METALLOGENETIC EVOLUTION OF THE CANADIAN CORDILLERAN OROGEN

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1. INTRODUCTION

The Canadian Cordilleran Orogenic Belt forms part of the circum-Pacific orogenic zone. It underlies an area of about 1,54 million sq. kilometres, is over 2400 kilometres long and 800 kilometres wide. The region is characteristically mountainous, much of it glaciated and alpine, containing plateaux, trenches, valleys, and fjords. The mountains, in general, rise to elevations between 2100 m and 3600 m above sea level, although Mount Logan in the St. Elias Mountains attains an altitude of 6000 m. The Canadian Cordillera is divided into two dominant orogenic belts: the eastern Columbian Orogenic Belt comprising deformed miogeosynclinal rocks and the western Pacific Orogenic Belt comprising allochthonous eugeosynclinal rocks. The Cordillera is further subdivided into five longitudinal tectonic belts within which rocks are broadly similar in type, age, and history. These belts are, from east to west: the Rocky Mountain Belt, the Omineca Crystalline Belt, the Intermontane Belt, the Coast Plutonic Complex, and the Insular Belt (Wheeler et al., 1972a). The Canadian Cordillera is important in that it contains: one of the world's largest lead-zinc-silver mine, Sullivan; the second-largest molybdenum mine, Endako; one of the most important concentrations of porphyry copper deposits, Highland Valley; Canada's largest tungsten mines, Cantung and Mactung; and Canada's second-largest silver district, Keno Hill (Sutherland Brown et al., 1971). In addition, it contains several large massive sulphide and lead-zinc deposits.

Major contributions on the geological and tectonic evolution of the Canadian Cordillera (Monger et al., 1972; Wheeler et al., 1972; Douglas et al., 1970; Gabrielse 1967; 1972; Souther, 1977; Monger, 1975; 1977; Coney, 1972; 1977; Eisbacher, 1974) in the context of Plate Tectonics have greatly improved the understanding of the distribution of the mineralization in space and time in this vast region. The processes leading to the concentration and distribution of metals in the region have been operative for a period equivalent to recorded geological history and predate the formation of the Cordilleran eugeosyncline. The mineralizing processes are varied and complex, however there exists a close relationship between the disribution of mineral deposits and the five tectonic belts of the Cordillera (see later). The relationship is apparent in the distribution of mineral deposits in regard to contained metals, morphological classes, and age of mineralization (Sutherland - Brown et al., 1971). There seems to be two dominant epochs of mineralization in the Canadian Cordilleran Orogenic Belt: the first extended from the Proterozoic to the Devonian and was dominated by lead and zinc mineralization of dominantly syngenetic origin and deposited in shelf sediments marginal to the craton; the second extends from Permian through to mid-Tertiary and is dominated by copper and molybdenum mineralization that is endogenetic and epigenetic. The post-mid-Tertiary period is not known to contain any significant mineralization. However, Zn-Mo geochemical anomalies in the Pliocene Mt. Edziza Volcanic massif suggest that mineralization may be presently taking place beneath the volcanic sites (Wolfhard and Ney, 1976). Besides Pb-Zn-Ag and Cu-Mo mineralization, other metallic minerals occur in significant quantities in the Cordillera. For the lead-zinc deposits of the northern Canadian Cordillera, two major groups of sedimentary host rocks are partitioned on the basis of depositional tectonics (McLaren and Godwin, 1979): a Proterozoic to Early Cambrian succession of carbonates and clastics is separated from a Late Cambrian to Devonian basinal shale and laterally equivalent platformal carbonate sequence by a regional erosional hiatus (sub-Upper Cambrian) and by an Upper Cambrian to mid-Ordovician carbonate unit which is relatively barren of mineralization. This can be used as an exploration criterion for further Pb-Zn deposits. A similar style of deposition is also recognized for the Pb-Zn-Ag mineralization in the Southern Cordillera. The Pb-Zn deposits are hosted by clastic rocks and by carbonate rocks. They occur in three dominant "belts", namely (from east to west): the Purcell Supergroup (mainly in the Purcell Anticlinorium), the Kootenay Arc, and the Shuswap Metamorphic Complex. The deposits decrease in age from east to west.

Copper is the most widely distributed metal in economic concentrations in the Canadian Cordillera and it is also widely distributed between the various kinds of mineral deposits. Copper and molybdenum are associated in a number of classes of deposits but only occur together in economic concentrations in certain types of porphyry deposits. Pure copper deposits are commonly associated with porphyries of the alkaline suite whereas pure molybdenum deposits are commonly associated with felsic members of the calc-alkaline suite.

There is a well-developed pattern of distribution of deposits in the Cordillera. In the Rocky Mountain and the Omineca Crystalline Belts the deposits are dominantly vein and stratiform - stratabound. In the Intermontane Belt deposits are dominantly of porphyry type. The Coast Plutonic Complex is dominated by mostly massive sulphide and magmatic deposits. The Insular Belt is dominated by skarn deposits and is typically characterized by deposits rich in iron. The Coast Plutonic Complex has polymetallic Fe-Cu-Zn and some Ni deposits. Cu-Mo deposits are typical of the Intermontane Belt, and Pb-Ag-Zn and Au-As deposits dominate the Omineca Crystalline and the Rocky Mountain Belts. Thus, most metallic mineral deposits of the Canadian Cordillera fit into a seven-fold classification, i.e. stratiform, veins, porphyry, massive sulphides, magmatic, skarn, and disseminations in lavas.

The purpose of this dissertation is to discuss the evolution of ore deposits in context of the geological evolution of the Canadian Cordillera and more specifically of the relations of metalliferous deposits to depositional and intrusive plutonic events, regional metamorphic and deformational events.

The exploration implications for the Cordilleran region will be discussed in terms of metallogenic evolution.

2. THE PHYSIOGRAPHY OF THE CANADIAN CORDILLERA

2.1 INTRODUCTION

In this section the physiographic history of the Canadian Cordillera will be discussed. This is essential in order that the reader should clearly understand the geological and tectonic evolution of the Cordillera. The Cordilleran geosyncline is thought to have been initiated by an episode of rifting within a large continental craton with the resultant drifting apart of sialic blocks as parts of two spreading lithosphere plates (Monger et al., 1972; Wheeler et al., 1972; Sears and Price, 1978). This is based upon the fact that the basement structural grain is truncated by Proterozoic Purcell sediments.

Major crustal units within the Cordillera can be identified on the basis of geophysical data interpretation (Berry et al., 1971). The North

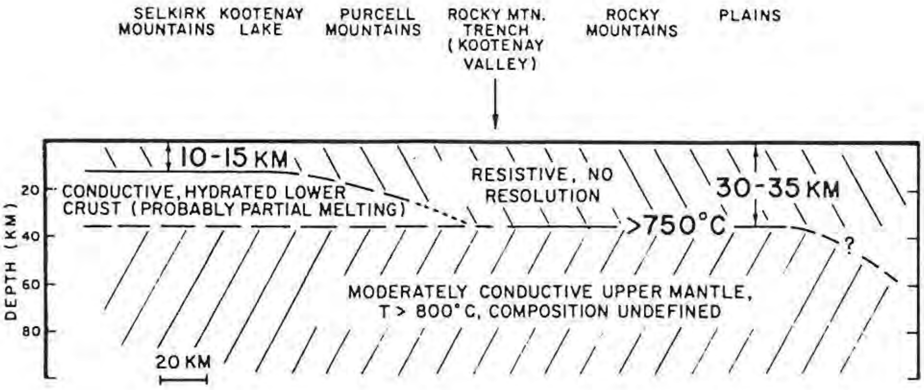
American craton, typified by a layered crust 45-50 km thick, underlies the Interior Platform and the Rocky Mountains. Two units within the craton have been recognized (fig. 2.1B): (i) the northern 50 km thick unit extending up to the Rocky Mountain Trench; and (ii) the southern 45 km thick unit continuing west of the Trench up to the Omineca Geanticline. Heat Flow data, plus the GDS, MT (fig. 2.1) and high level aeromagnetics suggest that the southern part of Omineca Crystalline and Intermontane Belts may be a northward continuation of the Cordilleran Thermal Anomaly Zone found in the western United States (Berry et al., 1971). Seismic data in central British Columbia indicate that the Fraser Lineament and the Pinchi Fault system mark a change in crustal structure from east to west. Seismic and gravity results show that the crustal thickness of the Insular Belt varies from 50 km or more in the south to between 25 and 30 km in the north and it has been suggested that Vancouver Island may not have been in its present position prior to the Jurassic. The continental margin off the Queen Charlotte Islands is marked by the active Fairweather-Queen Charlotte transform fault (fig. 2.1B) whereas west of Vancouver Island there appears to be no relative movement between the oceanic crust and that of the continent.

The geophysical interpretation as summarized above provides insight into the problem of current tectonic movements in the Cordilleran Orogen.* They also provide insight into the geological and structural evolution of the orogen.

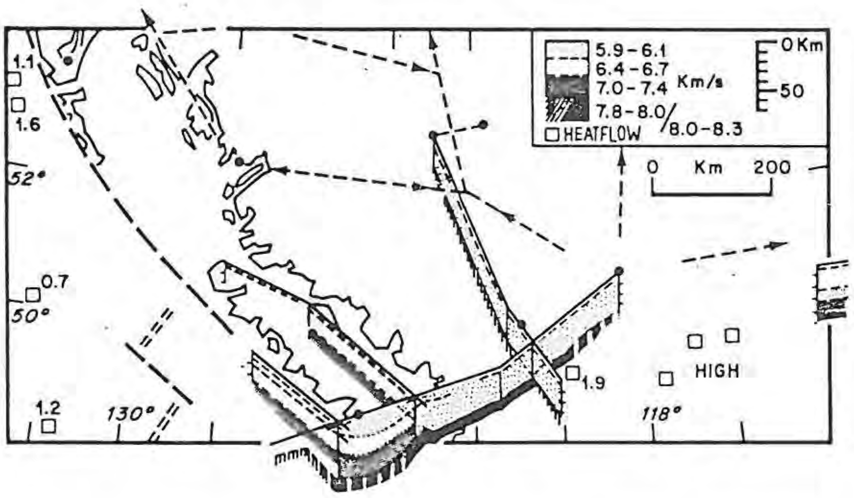
2.2. PHYSIOGRAPHIC REGIONS

The Canadian Cordillera can be divided into two fundamental tectono-stratigraphic parts (fig. 2.2): (a) the "pericratonic" Columbian Orogenic Belt consisting of deformed miogeosynclinal rocks; and (b) the "suboceanic" Pacific Orogenic Belt consisting of eugeosynclinal rocks which have been accreted to the North American craton. These parts are further subdivided into five distinct physiographic belts (fig. 2.2.) each with its own history. These belts are, from east to west: the Rocky Mountain Belt, the Omineca Crystalline Belt, the Intermontane Belt, the Coast Plutonic Complex, and the Insular Belt.

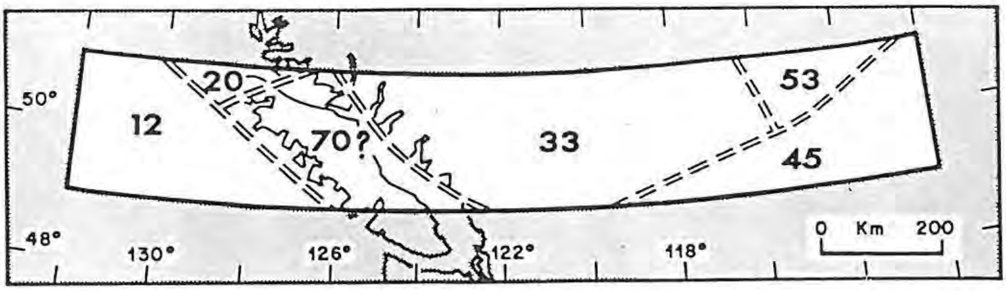
* FOOTNOTE: Orogen is used as a synonym of Orogenic Belt.



A. The crustal model for the southeastern part of the Cordillera, derived from GDS, MT, and aeromagnetic data (from Berry et al., 1971).



B. The crustal model of the Cordillera derived from seismic data. Note heat flow measurements (from Berry et al., 1971).



C. The crustal model for the southern part of the Cordillera derived from gravity data (from Berry et al., 1971).

FIG. 2.1: Geophysical interpretation of the Canadian Cordillera.

The Rocky Mountain Belt and the Omineca Crystalline Belt form rugged and blocky linear ranges sculptured in Palaeozoic and older carbonate and quartzite units flanked on the east by the clastic foothills. Serrated and glaciated peaks and spires in the Omineca Belt are developed in the eastern part of the Shuswap Complex and in granitic rocks. These range in elevation from 3 300 m in Columbia and Rocky Mountains to 2 600 m in Mackenzie Mountains (Bostock, 1970). The rugged Wernecke Mountains in the Mackenzie Mountain Area are formed of phyllite and massive subhorizontal carbonate. Liard Plateau, south of the Mackenzie and Selwyn Mountains is a region of tree- and tundra- covered hills (± 1 500 m elevation) which is underlain by shales and sandstones. Many summits are flat because of the attitude of strata but extensive remnants of former erosion surfaces are evident. The erosion surfaces are important in providing some understanding of the tectonic evolution of the Cordillera. The first buried erosion surface at the top of the Precambrian crystalline basement has been traced by seismic reflection from the Foothills where it is about 4 500 m deep to the Rocky Mountain Trench where it is at a depth of about 11 000 m. The second erosion surface is related to the evolution of the present physiography (fig. 2.3) (Wheeler et al., 1972). The Plateau basalts were extruded onto this gently undulating erosion surface.

The Intermontane Belt (fig. 2.2 and fig. 2.3) is an area of low relief (± 1 200 m) developed mainly on flat-lying lower Mesozoic and Tertiary volcanics. Landforms here consist of plains, plateaux, and mesas formed from the extrusion and subsequent erosion of the Plateau basalts. Shield volcanoes (such as the Edziza Peak) and tuyas occur in the Stikine Plateau of the Belt (Bostock, 1970).

The Coast Plutonic Complex is dominated by the Coast Mountains and the Cascade Mountains. The Coast Mountains are serrated tooth-like pinnacles attaining elevations between 1 800 and 7 200 m and stretching for 1 760 km. They are composed of crystalline gneisses and granitic rocks into which fiords and valleys have been sculptured by glaciers. St. Elias Mountains, lying en echelon to the northwest, are the highest and youngest mountains in Canada. The Cascade Mountains are separated from the southeast part of Coast Mountains by Fraser River Canyon and continue to the United States. They consist of calc-alkaline volcanic rocks (mainly andesite) intruded by quartz diorite and granodiorite batholiths which are exposed in erosional windows.

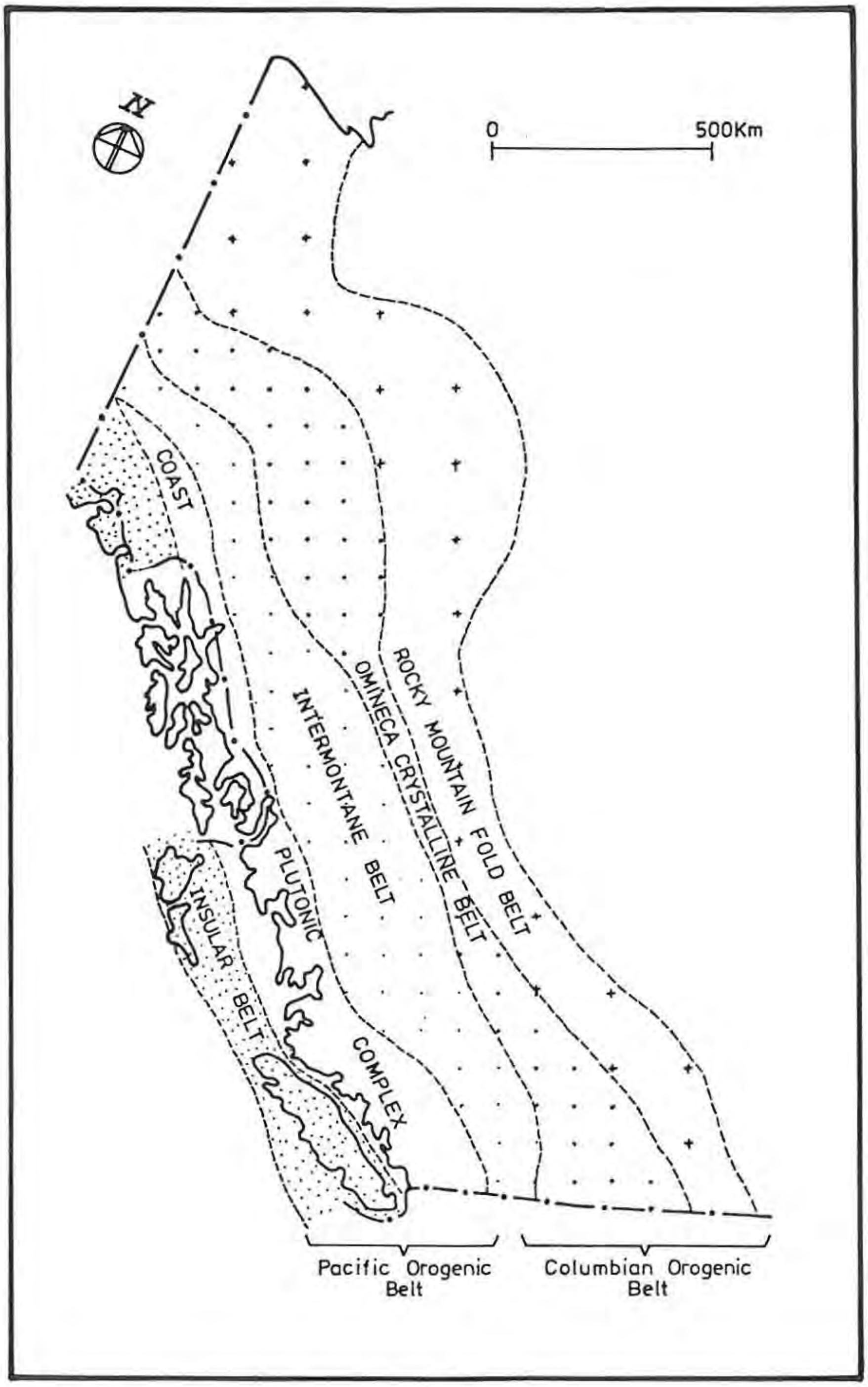


FIG. 2.2: Subdivisions of the Canadian Cordillera (after Wheeler et al., 1974).

The Insular Belt has a Median Uplift represented by glacially moulded mountain ranges of Queen Charlotte and Vancouver Islands rising to nearly 1 200 m and over 2 100 m respectively. The Pacific continental Shelf is very narrow west of Queen Charlotte Islands, where it is partly a fault line scarp. It widens southeastwards to a width of 64 km off southwestern Vancouver Island. The shelf edge is at a depth of 180 m and the slope extends to a depth of 2 300 m to the continental rise (Wheeler et al., 1972).

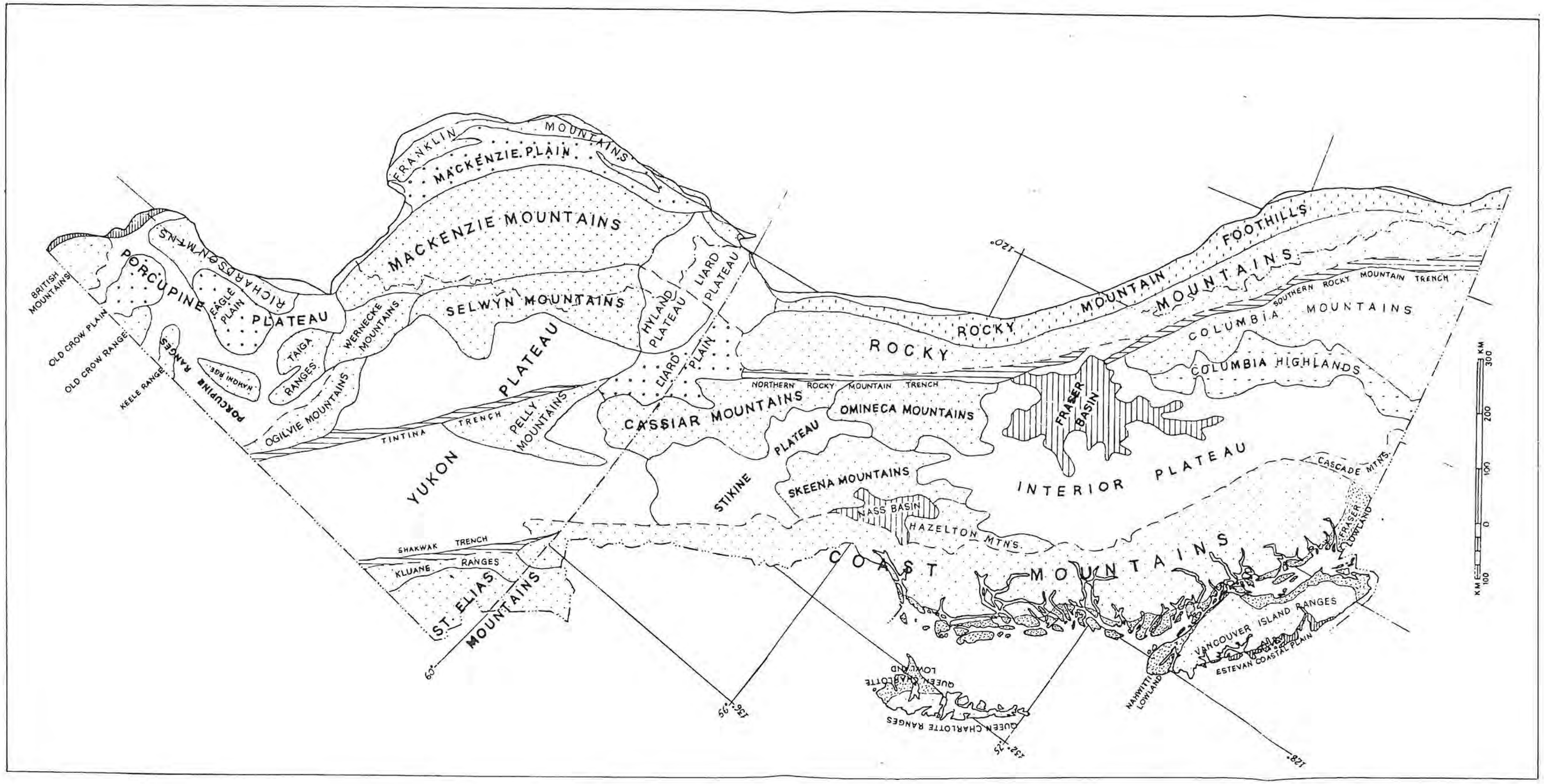


FIG. 2.3: Physiographic subdivisions of the Canadian Cordillera (Source: GSC Map 1254A, Scale 1:5 000 000, 1970).

The Cordillera is traversed by several remarkably linear northwest-trending valleys such as the Rocky Mountain Trench, Tintina Trench, and the Shakwak Valley between the St. Elias and Coast Mountains (fig. 2.3). Their floors lie at elevations of 660 to 900 m above sea level, although much of Tintina Trench is at about 330 m. The Cordillera is drained by a number of large rivers. The eastern section is drained by the Liard and Peace Rivers whereas the western section is drained by rivers such as the Yukon, Stikine, Skeena, Fraser, and Columbia.

A number of uplifts occurred during the evolution of the Cordillera. The late Palaeozoic clastic wedge in the northern Cordillera indicates uplift in northern Yukon and in the northwestern part of the Omineca Crystalline Belt. This uplift is the oldest and it took place in the mid-Triassic time. The granite-bearing debris in the Lower Jurassic of Whitehorse Trough and elsewhere reflects uplift in the volcanic arc lying to the southwest. The Late Jura-Cretaceous and Early Tertiary clastic sediments deposited in the successor basins and fore deeps also reflect the nature and timing of uplift and deformation in the Columbian and Pacific Orogenic Belts. The amount of uplift that has taken place is problematic, and various authors differ in their estimation of uplift. In general, the uplift varies from a few hundred metres to a few thousand metres.

Fig. 2.4 shows the tectonic elements of the Canadian Cordillera that controlled the nature of sedimentation and magmatism. This will be discussed in detail in section 3.

3 SEDIMENTARY AND MAGMATIC EVOLUTION OF THE CORDILLERA

3.1 INTRODUCTION

In this section the geological evolution of the Canadian Cordillera will be discussed with special reference to sedimentary and magmatic environments related to metallic mineralization.

The evolution of the Cordillera spans a period of more than 1 300 Ma – from the Proterozoic to Recent. The Cordillera is geologically subdivided into the eastern Columbian Orogenic Belt, consisting mainly of miogeosynclinal rocks, and the western Pacific Orogenic Belt,

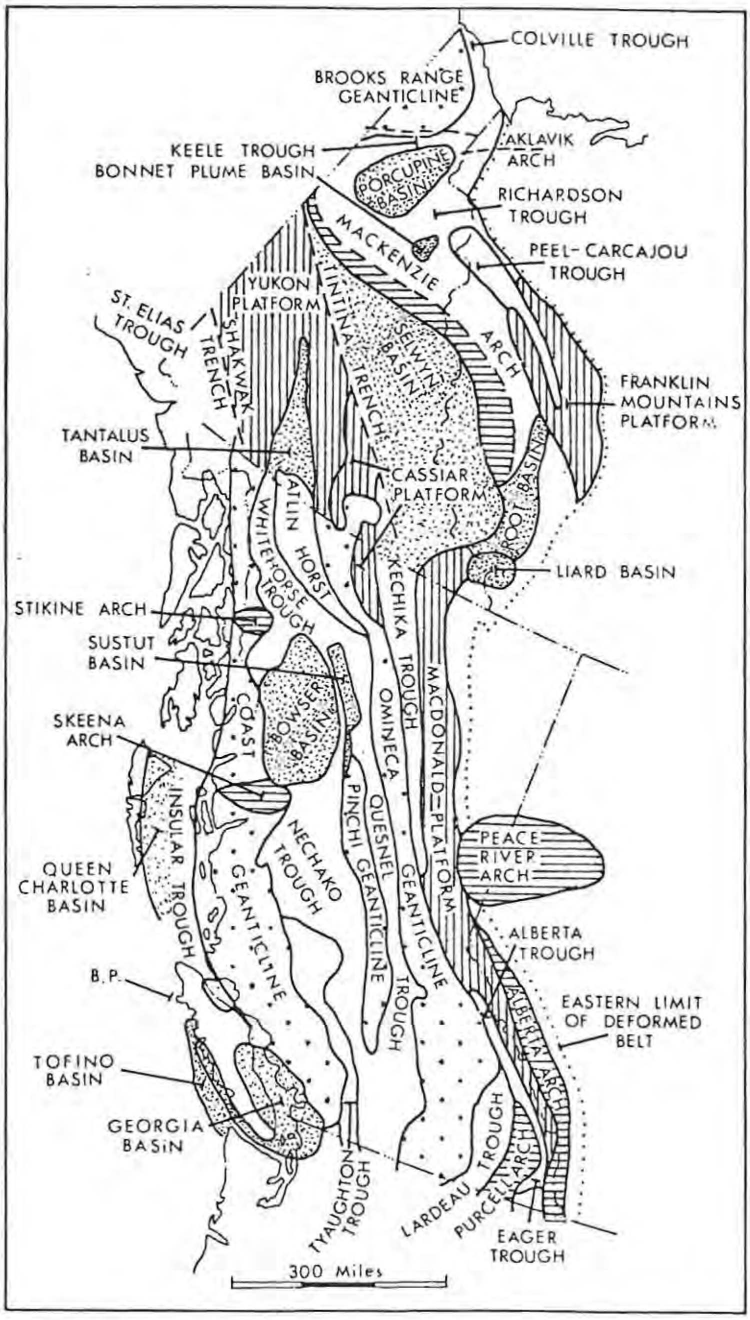


FIG. 2.4: Major tectonic elements of the Canadian Cordillera that controlled the nature and distribution of sedimentary and volcanic rocks. B.P. - Brooks Peninsula (after Wheeler et al., 1972a).

consisting of eugeosynclinal rocks. The miogeosynclinal assemblage is interpreted as a continental shelf : slope : rise assemblage fringing the western margin of the ancient North American craton whereas the Pacific Orogenic Belt is interpreted as consisting of a complex series of island arcs accreted to the North American continent starting in Late Palaeozoic time (Monger et al., 1972). Fig. 3.1 shows a tectonic chart summarizing the evolution of the Canadian Cordillera.

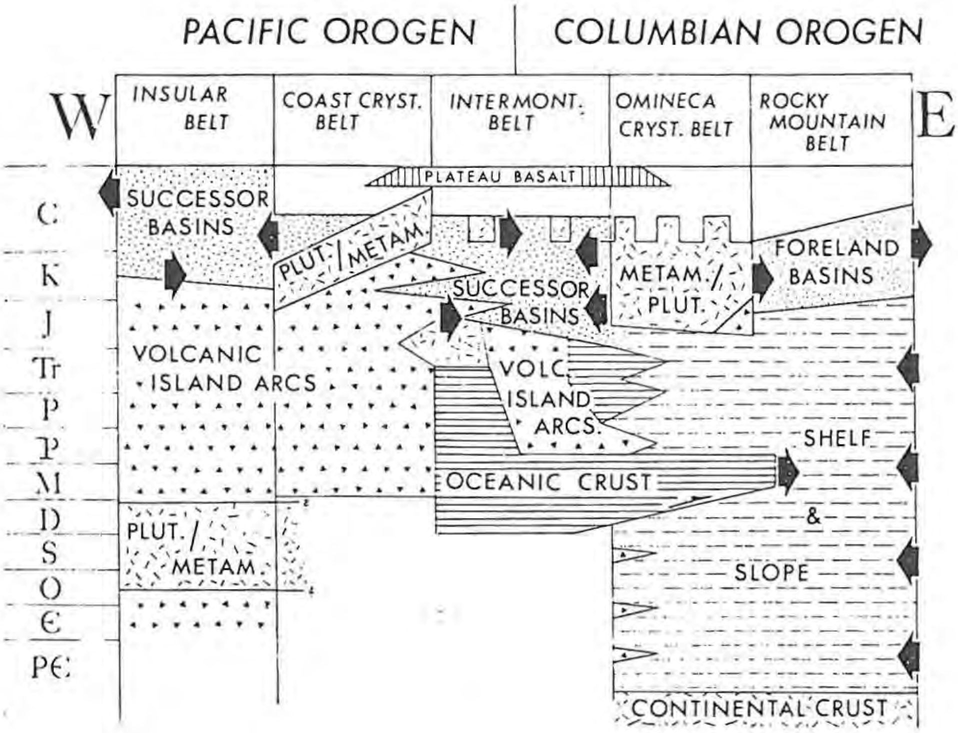


FIG. 3.1: Tectonic chart summarizing the evolution of the Canadian Cordillera (from Eisbacher, 1974).

3.2. THE PRECAMBRIAN BASEMENT (>1600 Ma)

The crystalline basement can be traced westward (apparently undisturbed) under the Rocky mountain Belt as far as the Rocky Mountain Trench, which bounds it on the west. Wedges of basement granitoid gneiss are thought to extend for at least 80 km further west under the Omineca Crystalline Belt (Monger et al., 1972). Crystalline basement gneiss has been observed east of Revelstoke (fig. 3.2), near Quesnel Lake (at the northern end of the Shuswap Metamorphic Terrane), and the Malton gneiss (fig. 3.2; Campbell, 1973). These gneissic rocks are thought to be pre-Windermere in age and may in fact prove to be remobilized Purcell strata or older crystalline basement (Brown, 1978). Cores of gneiss domes in the Shuswap metamorphic terrane are believed to be reactivated basement rocks. However, Reesor (1970) (in Monger et al., 1972) believes them to be metamorphosed Upper Precambrian and younger strata. Reesor's interpretation is supported by geophysical data (Berry et al., 1971). Wanless and Reesor (1975) have obtained an age of 1960 + 35/-45 Ma from zircons in granodioritic gneiss of Thor-Odin dome (fig. 3.2) and have suggested that similar gneissic rocks in cores of other domes in the Shuswap Complex may also be of this age. Simony (1979) concludes from detailed geological mapping of the Trail Gneiss (fig. 3.2.) that it is crystalline basement of Hudsonian age.

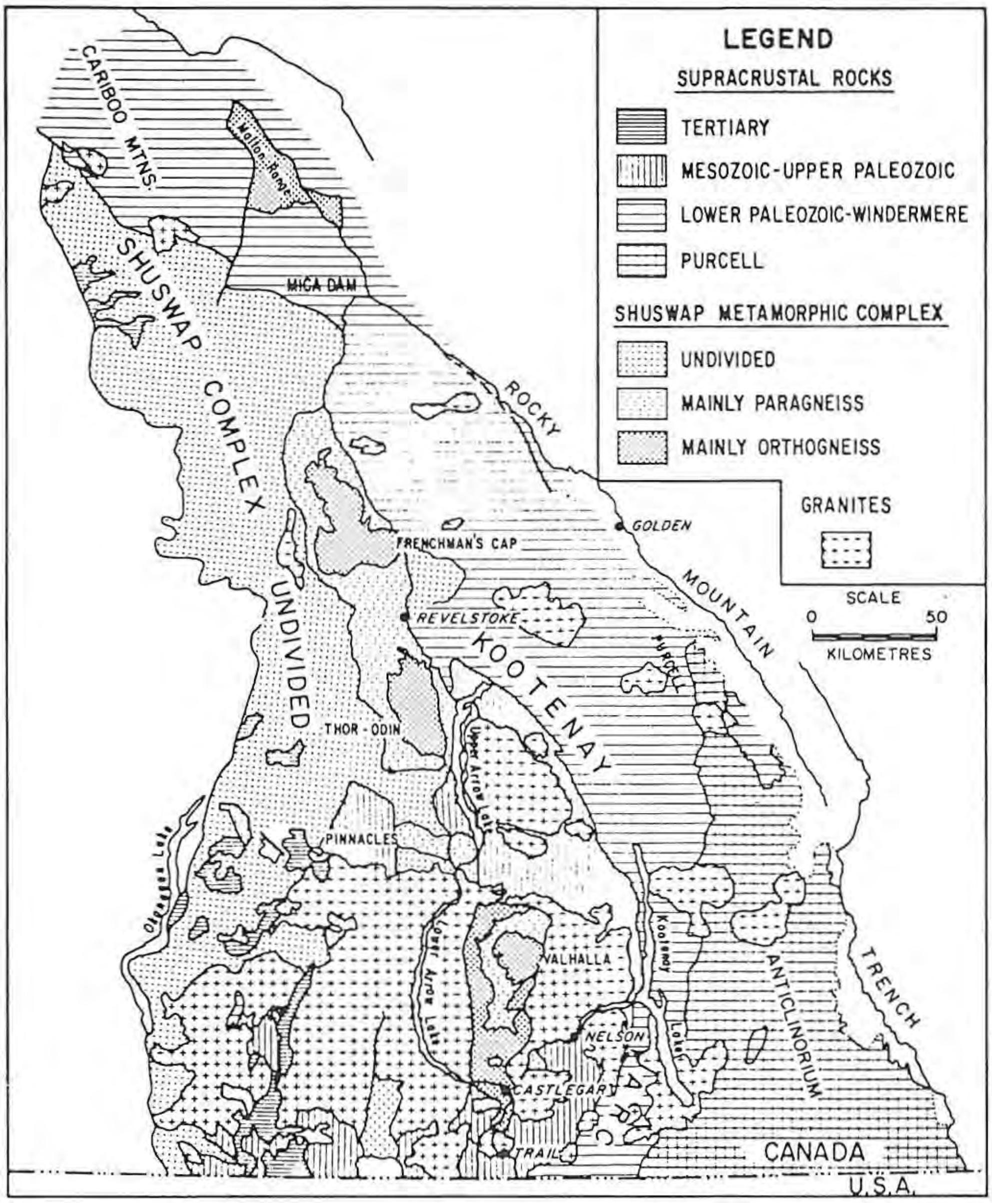


FIG. 3.2: Generalized regional map showing occurrence of major gneiss dome complexes, and the Shuswap Metamorphic Complex (from Simony, 1979).

West of the Omineca Crystalline Belt, crystalline basement occurs in the western Cascade Mountains where slices of gneiss, amphibolite, schist, and metadiorites are tectonically emplaced into younger strata (Misch, 1966). Mattinson (1972) has dated these rocks (in the Cascade Mountains of Washington, U.S.A.) at 1600 to 2000 Ma (zircon ages). Campbell (1973) is of the opinion that the crystalline basement in the west has been accreted to the North American craton. He deduces this from the fact that the basement in the west has been involved in structures of the core zone whereas the basement in the east is passive.

In southeastern Alaska, crystalline basement is represented in the Alexander Terrane by small areas of metamorphic rocks of the Wales Group (Thompson and Panteleyev, 1976).

Thus, it seems as though the western limit of Precambrian crystalline rocks that are part of the North American craton is either near the line of Rocky Mountain Trench or somewhere not too far to the west under the Omineca Crystalline Belt.

3.3 THE PROTEROZOIC TO LOWER PALAEOZOIC GEOLOGICAL HISTORY

Sedimentary rocks of Proterozoic age comprise two distinct stratigraphic assemblages: the Purcell Supergroup (1400-900 Ma) and its equivalent correlatives in the southern and northern Cordillera, and the Windermere Supergroup (800-600 Ma) and correlative strata which are almost continuously exposed for the length of the Cordillera (Gabrielse, 1972; Monger et al., 1972). Purcell rocks are the oldest component of the Cordilleran miogeosynclinal assemblage. They are restricted in outcrop to the southern Rocky Mountains and adjoining Purcell Mountains, to the northern Rocky Mountains, southern Mackenzie Mountains, northern Mackenzie Mountains, and to the Franklin Mountains. Total thicknesses range from less than 3000 m in eastern exposures to more than 9000 m in western ones (Monger et al., 1972).

Purcell rocks throughout the Cordillera display similar characteristics (fig. 3.3A). Generally, they are fine-grained well sorted clastic rocks - mainly argillite, siltstone, fine-grained sandstone, and well-laminated and stromatolitic carbonates, (fig. 3.3). Red-Bed facies are conspicuous in southern Mackenzie Mountains and in southern Rocky Mountains.

In Mackenzie Mountains pink-weathering siltstone and shale are intimately associated with, and are in part perhaps facies equivalent of bedded gypsum. Strata in the east are characterized by shallow-water or intertidal structures such as mud cracks, dessication breccias, and stromatolites, whereas equivalent strata to the west are in many cases turbidites of predominantly deep-water origin. Well-developed graded bedding, current markings, and slump structures are present in the Aldridge Formation (the oldest formation) of Purcell Mountains. These are indicative of turbidite deposition (Gabrielse, 1972). Minor

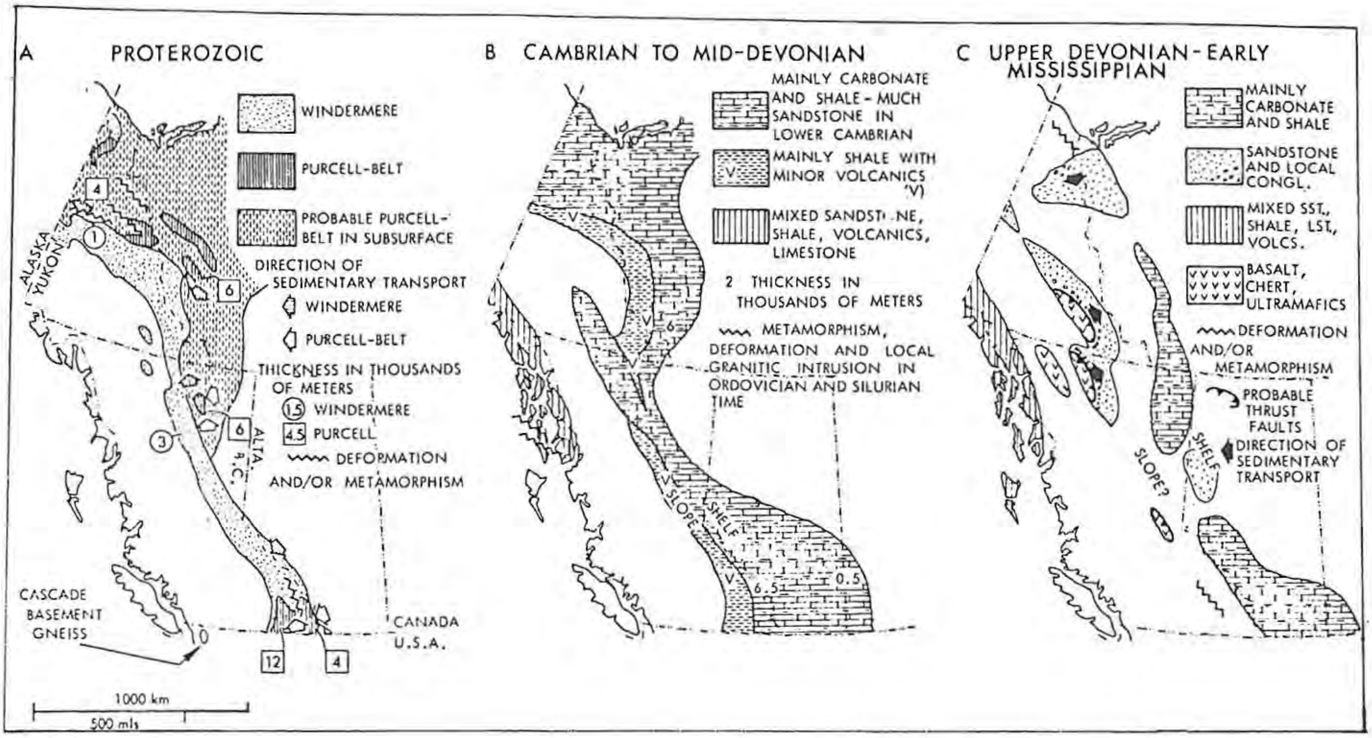


FIG. 3.3: Proterozoic to early Palaeozoic sedimentation and tectonism in the Canadian Cordillera (from Monger et al., 1972).

andesitic flows and gabbroic to dioritic dykes and sills are widely distributed in the Purcell sequence (fig. 3.4), and in the correlative

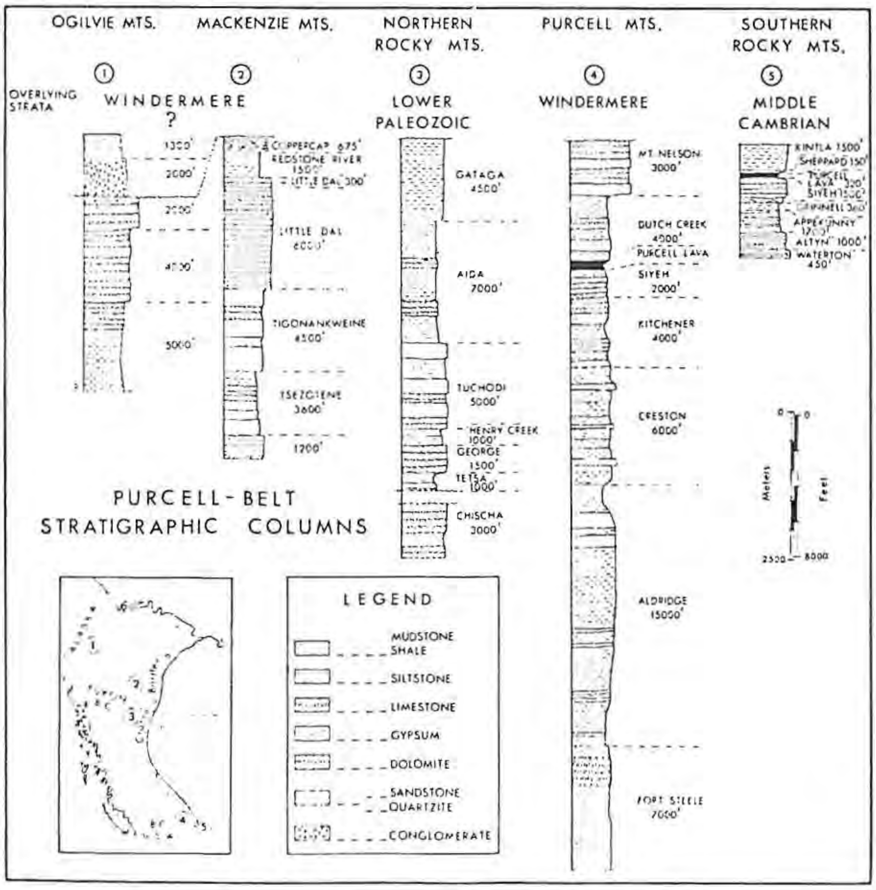


FIG. 3.4: Stratigraphic columns of Purcell rocks (from Gabrielse, 1972).

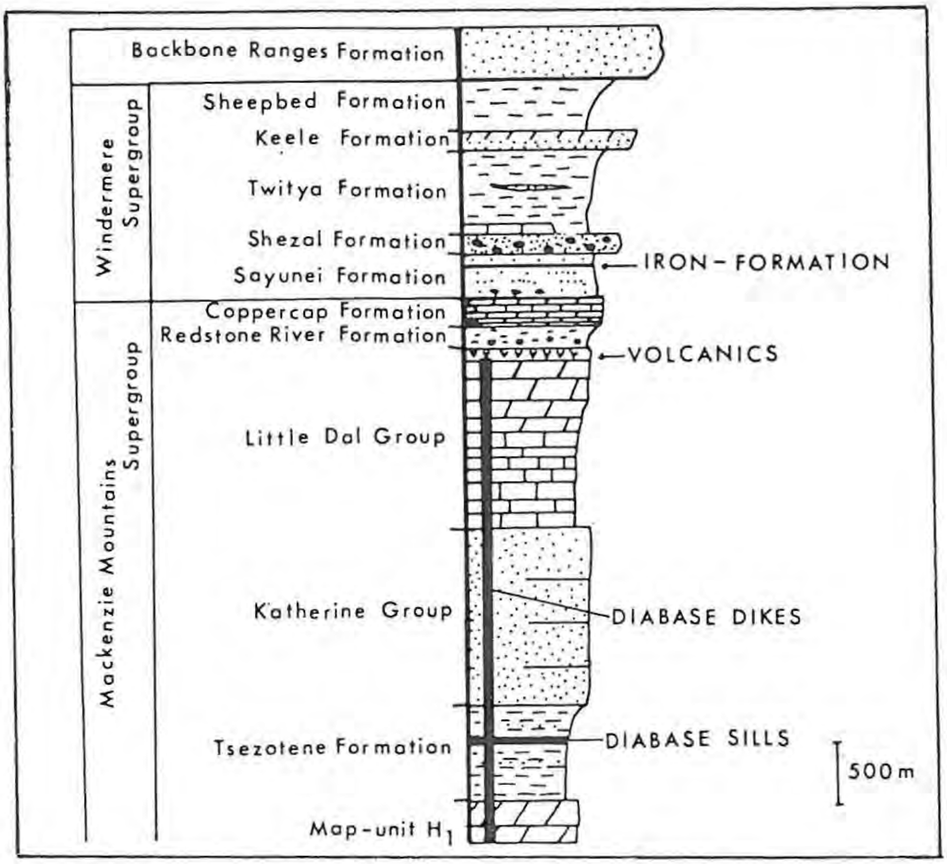


FIG. 3.5: Stratigraphic section of the Proterozoic succession in the Mackenzie Mountain, showing the position of intrusive diabase sheets (from Armstrong et al., 1982).

Mackenzie Mountain Supergroup (fig. 3.5). Sills are concentrated in the middle and lower parts of the Aldridge Formation. The Moyie intrusions of Purcell and southern Rocky Mountains are dioritic sills, possibly correlative with the Purcell lava. The Aldridge Formation and the Moyie sills have been intruded by the Hellroaring Creek Stock which occupies the core of an open, northwest plunging anticline. The Hellroaring Creek stock is dated at 1 260 Ma. (Ryan and Blenkinsop, 1971). The outer part of the miogeosynclinal trough in which the Purcell sediments accumulated underwent regional metamorphism, locally to sillimanite grade, prior to the East Kootenay Orogeny (Wheeler et al., 1972; Monger et al., 1972; Douglas et al., 1970).

The majority of Purcell rocks accumulated in shallow-water tidal flat and flood-plain environments as prograded continental terrace wedges deposited by low-energy river systems (Thompson and Panteleyev, 1976). Deeper water turbidite deposition occurred along the distal deep-water margin of the Purcell Supergroup. Monger et al. (1972) interprete the Purcell sequence as a continental shelf : slope : rise assemblage. In the southern part of the Canadian Cordillera the Purcell sequence developed in a slowly subsiding re-entrant on the North American craton, somewhat resembling an aulacogen (fig. 3.6; Harrison et al., 1974).

