STRUCTURAL GEOLOGY

TECTONIC FRAMEWORK

The relative position of the idealized tectonic elements of the region is illustrated on Figure 1. From west to east these elements include the Wrangell-Revillagigedo Metamorphic Belt, the Coast Plutonic Complex, and the Bowser Basin. The Bear River Uplift involves part of the Whitehorse Trough as well as part of the Bowser Basin and includes minor elements like Stewart Complex, Oweegee Dome, and Ritchie anticline. The terms Bear River Uplift, Stewart Complex, and Meziadin Hinge have been introduced in order to describe these structural elements within the regional framework.

**Bowser Basin:** The Bowser Basin evolved from the parent subtrough through geologic time as the result of the interplay of tectonic, volcanic, sedimentary, and igneous events which have produced a northwest-trending sedimentary basin about 150 kilometres wide and up to 500 kilometres long. The area of the basin is about 75 000 square kilometres, which in terms of basin size is considered moderate; the depth, based on unit thicknesses proposed by various workers in the area, appears to be variable. The basin is situated in a tectonically active zone; there are repeated periods of deposition, plutonism, uplift, and erosion revealed in the geologic sequence (Fig. 14).

Presumably the present Bowser Basin was initiated by Late Triassic time. Rocks exposed along the periphery include Middle Mississippian, Pennsylvanian, and Permian rocks which in part unconformably overlie an older complex (Fig. 7). Upper Jurassic Nass Formation marine sediments now cover a large part of the original basin. In the eastern Bowser Basin these sediments are generally overlain by nonmarine Cretaceous and early Upper Tertiary sediments which include some coal members. During the evolution of the Bowser Basin, the margins were marked by intrusive activity in Paleozoic, Triassic, Jurassic-Cretaceous, and Tertiary time (Grove, 1968a).

**Discussion:** The Bowser Basin is infilled by a thick succession of marine, brackish, and freshwater shales, greywackes, and conglomerates. These comprise the Bowser assemblage of latest Late Jurassic and Early Cretaceous age (Souther and Armstrong, 1966). Douglas (1970, p. 438) suggested that following the Nassian orogeny (Fig. 14) in the Western Cordillera, three discrete depositional basins, including the Bowser Basin, were developed. Fitzgerald (1960) stated:

'Superficially, the Bowser Basin is characterized by intensely folded sedimentary rocks ranging in age from Lower Jurassic to Lower Cretaceous.'

In the Smithers area Tipper (personal communication) re-examined the stratigraphic sequence. There a mainly sedimentary unit overlies tuffs and breccias that range in age from Middle Jurassic to early Late Jurassic. In the northern part of the Smithers area, Tipper also identified marine and nonmarine late Early Cretaceous (Albian) Skeena Group sediments that overlie the Late Jurassic rocks either unconformably or disconfor-
mably. This interpretation of the Mesozoic stratigraphy renders earlier published concepts of the age and extent of the Bowser Basin invalid.

**Bear River Uplift:** The term Bear River Uplift has been introduced for a physiographic-geologic unit that is bounded by the granitic coastal Boundary Ranges of British Columbia and Alaska on the west and the sedimentary Skeena Mountains on the east. The northern limit of this uplift is represented by the Iskut River valley and the southern margin by a low divide between Alice Arm and the Nass River. This physiographic unit includes minor mountain ranges which are higher than the adjacent coastal Boundary Ranges and Skeena Mountains and have extensive icefields. The Bear River Uplift is defined as a structurally controlled feature that has been uplifted and eroded at a faster rate than immediately adjacent basin sections. Lower to Middle Jurassic and older sedimentary, volcanic, and metamorphic country rocks occur within the limits of the Bear River Uplift. Blankets of mainly Upper Jurassic marine sediments deposited during the late phase of development, have been largely eroded, but trough-like sections of them are preserved as structural remnants within the uplift. The western portion of the Bear River Uplift has been named the Stewart Complex.

**Stewart Complex:** The Stewart Complex lies along the contact between the Coast Plutonic Complex on the west, the Bowser Basin on the east, Alice Arm on the south, and the Iskut River on the north (Fig. 1). A complex, as defined by the American Commission on Nomenclature (1961, p. 651), is composed of diverse rock types of many classes and is characterized by complicated structure. The Stewart Complex contains abundant diverse metallic sulphide mineralization.

The west boundary of the Stewart Complex is the contact with the Coast Plutonic Complex. The Leduc River sections expose old structures which have been truncated. The intrusive contact is generally steep, but satellite Tertiary plutons suggest that the Coast Plutonic Complex underlies part of the Stewart Complex at depth. It is suggested that the Anyox and Georgie River pendants represent an intrusive level comparable to the projected deep contact between the Stewart Complex and underlying intrusives in the Unuk-Leduc section.

The northern boundary of the Stewart Complex lies approximately along the Iskut River. Extensive deformation along the easterly trending Iskut River valley defines a major structural zone involving thrust faulting of Paleozoic strata south across Middle Jurassic and older units and younger tear faulting which has offset the northerly trending Forrest Kerr-Harrymel Creek fault. The junction of the easterly Iskut River zone, the Forrest Kerr-Harrymel zone, and the north-northeasterly Iskut River zone marks the vent of the Quaternary Iskut River lava flow. The southern limit of the Stewart Complex is marked by a line of Quaternary volcanic flows that occur just south of the east-northeasterly trending Alice Arm-Illiasa River lineament.

The Meziadin Hinge marks the eastern limit of the Stewart Complex from the Nass to the Iskut River, and also partly represents the physiographic boundary between the Nass Basin and the Boundary Range mountains (Fig. 1). It also roughly marks the easterly limit of the extensive lower Middle Jurassic Betty Creek Formation. It is possible that the major Fraser-Yalakom fault extends along the eastern margin of the Coast Plutonic Complex from southern British Columbia through Terrace to Tulsequah (Campbell, personal communication). Thus, the Meziadin Hinge may represent a 225-kilometre-long segment of this fault and may be related to the Denalai fault system of Alaska and the Yukon.

In summary, the Stewart Complex is bounded on the west by the intrusive margin of the Coast Plutonic Complex and on the south, east, and north by high-angle normal faults which are major tectonic features. It appears that the the Stewart Complex has been essentially frozen to the east margin of the Coast Plutonic Complex and has been involved in uplift along with the Coast Geanticline, whereas the adjacent basin is separated by normal faults and exhibits a relative depression.
STRUCTURAL RELATIONS BETWEEN FORMATIONS

Late Triassic and Older: The oldest fossiliferous rocks identified in the study area range from Karnian to Norian age and are found west of the Unuk River at McQuillan Ridge and west of Harrymel Creek. The McQuillan Ridge member is tightly folded in detail, but the major structure appears to represent an open, northeasterly trending anticlinal fold. At Gracey Creek northerly trending amphibolite-grade gneiss is overlain unconformably by comparatively fresh, well-bedded, northeast-trending Karnian sediments and basalt flows. Crushed equivalents of these Karnian rocks are found along parts of the west side of Gracey Creek immediately above the gneisses. The creek appears to follow a deformed 30-metre-wide breccia zone which probably represents a major fault. The attitude of the fault zone is difficult to determine, but lineations in the Triassic rocks plunge northerly at about 18 degrees, suggesting a low-angle fault plane that is roughly coincident with the east slope of Gracey Creek. The fault may be a thrust, which would be in keeping with compressional conditions in Oweegee Dome to the east. Both the gneiss zone and the Late Triassic rocks are truncated on the west by a salient of the Hyder pluton; there is little attendant deformation and a narrow contact metamorphic zone.

With the exception of the 3-kilometre-wide section between the south Unuk River and Gracey Creek and at Shirley Mountain, the contact between the Triassic rocks and the overlying Lower Jurassic Unuk River Formation is marked by an extensive cataclasite zone. In Gracey Creek area thick-bedded Lower Jurassic strata form northerly plunging slabs that overlie both the gneiss and Triassic sediments with fault relationships. At Shirley Mountain metamorphosed Triassic or older rocks are unconformably overlain by Lower Jurassic sediments and pillowved volcanics. The relationships between the Late Triassic and Jurassic rocks along the west limit of the Unuk River sheet are obscured by the Frankmackie Icefield, Quaternary volcanic flows, and the effects of deformation and plutonism.

Relations between Late Triassic rocks and the older gneisses imply that simple compressional folds were developed before the Karnian rocks were thrust over the gneisses. Lower Jurassic Unuk River Formation rocks are generally in fault contact with the Late Triassic and older rocks, as, for example, at Gracey Creek where the contact is a normal fault. Later cataclastic deformation along the Leduc-South Unuk-Harrymel lineament obscured contact relationships between the Triassic and Jurassic rocks along most of the zone.

Souther (1971) named the mid-Triassic uplift, folding, metamorphism, and plutonism, which affected the northwestern Cordillera, the Tahltanian Orogeny (Fig. 14). It is roughly equivalent to White's (1959) Cassiar Orogeny, which marked the close of mid-Triassic volcanism and preceded Late Triassic volcanism and sedimentation. Formation of the gneiss belt along the margin of the Coast Plutonic Complex between Leduc River and Gracey Creek may be correlated with the Tahltanian orogeny, although Hutchison (1970) also indicates a pre-Permian age for part of the Central Gneiss Complex.

