigorously enough to evaluate metal zonation, however, greatest variety of ore minerals and highest grades of Cu, Pb, Zn and Ag appear to occur near the top of the zone.

A similar style of epigenetic mineralization occurs in stratiform mineralization of Horizons B and E in diamond drill section 54/55 (Figure 11) where brecciation and partial dissolution of the ore has produced open boxwork cavities after pyrite, sphalerite and galena. Barite is commonly etched and partially dissolved. Pyrite, sphalerite, galena, chalcopyrite and minor amounts of tetrahedrite occur in quartz veins, disseminations and cavity fillings. Footwall rocks of Unit 3a are locally brecciated and mineralized with minor amounts of pyrite, galena, sphalerite, chalcopyrite and tetrahedrite in quartz veins and as disseminations.

GENESIS OF STRATIFORM BARITE AND BARITE-LEAD-ZINC DEPOSITS OF MACMILLAN PASS AREA

Review of Current Theories on Genesis of "Sedimentary-Exhalative" Deposits with Reference to the TOM West Zone

The TOM and JASON deposits exhibit many similarities with the McArthur (Australia), Meggen (West Germany), Rammelsberg (West Germany) and Sullivan (British Columbia) stratiform base metal deposits. Examination and comparison of the similarities between them serves to outline a model for their genesis. Characteristics of these deposits are summarized in Table I.

The syngenetic nature of this type of stratiform mineralization is almost universally accepted. Recent studies of these deposits have independently suggested an "exhalative" source for mineralizing fluids in each case. Conduits for mineralizing brines are theorized to have been located along deep-seated faults or fracture zones associated with the initiation of locally active tectonism expressed as rifting or differential subsidence of enclosing sedimentary strata.

Recent publications by Hodgson and Lydon (1977) and Lydon (1978) outline a physicochemical model for submarine exhalative systems associated with block faulting by comparison with active continental geothermal systems. Hydrothermal activity of this type is generated when and where an impermeable cap rock overlies a permeable aquifer and when discharge channels develop following faulting or fracturing of the cap. A heat source for the driving process could involve the tapping of heated groundwater or connate water by deep-seated faults or by the intrusion of magma bodies at depth along these fault zones. The generation of a hydrothermal fluid in a geothermal system then requires:

(i) a heat source,
(ii) an aquifer unit which acts as a reservoir for the heated solution, and
(iii) an overlying cap rock which contains the hydrothermal fluids, preventing the dissipation of heat by mass transfer, thus allowing the maintenance of elevated temperatures within the aquifer over an extended period of time.

Fluids in submarine geothermal systems possibly originate as recirculated seawater with the addition of hot connate or deep-seated ground waters and/or magmatic fluids depending on the tectonic, igneous and sedimentary history of the area.

Initial composition of discharge fluids in exhalative systems is determined by fluid-mineral equilibria in the aquifer. Aquifer rocks should then be altered and depleted in elements enriched in stratiform ores formed by the hydrothermal system. Aquifer pyrite, in the case of moderate to high temperature systems, would be oxidized. The oxidation of ferrous iron to ferric iron contributes to the inorganic reduction of seawater or connate fluid sulphate. Turbidites and associated clastic rocks of Unit 1 in the MacMillan Pass area satisfy the requirements for a paleoaquifer system. Coarse fractions of the turbidites have relatively high initial porosity and permeability which is augmented by alteration of matrix material and complete destruction of diagenetic pyrite grains. Clay mineral alteration in fine grained fractions of the turbidities is limited to areas adjacent to coarse grained laminae suggesting that alteration was accomplished by fluid movement through coarse clastic horizons in Unit 1.

The accumulation of heat energy in a geothermal system is favoured when and where an impermeable, insulating cap rock is present between the aquifer and the zone of submarine discharge. In the absence of a naturally occurring impermeable cap, many active hydrothermal systems contain "self-sealed" caps. Self-sealed caps form when near-surface boiling of hydrothermal fluids causes rapid precipitation of their constituents, forming an effective barrier to further fluid movement. Unit 2 massive chert pebble conglomerate which overlies Unit 1 aquifer turbidites has an extremely low porosity and permeability due to the almost complete destruction and replacement of matrix and matrix porosity by pervasive cryptocrystalline quartz cementation. Relatively minor amounts of sphalerite and siderite accompany secondary silicification of the conglomerate. Regionally, this rock unit does not display as well developed cementation. Indeed, the selective, locally occurring silicification of the conglomerate is difficult to explain without invoking some sort of secondary hydrothermal process.

If fluid boiling is a requirement for self sealing, then a massive sulphide ore horizon lying above a self-sealed cap should have an associated, cross-cutting zone of alteration and stringer mineralization related to discharge of boiling hydrothermal fluids at sites where the cap is breached. The funnel-shaped breccia body which underlies massive sulphide mineralization of the TOM West Zone probably served as the fluid discharge conduit for most of the West Zone ore deposition. Epigenetic mineralization and a coexisting zone of quartz-carbonate alteration within this body may have resulted from the precipitation of constituents of a geothermal brine during depressurization. Angular clasts of footwall rock which are incorporated into overlying stratiform mineralization may have resulted from steam-blast eruptions caused by periodic clogging of the discharge vent by mineral precipitation. General size grading of footwall clasts from coarse, cobble-sized fragments in massive sulphide mineralization of Horizon A to silt and sand sized detritus in the northern part of the West Zone reflects distance from the discharge vent.