The Aldridge Formation hosts one of the world's great base-metal deposits - the Sullivan Mine at Kimberley, British Columbia. Pb-Zn deposits in the Purcell Supergroup (fig. 3.7 see also fig. 4.1) seem to be stratigraphically confined to the Aldridge Formation, where they have been geologically classified as concordant or transgressive (Thompson and Panteleyev, 1976; Fyles, 1966). Elsewhere in the Purcell Supergroup, copper is the most common metal. Most known occurrences in the Purcell Supergroup are in the southeastern part of the outcrop area. The Yarrow-Spionkop deposit is in the upper part of the Grinnell Formation (a red-bed seccession) and is hosted in quartzite and green argillite. Stratiform copper deposits in the Mackenzie Mountains (e.g. Redstone, and Bonnet Plume deposits) occur in the upper part of a pink-weathering siltstone (Redstone River Formation). In northern Rocky

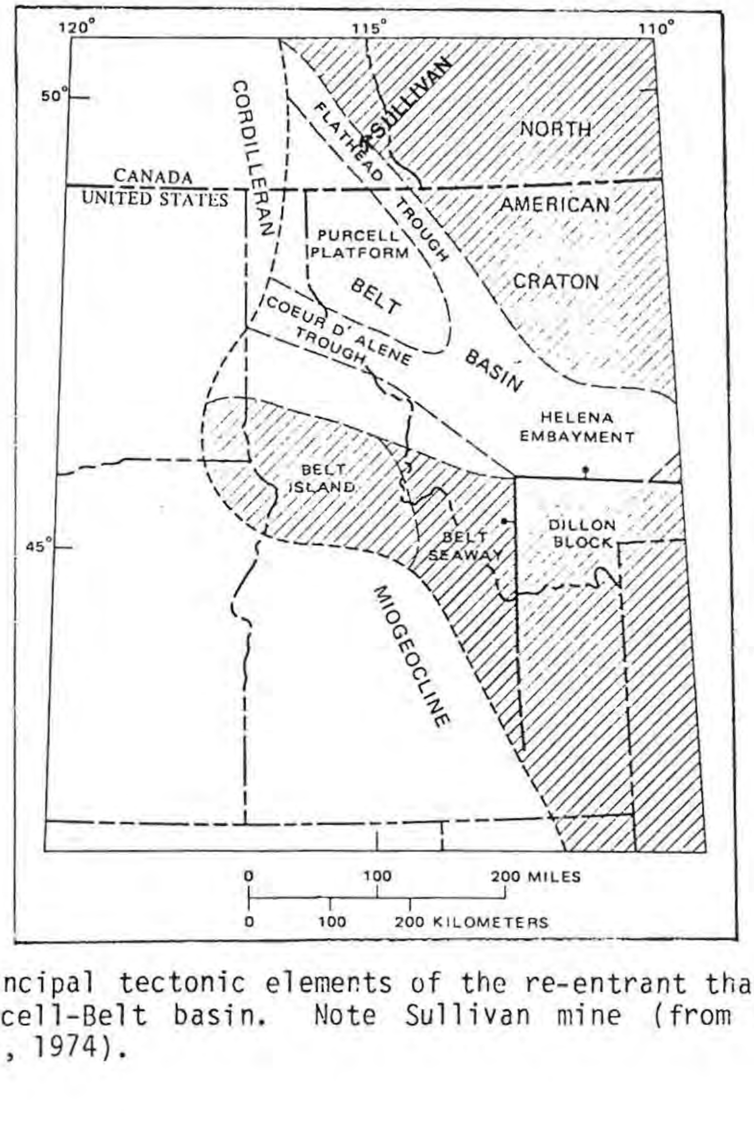
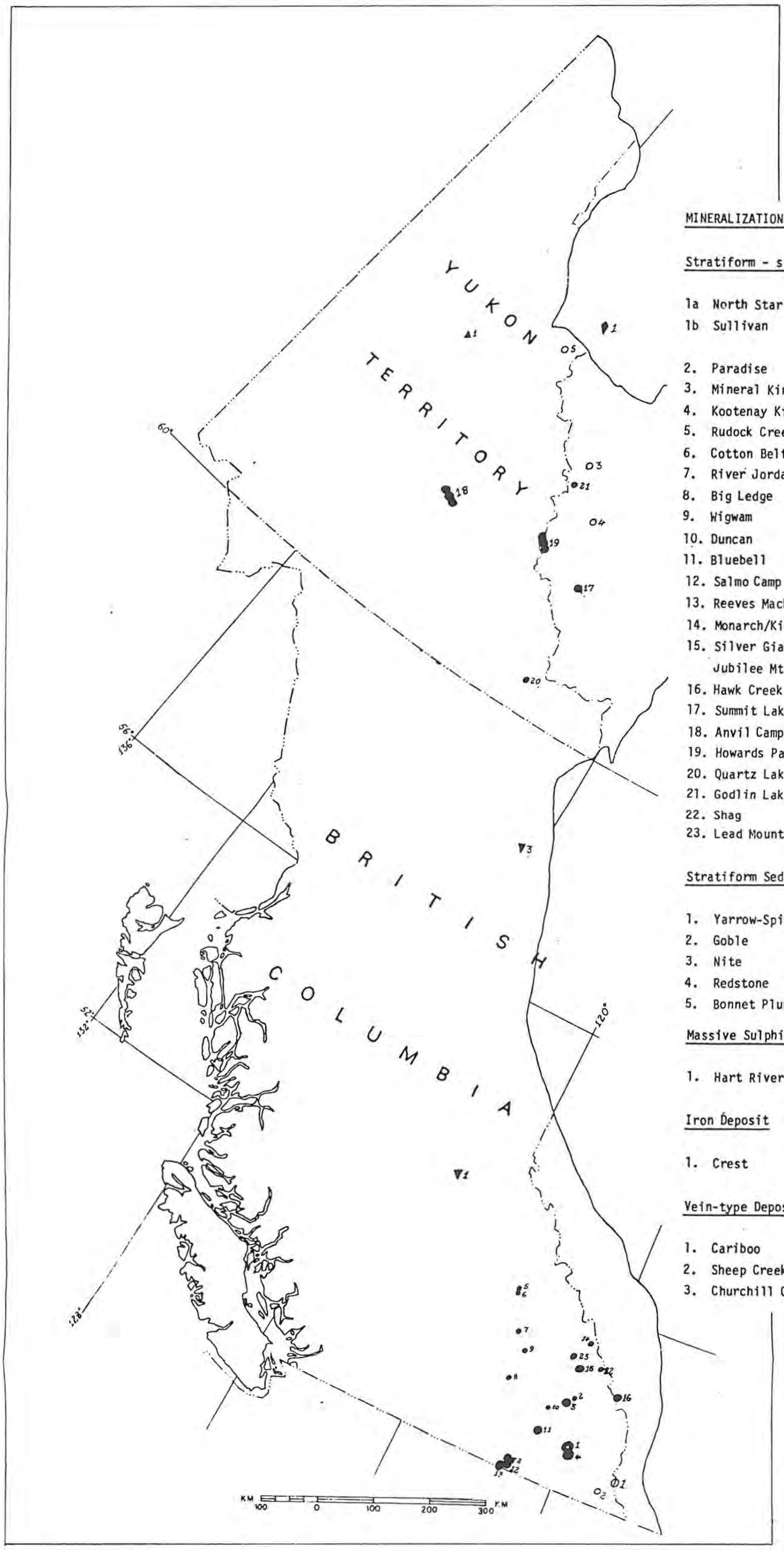


FIG. 3.6: Principal tectonic elements of the re-entrant that formed the Purcell-Belt basin. Note Sullivan mine (from Harrison et al., 1974).



MINERALIZATION IN THE PROTEROZOIC TO LOWER PALAEOZOIC

Stratiform - stratabound Pb-Zn-(Ag) ●

1a North Star	Proterozoic	Pb, Zn, Ag
1b Sullivan	1340 Ma	Pb, Zn, Fe, Ag, Sb, Cd, Bi, Sn, In, Cu
2. Paradise	Proterozoic	Pb, Ag, Zn, Cd, Au
3. Mineral King	800 Ma	Pb, Zn, Ba, Ag, Cd, Cu
4. Kootenay King	Purcell	Pb, Zn, Fe
5. Rudock Creek	Cambrian	Zn, Pb
6. Cotton Belt	Cambrian	Zn, Pb
7. River Jordan	Proterozoic	Zn, Pb
8. Big Ledge	Cambrian	Zn, Pb
9. Wigwam	Cambrian	Zn, Pb
10. Duncan	L. Cambrian	Zn, Pb
11. Bluebell	L. Cambrian	Zn, Pb, Ag, Cd, Cu
12. Salmo Camp	L. Cambrian	Zn, Pb
13. Reeves MacDonald	L. Cambrian	Zn, Pb
14. Monarch/Kicking Horse	M. Cambrian	Zn, Pb
15. Silver Giant Mine/ Jubilee Mt. prospect	M. Cambrian	Pb, Zn, Ag, Cu, Cd, Sb, Ba, A
16. Hawk Creek	M. Cambrian	Zn
17. Summit Lake	Ordovician	Zn, Pb
18. Anvil Camp	L. Cambrian	Pb, Zn, Ag
19. Howards Pass Camp	L. Silurian	Pb, Zn, Ag
20. Quartz Lake	Proterozoic	Zn, Pb
21. Godlin Lake	Camb.-Dev.	Zn, Pb
22. Shag	M. Cambrian	Pb, Zn, Ag
23. Lead Mountain	M. Cambrian	Pb, Zn, Ag

Stratiform Sedimentary Copper O

1. Yarrow-Spionkop	Proterozoic	Cu
2. Goble	Purcell	Cu
3. Nite	Pre-Rapitan	Cu
4. Redstone	Purcell	Cu
5. Bonnet Plume	Purcell	Cu, Co

Massive Sulphide ▲

1. Hart River	Proterozoic	Cu, Zn, Ag, Au

Iron Deposit ◆

1. Crest	700 Ma	Fe

Vein-type Deposits ▼

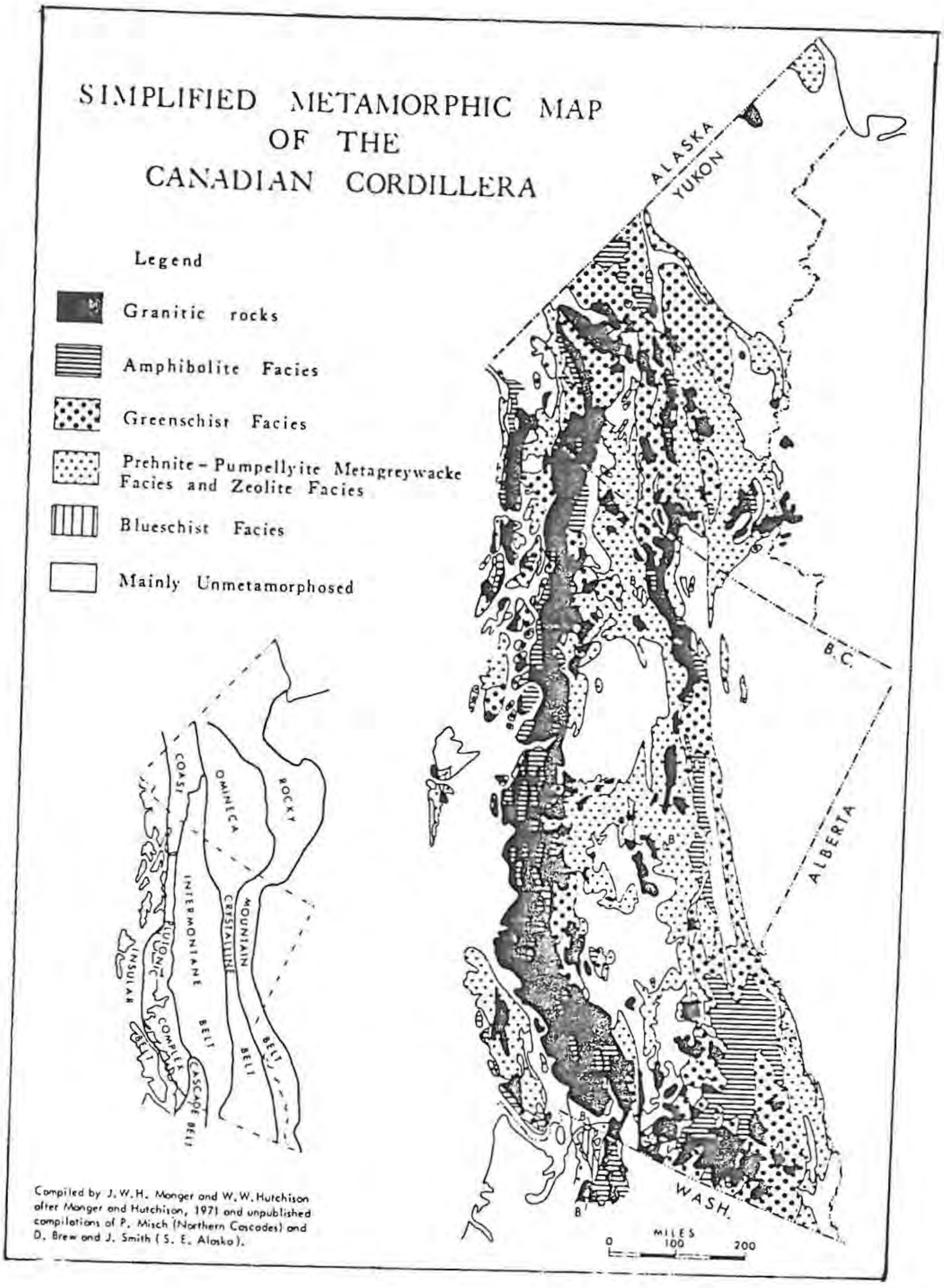
1. Cariboo	Precambrian ?	Au
2. Sheep Creek	Precambrian	Au
3. Churchill Cu district	Precambrian	Cu

FIG. 3.7: Mineral deposits of the Proterozoic to Lower Palaeozoic.

Mountains copper deposits (e.g. the Churchill Copper district) are spatially related to diabase dykes in Purcell strata, and it is possible that intrusion of the dykes facilitated concentration of copper already present in the sediments (Gabrielse, 1972).

Purcell sedimentation and magmatism was terminated by a period of uplift, folding, faulting, and regional metamorphism called the East Kootenay Orogeny in the southern Cordillera and the Racklan Orogeny in the northern Cordillera (Monger et al., 1972; Gabrielse, 1972). The dating of these orogenies is doubtful, but they are thought to have occurred at about 800 Ma ago. Deformation in the south appears to have been mild and uplift is recorded mainly in a regional unconformity beneath the Windermere Supergroup. Deformation in the north was intense as indicated by the unconformity separating Purcell and Windermere rocks (Monger et al., 1972). It produced tight, NNE trending folds in northern Selwyn Mountains and block-faulting accompanied by tilting farther east in Mackenzie Mountains. In these areas the Purcell strata are overlain unconformably by the Rapitan Group. Tight E-W folds northwest of Wernecke Mountains and north of Ogilvie Mountains and low grade regional metamorphism (fig. 3.8) in Wernecke, Ogilvie, and Richardson Mountains might also be related to the Racklan Orogeny (Gabrielse, 1972).

The Windermere Supergroup (fig. 3.3A and fig. 3.9)(800 - 600 Ma) is almost continuously exposed along the Cordillera in the Omineca Crystalline and Rocky Mountain Belts. Thick successions of heterogeneous, immature, clastic rocks were deposited west of Purcell rocks which acted as a pseudo-craton (Monger et al., 1972; Gabrielse, 1972). The lower part of the supergroup is characterized by phyllite, slate, siltstone, and sandstone interbedded with grits and pebble conglomerates. The latter contain opalescent bluish quartz grains thought to be derived from crystalline rocks of the shield. Extremely course, poorly-sorted conglomerate (diamictite) such as the Toby Conglomerate in the Southern Cordillera occurs, locally, at or near the base of the Windermere Supergroup. Subaqueous mudflows associated with widespread Late Proterozoic glaciation are thought to have produced the diamictite (Aalto, 1971). Andesitic volcanics overlie the Toby conglomerate in southern Selkirk Mountains, in southern Ogilvie Mountains, and near the British Columbia - Yukon border (Gabrielse, 1972). Eastern facies of the lower Windermere Supergroup are generally



Compiled by J.W.H. Monger and W.W. Hutchison after Monger and Hutchison, 1971 and unpublished compilations of P. Misch (Northern Cascades) and D. Brew and J. Smith (S. E. Alaska).

FIG. 3.8: Simplified metamorphic map of the Canadian Cordillera. (from Wheeler et al., 1972a)

coarser than those farther west, and sedimentary structures are better developed.

The upper part of the Windermere Supergroup is much more calcareous than the lower (fig. 3.9) and is much more variable in lithology. It includes thick well-bedded to massive limestones, dolomites, calcareous phyllites and slates. The Rapitan Group [correlated with the Windermere Supergroup (Thompson and Panteleyev, 1976)] in Mackenzie Mountains

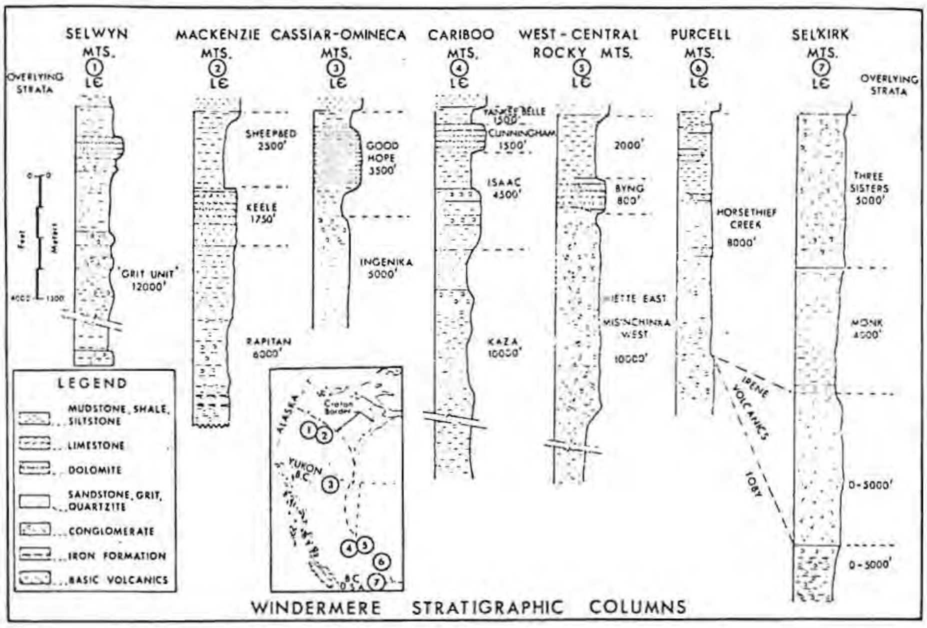


FIG. 3.9: Stratigraphic columns of Windermere rocks (from Gabrielse, 1972).

consists of a unique succession (up to 1 800 m) of conglomerate (diamictite) with sandstone, siltstone, shale, and bedded chert-hematite iron-formation (fig. 3.5). The chert-hematite iron-formation lies with a marked angular unconformity on Purcell strata and is thought to have originated as a volcanogenic exhalite bed (Gabrielse, 1972). The Rapitan Group strata display well-developed thin bedding with cross-bedding, ripple marks, load casts, and slump structures.

The lower part of the Windemere sequence could represent deposition in relatively deep water with the periodic introduction of course-grained material by turbidity currents. The fairly widespread carbonates in the upper part reflect a shallow-water regime attained when deposition reached wave base.

Cambrian to Middle Devonian strata occur mainly in the Rocky Mountain and Omineca Crystalline Belts (fig. 3.3.B) and are generally thickest in linear troughs marginal to the craton. In the eastern Cordillera, lower Palaeozoic strata are at least locally conformable on the Windermere Supergroup, but they are commonly finer-grained and better sorted than the Windermere rocks. This suggests reduction of relief and a general tectonic stability of the craton by the beginning of and during the Early Cambrian (Douglas et al., 1970). In the northern Cordillera, especially at Wernecke-, Franklin-, Selwyn-, Mackenzie-, Pelly-, and

Cassiar Mountains (fig. 2.3), the Lower Cambrian consists of a coarse-grained orthoquartzite and conglomerate overlain by fine-grained carbonates, siltstones, and argillites. In the southern Cordillera, Lower Cambrian strata occur in isolated remnants and fault-blocks as part of a thick lower Palaeozoic sections northwest of Moyie fault in Purcell Mountains and north of Dibble-Creek fault in Hughes Range east of Rocky Mountain Trench. Here, as in the northern Cordillera, the basal quartzite and conglomerate of the Cranbrook Formation lies unconformably over Proterozoic strata and locally contains a middle unit of magnesite. South of the Moyie and Dibble Creek faults the Lower Cambrian is absent and the Upper Devonian lies unconformably on the Proterozoic strata. In the Selkirk and Omineca Mountains the basal orthoquartzite is overlain by limestones, grits, phyllites, and schists. The limestones are fossiliferous.

Middle and Upper Cambrian rocks in the northern Cordillera overlie older rocks with regional unconformity. These rocks consist of argillaceous limestones, siltstones, shales, and minor sandstones and conglomerates. The limestones are fossiliferous at some places. In the southern Cordillera, the Middle and Upper Cambrian rocks of Purcell Mountains were deposited on the eastern flank of Purcell Arch which probably remained emergent until some time in latest Early or Middle Cambrian time (Douglas et al., 1970). They occur at intervals within Rocky Mountain Trench, and along its west side, and consist of unfossiliferous dolomite of the Jubilee Formation and the lower part of the overlying thin-bedded limestone and shale of the McKay Group (Douglas et al., 1970). In southernmost Selkirk Mountains fossiliferous Middle and Upper Cambrian strata in Lardeau Trough are the limestone, dolomite, and calcareous shales of the Nelway Formation. These rocks accumulated as carbonate banks fringing the southern part of Purcell Arch and the uplifted block south of Eager Trough.

Ordovician to Silurian rocks in the northern Cordillera consist of graptolytic shales, argillaceous limestone, limestone turbidite, siltstones and chert (fig. 3.3.B). In central Ogilvie and Wernecke Mountains the strata are dominantly carbonates with minor interbedded shale. An anomaly in the relatively simple pattern of sedimentation is the Cassiar Platform of the northern Omineca Crystalline Belt, which appears as a tongue of carbonate west of shale facies in fig. 3.3B. The facies are of shallow-water aspect and contrast with deeper-water shaley facies to the northeast (Monger et al., 1972). The Cassiar Platform lies west of the Tintina and northern Rocky Mountain Trenches, along which there was probable right lateral transcurrent movement in the Mesozoic, and possibly is displaced along these faults (Monger et al., 1972). An alternative suggestion is that the Platform represents a sialic block torn away from the North American craton during initial rifting but remaining close to it. In the southern Cordillera (at Purcell and Selkirk Mountains) the Ordovician to Silurian rocks consist of shales, argillaceous limestones, and finely crystalline silty dolomites (Douglas et al., 1970). Ordovician through Devonian rocks in the western part of the Cordillera are confined to the Insular Belt. They typically contain conspicuous volcanics. Near the northern Cascade Mountains occur Middle Devonian fine-grained clastic rocks, carbonate, and basic volcanics.

A body of granitoid gneiss (Mount Fowler Batholth) of Devonian age (372 Ma)(Okulitch, et al., 1975) lies between Adams and Shuswap Lakes and west of the Shuswap Metamorphic Complex. The gneiss is medium to coarse-grained, white to grey granite, quartz monzonite, and granodiorite. Evidence for its intrusive nature is deduced from relict textures and mineralogy and from the contact metamorphism of bordering sedimentary and volcanic rocks (Okulitch et al., 1975). This plutonism might have accompanied the Caribooan Orogeny.

Mineralization in the Lower Palaeozoic (fig. 3.7) is mostly Cu, Fe, Pb-Zn, and Au. The Windermere Supergroup hosts a large stratabound iron deposit - the Snake River (Crest) deposit located northeast of Mayo on the Yukon - Northwest Territories border. The deposit forms a ± 100 m thick unit in the lower part of the Rapitan Formation. The carbonate Pb-Zn deposits of Salmo, Monarch, and Robb Lake in British Columbia occur as conformable replacements in dolomite. The dolomite host rocks are broadly folded, faulted, brecciated, and are relatively unmetamorphosed. The Zn and Zn-Pb deposits in N.W.T. are not only associated with dolomite, but also with shale, as at Summit Lake. In the Selwyn Basin four Pb-Zn-(Ag) camps have been identified. The deposits occur within shales of three different ages. At the Anvil Camp, the biggest of these Camps, the Pb-Zn-(Ag) deposits are hosted by the Lower Cambrian graphitic phyllites. They are thought to have formed from moderate temperature exhalative brines (Carne and Cathro, 1980).

The Zn-Pb deposits of Ruddock Creek, Wigwam, Big Ledge, and Cottonbelt are hosted in calcareous units in mica schist-marble sequences. The mineralized layers are broadly and complexly folded as members in a metasedimentary succession. The gold-bearing veins of the Cariboo district are in fine clastic and carbonate rocks. The veins are related to faults and folds. The known lode deposits, concentrated along the northeastern flank of the Island Mountain anticlinorium, occur in the Cariboo Group in the area of tight folding (Sutherland-Brown and Holland, 1957).

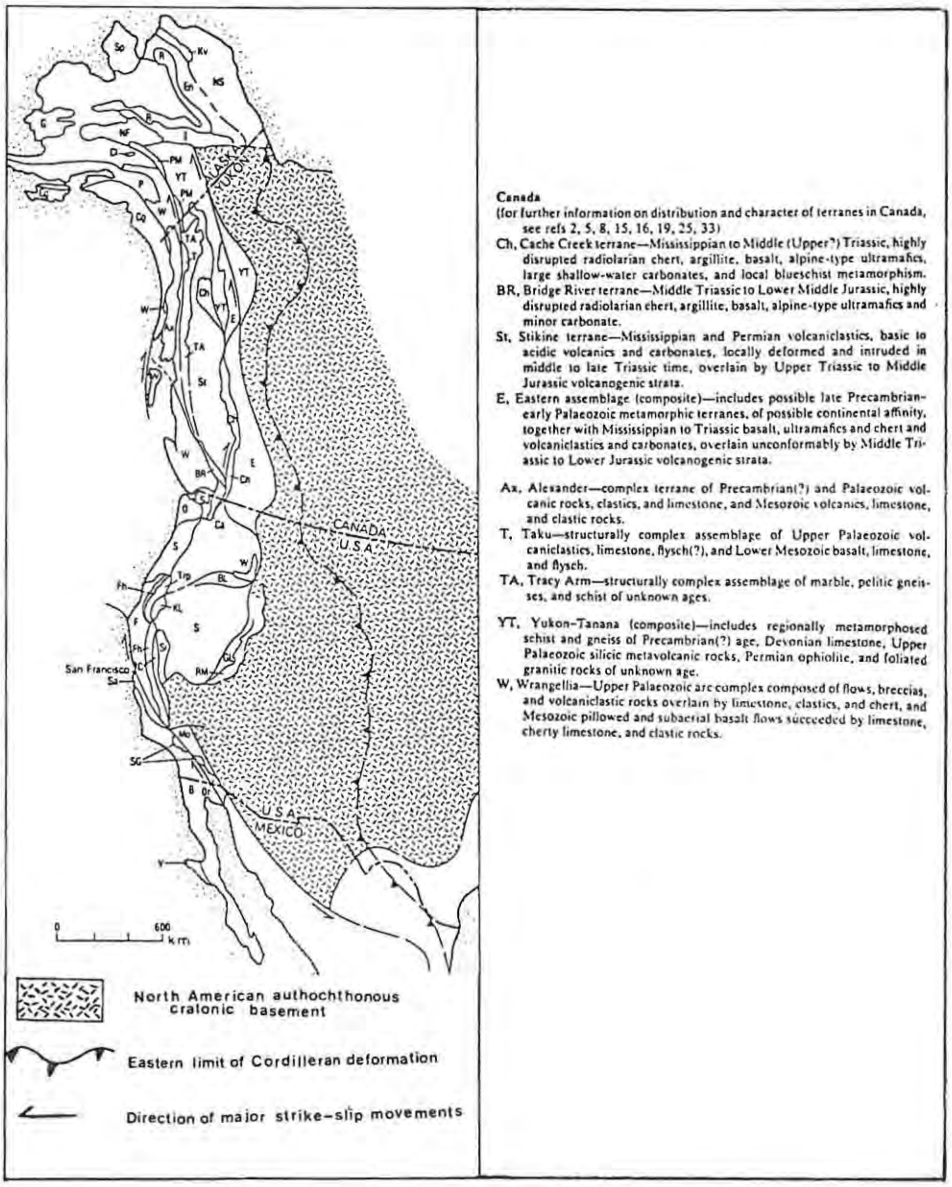
3.4 THE UPPER PALAEOZOIC TO MIDDLE TRIASSIC GEOLOGICAL HISTORY

The oldest rocks exposed west of the Omineca Crystalline Belt are Devonian-Mississippian. They are mainly clastic detritus shed eastward onto rocks that can be linked physically with the North American craton (fig. 3.1). This clastic detritus is thought to be allochthonous to the craton (Monger et al., 1972; Souther, 1977; Coney et al., 1980). This is deduced from the oceanic aspect of rocks in the Intermontane Belt. Coney et al. (1980) have referred to these allochthonous provinces as "suspect terranes" (fig. 3.10). The Stikine terrane is the largest of these "suspect terranes" in Canada. It has a basement of Upper Palaeozoic submarine arc rocks overlain by Upper Triassic to Middle Jurassic submarine and subaerial volcanic and sedimentary rocks. This terrane seems to have been accreted between early Triassic and mid-Jurassic time. The distribution of Upper Palaeozoic to Middle Triassic sedimentary and magmatic rocks can be described with reference to four longitudinal belts (fig. 3.11), each with its characteristic lithology, occurring south of about 60°N (Monger et al., 1972):

(1) Rocky Mountain Belt - a shelf:slope assemblage.
(2) Omineca Crystalline Belt - island arc environment.
(3) Intermontane Belt - oceanic or inter-arc basin.
(4) Coast Plutonic Complex and Insular Belt - island arc environment.

Fig. 3.12 shows the rock assemblages in these belts.

The Upper Palaeozoic was marked by a considerable change in regime throughout most of the Rocky Mountain Belt. The change is heralded by deposition in the region southeast of latitude 56°N of incomplete



Canada
(for further information on distribution and character of terranes in Canada, see refs 2, 5, 8, 15, 16, 19, 25, 33)
Ch, Cache Creek terrane—Mississippian to Middle (Upper?) Triassic, highly disrupted radiolarian chert, argillite, basalt, alpine-type ultramafics, large shallow-water carbonates, and local blueschist metamorphism.
BR, Bridge River terrane—Middle Triassic to Lower Middle Jurassic, highly disrupted radiolarian chert, argillite, basalt, alpine-type ultramafics and minor carbonate.
St, Stikine terrane—Mississippian and Permian volcaniclastics, basic to acidic volcanics and carbonates, locally deformed and intruded in middle to late Triassic time, overlain by Upper Triassic to Middle Jurassic volcanogenic strata.
E, Eastern assemblage (composite)—includes possible late Precambrian-early Palaeozoic metamorphic terranes, of possible continental affinity, together with Mississippian to Triassic basalt, ultramafics and chert and volcaniclastics and carbonates, overlain unconformably by Middle Triassic to Lower Jurassic volcanogenic strata.

Ax, Alexander—complex terrane of Precambrian(?) and Palaeozoic volcanic rocks, clastics, and limestone, and Mesozoic volcanics, limestone, and clastic rocks.
T, Taku—structurally complex assemblage of Upper Palaeozoic volcaniclastics, limestone, flysch(?), and Lower Mesozoic basalt, limestone, and flysch.
TA, Tracy Arm—structurally complex assemblage of marble, pelitic gneisses, and schist of unknown ages.

YT, Yukon-Tanana (composite)—includes regionally metamorphosed schist and gneiss of Precambrian(?) age, Devonian limestone, Upper Palaeozoic silicic metavolcanic rocks, Permian ophiolite, and foliated granitic rocks of unknown age.
W, Wrangellia—Upper Palaeozoic arc complex composed of flows, breccias, and volcaniclastic rocks overlain by limestone, clastics, and chert, and Mesozoic pillowed and subaerial basalt flows succeeded by limestone, cherty limestone, and clastic rocks.

FIG. 3.10: Generalized map of Cordilleran "suspect terranes" (after Coney et al., 1980).

sequences of carbonate, quartz sand, phosphate, and chert which are broken by several disconformities (Wheeler et al., 1972a). These rocks were derived from a source west of the Omineca Crystalline Belt (Monger et al., 1972) and accumulated in a relatively stable shallow-water platform. Northwest of latitude 56°N the region received a great flood of shale (Besa River shale) derived in part from a clastic wedge associated with the Devono-Mississippian orogeny in Northern Yukon and in part from uplift in the Eastern Core Zone related to the Caribooan Orogeny. In the southeastern Cordillera the latter orogeny is manifested by overthrusting, in the Kootenay Arc of western volcanic- bearing facies of the Windermere, over the deep-water pelites of the outer part of the miogeosyncline (Wheeler et al., 1972b). Such décollement

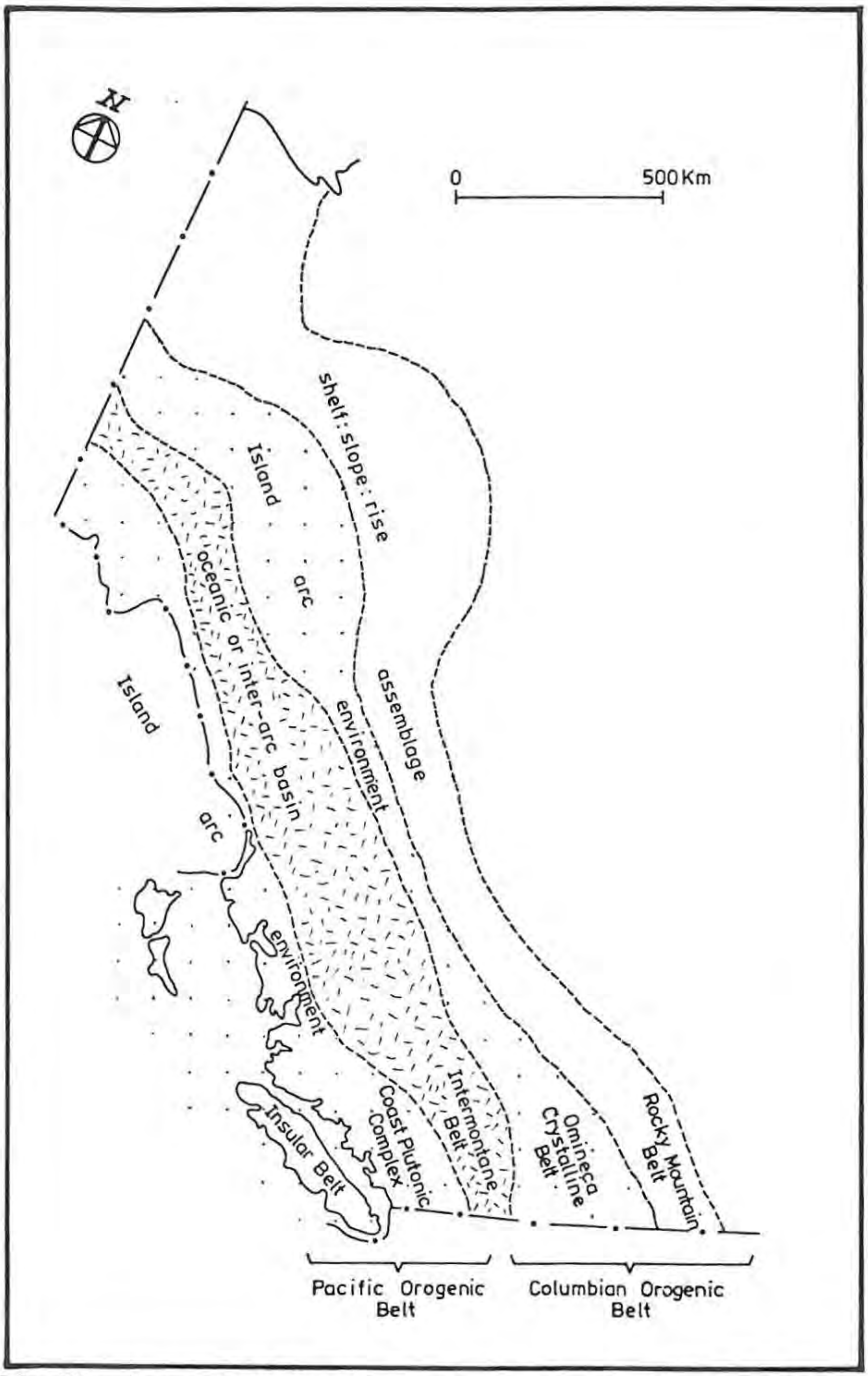


FIG. 3.11: The four geological environments of the Cordillera from the Upper Palaeozoic to the Mid-Triassic.

thrusting of the Caribooan Orogeny is in time and style comparable with the Antler Orogeny of the Western United States (Empsall, 1981). An additional feature in the northern Canadian Cordillera is the presence, above the clastic rocks of Cassiar Platform and the McDame synclinorium, of a thick assemblage of Upper Devonian (?) and Mississippian basalt, metabasalt, ultramafic rock, chert, and local gabbro (as at the Anvil Range and Sylvester terrane - see fig. 3.12A) that can be interpreted as an obducted slab of oceanic crust (Monger et al., 1972; Monger, 1977;

Souther, 1977). Rocks at the basal contact of this mass are highly deformed (Read and Okulitch, 1977), and no feeders to it are known to cut the underlying Proterozoic to Middle Devonian shelf-like assemblage of carbonates and shale. A similar mass forms the Slide Mountains Group, about 650 km along trend to the south-southeast (fig. 3.12A).

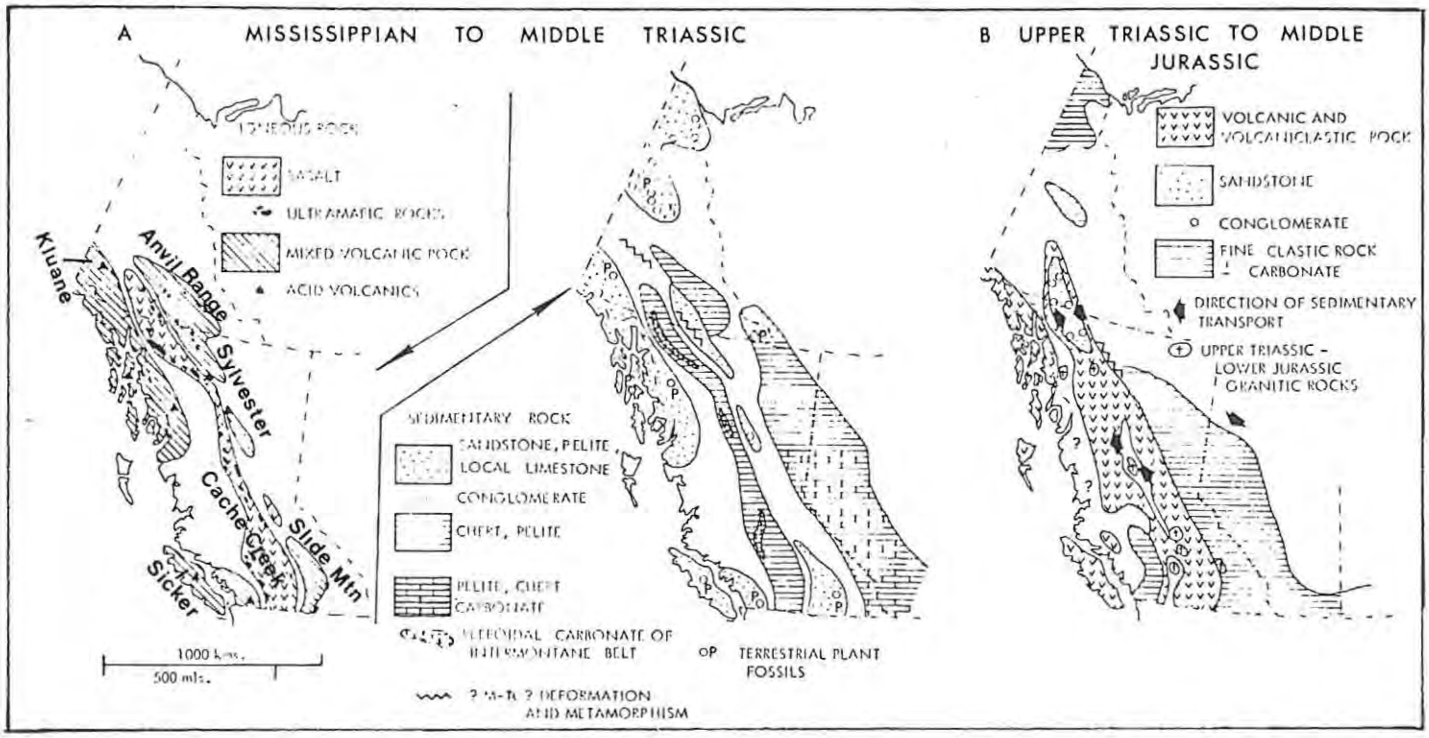


FIG. 3.12: Late Palaeozoic to Early Mesozoic sedimentation and tectonism in the Canadian Cordillera (after Monger et al., 1972).

Triassic deposits of the miogeosyncline-platform regime in the Rockies disconformably overlie the Permian — the hiatus increasing eastward (Douglas et al., 1970). Siltstone, shale, and sandstone, derived from the craton to the east and north, accumulated up to thicknesses of 1200 m in a marginal basin bordering the craton. The rocks in the Rocky Mountain Belt are interpreted as shelf:slope assemblages.

Along the Omineca Crystalline Belt where evidence of Caribooan Orogeny is best (Ross and Barnes, 1972), formations containing fossiliferous Mississippian strata overlie older units. The Mississippian to Permian rocks in the Omineca Crystalline Belt consist of locally abundant pyroclastic rocks, local acid and andesitic volcanic rocks, sandstones, shale, and carbonate with fusulinid fossils. In the Omineca Mountains these rocks also include pillowed greenstones, ribbon chert, and shale and are separated from older and younger formations by faults (Monger, 1977; Wheeler et al., 1972a). In the northern Cordillera these rocks locally overlie or are infolded with Upper Devonian and Mississippian basalt and ultramafic rocks. Nowhere in the eugeosynclinal Canadian Cordillera have Lower Triassic strata been recognized although strata of this age occur in Washington state just south of the International Boundary (Wheeler et al., 1972b). Where Middle Triassic strata do occur they have similar lithologies as the Permo-Carboniferous (greenstone, chert, limestone, slate). The relatively small proportion of clastic sediments suggests that the Permo-Carboniferous was a time of tectonic quiescence (Souther and Armstrong, 1966).

Granitic plutons may have been emplaced locally into the Omineca Geanticline as post-tectonic plutons following the Cariboan Orogeny. The Adamant Batholith in northern Selkirk Mountains and the Toby stock in Purcell Mountains, both hypersthene monzonite plutons, have yielded K-Ar dates of 281 Ma and 232 Ma respectively (Douglas et al., 1970). The Verity and Lonnie carbonatites occur in the Omineca Belt.

The rocks of the Omineca Crystalline Belt are interpreted as having formed in an island arc environment (Monger et al., 1972). The island arc itself is poorly defined but appears to have been active in at least Mississippian and Permian time, as evidenced by pyroclastics and flow rocks of various compositions of these ages. The arc appears to have developed at least partly on oceanic crust (some of which may have been overthrust in Devonian-Mississippian time) and partly on craton-derived sedimentary rocks. This volcanic arc must have been well removed from the Rocky Mountain Belt for no evidence of volcanism is found in this belt.

The Intermontane Belt is separated from the Omineca Crystalline Belt by the Teslin and Pinchi Faults (fig. 3.13). The Upper palaeozoic rocks (referred to as the Cache Creek Group - Monger, 1975; 1977) here are mainly comparable with those in modern ocean basins, with the exception of the thick Mississippian to Permian linear masses of shallow-water carbonate [thickest in the Atlin Horst (fig. 2.4) in northern British Columbia]. The Intermontane Belt consists of basalts (generally tholeiitic), pillow-lava, gabbro, and ultramafics of the Cache Creek Group. The sediments are mainly ribbon chert, commonly with radiolaria, and pelites. During Permo-Triassic time these were deformed and had several alpine-type peridotites (Trembleur Intrusions) emplaced within

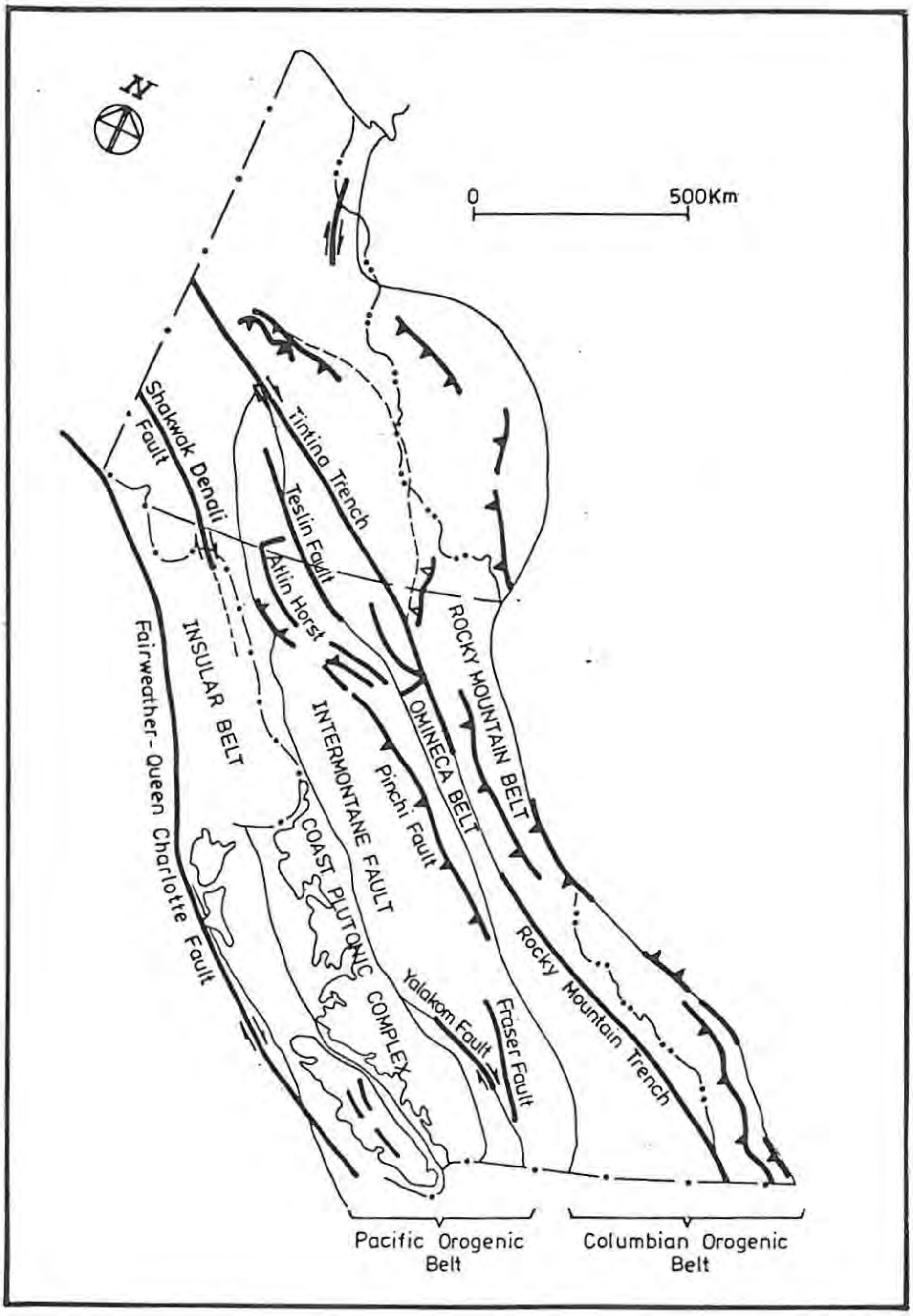


FIG. 3.13: Major faults which are possible subduction zones in the Canadian Cordillera, inferred largely from juxtaposition of oceanic crust : arc assemblages (after Monger et al., 1972 and Wheeler et al., 1974.

them (Ross, 1977). These intrusions show signs of tectonism and are serpentinized. The tectonism is evident along the Tintina Fault zone in the Yukon (fig. 3.13) where southwest dipping faults of Permo-Triassic age are found. Possibly these faults represent a southwest-dipping Permo-Triassic subduction zone (Monger et al., 1972). Blue schist metamorphism (fig. 3.8) is restricted principally to the eastern part of the Intermontane Belt and to the zone flanking the core of the Cascade segment. Eclogite and blue amphiboles also occur along Tintina Fault (Wheeler et al., 1972a; 1972b; Monger et al., 1972).

The rocks of the Intermontane Belt are interpreted as having formed in an oceanic or inter-arc basin. Monger et al., (1972) are of the opinion that the scarcity of clastic rocks coarser than pelites in the Intermontane Belt suggests that the belt assemblage was deposited far from the now adjacent coeval assemblages in the Omineca Crystalline Belt and Coast Plutonic Complex both of which contain abundant clastic rocks.

The Coast Plutonic Complex and Insular Belt consist, in general, of the following rock types, given in order of abundance: quartz diorite and granodiorite (50%); diorite, diorite migmatite and gabbro (15%); gneiss and migmatite (15% - but more in the north and less in the south); metasedimentary and metavolcanic rocks (10%); quartz monzonite (15%); and minor amounts of unmetamorphosed rocks. True granite is rare and syenite occurs locally. The volcanic rocks are basalt, andesite, and acid volcanics. Sedimentary rocks are sandstone, conglomerate, pelite, and carbonate of Mississippian, Pennsylvanian, and Permian ages. Ultramafic rocks occur locally along the Shakwak - Denali fault systems (fig. 3.13). No Mississippian rocks have been identified in St. Elias Mountains. However, Permian rocks are quite thick and include a basal unit of volcanic breccia (Douglas et al., 1970). In the Stikine region (fig. 3.10) the pyroclastic rocks are associated with the carbonates of the Cache Creek Group. In the Kluane Ranges of southwestern Yukon (fig. 3.12), Permian and older strata are co-extensive with the Skolai terrane of eastern Alaska. These rocks are similar to the Sicker Group of Vancouver Island which comprises up to 3000 m of volcanic breccia, tuff, argillite, greenschist, andesite, and dacite porphyry (Souther, 1977; Monger, 1977).

Complex events occurred in the Coast Plutonic Complex and the Insular Belt, and the greatest problem is dating these events. For much of the belts, the only guides are sparse radiometric dates (fig. 3.14). Approximately 80 km northwest of Prince Rupert a stock of quartz monzonite on Annette Island has been dated radiometrically as Silurian (Berg, 1970, in Roddick and Hutchison, 1972). On Prince of Wales Island a metamorphic complex has given pre-Ordovician ages (fig. 3.14). The

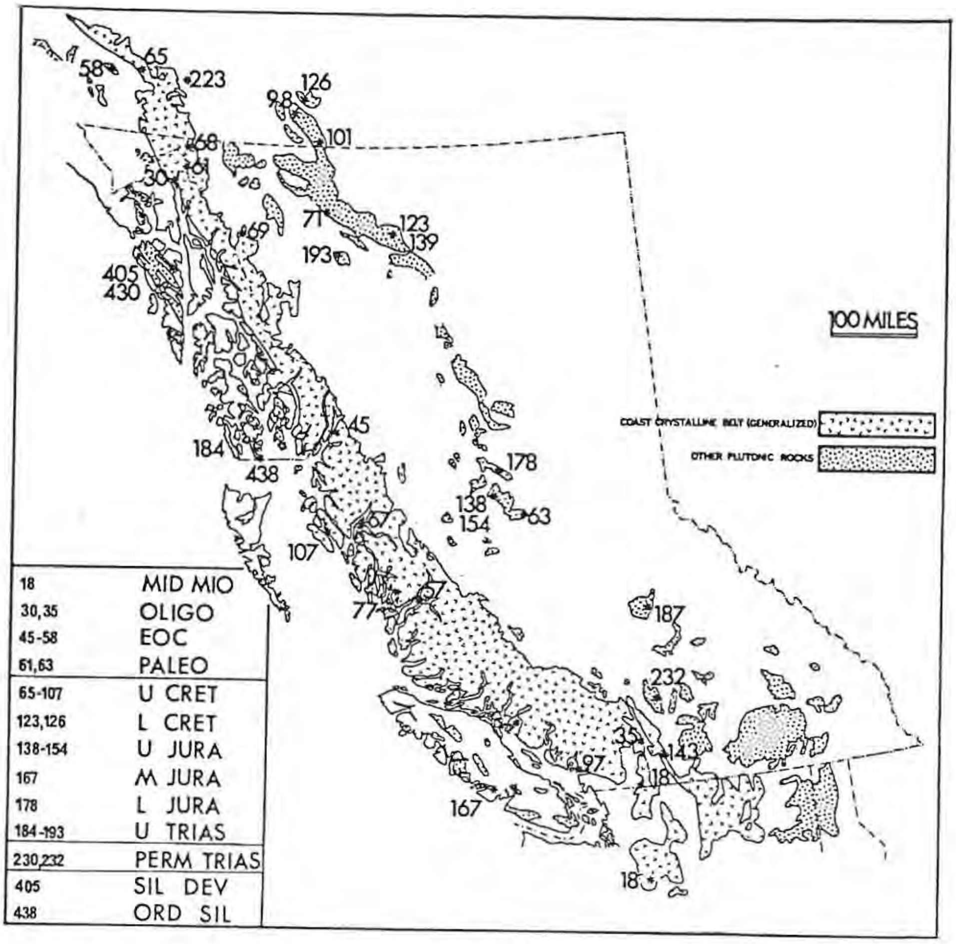


FIG. 3.14: K-Ar age determinations in the Coast Plutonic Complex and some adjacent plutons (from Roddick, 1966).