Jurassic: Relationships between various formations comprising the Jurassic Hazelton Group are generally simple; extensive Tertiary erosion has exposed the contacts. Within the Lower Jurassic Unuk River Formation interruptions in sedimentation and volcanism are marked by unconformities with conglomerate units such as are seen at Twin John Peaks, on Mount Shorty Stevenson on Bear River Ridge, and on Mount Rainey east of Stewart. The Unuk River Formation is folded, deformed, and separated from the early Middle Jurassic Betty Creek Formation by a regional angular unconformity, first recognized north of Stewart at Betty Creek. The Salmon River sequence was deposited on the Unuk River and Betty Creek Formations following limited deformation and during graben and half-graben development which produced an uneven surface. The Upper Jurassic Nass River Formation, which includes a basal, granodiorite-bearing cobble conglomerate, was deposited unconformably across the underlying Salmon River Formation; the contact is best displayed along the Meziadin Hinge. Extensive, narrow trough-like
accumulations of Salmon River and Nass River formation sedimentary rocks, marked by gravity slide features, illustrate almost continuous graben tectonics during these periods of marine sedimentation.

In the Stewart Complex the Lower Jurassic strata were deformed and intruded prior to lower Middle Jurassic sedimentation. Because of this relationship and the fact that the Middle Jurassic strata are relatively undeformed, it is suggested that Early Nassian Orogeny (Fig. 14) was mainly responsible.

The absence of Cretaceous and Tertiary strata in the Stewart Complex and in large parts of the western Bowser Basin reflects the extensive uplift and erosion that accompanied Late Laramide Orogeny.

**Quaternary:** Excluding glacial deposits and unconsolidated recent sediments, basalts in the Unuk River and Alice Arm districts are the only known Quaternary deposits in the general area. These are unconformable on all older rocks and appear to be related to tensional volcanic belts localized along graben-like features that originated in Tertiary time (Fig. 1).

**Summary:** There have been several distinct periods of metamorphism, plutonism, volcanism, and sedimentation in the area. The intensity of deformation has apparently decreased after the mid-Triassic Tahltanian Orogeny, but plutonism increased and climaxed in Tertiary time.

### MAJOR STRUCTURES IN THE STEWART COMPLEX

**Unuk River Folds:** The well-bedded mixed volcanic-sedimentary sequence exposed along the east wall of the South Unuk River valley extends northwesterly from the Tertiary intrusive contact at the South Leduc Glacier on the south to the vicinity of Twin John Peaks. At that point the sequence swings northeasterly toward Star Lake, then sharply southeast into the Treaty Glacier area. The main belt of exposed Unuk River Formation and scattered windows in the Frankmackie Icefield, form a major, north-northwesterly trending domical structure that extends from the Bowser River through Brucejack Lake toward the head of Storie Creek. Structural cross-sections (Fig. 3) illustrate subparallel, asymmetric north-northwesterly trending warps within the dome. Along the western flank of the dome major folds are mainly homomorph (Belloussov, 1960) similar folds inclined to the west. At Gracey Creek, there is a deformed, upright slab of Unuk River Formation; comparable strata along Harrymel Creek dip easterly and are preserved segments of an eroded, deformed syncline. In the Mitchell-Sulphurets Creek window, the major structure is a simple antiform or warp lying parallel to the axis of the major dome, which has been fragmented by plutons and faults.

**American Creek Anticline:** The American Creek anticline is one of many regional warps that have involved rocks of the Lower Jurassic Unuk River Formation. The fold is open and slightly inclined (Grove, 1971, Fig. 4). The northern axial section of the anticline is well exposed in American Creek and in Bear River Pass. North of Stewart, at Mount Mitre, it plunges about 15 degrees northwest under younger sediments. Southeast of Stewart the structure is partly exposed in the Bromley Glacier area where overlying Salmon River Formation rocks have been eroded.

**Bear River Pass Folds:** The general structure, based on observations at Bear River Pass (Fig. 2B) and in valleys north and south of the pass, defines a uniformly gentle, east-dipping sequence that is marked by gentle warps. The Mount Pattullo and Willoughby Creek sections, which lie along the eastern limits of the Stewart Complex, have not been studied in detail, but are apparently a warped easterly dipping essentially homoclinal succession, like that at the Bear River Pass and Alice Arm sections.
**Georgie River and Maple Bay Folds:** The Georgie River pendant includes a more or less uniform sequence of westerly to northwesterly trending epiclastic volcanic and sedimentary rocks that dip steeply to the south. No major folds were recognized but margins of the pendant are hornfelsed and the sequence has been extensively deformed and faulted.

At Maple Bay the Lower Jurassic pillow lava sandstone-carbonate sequence forms an open, northerly trending syncline. Deformation and normal faulting have reduced the syncline to parallel, northerly trending, fault-bounded segments. Many Tertiary plutons transect the older folds; these leave the structure essentially undisturbed.

**Alice Arm Folds:** Hanson (1935, p. 24) suggested that the entire Alice Arm district appeared to be a northerly trending anticline. Mapping by Carter (personal communication) disclosed northerly trending major folds in the rocks that underlie most of the area.

**Mount Rainey Syncline:** The Mount Rainey syncline represents a structural remnant that is underlain by intrusives, unconformably overlain by deformed Middle Jurassic Salmon River strata. Along Portland Canal, an apparent continuous homoclinal succession of green volcanic conglomerates dip easterly at a moderate angle. Thin-bedded members intercalated with these rocks were traced into the Marmot Glacier area where steep north dips prevail; they outline as a northeasterly trending asymmetrical fold overturned to the east and plunging northeasterly at about 60 degrees. Dragfolds and lineations mapped in thin-bedded sandstones in the Marmot River section show a steep northerly plunge.

**Mount Bunting Syncline:** The Mount Bunting syncline has been partially exposed on the upper east slope of Mount Bunting by recent ablation of ice and snow. The rocks forming the synclinal remnant consist of well-bedded red and green Hazelton volcanic sandstones and conglomerates, and minor breccias. Strata forming the west limb trend north-northwest with steep to vertical dips; beds along the east limb dip north at 30 degrees to 70 degrees. The axial plane of the syncline trends north-northeast and minor structures show that the fold plunges northeast at about 80 degrees. At the head of Donahue Creek the strata forming this minor fold trough unconformably overlie part of the lower Unuk River succession.

**Summit Lake Folds:** Westerly trending folds, that form a second set of minor structures, occur in Hazelton epiclastic volcanics along the west side of Summit Lake and in the Big Missouri Ridge section. Most of the epiclastics west of Summit Lake are thick-bedded conglomerates. Thin-bedded siltstones within the succession are well exposed north of August Mountain Glacier, where minor folds plunge at about 60 degrees west. Other west-plunging minor folds were mapped in fine-grained, thin-bedded, tuffaceous volcanic sandstone on Big Missouri Ridge, west of Fetter Lake, where quartz sulphide lenses similar to Big Missouri-type mineralization have been explored. The mineralization appears to be localized along axial planar fractures in the sandstones.

**STRUCTURES IN HAZELTON ROCKS:** Members of the Hazelton Group in the Stewart Complex form elongated, lenticular masses. In the third dimension as well they are apparently lenticular and illustrate what can be termed grossly a maceral structure in which each lens overlaps the others. Weak foliation, minor folds, and some lineations are variably developed in all the members of the assemblage. The degree of deformation depends on rock particle size and competency.

**Foliation:** Foliation, which includes all secondary planar structures, has developed in a number of ways with varying degrees of complexity. Least deformed cataclasites of shiny green, grey, or purplish laminations that transect primary features have been caused by smearing of the matrix. In mylonites, foliation laminae are more pronounced and accentuated by fine mineral layers. Semi-schists and schists developed in the Salmon River valley area exhibit planar structure resulting from the development of metamorphic minerals.
Well-foliated gneisses are rare, but alternating feldspar-hornblende laminations may occur along the margins of the plutons. Foliated rocks are largely in the contact zones of plutons or dykes. The large cataclastic zones developed in certain Hazelton members pre-date plutonism.

**Minor Folds:** Small open folds characterize the fine-grained strata, whereas major folds formed in the thick, coarse-grained beds. As a result, small-scale folds are most abundant in areas, such as Big Missouri Ridge and Summit Lake, where fine-grained members are prominent. Minor folds in medium-grained Hazelton strata west of Bear River Ridge have upright axial planes and plunge steeply west. East of American Creek, where the rocks are uniform sandstones, minor folds are open undulations plunging easterly at a moderate angle. South and east of Bear River the rocks are generally coarse grained and massive except in the Marmot River area where minor folds in thin-bedded, fine-grained sediments plunge steeply north.

**Lineation:** Outside the main cataclasite zones, lineation is not a conspicuous structural element in the area. Linear elements in the deformed volcanics are largely elongate rock and mineral clasts, and grooves in the foliation planes, which reflect lenticular mineral clumps. In the Unuk River and Cascade Creek areas lineations are more variable than elsewhere, but are crudely subparallel to minor fold axes.

**Summary:** The heterogeneous nature of strata of the Unuk River Formation resulted in variable responses to deformation. Except for local schist development, mineral recrystallization has not been a major feature of the overall deformation. Uniform structural features, combined with the evidence for limited recrystallization, suggest that deformation was related to a regional tectonic event, the uplift of the Coast geanticline, and related plutonism during the early phase of Nassian Orogeny.

**BETTY CREEK STRATA:** Folds in Betty Creek rocks are mainly large open flexures related to erosional troughs formed in Lower Jurassic and older country rocks. Thin wedges of fossiliferous Betty Creek conglomerate blanket the eastern flank of the Bruce-jack Dome; these form remnant, northeast plunging, synclinal sheets that are overlapped by younger formations at Treaty Creek. The bulk of the Betty Creek Formation, which extends from Treaty Glacier to the Bowser River at Mount Jancowski, is an open, basin-like syncline that plunges at a shallow angle to the southeast. From Mount Jancowski south to the top of Bear River Ridge opposite Bitter Creek, the Betty Creek Formation is a tighter syncline. The Jancowski syncline has its strongest development along the 3 000-metre-high Mount Jancowski-Mitre Mountain massif; the Betty Creek Formation thins rapidly to the south, roughly along the axis of the Divide-Long Lake valley. The Jancowski syncline is asymmetric and overturned slightly to the east; from the top of Bear River Ridge at Mount Shorty Stevenson, the canoe-shaped syncline plunges northerly toward the Bowser River at a shallow angle. At Bowser River it is transected by a series of south-side-down normal faults. The total length of the syncline, from Treaty Glacier to the top of Bear River Ridge, is 60 kilometres; it is one of the largest features in the area.