Table I. Summary of Important Characteristics of Some Sedimentary-Exhalative Deposits

Deposit	Age	Size (Standard tons x 10^6)	Published Overall Grade	Host Rocks	Possible Tectonic Control on Ore Genesis	Footwall Alteration Pipe Recognized?	Relative Strength of Mineral Zonation	Inferred or Indicated Brine Type (Sato 1972 & 1977)	References
McArthur, Australia	Middle Proterozoic	200	10% Zn 4% Pb 0.2% Cu 1.5 oz/ton Ag	dolomitic shale, shale	differential subsidence adjacent to active normal fault of regional extent	No	Unzoned	Type I	Lambert, 1976
Meggen, West Germany	Middle Devonian	66 16.5	10% Zn 1.3% Pb 0.2% Cu 96% $BaSO_4$	shale, turbidites, Pelagic limestone, adjacent limestone reef	differential subsidence adjacent to active normal fault	No	Low	Type I	Krebs, 1976
Sullivan, British Columbia	Middle Proterozoic	170	6.2% Pb 6.1% Zn 1.66 oz /ton Ag	turbidites shale	intersection of fracture zones and normal fault along rift(?) margin	Yes	Moderate	Type IIa	Kanasewich, 1968 Thompson and Panteleyev, 1976 Ethier et al, 1976 Ransom, 1977 Campbell et al, 1978
TOM, Yukon Territory	Upper Devonian	9*	8.6% Pb 8.4% Zn 2.8 oz/ ton ag 25% $BaSO_4$	shale, turbidites	differential subsidence adjacent to linear "hinge zone"	Yes	Moderate	Type IIa	Carne, 1976 Dawson, 1976 The present work
Rammelsberg, West Germany	Middle Devonian	33	19% Zn 9% Pb 1% Cu 3.0 oz/ ton Ag 22% $BaSO_4$	shale, tuffaceous shale, turbidites	differential subsidence adjacent to linear "hinge zone"	Yes	High	Type IIb	Hannak, 1968 Krebs, 1976
Gataga Lakes Barite Belt, Northeast British Columbia	Upper Devonian	-	-	turbidites, shale	not known	none recognized	unzoned (barren)	Type III	R.J. Cathro, pers. comm., 1978

* Initial development figures using an 8% combined lead and zinc cutoff grade

Based on stable isotope and fluid inclusion studies, submarine exhalative metal deposits are theorized to form from variations on three different types of geothermal brines (Sato, 1972; Sato, 1977). Low temperature (up to about 150°C) brines with relatively high salinities (Type I) may have evolved from formational or connate waters. Moderate temperature fluids (about 200°C) with moderate salinities (Types IIa and IIb) are derived from either magmatic waters or mixtures of evolved connate fluids and circulating seawater. Higher temperature hydrothermal fluids (greater than 200°C) with relatively low salinities (Type III) most likely originate from circulating seawater in areas of very high heat flow and fluid permeability such as oceanic rift zones.

In general terms, cationic composition of geothermal fluids is primarily determined by solution-mineral equilibria in the reservoir (Lydon, 1977). Solution-mineral equilibria are, in turn, regulated by temperature and salinity of fluids in the aquifer providing that metals are carried in chloride complexes.

Assuming that bulk metal ratios of stratiform ores represent bulk metal ratios of mineralizing fluids, stratiform ores rich in zinc and lead with low copper content would be expected to form from low to moderate temperature, relatively saline hydrothermal fluids because of the generally low stability of copper chloride complexes with respect to those of lead and zinc. Furthermore, the relatively unstable nature of lead chloride complexes with respect to zinc chloride complexes in these fluids should favour high zinc to lead ratios. Higher temperatures and lower brine salinities will favour an increase in relative amounts of lead and copper carried in solution with respect to zinc.

Behaviour of exhalative ore-forming fluids in seawater has been predicted by Sato (1972 and 1977) according to their varying physicochemical characteristics. Sato's calcualtions are based on the assumption that physical properties of geothermal brines can be approximated by those of the $NaCl-H_2O$ system and that modification of their behaviour in seawater by contributions of heat conduction, reaction heat and heat of dilution are negligible in comparison with behaviour predicted by heat capacity. Behaviour in seawater of four types of brines which are theorized to form exhalative deposits are shown in Figure 12.

Type I brines are low temperature brines of relatively high salinity which will theoretically produce deposits with high zinc to lead ratios and little to no copper. These fluids, upon their exhalation, will always be heavier than seawater during their cooling history and should be initially deficient in reduced sulphur species because of their poor leaching capability and negligible capacity to inorganically reduce sulphate of connate waters or circulating seawater. Consequently, distribution of stratiform mineralization formed by these brines will be controlled directly by supply of biogenically reduced sulphur at the site of deposition. Margins of the deposit with enclosing sediments will be diffuse and sulphide mineral laminae should be finely alternated with sediments as stagnant brines precipitate slowly when organically reduced sulphur becomes available. Homogenization of the pooled brines will produce very little metal zonation within the deposits. Since very little mixing with seawater occurs during the cooling history of the brines, barite (if present at all) will be largely separated from sulphide minerals at the margins of the anoxic depositional basin where sufficient seawater sulphate is available. Alteration zones or stringer mineralization in footwall sediments will be poorly developed or not present. Furthermore, discharge vents may be spatially removed from stratiform mineralization if they occur upslope from the eventual depositional basins. Examples of stratiform base metal deposits that probably formed from Type I brines include the Red Sea deposits, McArthur and Meggen.