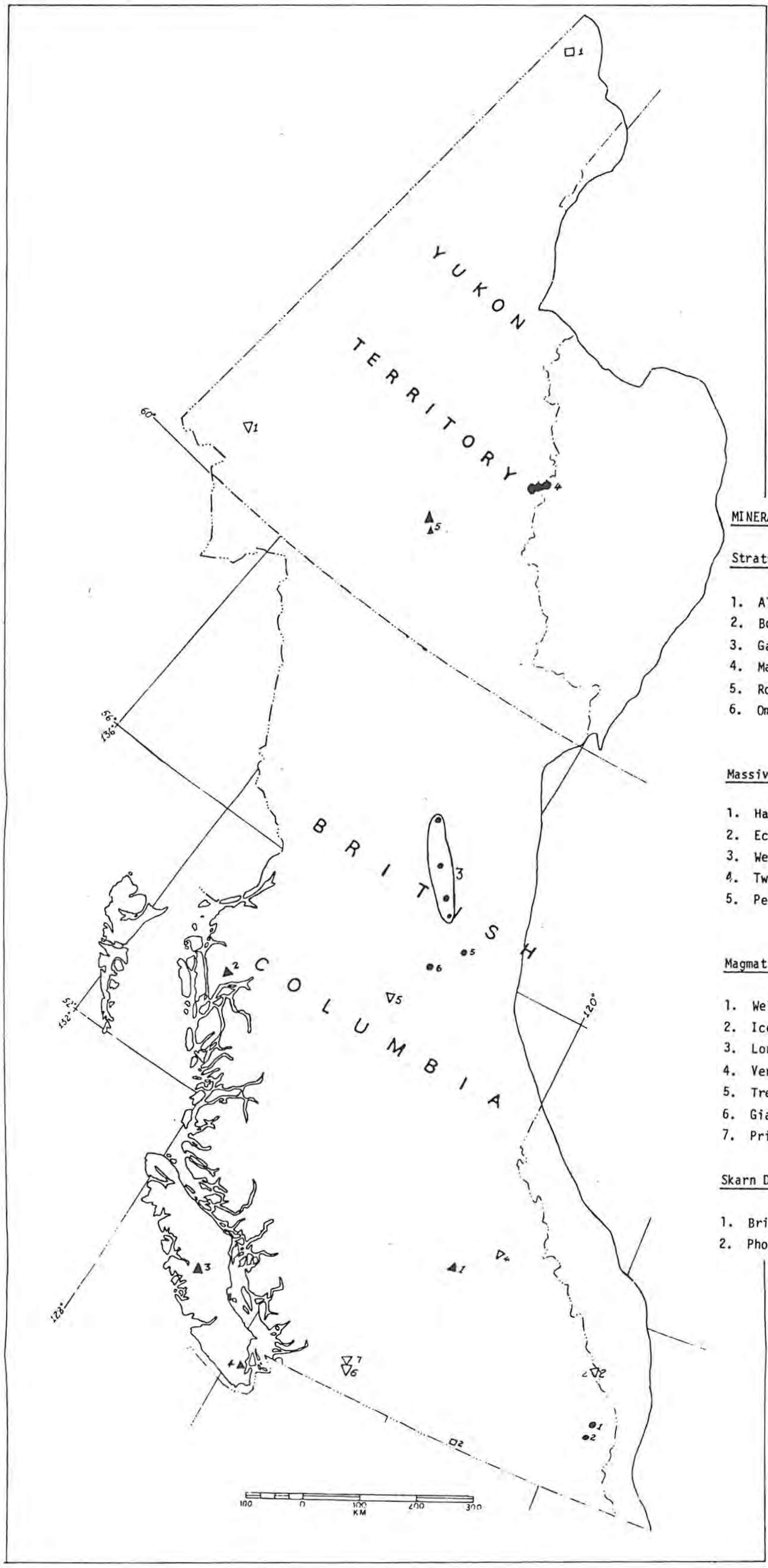
Central Gneiss Complex is thought to be pre-Permian in age (Armstrong and Runkle, 1979; Roddick and Hutchison, 1972). It is best developed in the northern part of the Coast Plutonic Complex, especially in the Skeena River - Douglas Channel region and becomes more fragmentary to the south. It comprises migmatites, paragneisses, and various gneisses of unknown origin (Roddick and Hutchison, 1972). Throughout the Coast Plutonic Complex the plutonic rocks are commonly cut by synplutonic dykes which are invariably altered and granitized by the plutons. These dykes may be folded, faulted, attenuated and even boudinaged to form a single line of boudin-shaped intrusions.

The Coast Plutonic Complex and the Insular Belt assemblages are thought to have developed in an island arc environment (Monger et al., 1972; Souther, 1977). These rocks may have developed at least partly on continental crust that evolved during Ordovician and Silurian orogeny in southeast Alaska. More than one arc system may be involved. It has been suggested that the rocks southwest of the Shakwak-Denali Faults (fig. 3.13) represent an old arc that was sutured to the continent in Permo-Triassic time along a subduction zone on the site of these faults. Fig. 3.13 shows a number of sutures of different geological periods in the Canadian Cordillera.

Mineral deposits of Upper Palaeozoic to Mid-Triassic in the Canadian Cordillera (fig. 3.15) include Pb-Zn deposits, volcanogenic massive sulphides, porphyry Cu-Mo deposits, Cr occurrences, and carbonatites with concentrations of Cb, Ta, Zr, Ti, and some U and Th. The Tom is a Zn-Pb deposit in the Yukon that shows evidence of thermal concentration possibly out of shales that have regionally anomalous contents of Mo and Zn (Wolfhard and Ney, 1976). Western and Twin J mines have similar orebodies in late Palaeozoic volcanic rocks of the Sicker Group. These deposits have a variety of ores similar to Kuroko. The Ecstall River pyrite deposit consists of concordant massive sulphide mineralization in strongly foliated metamorphic rocks in granitic rocks of the Coast Plutonic Complex (Thompson and Panteleyev, 1976). Harper Creek and Adams Plateau Cu-Zn deposits are associated with metasediments and with metamorphosed intermediate acid volcanics. The Trembleur Intrusions have some Cr deposits. W, Sn, and Mo occur in granitic plutons in Northern Yukon. The carbonatites of Ice River, Verity, and Lonnie contain minor concentrations of Cb, Ta, Zr, Ti etc.

3.5 THE UPPER TRIASSIC TO OLIGOCENE GEOLOGICAL HISTORY

The western Canadian Cordillera evolved from a system of island arcs in the Late Triassic and Early Jurassic, through an intermediate stage with deposition in epieugeosynclines (successor basins), to a continental Cordillera in the Late Cretaceous and Early Tertiary (figs. 3.12B; 3.16; 3.17). The final stage was perhaps similar to the present-day Andes and the main tectonic elements of the Cordillera (fig. 2.4) became established (Monger et al., 1972; Wheeler et al., 1972a; 1972b). This evolution resulted in the extrusion of abundant andesitic and basaltic volcanics, in part from centres along island arcs and in part as submarine flows in adjacent troughs and basins. The basins also received thick accumulations of volcanogenic and terrigenous sediments from the arcs (Douglas et al., 1970). Monger et al. (1972) ascribe most of this activity to processes above an eastward-dipping subduction zone (or zones).



MINERALIZATION IN THE UPPER PALAEOZOIC TO MID-TRIASSIC

Stratiform-stratabound Pb-Zn-Ag ●

1. Alpine	Devonian	Pb, Zn, Ag
2. Boivin	Devonian	Pb, Zn, Ag
3. Gataga Camp	U. Devonian	Pb, Zn, Ag
4. MacMillan Pass Camp	U. Devonian	Pb, Zn, Ag
5. Robb Lake	Devonian	Zn, Pb
6. Omineca	Devonian	Zn, Pb

Massive Sulphide Deposits ▲

1. Harper Creek	Penn. - Perm	Cu, Zn
2. Ecstall	Penn. - Perm	Cu, Fe, Zn
3. Western Mines	Penn. - Perm	Cu, Zn, Pb
4. Twin J.	Penn. - Perm	Cu, Zn
5. Pelly Mtns	U. Devonian	Cu, Zn, Pb, Fe

Magmatic Deposits ▽

1. Welgreen	Penn. - Perm	Cu, Ni
2. Ice River	340 Ma	Cb
3. Lonnie	?	Cb, Ta
4. Verity	?	Cb, Ta, V, P, Zr
5. Trembleur	Penn. - Perm	Cr
6. Giant Mascot	U. Palaeozoic ?	Cu, Ni
7. Pride of Emory	U. Palaeozoic	Ni, Cu

Skarn Deposits □

1. British Mountains	U. Palaeozoic	W, Sn
2. Phoenix	U. Palaeozoic	Cu, Au, Fe

FIG. 3.15: Deposits of the Upper Palaeozoic to the Mid-Triassic in the Canadian Cordillera.

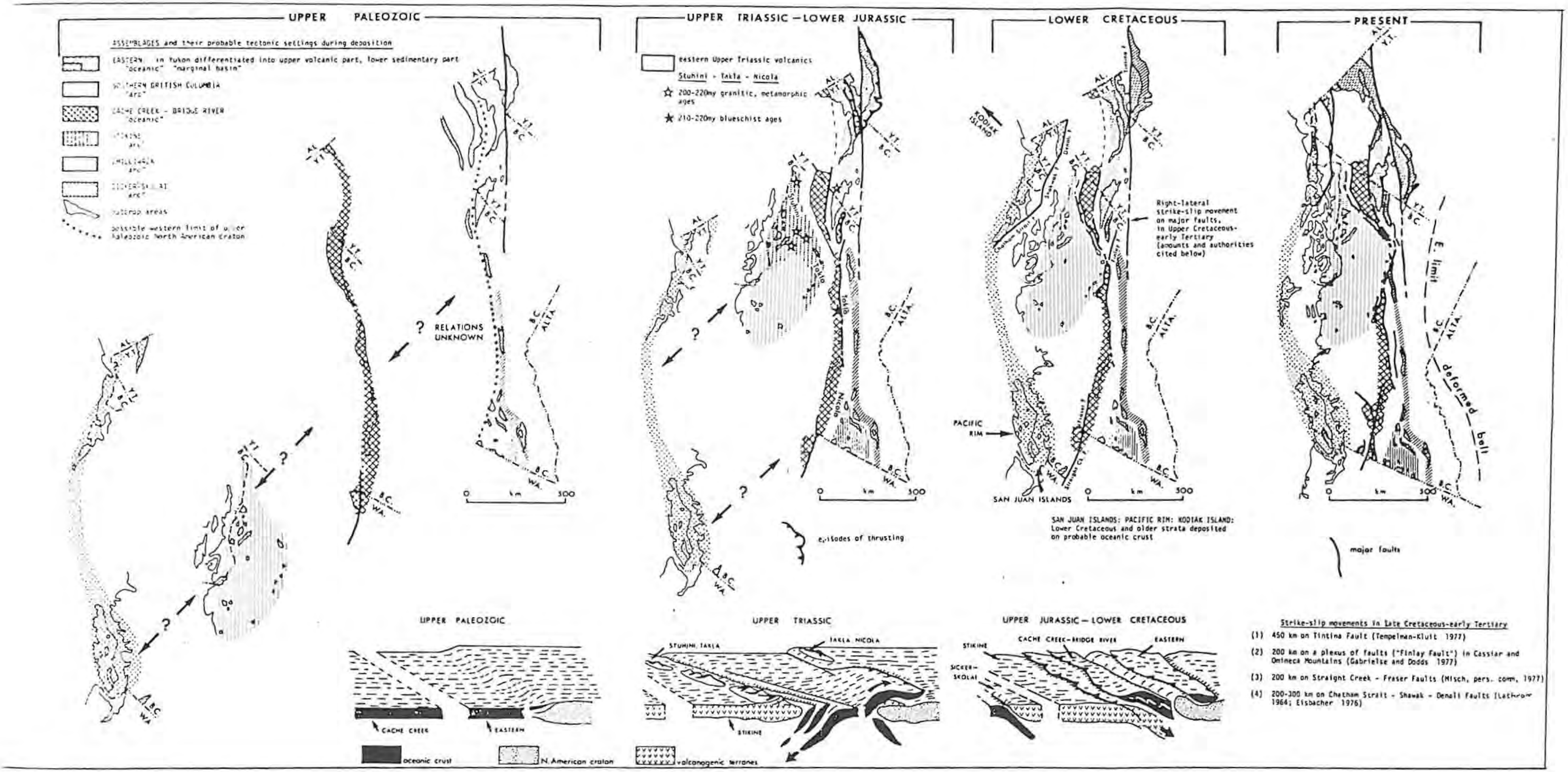


FIG. 3.16: Model showing the way in which the Upper Palaeozoic assemblages of the western Canadian Cordillera may have achieved their present relationships; not until the late Mesozoic were all the assemblages incorporated in the Cordillera (from Monger, 1977).

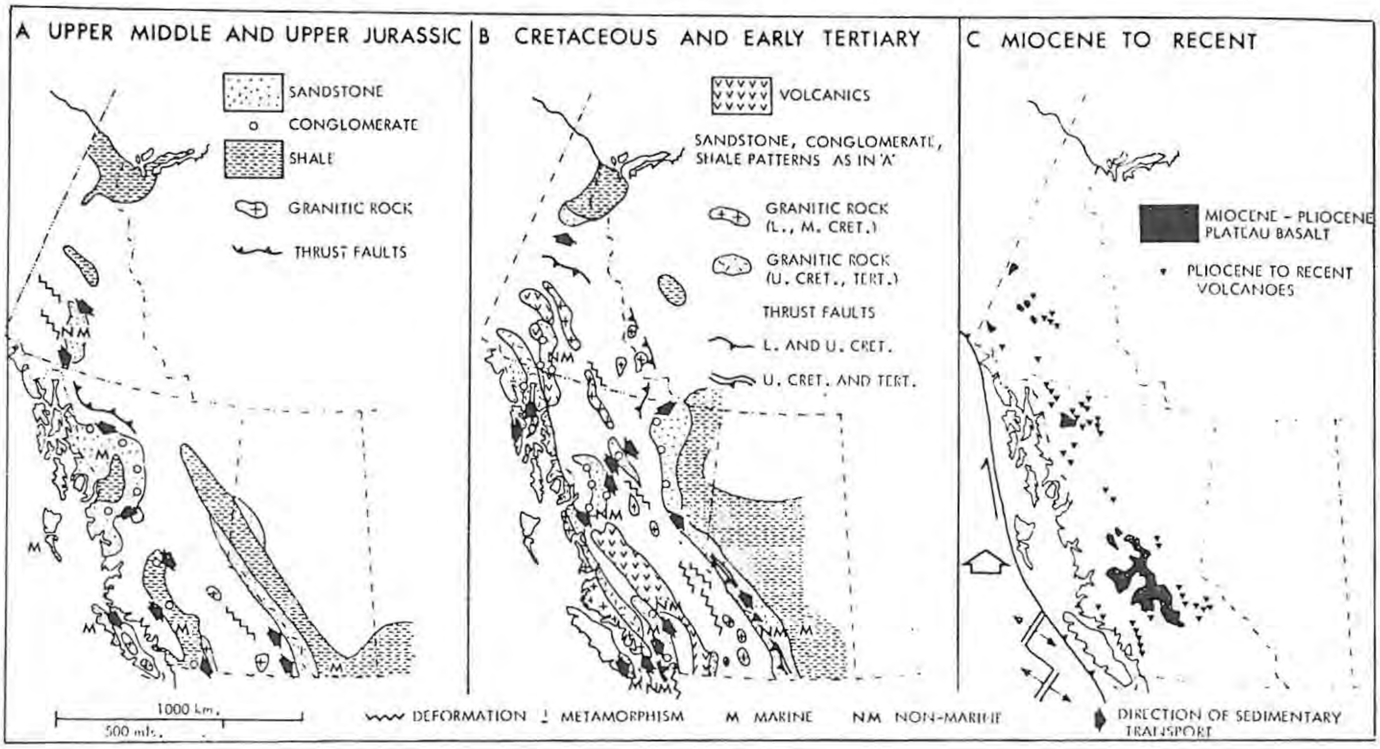


FIG. 3.17: Late Mesozoic to Recent sedimentation, magmatism, and tectonism in the Canadian Cordillera (from Monger et al., 1972)

In Late Triassic time volcanism was widespread (fig. 3.12B). Basalt, andesite flow, pyroclastics and fragmental rocks (Nicola-Takla Group) derived from centres within the troughs and on adjoining arches, accumulated in the interior troughs (Whitehorse, Nechako, and Quesnel - fig. 2.4), whereas 5650 m of tholeiitic pillow lava, pillow breccia, and aquagene tuff (Karmutsen Group) were extruded in the Insular Trough (Wheeler et al., 1972a; 1974). This volcanism had somewhat different characteristics in the Insular Belt and southern Coast Mountains, Omineca, and northern Coast Mountains (Eastern Belt in fig. 3.18) (Monger et al., 1972; Souther, 1977). The Nicola-Takla Group is correlated with the Stuhini Group, which curves west around the northern end of the Bowser Basin and extends further into the Stikine region, and the Lewis River Group, a branch continuing north into the central Yukon (see fig. 3.18). The Karmutsen Group is probably correlative with the Nikolai Greenstone of southeastern Alaska and southwestern Yukon (Souther, 1977).

The Nicola-Takla volcanics are commonly associated with a heterogeneous assemblage of volcaniclastic sediments, greywacke, minor siltstone, and discontinuous lenses of limestone (fig. 3.19; Souther, 1977; Wheeler et al., 1972a; Douglas et al., 1970). Further north, in Cassiar region, Triassic strata are thin, composed of clastics and carbonate, and indicate that the northern Omineca Geanticline was only slightly submerged in the Late Triassic. It separated Whitehorse Trough to the west, in which accumulated mainly volcanogenic sediments, from a basin or trough to the east that received clastics mainly from the craton. In central British Columbia, the occurrence of serpentine and chromite in basal Upper Triassic sediments east of the Pinchi Fault and the presence of clastic red beds further southwest indicate the Late Triassic emergence of the Pinchi Geanticline and its contained ultramafic rocks. Intrusive rocks in the central sub-belt of the Nicola-Takla volcanics range in composition from diorite to syenite and are considered to be coeval and comagmatic with the volcanics. In south-central British Columbia, the sedimentary and volcanic rocks of the Permian Cache Creek and Upper Triassic Nicola Groups are intruded by the 198 Ma old Guichon Creek Batholith. This is a concentrically zoned granitoid (diorite-quartz monzonite) pluton elongated slightly west of north and underlying an area of approximately 1 200 sq. km (Olade, 1976; McMillan, 1976). McMillan (1976) has described the intrusive history of

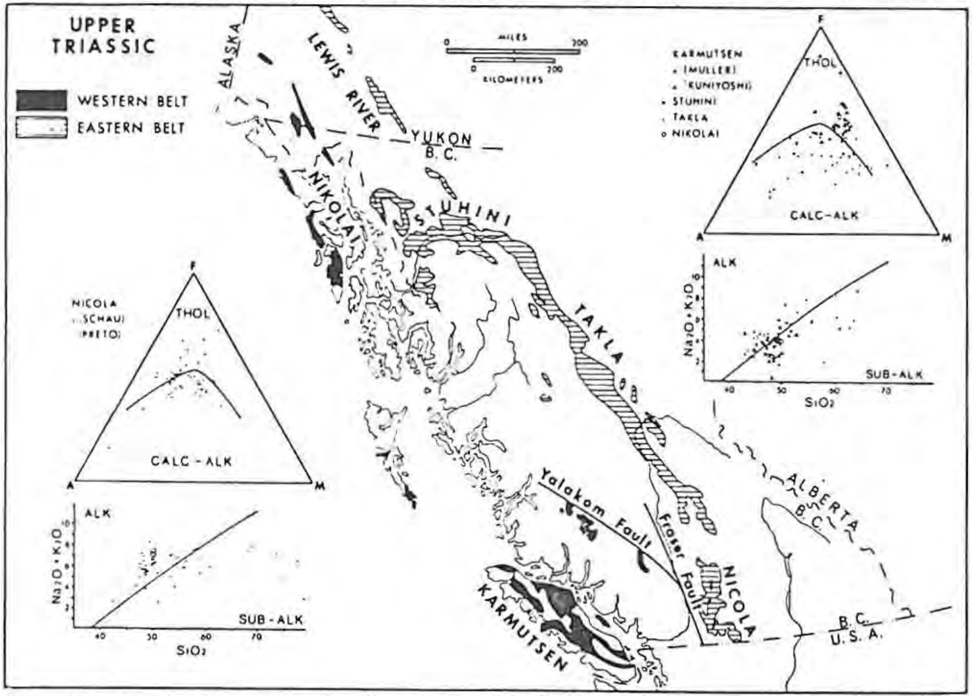


FIG. 3.18: Distribution and chemistry of Upper Triassic volcanic rocks. The Western belt comprises mainly tholeiitic basalt whereas the eastern belt includes intermediate to acid rocks of both calc-alkaline and alkaline affinity (from Souther, 1977).

the batholith. Its earlier phases are mesozonal, its later ones epizonal and subvolcanic. Initial Sr_{87}/Sr_{86} ratios indicate a mantle source (Chrismas et al., 1969). The batholith hosts several large producing and undeveloped porphyry copper deposits with the aggregate tonnage exceeding 1,8 billion tons of ore at 0,4% Cu (Olade, 1976).

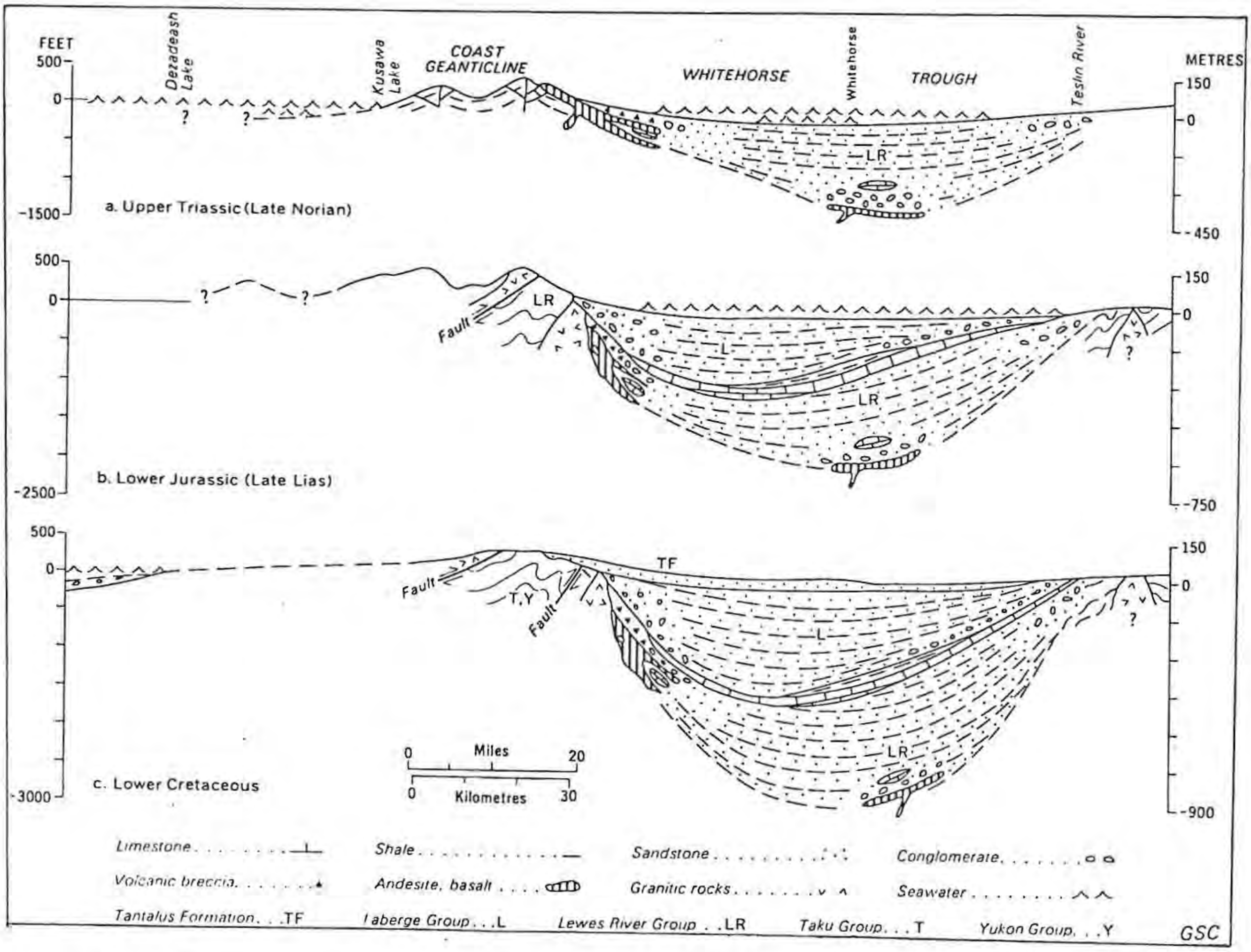


FIG. 3.19: Diagrammatic restored sections across Whitehorse Trough, Yukon Territory, during the Mesozoic era (from Douglas et al., 1970).

Elsewhere within the Nicola-Takla belt, the close spatial and temporal relationship between the volcanics and the intrusive rocks has been recorded. The Giant Mascot ultramafic body in southwest British Columbia has been dated at 119 to 95 Ma (McLeod et al., 1976; Aho, 1956) and is older than the adjacent diorite and tonalite. This ultramafic body (pyroxenite, peridotite) hosted the nickel-copper-pyrrhotite deposits of Giant Mascot mine. Fox (1975) (in Souther, 1977) contends that many alkaline plutons in the Quesnel Trough are comagmatic with Late Triassic Nicola volcanics. Farther north, in the McConnell Creek (Monger and Church, 1977) and Aiken Lake areas, several ultramafic-gabbro bodies are thought to be high temperature differentiates of Takla magma, fractionated in sub-volcanic intrusions. Pyroxenite bodies associated with the Stuhini volcanics in the Stikine region have fractionated to highly alkaline, syenitic end members (Barr, 1966). The Hotailuh Batholith (Gabrielse and Reesor, 1974 in Souther, 1977) a large intrusive body coeval with the Stuhini volcanics, contains phases that range in composition from diorite through quartz diorite to monzonite.

The Karmutsen-Nikolai volcanics differ from the Nicola-Takla in many respects. The Karmutsen is more uniformly basic and, except for a few relatively thin limestone bands, is not interbedded with sediments. The Karmutsen is not associated with ultramafic rocks or chert and stratigraphically overlies Upper Palaeozoic rocks that can best be interpreted as island arc assemblages.

Volcanic rocks in the two Upper Triassic belts are the product of an enormous volume of magma that was erupted during a relatively short (20 Ma) interval. The Nicola-Takla assemblages can be interpreted as old island arcs. The Karmutsen is problematical in that, in chemistry it is very close to basalts formed on oceanic ridges (Monger et al., 1972; Souther, 1977).

At the end of the Triassic, volcanism momentarily stopped and there was widespread deposition of carbonate.

During Early- and early Mid-Jurassic time, volcanism flourished south of the Stikine Arch and in the Insular Trough and it ceased northwest of the Stikine Arch. Pillow lavas were extruded and elsewhere the volcanism was andesitic and explosive (Wheeler et al., 1972a; 1972b; 1974). In southernmost Omineca Geanticline Lower Jurassic volcanics lie unconformably on Upper Palaeozoic rocks and intertongue eastward with Lower Jurassic sediments (Douglas et al., 1970). Most of the Lower Jurassic clastic sediments were deposited in the troughs. The near-shore clastics that commonly contain shelly fauna, plant fossils and coal grade locally into the more distal turbidite facies as in Whitehorse Trough (figs. 3.12B and 3.19).

In latest Triassic and earliest Jurassic time, plutons, some of which contain important porphyry copper and molybdenum deposits were further intruded into contemporaneously warped and faulted Upper Triassic rocks, uplifted, and unroofed. In the Yukon Territory, Palaeozoic rocks are intruded by the Late Triassic Klotassin quartz diorite and the middle Jurassic pink quartz monzonite (Le Couteur and Tempelman-Kluit, 1976). These plutons define the extension of plutonism related to the Intermontane Belt (fig. 3.20A). In the Princeton and Okanagan Lake

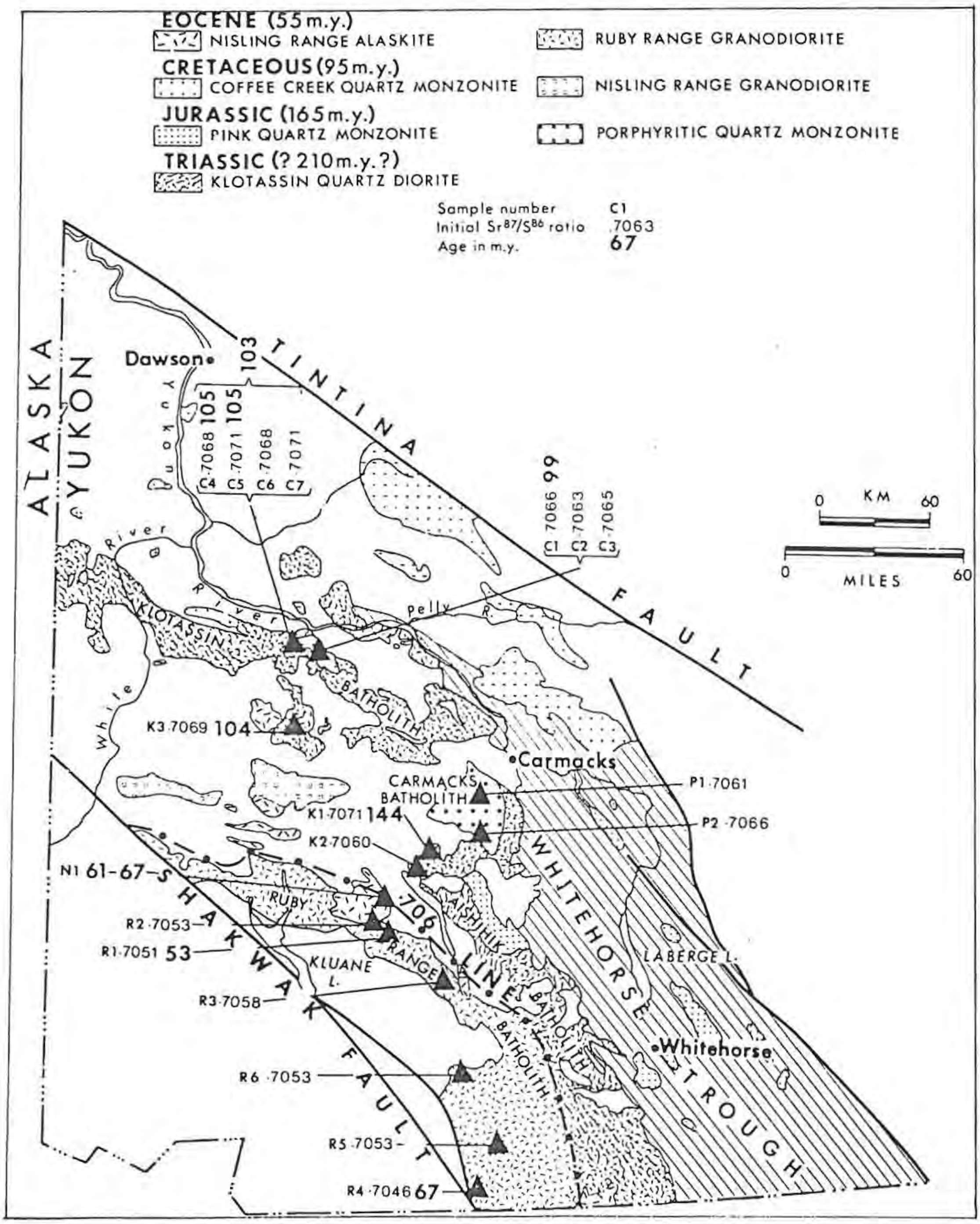


FIG. 3.20A: Distribution of Mesozoic and Tertiary plutonic rocks in the Yukon Crystalline Complex (from Le Couteur and Tempelman-Kluit, 1976).

areas, Petö and Armstrong (1976) found that K-Ar and Rb-Sr data for granodiorite, quartz monzonite, and granite, which intrude the Upper Triassic Nicola Group, are concordant with a Late Jurassic age of 156 ± 6 Ma and K-Ar dates suggest that diorite and quartz diorite and porphyritic andesite are older, at 165 to 186 Ma. These intrusive rocks are thought to be comagmatic and related by a process of magmatic differentiation involving crystal fractionation of amphibole and plagioclase. The Hedley Intrusive Complex is of similar age and is thought to be comagmatic with the Okanagan Batholithic Complex (Roddick et al., 1972). Further to the north of Okanagan Batholith granitic plutons of the Quesnel Trough (fig. 3.20B) range in age from 200 Ma to 50 Ma and some of them host important Cu-Mo porphyry deposits, Cu, and Cu-Au deposits (Preto et al., 1979).

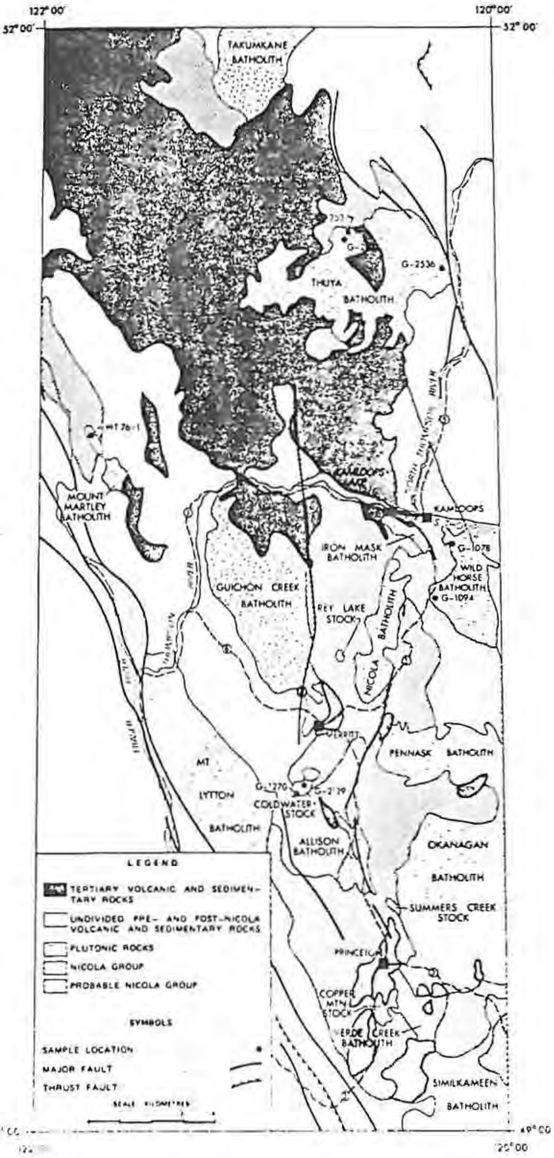


FIG. 3.20B: Granitic plutons of the Quesnel Trough in south-central British Columbia (from Preto et al., 1979).

The mid-Middle Jurassic was a time of deformation and uplift (Nassian Orogeny) in the western Cordillera. The eugeosynclinal belt was segmented by the emergence of the northeast-trending Skeena and Stikine Arches and the rising of the Atlin Horst. This segmentation resulted in the development of syntectonic epieugeosynclinal successor basins (Douglas et al., 1970; Wheeler et al., 1972a; 1972b; 1974; Eisbacher, 1974) superimposed on both the troughs and the geanticlinal arches of the older eugeosyncline.

These successor basins developed in the Rocky Mountain, Intermontane, and Insular Belts due to contemporaneous uplift and emergence of metamorphic and plutonic complexes along the basin hinges. The oldest of these successor basins is the Laberge Basin (fig. 3.21). Its assemblage represents synorogenic clastic wedges containing plutonic debris derived from within the eugeosynclinal domain. The Laberge rocks crop out along the western edge of the Columbian core zone and are well exposed along the northern part of the core. In the southern parts of the Cordillera, outcrops are small and tectonically disrupted (fig. 3.21). The assemblage consists of conglomerates, greywackes, shales, and rare autoclastic limestone blocks (Eisbacher, 1974). In the Intermontane and Insular Belts occur rock units in a number of successor basins (fig. 3.22) of middle Jurassic to Early Cretaceous age collectively called the Bowser Assemblage. This assemblage represents a series of predominantly marine synorogenic clastic wedges that strongly reflect deformation and initial uplift along the western edge of the Omineca Crystalline Belt (Souther and Armstrong, 1966; Eisbacher, 1974). The sedimentary assemblage was deposited in coastal plain, delta, prodelta, and continental slope environments. The sedimentary sequences, consisting of conglomerates, sandstones, greywacke, and shale, are characterized by abrupt changes in facies and thickness and by several intraformational unconformities. The Sustut and Georgia Assemblages (fig. 3.23) (Upper Cretaceous and Palaeogene) constitute late orogenic deposits, their sedimentation, uplift, shallow-level plutonic intrusion, and deformation being intricately interwoven within the confines of the basins. These basins consist generally of coal-bearing clastic rocks including conglomerates, sandstones, and shales. These rocks were deposited in different sedimentary environments.

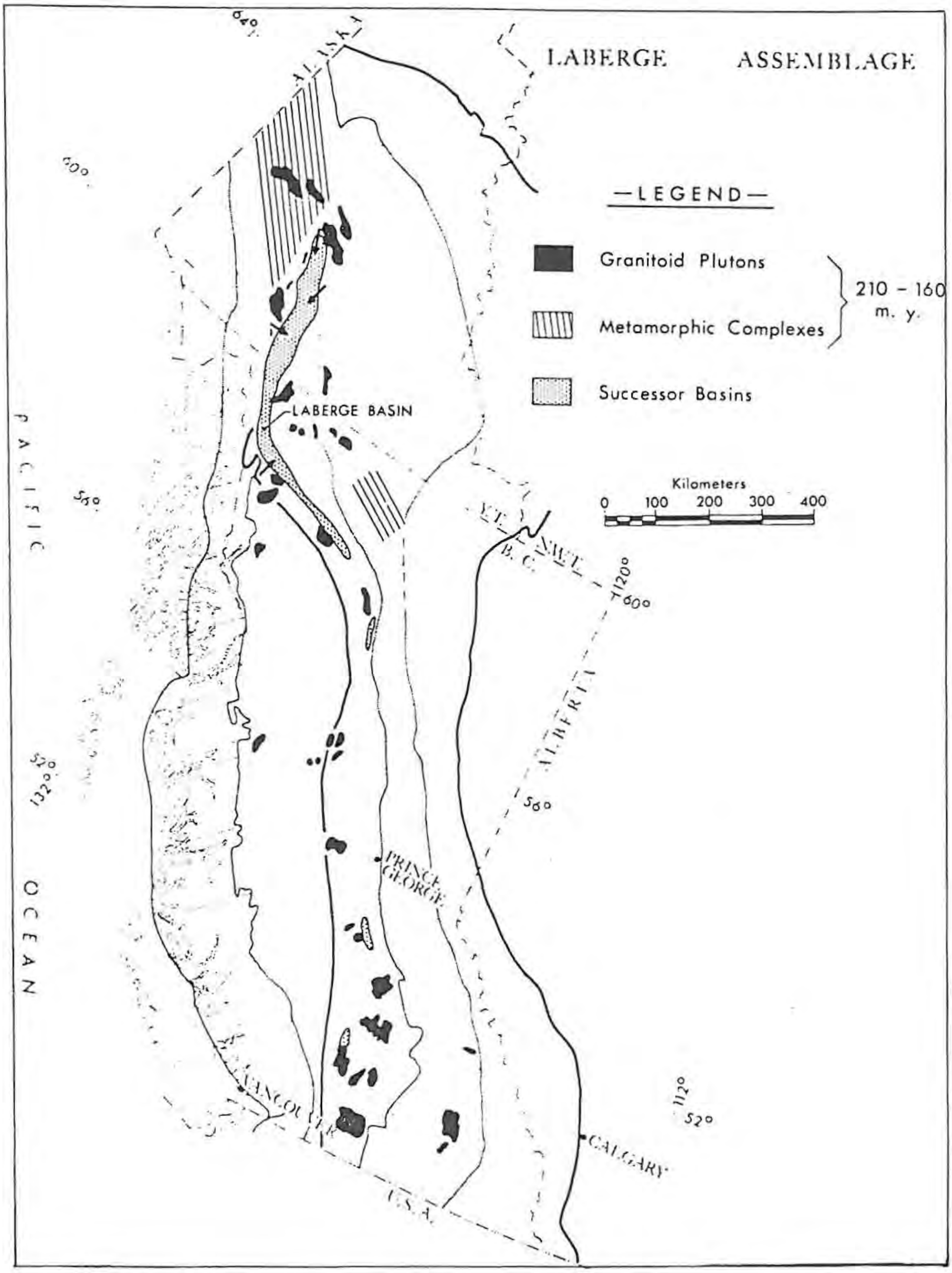


FIG. 3.21: Generalized distribution of Laberge Assemblage and inferred contemporaneous uplift of plutonic and metamorphic terranes (from Eisbacher, 1974).

The important point to note regarding the evolution of the successor basins is that, at a certain stage in the development of the eugeosyncline, some of the subsiding crustal segments began to receive large quantities of clastic sediments, which succeeded earlier volcanogenic deposits. The sequence of events also suggests a gradual

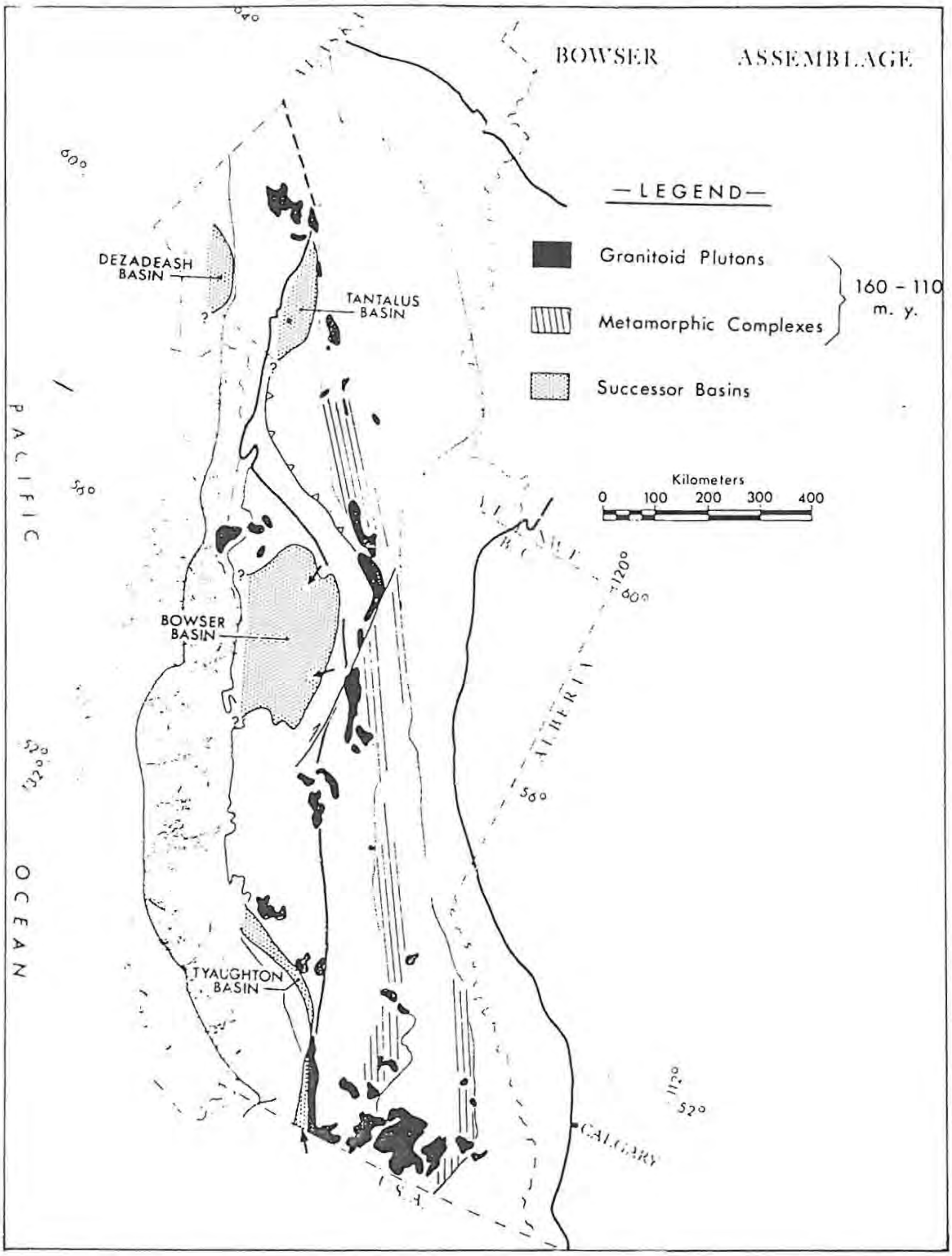


FIG. 3.22: Generalized distribution of Bowser Assemblage and inferred contemporaneous uplift of plutonic and metamorphic terranes (from Eisbacher, 1974).

regression of the sea. This fundamental change in the character of the basins must have been accompanied by changes in the crust underlying the successor basins (fig. 3.24; Eisbacher, 1974).

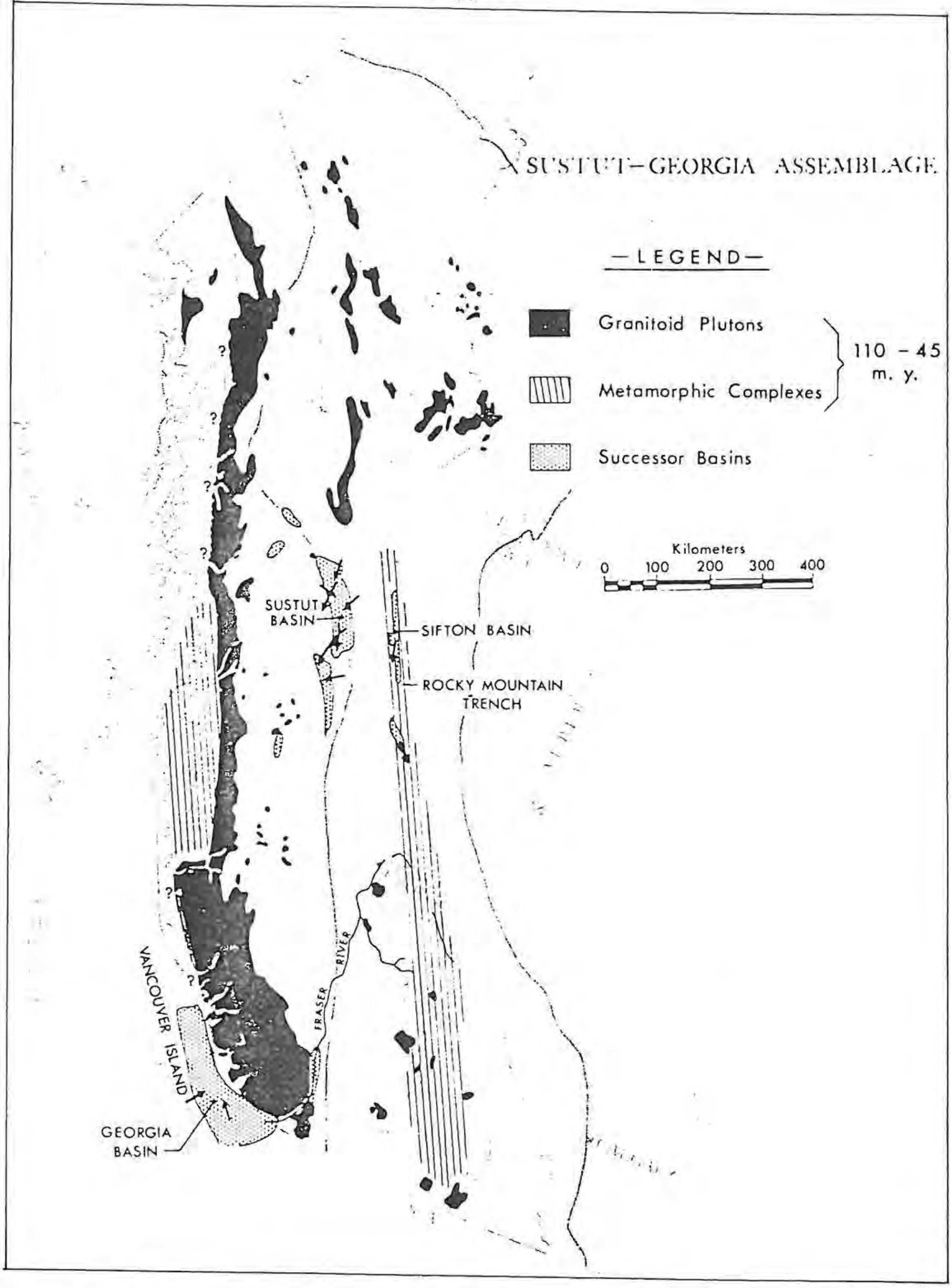


FIG. 3.23: Generalized distribution of Sustut and Georgia Assemblages and inferred contemporaneous uplift of plutonic and metamorphic terranes (from Eisbacher, 1974).

The development of the successor basins was terminated about 50 to 40 Ma ago by broad regional uplift and shallow-level plutonic activity that was accompanied by widespread acidic to intermediate volcanism.