In the Bear River Pass section Betty Creek strata blanket the Lower Jurassic sequence, filling in the old erosional surface, and as a result, Betty Creek rocks have been left as irregular, slightly warped erosional remnants.

In the Alice Arm district, correlatives of the Betty Creek strata blanket part of the easterly flank of the Lower Jurassic rocks much as they do in the Bear River pass section.

At Anyox, the volcanic flow and pillow lava sequence defines northerly trending open asymmetric folds that are moderately overturned to the east, like the Jancowski syncline. Parallel folds in the pillow volcanic sequence at Anyox have an important bearing on the present location of ore deposits. A major fold that involves overlying Salmon River Formation rocks has been called the Bonanza syncline (Fig. 2C).
Summary: Rocks comprising the Betty Creek Formation were deposited as a thick blanket on the folded, faulted, and eroded Lower Jurassic Unuk River Formation. Normal faulting and pre-late Middle Jurassic uplift and erosion have left irregular remnants of Betty Creek strata in the area. Major folds in the Betty Creek Formation are restricted to a northerly trending belt along the central part of the Stewart Complex, where extensive northerly trending faults also are localized. Minor folds, lineations, and foliations are rare.

SALMON RIVER STRATA: Bajocian Salmon River strata comprise the northerly, easterly, and southerly limits of the study area; like Betty Creek strata, rocks of this unit are found as erosional remnants on the older rocks from Iskut River south to Alice Arm.

Large outliers of Salmon River Formation are shown on the geological maps at Sulphurets Creek, Bowser River, Bear River Ridge, Bitter Creek, and in the Anyox and Alice Arm districts. These remnants are all synclinal marking fault-controlled trough-like basins of deposition in underlying Betty Creek and Unuk River strata. These depositional basins generally trend northerly to northwesterly and, where best exposed, usually contain upright, canoe-like folds. They have all been subjected to variable amounts of plutonism, metamorphism, deformation, and alteration.

Along the northern limits of the Stewart Complex the edge of the overlying Salmon River Formation has been mapped in some detail (Fig. 2A). The finger-like extensions of these rocks across the older strata are localized along fault or shear zones where erosion in the Betty Creek and underlying Unuk River rocks was more extensive. Salmon River rocks and younger Nass strata in this area display a disharmonic, nonplanar, noncylindrical fold pattern (Badgley, 1965, pp. 50–94). The Dillworth Syncline typifies structures in the Salmon River strata.

Mount Dillworth Syncline: The Mount Dillworth syncline lies in a parallel structural trough astride the westerly limb of the American Creek anticline. The fold is open, slightly inclined, and exhibits fold disharmony typical of structures involving strata of variable competency and thickness. Overall, the fold has a canoe-like shape with the ends resting on the south shoulder of Mount Mitre and on Bear River Ridge at Mount Shorty Stevenson. From the northerly apex of the fold on Mount Mitre, the structure plunges south into Betty Creek at about 40 degrees. The keel section has a maximum thickness of about 1 800 metres in the Mount Dillworth section. The plunge of the syncline north from Mount Shorty Stevenson is about 25 degrees. The contact between Salmon River and older rocks outlines the Dillworth syncline (Grove, 1971, Fig. 3), and displays several complex digitations.

Salmon River siltstones and greywackes overlying competent Hazelton epiclastic volcanics illustrate fold attenuation at the south end of Summit Lake, whereas the smooth, apparently conformable zone along the west side of American Creek represents a contact between physically similar rock types. Minor folds are visible on all scales and many are disharmonic. In these rocks the minor folds are difficult to trace because of the general lack of marker horizons. Complex folds mapped west of Little John Lake on Troy Ridge are perhaps the best examples of disharmonic folds in the sequence (Grove, op. cit., Plate XI).

Minor Structures: Salmon River strata are preserved as structural remnants lying in contorted trough-like or canoe-shaped depressions in the underlying Hazelton. These troughs are largely tectonic, but they partly reflect Middle Jurassic erosion. The sediments deposited in these depressions were thick and because of subsequent deformation have been preserved from erosion.

Cleavage: Cleavage is a conspicuous feature in the thinly laminated argillaceous siltstones of the Salmon River assemblage. Phyllites are prominent at Slate Mountain, where the siltstones unconformably overlie Hazelton epiclastics and cataclasites. At the south end of Slate Mountain cleavage is generally horizontal, cutting across the steep axial planes of minor folds. Cleavage is also apparent as a thin phyllitic zone developed below and parallel to the unconformity in underlying Unuk River Formation strata. To the north
cleavage patterns show no direct relationship to the minor folds. Well-developed cleavage south of the Long Lake dam and along the west side of Slate Mountain cuts across all visible minor fold axes parallel to a small, steep, northerly trending fault (Grove, op. cit., Fig. 3). Phyllitic siltstones are well developed along this section, and the fault-related cleavage has been superimposed on an undulating, contact-controlled cleavage. The foliations are related to thrust faulting and to sliding of Salmon River strata across the old surface with the production of slip cleavage.

Minors Folds: Folds of different styles are visible at various scales in almost all the Salmon River rocks. In size, the minor folds range from centimetre scale, complex folds to simple troughs up to 8 kilometres long. The multitude of structures precludes using a simple nomenclature such as was used for folds in the older Hazelton rocks. Instead, generalized groups of folds are named and described with examples in the following paragraphs.

Small-scale ripple-like structures occur in thinly striped grey to buff argillaceous siltstones to 2 centimetres. In all the laminae examined the peaked crests indicated stratigraphic such as are exposed at the south end of Slate Mountain; the amplitude seldom exceeds 1 tops. Where completely exposed these structures exhibit separate peaks rather than the elongate ripple wave form. In foliated laminae, the ripple-like structures are asymmetric and disharmonic.

Folds larger than centimetre scale but less than 25 metres in amplitude are found in all Salmon River Formation siltstones. These vary in form from simple, open, upright flexures to complex, rigidly recumbent folds. These structures are generally restricted to thin-bedded siltstones intercalated in sandstones. The small-scale isoclinal folds are typically found where the containing sandstone members are strongly flexed, such as in the crest of a fold. Flexure folds are common on Mount Dillworth in siltstones within the sandstone unit.

Complex isoclinal fold zones are most common in thick siltstone units in which there are faults and igneous intrusions. The Glacier Creek-Maude Gulch section exemplifies such a zone, and complex, large amplitude isoclinal folds abound.

Folds with amplitudes greater than 25 metres are common in siltstone members within the Dillworth syncline. These can be mapped by using marker horizons and are also traceable on air photographs. Grove (op. cit., Fig. 2) shows the most prominent of these minor folds. Along the west side of the main trough these folds are generally asymmetric with Z and box-like geometry. At Long Lake folds plunge northerly; on the north slope of Mount Dillworth they plunge southerly into the trough. To the east, toward Bear River Ridge, the folds become upright. The folds show both concentric and similar styles. Canoe-folds at outcrop and larger scales are common in the Divide Lake area.

Hidden Creek Syncline: The Hidden Creek syncline at Anyox represents one of the smaller Salmon River structural remnants, but economically is the most important yet found. All major known massive sulphide deposits in the Anyox pendant lie at, or near, the contact between the pillow volcanics and the overlying siltstones. At the Hidden Creek mine (Hanson, 1935, p. 9) suggested that the argillites (Salmon River Formation) dip easterly at surface, then westerly to a depth of 600 metres. Nelson (1948) concluded that these sediments, although folded, dipped westerly under the ‘amphibolites’ which intruded the sedimentary sequence.

The supposed ‘intrusive amphibolite’ at Anyox is a thick pillow volcanic sequence that is in part conformably overlain by a thick calcareous siltstone and greywacke sequence. The major northerly trending ‘Anyox’ syncline includes both the pillow volcanics and the overlying siltstones. The restricted, highly folded, northerly trending belt of Salmon River siltstones lying along the west side of Hastings Arm comprises the Bonanza syncline (Fig. 2C).
The Bonanza syncline is a shallow plunging structure, and, like the Dillworth syncline, is overturned to the east. Minor folds in the rocks are disharmonic, nonplanar, noncylindrical folds with noncylindrical axial surfaces. The axial plane area of the fold between Cascade and Bonanza Creeks has been penetrated by Tertiary plutons; these deform an already complexly folded section. Contacts show a variety of small-scale features developed in both the underlying pillow volcanics and the overlying sediments. In the axial zone at Bonanza Creek the pillow lava sequence is gradational through banded cherts into the overlying calcareous siltstones. On the east limb of the syncline, pillows are sharply flattened parallel to the fold axis; pillows along the upright to overturned west limb are less flattened. Minor folds are variably developed south of Hidden Creek and foliation and lineation are virtually absent in the broad open fold to the north.

Summary: Fold structures in Salmon River strata are related to plutonic emplacement and gravity tectonics. Plutonism was most significant at the margins of the plutons and in the dyke swarms. The maximum observed width of a deformation halo around an intrusion is about 1500 metres along the margin of the Texas Creek pluton. At Anyox, deformation related to the plutons is minor and apparently restricted to the axial zone of part of the Hidden Creek syncline.