Type II brines are moderate to high temperature fluids of moderate salinity that will theoretically produce deposits with high zinc and lead content and low copper content. Because of their relatively high temperatures, the brines have increased leaching capacity in the aquifer and may carry higher quantities of inorganically reduced sulphur than Type I brines. Brines of Type IIa are heavier than seawater. Upon exhalation, minor mixing with seawater takes place (Figure 12) and, if some reduced sulphur is

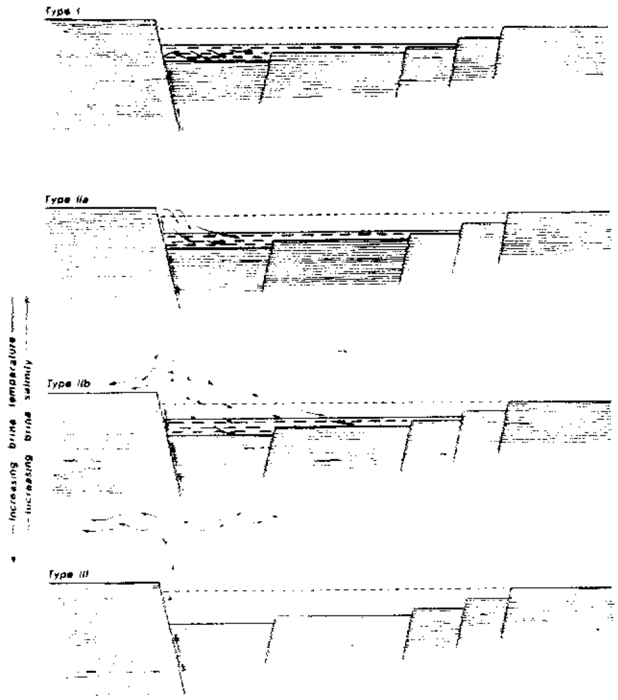

Figure 12. Theoretical behaviour of four types of exhalative fluid in seawater. Dashed line represents interface between anoxic and normal seawater. Shaded areas are pooled exhalative brines (modified after Sato, 1972).

carried in solution, a massive sulphide body may precipitate near the vent while much of the brine will flow downslope and pool in topographic depressions as in the case of Type I. Relatively slow precipitation of pooled brines should produce a deposit which contains a higher degree of intercalated sedimentary laminae than associated massive sulphide bodies. Barite, if present, would be concentrated at margins of the brine traps where oxygenated waters are present although, since some mixing with seawater occurs at exhalation, nucleated barite crystals may be carried downslope with the brines and persist metastably in the brine pools. Alteration pipes or stockwork stringer mineralization should underly massive sulphide deposits. Both the Tom deposit and Sullivan Mine exhibit many of the characteristics of deposits that are theorized to form from the submarine exhalation of Type IIa brines.

Type IIb brines are slightly hotter than Type IIa and, perhaps, less saline. Upon exhalation into seawater, the density of these fluids will be less than, but will eventually exceed, that of seawater as convection-like mixing above the vent causes cooling (Figure 12). Consequently, distribution of stratiform mineralization formed from Type IIb brines will not be controlled by basin topography to the same extent as those formed from Type I or Type IIa brines. Rapid precipitation of fluid constituents will occur as disequilibrium is reached at exhalation forming high grade, and commonly cupriferous, sinter-like deposits of massive sulphide mineralization about the vent. Degree of metal zonation away from the discharge site, both vertically and laterally, will vary with temperatures of exhaled brines. Boundaries of deposits formed by Type IIb brines will be sharp and enclosing sediments will usually not contain anomalous amounts of metal. Since some mixing with seawater occurs immediately after exhalation, barite when present will be intimately associated with layered sulphides. Alteration pipes or zones of stringer mineralization along brine conduits in footwall sediments should be well developed. Rammelsberg, which is strongly zoned and contains a well mineralized alteration pipe, may have formed from Type IIb brines.

Type III brines are high temperature, dilute solutions which are always lighter than seawater during their cooling history. Accordingly, the fluids will rise until they reach surface water or until they are infinitely diluted by seawater. Because reduced sulphur is not readily available in surface water, constituents of Type III brines will probably precipitate as oxides, although some sinter deposits of sulphide mineralization may form about the vent. Initial chemical studies on bedded barite of the Muskwa Ranges, northeast British Columbia, using barium-strontium ratios as a guide to relative temperatures of deposition, indicate that barren barite deposits which occur at the same stratigraphic interval as Upper Devonian stratiform barite-lead-zinc mineralization at Driftpile Creek (N.T.S. 94 K/4) formed at higher temperatures than the barite which accompanies mineralization (R.J. Cathro, pers. comm., 1977). The barren barite deposits, which attain thicknesses of as much as 30 m and strike lengths of more than one kilometre, are contained within a horizon of extremely siliceous and pyritic black shale which carries anomalous but subeconomic quantities of lead, zinc and silver. These barren barite deposits and similar deposits in the Selwyn Mountains may have resulted from exhalation of Type III geothermal brines. Rapid cooling and dispersion of this type of fluid in seawater prevents the effective concentration of base metals while barite, which precipitates immediately on contact of the brine with seawater sulphate, will be deposited as a "snowfall" of barite crystals in close proximity to the vent, producing blanket-like deposits of relatively pure barite. This mechanism may help to explain why most stratiform barite deposits of Yukon Territory and northeast British Columbia are not intimately associated with significant quantities of base metals.