At about the same time as the successor basins were being formed, the Omineca and Pinchi Geanticlines continued to be uplifted and they

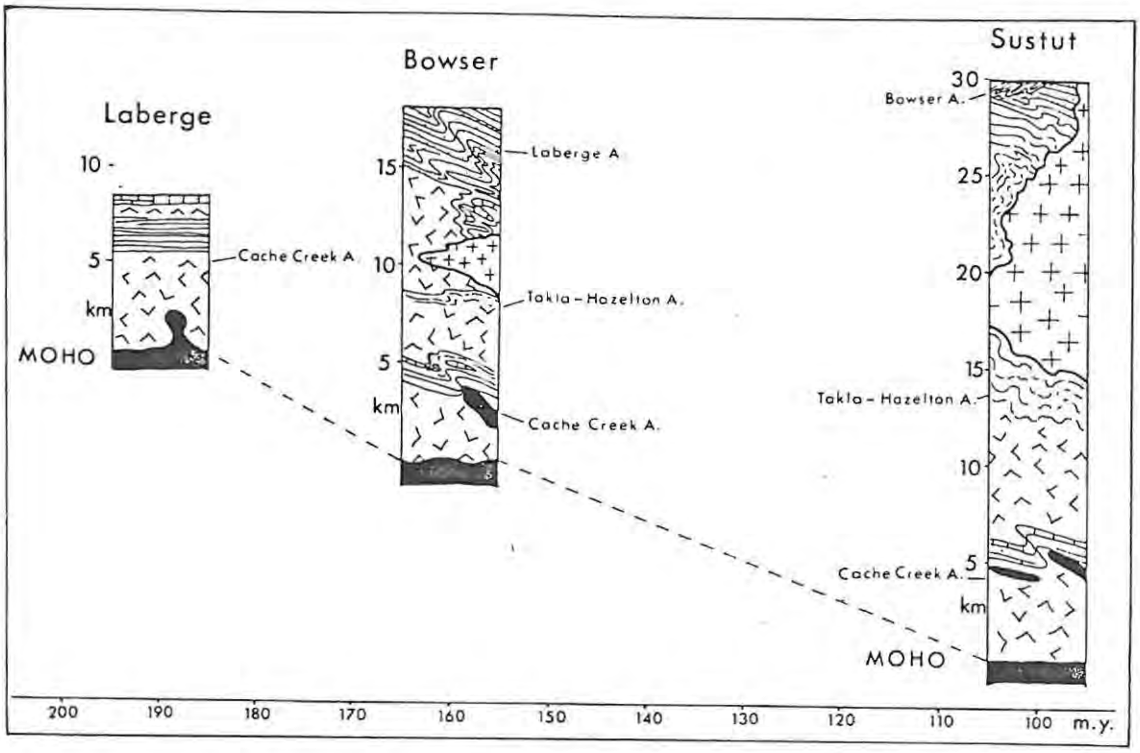


FIG. 3.24: Hypothetical scheme for evolution of crust underlying successor-basin assemblages of the Canadian Cordillera (from Eisbacher, 1974).

eventually merged into a single landmass. Contemporaneous deformation of this landmass resulted in the Omineca Geanticline being the core zone of the Columbian Orogenic Belt (Wheeler et al., 1972a; 1972b). Early Middle Jurassic and older strata were deformed prior to the emplacement of a discordant 164 Ma old satellitic stock of the Nelson Batholith. The deformation migrated eastward terminating in the Rocky Mountain Thrust and Fold Belt and westward ending with southwestward thrusting and folding of the Atlin Horst and Whitehorse Trough (fig. 3.17). The Insular Belt also underwent uplift, mild deformation (open folding and faulting), and was intruded by several elongate northwest-trending granodiorite plutons giving K-Ar dates of 165 Ma (fig. 3.14).

In Late Cretaceous and Eocene time, a period when compressive deformation was nearing its completion in the Rocky Mountain Thrust and Fold Belt but was still active in the St. Elias Fold Belt, the Cordillera experienced extensive continental explosive acidic to intermediate volcanism (Wheeler et al., 1972a; Monger et al., 1972; Souther, 1977). In the north, extensive sheets of ignimbrite are associated with flows and pyroclastic rocks. Elsewhere there is a considerable range in composition, from rhyolite through trachyte and trachyandesite to phonolite. Extrusion of these rocks, accompanied by block faulting (resulting in grabens and tilted half-grabens) and local cauldron subsidence, was coeval with the emplacement of ring dykes, high-level quartz-monzonite, granite, and syenite (Monger et al., 1972; Wheeler et al., 1972a). Cretaceous to Eocene intrusions in the Yukon Territory are the Coffee Creek quartz monzonite and the Nisling Range alaskite (fig. 3.20A). They give ages of 95 Ma and 55 Ma respectively (Le Couteur and Tempelman-Kluit, 1976). Southern extensions of these plutons occur in the Whitehorse Trough (fig. 3.20A). Morrison et al. (1979) have defined four plutonic suites in the Whitehorse area which are comparable with other plutons in the adjacent areas. These plutons and associated sediments host important vein, skarn, porphyry, and other deposits (see below). In the Coast Plutonic complex near Prince Rupert, the Ecstall and Quottoon Plutons have been dated at 80 Ma and 51 Ma respectively (Harrison et al., 1979; Armstrong and Runkle, 1979). The Quottoon Pluton is granodioritic whereas the Ecstall is granitic and it contains concentric phases from diorite on the periphery to quartz monzonite (Harrison et al., 1979; Armstrong and Runkle, 1979).

Eocene rocks on the Pacific Continental Shelf are mainly pillow basalts, minor pyroclastics and sediments that were deposited off the edge of the continent at the northern side of a marine embayment south of Vancouver Island. Subaqueous pyroclastic breccias with rhyolitic ashflows, tuffs, breccias, and dacitic and basalt flows were extruded on Queen Charlotte Islands (Wheeler et al., 1972a; 1972b). Oligocene strata are rare on the mainland of the Western Cordillera.

The two Canadian Cordilleran belts of Mesozoic high-grade regional metamorphic and granitic intrusions contrast strongly with the Sierra Nevada granitic and metamorphic terrane of the United States. The single system of the Sierra Nevada is explained by a process of nearly continuous subduction of oceanic crust beneath the North American Plate. The double system of the Canadian Cordillera resulted from the interruption of the subduction process caused possibly by the arrival at the subduction zone in early Mesozoic time of low specific gravity material of the Upper Palaeozoic arc assemblage of the Coast Plutonic Complex and Insular Belt and possibly old continental crust formed by Ordovician-Silurian orogeny in southeastern Alaska (Monger et al., 1972). This material blocked off the Late Palaeozoic and Middle Triassic subduction zone, causing it to jump oceanward (fig. 3.25).

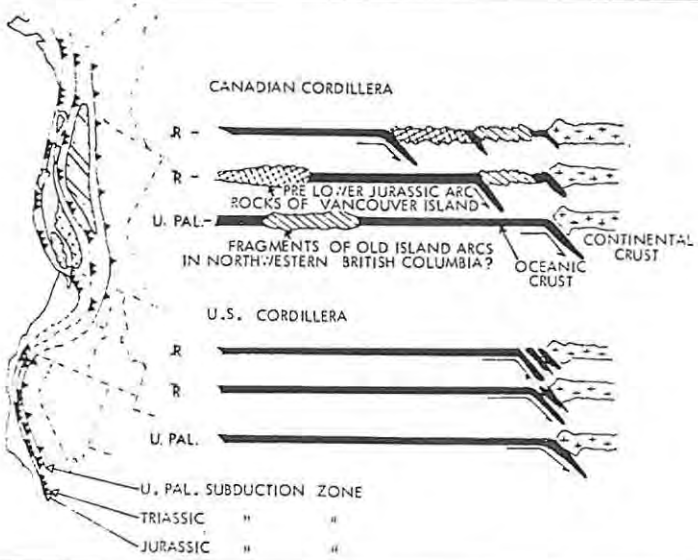


FIG. 3.25: Comparison of the Canadian and United States segments of the North American Cordillera, explaining the "jumping-out" of subduction zones in the Canadian Cordillera as the result of incorporation of blocks of light crustal material (from Monger et al., 1972).

The Triassic to the Tertiary is the period with the greatest concentration of porphyry Cu-Mo deposits. Other deposits occurring in this period include skarn deposits, disseminated base metal deposits, massive sulphide deposits, and some vein deposits.

Occurrences of Cu minerals, mainly chalcocite, are found filling primary porosity in the tholeiitic basalt-andesite flows of the Karmutsen Group on Vancouver Island and in calc-alkaline Nicola-Takla rocks of Smithers, Princeton, and Toodoggone areas (Wolfhard and Ney, 1976). Locally mineralization occurs in restricted sedimentary layers (North Star). The Sustut copper deposit of north-central British Columbia is hosted in tuff breccia and conglomerate beds of the Upper Triassic Takla Group. 30 million tons at 1% Cu have been found. The Silver City and Johobo occurrences in the Mush Lake Group of southwest Yukon include concentrations of native copper and are correlated with the widespread occurrences in the calc-alkaline Nikolai greenstones of Alaska (Mackevett, 1974, in Wolfhard and Ney, 1976). The massive sulphide deposits of Granduc are hosted in highly deformed shallow-marine succession of thick andesitic pillow lavas, siltstone, crystal tuff, conglomerate, volcanic sandstone, and some rhyolite and chert members that trend north and dip steeply to the west (Thompson and Panteleyev, 1976). The ore is mainly banded chalcopyrite, sphalerite, pyrrhotite, and magnetite layered with these tuffaceous sediments. Anyox orebodies are pipe-like to sheet-like lenses of massive pyrite, pyrrhotite, chalcopyrite with minor sphalerite, galena, magnetite and arsenopyrite in a gangue of quartz, calcite, sericite and minor epidote, and garnet. They are hosted in pillow lavas traversed by basic dykes and overlain by turbidite siltstones and argillite. The volcanogenic deposits of Britannia Mine appear to be associated with dacitic rocks proximal to eruptive volcanic centres. The orebodies are localized in the upper part of a 170m thick volcanic unit composed mainly of coarse lapilli tuffs, intercalated epiclastic rocks, and overlying tuffaceous sedimentary rocks (Thompson and Panteleyev, 1976). The structural relationships are complex as a result of repeated deformation. Other small massive sulphide deposits occur in the Cordillera.

Iron-copper skarns occur in the Insular Belt (fig. 3.26). They range in age from about 180 Ma to 120 Ma. They are often associated with diorite intrusive into a persistent limestone unit that overlies the Karmutsen Group. It is thought that the iron in these deposits is leached from the underlying Karmutsen rocks by plutons which had advanced high enough in the crust to form chonoliths (Wolfhard and Ney, 1976). Eastwood (1966) emphasizes the ubiquitous presence of andesite porphyry dykes and the influence of a structure in the formation of these deposits. In the Whitehorse Trough, Cu-Fe and Cu skarn deposits, typified by the Whitehorse Copper Belt, are in Upper Triassic dolomite, limestone, and volcaniclastic rocks in contact with unaltered and unmineralized diorite and quartz diorite of the mid-Cretaceous suite (Morrison et al., 1979). Several other Cu-Fe skarns are hosted in these rocks but are associated with younger plutons. The volcaniclastic rocks seem to be the principal source of metals in these deposits (Morrison et al., 1979). Several other low grade W skarns occur in British Columbia and in the Yukon Territory. They are genetically related to quartz monzonite and granitic stocks. The W Skarn deposits on the Clea property in the Selwyn Mountain of Yukon occur in metasediments, with maximum tungsten near the contact of these rocks with granite (Godwin et al., 1980).

Porphyry deposits of the Upper Triassic to Oligocene may be subclassified according to lithology, morphology, and erosional level

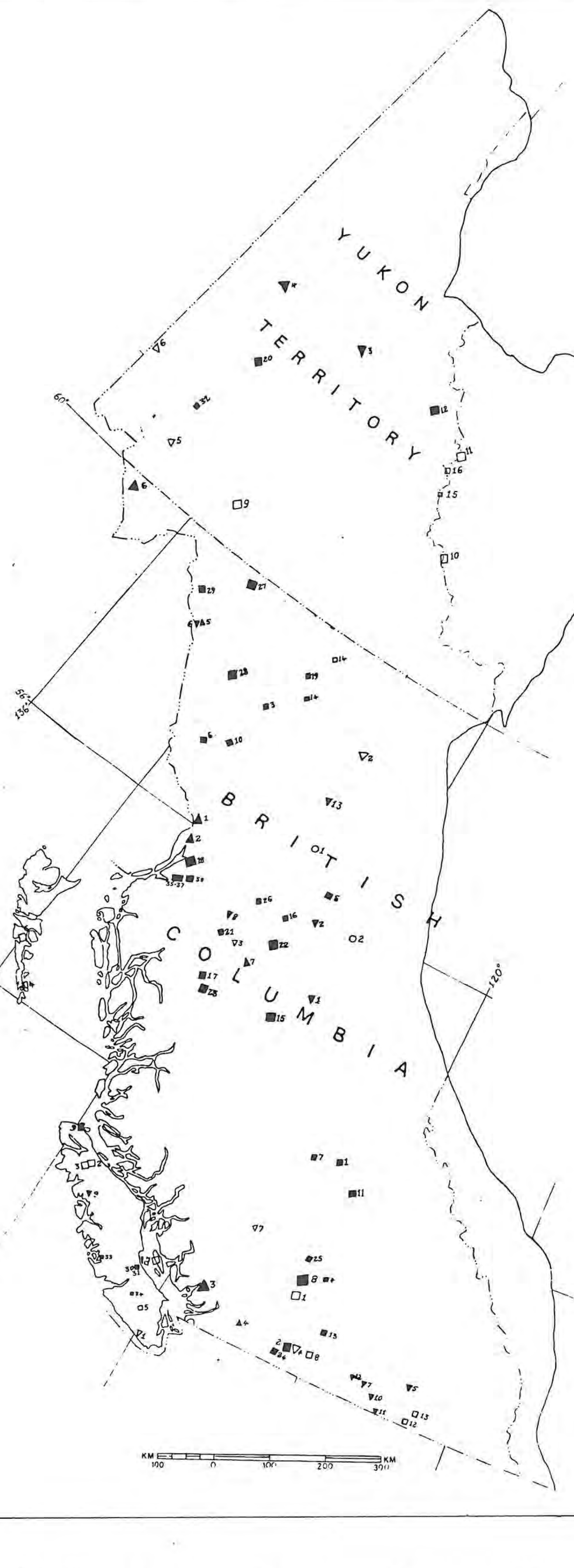


FIG. 3.26: Mineral Deposits of the Upper Triassic to Oligocene age in the Canadian Cordillera.

MINERALIZATION IN THE UPPER TRIASSIC TO OLIGOCENE

Stratiform - stratabound Copper deposits ○

1.	Sustut	U. Triassic	Cu
2.	North Star	U. Triassic	Cu

Massive Sulphide deposits ▲

1.	Granduc	U. Triassic	Cu, Fe, Zn
2.	Anyox	U. Triassic	Cu, Fe
3.	Britannia	U. Triassic	Cu, Zn, Au, Ag, Cd, Pb
4.	Seneca	Jurassic	Cu, Zn, Pb
5.	Tulsequah Chief	U. Triassic	Cu, Fe, Zn
6.	Windy-Craggy	U. Triassic ?	Cu, Fe
7.	Sam Goosly	?	Cu, Ag

Magmatic Mineralization ▽

1.	Jordan River	39 Ma	Cu
2.	Toodoggone	U. Triassic	Cu
3.	Smithers	U. Triassic	Cu
4.	Princeton	U. Triassic	Cu
5.	Johobo	U. Triassic	Cu
6.	Silver City	U. Triassic	Cu
7.	Minto	U. Triassic	Cu

Vein-type deposits ▼

1.	Pinchi Lake	Tertiary	Hg
2.	Bralorne Takla	Tertiary	Hg
3.	Keno Hill-Galena Hill	Tertiary	Pb, Zn, Ag
4.	Klondike district	Early Palaeozoic ?	Au
5.	Slocan district	Cretaceous ?	Pb, Zn, Ag
6.	Polaris Taku	Cretaceous ?	Au, As, Sb
7.	Beaverdell	Cretaceous ?	Ag, Pb, Zn
8.	Red Rose	Tertiary	W, Cu
9.	Zeballos Veins	38 Ma	Au, Ag, Cu, Pb, Zn

10. Rossland	Tertiary	Cu, Au, Mo
11. Velvet	Tertiary	Cu, Au, W, Ag
12. Dusty Mac	Tertiary	Au, Ag
13. Chapelle	L. Jurassic-U.Triassic	Au, Ag

Skarn Mineralization □

1. Craigmont	U Triassic-198 Ma	Cu, Fe
2. Coast Copper	L. Jurassic	Cu, Fe
3. Empire Development	L. Jurassic	Fe, Cu
4. Jedway	Jurassic	Fe
5. Kennedy Lake	M. Jurassic	Fe, Cu
6. Tasu	Jurassic ?	Fe, Cu
7. Texada	L. Cretaceous	Cu, Fe, Au, Ag
8. Hedley	110 Ma	Au, As
9. Whitehorse Copper	?	Cu, Fe
10. Cantung	U. Cretaceous	W, Sn
11. Mactung	U. Cretaceous	W, Sn
12. Emerald	Cretaceous	W
13. Jumbo	?	W, Mo
14. Haskins Mountains	Tertiary	Pb, Zn, Mo, Bi
15. Clea	L. Cretaceous	W, Sn
16. MacMillan Pass	L. Cretaceous	W, Sn

Porphyry Mineralization ■

1. Cariboo Bell	?	Cu, Au
2. Copper Mountain	U. Cretaceous	Cu, Au
3. Gnat Pass	U. Triassic ?	Cu
4. Iron Mask	L. Jurassic	Cu, Au, Ag
5. Lorraine	L. Jurassic	Cu
6. Stikine	U. Triassic	Cu
7. Gibraltar	U. Triassic ?	Cu, Mo
8. Highland Valley (Collectively)	U. Triassic, 198 Ma	Cu, Mo
9. Island Copper	M. Jurassic, 154 Ma	Cu, Mo
10. Liard Copper	U. Triassic	Cu, Mo
11. Boss Mountain	L. Cretaceous	Mo

12. Potato Hills	U. Cretaceous	W
13. Brenda	M. Jurassic 148 Ma	Mo, Cu
14. Eaglehead	L. Cretaceous	Cu, Mo
15. Endako	U. Jurassic 141 Ma	Mo
16. Bell Copper	52 Ma	Cu
17. Berg	48 Ma	Cu, Mo
18. Alice Arm Deposits	Tertiary	Mo
19. Cassiar Moly	68 Ma	Mo
20. Casino	70 Ma	Cu, Mo
21. Glacier Gulch	69 Ma	Mo, W
22. Granisle	51 Ma	Cu, Mo
23. Huckleberry	83 Ma	Cu, Mo
24. McBride Creek	Tertiary ?	Cu, Mo
25. Maggie	Tertiary	Cu, Mo
26. Mt. Thomlinson	Tertiary	Mo
27. Adanac	Tertiary	Cu, Mo
28. Tatsamenie	62 Ma	Mo
29. Molly Atlin	Tertiary	Mo
30. Mt. Washington	38 Ma	Cu, As, Au
31. Faith Copper	39 Ma	Cu, Mo
32. Mt. Nansen	58,4 Ma	Cu, Mo
33. Catface	48 Ma	Cu, Mo
34. Corrigan Creek	38 Ma	Cu, Mo
35. Ridge	49 Ma	Mo
36. Valley	52 Ma	Mo
37. Kay	53 Ma	Mo
38. Mt. Priestly	49 Ma	Mo

(Wolfhard and Ney, 1976). The syenite deposits appear to be cogenetic with the Triassic Nicola Group or its equivalents. They are characterized by high alkali feldspar content, deficiency of quartz, a comparatively restricted pyrite halo and no phyllic alteration zone. The important deposits are the Stikine Copper and Copper Mountain. The Island Copper porphyry system is of the quartz monzonite type and is regarded as cogenetic with the Bonanza Group explosive volcanic rocks. Several porphyry Mo deposits are associated with the quartz monzonite plutons, for example, the Endako Mo deposit (40 Ma), the Boss Mountain Mo deposit and a number of Mo occurrences to the south and southeast which were formed about 110-100 Ma ago. In British Columbia some porphyry deposits occur in isolated settings. The Tertiary Maggie deposit is in Cache Creek host rocks and is associated with the Maggie stock, an elongate, northwest-trending intrusion of biotite-quartz monzonite porphyry. It has ore reserves of 181 million tons at 0,28% Cu and 0,029% Mo (Miller, 1976). The McBride Creek Cu-Mo porphyry prospect is associated with a quartz monzonite plug that intrudes Cretaceous or Tertiary acid volcanics. The Mt Haskins Mo porphyry has a Pb-Zn bearing skarn associated with it. Adanac and other deposits near Atlin are plutonic.

Finally, vein deposits (Sb-Ag, Au-Ag, Ag-Pb, and polymetallic Au-Ag-Pb-Zn-Cu types) occur, for instance, in the Whitehorse area. In Vancouver Island, gabbroic intrusions in volcanics dated at 38 Ma contain Cu deposits (Jordan River) that are both vein-like and magmatic in character (Wolfhard and Ney, 1976). In south central British Columbia the syenite-monzonite Coryell Intrusions (50-80 Ma) have the vein Au-Cu deposits of Rossland and the Velvet Cu, Au, W vein deposits associated with it. Along the Pinchi Lake fault zone occur the Pinchi Lake and Bralorne Takla Mercury Mines. These mercury deposits are hosted in dolomitized Cache Creek limestones (Armstrong, 1966).

3.6 THE MIOCENE TO RECENT GEOLOGICAL HISTORY

The last phase of Cordilleran history is mainly a post-orogenic regime of sedimentation, volcanism and uplift. The sedimentation was restricted to a few basins and the volcanism was of alkaline olivine basalt type ("Plateau basalt"), occurring mainly in the Intermontane Belt. The Pacific Continental margin west of Vancouver Island is composed of Eocene-Oligocene bathyal sediments lying unconformably on older rocks along the inner-shelf and overlain seaward by Miocene and Pliocene strata (Tiffin et al., 1972). A thick regressive sequence of Pliocene sediments overlapping the Tertiary sediments occurs at the south end of Tofino Basin. On the mainland of the Western Cordillera, Miocene silts, sands and gravels occur along the valleys of the Fraser River, Thompson River, and southernmost Rocky Mountain Trench and indicate that the major drainage routes were established by the Miocene, preceeded by a long interval of erosion (Wheeler et al., 1972a).

The flat-lying plateau basalts of the Cordillera (fig. 3.17) overlie and interfinger with clastic sediments containing late Miocene flora and locally some diatomites. These volcanic rocks were erupted from fissures and shield volcanoes onto a gently undulating erosion surface. In the east of the Intermontane Belt, these lavas flowed into valleys bordering Columbia Mountains whereas in the west they have been upwarped by post-Miocene uplift of the Coast Mountains and have been mainly eroded (Souther, 1977; Monger et al., 1972; Wheeler et al., 1972a; Douglas et al., 1970). A linear belt of epizonal plutons (dated at 18 to 7,8 Ma) and two deeply eroded cauldron complexes, the Mount Silverthrone and Franklin Glacier Complexes, extends northwesterly along the axis of the Coast Mountains from near the U.S. border east of Vancouver to King Island on the British Columbia Coast. The plutons are believed to be subvolcanic bodies associated with the Miocene volcanic front that was active during the early stages of subduction of Juan de Fuca Plate (Souther, 1977). The plateau lavas were erupted behind the volcanic front in what was probably an extensional tectonic environment. In St. Elias Mountains the lava flows interbedded with glacial sediments have been dated at 36 Ma to 10 Ma and are unconformably overlain by Pleistocene till sheets younger than 2,7 Ma. Thus the St. Elias Mountains were subjected to glaciation in Miocene and Pliocene times and in latest Pliocene underwent tilting and faulting during uplift (Wheeler et al., 1972a).

The late Pliocene through to Quaternary style of volcanism changed somewhat, although most lavas still seem to belong to the alkali-olivine basalt suite. In contrast to the Miocene lava sheets, these are mainly small separate centres, some merely isolated cinder cones active as recently as 200 years ago. These younger volcanoes fall within two narrow northerly trending belts and a westerly trending belt (fig. 3.27; Stacey, 1974; Wheeler et al., 1972a). The composite volcano Mount Edziza in the northern belt, where the volcanics range from picrite basalt to rhyolite (Stacey, 1974; Monger et al., 1972), is related to a zone of northerly trending faults active into Recent time. In southwestern British Columbia the Mount Garibaldi Centre is more andesitic in overall composition and perhaps is the northernmost centre in the chain of volcanoes in the Cascades of the northwestern United States (Monger et al., 1972). In northern British Columbia several volcanic cones consisting mainly of volcanic ash capped by flat-lying flows are thought to have been emplaced at a time when the region was covered by ice (Wheeler et al., 1972a).

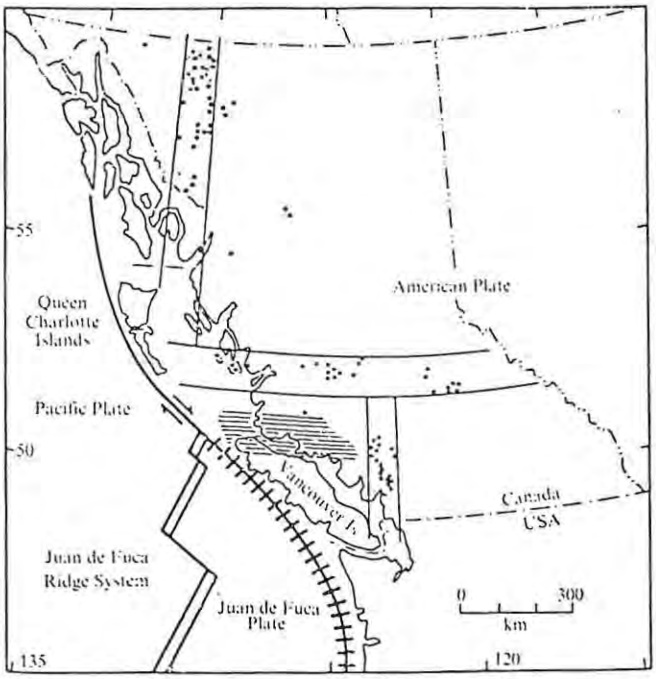


FIG. 3.27: Volcanic belts of the Canadian Cordillera (from Stacey, 1974).

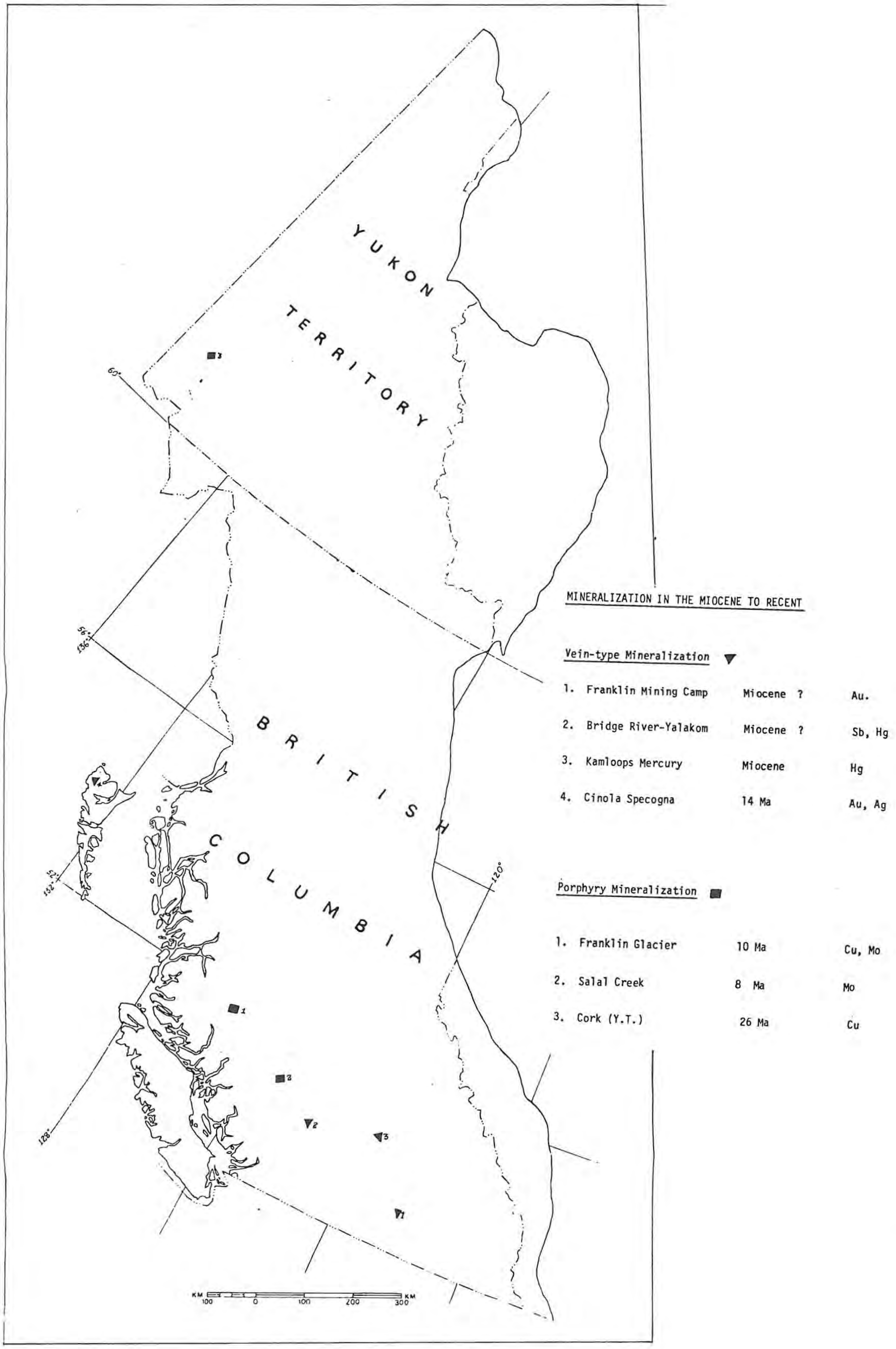
Monger et al. (1972) interprete the Eocene and older volcanics as having formed above an east-dipping, offshore subduction zone, and the Miocene and younger as having formed directly by partial melting of mantle material (probably unrelated to any subduction zone). This is related to changes along the boundary between the Pacific and North American Plates. At about Late Oligocene - early Miocene time the plate boundary changed from a consuming margin, in which the Pacific Plate was being driven under the North American Plate at some oblique angle, to the present-day situation where most of the margin of the Canadian part of the North American Plate is the transform Fairweather-Queen Charlotte Fault (figs. 3.17 and 3.27). Intermittent subduction occurs only in the small Juan de Fuca Plate, causing formation of volcanic rocks of the Cascades and Mount Garibaldi (Monger et al., 1972).

During this last phase of the geological history of the Cordillera, there was a sharp decline in porphyry mineralization. The extensive and relatively untectonized plateau basalts are nowhere known to be mineralized. No mineral deposits are known to be associated with the Queen Charlotte plutons. In the Harrison Lake structure, along which a number of small volcanic centres are located, occur the Cu-Mo mineralization of Franklin Glacier and the Salal Mo deposit hosted in a 7,9 Ma stock. Minor Cu showings occur in a volcanic structure northwest of Hope and vein and skarn deposits occur adjacent to the Chilliwack Pluton. In the Bridge River - Yalakom district there are several Sb veins, telescoped Au-As veins, and several Hg occurrences. Some of these deposits seem to be related to the post-Eocene-pre Upper Miocene Fraser River-Yalakom faults. Along the Fraser-Yalakom fault zone and along the Pinchi Lake fault zone Hg deposits are commonly associated with bodies of altered serpentine (Armstrong, 1966). Finally, Zn-Mo geochemical anomalies in the Mt. Edziza massif suggest that mineralization may be presently taking place beneath these volcanic sites (Wolfhard and Ney, 1976).

3.7 THE GEOLOGICAL STRUCTURE OF THE CORDILLERA

3.7.1 INTRODUCTION

The Columbian and Pacific Orogenic Belts dominate the structure of the Canadian Cordillera. These two Orogenic Belts coalesce in the Intermontane Zone (Hinterland Belt)(fig. 3.29). The Yukon Crystalline Complex and the St. Elias Fold Belt are parts of more extensive units projecting into Canada from Alaska. Each orogenic belt consists of an uplifted core zone and of variably deformed relatively unmetamorphosed bounding regions (Wheeler et al., 1972a). The core zone contains elongate tracts of complexly deformed high-grade metamorphic rocks and numerous granitic plutons. The bounding regions show less complex deformation. The Columbian Orogenic Belt consists of: (i) the Foreland Thrust and Fold Belt; (ii) the Omineca Crystalline Belt - the core



MINERALIZATION IN THE MIOCENE TO RECENT

Vein-type Mineralization ▼

1. Franklin Mining Camp	Miocene ?	Au.
2. Bridge River-Yalakom	Miocene ?	Sb, Hg
3. Kamloops Mercury	Miocene	Hg
4. Cinola Specogna	14 Ma	Au, Ag

Porphyry Mineralization ■

1. Franklin Glacier	10 Ma	Cu, Mo
2. Salal Creek	8 Ma	Mo
3. Cork (Y.T.)	26 Ma	Cu

FIG. 3.28: Mineral Deposits of the Miocene to Recent age in the Canadian Cordillera

zone; and (iii) the western hinterland Belt (fig. 3.30). The Pacific Orogenic Belt consists of: (a) the Intermontane Thrust and Fold Belt; (b) the Coast Plutonic Complex and Cascade Axial Zone - the core zone; and (c). the western Insular Belt which continues into southeastern Alaska.

Deformation of the Cordilleran Orogen occurred at various times prior to the Mesozoic. However, the period from the Mesozoic to the Early Tertiary is the period during which tectonism produced the structural style of the Cordillera as we know it today. In the two orogenic belts, deformation migrated away from the core zones. In the Columbian Orogenic Belt it took place earlier in the north than in the south. In the Pacific Orogenic Belt it occurred later than in the Columbian Orogenic Belt.

3.7.2 THE COLUMBIAN OROGENIC BELT

The Foreland Thrust and Fold Belt (figs. 3.29, 3.30 and 3.31) is a zone of easterly verging shallow thrust faulting and décollement folding. It is 300 km wide and follows the boundary between the Cordilleran miogeosyncline and the North American craton from the Yukon Territory of northern Canada to southeastern California (Wheeler et al., 1972; 1974). Within this zone of "thin-skinned" deformation, an easterly tapering wedge of supracrustal rocks was horizontally compressed and tectonically thickened as it was displaced eastward relative to underlying undeformed basement (Price, 1981).

In the Foreland Thrust and Fold Belt of the southern Canadian Rocky Mountains the well-layered strata were deformed by numerous southwest-dipping, concave-upward, locally folded thrust faults. The sediments have been thrust northeastward as much as 200 km relative to the crystalline basement, to where they are now stacked up in a series of thrust sheets on the edge of the North American craton. Many thrust faults die out upward in the cores of anticlines or downward in the cores of synclines, where they mark the centres of curvature for strata that are concentrically folded (Price, 1981). The structural style and density of thrusting are related to the competence and structural anisotropy of the rocks, which in turn, are governed by the stratigraphic level and facies exposed. Thrust faults are thus most

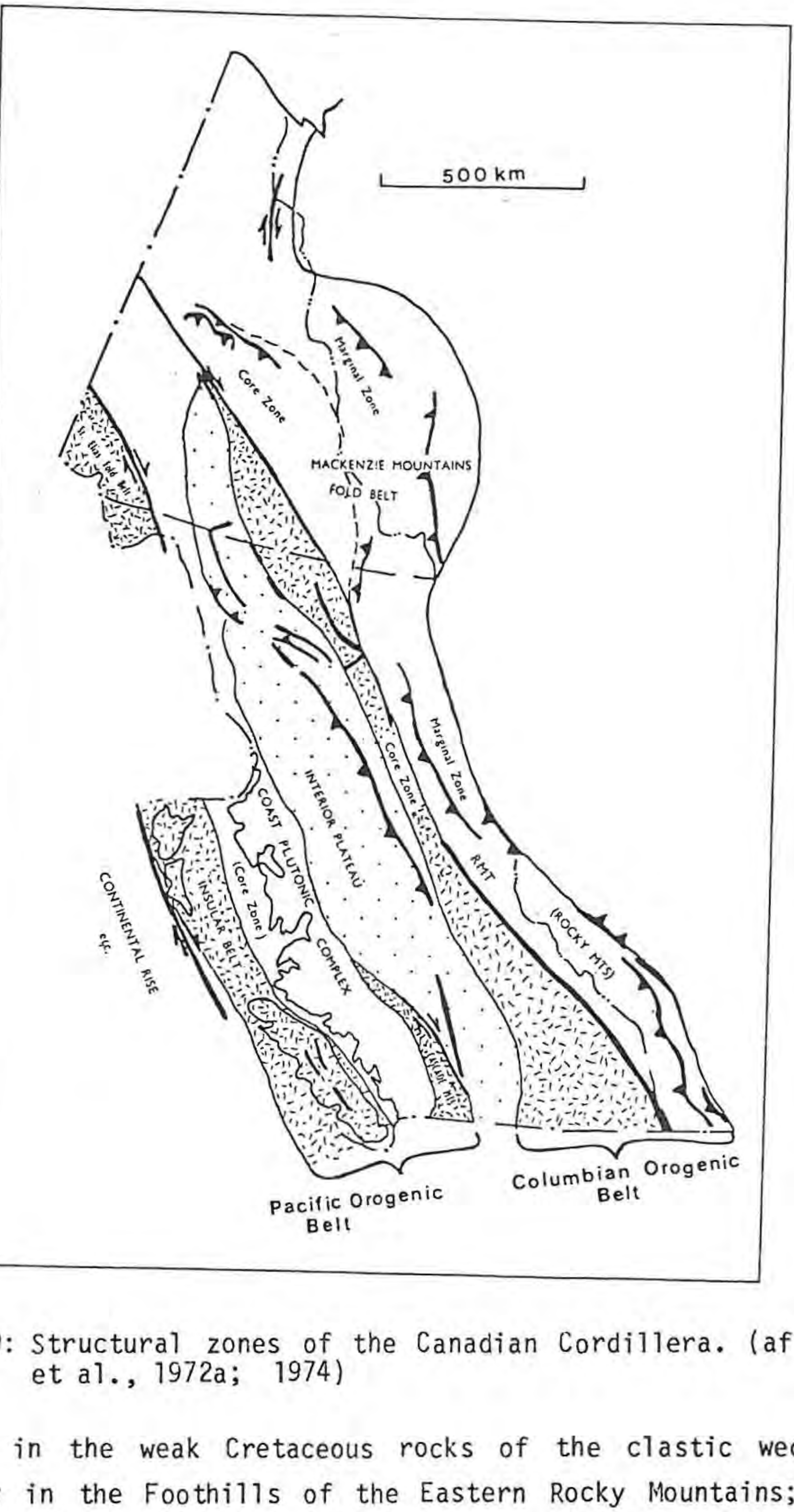


FIG. 3.29: Structural zones of the Canadian Cordillera. (after Wheeler et al., 1972a; 1974)

numerous in the weak Cretaceous rocks of the clastic wedge exposed primarily in the Foothills of the Eastern Rocky Mountains; they are abundant in the Devonian-Jurassic miogeosynclinal-platform sequence of the Front Ranges; and they are comparatively rare in the thick competent lower Palaeozoic miogeosynclinal succession of the eastern Main Ranges (Wheeler et al., 1972a; 1972b). Penetrative slip folding predominates in the shaly incompetent facies of the Western Main Ranges whereas concentric folding predominates in the range to the east (Brown, 1978).

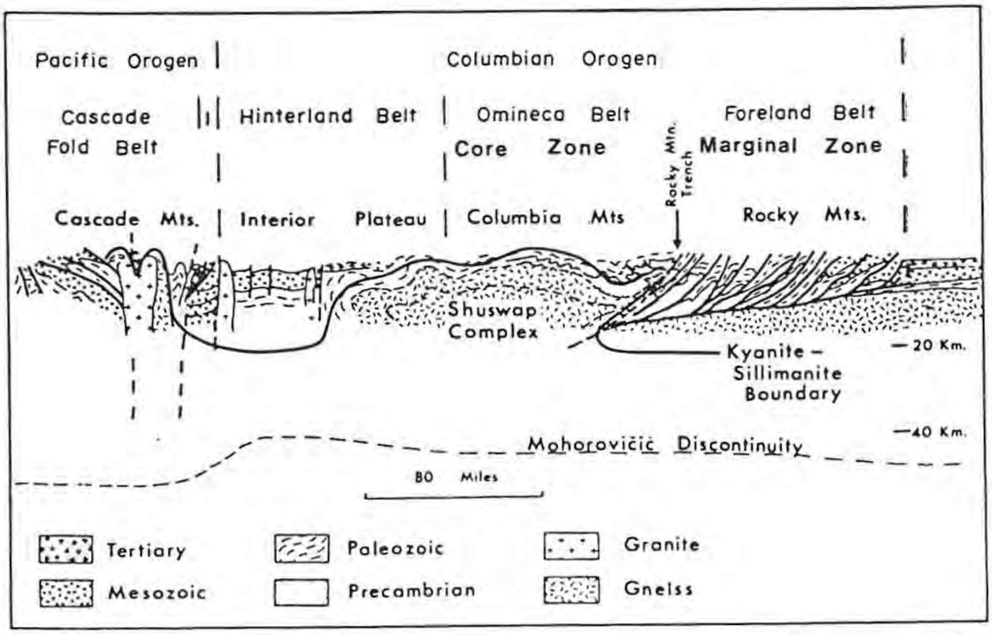


FIG. 3.30: Schematic section across the southern Canadian Cordillera (from Wheeler et al., 1972b).

The Malton gneiss (fig. 3.2)(Wheeler et al., 1972; Campbell, 1973), in the hangingwall of the Purcell Fault, has locally overriden Cambrian and older rocks in the Rocky Mountains along the Rocky Mountain Trench near Valemount. The Malton gneiss consists of paragneiss, schist, amphibolite, and granite gneiss (Brown, 1978). The structures in the Main Ranges are apparently related to the northeastward emplacement of the gneiss, and perhaps also to deformation of the basement beneath the sedimentary pile. Structures in the Front Ranges and Foothills do not reflect the influence of the emplacement of the gneiss. South from Valemount the Purcell Fault progressively diverges from the more westerly structural trends of the Rocky Mountains thus truncating structures of the Western Ranges. These ranges are composed of transverse faulted and strike-faulted lower Palaeozoic rocks overturned to the southwest on the southwest limb of the fan shaped Porcupine Creek anticlinorium (Brown, 1978; Wheeler et al., 1972).

In the southern Canadian Cordillera thrust faulting was followed, in the Early Tertiary, by the final episode of block faulting. Northwesterly-trending southwest-dipping normal (listric?) faults are consistently later than the thrust faults and apparently do not truncate the crystalline basement.

The northern Rocky Mountains, narrower and less fore-shortened than the southern Rocky Mountains, comprise a rugged, structurally complex

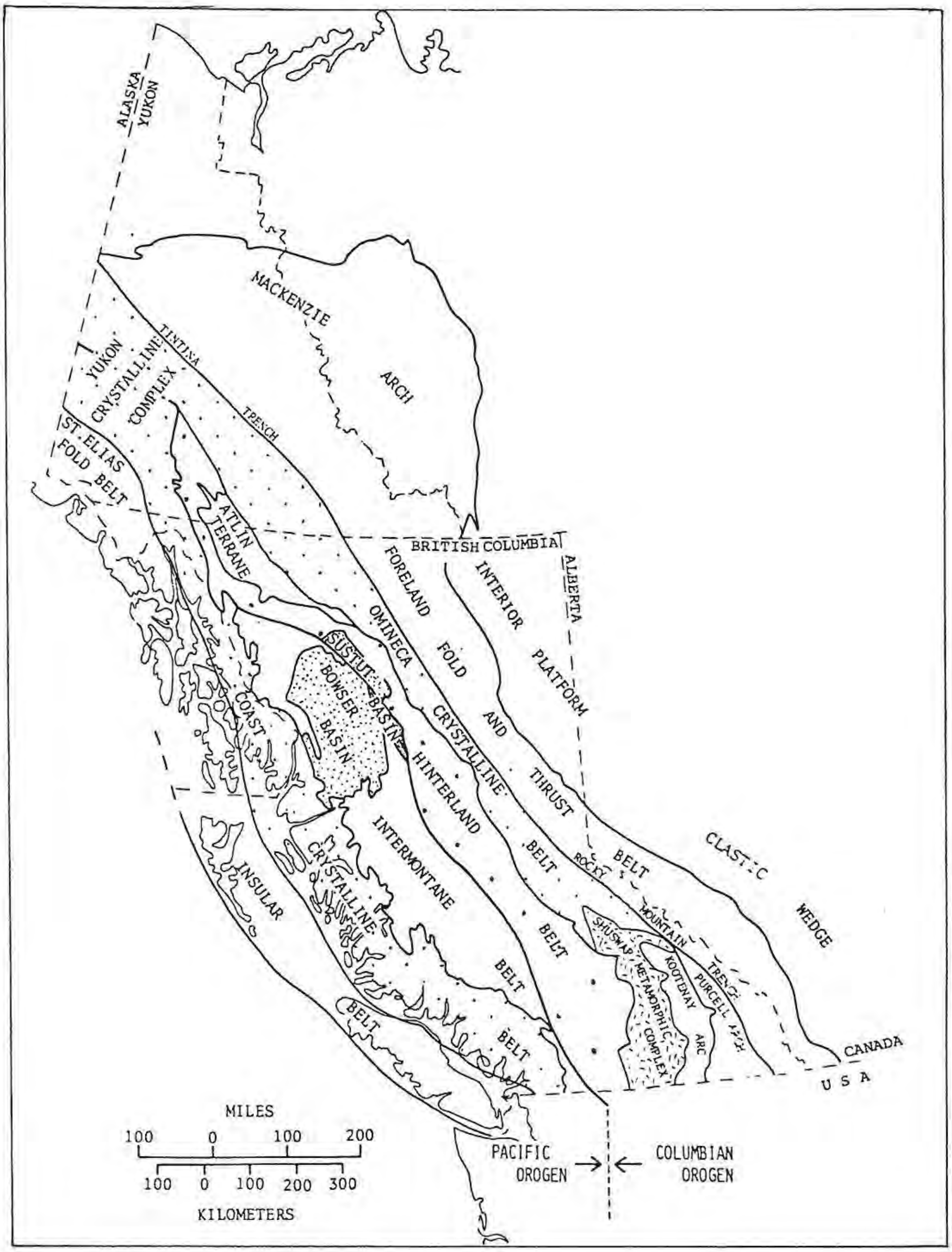


FIG. 3.31: Major structural elements of the Canadian Cordillera (from Thompson and Panteleyev, 1976).

Foothills subprovince of large amplitude box and chevron folds*, and a structurally diverse Rocky Mountain subprovince. The boundary between the two subprovinces is, in some regions, defined by the unfaulted east-dipping limbs of an en echelon sequence of large mountain-front

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* Footnote: Box and chevron folds also occur farther north along the eastern margin of the Mackenzie Mountains.

anticlines (fig. 3.32; Thompson, 1981). These anticlines (e.g. Tuchodi anticline, Robb anticline, and Laurier anticlinorium) have been displaced relatively eastward as much as 10 or more kilometres on flat thrusts - "blind" thrusts (Thompson, 1981).

In the Foreland Thrust and Fold Belt of the northern Canadian Rocky Mountains the pattern of imbricate thrusts that is typical of the southern Canadian Rocky Mountains is poorly developed or even lacking. However, the lack of these major thrust faults is more apparent than real (Thompson, 1979; 1981). Most remain buried disharmonically within the incompetent Devonian and Mississippian strata and as such, Thompson (1981) refers to them as "blind" thrusts. Despite previous thinking (e.g. Stott and Taylor, 1972), Thompson (1981) concludes that the northern Rocky Mountains can also be interpreted as a result of "thin-skinned" tectonics similar to, but orogenically less mature than the southern Rocky Mountains. The difference in structural style between the southern and northern Rocky Mountains is consistent with changes in the stratigraphic character of the rock prism that was deformed: the proportion of thick incompetent shale units increases northward, and major lateral carbonate to shale facies transitions predominate in the Rocky Mountain subprovince (Thompson, 1979; 1981).

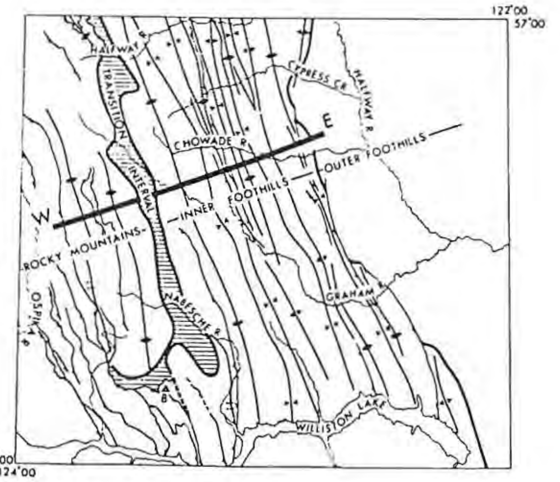


FIG. 3.32: Map of part of the northern Canadian Rocky Mountains (at Halfway River) showing major geological subdivisions, axial traces of prominent folds, and traces of important thrust faults (from Thompson, 1979).

The core zone of the Columbian Orogenic Belt comprises several structural elements. The Shuswap and Wolverine Metamorphic Complexes and other metamorphic culminations occur at intervals along the Omineca Belt (fig 3.33) and in western Selwyn Basin.

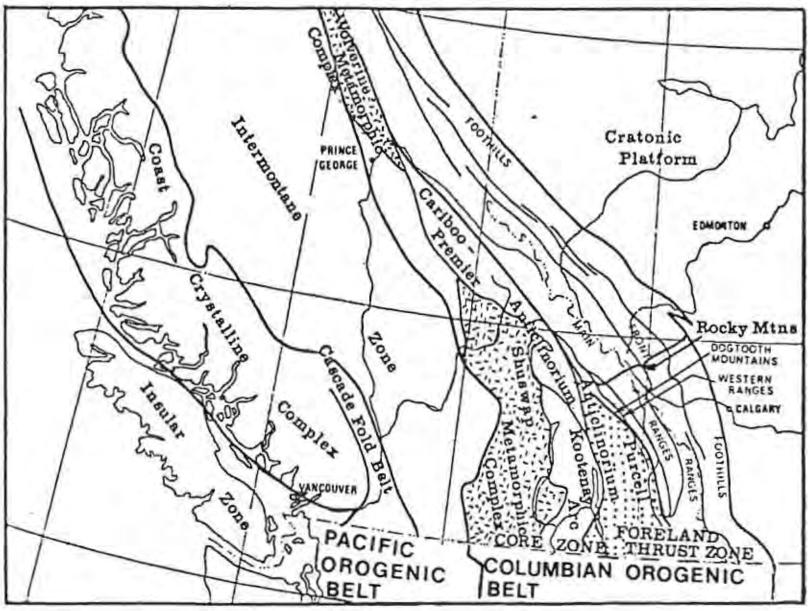


FIG. 3.33: The Core zone of the Columbian and Pacific Orogenic Belts (after Wheeler et al., 1972b).