Gravity tectonics played a major role in the development of fold structures in the Salmon River strata and produced numerous slump features and minor fold structures within the stratigraphic sequence. These structures, which are found throughout the Salmon River sequence, indicate a close relationship between deformation and basin subsidence.

CATACLASITE ZONES

Several major cataclasite zones have been mapped in the Stewart Complex (Figs. 2 and 13). These zones were not recognized by earlier workers and they were important in localizing certain mineral deposits. It is significant that none of the cataclasite zones mapped extend into strata of the Betty Creek or Salmon River Formations. Also, as shown on Figure 2, the cataclasites were largely, if not exclusively, confined to a sequence consisting of acid lava, mixed conglomerate, sandstone, and limestone.

South Unuk Zone: The South Unuk cataclasite zone has been traced from the South Leduc Glacier, where it is cut by Tertiary granite, north along the west slope of Granduc Mountain to the west slope of Mount George Pearson, where it lies between the thick pillow volcanic unit and the hornblende diorite stock. It then continues northwesterly toward the lower east slope of the South Unuk River and past the Unuk River junction to join the narrow Harrymel Creek fault zone, which appears to die out toward the Iskut River. In this 45-kilometre length, the zone of deformation includes, or follows, the carbonate-rich sequence of the Unuk River Formation, has a steep to vertical dip, and strikes northerly to northwesterly, essentially parallel to attitudes of the involved members. At Granduc Mountain, the zone is bounded on the west by north-trending, steep-dipping gneisses and on the east by faulted massive pillow volcanics and foliated thick volcanic conglomerates. In this 2-kilometre-wide section the zone includes a diverse group of metamorphic rocks consisting of calc-silicate cataclasites and mylonites, pelitic mylonites, ultramylonites, blastomylonites, boudinaged carbonate lenses, and phyllomites, as well as the extensive sulphide lenses that constitute the Granduc ore deposit. The zone has been intruded by northwesterly trending Tertiary Hyder phase dykes and cut by northerly trending graphitic fault zones that offset these dykes and the orebodies. At Sawyer Glacier, the zone includes two deformed syenite stocks as well as the mixed sedimentary-volcanic sequence consisting of limestone lenses, tuffaceous sandstones, cherts, andesitic volcanic flows, and quartz boulder and cobble conglomerates. Toward Unuk River, where the amount of limestone and fine-grained sediments decreases, the cataclasite zone narrows rapidly; at Harrymel Creek it is a narrow, vertical, chloritic schist zone.

At Granduc Mountain dark and light mineral segregations produce a well-developed colour banding in the cataclasite zone. This banding typifies most of the length of the zone.
and extensive underground mine workings provide outstanding examples of metamorphic differentiation by mechanical deformation (Plate XIII). Although Prinz and Poldervaart (1964) suggested that distinctly layered mylonites are rare, the Unuk River, Cascade Creek, and Maple Bay cataclasite zones are characteristically so well layered that they have generally been described as volcanic tuffs, sediments, and schists in the older literature (Norman, 1962). Most of the limestone lenses or bands within the deformed zone are boudinaged and tightly folded, as illustrated on the geological maps (Figs. 2A and 2B). Some of these lenses have been deformed, producing simple tight folds with crests thickened up to 10 times the thickness of the stretched limbs; extensive 6-metre-thick lenses have been partly balled up to form 120-metre-thick piles. Other large features in the zone include crushed syenite stocks, now seen as lumps of broken coarse red microcline crystals in a mylonitic feldspar matrix. Diorite dykes and stocks in the zone are boudinaged and crushed to an extent that they are now kakirites. Rhyolite, chert, and quartz cobbles and pebble conglomerate lenses traced from the Sawyer Glacier area into the Granduc Mountain section are represented by the weakly foliated, thick ultramylonite lenses in the sulphide ore zone. Definite relationships have not been established between all the primary and deformed units. Sulphide and oxide bodies within the zone are also deformed; they are preserved as overlapping, pancake-like lenses within the mylonite-phyllonite-ultramylonite sequence.

Layering, colour striping, and banding of rocks in the South Unuk cataclasite zone reflect the mineral differentiation effected by the deformation. Unaltered, broken, or rolled layers of brown hornblende form the darker bands, broken angular diopside and epidote form green layers, and quartz, feldspar, and recrystallized calcite form light-colored layers. Recrystallization appears to be restricted to calcite, quartz, apatite, and magnetite (excluding sulphide minerals) with very fine-grained fresh brown biotite prominent as discrete folia in the phyllonite layers. Lenses and streaks of recrystallized quartz are characteristic of the phyllonites; these were originally constituents of pebble conglomerates (Plate XV).

Discussion: Knopf (1931) and Theodore (op. cit.) suggested that the physical conditions that existed during mylonitization can be determined by a study of phase petrology and textural relations of the mineral components. The minerals in the pelitic and calc-silicate mylonites forming a large part of the South Unuk cataclasite zone remained stable, whereas minerals in the carbonate lenses underwent complete recrystallization. Limestone samples from the cataclasite zone contain about 0.23 per cent MgO; using Theodore's (op. cit., p. 444) temperature calibrations for Mg content of calcite in dolomitic marble, this indicates that deformation in the Unuk River zone took place at temperatures less than 300 degrees Celsius. Epidote remained stable throughout the zone, and only biotite in the phyllonites indicates minor recrystallization of hydrous phases. The evidence suggests that much of the rock in the zone deformed by shear at low temperature rather than by plastic flow in the presence of an aqueous fluid phase where rock strengths are negligible.
The zone cuts Lower Jurassic rocks but, at the head of Harrymel Creek, it is overlain by Middle Jurassic sediments. It is suggested that the cataclasite zone developed as a result of local tectonic overpressures related to Middle Jurassic or earlier plutonism, represented near Stewart by the Texas Creek intrusion and evidenced in the Unuk area by granodiorite boulder conglomerates at the base of the Middle Jurassic Salmon River Formation.

**Cascade Creek Zone:** The Cascade Creek zone extends 12 kilometres along the lower west slope of Bear River Ridge between Mount Dolly and Mount Dillworth. The maximum width of the zone is 2 kilometres along the Cascade Creek section immediately north of the Alaska border.

The Cascade Creek unit includes cataclasites, mylonites, minor kakirites, semischists, and panels of country rock. The zone trends northerly and is convex to the east; minor structures in the zone indicate an overall moderate to steep westerly dip. Foliations vary widely, but lineations show a consistent westerly plunge.

Petrography (see Chapter 3) indicates that the parent materials were derived by sedimentary processes from a pre-existing sequence of epiclastic volcanics; abundant relict textures survived the dynamothermal metamorphism. Surface weathering and limited recrystallization locally obscure the primary features; these have led, in the past, to the conclusion that the rocks are volcanic extrusives, and disregarded the effects of metamorphism.

The dynamothermal metamorphic zone is narrow and lies along the margin of the Texas Creek granodiorite and Hyder quartz monzonite intrusives. The event was low grade, as indicated by the relict structures and textures, but involved a complex interplay of cataclastic and crystalloblastic processes that produced the various mylonites, cataclasites, and low-grade schists which now comprise most of the Unuk River strata in this zone. Textures in the schists suggest that recrystallization outlasted the deformational events. Undeformed micas are aligned in planes of schistosity produced during cataclasis and recrystallized quartz and plagioclase grains show no sign of strain or granulation.

Field relationships indicate that the Cascade Creek cataclasite zone is overlain by Middle Jurassic sediments in the Mount Dillworth section and is truncated by Tertiary Hyder phase plutons. The zone developed prior to Texas Creek plutonism and associated metasomatism, but was closely related in time to that plutonism.

**Maple Bay Zone:** A mylonite-cataclasite zone 3 kilometres wide and 11 kilometres long is preserved at Maple Bay within the Anyox pendant. A narrow mylonite zone in the Georgie River pendant, which is on strike with the Maple Bay zone, may have been a northerly extension prior to the intrusion of Tertiary plutons.

The Maple Bay cataclasite zone includes a broad area of cherty looking, weakly foliated ultramylonites bounded on the west by chloritic biotite schists and on the east by phyllonites. Foliation in these rocks is essentially vertical and northerly trending. In the central ultramylonite zone, where irregular blocks of weakly crushed hornblende are crudely aligned in a northerly direction, the zone has been closely faulted and extensively veined by quartz sulphide lenses. The deformed zone and quartz veins are cut by Tertiary intrusives forming the north and south boundaries of the Anyox pendant.

**Summary:** The Unuk River, Cascade Creek, and Maple Bay cataclasite zones are all steep, northerly trending structures developed within Lower Jurassic sedimentary and volcanic rocks, dykes, and small plutons. The mylonites were developed largely in response to intense differential deformation accompanied by some metamorphic recrystallization. The temperature at which this mylonitization occurred in the Unuk River zone, as indicated by MgO content in limestone, is below 300 degrees celsius. The apparent lack of chemical degradation of the finely comminuted plagioclase phyllonites suggests a generally dry environment during mylonitization.
The high-pressure, dry, low-temperature deformational events recorded here appear to be comparable to reported small-scale or restricted zones found in many parts of the world. Similar zones are rare in Western Cordilleran literature. The general lack of recognition of cataclasite zones in the Western Cordillera can be partly attributed to an extensive cover of glacial debris, and partly to the tendency to map banded, fine-grained greenish rocks as volcanic tuffs (Schofield and Hanson, 1922; Hanson, 1929, 1935, etc.) and zones as fault lineaments.

FAULTS, LINEAMENTS, AND FRACTURES

Many of the major topographic features in this area were controlled by extensive fault and fracture systems, along which apparent movement has been limited but is of local importance. The abrupt direction changes of erosional features, such as the fjords and glacier and river valleys, are attributed to these zones of limited movement.