Barite is an important volumetric component of many massive sulphide deposits. The distribution of barite within deposits can be satisfactorily explained by physicochemical models of ore deposition from exhalative brines but controls on the initial presence of barium in these fluids is not well understood. The model proposed here for the genesis of sedimentary-exhalative base metal deposits does not satisfactorily explain the presence or absence of barite. The TOM deposit is located at the same stratigraphic interval as literally hundreds of sulphide-deficient bedded barite deposits in southeast Yukon and northeast British Columbia. Since bedded barite occurs at the same stratigraphic interval position and is morphologically similar to barite of the TOM deposit, these barite and barite-lead-zinc deposits probably share a similar genetic history.

Theories on the genesis and distribution of these stratiform barite and barite-lead-zinc deposits must, of course, be refined with isotopic and temperature data. The geothermal theory proposed for the genesis of hydrothermal solutions by Hodgson and Lydon (1977) and Lydon (1978) in combination with Sato's (1972 and 1977) exhalative brine models can be used effectively, however, to broadly predict the characteristics of a particular sedimentary-exhalative deposit once preliminary data about its morphology, metal content and relationships to host rocks are known.

Probable Genetic History of the TOM West Zone

Based on the assumption that the upper surface of stratiform mineralization will be horizontal following its complete deposition, stages leading to the deposition of the TOM West Zone section shown in Figure 11 were determined by successively removing individual sedimentary and mineralized horizons and restoring the "new" surface to horizontal (Figure 13). Three locally occurring tectonic events which are expressed as differential subsidence correlate with mineralizing events. Succession and morphology of ore types, their relationship to epigenetic mineralization and metal distribution suggest the following sequence of events leading to the formation of the TOM West Zone.

Stage 1: Deposition of Unit 1 turbidites and associated clastic rocks was followed immediately by deposition of the coarse grained, unsorted debris flow deposits of Unit 2 on a flat or gently sloping seafloor after uplift and erosion of Road River Formation(?) cherts to the west and northwest. Local deposition of Unit 3a slide and slump debris deposits followed movement on deep seated faults within the MacMillan Pass area. Heated connate waters moved upward along deep seated faults mixing with circulating seawater to some degree (Figure 13).

Stage 2: Rapid, differential subsidence continued in the MacMillan Pass area (Figure 13). Geothermal fluids rose along active fault and fracture zones until they reached the porous and permeable strata of Units 1 and 2. Movement of hot brines through Unit 1 and underlying shales released metals through alteration of silicate minerals and oxidation of pyrite. Fluid boiling in the near surface Unit 2 conglomerate released silica which cemented the unit and formed a self-sealed cap over the geothermal system. Renewed localized differential subsidence in now cemented Unit 2 formed the funnel-shaped breccia body as a result of faulting and/or explosive release of pressurized geothermal brines ascending along a fracture system. Type IIb brines discharging through the breccia body resulted in alteration and mineralization of the breccia as well as the eventual precipitation of massive sulphide mineralization near the vent (Horizon A) and interlaminated sulphides and silicified sediments away from the vent (Horizon B). Bedded siderite found at the base of the massive sulphide body is probably indicative of a relatively high initial dissolved CO_2 component to the brines, released by depressurization. Copper-bearing minerals such as chalcopyrite, chalcocite, tetrahedrite and other sulphosalts precipitated in the fluid conduits and in stratiform mineralization near the vent because of the relatively low stabilities of copper-chloride complexes. Both vertical and lateral zonation of galena and sphalerite within Horizons A and B may reflect the relative stabilities of lead and zinc chloride complexes in moderate to high temperature brines. Some of the sulphide sulphur of Horizon A may have originated with the exhalative fluids while interlaminated sediments and stratiform mineralization of Horizon B probably precipitated slowly as biogenically reduced seawater sulphate became available.

Stage 3: Continued subsidence formed a small sub-basin immediately north of the vent area (Figure 13). Exhalative fluids, because of their slightly cooler nature, now behaved as Type IIa brines and were pooled in the depression, precipitating slowly to form ore Horizons C and D. Some mixing with seawater may have occurred immediately over the vent, where interlaminated sulphides and argillite of Horizon C approach massive sulphide quantities. As mixing occurred about the discharge area, barium combined with seawater sulphate to form very fine barite crystals which were carried downslope in suspension with the heavy Type IIa brines. Interstitial sphalerite and galena in barite of Horizon D probably precipitated in situ in the barite mud created by settling of barite crystals from the brines. Cyclic alteration of sulphide mineral, barite and siliceous argillite laminae of Horizon D probably resulted from individual exhalative episodes. Barren siliceous argillite laminae reflect periods of normal pelagic sedimentation when the rate of exhalative discharge was minimal. Episodic discharge from submarine geothermal systems may be related to "seismic pumping" (Lydon, 1978) in which pore solutions of reservoir rocks are expulsed from the focus of shallow earthquakes by collapse of the dilatant zone. Generation of earthquakes was likely related to local differential subsidence which continued through deposition of Horizons C and D (Figure 13). Discharge rate of geothermal brines gradually waned as pressure within the system decreased and fluid conduits became clogged by mineral precipitation. The 2 cm to 4 cm thickness of barren, pyritic chert which caps Horizons C and D probably represents the last significant contribution from this discharge site in a situation analagous to volcanogenic-exhalative systems (e.g. ferruginous chert horizons which overlie Kuroko massive sulphide deposits).