The Shuswap Metamorphic core complex is an elongate zone of high grade metamorphic rocks. It is marked on its eastern flank by a series of gneiss domes at about 80 km intervals (Brown, 1978; Wheeler et al., 1972). The domes are characterized by cores of migmatitic granitoid gneiss enveloped by mantles of metasedimentary gneiss, and, locally, nepheline syenite gneiss fringed with metasedimentary gneiss which is riddled with pegmatite. The complex is considered to be an allochthon (in contrast to an autochthon of Campbell, 1973) that has been internally deformed, uniformly uplifted approximately 11 km, and relatively displaced for a distance of between 200 km and 35 km (Brown, 1978; 1981). Deformation has involved the underlying basement (see fig. 3.34). Deformation features polyphase, locally recumbent folding in which the earliest folds commonly trend normal to the trend of the orogen. These folds, which involve interfolded granitoid gneiss sheets and metasediments, are also parallel to the direction of stretching of the regional northwesterly trending folds. Later folds in the complex trend north and northwesterly and are partly related to the diapiric rise of gneiss domes (Wheeler et al., 1972). Much of the metamorphic terrane is characterized by gentle dips of bedding and foliation. The migmatitic gneisses have been flattened with attendant development of boudinage in competent units. The principal deformation and high grade metamorphism of the complex occurred in post-Late Triassic or Early Jurassic time (Brown, 1981; Wheeler et al., 1972).

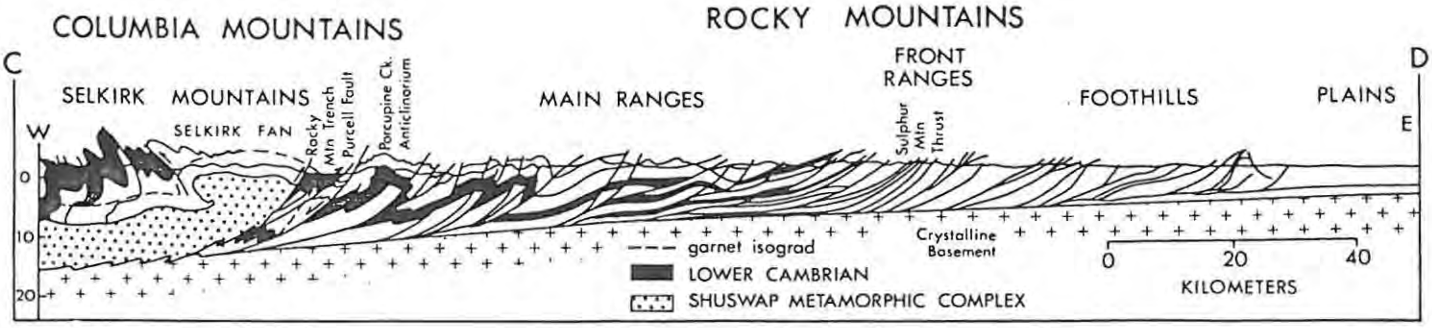


FIG. 3.34: Structural cross-section of the southeastern Canadian Cordillera (from Brown, 1978).

The Shuswap Metamorphic complex in conjunction with the Foreland Thrust and Fold Belt has been described as the best documented example of an Andean-type orogenic belt (Crittenden et al., 1978). Monger et al. (1972) attributed the principal deformation to an Andean-type subduction system.

East of the Shuswap Complex, in Selkirk Mountains, polyphase deformation involves lower Palaeozoic rocks of greenschist facies. Early, probably mid-Palaeozoic, westerly and northwesterly trending isoclines and a related allochthon of Proterozoic clastics are refolded by northwest-trending upright folds. These, in turn, are locally backwarped to produce fan structures. Brown and Tippett (1978) have described the evolution of the Selkirk fan structure, and are of the opinion that the Selkirk is structurally the western extremity of the Rocky Mountain Thrust and Fold Belt.

Farther east the structural style changes rapidly into the box-shaped Purcell anticlinorium underlain mainly by Proterozoic Purcell sedimentary rocks. The Purcell anticlinorium is composed of several north-plunging segments separated by transverse faults that may be early normal faults and subsequently the site of oblique movement or folded thrusts (Dahlstrom, 1970 _in_ Wheeler et al., 1972b). The eastern margin of the anticlinorium is marked by two generations of northeasterly directed thrust faults — an earlier one congruent with concentric folding and a later one trending more northerly. The latter is examplified by the west-dipping Purcell Fault which truncates structures on both sides of the Rocky Mountain Trench, i.e. it juxtaposes structures on both sides of the trench (Brown, 1978). On the east it truncates the western Ranges and Main Ranges structrues and on the west it truncates Purcell anticlinorium, Dogtooth Range, northern Selkirk Mountains, Northern Monashee, and southeasternmost Cariboo Mountain structures of the Omineca Crystalline Belt (Nielsen, 1982; Wheeler et al., 1972). In the Kootenay Arc the youngest deformation involves early Middle Jurassic strata and all phases are cut by discordant granite plutons of Middle Jurassic age.

North of Fraser Structural Depression (fig. 3.31) an element of northeastward tectonic transport is inferred. If such an element existed it has been truncated along the trench. All structures west of the trench, including those in the Wolverine Complex, are directed southwesterly and Proterozoic strata are thrust southwestward over Carboniferous and Upper Triassic rocks that show similar structural asymmetry near the fault. Further northeast, the structures of the Cassiar Thrust and Fold Belt are characterized by northeasterly directed, locally folded thrusts that bring lower Palaeozoic carbonates and greenschists onto upper Palaeozoic carbonates and quartzites and are similar cleavage folds in pelitic sequences. More to the west, these structures become steeply inclined and more open. They eventually pass into a broad synclinorium that contains a possibly allochthonous upper Palaeozoic volcanic-ultrabasic assemblage intruded by Cassiar batholith. West of Cassiar batholith and plutons northwest of it in Pelly Mountains, Carboniferous and older rocks (which are locally metamorphosed) are deformed into broad, northwest-trending anticlinoria and synclinoria.

Hinterland Belt

The southern part of the Hinterland Belt (in Quesnel Trough) consists of a medial belt of moderately deformed upper Palaeozoic (Cache Creek Group) basic volcanics, ultramafics, pelites, melange, ribbon chert, and limestone. It is characterized by broad folds and numerous steep faults (Douglas et al., 1970). The folds are tighter and inclined to the west locally along the eastern margin of the belt indicating that there was southwestward tectonic transport in the western part of the Omineca Belt (Wheeler et al., 1972). The structure at Pinchi Geanticline is complex and not well understood. In the northwest the Lower and Middle Jurassic succession of Whitehorse Trough is sedimentary in contrast with the volcanic facies in Quesnel Trough. In the Whitehorse Trough, the Lower Jurassic offshore turbidite facies were thrusted, in a southwesterly direction, onto Lower and Middle Jurassic western near-shore facies. In Yukon, the latter facies is thrust onto Jura-Cretaceous non-marine clastics. Folds are concentric and inclined to the southwest above King Salmon thrust - a regional décollement in the Upper Triassic sediments. Folds in the conglomeratic facies are broad and open (Wheeler et al., 1972)

The core of the Whitehorse Trough is occupied by a partly fault-bounded block of Upper Palaeozoic oceanic and volcanic-arc rocks of the Atlin Horst. The horst is thought to be a large thrust sheet in which abundant folds are overturned to the southwest, similar to those of the Mesozoic rocks of Whitehorse Trough. These recumbent folds are associated with small thrust faults and slides. The deformation here is accompanied by penetrative foliation not found in Upper Triassic rocks (Wheeler et al., 1972; Douglas et al., 1970).

3.7.3 THE PACIFIC OROGENIC BELT

Intermontane Thrust and Fold Belt.

The Intermontane Thrust and Fold Belt includes three elements: (i) Upper Palaeozoic tightly folded volcanic arc assemblage on Stikine Arch (fig. 3.4); (ii) thrust and block-faulted Lower Mesozoic volcanic arc-interarc basin assemblages deposited in Nechako Trough and on Stikine and Skeena Arches; and (iii) tightly folded and thrust-faulted late Mesozoic and Early Tertiary layered rocks of the Bowser, Tyaughton, and Sustut successor basins. Thrust faulting and folding (directed northeastward) is dominant in the Intermontane Belt. The tectonic style is closely similar to that in the Foreland Thrust and Fold Belt, and varies with the character of the individual tectono-stratigraphic units involved in the deformation (Wheeler et al., 1972). Palaeozoic to Middle Triassic rocks in Stikine Arch are closely folded along northerly trends as in the Atlin Terrane. They are overlain unconformably by lower Mesozoic volcano-sedimentary units that form a mosaic of fault blocks within which the structural style of generally northwest-trending folds varies in relation to the competency of the rocks. In Skeena Arch and northwestern Nechako Trough late Lower Cretaceous strata are cut by northeastward directed thrust faults and by northeast- and northwest-trending Tertiary normal faults.

In the successor basins deformation is more intense. In the Bowser Basin (fig. 3.31) folds are commonly of concentric and chevron style developed above décollement surfaces. They conform in trend roughly to the basin boundaries. Along the eastern margin of the basin, Upper Jurassic sediments are folded with and thrust over the Upper Cretaceous part of the non-marine clastics of Sustut Basin adjoining to the east. Folds in the western part of Sustut Basin are dominated by smoothly concave synclines and tight piercing anticlines which pass rapidly along strike into northeast-directed thrusts.

Deformation of the Tyaughton Trough is variable. The widest area of the trough is characterized by broad over folds, and the western parts have several gently west-dipping northeast-directed thrusts locally associated with isoclinal folds involving early Lower Cretaceous strata. East of the Cascade Axial Zone, where the trough is narrow, the structure is dominated by several concentric synclines whose eastern limbs are imbricated by west-dipping thrust-faults. Mesozoic sediments of the trough are deformed by several northwest-trending dextral transcurrent faults with which some northerly directed thrusts are related. Movement along these faults took place over a long period because the amount of displacement increases in relation to the increased age of the rocks involved (Wheeler et al., 1972; Douglas et al., 1970).

Coast Plutonic Complex and Cascade Axial Zone.

The Coast Plutonic Complex, connected en echelon to the plutonic zone of the Cascade Fold Belt (fig. 3.33), extends for 1760 km northwest where it merges with Yukon Crystalline Platform (fig. 3.31). The complex comprises a mosaic of coalescing northwesterly elongate granitic plutons and subordinate, relatively narrow northwest-trending belts of metamorphic rocks. The metamorphic rocks display polyphase deformation. The Axial Zone is bounded by belts of Mesozoic clastic and subordinate volcanic rocks. Lower Tertiary clastics are restricted mainly to the north-trending Fraser River Fault zone, whereas Tertiary volcanics occur patchily.

The principal structures of the Cascade Fold Belt are westerly and easterly spreading thrust faults that root near the Axial metamorphic zone. Those in the west dip gently to the southeast and are associated with northeast-trending recumbent folds. Those in the east dip steeply west and strike northwesterly. The most important thrust faults on both sides of the fold belt have ultramafic rocks associated with them. Those in the west near the International Boundary contain metamorphic rocks of blue schist facies and tectonic slivers of crystalline rocks similar to nearby pre-Devonian crystalline basement.

Insular Belt.

The Insular Belt comprises a broadly folded and much faulted Median Uplift of Upper Palaeozoic and Lower Mesozoic volcanics and sediments that outcrop off Queen Charlotte and Vancouver Islands. The Uplift is flanked on the east by Queen Charlotte and Georgia Basins and on the west by the outer continental shelf which contains Tofino Basin (fig. 2.4) west of Vancouver Island. The rocks of the Median Uplift display structures similar to those of the Quesnel Trough of the Columbian Hinterland Belt. Faulting, broad concentric folding, and minor tight folding (related to fault-block movement) are the dominant structural styles. Over a long period some northwesterly-trending Mesozoic to Early Tertiary faults controlled facies distribution in Triassic volcanics, and localized volcanic centres of Middle Jurassic assemblages, syntectonic plutons, mid-Mesozoic sedimentation, post-tectonic plutons (diorite, quartz-diorite, granodiorite, and quartz monzonite), and recent earthquakes. Repetitive movement along these faults is evidenced by progressively smaller displacements of younger relative to older formations (Sutherland Brown, 1968 in Wheeler et al., 1972a). Northwesterly, northerly, and easterly normal faults of Tertiary age cut Cretaceous sediments and delimit half-grabens that are tilted southwestward in northern Vancouver Island and Queen Charlotte Islands and northeastward in central southern Vancouver Island and in Western Georgia Basin. Reverse faults are present in upturned and overturned Cretaceous sediments of western Georgia Basin. The structure in Queen Charlotte Basin is characterized by gentle folds in the Tertiary sediments deposited on a surface of uneven topography carved on Tertiary volcanics.

The structure of the continental margin varies and widens southeastward from west of Queen Charlotte Islands where the shelf is virtually absent and the continental slope is traversed by the seismically active Queen Charlotte fault. At the bottom of the slope, oceanic basement, overlain by a thin cover of sediments, dips inwards towards the continent.

The shelf northwest of Brooks Peninsula on Vancouver Island comprises seaward-dipping strata that are faulted locally. The upper continental slope is a fault scarp along which strata underlying the shelf are truncated. Beyond the base of the slope, sediments are relatively undeformed in the northern part of Wenona Basin but are folded to form northwest trending ridges in its southern part off Brooks Peninsula (Wheeler et al., 1972a). The compressional structure southeast of Brooks Peninsula, characterized by folds, thrusts, and faulted-diapirs, contrasts strongly with the steep faulted slope to the northwest similar to that along Queen Charlotte Fault.

In Tofino Basin thick Miocene and Pliocene strata are involved in post-Early Pliocene folding. To the southeast the folding is associated with mudstone diapirism. The elongate, fault-bounded diapiric structures aligned parallel to the shelf edge, breach the shelf surface in many areas. Structures indicated by seismic reflection data, including thrust-faulted anticlines, show local detachment from the basement.

3.7.4 THE NORTHERN YUKON FOLD COMPLEX AND THE ST. ELIAS FOLD BELT

The Northern Yukon Fold Complex is structurally and stratigraphically linked to the structures of Mackenzie Arc and those of northern Alaska. The Mackenzie Arc structures, which end abruptly against the fault blocks of Wernecke and Richardson Mountains, are dominated by upright, open folds (Douglas et al., 1970). Some of the folds are linked en echelon and others are paired. Steeply dipping faults parallel the fold axes. The principal tectonic elements in Richardson Mountains are ancient, near-vertical, south-trending faults that were active intermittently from the Late Precambrian to the Early Tertiary (Wheeler et al., 1972a). Some of these faults now have right-lateral separation. They also occur southeastwards in Wernecke Mountains where they have thrusted Precambrian and early Palaeozoic strata. The northern Richardson Mountains are characterized by broad, ovate domes flanked by subvertical, strike-slip faults. These structures swing northeast parallel to Aklavik Arch (fig. 2.4) and plunge beneath Mackenzie Delta. The dome structures and the strike-slip faults are also observed in Barn-and British Mountains and in the Old Crow Basin.

In the Taiga Ranges (fig. 2.3), upright folds are cut by moderately dipping thrust faults trending northwest parallel to the structural grain in Wernecke Mountains. These structures also occur in the Nahoni Range fold belt.

The St. Elias Fold Belt lies en echelon west of the northernmost part of the Coast Plutonic Complex from which it is separated by the Shakwak fault. The core zone of metamorphic and granitic rocks is bounded on both sides by inward-dipping thrust faults that separate it from folded and thrust faulted marginal zones. The area between the crystalline zone and the Shakwak fault is occupied by highly deformed mid-Palaeozoic to Lower Cretaceous volcanic and sedimentary strata overlain unconformably by flat-lying and locally deformed Pliocene and older volcanics and sediments. The structural pattern of the fold belt developed during mid-Jurassic and mid-Cretaceous tectonism. Further deformation occurred in the Cenozoic and in the late Pliocene and Pleistocene. Recent dextral transcurrent movement took place along strands of the Fairweather and Denali fault systems.

4. METALLOGENY RELATED TO SEDIMENTATION AND MAGMATISM IN THE CANADIAN CORDILLERA

4.1 MINERALIZATION IN THE PROTEROZOIC TO LOWER PALAEOZOIC

4.1.1 Introduction

This period includes the Redstone and the Kicking Horse Epochs of Wolfhard and Ney (1976). In the Eastern Cordillera, it is marked by the occurrence of Purcell Supergroup rocks in southeastern British Columbia, pre-Rapitan Group rocks in northeastern Yukon, and the Mackenzie Mountains Supergroup in Northwest Territories. These rocks are separated from the overlying Windermere Supergroup (and correlative) rocks by the East Kootenay and Racklan unconformities. The Windermere

Supergroup is overlain by Cambrian to Devonian carbonates and clastics which, in the Yukon area, appear to have a provenance in the west. Basaltic lava and diorite sills are characteristic of the Purcell Supergroup and its correlatives in the northern Cordillera. The base of the Windermere Supergroup and its correlatives is characterized by the diamictitic conglomerates, for example the Toby Conglomerate. Magmatism in this period is very much localized. A number of mineral deposits are associated with the Proterozoic to Lower Palaeozoic sedimentation. Stratiform - stratabound Pb-Zn-(Ag) deposits predominate. Stratiform sedimentary copper deposits, massive sulphide deposits, an iron deposit, and some vein-type deposits also occur. Examples of these deposits will be briefly discussed.

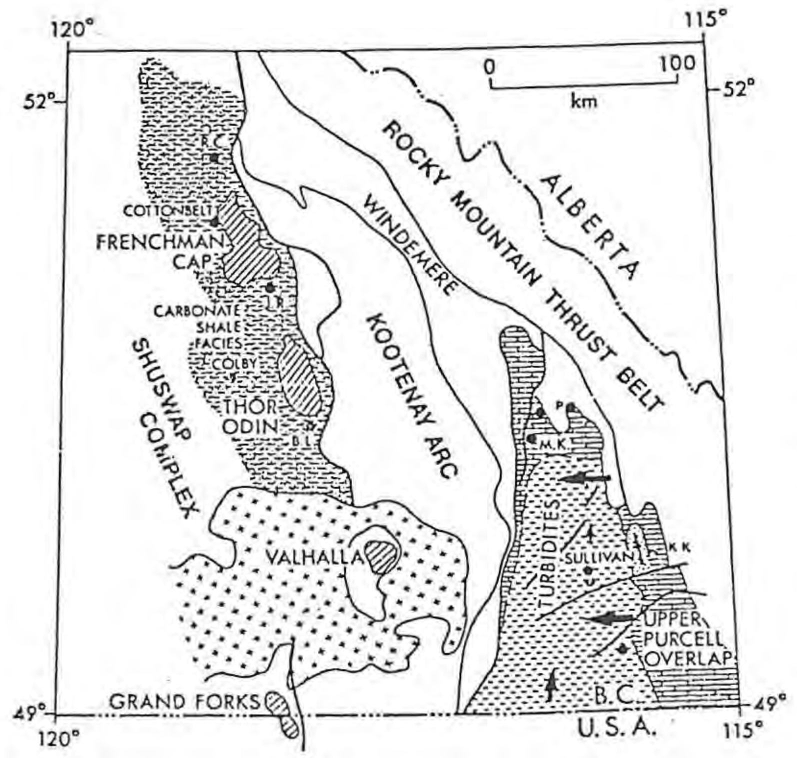
4.1.2 Stratiform - stratabound Pb-Zn-(Ag) deposits

Pb-Zn-(Ag) deposits of Proterozoic to Lower Palaeozoic age occur in at least four broad environments in the Canadian Cordillera. In southeastern British Columbia, the Pb-Zn-(Ag) deposits (fig. 4.1) occur in the Purcell anticlinorium, the Kootenay Arc area, and in the Shuswap Metamorphic Complex. In the northern Cordillera the Pb-Zn-(Ag) deposits occur in the Selwyn Basin of Yukon, N.W.T. and northern British Columbia.

A. DEPOSITS IN THE PURCELL SUPERGROUP

(a) Clastic-hosted deposits

The biggest clastic-hosted deposit is Sullivan, which had initial reserves of 170 million tons at 9% combined Pb and Zn and has current reserves of 50 million tons at 4,5% Pb, 5,9% Zn and 37g/t Ag (Höy, 1980). Sullivan lies on the eastern limb of a broad, northerly-plunging Purcell anticlinorium (Freeze, 1966; Thompson and Panteleyev, 1976). Secondary open folds and minor overturned folds are developed on the major Purcell anticlinorium. These folds are broken up by several northeasterly-trending reverse or thrust faults, a few of which extend for remarkable distances and the stratigraphic displacement across some of them is very large (Freeze, 1966). The orebody, which is approximately 2 000 m in width and 100 m in thickness, lies between the north-dipping Hidden Hand and Kimberley faults and is contained within a 30-90m interval of well-laminated argillite at the base of the Aldridge



R.C. - Ruddock Creek
J.R. - River Jordan
B.L. - Big Ledge
M.K. - Mineral King
K.K. - Kootenay King
P. - Paradise

FIG. 4.1: Distribution of Purcell Supergroup and Shuswap Metamorphic Complex and location of mineral deposits (from Höy, 1980).

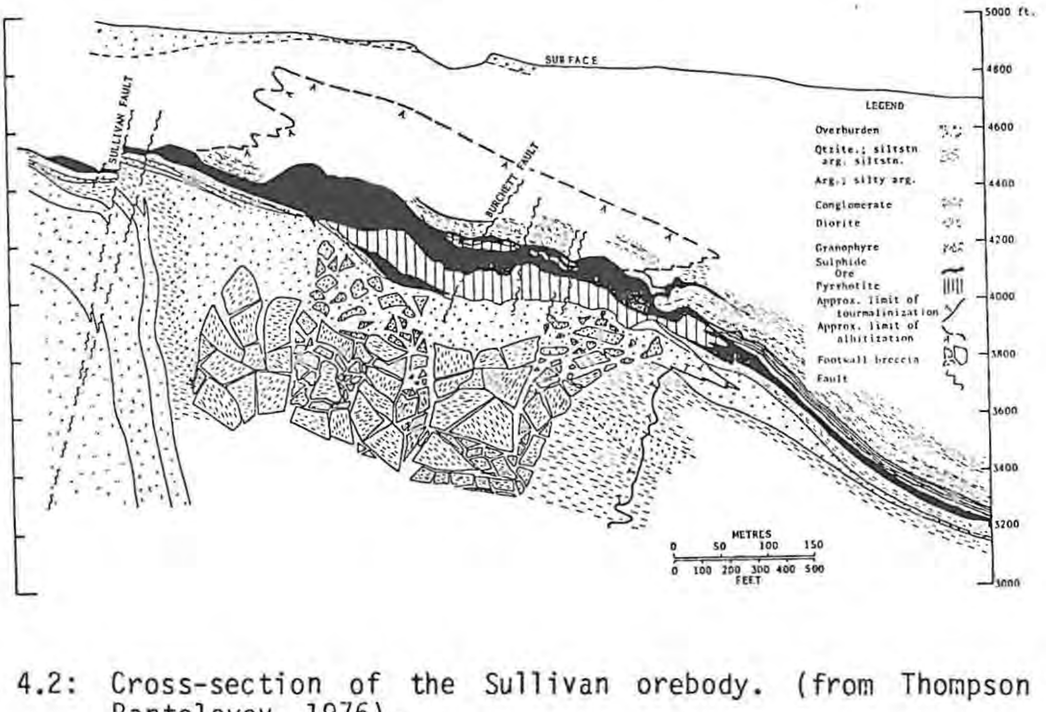


FIG. 4.2: Cross-section of the Sullivan orebody. (from Thompson and Panteleyev, 1976).

Formation. It is generally stratiform, although it can be slightly transgressive in parts. In cross-section (fig. 4.2) it can be divided into two contrasting zones. The western part comprises massive pyrrhotite containing occasional wispy layers of galena overlain by layered pyrrhotite, sphalerite, galena, and pyrite, all intercalated with clastic beds (Höy, 1980; Thompson and Panteleyev, 1976; Freeze, 1966). The eastern part, separated from the more massive western part by an irregular transition zone, includes five distinct conformable layers of generally well-laminated sulphides separated by clastic rocks. The sulphide layers thin to the east away from the transition zone (fig. 4.2) and are replaced at the limits of the ore deposit by iron sulphide bands (Höy, 1980). An extensive, cylindrically-shaped, brecciated and tourmalinized footwall zone underlies the massive western part of the orebody. This footwall zone contains some disseminated and vein-sulphides. Albite-chlorite-pyrite alteration occurs in the hangingwall of the western part (fig. 4.2)(Freeze, 1966; Campbell et al., 1980).

The deposit is zoned with Pb-Zn and Ag values decreasing towards the margin in the eastern part. In the western part, cassiterite is concentrated in an extensive fracture (transgressive vein) that cuts the sulphide zone. This fracture has been traced to depth (Freeze, 1966). In general, metal distribution patterns are directly related to proximity to the footwall breccia. Higher absolute values and higher Pb/Zn and Ag/Pb ratios overlie the breccia zones. Tin and arsenic are confined to the outer margins of the pyrrhotite zone whereas antimony is concentrated nearer the periphery of the deposit (Höy, 1980). Sullivan is considered to be a hydrothermal synsedimentary deposit that formed in a small sub-marine basin. Its western part is believed to lie directly above its conduit zone — the brecciated and altered footwall (Höy, 1980). Although the Belt-Purcell Basin is quite extensive, Sullivan seems to be the only deposit of its kind. This is rather enigmatic and is probably due to the fact that the Sullivan mineralization was deposited in a fault-bounded submarine basin. However, Sullivan (1978) believes that the Sullivan orebody is not unique and in fact similar orebodies will be found.

The Kootenay King deposit (100 000 tons) occurs in Middle Aldridge clastic sedimentary rocks east of the Sullivan mine. The mineralization occurs near the hinge of a large anticlinal fold that is thrust eastward on to younger Palaeozoic strata. It consists of a layer of finely laminated sphalerite, galena, and pyrite intercalated with dolomitic to argillaceous siltstone in a grey quartzite unit (Höy, 1980) interpreted to be a channel sandstone that was deposited in a small fault-bounded marginal basin (fig. 4.3).

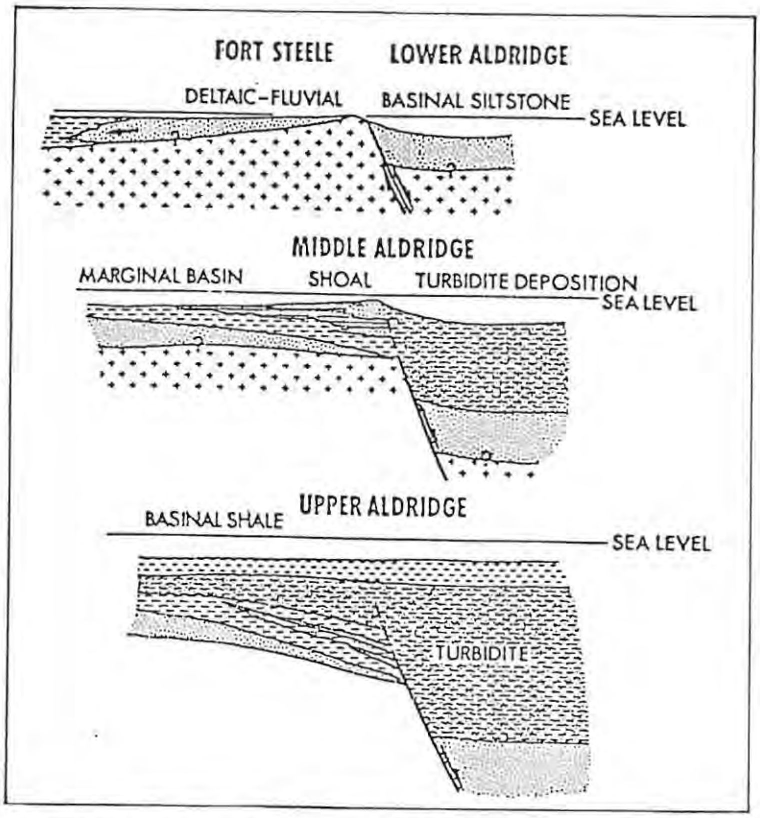


FIG. 4.3: Evolutionary stages of the fault-bounded Kootenay King basin. (from Höy, 1980).

The Stemwinder deposit lies nearly half-way between the Sullivan and the North Star mines. It is mineralogically similar to Sullivan, though the sulphides are not banded. It is hosted by numerous lenses of intraformational conglomerate that interfinger with lenses of thin bedded or laminated argillite and silty argillite. The orebody occurs along the axial plane of a doubly-plunging syncline that trends northerly, approximately parallel to the Sullivan-type faults and fractures, which are thought to have been conduits for mineralizing fluids (Freeze, 1966).

(b) Structural and stratigraphic control of clastic-hosted mineralization

In southeast British Columbia, especially in the Purcell Mountains, a pronounced northeast-trending structural grain is delineated by transverse faults with attendant localization of granitic intrusions. These faults influenced the deposition of Purcell rocks as evidenced by rapid lateral facies changes, local variations in sediment thickness, and intraformational conglomerate (Höy, 1980; Freeze, 1966). Areas of tourmalinization (boron concentration) (Ethier and Campbell, 1977) and clastic-hosted Pb-Zn-(Ag) deposits occur along these transverse faults (fig. 4.4). The anomalous thickness of the Middle Aldridge turbidites and the pronounced Bouguer gravity low and southwesterly magnetic lineation trend south of Kimberley in the vicinity of the St Mary-Boulder Creek fault and Moyie-Dibble Creek fault led Kanasewich (1968) (see also Kanasewich et al., 1969) to suggest that the Pb-Zn-(Ag) deposits were deposited in a Precambrian rift which stretches from southern Alberta through southeast British Columbia to the northwestern United Stated (fig. 4.4).

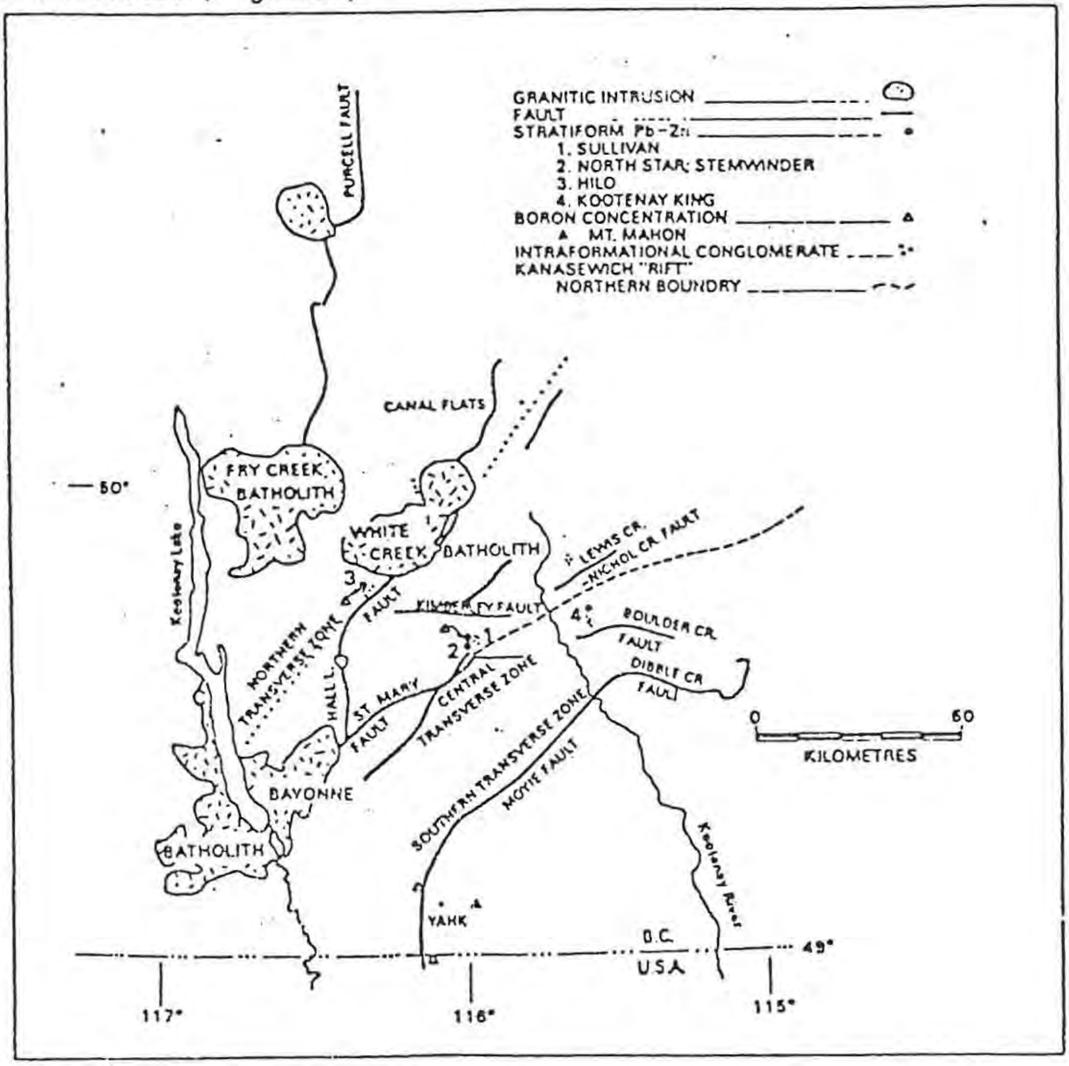


FIG. 4.4: Location of northeast-trending structures and distribution of stratiform Pb-Zn occurrences, boron concentrations, and intraformational conglomerate. (from Höy, 1980).

(c) Replacement (Carbonate-hosted) deposits.

The Mineral King, Paradise, and Ptarmigan deposits (the largest was Mineral King which produced more than 2 million tons at 1,76% Pb, 4,12% Zn, and 24,8g/t Ag) occur in dolomite of the Mt. Nelson Formation on the northern edge of the Purcell anticlinorium (Höy, 1980). The Mt. Nelson Formation, in the upper part of the Purcell Supergroup, consists of a prominent basal quartzite overlain by a thick succession of dolomite and interlayered argillite. It is underlain by the dark grey argillite and slate of the upper part of the Dutch Creek Formation and overlain unconformably by the Toby Conglomerate. The Pb-Zn-(Ag) deposits consist of sphalerite, galena, and pyrite in a dolomite, barite, and quartz gangue. They occur as replacements of dolomite by barite and sulphides in a complexly folded and faulted terrain (Höy, 1980). The deposits are irregular in shape and some of the mineralization may have been remobilized into faults and fractures as at the Paradise deposit.

B. DEPOSITS IN THE SHUSWAP METAMORPHIC COMPLEX

The Shuswap Metamorphic Complex, the core of the Columbian Orogenic Belt, consists of deformed granitic gneisses and migmatites regarded as the Precambrian (2,1 Ga) crystalline basement of the Cordillera. The core gneisses are overlain by a heterogeneous assemblage of calc-silicate gneisses, pelitic gneisses, quartzite, and marble of Proterozoic age. This succession of paragneisses (which overlie the Frenchman Cap and Thor Odin "domes" - fig. 3.2) hosts a number of Proterozoic massive and lens-like Pb-Zn-(Ag) deposits (fig. 4.1) which are folded and metamorphosed along with the country rocks (Höy, 1980). The deposits are Cottonbelt, River Jordan, Ruddock Creek, and Big Ledge. They comprise a thin, but regionally very extensive sulphide-rich layer in a calcareous succession. the immediate host is generally a calcareous schist. The sulphides are dominantly pyrrhotite and sphalerite with minor galena and pyrite. Magnetite is the abundant iron phase at Cottonbelt.

The deposits generally occur in synformal structures. The Cottonbelt orebody is in the hinge zone of a tight synclinal structure that is draped around the northwestern margin of Frenchman Cap dome (Höy, 1980). The River Jordan sulphides occur in the limbs and hinge of a tight south to southeast plunging Copeland synform. Reserves in the south limb are about 2,6 million tons at 5,1% Pb, 5,6% Zn, and 35g/t Ag (Höy, 1980).

C. KOOTENAY ARC DEPOSITS OF LOWER PALAEOZOIC AGE

The Kootenay Arc is an arcuate structural belt of complexly deformed sedimentary, volcanic, and metamorphic rocks of Palaeozoic age. Its western margin is in a fault contact with the Shuswap Metamorphic Complex or is obscured by Mesozoic batholiths and its eastern margin merges with the Purcell anticlinorium. Stratabound Pb-Zn-(Ag) occurrences in the Kootenay Arc (fig. 4.5) are contained within a thin Lower Cambrian limestone unit (called the Reeves limestone in the south and the Badshot limestone in the north) which extends from south of the International Boundary to the northern Selkirk Mountains (fig. 4.5; Thompson and Panteleyev, 1976; Höy, 1980). The grey to white, medium- to course-grained Reeves-Badshot limestone is underlain by a thick

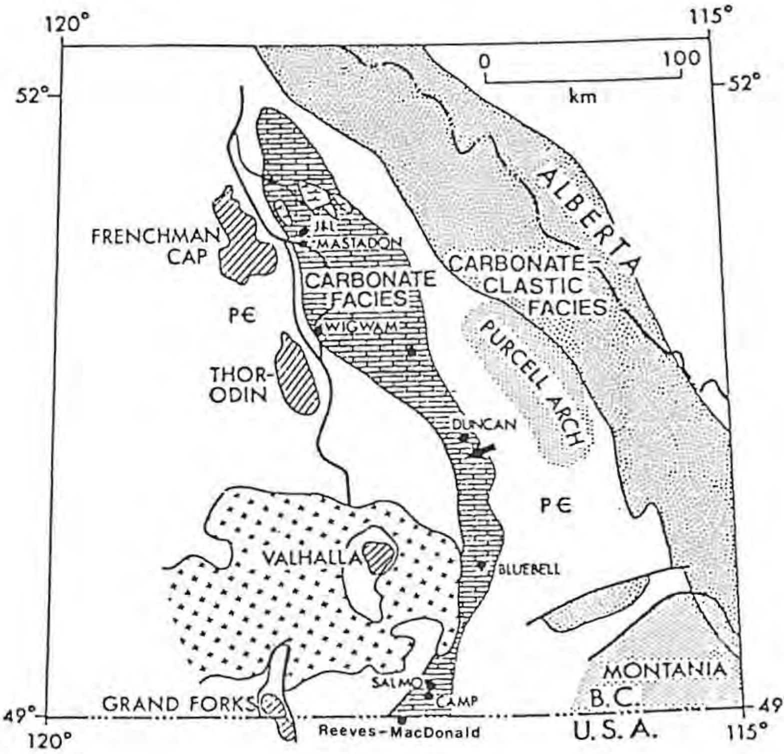


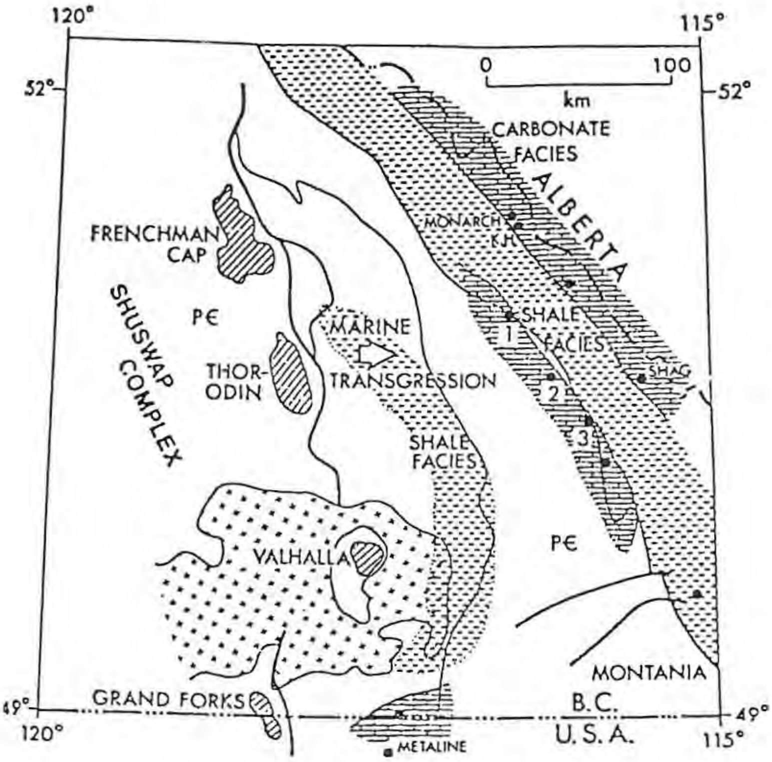
FIG. 4.5: Distribution of Lower Cambrian rocks and location of deposits. (from Höy, 1980).

succession of orthoquartzites and calcareous pelites (Hamill Group) and overlain by a thick succession of black argillite and pelite, carbonaceous limestone, thin quartzites, volcanic rocks, and grit (Lardeau Group). Thus it marks a transition from shallow-water platformal deposition during Precambrian and Lower Cambrian time to deeper-water basinal deposition during Ordovician to Silurian time (Thompson and Panteleyev, 1976). The larger deposits range in size from 6 to 10 million tons at 1-2% Pb, 3-4% Zn, and traces of Ag (Höy, 1980). The deposits consist of lenses, irregular bands, disseminated grains, or massive bodies of sphalerite, galena, and pyrite in dolomite.

A fine-grained, at places brecciated, dolomite hosts deposits in the Salmo camp. The distribution of dolomite and contained sulphides is controlled by fold structures (e.g. the Salmo River anticline at Reeves-MacDonald). The Duncan deposit (9 million tons at 2,7% Pb and 2,9% Zn) includes a number of separate sulphide zones located in the complexly deformed and faulted hinge zone of the Duncan anticline. Fine-grained pyrite and small amounts of sphalerite, galena, and pyrrhotite are concentrated in thin layers in siliceous slightly brecciated dolomite or chert.

The Lower Cambrian deposits formed during late diagenesis or as epigenetic ores in cavities in the Reeves-Badshot limestone, or in collapsed breccia zones (Höy, 1980). External precipitation or mechanical deposition of sulphides may have occurred locally.

Deposits within the Middle Cambrian rocks occur in thick shallow- water platformal carbonate successions adjacent to laterally equivalent shale facies (fig. 4.6). Monarch, Kicking Horse, and Shag deposits are hosted by the Cathedral Formation whereas the Silver Giant Mine, Lead Mountain Mine, Jubilee Mountain prospect, and Steamboat deposit are hosted by the Jubilee Formation. The deposits consist of pyrite, sphalerite, and galena (with secondary calcite) disseminated in layered limestone or dolomite, filling fractures in massive dolomite or barite, or disseminated throughout the matrix of coarse fragmental breccias. The majority of the Middle Cambrian deposits are preferentially distributed within a dolomitized breccia zone adjacent to a platformal bank margin (Höy, 1980). This suggests a regional stratigraphic control



1. Lead Mtn
2. Silver Giant Mine, Jubilee Mtn prospect
3. Steamboat

FIG. 4.6: Distribution of Middle Cambrian rocks and location of deposits. (from Höy, 1980).

of the mineralization. Local ore controls in the Jubilee Formation deposits are breccia zones that appear to be related to cavern and karst development in reefs.

D. Pb-Zn-(Ag) DEPOSITS OF LOWER PALAEOZOIC AGE IN SELWYN BASIN

Pb-Zn-(Ag) deposits in the Selwyn Basin (fig. 4.7) occur within shales of three different ages. In the Lower Cambrian Pb-Zn-Ag-Ba Anvil Camp in central Yukon seven deposits have been found in a belt 40 km long. Lower Silurian Zn-Pb mineralization occurs in the Howards Pass Camp along the Yukon -N.W.T. border. Upper Devonian Zn-Pb-Ag deposits (to be discussed in section 4.2) occur in the MacMillan Pass Camp of Yukon and the Gataga Camp of northeastern British Columbia. Other Pb-Zn showings at preliminary stages of exploration do occur in the Selwyn Basin. These may prove to be of economic importance in the future.

(i) Anvil Camp

The Volcano-sedimentary rocks of the Anvil Range have been subdivided into two structural packages (fig. 4.8) which have been uplifted into a broad arch by the intrusion of the Cretaceous Anvil Batholith, a porphyritic biotite quartz monzonite and granodiorite body (Carne and

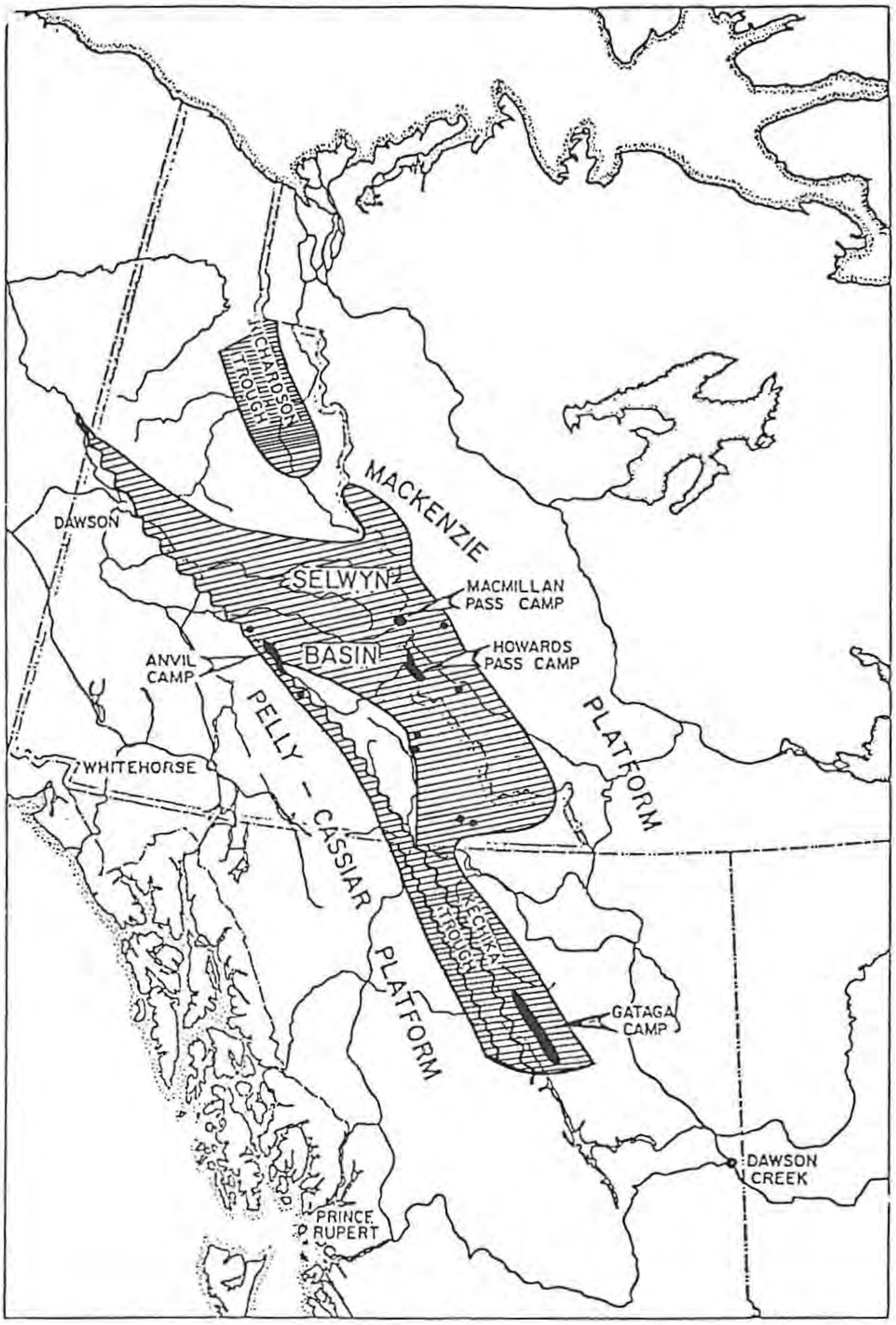


FIG. 4.7: The Selwyn Basin and the distribution of Pb-Zn-(Ag) Camps (after Carne and Cathro, 1980).