Four fault systems can be deduced from the geologic map; these comprise northwesterly, northerly, northeasterly, and easterly sets. However, in any attempted stress analysis, the time factor would show that each set has been reactivated several times. Later faults, which affect the majority of the rocks in the area, mainly represent simple displacement features where rock competency has played a role in determining the attitude and the degree of development of the faults. Both strike-slip and thrust faults are prominent in Salmon River and Nass Formation rocks, but strike-slip faults are more extensive, involve the underlying Hazelton rocks, and include most of the faults shown on Figure 2.

Faults are common features in all the mines and mineral deposits in the Stewart Complex. They have generally small movements and played a minor role in controlling sulphide mineralization.

Simple rock fractures have not been subjected to any rigorous treatment but they have been considered significant in the study of mineral deposits. Fractures were found useful as a means of discriminating between dyke rocks, various plutonic rocks, and other country rocks. At the Silbak Premier mine, for example, it was found that rock fracture sets could be used to differentiate between similar-looking altered country rock and the Premier porphyry.

TECTORIC EVOLUTION OF THE STEWART COMPLEX

The Stewart Complex lies along the west margin of the Bowser Basin where, because of essentially continuous tectonic activity, an important part of the evolution of the Bowser Basin and the adjoining Coast Plutonic Complex has been revealed. Evidence for the pre-Permian history of the Coast Plutonic Complex has been mainly derived from southeastern Alaska or from more remote points. Scattered evidence from Alaska, Washington, and California suggests that Precambrian crust underlies considerably more of the Western Canadian Cordillera than is generally accepted. In southeastern Alaska, Budding and Chapin (1929) presented the first evidence for Early Paleozoic granite emplacement, as shown by the presence of granite cobbles in Silurian-Devonian sediments.

Radiometric age dates (Lamphere, et al., 1965) indicate the presence of Ordovician (or Silurian) plutons at Annette Island near Prince Rupert and 400 to 433-million-year-old ultramafic rocks west of Ketchikan. In Washington, Misch (1966) has implied the emplacement of Early Paleozoic plutons as part of a pre-Middle Devonian complex. Roddick, (1966), Roddick, et al. (1967), and Brew, et al. (1966) suggested that pulse-like activity extended through the Paleozoic becoming more frequent in the Mesozoic and culminating in Late Cretaceous and Early Tertiary time (Fig. 14). Gilluly (1972) has compiled the available radiometric age dates from plutonic and volcanic rocks in the Western Cordillera.
and indicated that plutonism was an essentially continuous process since the Carboniferous, rather than widely separated major episodes as was once widely accepted. He suggested that the apparent dominance of Tertiary plutons relates more to accessibility than volume.

The evolution of the Sierra Nevada of California (Kistler, et al., 1971) and the Coast Plutonic Complex has followed similar trends. However, Hutchison (1970) pointed out that, while the Sierra Nevada includes early, mantle-derived gabbroic and ultrabasic phases, none have been found in the Prince Rupert area. He concluded that the bulk of the plutons in this segment were generated along parallel zones within the Central Gneiss Complex, and probably represent a deeper level not now exposed in the Sierra Nevada. On the basis of plutonic compositions recognized by Buddington (1927) in Alaska, Hutchison proposed the concept, later expounded by Moore (1959, 1962), of a quartz diorite line that separated first cycle granitic rocks derived from eugeosynclinal volcanic and sedimentary rocks on the west, from platform or crust-derived granitic rocks on the east. The three major parallel zones, outlined by Hutchison (1970) in the Central Gneiss Complex, represent a single Barrovian-type metamorphic belt composed of uplifted blocks with the oldest on the west and the youngest on the east. These formed at the margin of a Precambrian crust and involved continuous small contributions from the mantle. In terms of the tectonic framework of the Western Cordillera in general and the Stewart Complex in particular, the Coast Plutonic Belt has been a prominent structural feature.

In the Portland Inlet section Hutchison (1967) has shown the Central Gneiss Complex to be Late Paleozoic or older; at Terrace, Duffell and Souther (1964) indicated that Permian strata rest unconformably on a gneiss complex. Roddick (1970) has also assigned a Permian or older age for the Gneiss Complex southeast of Kitimat. At Anyox and along Portland Canal there is a narrow belt of agmatitic migmatite consisting of Hazelton Group strata veined by Hyder phase granitic material that forms the margin of Hutchison's proposed younger eastern metamorphic zone. In the Unuk River and Leduc River sections of the Stewart Complex, equivalent amphibolite-grade gneisses are overlain by Late Triassic and Early Jurassic country rocks; these are thought by the writer to represent Middle Triassic or older metamorphic rocks such as observed by Souther (1971) in the Tulsequah area. The presence of a Late Permian carbonate sequence at Oweegee Peaks, where Late Triassic faulting and younger uplift have brought a small segment of the Paleozoic basement to the surface, confirms the regional evidence that stable shelf conditions prevailed at that time. The apparent absence of Paleozoic strata within the Stewart Complex, although they have also been preserved to the west and north along the Iskut River and to the south near Terrace, suggests that pre-Late Triassic uplift and erosion, the Tahltanian Orogeny of Souther (op. cit.), was essentially confined to the Gneiss Complex and the Coast geanticline (Fig. 5). Early Late Triassic sedimentation and volcanism, locally expressed by the McQuillan Ridge sequence of intercalated volcaniclastics, carbonates, cherts, and thin basaltic and andesitic flows, followed the Tahltanian Orogeny. Parts of the Coast geanticline and Insular Belt remained emergent during the Late Triassic. During this time volcanism was extensive; subsidence and more stable conditions returned during the Norian epoch. Deposition of volcaniclastics, silts, and shales was followed by carbonate deposition, well represented by the Sinwa Formation that occurs in parts of the Unuk River area and as scattered thin carbonate lenses elsewhere in the Whitehorse Trough. Souther (op. cit.) suggested that thinning of the Sinwa Formation indicated slight emergence of the Stikine Arch. This and accompanying uplift in the Coast geanticline became more extensive and marked the early evolution of the Taku embayment in the Tulsequah area and the Bowser Basin (Souther, op. cit.). Extensive Late Triassic to early Early Jurassic uplift and erosion uproofed Late Triassic plutons and the gneiss complex; this resulted in deposition of the thick Early Jurassic Unuk River strata in the western part of the Bowser Basin and the Inklin strata in the Tulsequah area. Most of southeastern Alaska was emergent during Early Jurassic time resulting in a broadening of the Late Triassic Coast geanticline (Fig. 8).
In the Stewart Complex, widespread late Early Jurassic volcanism and sedimentation, assumed here to represent shallow marine conditions, were followed by post-Toarcian folding and plutonism related to regional compression. This was accompanied by cataclastic deformation, metasomatism, and normal faulting, then regional uplift and extensive erosion of the Lower Jurassic Unuk River Formation. In the Tulsequah area, Souther (op. cit.) included both the Lower Jurassic and Middle Jurassic sediments within the Takwahoni sequence, although he noted that it was possible that a break in deposition occurred between Early and Middle Jurassic time. A break, recognized in the Stewart area, has also been mapped by Tipper (1971) in the Smithers area. Baer (1969) suggested that a second orogenic cycle, involving andesitic volcanism, plutonism, and sedimentation in the south-central Cordillera and Coast Plutonic Complex, began during Middle Jurassic time; he cited as evidence Middle Jurassic volcanics lying unconformably on crystalline rocks of the first cycle.

Following late Early Jurassic erosion in the Stewart Complex, the early Middle Jurassic Betty Creek strata were deposited across the depressed surface, filling in trenches and troughs, essentially resurfacing the old highland. The Betty Creek Formation includes volcaniclastics, volcanic flows, and pillow lavas thought to have been largely deposited in a shallow marine environment.

Betty Creek sedimentation and volcanism were followed by normal faulting, graben development, minor folding, uplift, and erosion. Uplift and erosion appear to have been greatest along the northwest edge of the Stewart Complex and restricted to fault blocks. At Anyox, Betty Creek volcanism was followed by a conformable marine sedimentary sequence. The deposition of the Bajocian Salmon River Formation marked a time of transgression with fine-grained marine sediments again filling fault-controlled troughs in older country rocks. Sedimentation was widespread; equivalent rocks have been mapped by Souther (op. cit.) as the Upper Takwahoni Formation in the Tulsequah area, and a similar unit has been outlined by Tipper (op. cit.) at Smithers. Granitic clasts in the basal Salmon River Formation indicate the uproofing of Middle Jurassic or older plutons along the Coast Geanticline immediately to the west prior to the major depression and broadening of the basin (Fig. 11).

The Middle and Upper Jurassic units within the Stewart Complex are similar in all respects and have been separated only by a granite cobble zone lying below fossiliferous Oxfordian-Kimmeridgian strata. Tipper (personal communication) has stated that 'this is precisely the situation in Taseko Lakes and Mount Waddington, and has an analogy with Crickmay's stratigraphy in Harrison Lake'. It appears to be more than a local feature and probably represents uplift of the Coast geanticline. Deposition of the Upper Jurassic Nass Formation was largely restricted to the Bowser Basin, although Campbell (1966) recorded a narrow basin of roughly correlative rocks in a southerly remnant of the deformed Nechako trough. The Nass and Salmon River Formations exhibit similar complex disharmonic fold structures in part related to gravity tectonics and in part to Tertiary plutonism. Faults are common and the major zones of movement appear to represent revived older structures. Correlatives of the Nass Formation in northeastern British Columbia include the Fernie Passage beds. Province-wide erosion followed Nass sedimentation and was followed by deposition of the Hauterivian and Albian Skeena Group. These rocks have not been preserved in the Stewart Complex.