Stage 4: Differential subsidence continued locally in an area northwest of the now dormant vent (Figure 13). Highest degree of soft-sediment deformation in drill core from Horizons A, B and D occurs on the flanks of the subsiding basin, reflecting the post-depositional instability of the poorly consolidated chemical and pelagic sediments. Fluids under high pressure in the sealed geothermal system broke through to the seafloor along a zone of weakness coincident with the axis of greatest subsidence. These hot and acidic solutions leached and altered the brecciated footwall rocks and chemical sediments of Horizons B and D. Fluids were probably similar to the Type IIa brines which formed the earlier Horizon C and D mineralization. The significant amount of barium carbonate minerals in Horizon E reflects a relatively high dissolved CO_2 content in the brines. Time equivalent barite-lead-zinc mineralization of Horizon F precipitated from pooled brines in a manner similar to underlying mineralization of Horizon D.

Stage 5: Subsidence continued along the earlier formed trough (Figure 13). Exhalative fluids now behaved in a manner akin to Type I brines as temperature of the geothermal system decreased. Lack of well developed metal zonation, abundant interlaminated sediments and the absence of barite in Horizon G suggests that the relatively cool brines precipitated slowly in a shallow topographic depression. Location of a discharge site for these fluids is not indicated within the section studied but it is not inconceivable that it may have been located off the plane of the section.

Currently available information about the TOM deposit does not provide insight into true plan view and metal distribution of down dip extensions of the West Zone mineralization discussed in the preceeding pages. Exhalative sites or geothermal vents were probably located at the intersections of fracture zones or along fault zones where interstratal permeability is highest. In addition to ore horizons established for the adit-level cross-section, additional drilling down-dip may reveal significantly different deposit morphology and metal content as distances from exhalative centres vary.

The scenario presented in the preceeding pages will, of necessity, remain speculative until data is obtained on the salinity and temperature of ore-forming fluids and on the source of sulphur in the ores. Studies of the type described can, however, be instrumental in determining continuity or possible extensions of sedimentary-exhalative deposits which are in the advanced exploration stage.

GUIDES TO FURTHER EXPLORATION FOR STRATIFORM BARITE-LEAD-ZINC DEPOSITS IN EASTERN YUKON TERRITORY AND NORTHEASTERN BRITISH COLUMBIA

Stratiform barite-lead-zinc mineralization at MacMillan Pass is a direct consequence of geothermal activity generated from local tectonism which provides a tapping mechanism for heated deep-seated fluids, conduits for fluid transport and basins for the containment of exhaled metalliferous brines. Genesis of stratiform mineralization, although spatially controlled by local tectonic activity is temporally controlled by some sort of much more fundamental metallogenic event. Literally hundreds of barren stratiform barite deposits occur in the same stratigraphic interval as barite-lead-zinc mineralization at MacMillan Pass and Driftpile Creek, northeast British Columbia. Search for similar deposits should, then, be restricted to the lower "Black Clastic" Group of Upper Devonian to Lower Mississippian age. Any evidence for localized deep-seated faulting or marked differential subsidence, such as anomalous thickening of overlying rocks, should be investigated carefully.

Altered and leached reservoir rocks are an integral result of the ore forming process at MacMillan Pass. Although geothermal reservoirs need not be located in immediate spatial proximity to eventual sites of submarine discharge, the search for widespread alteration zones in these rocks should be of high priority. Similarily, vein or breccia mineralization occurring in Lower Black Clastic or older strata should be considered as possible fluid conduits and adjacent overlying rocks should be evaluated carefully.

Apparently barren barite deposits, such as the large TEA barite deposit (N.T.S. 105 O/8) should also receive careful attention. If mineralizing brines are relatively cool and saline, barite will precipitate only at margins of euxinic basins where sufficient seawater sulphate is present. For example, the Meggen deposit (West Germany) consists of a 66 million ton pyritic orebody which is surrounded by a fringing barren barite body which contains about 16.5 million tons of material grading 96% $BaSO_4$ and which contains virtually no sulphide minerals.