Cathro, 1980). The upper package consists of Devonian-Mississippian imbricate thrust slices of black phyllites, chert conglomerate, chert, and basalt flows. The lower package consists of Proterozoic to Lower Cambrian non-calcareous phyllite, calc-silicate phyllite, marble and minor metabasite, and graphitic phyllites. These rocks are overlain by Mid-Cambrian to Mid-Ordovician calcareous phyllites, graphitic phyllites, metabasites, and mafic metavolcanic rocks (dominantly

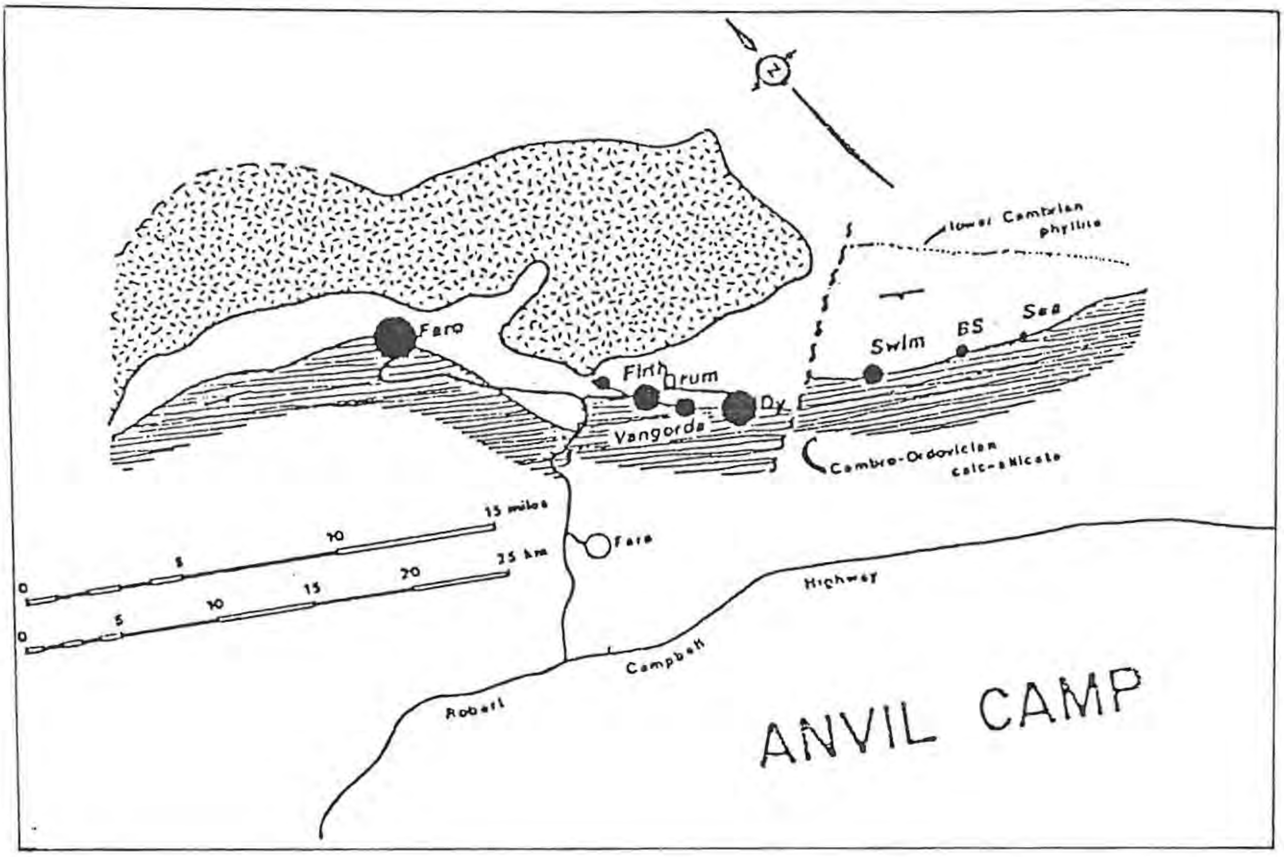


FIG. 4.8: Pb-Zn deposits of the Anvil Camp (after Carne and Cathro, 1980).

breccias, tuffs, and pillowed to massive flows). The Pb-Zn mineralization is hosted by the Lower Cambrian graphitic phyllites (Carne and Cathro, 1980; Thompson and Panteleyev, 1976). The mineralogy is quartz, pyrite, sphalerite, galena, pyrrhotite, chalcopyrite, marcasite, and barite. The deposits show a vertical and lateral zonation and have an alteration envelope which is best developed in the footwall. They have undergone polyphase deformation and high grade metamorphism (Carne and Cathro, 1980; Thompson and Panteleyev, 1976). There is a very weak genetic link with volcanism and most of the volcanic material is younger than the mineralization. They are thought to have formed from moderate temperature exhalative brines in an intracratonic rift setting. The Vangorda deposit has reserves of 10 million tons. A total of 140 million tons of ore have been identified in the Anvil Camp. There is potential for more (Carne and Cathro, 1980).

(ii) Howards Pass Camp

The Howards Pass deposits (XY, Anniv, and Op - fig. 4.9), found in 1972, are contained within the Ordovician and Silurian Road River Formation

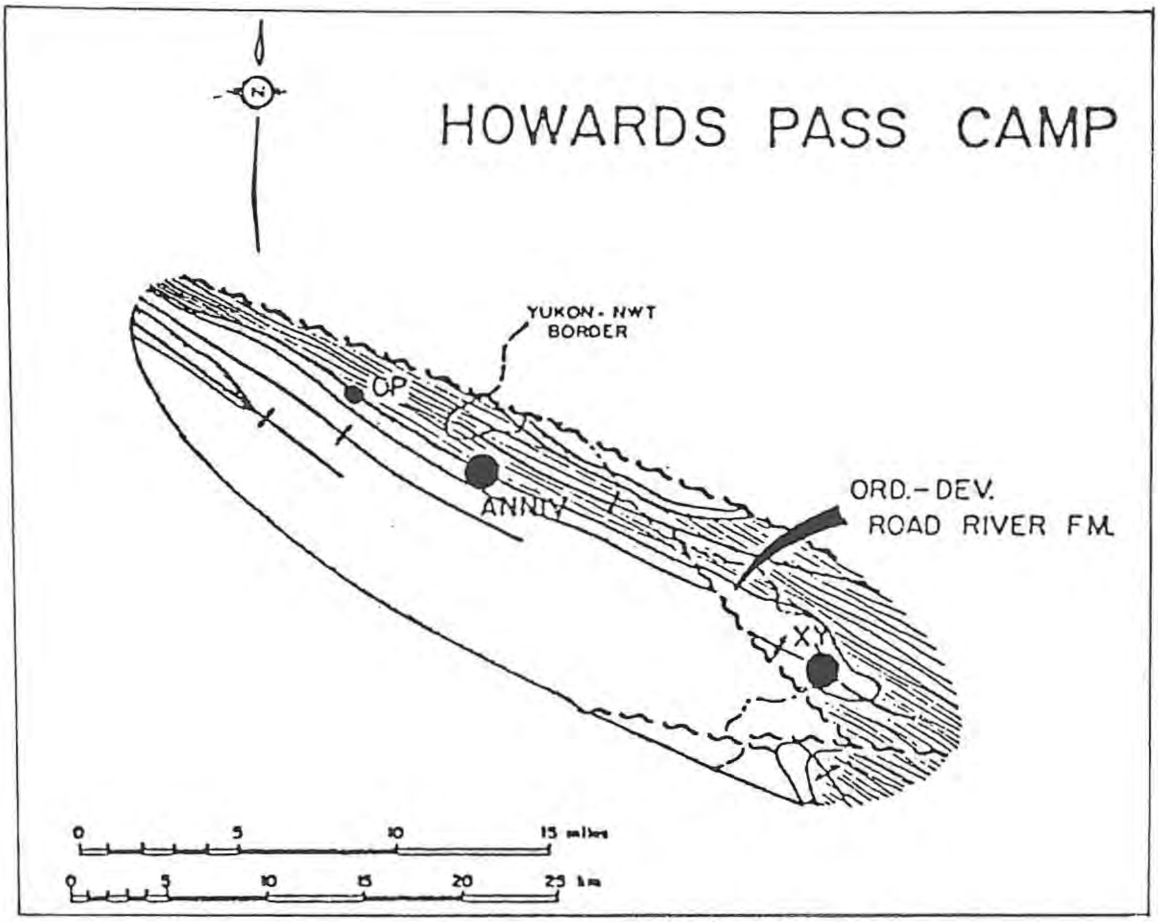


FIG. 4.9: Pb-Zn deposits of the Howards Pass Camp (from Carne and Cathro, 1980).

along the southwest flank of a 75 km long anticlinorium. The Road River Formation consists of a cyclic sequence of intercalated chert, cherty mudstone, carbonaceous mudstone and limestone (Carne and Cathro, 1980). The individual deposits are arranged along a linear trend and consist of saucer-shaped bodies of laminated to massive sphalerite, galena, and minor pyrite. Barite is absent and the silver content is very low. The deposits are very large, for example the XY deposit is about 7 600 m long and about 2 400 m wide. They are thought to have formed from exhalation of low temperature brines in palaeotopographic depressions (Carne and Cathro, 1980). This is deduced from the weakly zoned nature of the mineralization, the high degree of sedimentary intercalations, the preponderance of zinc sulphides with respect to lead, relatively low silver and copper values, and the absence of an identifiable feeder zone or fluid conduit within 10 km of the deposits.

4.1.3 Stratiform - Stratabound Sedimentary Copper Deposits

In the southern Cordillera copper deposits are found in rocks of the Purcell Supergroup, especially the Appekuny, Grinnell, and Siyeh Formations in southwest Alberta and southeast British Columbia. Primary permeability, grain size, and sedimentary structures seem to have influenced the distribution of copper mineralization in these deposits. They are hosted by a quartz sandstone composed of well-rounded and sorted quartz grains through which metalliferous solutions migrated (Thompson and Panteleyev, 1976).

Copper sulphides occur as disseminations and discrete blebs along bedding planes, in the coarser parts of graded beds, in other sedimentary structures, and as replacements of the groundmass and the clasts. The sulphides in low grade horizons are chalcopyrite, pyrrhotite, and sphalerite; and in high-grade horizons are bornite, covellite, anilite, digenite, idaite, wittichenite, tennantite, and magnetite (Goble, 1970 in Thompson and Panteleyev, 1976).

The Yarrow-Spionkop deposit, the bigger of these deposits, occurs in the upper part of the Grinnell Formation, a red-bed succession with quartzite and green argillite interbeds (Morton et al., 1974). Copper mineralization occurs in the quartzite and adjacent green argillite beds which range from a few millimetres to hundreds of metres. Grades (up to 6,4% Cu) have been enhanced by sulphides replacing argillite pebbles occurring as inclusions in some of the quartzite beds, and in zones proximal to diorite and diabase Moyie sills (Thompson and Panteleyev, 1976; Morton et al., 1974). The Goble deposit, southwest of Yarrow-Spionkop, is also hosted in a red-bed succession.

In the Mackenzie Mountains of the northern Cordillera, copper deposits occur at Redstone, Bonnet Plume, and Nite. The Redstone deposit, preserved in a down-faulted block, occurs at the transition zone between the Redstone River Formation — a well-bedded, red, argillaceous siltstone succession — and the overlying Coppercap Formation — a carbonaceous limestone succession that forms the upper part of Purcell strata in this area. The cupriferous zone is 65-115m thick and contains up to seven mineralized beds comprising grey limestone and dolomite with variable proportions of silt. The mineralized beds are in contact, above and below, with green chloritic (secondary alteration?) siltstone and mudstone which in turn are in contact with red and maroon (hematitic) siltstone and mudstone. Dessication features in some green beds indicate intermittent exposure in a shallow-water oxidizing environment. Pyrite, bornite, digenite, chalcocite, covellite, tennantite, and galena occur as fine-grained disseminations throughout the mineralized beds both interstitial to the rock clasts and as replacements. Malachite, azurite, and limonite occur on weathered surfaces. Anomalous silver and vanadium do occur. Copper mineralization is also present above the cupriferous zone as vein-fillings, in a major fault that intersects the cupriferous zone, and as a replacement in limestone near the fault.

The Nite Copper deposit occurs in dolostones of Purcell age. The mineralization occurs beneath the unconformity with the Rapitan Group (Helmstaedt et al., 1979; Wolfhard and Ney, 1976). The thickness of the mineralized dolostone and the grade of the mineralization decrease downwards and away from the unconformity. The sulphides are mainly bornite, chalcopyrite, chalcocite, and pyrite. Bonnet Plume occurs in a lens of siliceous dolomite within a thinly laminated siltstone sequence.

4.1.4 Massive Sulphide Deposits

The only recorded example of a volcanogenic massive sulphide of Precambrian age in the Cordillera is the Hart River deposit. The mineralization resembles that of felsic volcanogenic deposits in having Cu, Zn, Pb, Au, and Ag together in a high-sulphide matrix (Wolfhard and Ney, 1976). The ore is hosted by sheared argillaceous sediments and is closely associated with a mass of andesite.

4.1.5 Iron Deposit

The only iron deposit of Proterozoic age in the Cordillera is the stratabound Snake River (Crest) deposit, located northeast of Mayo on the Yukon - N.W.T. border. It forms a unit in the lower part of the Rapitan Formation, a thick conglomerate-sandstone-shale sequence of Windermere age (Little et al., 1970; Wolfhard and Ney, 1976; Thompson and Panteleyev, 1976). The iron formation is about 100 m thick and comprises well-bedded and laminated blue specular hematite and red pisolitic jasper interbedded with diamictites of the Rapitan Group. It lies with a marked angular unconformity on Purcell strata (Gabrielse, 1972) and its thickness and lateral extent was controlled by the palaeotopographic surface during deposition (Thompson and Panteleyev, 1976). Pinch-outs occur adjacent to palaeo-highs. The hematitic units have an average iron content of about 40% and an average silica content of about 25% whereas the clastic units (diamictites) have an average iron content of 15-20% and an average silica content of 40-60%. The ore reserves were estimated to be 20 billion tons of which 5 billion could be mined by open pit (Little et al., 1970). The origin of the iron formation is thought to be volcanogenic exhalative (Gabrielse, 1972; Gross, 1965 in Thompson and Panteleyev, 1976).

4.1.6 Vein-Type Deposits

Vein-type Cu and vein-type gold deposits occur in the Proterozoic to Lower Palaeozoic rocks of the Cordillera. Lode and placer mineralization of the Cariboo deposit (fig. 4.10) occurs within fine clastic and carbonate rocks of the Cariboo Group in the area of tight folding (Sutherland Brown and Holland, 1957). The deposits are concentrated along the flanks of anticlinoriums. Lode deposits occur in numerous small, transverse and diagonal veins. The strike veins are barren (Barr, 1980; Bacon, 1978). The richer replacement ore occurs in the Baker limestone beds. It is tabular and parallel to bedding on the limbs of folds, and pencil-shaped on the crests of folds. The mineralogy of the quartz veins and replacement bodies is similar. Metallic minerals consist of auriferous pyrite and associated free gold with minor galena, sphalerite, cosalite, bismuthinite, scheelite, pyrrhotite, arsenopyrite, and chalcopyrite. Gangue minerals are quartz, ankerite, and muscovite (Barr, 1980). Folding and faulting control the localization of the ore deposits (Sutherland Brown and Holland, 1957). The Sheep Creek gold deposits occur as narrow ore shoots in steeply dipping quartz veins whose distribution is controlled by fault patterns. The veins cross-cut quartzite, argillite, and limestone contained in two northerly-trending anticlinal structures.

Vein-type copper deposits occur in the Churchill Copper district where a great number of chalcopyrite-carbonate-quartz veins are found in clastic sediments correlated with the Purcell Supergroup. The veins are

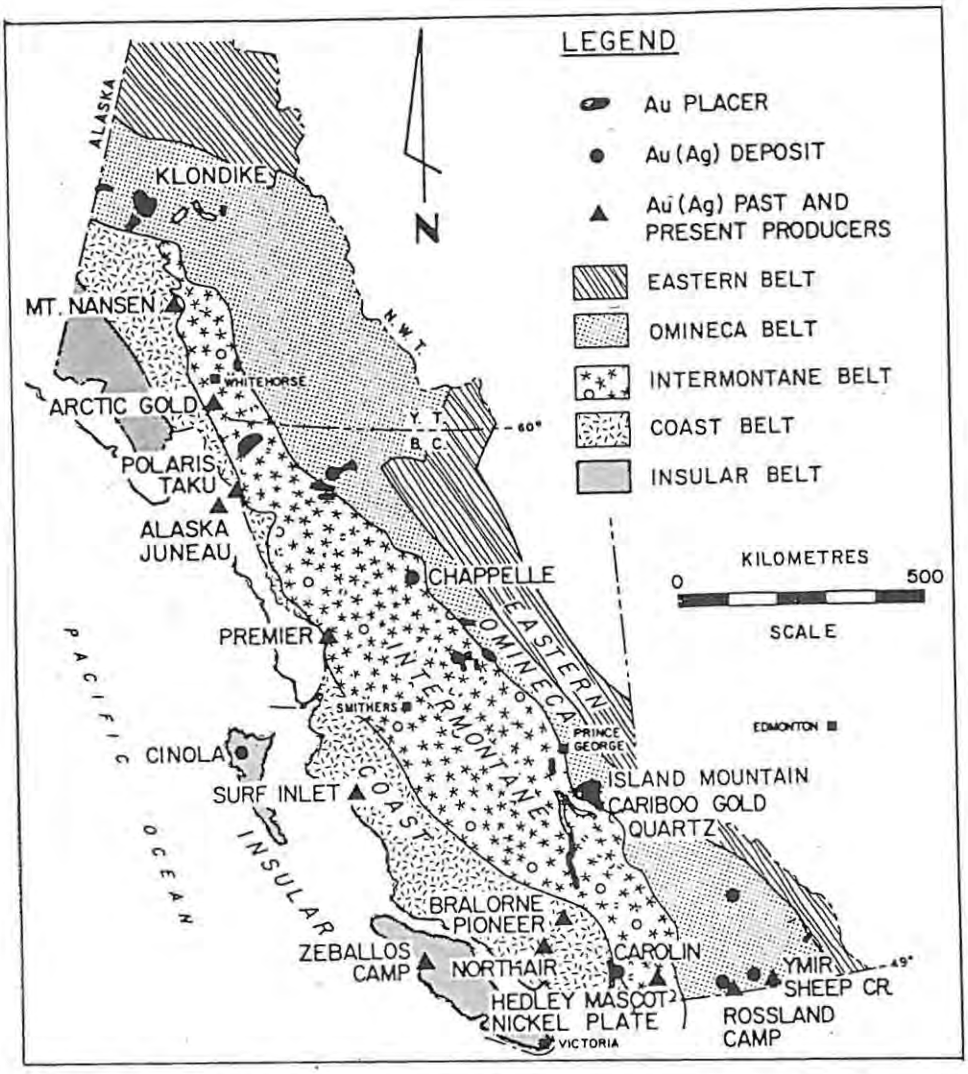


FIG. 4.10: Principal lode and placer gold deposits of the Canadian Cordillera (from Barr, 1980).

associated regionally and directly with a swarm of diabase dykes that are post-mineral in age and are Precambrian by their stratigraphic relations (Wolfhard and Ney, 1976). The copper in the veins is thought to have been remobilized from the stratiform dispersions which are known to occur nearby in the Churchill copper district. These deposits are thought to have formed in an aulacogen-type of environment similar to Sullivan (Kirkham, 1973 in Wolfhard and Ney, 1976).

4.2 MINERALIZATION IN THE UPPER PALAEOZOIC TO MID-TRASSIC

4.2.1 Introduction

This period corresponds to the Trembleur Epoch of Wolfhard and Ney (1976). It is marked by the appearance, in the northern Rocky

Mountains, of clastics having a western provenance and by an early to late Devonian regional unconformity in the southern Rocky Mountains. It includes the Upper Palaeozoic chert-volcanic sequence of the Cache Creek Group and its equivalents and it ends on the onset of Karmutsen-type volcanism. Intrusive rocks in this Epoch are the Trembleur Intrusions of north central British Columbia, granitic plutons in the northern Yukon, and the three carbonatite complexes in the Rocky Mountain and Omineca Crystalline Belts. There are few important mineral deposits. Massive sulphide deposits and Devonian Pb-Zn-(Ag) deposits dominate. Minor showings of Ni-Cu, Cr, and metals associated with carbonatites also occur. The skarn deposits of the Phoenix Camp occur in this period.

4.2.2 Stratiform - stratabound Pb-Zn-(Ag) mineralization

(a) Devonian Pb-Zn-(Ag) deposits in the Kootenay Arc

Upper Devonian rocks east of the Kootenay Arc comprise shallow-water platformal carbonates of the Palliser Formation which host, in the Lower (Morro) member, the Pb-Zn-(Ag) deposits of SOAB, Alpine, and Boivin (fig. 4.11). The Morro member is in the lower overturned limb of an eastward-verging asymmetrical anticlinal fold that is thrust against Mississippian carbonates to the east (Höy, 1980). The mineralization occurs in the distinctive carbonate rock called the "zebra facies" (spar dolomite crescents in a fine-grained granular dolomite matrix), interpreted to be of supratidal algal origin (Höy, 1980). The "zebra facies" is overlain and underlain by massive, subtidal limestone. Disseminated sphalerite mineralization is concentrated in a number of discreet zones generally less than a metre thick and a few metres in length. Boivin is about 12 m long and 2 m wide and contains up to 20% Zn (Gibson, 1979 in Höy, 1980). An early syngenetic to diagenetic origin is suggested by the disseminated nature of the sphalerite and its restriction to the Morro carbonate member.

(b) Devonian Pb-Zn-(Ag) deposits in the Selwyn Basin

(i) MacMillan Pass Camp

Pb-Zn-(Ag) mineralization in the MacMillan Pass Camp (fig. 4.7) occurs in several localities within a poorly defined 10 km wide Upper Devonian

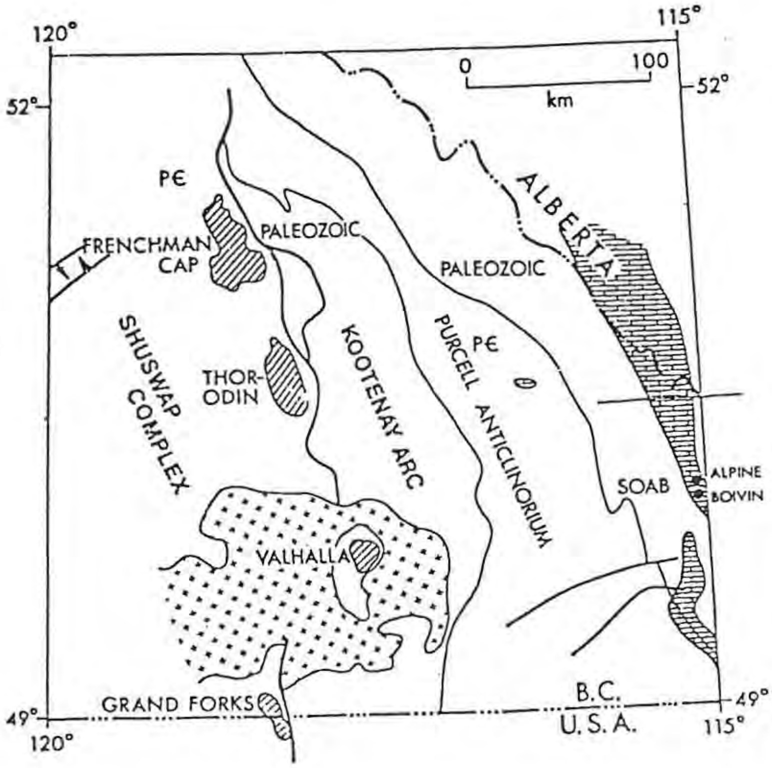


FIG. 4.11: Distribution of Devonian rocks and the Alpine and Boivin deposits (from Höy, 1980).

graben-like trough or rift (fig. 4.12). The orebodies are hosted by the Devono-Mississippian Black Clastic Group occurring near the transition from a lower assemblage of coarse clastics to an overlying carbonaceous and siliceous shale (Carne and Cathro, 1980). The Tom deposit consists of two tabular bodies 3 to 60 m thick composed of finely

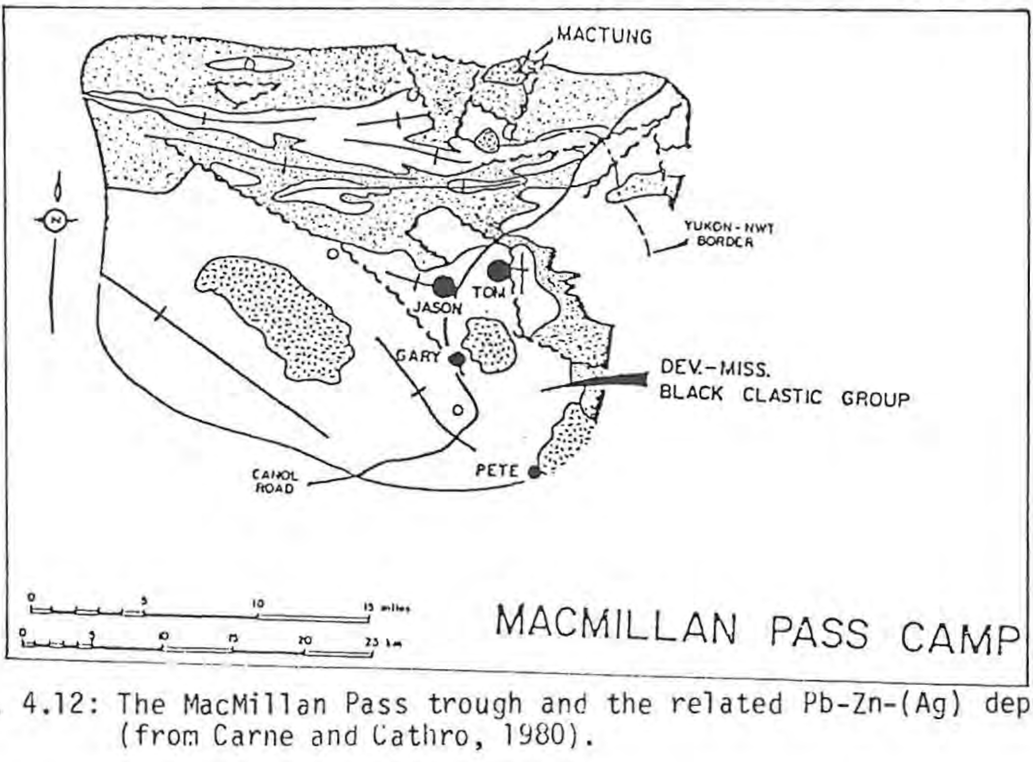


FIG. 4.12: The MacMillan Pass trough and the related Pb-Zn-(Ag) deposits (from Carne and Cathro, 1980).

finely interlaminated chert, pyrite, sphalerite, galena, barite, and black shale. There is well-developed vertical and lateral zonation. Basal and proximal sections carry best Pb and Ag values while upper and lateral parts are Zn- and Ba-rich. Cu-, Pb-, and Ag-rich stringer and alteration zones occur beneath the highest grade of the mineralized bodies. The Jason deposit, like the Ordovician Summit Lake deposit, is similar to the Tom. Genesis of these deposits was probably related to rifting, with the basin margin faults providing conduits for exhalative fluids (Carne and Cathro, 1980).

(ii) Gataga Camp

The stratigraphic setting of shale-hosted Pb-Zn-Ag-Ba deposits in the Gataga Camp is similar to that of Devonian deposits in the MacMillan Camp (MacIntyre, 1980). The deposits occur within an extensive belt of Upper Devonian to Lower Mississippian coarse clastic sedimentary rocks and siliceous pyritic shales of the Black Clastic Group (fig. 4.13). The siliceous pyritic shales are interfingered with proximal to distal turbidites and are overlain by deeper-water basinal black shales. This indicates that the timing of the mineralization coincides with the early stages of a major marine transgression which may also have been a time of tectonic activity within the shale basin (MacIntyre, 1980).

At the Driftpile Creek deposit, several southwest-dipping finely laminated pyrite and bedded barite horizons occur within siliceous shales of Middle Devonian age. These rocks are folded and faulted and probably some of the mineralized horizons may represent fault repeats. Mineralization varies from coarse - bedded barite with minor sulphides to massive, poorly bedded galena, sphalerite, and pyrite (Carne and Cathro, 1980; MacIntyre, 1980). The Mount Alcock deposit occurs in a fault-bounded wedge of siliceous shale. The Cirque deposit has about 33 million tons at 2,3% Pb, 7,9% Zn, and 49 g/t Ag hosted within a thrust panel of Devonian shales which has been segmented by a series of southwest-dipping imbricate thrust faults. The Devonian rocks occur in the northeast limb of an overturned synclinal structure which has been overridden and preserved beneath thrust plates of Silurian siltstone (MacIntyre, 1980). Mineralization typically consists of galena, sphalerite, and minor pyrite disseminated in fine-grained, thin to medium bedded barite. Similar smaller deposits occur at Elf, Fluke, Pie, Red and Bear.

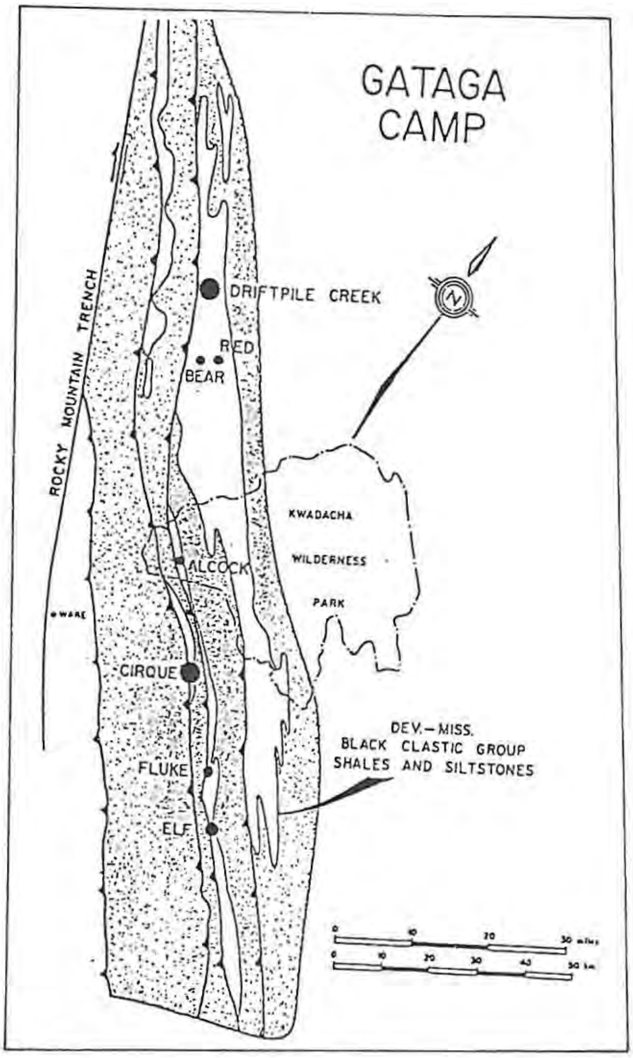


FIG. 4.13: Pb-Zn-(Ag) deposits of the Gataga Camp (from Carne and Cathro, 1980).

The Pb-Zn-(Ag) deposits of the Gataga Camp appear to be associated with northwest-trending rifts bounding tilted fault blocks. The mineralization formed from pooling of low to medium temperature exhalative brines in topographic depressions (Carne and Cathro, 1980).

4.2.3 Massive sulphide mineralization

Massive sulphide deposits of Upper Palaeozoic to Mid-Triassic age occur in a number of places in the Cordillera. The prominent ones are at Harper Creek in the Shuswap Metamorphic Complex, at Ecstall in the Coast Plutonic Complex, and at Western and Twin J in Vancouver Island (fig. 3.15). The Harper Creek deposits are associated with metasediments and with metamorphosed intermediate to acid volcanics in the Shuswap terrane. Pyrite, pyrrhotite, chalcopyrite, magnetite and some minor sulphides occur in schistose rocks. The highest grades and most massive mineralization forms strongly concordant lenses within a much larger zone of dispersed sulphide mineralization (Thompson and Panteleyev, 1976). The hydrothermal sulphide minerals are localized by foliations associated with deformation. Just like Harper Creek, the concordant massive sulphide mineralization at Ecstall occurs in strongly foliated metamorphic rocks of the Coast Plutonic Complex. The mineralization is similar to that of Harper Creek but is coarse-grained. Twin J and Western Mines have similar orebodies in Late Palaeozoic volcanic rocks of the Sicker Group. They have a variety of ores. The two main types of ore are barite ore containing massive sphalerite and pyrite lenses, and siliceous or quartz ore containing chalcopyrite and pyrite with quartz gangue in massive lenses that grade into more dispersed stockwork mineralization. Galena, bornite, and minor tetrahedrite also occur.

Western Mines orebodies are mainly concordant stratiform massive sulphide lenses localized in or adjacent to sheared rocks of a large fault zone where it cuts quartz sericite schists derived from massive rhyolite flows, breccias, and tuffs (Thompson and Panteleyev, 1976). The zone of shearing and faulting is the dominant ore control in the mine. The ore zones at twin J mines are concordant, stratabound bodies contained in a narrow, folded band of cherty tuffs and graphitic schists. The Western and Twin J mines are thought to be of volcanic exhalative origin similar to the Kuroko deposits of Japan.

Unlike the massive sulphide deposits that have been discussed above, the massive sulphide deposits of the Pelly Mountains (fig. 4.14) in southeastern Yukon Territory occur in highly alkaline volcanic rocks

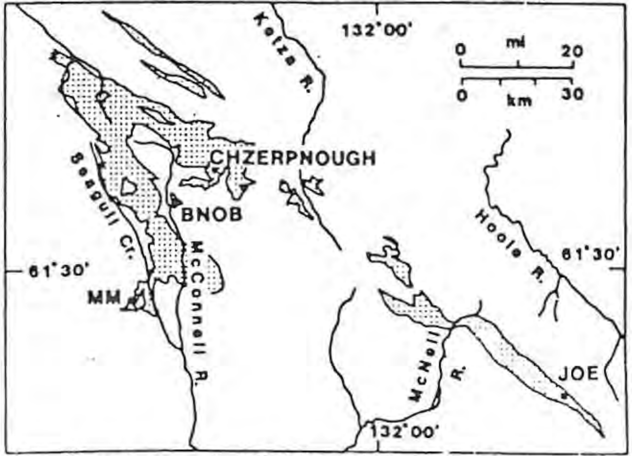


FIG. 4.14: Distribution of Middle Mississippian volcanics (stippled) and associated stratiform-stratabound volcanogenic massive sulphide deposits in the Pelly Mountains (from Mortensen and Godwin, 1982).

(Mortensen and Godwin, 1982). These deposits have similarities with the Kuroko-type deposits. The main difference is that: while the Kuroko-type deposits are linked to rifting within active calc-alkaline arcs, the Pelly Mountains volcanogenic massive sulphide deposits occur in an intracratonic extensional tectonic setting. The following account of the MM deposit (figs. 4.14 and 4.15), the only one that has been test-drilled, is summarized from Mortensen and Godwin (1982). The mineralization at the MM deposit occurs within tuffaceous rocks that are both underlain and overlain by and intercalated with, carbonaceous pelitic sediments. To the southwest (fig. 4.15) the volcanic sequence passes laterally into a massive trachyte dome flanked by coarse volcanic breccia. Pelitic sediments occur above the dome. The sulphides occur as narrow lenses in the middle and upper parts of the volcanic sequence and immediately above the dome. They consist of pyrite and pyrrhotite with varying amounts of galena, sphalerite, chalcopyrite, and quartz. Stringer mineralization occurs in the massive trachyte. Some metal zonation has been observed. The controls of the mineralization are not as yet clear but seem to be the mixed pelitic and tuffaceous rocks. The tectonics of the southeastern Yukon are unusual, in that rifting, with associated felsic volcanism, appears to have occurred within a previously miogeosynclinal area, resulting in felsic volcanic centres in a euxinic shale basin from which ore fluids were extracted.

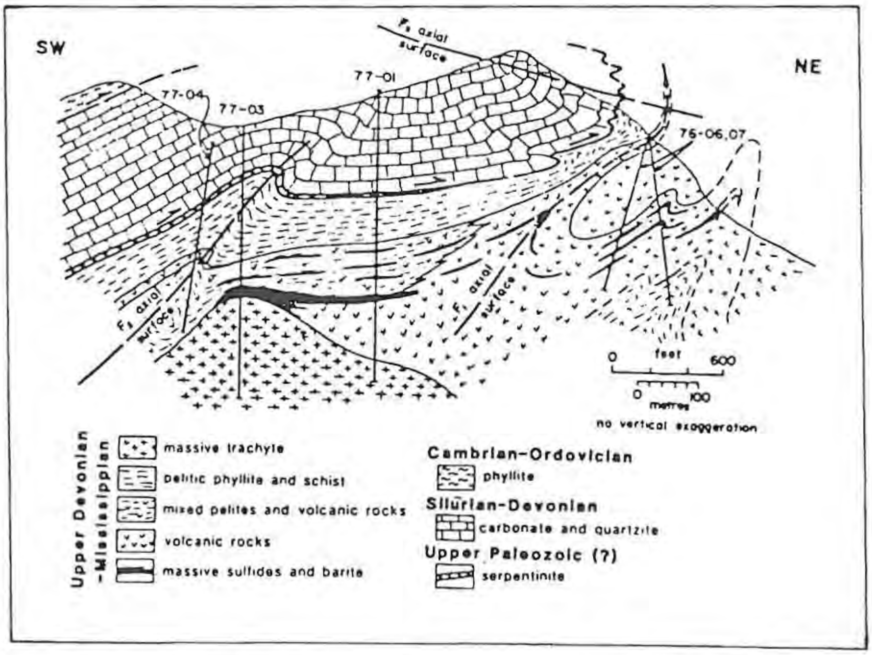


FIG. 4.15: Cross-section through the MM deposit, Pelly Mountains (from Mortensen and Godwin, 1982).

4.2.4 Cr, Cu, Ni-Cu, and carbonatite deposits related to magmatic activity

Minor uneconomic Cr occurrences are associated with the Trembleur Intrusions of north central British Columbia. The carbonatites of Ice River, Verity, and Lonnie contain concentrations of Cb, Ta, Zr, Ti, and U and Th, but none are considered economic (Wolfhard and Ney, 1976).

The nickeliferous ultramafics of the Giant Mascot Mine (formerly Pacific Nickel) of Hope, B.C., form part of the core of a wide block of Late Palaeozoic metamorphic rocks and Mesozoic intrusions which extend north-south between the coast batholith of British Columbia and the Chelan batholith of Washington (Aho, 1956; 1957). The margins of this block are faulted in part against less metamorphosed volcano-sedimentary rocks of Jura-Cretaceous age. The mineralization occurs within a medium-grained hornblendic pyroxenite with peridotitic to dunitic cores (McLeod et al., 1976). It is cut by genetically related diorites and norites of Late Mesozoic age. It consists of disseminated and massive pyrrhotite, with subordinate pentlandite and chalcopyrite (Aho, 1957). There are two general structural trends at Giant Mascot: the north-south trend, and the east-west trend which appears to control the mineralization. All of the known ore occurs in a broadly linear N75^{o}W-trending zone which extends for about 2 km. The orebodies in this zone occur as steeply plunging pipe- or parsnip-shaped, sulphide-rich ultrabasic assemblages, commonly with olivine-rich cores and bronzitic borders. The genesis of these Ni-Cu sulphides is thought to be magmatic segregation followed by injection and minor replacement (Aho, 1957).

4.2.5 Skarn deposits

These deposits have disseminated rather than massive sulphide mineralization and are distantly or indirectly related to major intrusive masses. In the British Mountains of northern Yukon some anomalous concentrations of W and Sn occur in skarns indirectly related to granitic stocks. These deposits are not economic. In the Boundary Creek of southern British Columbia occur the Cu-Fe-(Au) skarns of the Phoenix Camp. These deposits are in the Triassic Brooklyn Formation consisting of conglomerate, limestone, greywacke, and andesitic tuff with minor shale and basalt (Seraphim, 1957; Fahrni, 1966). The Brooklyn Formation lies in an open synclinal structure. North-south and east-west block faults offset the ore formation. A number of north-south, east-dipping calcite-filled fractures carry ore minerals and these might have been the local controls of the mineralization. The ore was deposited in carbonates which were altered to a skarn of epidote, chlorite, carbonate, garnet, hematite, magnetite, pyroxene, and amphibole. The Nelson Batholith and the Coryell Intrusions occur at a distance from the Camp (Fahrni, 1966). The primary sulphides are pyrite and chalcopyrite. The latter is most abundant in carbonate-rich bands and in carbonate veinlets traversing the bedding. Malachite, azurite, and iron oxides occur in oxidation zones. Minor amounts of gold and silver are recovered.

4.3 MINERALIZATION IN THE UPPER TRIASSIC TO OLIGOCENE

4.3.1 Introduction

This period includes the Vancouver, Columbia, Skeena, and the early half of the Cascade Epochs of Wolfhard and Ney (1976). It extends from the beginning of the Karmutsen volcanism and ends just before the onset of the Miocene Plateau basalt volcanism, i.e. at about 26 Ma. This period is dominated by calc-alkaline volcanism, the development of successor basins and their related sedimentation and volcanism, and the intrusion of alkaline (syenitic) and calc-alkaline plutonic suites. These events took place mainly in the Intermontane Belt, Coast Plutonic Complex, and the Insular Belt. This is the predominant metallogenic period in the Canadian Cordillera, being dominated mainly by porphyry-type deposits, massive sulphide deposits, skarn deposits, and vein-type deposits. Minor occurrences of stratiform copper deposits and uneconomic copper showings related to magmatic activity also occur. Porphyry-type deposits occur in the three western tectonic belts, whereas the other types of deposits occur in all the belts, with rare occurrences in the Rocky Mountain Belt.

During this period, there was the formation of Hg and Pb-Zn-Ag lodes in addition to the gold-quartz lodes. Skarn deposits may be directly or indirectly related to intrusive plutons. The massive sulphide deposits occur in a volcanic or metavolcanic setting without obvious spatial or genetic connection with granitic intrusions. The porphyry-type deposits are related to either the alkaline or calc-alkaline magma suite and are subdivided on the basis of structural complexity into simple-, elaborate-, complex-, and plutonic-type of porphyries (Sutherland Brown et al., 1971). Simple porphyry deposits are those associated with small cylindrical plugs, for example Ox Lake and Red Bird deposits. They display well developed zonation of ore, alteration and metamorphic minerals. The elaborate type is similar to the simple type but it is associated with plugs that have one or more of a number of structural elaborations like dyke swarms, plugs of related phases, brecciation of peripheral rocks, etc. Examples are Lucky Ship, Granisle, Glacier Gulch, Boss Mountain, and Casino. The complex porphyry deposits are less ordered and have more structural complexities. They occur within or peripheral to zoned plutons and their ore zones usually bear a spatial relationship to faults. Examples are the Highland Valley deposits, Iron Mask, Copper Mountain, Island Copper, and Liard Copper. Plutonic porphyry deposits are gradational to the complex type. Like the other porphyry types, they have common ore and alteration mineralogy and are associated with plutons of moderately large size. Their ore zone has a spatial relationship to faults. They differ in that they are associated with scarcely porphyritic or non-porphyritic granitic plutons, and breccia zones and pipes are unknown or unimportant (Sutherland Brown et al., 1971). Examples include Brenda, Endako, and Adanac.

A summary description of the various deposits occurring in this period follows.

4.3.2 Stratiform-stratabound copper deposits

A number of stratiform copper deposits occur in rocks of Upper Triassic to Oligocene age. The Sustut Copper deposit occurs in the Swannell Range of the Cassiar-Omineca Mountain Belt in north-central British Columbia. The oldest rocks in the area are inliers of Permo-Triassic sedimentary and volcanic rocks of the Asitka Group which are unconformably overlain by outliers of the Jura-Triassic Takla-Hazelton Groups - a thick sequence of volcanic flows and volcaniclastics with minor non-volcanic sedimentary rocks (Harper, 1977). The copper mineralization is hosted by the sheet-like upper volcaniclastic unit of the Middle Formation (Takla Group) consisting of green and red basaltic andesite tuff and agglomerate, volcanic breccia, and derived volcanic sediments - mainly conglomerate (Harper, 1977; Thompson and Panteleyev, 1976). The mineralization consists of disseminated native copper and copper sulphides in a tabular stratabound body averaging about 12 m, but up to 40 m and more, in thickness. Hematite occurs throughout the mineralized horizon. The mineralization is symmetrically zoned. The core of the mineralized zone contains native copper-chalcocite-bornite that passes outward into chalcopyrite-bornite, and finally into a pyritic envelope with sparse, disseminated, small pyrite grains (Thompson and Panteleyev, 1976). Lensing veins of massive bornite, chalcocite, and native copper up to 20 cm wide are found in some epidote-, quartz-, and calcite-filled fractures (Harper, 1977). In the mineralized zone some 30 million tons of ore at 1% Cu have been indicated (Thompson and Panteleyev, 1976).

A number of nearby deposits presumably genetically related to the Sustut deposit are found in andesitic lavas and also in interlava siltstones at the base of a stratigraphically higher volcaniclastic unit.

Elsewhere in the Cordillera, numerous occurrences of copper sulphide and native copper mineralization in basic volcanic rocks and interlava sediments are found in rocks of Triassic and Early Jurassic age.

4.3.3 Deposits related to magmatic activity

These deposits are not of economic importance. They include minor disseminations of copper minerals, predominantly chalcocite, found filling primary porosity in the tholeiitic basalt-andesite flows of the Karmutsen Group on Vancouver Island and in calc-alkaline Nicola-Takla rocks of Smithers, Princeton, and Toodoggone areas (fig. 3.26) (Wolfhard and Ney, 1976; Sutherland Brown et al., 1971). The Silver City and Johobo occurrences in the Mush Lake Group of southwest Yukon include concentrations of native copper. They may be correlated with the widespread occurrences in the calc-alkaline Nikolai Greenstone of Alaska. 39 Ma old gabbroic intrusions in volcanics of southern Vancouver Island contain copper deposits (Jordan River) that are both vein-like and magmatic in character (Wolfhard and Ney, 1976).

4.3.4 Massive sulphide deposits

A number of massive sulphide deposits occur in this period. The well-known deposits of Granduc, Anyox, and Britannia Mine (fig. 3.26) are hosted by Jurassic volcanic-sedimentary rocks of the Coast Plutonic Complex. In the Britannia Mine (north of Vancouver) a cluster of ten orebodies is found over a distance of 4 km. in rocks comprising a northwesterly-trending "roof pendant" (fig. 4.16) within and in part metamorphosed by the Coast Plutonic Complex (Payne et al., 1980; Thompson and Panteleyev, 1976). The volcanic and sedimentary rocks comprise andesite and dacite flows, flow breccias, tuffs, epiclastic volcanic rocks, shale, and siltstone of the Gambier Group (Sutherland Brown, 1972). Andesitic and dacitic dyke swarms intrude these stratified rocks. They occupy a gently south-dipping monoclinal panel that has been folded into a complex antiform-synform couple that is disrupted along the fold axis of the antiform by faults and the Britannia shear zone - a complexly deformed 400-800 m wide zone of fracturing, shearing, and faulting that transects the "roof pendant" in a west-northwesterly direction (Sutherland Brown, 1972; Thompson and Panteleyev, 1976). The deformation is post-mineralization. The polymetallic sulphides (pyrite, chalcopyrite, sphalerite, minor galena, and tetrahedrite-tennantite with quartz, barite, anhydrite-gypsum, carbonate gangue) are localized in the Britannia shear zone. They occur as massive and stringer deposits, and as disseminated and bedding plane concentrations in pyritic sedimentary rocks. The deposits also contain significant Au, Ag, and Cd. These deposits are similar to Kuroko

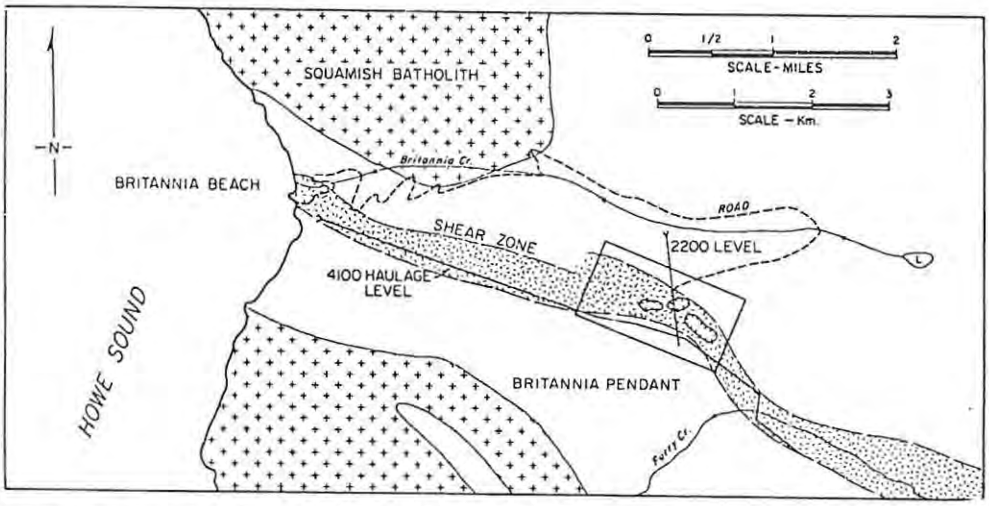


FIG. 4.16: Geological setting of Britannia mine (from Sutherland Brown, 1972).

deposits and also have features similar to the Archaean volcanogenic deposits of Canada. They appear to be associated with dacitic rocks proximal to eruptive volcanic centres and are thus thought to be formed from volcanogenic hydrothermal solutions (Payne et al., 1980). Britannia Mine has reserves of 55 million tons (Thompson and Panteleyev, 1976).

The Granduc deposit near Stewart in northwestern British Columbia has similarities with Britannia but has more consistently concordant mineralization (Thompson and Panteleyev, 1976). The massive sulphides are localized within a Lower Jurassic volcano-sedimentary sequence (Hazelton Group) of thick andesitic pillow lavas, siltstone, crystal tuff, conglomerate, volcanic sandstone, and some rhyolite and chert members trending north and dipping steeply to the west. The hangingwall rocks are graphitic siltstones, gypsum-bearing limestones, conglomerate lenses, quartzites, and cherty tuffs. The footwall rocks are porphyritic andesites. These rocks have been deformed by polyphase folding and faulting (Norman and McCue, 1972; 1966). The ore minerals comprise fine- to medium-grained intergrowths of pyrite, chalcopyrite, and pyrrhotite with rare small lenses of sphalerite, galena and traces of arsenopyrite, and cobaltite in a gangue of quartz, calcite, calc-silicates, magnetite, and apatite (Thompson and Panteleyev, 1976). Weakly mineralized pyritic stockworks and low grade stringer lodes also occur. The mineralization is controlled by cross-folding and by andesitic dykes which cross-cut the folds. Over 43 million tons of ore at 1,73% Cu were estimated at Granduc (Norman and McCue, 1972).

The twelve orebodies of Anyox occur in a roof pendant of volcano-sedimentary rocks near the eastern margin of the Coast Plutonic Complex. The mineralization is hosted by Middle Jurassic "greenstones" that were derived from a thick altered succession of pillow lavas, pillow breccias, and dykes with intercalated, thinly bedded marine siltstone units. Orebodies are pipe- to sheet-like lenses of massive pyrite, pyrrhotite, chalcopyrite with minor sphalerite, galena, magnetite, and arsenopyrite in a gangue of quartz, calcite, sericite, and minor epidote, and garnet. Sulphides also occur along the contact of the pillow lavas and the overlying siltstones. Tops of orebodies are commonly in siltstones and are composed of massive sulphides having sharp boundaries with waste rocks. Footwall zones are in pillow lavas and have more dispersed sulphide mineralization with diffuse boundaries forming low-grade zones in silicified pyritic rocks (Thompson and Panteleyev, 1976). Polyphase deformation has resulted in complex fold patterns with local shearing. Remobilized and replacement mineralization is evident in narrow shear zones. The deposits are thought to be of volcanogenic origin, formed in sea-floor depressions during degassing of the volcanic pile at the end of a submarine volcanic cycle prior to marine sedimentation (Thompson and Panteleyev, 1976). Ore reserves are estimated to be 24 million tons. The Windy-Craggy deposits are similar to Anyox and have stratiform cupriferous pyrite mineralization associated with Lower Jurassic pillow lava and silstone.

4.3.5 Skarn deposits

The Craigmont deposit is a skarn deposit indirectly associated with the Guichon Creek Batholith of south-central British Columbia. The copper-iron skarn deposit is situated adjacent to the southern margin of, and within the contact aureole of, the batholith. The ore is hosted by volcanic and sedimentary rocks of the western calc-alkaline belt of the Upper Triassic Nicola Group (Morrison, 1980). In the mine area, the host rocks consist of interbedded lime sandstone, lime siltstone, quartzo-feldspathic siltstone, calc-silicate skarns, and argillite. These rocks are unconformably overlain by andesitic to rhyolitic flows, breccias, and tuffs of the Cretaceous-Tertiary Kingsvale Group. The orebodies occur in steeply dipping, drag-folded section of the carbonate and skarn rocks (Chrismas et al., 1969). Only two-thirds of the Craigmont ore is developed in skarn, the balance being in brecciated and veined hornfelsed clastic rocks.