Tertiary plutons that occur along the margin of the Central Gneiss Belt and as satellite plutons and dyke swarms east of the margin, followed predominantly northwesterly trends that cut across northerly trends of the older gneisses, Triassic and Jurassic sediments and volcanics, and the Mesozoic plutons. Quaternary volcanism was concentrated along a northerly trending Cenozoic tension zone (Souther, op. cit.) and along a northeasterly zone outlined by the writer (Fig. 1). To the east, Cenozoic volcanism has been largely confined to the margins of the Bowser Basin.
Summary: The bulk of the evidence favours the evolution of the Stewart Complex portion of the Western Cordillera eugeosyncline by continuous plutonism, volcanism, and contemporaneous sedimentation. Early Paleozoic evidence of plutonism in the Coast Plutonic Complex indicates that this feature has evolved along the continental margin accompanied by trough and successor basin development along both flanks. Folding as an expression of directed stress has played a minor part in the regional tectonics. Block-like uplifts related to faults and sequential vertical tectonics have responded to and accompanied motion of the major tectonic units.

Unconformities between major stratigraphic units as well as within the units result from block movements along well-defined faults, developed in response to regional tectonism. The mainly Mesozoic Stewart Complex responded to the development of the Coast geanticline and finally, as a result of Tertiary plutonism, was essentially fused to the geanticline. Overall, lithostructural evidence supports the dominant role of vertical tectonics in the development of this region.
MINERAL DEPOSIT DISTRIBUTION IN THE WESTERN CORDILLERA

Concepts regarding mineral belt and mineral deposit distribution in the Canadian Cordillera were originally developed during the period 1871 to 1905 by Richardson, Selwyn, Dawson, McConnell, Bauerman, Brock, and others. The general concept developed by the early workers related mineral deposits to two main belts, separated by the Coast Range batholith. The westerly zone was called the Pacific belt and included the Anyox and Britannia deposits. The easterly zone, called the Interior belt, included the Silbak Premier deposit at Stewart, the Dolly Varden at Alice Arm, and small prospects near Terrace and Smithers. This concept led to the general acceptance that copper mineralization was concentrated at the western margin of the batholith and that gold, silver, and lead were localized near the eastern margin. Schofield (1921) suggested that this apparent distribution was related to the contrasting metamorphic grades found at the batholith's margins and to different levels of erosion.

Souther and Armstrong (1966) suggested that copper and molybdenum deposits in northwestern British Columbia are most frequently associated with relatively young syenitic or monzonitic phases of the Coast Range batholith. They also suggested that the Anyox, Granduc, and other large copper deposits in the Western Cordillera were closely associated with an arcuate belt of Triassic pillow lavas which extended from near Tulsequah, south through the Stikine and Iskut River areas to include the Granduc and Anyox deposits within the Stewart Complex. Recent discoveries suggest that mineralization in the Stewart Complex is related to several ages and types of plutons, not only to major Tertiary intrusives which comprise the east margin of the Coast Plutonic Complex.

The regional patterns of mineral distribution can no longer be related simply to intrusives. The Stewart Complex represents one of the marginal uplifts of the Mesozoic Bowser Basin where a variety of mineral deposits can be shown to be directly related to certain plutons, distinct structural features, and unique lithologic controls.
Figure 17. Metal distribution zones, Stewart Complex.
DISTRIBUTION PATTERNS OF MINERAL DEPOSITS IN THE STEWART COMPLEX

The distribution of mineral deposits in the Stewart Complex (Fig. 13) can be related to several factors. Most occur in low-lying areas accessible from the fjords and streams, and below the snow and ice cover. The blank areas reflect the presence of barren Middle and Late Jurassic sedimentary strata, and the generally barren Coast Plutonic Complex and its satellite plutons. Mineral belts in the Stewart Complex are apparently restricted to northerly trending elongate clusters. These belts follow the South Unuk River, Cascade Creek, Bear River-American Creek, and Kitsault River topographic lineaments; however, the Maple Bay and Anyox belts are apparently unrelated to topographic features. All of these mineral belts include deposits of different ages, variable mineralogy, and different local geological environments. These mineral belts, or map features, lie along the northerly structural trends, but metal zoning within each belt is difficult to relate to an overall controlling feature.

Distribution Patterns of Major Metals in the Stewart Complex: Although Hanson (1935) dismissed the possibility of local mineral or metal zoning in part of the Stewart Complex, Buddington (1929) related the vein-type mineralization in the Hyder district to the Texas Creek pluton and related local zoning of gold, silver, and sulphides to the margins of the pluton. He recognized that the Texas Creek was an older pluton, and also that the younger Hyder pluton, as well as the Coast Range batholith of Hanson (1929, 1935), were unmineralized and unrelated to the majority of the local mineral deposits. The writer has recognized metal zoning on both a local and a regional scale.

In the Stewart Complex, deposits tend to occur in linear clusters. These lines or belts appear to reflect topographic lows which in part reflect local structures. However, younger sediment cover as well as ice and snow, partially mask the overall pattern. Gold, silver, copper, lead, zinc, and molybdenum are the most important metals found in the Stewart Complex. Because of their high value and wide distribution, gold, silver, copper, and molybdenum have been the primary exploration targets, and their abundance is well documented. The writer has utilized these metals to separate the Stewart Complex into four simple areas or cells dominated by gold, silver, copper, and silver-gold (Fig. 17). In this way, a broad pattern of regional zoning of the mineral belts becomes visible. The zones outlined illustrate the dominance of silver-rich, gold-poor deposits in the Alice Arm district, silver-gold deposits in the Stewart district between Georgie River and Summit Lake, and gold-rich, silver-poor deposits in the Bowser River area. The gold and silver zones are bounded on the west by copper deposits at Anyox, Maple Bay, and Granduc Mountain, which together form a northwesterly trending zone which has been partly transected by the Tertiary Hyder pluton. The easterly boundary of the gold and silver zones is formed by the extensive cover of Middle and Upper Jurassic sediments.

Mineral zones of less abundant metals that lie within the framework of the four main zones have also been defined. The distribution of arsenic and antimony has previously been shown to be related to the margins of the Glacier Creek plutons where these bodies have intruded Middle Jurassic siltstones. Pyrrhotite is localized within the copper zone where it occurs in the massive sulphide deposits and in the vein-type copper deposits. Molybdenite is unusual in that it occurs in all four zones, where it is associated with a variety of rock types of different ages. The most important molybdenite belt is related to the Tertiary Alice Arm Intrusions that border the eastern margin of the Coast Plutonic Complex between Bear River Pass and the southern limit of the study area. This molybdenite belt can be traced along the margin of the complex from the Yukon, south through British Columbia into the United States.

Field evidence indicates that regional metal distribution is related to mineralization epochs which in turn are related to well-defined plutonic, volcanic, and tectonic events (Fig. 18). The large copper deposits concentrated at the western margin of the Stewart Complex in
Figure 18. Relationships between plutonism, volcanism, and mineralization, Stewart Complex.

The copper zone represent Late Triassic (Max), Lower Jurassic (Granduc), and Middle Jurassic (Hidden Creek) mineralization. The silver-rich deposits in the Alice Arm district, such as the Torbrit, are virtually gold-free; they represent either Late Jurassic or possibly Tertiary mineralization. At Stewart, the silver-gold deposits range in age from Middle Jurassic to Tertiary; the oldest deposits are represented by gold-rich mineralization, such as the Big Missouri and Silbak Premier; younger silver-rich deposits in the same area are cut by dykes and provide examples transitional between the Silbak Premier and Torbrit-type deposits. In the gold zone at the north end of the Stewart Complex, the mineral deposits are mainly confined to Lower Jurassic rocks.

The result of major faulting has been differential uplift of portions of the Stewart Complex; subsequent erosion has exposed the oldest country rocks in the Unuk River and Anyox areas. As a result the copper zone deposits at Anyox and Granduc Mountain, and the gold and gold-silver deposits near Stewart have been exposed. At Alice Arm where the country rocks were depressed and less eroded, only young silver-rich, gold-poor deposits are exposed. The mineral deposit distribution therefore, represents the depth of erosion within various parts of the Stewart Complex. This concept, based on the tectonic evolution of the region, eliminates the need to relate regional metal zoning to hypothetical deep-seated magmatic events or to granitization of the sediments, or to the migration of elements in response to a regional thermal gradient.

CLASSIFICATION OF MINERAL DEPOSITS IN THE STEWART COMPLEX

A study of the spatial relationships of the deposits to their wallrocks provides a simple means of separating the many deposits into groups.

The majority of the mineral deposits in the Unuk River, Stewart, Maple Bay, Anyox, and Alice Arm districts are veins that transect the country rocks. Principal examples of the vein deposits are the Esperanza mine at Alice Arm and the Prosperity-Porter Idaho mine near

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<tr>
<th>PERIOD</th>
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<th>TECTONIC EVENT</th>
<th>PLUTONS</th>
<th>VOLCANICS</th>
<th>FORMATIONS</th>
<th>MINERALIZATION</th>
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<td>Basalt dykes</td>
<td>Flows</td>
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<td>Erodis. Cell</td>
<td>Dykes, sills</td>
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<td>Vein deposits: silver, lead, zinc</td>
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<td>E Eocene</td>
<td>Folding &amp; faulting</td>
<td>Hyder plutons etc, Alice Arm intrusions</td>
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<td>Satellite plutons</td>
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CLASSIFICATION OF MINERAL DEPOSITS IN THE STEWART COMPLEX

A study of the spatial relationships of the deposits to their wallrocks provides a simple means of separating the many deposits into groups.