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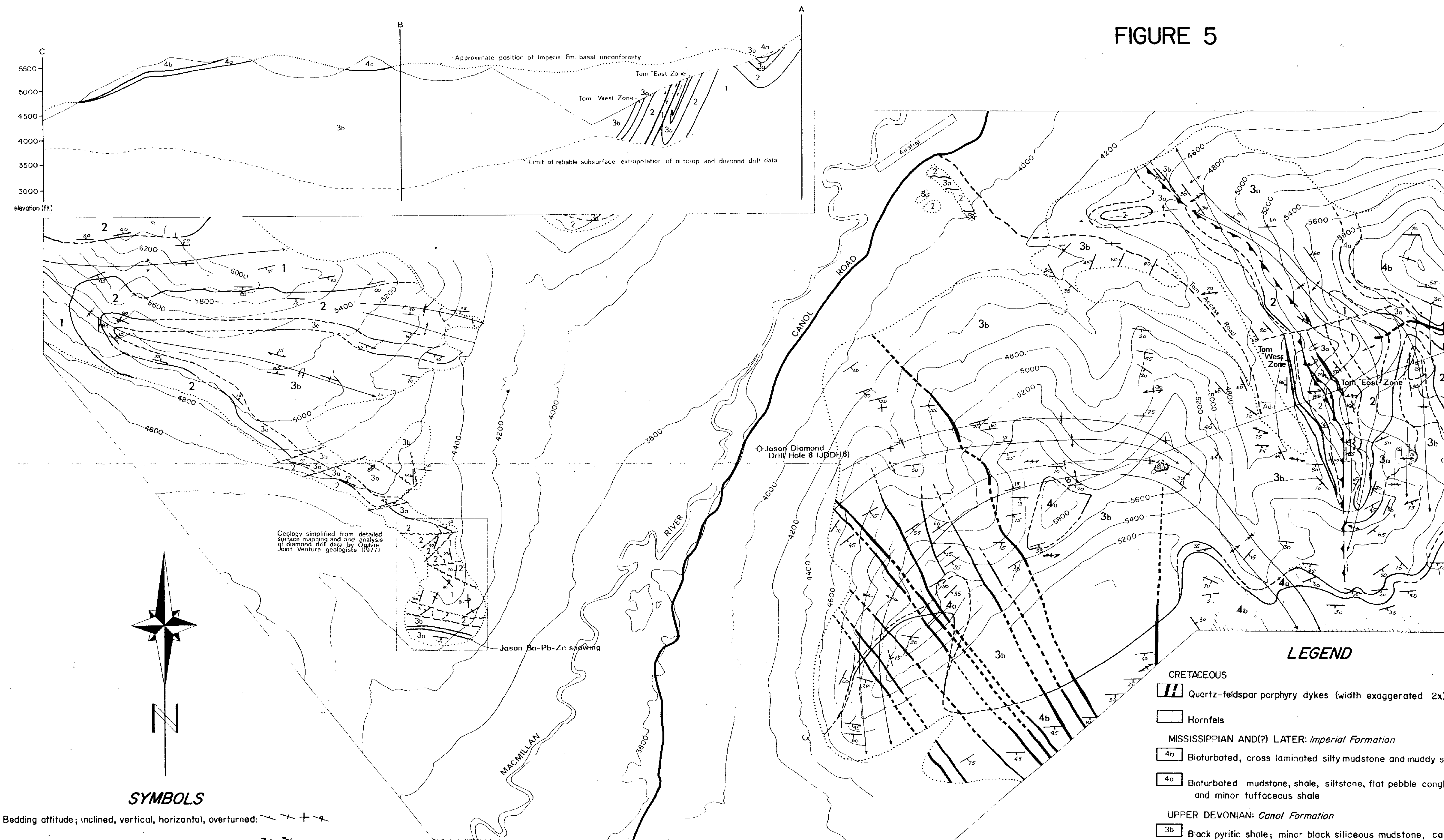
GEOLOGY OF MACMILLAN PASS AREA, YUKON TERRITORY

FIGURE 5



SYMBOLS

Bedding attitude; inclined, vertical, horizontal, overturned:

Slaty cleavage attitude; inclined, vertical:

Attitude of shear plane or mylonitized zone:

Fold axis; syncline, anticline (with direction of plunge):

Fault; inferred, displacement unknown:

Thrust fault; known, inferred:

Lithological contact; defined, approximate:

Limit of drift, alluvium and vegetation cover:

feet: 1000 500 0 1000 2000 3000 4000

1 inch = 1000 feet

metres: 300 200 100 0 300 600 900

0.9 cm = 100 m

Geology by R.C. Carne, July and August, 1976; August, 1977.

LEGEND

CRETACEOUS

Quartz-feldspar porphyry dykes (width exaggerated 2x)

Hornfels

MISSISSIPPIAN AND(?) LATER: *Imperial Formation*

4b Bioturbated, cross laminated silty mudstone and muddy siltstone

4a Bioturbated mudstone, shale, siltstone, flat pebble conglomerate and minor tuffaceous shale

UPPER DEVONIAN: *Canol Formation*

3b Black pyritic shale; minor black siliceous mudstone, calcarenite turbidites and black fetid limestone

Stratiform barite-lead-zinc-silver mineralization (extrapolated to surface from diamond drill records)

3a Pyritic shale, siltstone, pebbly mudstone, intraformational conglomerate, slump deposits and turbidites