There are two stages of skarn formation (Morrison, 1980) and the associated metallization (Christmas et al., 1969). The initial phase of disseminated magnetite, chalcopyrite, and specularite occurred contemporaneously with the formation of actinolite-epidote-magnetite skarn and epidote-garnet skarn. The second phase formed when the temperature decreased, causing the rocks to become brittle and to form fractures that acted as channels and loci of deposition for mineralizing fluids. This phase is characterized by irregular discontinous vein formation comprising coarse pink K-feldspar with associated chalcopyrite and specularite which replaces magnetite. Three ore types occur at

Craigmont : magnetite ore, specularite ore, and stringer ore. They all have chalcopyrite, magnetite, and specularite as the only significant ore minerals. Fissures due to dragfolding were likely an important control of the mineralization. Secondary cross faulting controls the younger mineralization. Carbonate and skarn may also be the local controls of the mineralization.

The Craigmont deposit has more features in common with Cu-Fe deposits hosted in metavolcanic and metasedimentary rocks (Morrison, 1980) than it has with typical skarn deposits associated with porphyry copper deposits (Wolfhard and Ney, 1976) and as such it may be regarded as a pyrometasomatic deposit (Chrismas et al., 1969; Morrison, 1980). The deposit might have resulted from the concentration of metal contained within the Nicola Group rocks rather than from the mineralizing event associated with the Guichon Creek Batholith.

The Texada Cu-Fe skarn deposits occur in the Insular Belt. The area in the vicinity of the deposit is underlain by volcanics of the Karmutsen Group which are in turn overlain by a massive Upper Triassic limestone of the Quatsino Formation. These rocks are intruded by a number of plutons, the Gillies stock (120 Ma) being the main pluton emplaced at the southern termination of the limestone belt. This stock is responsible for the structure and metasomatism of the limestone and basalt (Sutherland Brown, 1972). Garnet-pyroxene-epidote and actinolite skarn and magnetite sulphide bodies may replace basalt, limestone, Gillies stock, or diorite porphyry with textures commonly diagnostic of each. In general, skarns replacing limestone are garnet-rich, those replacing volcanic rocks epidote-rich, and ore replacing limestone commonly is sulphide-rich.

The orebodies (fig. 4.17) are clustered around a salient at the north end of the stock. The structure of the eastern orebodies differs from the western ones (Sutherland Brown, 1972). The deposits display some zonation. The orebodies are composed mainly of low-titanium magnetite with a variable but small amount of calc-silicate minerals or calcite and some chalcopyrite and pyrite and traces of pyrrhotite, arsenopyrite, and rarely, sphalerite. They are arranged around the pluton with conduits, breccia zones or faults, apparently leading in toward it. The ore and skarn bodies are well-developed where the conduit system (pipes or flat faults) reaches the limestone (Sutherland Brown, 1972).

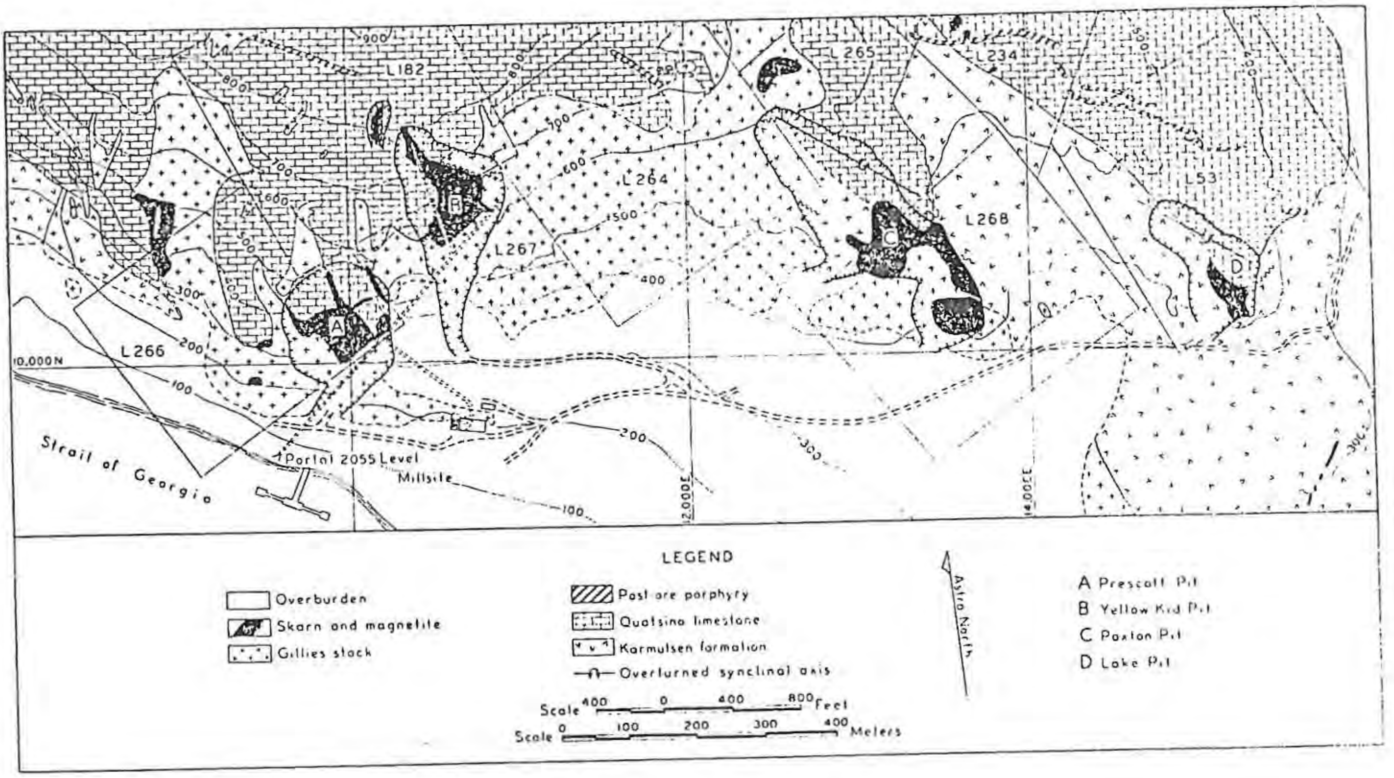


FIG. 4.17: Geology of the mine area, Texada Mines (from Sutherland Brown, 1972).

Like Texada, the Tasu Fe-Cu skarn orebody in Queen Charlotte Islands replaces basalt, limestone and a diorite porphyry laccolith. The basalt and diorite porphyry were altered in preference to limestone. The warped and faulted basalt-diorite porphyry contact is the locus of ore deposition. The skarn is composed of actinolite, anthophyllite, tremolite, and brown garnet in varying proportions and abundance, and occurs as stratiform sheets and lenses commonly elongated along the northwesterly plunge of fold axes (Sutherland Brown, 1972).

The orebodies occur within the general stratiform skarn zones as irregular sheets or mantos with local thickenings and vein-like protrusions along faults and dykes. The ore is massive magnetite with small amounts of pyrite, pyrrhotite, chalcopyrite, and rare sphalerite. A paragenetic sequence is evident. Magnetite replaces skarn or less commonly limestone and in places cements brecciated skarn. Sulphides occur interstitially or occupy fractures in magnetite. Initial mine ore reserves were 43 million tons (Sutherland Brown, 1972).

In the Whitehorse Copper Belt, Cu-Fe skarns are in Upper Triassic dolomite, limestone, and volcaniclastic rocks in contact with unaltered and unmineralized diorite and quartz diorite of the Mid-Cretaceous suite

(Morrison et al., 1979). Several other Cu-Fe skarns occur in the same rocks but are associated with younger plutons. It has been suggested that the volcaniclastic rocks are the main source of metals in these deposits (Morrison and Hodder, 1977 in Morrison et al., 1979).

In the northeastern Canadian Cordillera, the tungsten skarn deposits occur in the Logan-Mackenzie Mountain belt at the Northwest Territories-Yukon Territory border. Known deposits are the Cantung and Mactung deposits. The Clea tungsten skarn prospect occurs in the Selwyn Mountains.

The Cantung area is underlain by a thick series of sedimentary rocks of Precambrian to Upper Cambrian age - part of the northern Cordilleran geosyncline (Cummings and Bruce, 1977). In the southwest, these rocks have been intruded by several granitic stocks (quartz monzonites) thought to be apophyses of the larger Cretaceous batholith. The major regional structure is a syncline trending north-northwest. The skarns occur in Lower Cambrian carbonate strata that have been folded into an overturned anticline in the flank of the major syncline (Cummings and Bruce, 1977). Two major scheelite-chalcopyrite orebodies have been located at Cantung: the Pit, or WO, orebody, now mined out, and the E-Zone orebody (Archibald et al., 1978; Cummings and Bruce, 1977). Both are exoskarn bodies consisting mainly of massive, disseminated, and vein pyrrhotite intergrown with scheelite, minor chalcopyrite, and skarn silicates. The skarn orebodies overlie the irregular roof of the quartz monzonite pluton. The Pit orebody contained 1,5 million tons at 2,47% WO_3 and 0,5% Cu and the E-Zone contains over 4 million tons at 1,6% WO_3 and 0,23% Cu.

The tungsten skarn deposits on the Clea property in the Selwyn Mountains, Yukon Territory, are genetically related to a quartz monzonite stock (Godwin et al., 1980) which intrudes complexly folded and faulted Lower Palaeozoic sedimentary rocks and produced an alteration halo about 5 km in diameter in the invaded sedimentary units. Alteration of clastic rocks has produced slightly metamorphosed graphitic argillite to highly metamorphosed, resistant hornfels; calcareous beds have been metamorphosed to marble and skarn. Beds and axial planes strike generally northwest and dip moderately southwest; fold axes plunge northwest (Godwin et al., 1980). High-grade tungsten-bearing skarn mineralization within the altered sedimentary rocks is of two types: sulphide-rich pods and calc-silicate beds. The latter contain significant scheelite concentrations especially near or adjacent to the quartz monzonite stock. Scheelite occurs as fine disseminations with more than 60% massive sulphide minerals, including pyrite, pyrrhotite, chalcopyrite, and minor amounts of bornite and sphalerite. Godwin et al., (1980) are of the opinion that, in the northern Cordillera, granitic rocks associated with tungsten deposits appear to have high initial $^{87}Sr/^{86}Sr$ ratios which indicate that they were generated largely from old, sialic, cratonic rocks. Further, these granitic rocks have similar compositions (mainly quartz monzonites) and were generated in Late Cretaceous times. The MacMillan Tungsten Property, in the same geological setting as the Clea Property, has reserves of 30 million tons at 0,9% WO_3 (Harris, 1976).

The Hedley Camp gold skarn deposits (fig. 4.18) occur in a bowl-shaped skarn zone formed from Triassic limestones, limey argillite, and quartzite resting on a relatively flat floor of the Toronto granodiorite

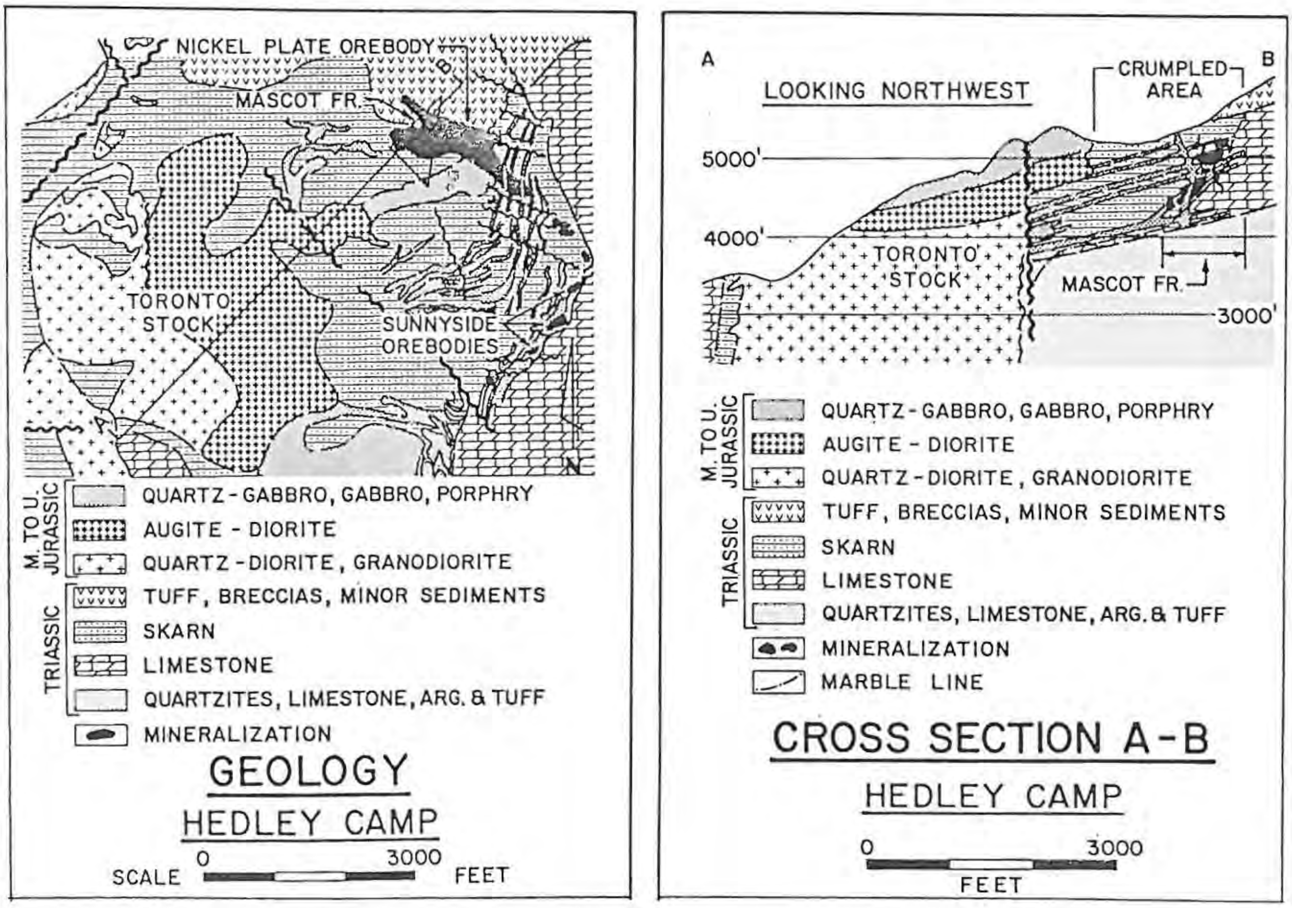


FIG. 4.18: Geology and cross-section of the Hedley Camp (from Barr, 1980).

stock. Numerous sills and dykes of porphyritic gabbro-diorite have been injected into the sedimentary sequence (Bacon, 1978; Barr, 1980). The basic sills and dykes were barriers to ore-bearing solutions which deposited auriferous arsenopyrite and minor pyrite and sphalerite in skarn and locally in fractures in the sills and dykes (Barr, 1980). Bornite, chalcopyrite, pyrrhotite, molybdenite, chalcocite, covellite and cobaltite occur locally (Lamb, 1957). The orebodies are tabular and vary in thickness from about 3 m to more than 35 m. Some orebodies are located in the crest and trough of large drag folds whereas others are localized in the competent skarn beds rather than the limey beds and others are localized at the junction of steep structures and dykes (Lamb et al., 1957).

4.3.6 Vein deposits

In the younger rocks of the Canadian Cordillera there is development of mercury veins and lead-silver veins in addition to the gold-quartz veins. The mercury veins are concentrated in central British Columbia (Armstrong, 1966) and the lead-zinc lodes occur in the Keno Hill-Galena Hill area (Boyle, 1957; Morin, 1980).

The Pinchi Lake and the Bralorne Takla mercury mines occur along the Pinchi Lake fault zone (fig. 4.19) in dolomitized Cache Creek limestones which have varying sizes of solution cavities, some of which are partly filled with calcite (Armstrong, 1966). Cinnabar, the only mercury mineral, occurs as veinlets, blebs, and individual grains filling pre-existing openings such as fissures, solution cavities, and interstices between grains, and replacing the limestone adjoining the openings. The best ore occurs in rocks where there was an abundance of pre-existing openings (Armstrong, 1966). Scattered grains of pyrite occur. The common gangue minerals are quartz and calcite.

The mercury is thought to have formed from hydrothermal ore-forming solutions of deep-seated origin which were channelled through the fault zones. In many places along the Pinchi fault zone, relatively impervious cap rock and fault gouge acted as traps to the rising mercury-bearing solutions which were eventually precipitated in the limestone host rock (Armstrong, 1966).

The Yukon Territory is an important metallogenic province for lode gold deposits. Besides the minor lode gold deposits associated with the copper-bearing skarns and the lead-silver veins, the Yukon is known for mesothermal quartz veins in the Klondike schists and the epithermal quartz veins in fractures and faults in Cretaceous volcanic and granitic rocks (Morin, 1980). The age of the lode gold deposits in the Klondike

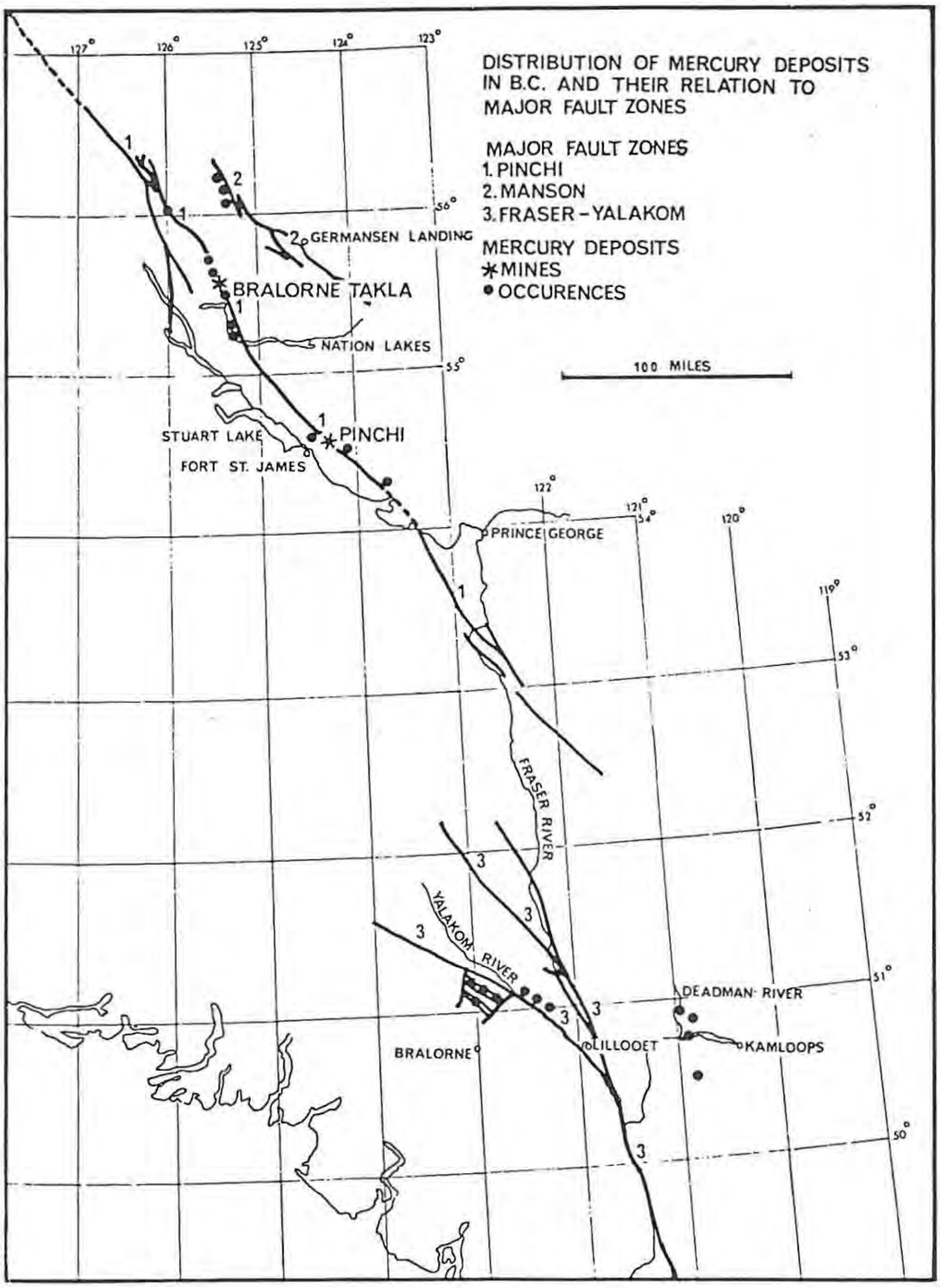


FIG. 4.19: Distribution of mercury deposits in British Columbia (from Armstrong, 1966).

Placer district (fig. 4.10) is not known but it may be Early Palaeozoic (Barr, 1980). These deposits occur in irregular veins, veinlets and stockworks in sericite and chlorite schist and are locally conformable with the metamorphic foliation (Morin, 1980). The schist is an assemblage of volcano-sedimentary rocks sheared and metamorphosed in an island arc-suture zone (Teslin suture - fig. 3.13) during the Early Mesozoic. Vein paragenesis is quartz-pyrite-galena-native gold, with rare barite, chalcocite, arsenopyrite, chalcopyrite, and tetrahedrite.

The epithermal vein deposits of the Mount Nansen-Mount Freegold area in south-central Yukon are hosted in a high-level igneous system of Late Cretaceous or Early Tertiary age. Hypabyssal porphyry dykes and shear zones in volcanic rocks contain veins, lenses and stockworks of quartz. The mineralized areas have extensive argillic, pyritic, chloritic, and silicic alteration. The paragenesis of vein minerals is quartz-pyrite-arsenopyrite-galena-sphalerite, with minor stibnite, barite, and a variety of sulphosalts (Morin, 1980).

The Windy Arm and Wheaton River districts of south-central Yukon contain auriferous quartz veins localized by faults and fractures in andesite and associated intrusive rocks of Late Cretaceous age. The minerals are quartz-arsenopyrite-pyrite-galena-sphalerite-cerussite, with minor pyrargyrite, yukonite, realgar, orpiment, argentite, tetrahedrite, native silver, chalcopyrite, jamesonite, chalcocite, malachite, and native antimony (Morin, 1980).

The Keno Hill-Galena Hill area in central Yukon contains the lead-zinc-silver lodes hosted in thick-bedded quartzites and greenstones (Boyle, 1957) which may be of Palaeozoic age. These rocks occur in a large open anticline. The lodes are located at the junction of two or more vein faults (fig. 4.20), or at the junction of a vein fault and sudsidiary fracture. Other lodes occur in quartzites or greenstones at or near the sites where the vein faults pass upward into schists or thin-bedded quartzites (fig. 4.21). Two stages of mineralization have been observed (Carmichael, 1957), with quartz-arsenopyrite-pyrite-galena-sphalerite, and minor siderite deposited in the above-mentioned structural sites. Some of the arsenopyrite veins are gold-bearing (Carmichael, 1957). There is a well-developed supergene enrichment zone, with lead and silver enrichment and zinc depletion in the oxidized zone (Boyle, 1957). The zone of reduction has concentrations of supergene galena, sphalerite, and hawleyite.

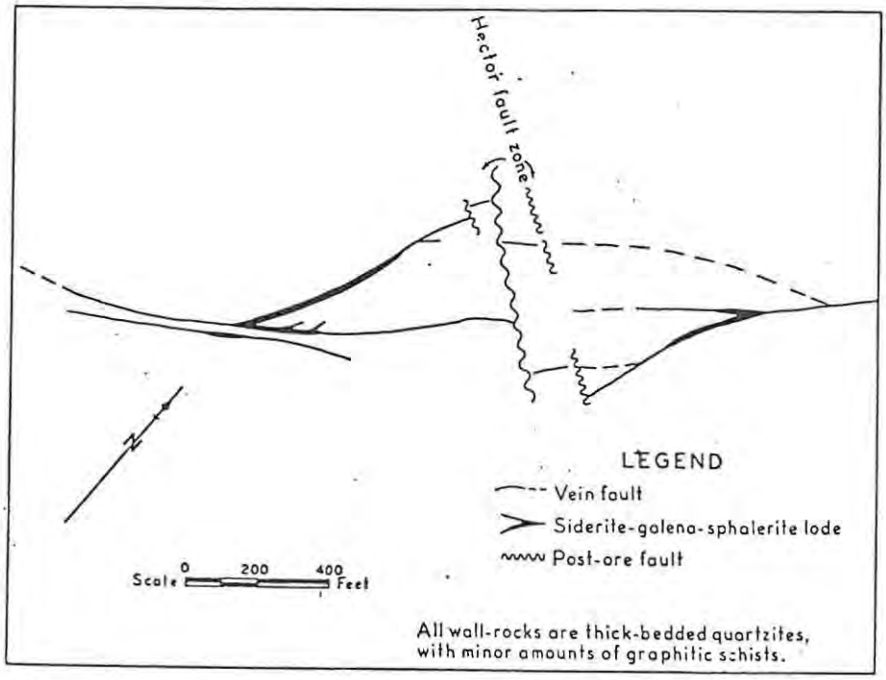


FIG. 4.20: Location of Pb-Zn lodes at the intersection of vein faults (from Boyle, 1957).

4.3.7 Porphyry Cu-Mo and porphyry Mo deposits

(a) Introduction

Porphyry Cu-Mo and porphyry Mo deposits are by far the dominant deposits in the Cordillera and are mostly concentrated in the Intermontane and Insular Belts, with few occurrences in the Omineca Crystalline Belt and the Coast Plutonic Complex. They range in age from Jurassic to Miocene in the Insular Belt and from Triassic to Eocene in the Intermontane Belt (Christopher and Carter, 1976). Mineralized porphyry intrusions in the Cordillera belong to either the calc-alkaline magma suite or the barely saturated syenite (alkaline) magma suite (Sutherland Brown et al., 1971). The composition of the former suite is dominantly quartz monzonite, but less commonly granodiorite, quartz diorite, or granite. The composition of the syenite suite is varied, but is mostly monzonite.

In addition to copper and/or molybdenum, gold, silver, and tungsten are normally recovered in accessory amounts. Porphyry deposits have a simple major ore and alteration mineralogy, together with a number of minor minerals. The common primary ore minerals are chalcopyrite, bornite and/or molybdenite, and pyrite. Scheelite and wolframite are

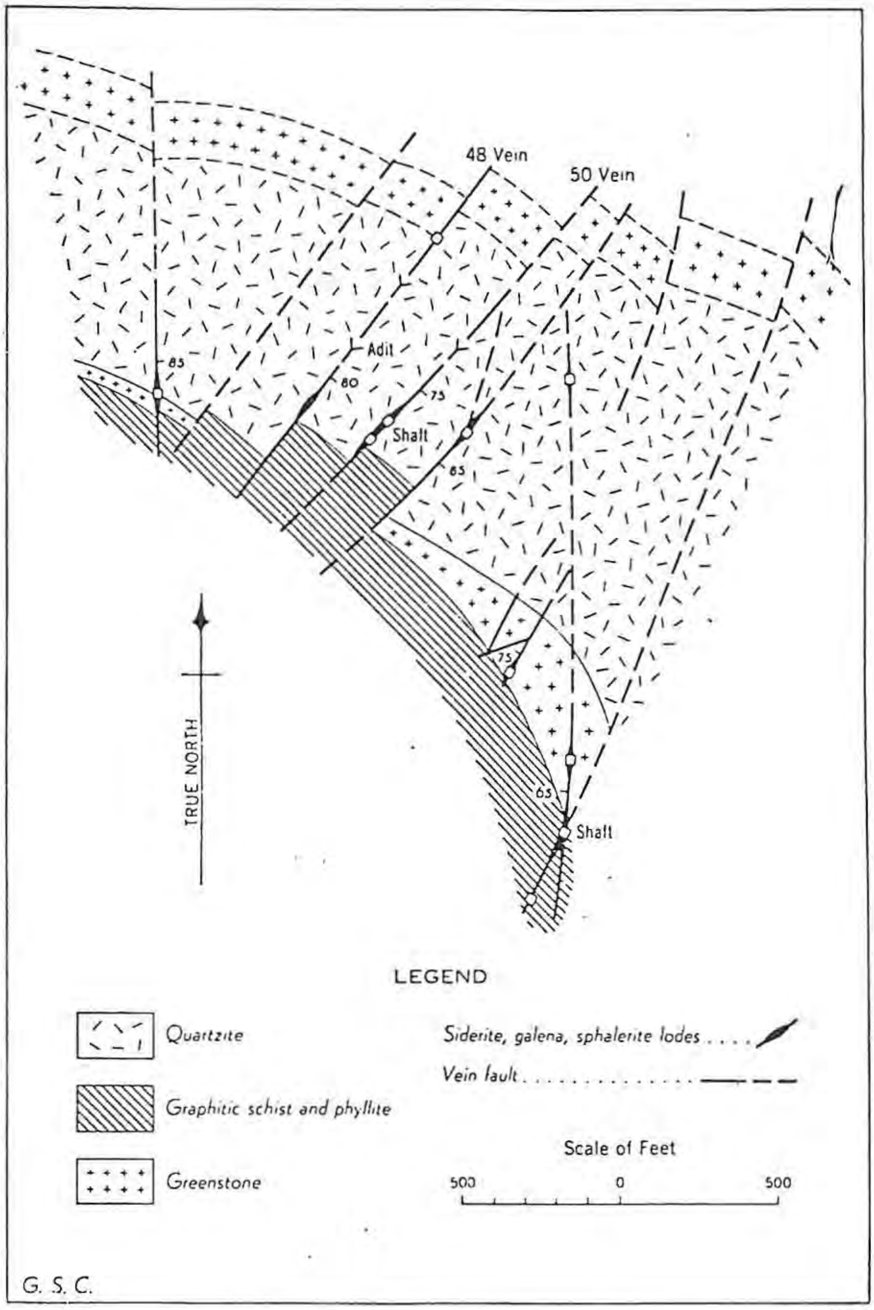


FIG. 4.21: Plan showing location of ore shoots and mineralized zones, Bellekeno system (from Boyle, 1957).

important in rare instances. Minor amounts of galena, sphalerite, and many sulphosalts may be present in late, banded or drusy veinlets of carbonate and quartz (Sutherland Brown et al., 1971). Secondary chalcocite usually replaces pyrite and chalcopyrite. Minor copper oxides and carbonates also occur. A stockwork of quartz veinlets, commonly of several generations, is associated with the mineralization in all but the syenitic porphyries. Gypsum, anhydrite, apatite, and fluorite occur in the stockwork. Potassic, phyllic, argillic, and propylitic zones of alteration (fig. 4.22) are usually observed. Porphyry deposits are regarded as products of material regenerated at converging plate margins in subduction zones and emplaced at high levels in the crust in plutons of calc-alkaline or alkaline affinity (Sillitoe, 1972).

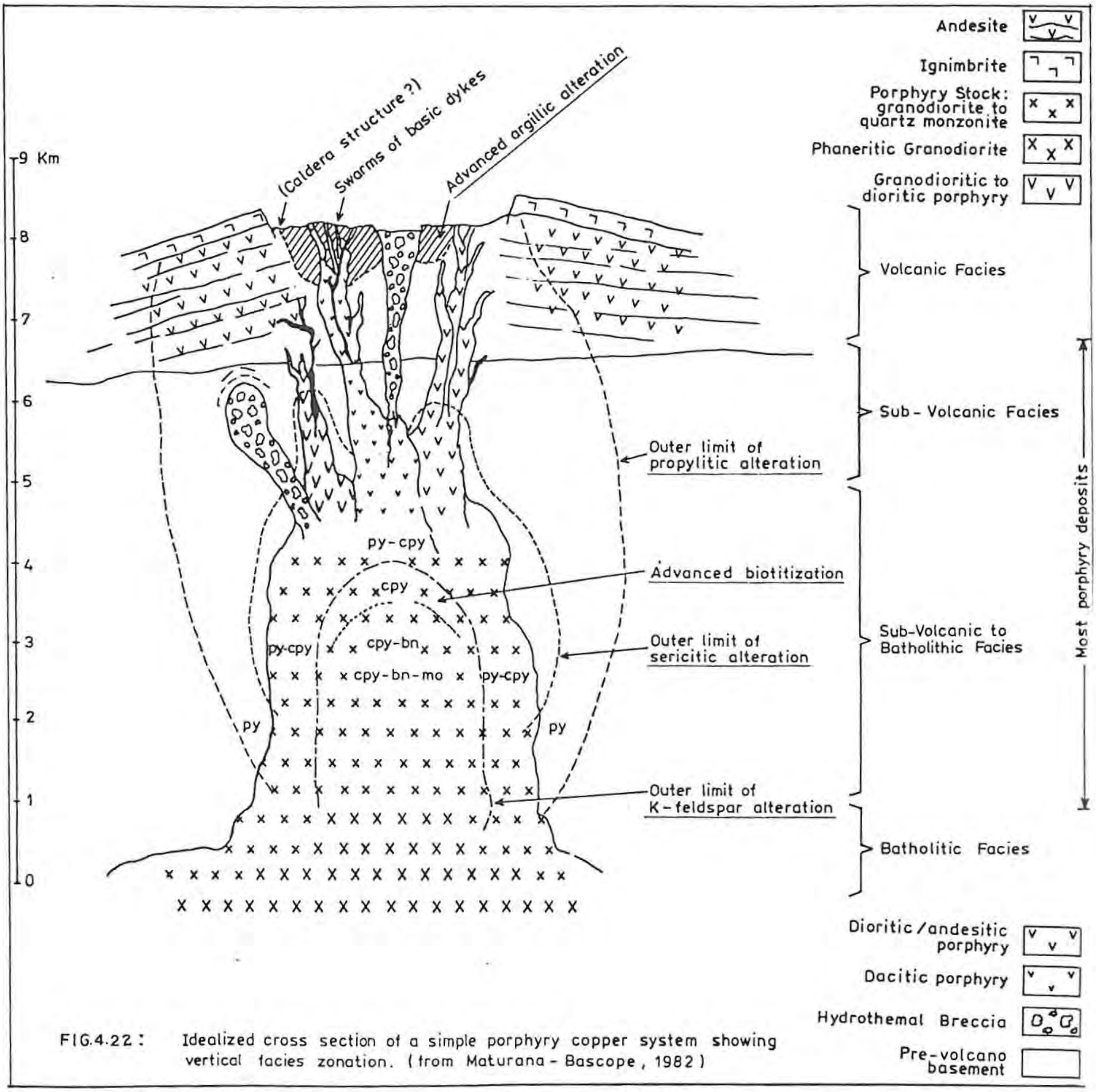


FIG.4.22: Idealized cross section of a simple porphyry copper system showing vertical facies zonation. (from Maturana - Bascope, 1982)

(b) Porphyry deposits associated with calc-alkaline plutons The Highland Valley porphyry copper camp

This porphyry copper district is located 40 km southeast of Cache Creek and 54 km southwest of Kamloops. The porphyry copper deposits (fig. 4.23) are of the complex type. They lie within the 1 200 km^2 Triassic

Guichon Creek Batholith, a semi-concordant domal body elongated slightly west of north, and which has several concentric phases with locally sharp, but generally gradational, contacts (fig. 4.23). It intrudes sedimentary and volcanic rocks of the Permian Cache Creek and Late Triassic Nicola Groups and is unconformably overlain by sedimentary and volcanic rocks of Early Jurassic to Middle Tertiary age (fig. 4.23; McMillan, 1972; 1976; Olade, 1976).

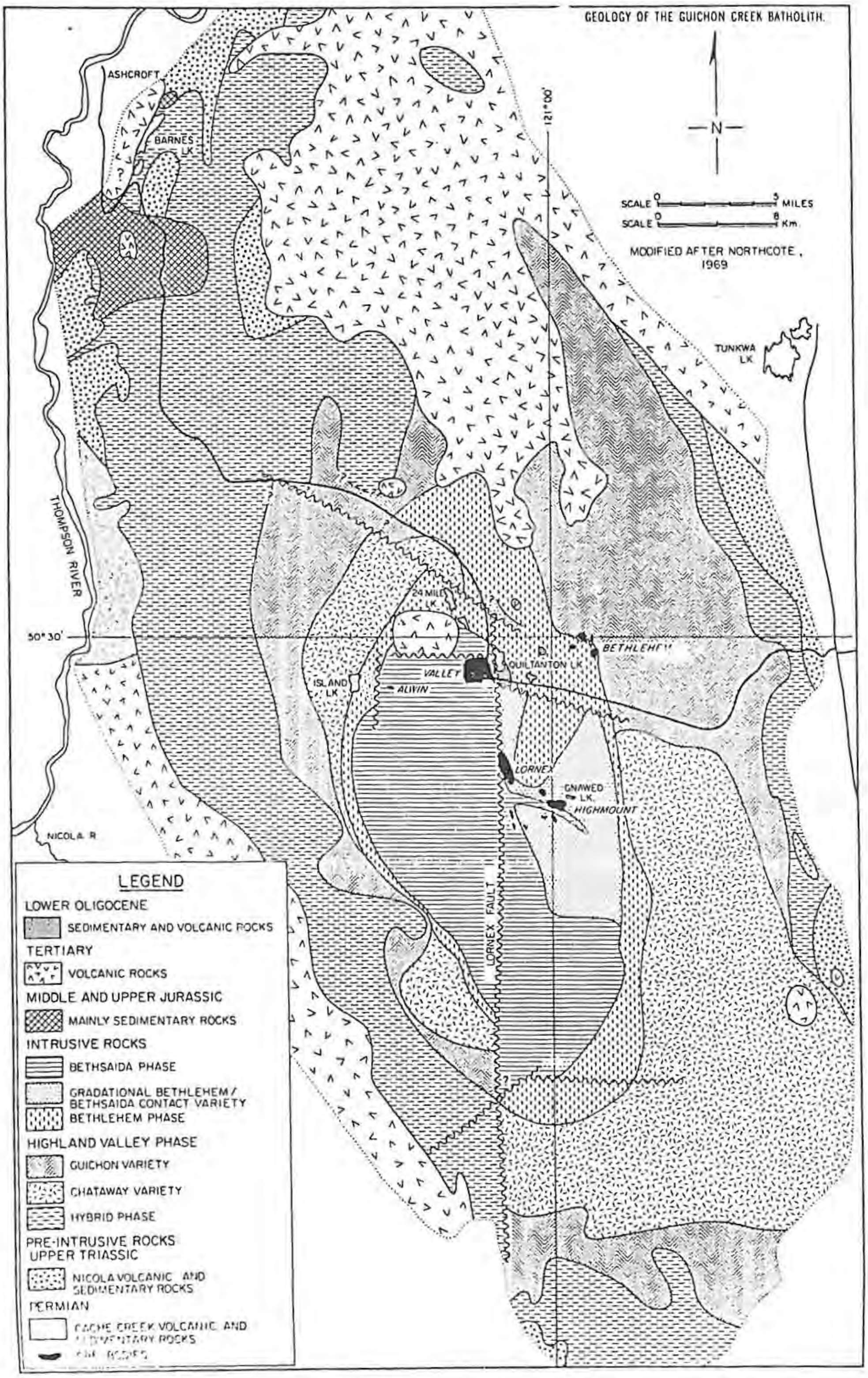


FIG. 4.23: The geology of the Guichon Creek Batholith and the related porphyry Cu-Mo deposits (from McMillan, 1972).

Fig. 4.24 shows the geology of the Highland Valley area. The Krain and the South Sea deposits occur in the Guichon Quartz Diorite which is riddled with predominantly north-trending dykes. In the former deposit, the mineralization is associated with a sheet-like body of granodiorite, whereas in the latter the mineralization occurs in breccia pipes which have Guichon fragments and rhyolite porphyry fragments (McMillan, 1976). Mineralization at Bethlehem Copper occurs within a dyke swarm in breccias and fractured zones along and adjacent to the Guichon Quartz Diorite and Bethlehem Granodiorite contact (Carr, 1966; McMillan, 1972; 1976). The J.A. deposit has a similar geological setting to the Bethlehem orebodies but differs in that the mineralization is closely associated with, but post-dates, a quartz monzonite porphyry stock that appears to be an offshoot from the Bethsaida Quartz Monzonite. The Highmont deposits (Minex, Ann No. 1, Lornex) are closely associated with the Gnawed Mountain dyke. Local tourmalinized breccia bodies occur both within and adjacent to the Gnawed Mountain dyke. They are locally cut by sulphide mineralization, as at Minex and the southeast corner of Highmont's No. 1 zone (Reed and Jambor, 1976). No breccias have been found at Lornex. The Valley Copper deposit lies within the Bethsaida Quartz Monzonite and has few mineralized and unmineralized dykes associated with it but no breccia bodies are known (McMillan, 1976).

Structure is the important ore control at Highland Valley because almost all the sulphide mineralization is either in or closely associated with veins, fractures, faults, or breccias. Good copper grades are found where swarms of fractures occur or where sets of fracture swarms overlap. In the Highmont area, good mineralization occurs where northeast- and northwest-trending swarms of fractures overlap in a general zone of fracturing adjacent to the Gnawed Mountain dyke (Reed and Jambor, 1976). At Lornex, good grades occur at the intersection of north-northeast-, northeast-, and east-trending sets of fractures (Waldner et al., 1976). In the Bethlehem deposits, good mineralization seems to be related to the horsetailing fault pattern (Carr, 1966). At Valley Copper, good grades occur at the intersection of fractures which run parallel to the two regional faults: the northerly-trending Lornex fault and the easterly-trending Highland Valley fault (Osatenko and Jones, 1976).

The Highland Valley deposits display varying alteration patterns and late stage veining. Most of these deposits have a fairly well developed

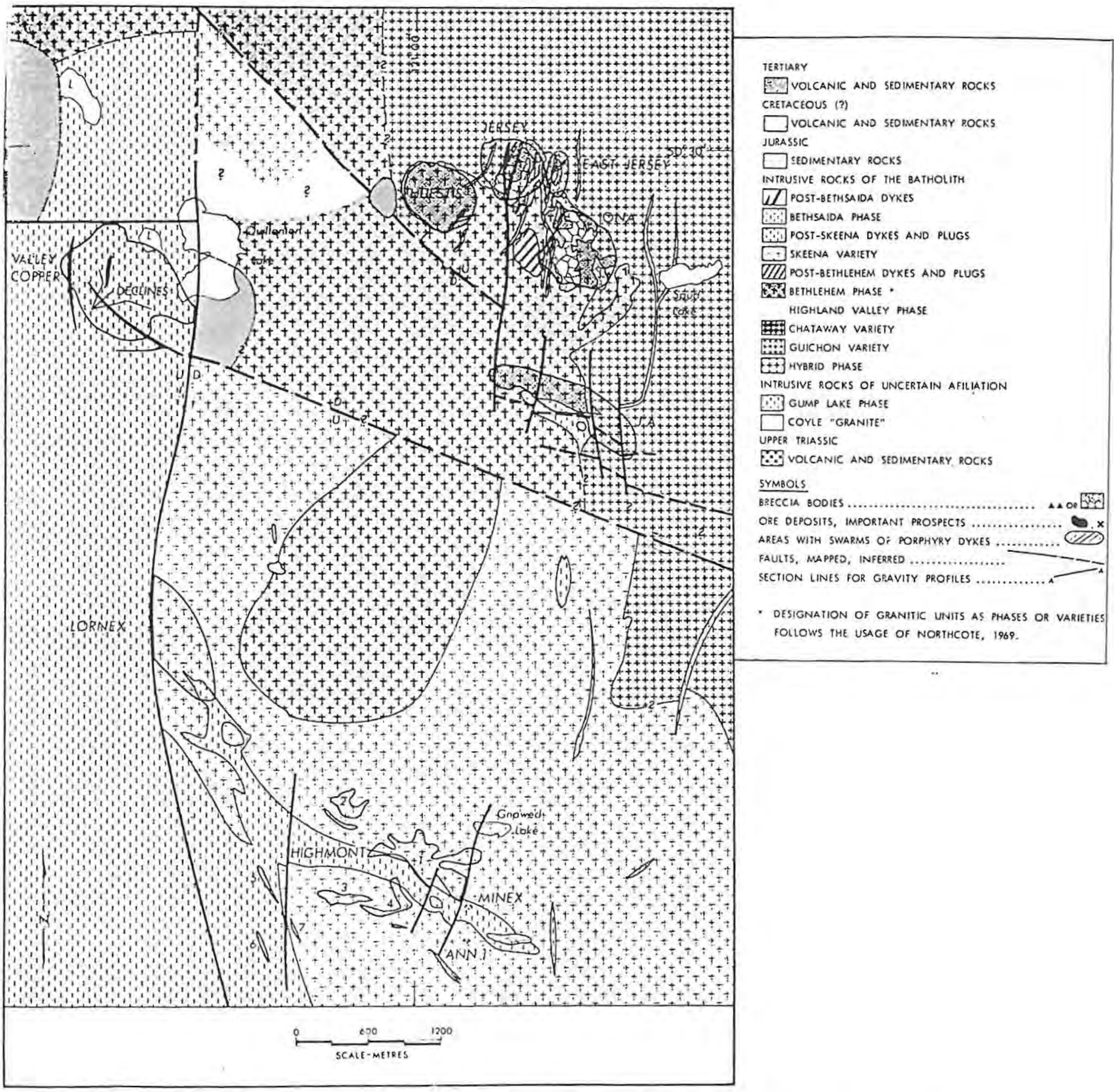


FIG. 4.24: Generalized geology of the Highland Valley area (from McMillan, 1976).

metallic mineral zoning, but, because grades are structurally controlled, these patterns do not always correlate closely with grade distribution patterns (fig. 4.25; McMillan, 1976). The mineralization consists of pyrite, bornite, chalcopyrite, molybdenite, specularite, and chlorite, epidote, sericite, calcite, quartz, zeolites, biotite and tourmaline. Some deposits have well-developed secondary enrichment. The ore reserves of the Highland Valley deposits combined amount to about 2 billion tons at 0,45% Cu (McMillan, 1976).

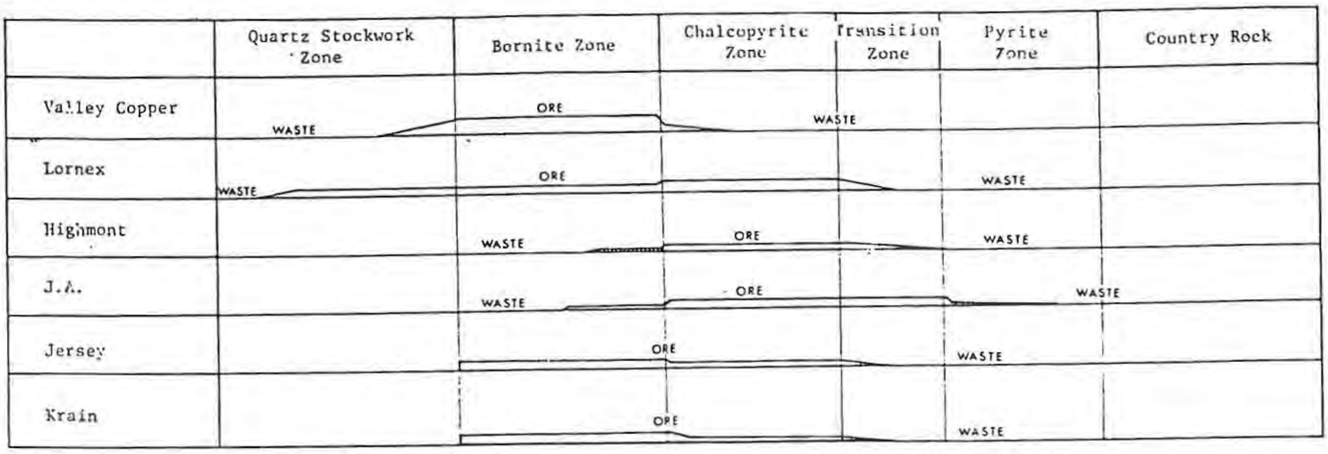


FIG. 4.25: Relationship between ore distribution and sulphide zoning in Highland Valley deposits (from McMillan, 1976).

Porphyry deposits in the northern Canadian Cordillera

In the northern Cordillera, especially in the Yukon Territory, several porphyry Cu-Mo deposits occur in the Dawson Range. The Casino Cu-Mo deposit is related to the Mt. Nansen volcanics (Wolfhard and Ney, 1976) and the mineralization occurs in breccias. The biggest porphyry Cu-Mo deposit found in the Dawson Range is the Cash porphyry Cu-Mo deposit (Sinclair et al., 1981). It is associated with the Big Creek fault, a major tectonic feature, and is genetically associated with a subvolcanic complex of small, irregular stocks and dykes of feldspar porphyry and related breccias of Late Cretaceous age. Primary sulphide minerals are pyrite, chalcopyrite, molybdenite, and bornite. They occur along fractures, in quartz veinlets and disseminated in feldspar porphyry and intruded metasedimentary and older intrusive rocks (Sinclair et al., 1981). Cross-cutting relationships between veinlets and fractures indicate multistage development of sulphides. Higher-grade zones of copper and molybdenum have associated potassic alteration. Phyllic alteration is, in part, superimposed on potassic alteration whereas argillic alteration occurs locally. In essence, these deposits are similar to the calc-alkaline porphyry deposits of British Columbia.