The majority of the mineral deposits in the Unuk River, Stewart, Maple Bay, Anyox, and Alice Arm districts are veins that transect the country rocks. Principal examples of the vein deposits are the Esperanza mine at Alice Arm and the Prosperity-Porter Idaho mine near
Stewart. The Silbak Premier gold-silver deposit near Stewart represents a complex quartz-carbonate-sulphide replacement vein restricted to an altered portion of the Cascade Creek cataclasite zone. Extensive quartz sulphide fissure veins at Maple Bay also occur in rocks of the Maple Bay cataclasite zone. Other vein deposits are localized in granitic bodies, such as the Texas Creek pluton, many of the satellite plutons, and members of the various dyke swarms.

Gold, silver-gold, and silver-bearing minerals are localized within these tabular, quartz-rich bodies as discrete, *en echelon*, and composite lenticular shoots. The larger vein-type deposits are generally distinguished by replacement features and are typified by the Torbrit deposit near Alice Arm and the Silbak Premier deposit near Stewart. The Silbak Premier deposit was once considered (Cooke and Johnston, 1932, p. 39) to be a typical, vein-type, gold-silver British Columbia ore deposit. This concept that bonanza ore mined at Premier before 1930 was typical of these deposits was that the apparent shallow depths of the ore, as compared to Precambrian gold deposits, was related to topographic features and locally partly resulted from secondary enrichment. Two frequency distribution diagrams (Figs. 19, 20) relate the major Torbrit and Silbak Premier deposits to all the known properties in British Columbia that have recorded gold and silver production. As shown by these diagrams, the Silbak Premier property is unique in terms of rank and cannot be considered typical.

Fissure vein and replacement vein deposits in the Stewart Complex comprise a common group with simple ore and gangue minerals. Wallrock alteration associated with these deposits is generally simple and cannot be defined as a characteristic of the complex. Secondary enrichment is not significant in any of the deposits and is generally absent throughout the Stewart Complex. The orebodies are typically shallow and appear to be related to surface topography; this feature is in fact related to the general method of mine development and exploration. The orebodies at the Silbak Premier represent the maximum extent to which any of the vein deposits have been mined. These orebodies comprise a series of *en echelon* lenses which have been developed over a strike length of 1700 metres and through a vertical range of 600 metres. The main ore zone at the Dunwell mine, north of Stewart, consisted of one main shoot 40 metres long, 1 metre wide, and 120 metres deep, lying within a quartz fissure vein having a known length of 300 metres and a depth of 170 metres. In general, the ore shoots of other vein deposits in the study area formed a smaller part of the veins.

A frequency distribution of the attitudes of veins and vein systems is shown on Figure 21. This diagram illustrates the distribution pattern for veins in the different country rocks as well as the dominant fracture systems. Northwesterly trends dominate in the Texas Creek and other plutons, as well as in the Lower Jurassic country rocks. Northerly trends dominate in Middle Jurassic rocks in the Stewart district whereas in the Hyder district the vein trends are easterly. The bulk of the veins trending northwesterly, northerly, and easterly are generally unproductive, fissure-type quartz-breccia veins. The unique Silbak Premier deposit includes both northwesterly and northeasterly vein systems but the latter predominates and, as shown on Figure 21, represent a small fraction of the vein systems in Lower Jurassic rocks. Ore shoots in the Silbak Premier vein system mainly comprise banded massive sulphide lenses and have caused considerable discussion in the past. In referring to massive sulphide deposits, Gunning (1959, p. 319) suggested that perhaps the puzzling Silbak Premier ore shoots could be placed in the general massive sulphide classification. The writer prefers to characterize the deposit as a replacement vein system.

Massive sulphide deposits at Granduc Mountain and Anyox represent the largest and most productive deposits in the Stewart Complex. These deposits are confined to volcanic-sedimentary strata which have suffered complex deformation and intrusion. Unlike the vein mineralization, these massive sulphide deposits are largely concordant with the enclosing country rocks and form a distinct class. The Max massive magnetite-chalcopyrite deposit at McQuillan Ridge is not sufficiently known to classify it.
Granduc has been termed a sulphide lode deposit by Ney (1966), a stringer lode deposit by Norman and McCue (1966), a lode deposit by White (1966), and a massive sulphide deposit by Sutherland Brown, et al. (1971). The Granduc ore zones lie within the South Unuk cataclasite zone and are extensively deformed. They can be characterized as flattened lenses and physically compare with the 'Kieslagerstatten type' described from various parts of the world (Vokes, 1969). The full extent of these orebodies has not been determined, but they are known to extend over a vertical depth of at least 900 metres, with a length of 1700 metres, and a width of up to a few hundred metres. Granduc is presently the only known deposit of this type in the Western Cordillera.

In the past Hanson (1935), Nelson (1948), and others concluded that the Anyox orebodies represented simple contact metamorphic deposits. These deposits, which include the Hidden Creek, Double Ed, Red Wing, and Bonanza properties, are actually pipe-like to tabular massive sulphide lenses unrelated to any known intrusives. The Hidden Creek orebodies represent the largest sulphide masses in the Stewart Complex and compare in size to the ore lenses at Britannia near Vancouver. Most of the Anyox orebodies are near vertical lenses that have been traced to a depth of 500 metres, up to 250 metres in strike length, and 100 metres in width. Mapping has shown that the Anyox deposits are confined to pillow volcanics and that the contact metamorphic concept is invalid.
Porphyry-type deposits confined to an individual pluton are restricted to the satellite intrusives. The main representative of this class is the B.C. Molybdenum mine at Lime Creek, near Alice Arm. There are at present no known major mineral deposits in rocks of the Central Gneiss Complex, the Hyder pluton, or the basalt dykes and flows. Other mineral deposits related to stock-like plutons include the nickelliferous gabbro body at Snippaker Creek, and zones of disseminated replacement copper-molybdenum-gold mineralization related to the syenodiorite complex at Mitchell-Sulphurets Creeks.
The simple porphyry-type molybdenite deposit at Lime Creek appears to be typical of porphyry deposits in the Western Cordillera in that the economic mineralization lies entirely within a portion of a small quartz monzonite stock. The widespread copper-molybdenum mineralization at Mitchell-Sulphurets Creeks represents low-grade disseminated sulphide mineralization spatially related to differentiated intrusions and to pervasive quartz sulphide veining of the country rocks. If this deposit proves economic, it will be considered a porphyry deposit in the mining sense, that is, a deposit denoting extensive, low-grade mineralization.

The mineral deposit at Nickel Mountain represents the only known major nickel occurrence in northern British Columbia that is localized in a pipe-like basic pluton. Very little of this mineralized, stock-like body is exposed. The evidence suggests that sulphide minerals are restricted to one edge of the pluton in the upper 450 metres of the contact zone with Unuk River siltstones. Other minor nickel-bearing deposits have been found in hornfels zones near the contacts between Tertiary plutons and Unuk River strata in the area west of the Unuk River and near Anyox.

The preceding brief descriptions of a few significant mineral deposits illustrate the wide variety, character, and size of mineral deposits in the Stewart Complex. As indicated by the mineral occurrence map (Fig. 13) there are many major deposits in the Stewart Complex. These cannot be treated individually in this study but have been grouped by their major characteristics as vein, massive sulphide, and porphyry types.

**Summary:** The classification of mineral deposits in this area is therefore essentially based upon the relationships of these deposits to their geological environment as follows:

1. Vein deposits — fissure veins and replacement veins.
3. Porphyry deposits.

**VEIN DEPOSITS**

**Fissure Veins:** Vein deposits represent the largest class of mineral deposits in the Stewart Complex; they include a variety of discordant tabular epigenetic bodies dominantly composed of quartz, carbonate, and barite. Many represent fissure-filling deposits in which fragmented particles of wallrock form a significant portion of the body. Textures include banding, drusy cavities, and comb structures. Alteration is generally not a significant feature and wallrock replacement is generally minimal. Many of the massive quartz veins in the Anyox district have been mined over a length of 900 metres and to a few hundred metres in depth, and exhibit no evidence for significant replacement or alteration of the country rock. These deposits generally have low silver values, contained in argentiferous native gold; they rarely contain any sulphides. The majority of these sulphide-deficient, quartz fissure veins are spatially related to the margins of the quartz-rich Hyder pluton.

Vein deposits in the Maple Bay section are represented by fracture-controlled, tabular quartz veins characterized by drusy, finely crystalline quartz in which the open spaces are irregularly filled with interstitial chalcopyrite, pyrrhotite, and minor pyrite; ore shoots are lenticular. These veins have been traced on the surface for over 1000 metres and are known to extend to depths of more than 600 metres. This group of veins occupies dilation features controlled by intersecting fracture sets within the ultramylonite segments of the Maple Bay cataclasite zone. They are cut by Hyder plutons and are probably epigenetic deposits related to Middle Jurassic Texas Creek plutonism.

Fissure veins in the Alice Arm district are characterized by argentiferous sulphides and native silver; they have negligible gold content. Stewart district veins are generally comparable, but have a greater variety of sulphide minerals; they commonly contain native silver and rarely native gold and electrum.
Veins localized within the regional gold zone (Fig. 17) are mainly small massive quartz lenses in Lower Jurassic country rocks. They generally carry native gold, sulphides, and low to negligible silver content.

**Replacement Veins:** These deposits represent the most productive gold-silver deposits in the Stewart Complex and include the Torbrit silver mine at Alice Arm and the Silbak Premier mine near Stewart. This type of vein system constitutes less than 5 per cent of all the mineral deposits within the Stewart Complex, but has contributed more than 90 per cent of the total gold, silver, lead, and zinc mined. The Torbrit deposit at Alice Arm is representative of the low-gold replacement vein deposits; it consists of discordant lenses comprising mainly banded quartz, barite, jasper, feldspar, carbonates, and minor country rock. The ore shoots include sulphides and native silver that along with the main vein material formed partly by emplacement within fractures and partly by replacement of wallrock. The principal representative of this class of vein deposit is the Silbak Premier mine.