2 Massive chert pebble conglomerate debris flow and turbidites

1 Siltstones and shales (turbidites), minor lensoid chert pebble conglomerate debris flows near the top

TO ACCOMPANY YUKON GEOLOGICAL REPORT I, INDIAN AFFAIRS AND NORTHERN DEVELOPMENT

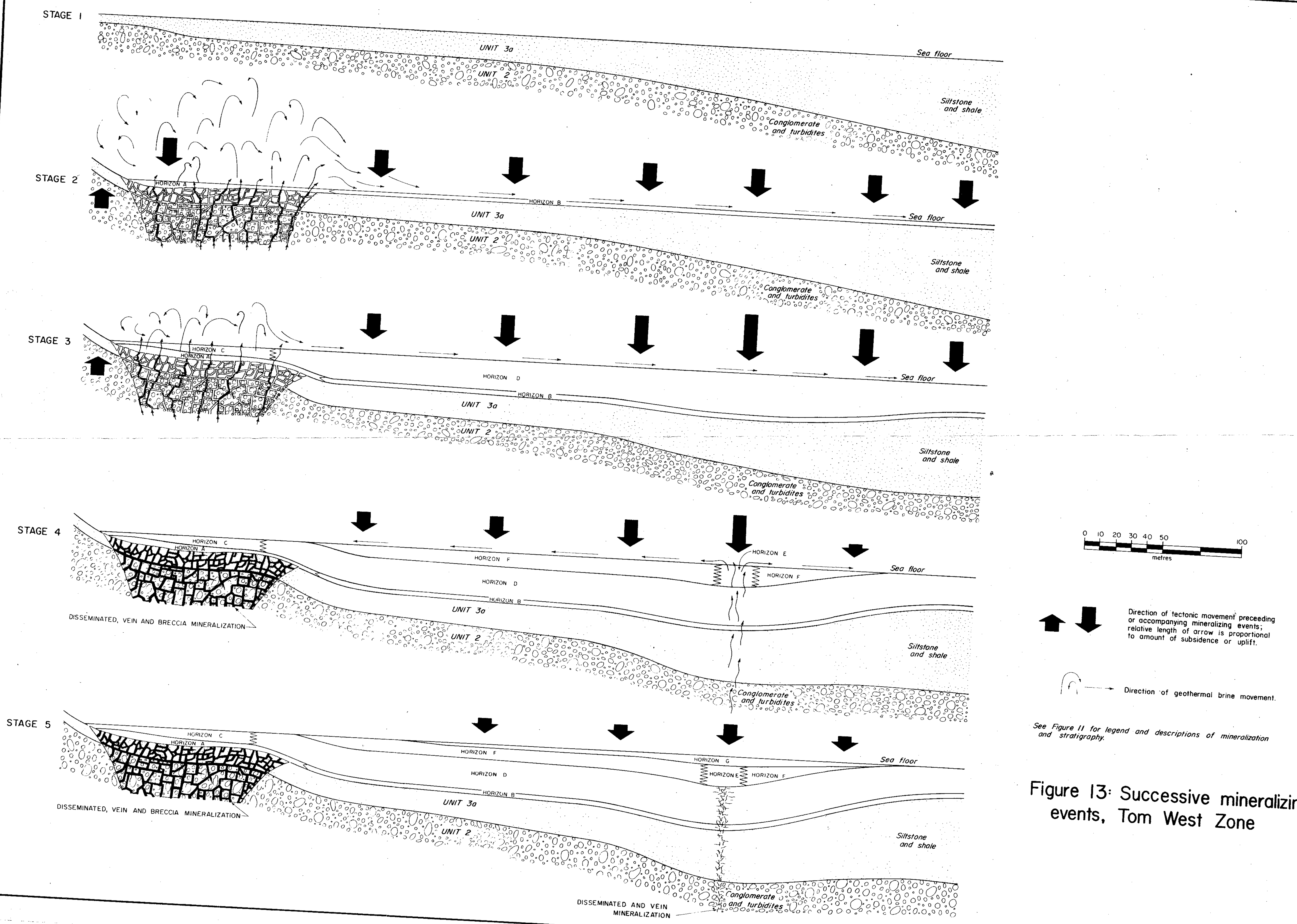


Figure 13: Successive mineralizing events, Tom West Zone

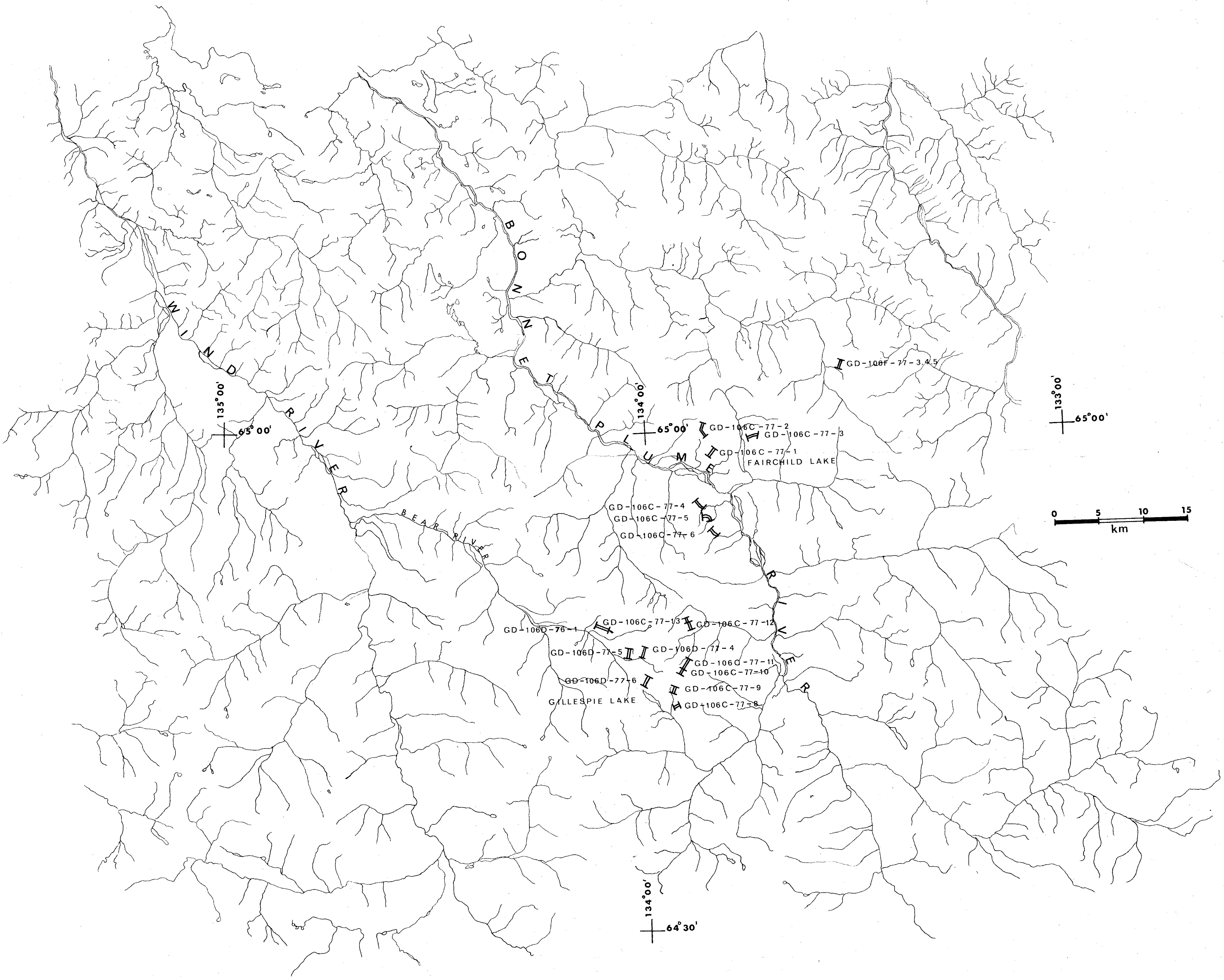
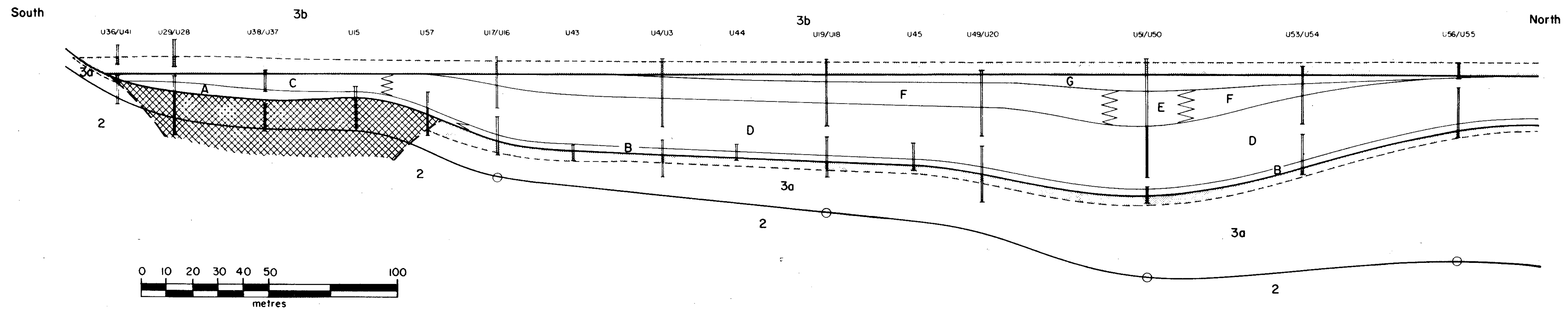


FIGURE 3 LOCATION DIAGRAM OF STRATIGRAPHIC SECTIONS



Stratigraphy

- **3b** Siliceous, pyritic black shale
- **3a** Pyritic siltstone and shale
- **2** Chert pebble conglomerate and turbidites
- Limit of pervasive silicification and pyritization of footwall and hanging wall rocks

Mineralization

- **G** Finely laminated black cherty argillite, pyrite, sphalerite and galena
- **F** Finely laminated barite, sphalerite and galena
- **E** Finely laminated witherite, barite, sphalerite, galena and pyrite
- **D** Finely laminated barite, galena and sphalerite
- **C** Finely laminated black cherty argillite, pyrite, barite, sphalerite and galena
- **B** Finely laminated black cherty argillite, pyrite, sphalerite and galena
- **A** Massive, poorly laminated galena, sphalerite, pyrite, siderite, barite, chalcopyrite and quartz
- Vein, disseminated and breccia matrix pyrite, quartz, siderite, sphalerite, galena, chalcopyrite and minor barite, tetrahedrite, chalcocite, bournonite, boulangerite

Symbols

- U45 Underground diamond drill hole
- Lithological contact extrapolated to plane of section from surface diamond drill hole
- Epigenetic mineralization and/or alteration seen in diamond drill core

Figure II: Structurally restored, true stratigraphic section of the Tom West Zone (south half).

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