(c) Porphyry copper deposits of the alkaline suite

Alkaline-suite porphyry copper deposits (fig. 4.26) and related intrusions occur in the Intermontane Belt. They are spatially and genetically related to the Upper Triassic Nicola-Takla-Stuhini volcanics

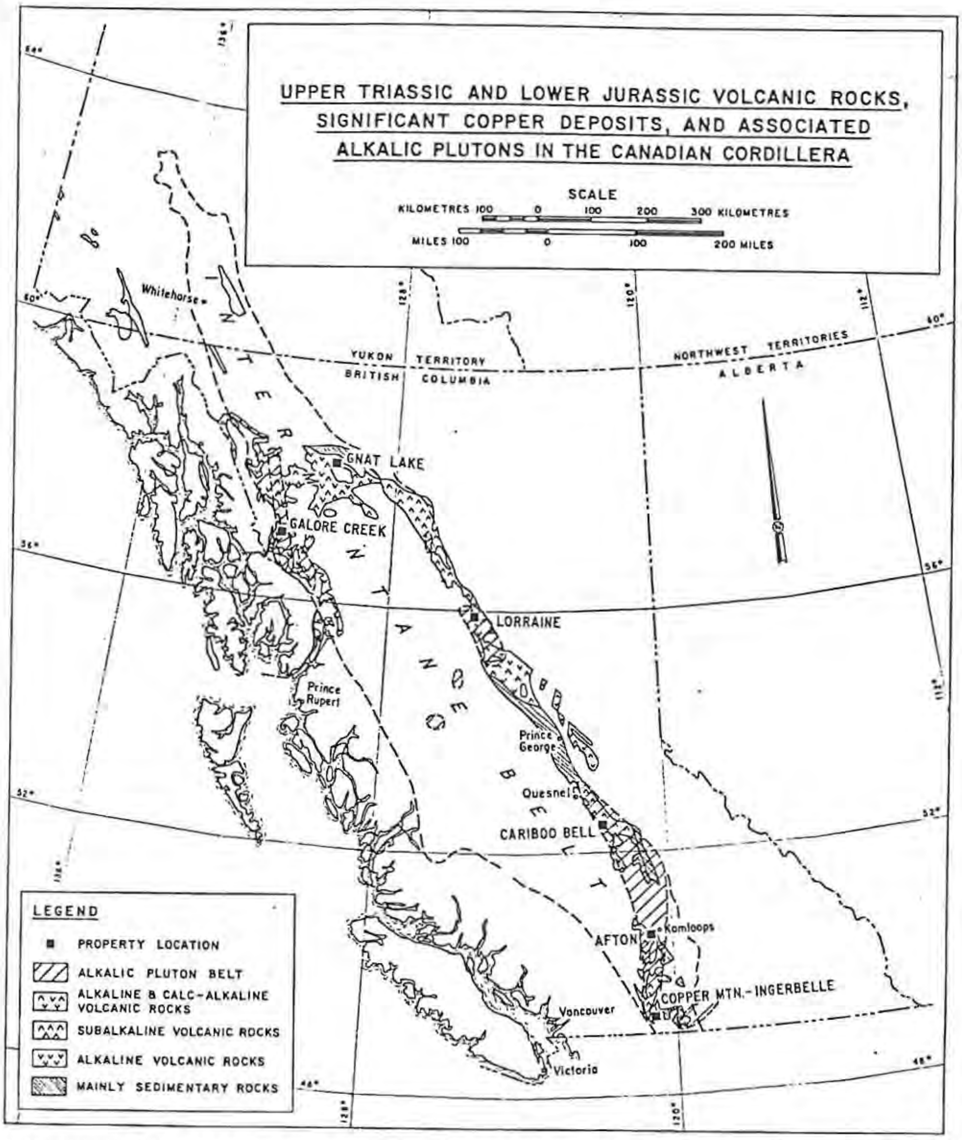


FIG. 4.26: Upper Triassic and Lower Jurassic volcanic rocks, significant copper deposits and associated alkaline plutons in the Canadian Cordillera (from Barr et al., 1976).

and comagmatic alkaline plutons (Barr et al., 1976). For instance the copper deposits of the Copper Mountain Camp occur in rocks of the Nicola Group which are bounded in the south by the Copper Mountain stock, in the north by the dioritic to syenitic porphyries and breccias of the Lost Horse Complex, and in the west by the Boundary fault system (fig. 4.27; Fahrni et al., 1976). The Afton deposit occurs in the late phase latite porphyry and breccia of the dioritic to syenitic Iron Mask pluton which intrudes the Nicola Group in the Quesnel Trough (Carr and Reed, 1976). The Galore Creek deposits are hosted by volcanic breccias, bedded and crystal tuff, trachyte and pseudoleucite phonolite which are intruded by syenite porphyry dykes and plugs (Allen et al., 1976). Cariboo Bell, Gnat Lake, and Lorraine are also related to alkaline

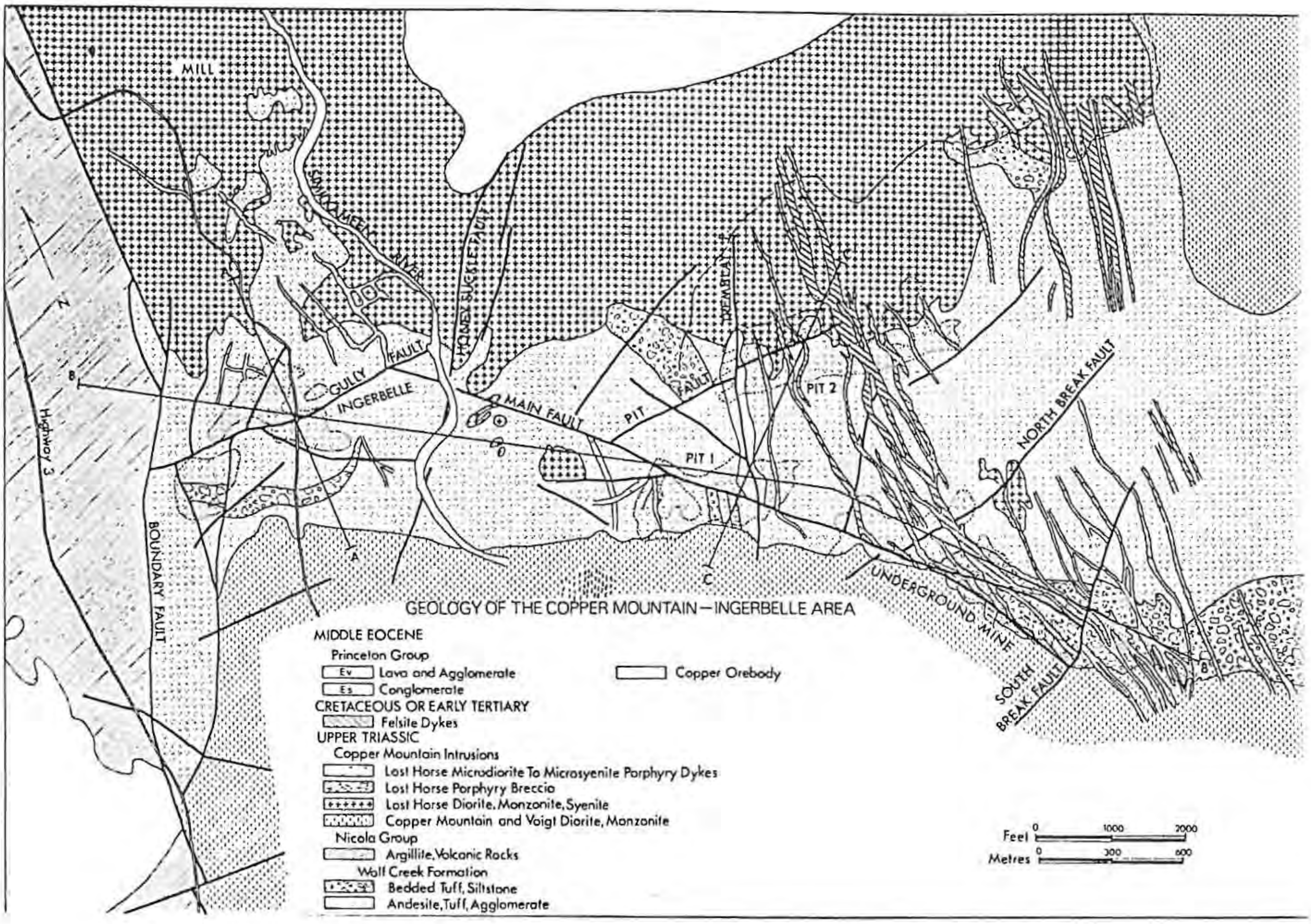


FIG. 4.27: The geology of the Copper Mountain - Ingerbelle area (from Fahrni et al., 1976).

plutons which intrude the Upper Triassic volcanics (Hodgson et al., 1976; Wilkinson et al., 1976).

Compared to the calc-alkaline suite deposits, these deposits commonly grade into pyrometasomatic or skarn deposits, they lack appreciable amounts of molybdenite, and are usually richer in gold and silver. Further, the ore zones and the related intrusions are spatially associated with regional faults. These faults seem to be the dominant ore controls. In the Afton deposit, the Iron Mask pluton and the related volcanics were emplaced along long-active and deep-seated faults. The ore minerals occur in fractures (Carr and Reed, 1976). The ten tabular to manto-shaped deposits of the Galore Creek Camp are dominantly controlled by syenite dyke contacts and zones of structural weakness (Allen et al., 1976; Barr, 1966). Figure 4.27 shows the relationship of orebodies with faults at the Copper Mountain deposits. These north-trending high-angle faults form an ancient, long-lived rift system that extends from the U.S. border (Fahrni et al., 1976). Four of the six orebodies at Cariboo-Bell are complex intrusion and crackle breccias adjoining a lens of syenodiorite (Hodgson et al., 1976). They seem to be related to faults (fig. 4.28).

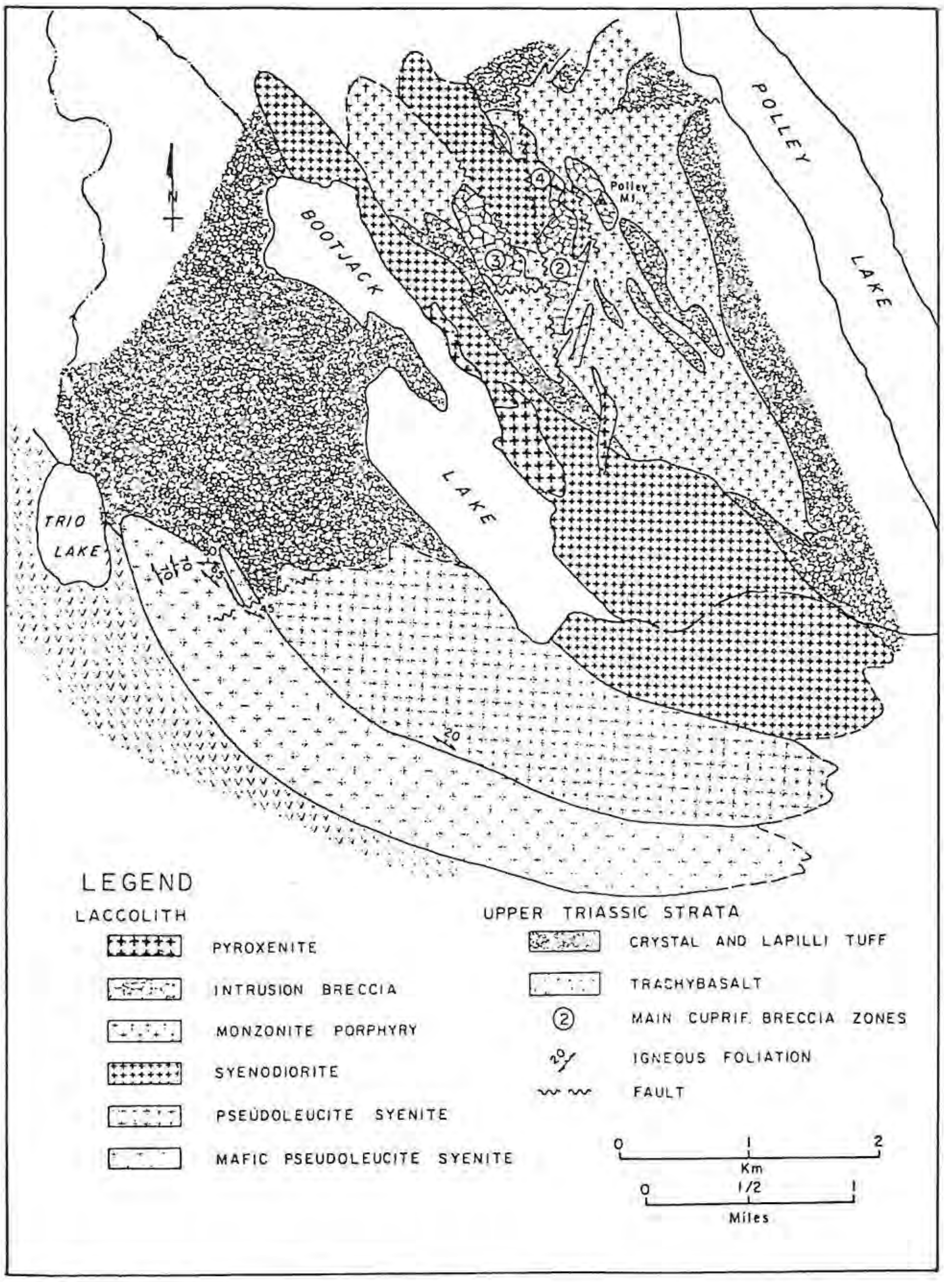


FIG. 4.28: The geology of Cariboo Bell deposits (from Hodgson et al., 1976).

The dominant alteration products related to mineralized zones are potash feldspar and biotite. Propylitic zones commonly fringe the deposits. Phyllic and argillic alteration zones are notably absent or poorly developed in these deposits. The ore zones occur in all alteration units, the ore zones in the Galore Creek deposits, are associated with the potassic alteration zone close to the related alkaline pluton (Barr et al., 1976; Allen et al., 1976). Alteration patterns and sulphide distribution are complicated by telescoping and overlapping of various alteration zones.

Primary sulphides are pyrite, chalcopyrite, bornite, chalcocite, and pyrrhotite. Pyrite is the most abundant sulphide mineral and at the Galore Creek and Cariboo Bell deposits it occurs peripheral to the main mineralized zone. The sulphides occur as fracture fillings, veins, disseminated grains, massive lenses and pods, and in breccias. Magnetite and, locally, hematite may occur with the sulphides. No significant supergene enrichment has occurred in the porphyry deposits related to alkaline suites. In the Copper Mountain deposits, no supergene enrichment has taken place since Pleistocene glaciation (Fahrni et al., 1976). The Afton deposits contain supergene minerals (native copper, chalcocite, and copper oxides) to great depths (Carr and Reed, 1976). The Lorraine deposit contains secondary copper oxides and carbonates in the highly oxidized Upper Zone (Wilkinson et al., 1976). In the other deposits, supergene copper minerals are relatively sparse and unimportant.

Table 1 summarizes the important properties of these deposits, and also shows the ore reserves of the different deposits.

(d) Porphyry molybdenum deposits of the calc-alkaline suite

All economically significant porphyry molybdenum deposits are within the Intermontane Belt of central British Columbia. Minor porphyry deposits occur in the adjacent Coast Plutonic Complex and Omineca Crystalline Belt, with the third group occurring in the Insular Belt. The distribution of the deposits within each tectonic belt is erratic and is controlled by clusters of coeval intrusions, some of which are barren. These intrusions are composite, silicic, leucocratic quartz monzonite stocks and late stage composite quartz monzonite batholiths as at Endako and Adanac. In the mine area, the host rocks are usually cut by pre-mineral and post-mineral dykes. The Endako deposit, the largest molybdenum producer in Canada and the second largest in the world after Climax, is an elongate stockwork of quartz molybdenite veins developed

TABLE 1 — Summary of Geology and Exploration Data — Significant Copper Deposits Associated with Alkalic Plutons in the Canadian Cordillera

Name Ownership	Afton (Teck. Corp.)	Cariboo Bell (Teck Corp.)	Copper Mountain/Ingerbelle (Similkameen Mining)		Galore Creek (Stikine Copper)	Gnat Lake (H.B.M. & S.)	Lorraine (Granby-Kennco)	
PLUTON								
Type	Diorite, diorite phy, syenite phy.	Syenodiorite, monz. phy.	Syenite-monzonite-diorite complex		Syenite phy. complex	Syenite porphyry, quartz monzonite	Syenite migmatite, leucocratic syenite, pyroxenite	
Age	198 ± 6 m y	184 ± 7 m y	U. Triassic (193 ± 8 m y)		L. Jurassic (198 ± 7 m y)	L. Jurassic	175 ± 5 m y	
Host Rock	U. Triassic tuffs, agglоms., flows	L. Jurassic tuffs, breccias, flows	U. Triassic volcs., minor seds.		U. Triassic metavolcs, minor seds.	U. Triassic andesites, dacites, rhyolites	Mesocratic phase of migmatite	
Alteration zoning sequence from center	Potassic-propylitic	Potassic-propylitic	Wk. potassic-propylitic		Potassic-propylitic	None recognized	None recognized	
STRUCTURE	Stockwork, breccia	Breccia	Dissem., stockwork		Disseminated stockwork, breccia	Disseminated stockwork	Disseminated	
PYRITE ZONE								
Size (meters)	850 × 300	4500 × 600	Undetermined	1200 × 850	1500 × 600	Not defined	None	
Volume %	0 — 10	5 (avg)	0 — 1	2 — 10	2 — 10	1 — 3	Less than 1	
Cu MINERALIZATION %							Upper Zone	Lower Zone
Chalcopyrite	9	74	50	100	90	100	30	50
Bornite	10	—	50	—	9	—	30	40
Chalcocite	22					—	20	10
Native Copper	56	26	—	—	1	—	—	—
Other Secondary	3					—	20	—
MAGNETITE %	Not available	3 (avg)	0 — 1	0 — 1	2 — 10	0 — 20	0 — 5	
SIGNIFICANT ALTERATION								
K-feldspar	x	x	x		x	x	x	
Biotite	x	x	x	x	x		x	
Garnet		x			x			
Anhydrite					x			
Chlorite	x	x		x	x	x		
Carbonate	x	x		x	x	x		
Albite	x	x		x		x		
Scapolite				x				
Epidote	x	x		x	x			
Tourmaline						x		
RESERVES & PAST PRODUCTION							Upper Zone	Lower Zone
Tons (× 10^6)	31 (indicated)	25 (indicated)	32 (past production)	65 (pre-production)	125 (indicated & inferred)	25 (drill inferred)	5 (3)	5 (3)
Cu %	1.0	0.49	1.08	0.53	1.06	0.44	0.75	0.60
Ag oz t	0.10	0.04	0.12	0.02(2)	0.25	Undetermined	Undetermined	
Au oz t	0.015	0.025	0.005	0.005(2)	0.013	Undetermined	0.01	0.003
APPLICABLE DISCOVERY METHODS								
Date of Discovery	1970	1964	1884	1966	1955	1960	1945	1970
Methods(1)	Prosp. (IP, Gc)	Magnetics (Prosp., Gc)	Prosp.	Prosp. (IP, Rock Gc)	Prosp. (Gc, IP, Mag)	Prosp. (IP. Gc, Mag)	Prosp.	Prosp. (Gc)

(1) Actual discovery methods with applicable or helpful methods in brackets.
(2) Recovered 1972-73 production.
(3) Indicated potential.

Abbreviations:

Tons = Metric tons
IP = Induced Polarization
Gc = Goechemical
Prosp. = Prospecting
Mag = Magnetic
Wk = Weak
phy = porphyry
monz = monzonite

SOURCE: Barr et al., (1976)

within the Endako quartz monzonite phase of the Topley Intrusions (Dawson and Kimura, 1972; Kimura et al., 1976) which, in the mine area, is intruded by pre-mineral and post-mineral dykes (fig. 4.29).

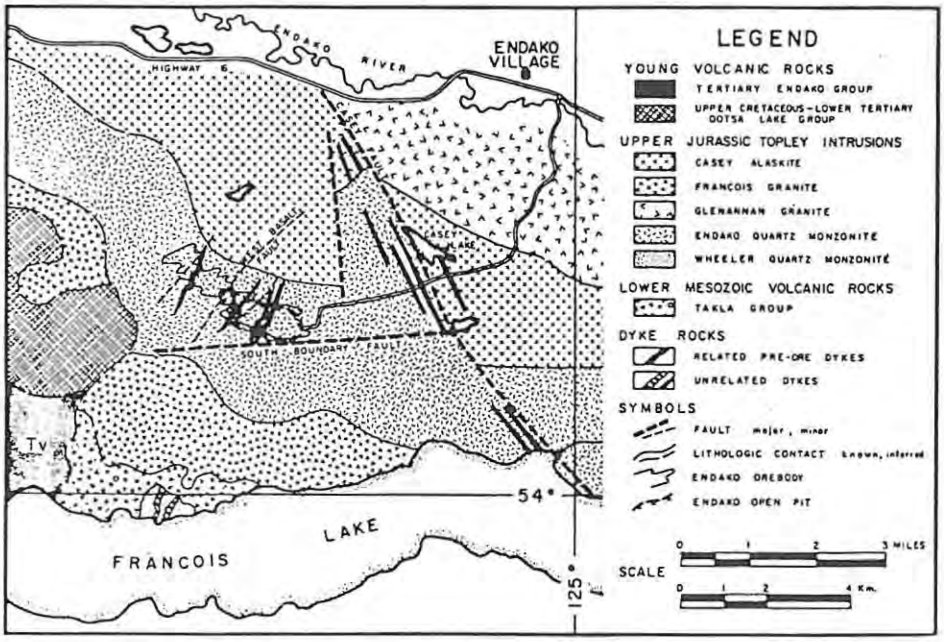


FIG. 4.29: The geology of the Endako area (from Kimura et al., 1976).

The Alice Arm deposits occur in a number of molybdenum-bearing granitic stocks, collectively called the Alice Arm Intrusions, emplaced in sedimentary rocks near the western edge of the Bowser successor basin and marginal to the Coast Plutonic Complex (fig. 4.30; Woodcock and Carter, 1976). Most of the plutons exhibit features of multiple intrusions and are all cut by lamprophyre dykes of post-mineral age.

The Boss Mountain molybdenum deposit occurs within rocks of the composite Takomkane batholith near a genetically related Cretaceous quartz monzonite Boss Mountain stock (fig. 4.31; Soregaroli and Nelson, 1976). The Takomkane batholith intrudes Upper Triassic Nicola Group volcanic rocks. the molybdenum mineralization is spatially and genetically related to dykes of rhyolite porphyry, rhyolite and quartz latite porphyry, and three phases of the Boss breccias (fig. 4.31). Other porphyry molybdenum deposits like the Glacier Gulch and Adanac also display the spatial relationship of molybdenum mineralization and structure.

Potassic alteration, mainly biotite and potash feldspar, is most closely related in time and space to molybdenum mineralization. Sericite

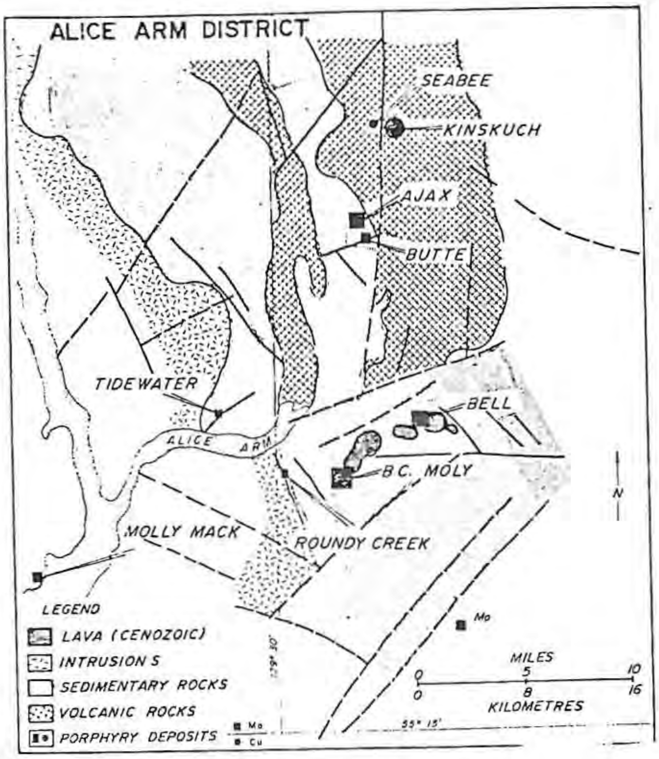


FIG. 4.30: Geology of the Alice Arm district. The deposits south of the NE-trending Alice Arm lineament appear to be spatially related to a system of NE-trending lineaments, and those north of the Alice Arm lineament to a north-trending lineament (from Seraphim and Hollister, 1976).

(muscovite) is important in some deposits and is actually related to the mineralization as at Endako, Boss Mountain, Adanac, Glacier Gulch.

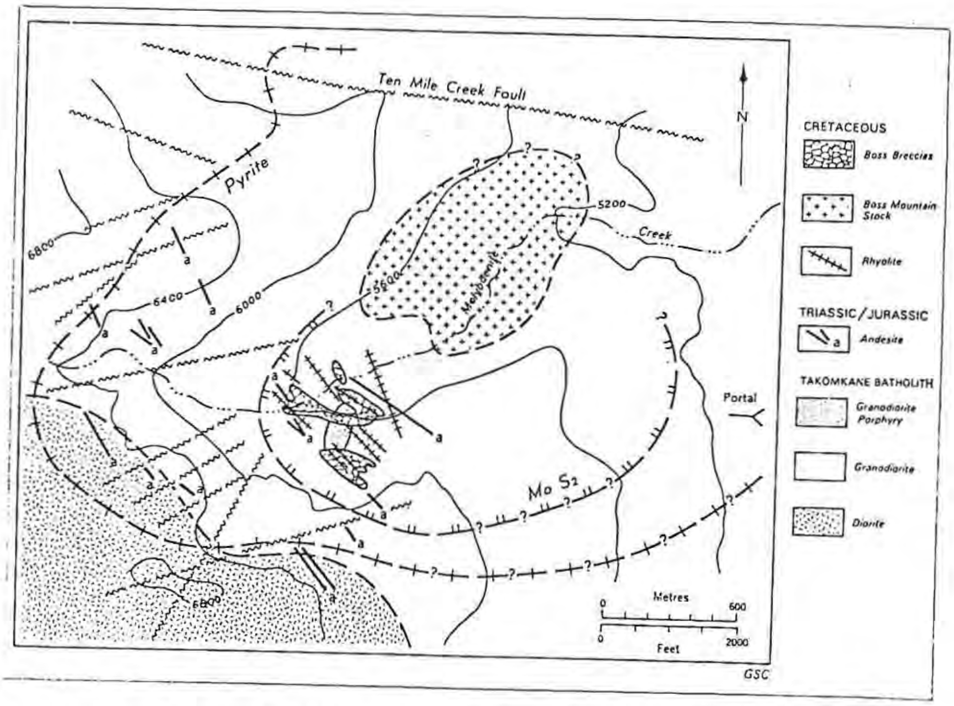


FIG. 4.31: Geology of the mine area at the Boss Mountain deposit (from Soregaroli and Nelson, 1976).

Argillic alteration is important at Endako and it accompanies molybdenum mineralization. Silicification has restricted distribution. Propylitic alteration is common in the outer parts of many deposits and may have been more widespread prior to the development of other alteration assemblages.

Molybdenum deposits are formed by fracturing, veining, alteration and intrusion, with a general sequence that progresses from an early barren stage, through a molybdenum stage and then ends with a weak or barren stage containing base-metal sulphides (Table 2; Soregaroli and Sutherland Brown, 1976). Molybdenum mineralization is largely fracture-controlled. Stockworks are most common, although breccia pipes, multiple vein systems and disseminations are important in some deposits. In the Boss Mountain deposit, molybdenum mineralization, which was introduced during at least three separate periods of hydrothermal activity, is contained within quartz veins or breccia bodies (Soregaroli and Nelson, 1976.) A swarm of veins form economic molybdenite in what is called the Stringer

TABLE 2 — Stages of Mineralization

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Endako....................	qz, py, mo, (mt)	qz, py (cp, mt)	qz, mo, py (cp, mt)	qz, py	qz, cal, sp	
Adanac....................	qz, mo, py	qz, mo	mo	sp, gn, asp		
Boss Mtn..................	qz, py	qz, py (mo)	qz, mo, py	(a) qz, mo, py/ (b) qz, py, cp, bi, (sc, mt, gn, sp)	qz, mo, py	
Glacier Gulch..............	qz	qz, mo, py. mt (cp, sc)	qz, mo, mt (cp, sc)	qz, mo, py, mt (cp, sc)	qz, car, py, sp, gn, (cp)	
BC Moly...................	mo	qz, mo, py	qz, mo, py	qz, mo	qz, py, gn, sp (mo)	
Roundy....................	(mo) (dissem. in dyke)	qz, mo, py stockwork	(preliminary observations)			
Bell Moly..................	qz	qz, mo (py)	qz, mo (py)	qz, car, py gn, sp		
Ajax.......................	qz, po	qz, mo	qz, mo	qz, py, gn sp, cp		
Red Bird..................	qz	qz, mo (py)	qz, mo (py)	qz, mo (py)	qz	py (mo)
Lucky Ship................	mo	qz, mo, py				

Parentheses designate minor constituents

Source: Soregaroli and Sutherland Brown (1976).

Zone. At Endako, the large veins may swell, pinch, horsetail and show local flexures, but the structural continuity of these veins is generally strongly developed (Kimura et al., 1976). These veins contain molybdenite, pyrite, and magnetite, with minor amounts of chalcopyrite and traces of bornite, bismuthinite, scheelite, and specularite. The better grades of molybdenite mineralization at Alice Arm are structurally and lithologically controlled. Fracturing and attendant quartz- molydenite veining are best developed near stock contacts (Woodcock and Carter, 1976). Later alaskite intrusive phases may contain disseminated to nearly massive molybdenite. Table 3 shows the ore reserves of some of the porphyry molydenum deposits.

From this brief account of the porphyry molybdenum deposits, it is clear that these deposits are associated with deep crustal structures and with intrusions of calc-alkaline affinity. This suggests that both the magma and the molybdenum are of deep crustal or upper mantle origin (Soregaroli and Sutherland Brown, 1976).

4.4. MINERALIZATION IN THE MIOCENE TO RECENT

4.1.1 Introduction

This period, which is the last phase of the geological history of the Canadian Cordillera, includes the later half of the Cascade Epoch of Wolfhard and Ney (1976) - stretching from about 26 Ma ago to the present. The period is marked by the extensive extrusion of "Plateau basalts" in the Intermontane Belt. To the west of the Intermontane Belt, the lavas have been upwarped by post-Miocene uplift of the Coast Mountains and have been eroded (Monger et al., 1972). The occurrence of small separate volcanic centres marks the Pliocene to Quarternary volcanism. The remarkable event in this period is that along the British Columbia coast there was a change from a consuming to a strike-slip continental margin. During this period, there was a sharp decline in the porphyry mineralization. The plateau basalts are nowhere known to be mineralized. Small Cu and Mo deposits occur at Franklin Glacier, Cork (Yukon Territory), and Salal Mo (Wolfhard and Ney, 1976). Franklin Glacier, in the Central Coast Range, has weak Cu-Mo mineralization developed in an intrusion with associated volcanic formations that are about 10 Ma old. Salal Mo is in a 7,9 Ma old stock. These deposits, together with a number of small Pleistocene

Table 3: Properties of some of the porphyry molybdenum deposits

Deposit	Minerals	Metals	size (tons x 10^6)	Grade % MoS_2	Age (Ma)	Remarks
Endako	mo	Mo	197,8	0,15	141 ± 5	Initial reserves: 276 m.t.
Boss Mountain	mo	Mo	1,2	0,40	102 ± 4	Additional low-grade potential
Cascade Moly	mo, Au	Mo	1,36	0,27		
Red Bird	mo	Mo	27,2	0,25	49,0 ± 2	
Lucky Ship	mo	Mo	18,0	0,17	49,9 ± 3	Submarginal. Potential for more.
Glacier Gulch	mo, sc.	Mo (W)	90,72	0,29	73,3 ± 3,4	
Mt. Thomlinson	mo	Mo	40,82	0,12	53,8	Submarginal
Bell Moly	mo	Mo	31,75	0,11	52,9 ± 2	Submarginal
Ajax	mo	Mo	178,54	0,121	53,5 ± 5	Submarginal. Very high stoping ratio, with total reserves of 417,3 x 10^6 tons at 0,09% MoS_2.
Roundy Creek	mo	Mo	1,36	0,347	52,5 ± 2	
Mt. Haskins	mo, sl, cp.	Mo, Cu	12,25	0,15	49,8 ± 0,7	Submarginal. Molybdenum-bearing stockwork with adjacent skarn.
Adanac	mo, sc.	Mo (W)	94,53	0,16	62	Potential for more tonnage.

Source: Soregaroli and Sutherland Brown (1976).

volcanic centres, lie along the Harrison Lake structure (Wolfhard and Ney, 1976). Minor vein and skarn deposits occur adjacent to the Chilliwack Pluton in southern British Columbia. Minor Zn-Mo geochemical anomalies occur in the Mt. Edziza volcanics. Vein-gold deposits are those of Cinola (Champigny and Sinclair, 1980) and the Franklin Mining Camp. Mercury vein deposits occur at the Bridge River - Yalakom area and the Kamloops area (Armstrong, 1966). Vein-type deposits of this period will be briefly discussed.

4.4.2 Vein-type deposits

The Cinola gold deposit lies 16 km. south of Masset Inlet on Graham Island, Queen Charlotte Islands. The area is underlain by gently dipping Late Cretaceous clastic sequence of a lower shale unit (Haida Formation) and an overlying interbedded sequence of pebble conglomerate and coarse-grained sandstone (Skonun Formation) of Miocene age (Champigny and Sinclair, 1980; Barr, 1980) which is thought to have formed as an alluvial plain facies in a braided river system discharging into a marine basin. These units are intruded by a stock and dykes of rhyolite porphyry, which, together with the mineralization, have been dated at 14 Ma (Champigny and Sinclair, 1980). A splay of the Sandspit fault system constitutes the footwall on the west of the deposit (fig. 4.32) and marks a sharp contact with the adjacent Haida shales to

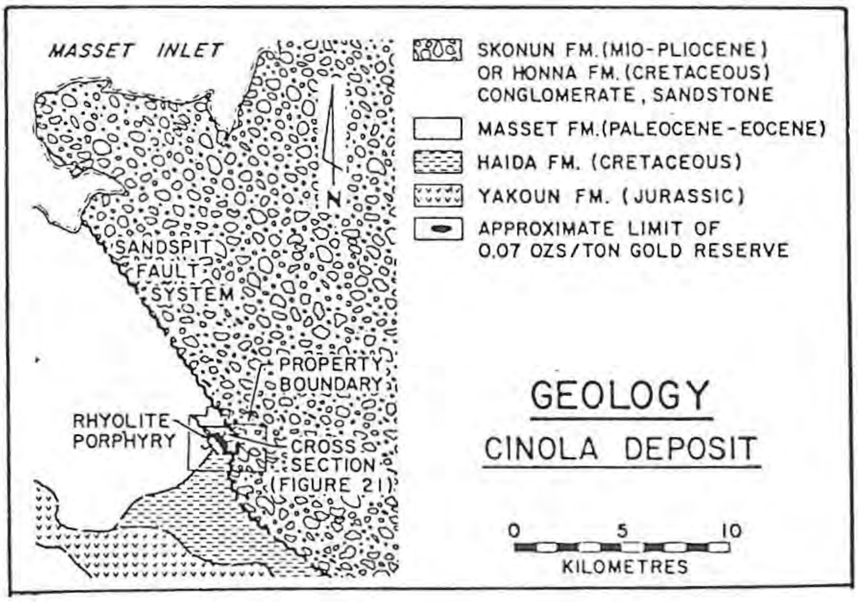


FIG. 4.32: Geology of the Cinola deposit (from Barr, 1980).

the west. Gold and silver mineralization occurs in intensely silicified rocks east of the splay of the Sandspit fault system and decreases gradually to the northeast (fig. 4.33). Within the mineralized area and at its margins, anomalous concentrations of mercury and arsenic and minor concentrations of antimony, copper, and zinc occur (Barr, 1980).

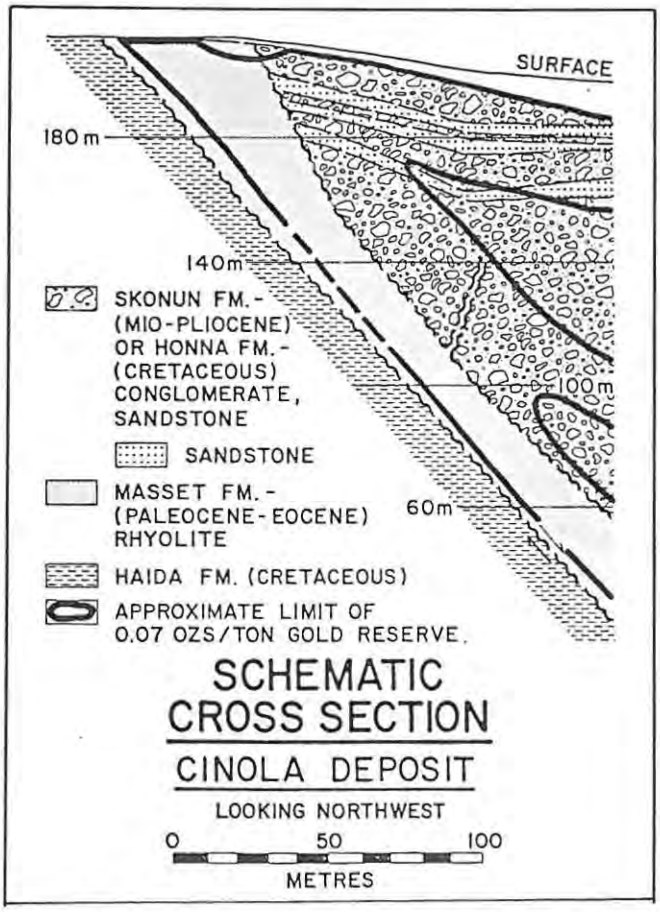


FIG. 4.33: Schematic cross-section, Cinola deposit (from Barr, 1980).

Good gold grades occur in quartz veins and at the contact between the rhyolite porphyry and the Skonun Formation clastic rocks. The sulphides and oxides are mainly pyrite, marcasite, limonite, hematite, native gold, cinnabar, chalcopyrite, sphalerite, pyrrhotite, galena, and rutile (Champigny and Sinclair, 1980). The gold occurs in very fine-grained particle sizes. Possible major controls of mineralization include proximity to an unconformity, proximity to a major fault, and permeability of the host rocks (Richards et al., 1976).

The association of very fine-grained gold mineralization together with anomalous mercury, arsenic and antimony with intense silicification, pyritization, and clay alteration in permeable rock units adjacent to a major structure suggests that the deposit is of Carlin-type (Barr, 1980; Champigny and Sinclair, 1980; Richards et al., 1976). The ore reserves are estimated to be about 50 million short tons at 0,06 oz/ton Au and 0,1 oz/ton Ag (Champigny and Sinclair, 1980; Richards et al., 1976).

The Bridge River - Yalakom River and the Kamloops Lake mercury deposits occur in central British Columbia (fig. 4.19). Along the Pinchi Lake fault zone and along the Fraser - Yalakom fault zone in the Yalakom River area cinnabar deposits are commonly associated with bodies of altered serpentine. Zones of shearing and faulting with resultant brecciation along the contacts has provided conduits for hydrothermal solutions migrating through the altered (silicified and ankeritized) serpentine and volcanic and sedimentary rocks. Cinnabar occurs in minute veinlets filling the fractures and coating breccia fragments and replacing the wall-rock (Armstrong, 1966).

The deposits of the Kamloops area and the Tyaughton Creek area of the Bridge River Camp and the minor occurrences along the Pinchi, Manson, and Fraser-Yalakom fault zones occur in faulted, sheared, fractured, and altered volcanic and sedimentary rocks of Mesozoic age. These volcanic and sedimentary rocks have undergone silicification and ankeritization. Cinnabar in the Kamloops deposits occurs in or at the edge of dolomite veins or stringers and in silicified rocks. In addition to cinnabar, there occur realgar, tetrahedrite, malachite, and azurite.

5. CONCLUSIONS

The Canadian Cordillera consists of five distinct longitudinal tectonic belts within which rocks are broadly similar in type, age and history. The belts are, from east to west, the Rocky Mountain Belt, the Omineca Crystalline Belt, the Intermontane Belt, the Coast Plutonic Complex, and the Insular Belt. The Cordillera is thought to have been initiated by an episode of rifting in the mid-Proterozoic. Subsequently a miogeosyncline developed along the western margin of the North American craton in the Rocky Mountain and Omineca Crystalline Belts. In late Devonian time, clastic detritus (resulting from the interaction between the North American Plate and the Pacific Plate), was shed eastward from oceanic crust into the miogeosyncline. This was accompanied by the strong development of stratiform and stratabound sedimentary - hosted lead-zinc-silver, copper and iron deposits.

In late Palaeozoic time the geological evolution of the Cordillera resulted in shelf:slope:rise assemblages in the Rocky Mountain Belt, island arc assemblages in the Omineca Crystalline Belt, oceanic or inter-arc assemblages in the Intermontane Belt, and island arc assemblages in the Coast Plutonic Complex and the Insular Belt. The geological terranes west of the miogeosyncline are inherently suspect because of the uncertainty in their palaeotectonic setting with respect to the North American craton and as such are allochthonous to the craton (Monger et al., 1972; Wheeler et al., 1972; Coney et al., 1980). This geological phase of the Cordillera is accompanied by the development of stratiform - stratabound lead-zinc-silver and copper deposits, massive sulphide deposits, skarn deposits, minor chromium and copper-nickel deposits associated with magmatic activity (for example the Trembleur Intrusions), and minor carbonatite deposits.

During the Mesozoic the western Cordillera evolved from a system of island arcs in the Triassic and Early Jurassic, through an intermediate stage of successor basins and troughs that were filled partly by detritus from actively uplifted granitic and metamorphic rocks of the Omineca Crystalline Belt and Coast Plutonic Complex, to a final stage in the Late Cretaceous and Eocene of a continental Cordillera comparable to the present-day Andes. In this period there was extensive magmatism which is related to the development of subduction zones. Porphyry-type deposits predominate. These are genetically related to both the calc-alkaline and alkaline magmatic suites. Skarn and massive sulphide mineralization also occur.

Finally, in the Miocene time, there was widespread extrusion of plateau basalts in the Cordillera. This volcanism differed markedly from the earlier calc-alkaline volcanism. This change in volcanism is related to changes along the boundary between the Pacific and North American plates (Atwater, 1970); that is, the boundary changed from a consuming margin to the present-day transform Fairweather-Queen Charlotte Fault. Only in the south is there intermittent subduction of the small Juan de Fuca plate (fig. 3.27), causing formation of volcanic rocks of the Cascades and Mt. Garibaldi. Minor mineral deposits (vein-type and porphyry-type) are associated with this last evolutionary phase of the Cordillera. The plateau basalts are nowhere known to be mineralized.

As evident from the above description, the evolution of metalliferous ore deposits in the Canadian Cordillera follows a definite pattern which began in the Precambrian, before the initiation of the Cordilleran eugeosyncline. The period from the Proterozoic to the Devonian is dominated by stratiform lead-zinc-silver, copper, and iron mineralization mainly in shelf sediments marginal to the craton. The period from the Upper Triassic to the Eocene is dominated by porphyry-type and related skarn mineralization and massive sulphide mineralization. The distribution of mineralization also follows a somewhat definite trend. The Rocky Mountain and Omineca Crystalline Belts have mainly stratiform-stratabound mineralization; some skarn deposits do occur in the Omineca Crystalline Belt especially in the northern Cordillera. The Intermontane Belt is dominated by porphyry-type deposits. The Coast Plutonic Complex has massive sulphide mineralization together with minor porphyry-type deposits. The Insular Belt is dominated by skarn mineralization with minor occurrences of massive sulphide and porphyry-type mineralization. Vein-type mineralization occurs in all the tectonic belts.

The overall tectonic environment is an important control on the sedimentation and magmatism and the related mineralization. Subduction and extensional environments in particular are favourable for the development of magmatism and the related sedimentation. The miogeosynclinal environment has very restricted and localized magmatism which is indirectly related to the mineralization. The stratiform-stratabound mineralization is mainly syngenetic or early diagenetic. The skarn deposits are only distantly related to plutons. The porphyry-type deposits are related to both types of magmatic suites. Unlike the calc-alkaline porphyry coppers, the alkaline porphyry copper deposits commonly grade into skarn deposits, they lack appreciable amounts of molybdenite, and are usually richer in gold and silver. The porphyry molybdenum deposits are mainly related to the calc-alkaline suite. Massive sulphide deposits are related to calc-alkaline volcanics; however, an exceptional deposit is that in the Pelly Mountains, Yukon Territory, which is related to highly alkaline volcanics which are thought to have been generated in an intracratonic extensional environment (Mortensen and Godwin, 1982).

In the Canadian Cordillera, much of the magmatism, sedimentation, and the related mineralization seems to be associated with regional, long-active, and deep-seated lineaments. These lineaments are expressed by surface features such as faults, fractures, the alignment of volcanic centres, or even the alignment of mining camps (see for example figures 3.13; 3.20A and B; 3.27; 4.4; 4.7; 4.9; 4.13; 4.24; 4.27; 4.29; 4.30). These lineaments may have been responsible, over a long period, for the transmission of metal bearing fluids from the mantle and/or for circulation, scavenging and recycling metals in the crust. Their continuing activity may be related, partly, to jostling of the craton during periods of change in subcrustal flow (Sutherland Brown et al., 1971).

Finally, a few significant points on the exploration criteria for the Cordillera will be mentioned. In recent years, grass roots exploration combined with geophysical and geochemical techniques has met with overwhelming success. This is evidenced by the number of recent discoveries. These are, for instance, lead-zinc-silver deposits in the Selwyn Basin, massive sulphide deposits in the Pelly Mountains, vein-gold deposits in the Intermontane and Insular Belts (e.g. the Chapelle and Cinola deposits), and porphyry Cu-Mo deposits mainly in the Intermontane Belt. Further discoveries are still going to be made because vast areas in the Cordillera are still untouched.

Exploration for lead-zinc-silver deposits in the northern Cordillera (especially the Selwyn Basin which has great potential for more lead-zinc-silver deposits) can be confined to Proterozoic-Early Cambrian carbonate and clastic rocks and to Late Cambrian - Devonian basinal shale and laterally equivalent platformal carbonates (mainly in fault-bounded basins) which have been found to be the dominant hosts of the lead-zinc-silver mineralization. Most of the deposits in the Selwyn Basin were found by conventional prospecting aided by geochemical sampling (Carne and Cathro, 1980). The main obstacle will be the locating of blind deposits beneath either thick overburden or cap rock within the camps. Geophysics is reported to have had only limited success because most of the deposits have a low sulphide content (Carne and Cathro, 1980). However where regional metamorphism has affected the deposits, as at the Anvil Camp, high sulphide iron content occurs. EM can be used as a mapping tool for tracing graphitic horizons in shales, although sulphide conductivity is usually undetectable. Lead is the most important geochemical indicator because zinc background is often so high in shales that it masks sulphide response (Carne and Cathro, 1980). In the southern Cordillera, search for these deposits can be confined to Proterozoic - Devonian rocks in three broad environments, namely: the Purcell Anticlinorium, the Kootenay Arc, and the Shuswap Metamorphic Complex. With the exception of Sullivan, the majority of these deposits seem to be very small.

There seems to be a great potential for stratiform sedimentary copper and stratiform iron deposits in the Cordillera. The transition zone between the Redstone River Formation and the Coppercap Formation seems to be the potential host for stratiform-stratabound sedimentary copper deposits. However, the post-Windermere erosion removed the two formations in a large part of the northern Cordillera. Thus search for sedimentary copper of the Redstone-type should be concentrated in down-faulted blocks where these two host formations might be preserved. This is supported by the fact that the Redstone Copper deposit is preserved in a down-faulted block. Search for stratiform iron deposits of the Crest-type should be confined to the Rapitan Formation and its correlatives, especially where there is the occurrence of the distinctive diamictitic conglomerates. The fact that the Rapitan Formation and its correlatives are extensive lends itself to the possibility that there is a potential for more stratiform iron deposits.

Although the host rocks are thought to be glacial (Aalto, 1971), it is unlikely that the Fe was derived from a continental source but more likely that it was volcanogenic (Gabrielse, 1972).

Massive sulphide mineralization in the Canadian Cordillera is thought to be genetically related to island arc volcanism. No spreading centre, Cyprus-type deposits of ophiolitic affiliation have been recognized. The majority of known deposits are found in Upper Triassic to Middle Jurassic volcanic rocks that flank or lie within the Coast Plutonic Complex. The potential geological environments for massive sulphide mineralization are well known and thus will not be mentioned here. However, the recommendations of Sullivan (1978) will be re-iterated here: that is, exploration for massive sulphides should also be concentrated in pyritized rhyolites, rhyolite-andesite contacts, rhyolite-sedimentary transition zones, rhyolite breccias, and rhyolitic fragmentals. It should also be mentioned here that excessively restrictive criteria should not be set for the identification of potential massive sulphide environments as some massive sulphide mineralization may occur in highly alkaline or peralkaline volcanic rocks.

Exploration for porphyry-type deposits is staightforward. The favoured locale of these deposits in the Cordillera is a sub-volcanic environment of magmatic intrusion and differentiation. These intrusions, which are separate from the great plutonic complexes, range in age from 200 to 50 Ma. The intrusions younger than 50 Ma host minor deposits. In the search for porphyry copper deposits of alkaline affinity, search should also be made for skarn deposits especially where Upper Triassic carbonate reef complexes occur within the contact aureole of large plutons of any age. In the Whitehorse Trough, the Late Cretaceous and Eocene suites seem to be highly anomalous in base metals. Thus exploration for porphyry, vein, and Pb-Zn skarn and replacement deposits can be concentrated near subvolcanic phases of the Late Cretaceous and Eocene suites.

The dominant metallogenic provinces for skarn deposits seem to be the northeastern Cordillera (especially the Selwyn Mountains, where the Cantung, Mactung, Clea and MacMillan Pass deposits occur), the Intermontane Belt, and the Insular Belt. The Selwyn Mountains have mainly tungsten-tin skarns, the Intermontaine Belt has copper-iron-(tungsten) skarns, and the Insular Belt has iron skarns. The important exploration criterion for tungsten-tin deposits in the northern Cordillera is that these deposits are associated with granitic rocks of quartz monzonitic composition) which appear to have high initial $^{87}Sr/^{86}Sr$ ratios and which were generated in Late Cretaceous time. Similar exploration criteria can aid in the search for these deposits in the other belts.

Exploration for vein-type deposits is a rather difficult task. In particular, the deposits without moderate to high sulphide mineral contents constitute one of the most difficult targets for modern exploration techniques. This is particularly true for the Carlin-type gold deposits. However, Champigny and Sinclair (1982) suggest that Au, Ag, Hg, and As are potential elements to determine in geochemical exploration for Carlin-type deposits similar to the Cinola deposit of Queen Charlotte Islands. In general, the regional guide in exploring for gold deposits in the Cordillera appears to be their localization in eugeosynclinal environments at or within the margins of the major crystalline belts, as most of the major placer and lode gold deposits occur in such environments (see fig. 4.10; Barr, 1980). One other feature of vein-type deposits is that they are usually related to major fault zones (for example the British Columbia mercury deposits) and fault splays (Cinola deposit).

In conclusion, it must be emphasized that the exploration criteria mentioned above are not in any way exhaustive, especially for a topic as big as this. The increased geological understanding of mineral deposits in terms of plate tectonics, the further development of exploration models and the use of plate tectonic reconstructions in metallogenic speculations will enhance the probability of more discoveries in the Canadian Cordillera.

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