**GEOLOGY OF THE SILBAK PREMIER MINE**

The Silbak Premier mineral deposit (Fig. 22), as well as a large number of small fissure veins, occurs within the boundaries of the Cascade Creek cataclasite zone (Fig. 2B). Unlike the fissure veins, Silbak Premier mineralization is within a metasomatized zone adjacent to the margin of the Texas Creek pluton (Fig. 22). During the operating life of the mine it produced in excess of 4.2 million tonnes of ore containing 56.6 million grams of gold, 1.281.4 million grams of silver, and appreciable amounts of copper, lead, zinc, and cadmium.

The Silbak Premier ore deposit lies in altered Lower Jurassic green volcanic conglomerates (Plate XVII) and intercalated crystal and lithic tuffs that are unconformably overlain by Middle Jurassic sediments and intruded by the Texas Creek pluton and numerous dykes (Fig. 22). The metasomatic, porphyritic rock in which the replacement veins occur has been called the Premier Porphyry (Plate XVIII). This porphyritic zone is characterized by intense fracturing and quartz-carbonate-K-feldspar alteration, and is the site of the sulphide ore shoots. On Figure 22 the principal types of alteration and the ore shoots are shown in relation to the generalized surface geology.

Apart from the Premier Porphyry, the nature of the parent country rock has been largely preserved in spite of the incipient dynamic metamorphism and later metasomatism. The country rock immediately surrounding the ore zones forms part of the local epiclastic volcanic sequence.

In the past, many of the cataclasites in the mine area were interpreted to be volcanic flows, possibly because of their pseudoporphyritic appearance; the deformed character of this rock type is illustrated on Plate XIX.

The Premier Porphyry is a distinctive unit in which coarse-grained pink orthoclase and medium-grained brown hornblende are conspicuous (Plate XVIII). In composition it is comparable to the border phase of the nearby Texas Creek pluton, with which it appears to be genetically related. The Premier Porphyry exhibits various stages of alteration related to mineralization. In weakly altered zones orthoclase porphyroblasts are partly altered to sericite and carbonate along cleavage and fracture planes, and plagioclase and hornblende are replaced; the groundmass alters almost entirely to a dense mixture of sericite, carbonate, epidote, and minor chlorite. In more completely altered zones orthoclase crystals are ghost-like pseudomorphs and both plagioclase and hornblende are indistinct. In most of the porphyry, blebs of quartz in the groundmass comprise 5 to 8 per cent of the rock; these grains are typical of the local cataclasites and have survived both metasomatism and subsequent mineralization-alteration. Secondary quartz is present in most of the porphyry as irregular patches with microcomb structure. Sphene and cubic pyrite are accessory minerals.
Country rocks immediately adjacent to the Premier Porphyry, termed greenstones in the old literature, comprise part of the Cascade Creek cataclasite zone. These rocks have been pervasively altered to fine-grained mixtures of equigranular quartz with sericite, carbonate, epidote, pyrite, and minor magnetite. These rocks generally consist of about 70 per cent quartz and 15 per cent sericite; locally pyrite is up to 25 per cent.

The numerous dykes which cut across the Silbak Premier property (Fig. 22) were described in Chapter 3. The most obvious in the mine area are dykes of the Premier swarm. Most of these swing past the ore zone but one, the 120-metre-wide Main dyke, cuts across the northern ore zone. Lamprophyre dykes occur throughout the mine with the exception of the glory hole area, where large massive sulphide lenses are localized and alteration is most intense.

**Structure:** The structural geology of the Silbak Premier area is shown on Figure 22 and described in Chapter 4. Steep, west-dipping, northerly trending Lower Jurassic strata, forming part of the west limb of the American Creek Anticline, are crossed at an acute angle by the Cascade Creek cataclasite zone, and unconformably overlain by Middle Jurassic epiclastic volcanics and siltstones. The Premier Porphyry zone is elongate and lies within the cataclasite zone adjacent to the irregular contact of the nearby Texas Creek pluton. The former structural interpretation of a shallow, west-dipping volcanic sequence with interlayered ‘porphyry’ is inconsistent with data presented here.

In the past, incipient foliation developed in most of the country rocks in the Premier area has erroneously been taken as lithologic layering or bedding. Dominant foliation on the property trends northerly and dips 35 degrees to 45 degrees west. In detail however, trends vary from northwest to northeast and to the south dips increase and become nearly
vertical. Rather than intersecting shears, these variations appear to represent rolling flexures that follow the sinuous contact between Premier Porphyry and the enveloping wallrocks.

In the mine area, joint sets are well developed in most of the rocks. Patterns vary from one rock type to another and from dyke to dyke. The Premier Porphyry and ore have a distinctive vertical joint set striking north, whereas the less altered cataclasites are typified by a set dipping 45 degrees west and striking north. Dykes in the mine belonging to the same petrologic group also have distinctive joint sets. Joint patterns may be useful in the mine area and the Stewart area in general in defining the rock types where the rocks are altered.

In the mine area the dykes follow the dominant joint sets and are clearly visible on the air photographs. Northwesterly dyke swarms are also prominent on the property. The less
conspicuous north 70-degree east trend (Fig. 21), which appears to represent a major ore control at the mine, has also been followed by the lamprophyre dykes. The Silbak Premier area is one of the few places in the Stewart district where the two intersecting joint sets are marked by extensive, intersecting dyke swarms.

Orebodies: The distribution of the orebodies at the Silbak Premier is shown on Figures 22 and 23, which represent a longitudinal section of the ore zone and illustrate the main stope areas.

Mineralization in the Silbak Premier system consists of an extensive replacement vein with a quartz zone enclosing, or partially enclosing, a large number of sulphide-rich ore shoots from which the main gold-silver production was derived. Quartz represents the main gangue material and is accompanied by lesser amounts of calcite and barite, minor adularia, and country rock. The ore shoots contain an average of 20 per cent sulphides, but in the lenses of bonanza ore this amounted to as much as 80 per cent, the rest being altered wallrock and quartz-calcite veins. Pyrite is the most abundant sulphide and occurs in most of the sub-ore gangue and surrounding wallrock as well. The other major sulphides in decreasing order of abundance are sphalerite, galena, chalcopyrite, and pyrrhotite, with small amounts of argentite, tetrahedrite (and freibergite), polybasite, pyrargyrite, stephanite, electrum, native gold, native silver, and rare mercury.

During the early mining period at the mine, Dolmage (1920) divided the glory hole ore into the following zones:

(1) Stephanite-native silver ore in a few small veins (approximately 100 000 grams per tonne).
(2) Black sulphide ore (17 000 to 34 000 grams silver per tonne).
(3) Lower grade siliceous ore.
Since then no other reports of stephanite have been recorded. Electrum has been noted and identified in high-grade and bonanza ore shoots between the surface and 3 level but rarely below (Fig. 23, in pocket). Native gold apparently has a much more extensive distribution because of its common association with pyrite, but coarse veinlets found in the bonanza-type shoots have a very limited range. Native silver has been identified in most of the ore but none was seen in drill core from below 6 level. Both mercury and amalgam have been recognized but only in surface bonanza or black sulphide ores. Sphalerite has been found universally in the ores along with galena, chalcopyrite, and tetrahedrite from surface to the 8 level area. Within the ore shoots however, sphalerite displays colour variations and also shows an apparent overall colour change from surface to 8 level. This colour varies from black-brown at the surface to amber at depth and indicates a variable iron content within each shoot as well as over the known vertical range of the deposit. Argentite, the most prominent silver mineral at the mine, shows a general decrease in abundance with depth.

An analysis of the stope production records shows a marked decrease in silver at depth. To illustrate this change the silver-gold ratios for various stopes in the main Premier section are plotted in their respective areas on the longitudinal section (Fig. 23). The ratios clearly show a semicircular zonation with silver content decreasing from a high of 112:1 just north of the 110 sublevel projection to lower values to the west and east, and to depth, where the value 6:1 predominates. Another indication of the zoning both along strike and at depth is given in Table 5 where ore production from the four main mine zones has been summarized.

TABLE 5. SILVER-GOLD RATIOS, SILBAK PREMIER VEIN SYSTEM

<table>
<thead>
<tr>
<th>Working Area</th>
<th>Silver-Gold Ratio</th>
<th>Copper Per Cent</th>
<th>Lead Per Cent</th>
<th>Zinc Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.C. Silver</td>
<td>40.0:1</td>
<td>0.01</td>
<td>0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Premier</td>
<td>24.5:1</td>
<td>0.04</td>
<td>0.41</td>
<td>0.56</td>
</tr>
<tr>
<td>Silbak Premier</td>
<td>17.0:1</td>
<td>0.054</td>
<td>0.98</td>
<td>5.00</td>
</tr>
<tr>
<td>Premier Border</td>
<td>28.0:1</td>
<td>0.01</td>
<td>4.2</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Various mineralogical studies of the ore revealed no anomalous features. Both Burton (1926) and White (1939) found the apparent paragenetic sequence to be normal. Supergene enrichment was thought by the early workers to have been the main process by which the bonanza and high-grade silver shoots were formed, but studies by White (op. cit.) found that the bulk of the silver minerals are primary. Minor amounts of secondary argentite, wire silver, and minute gold particles are present in vugs in the black sulphide ore as well as in late vuggy quartz-tetrahedrite-polybasite veins which cut the main sulphide lenses.

In the orebodies that can now be seen at the mine the sulphide banding first mentioned by Burton (op. cit., p. 589) is prominent (Plate XX) in pyritic bonanza ore with altered wallrock cut by sulphides and electrum. The mineral banding reflects a late-stage deformation in which relatively soft argentite-galena-sphalerite sections flowed and recrystallized and 'hard' pyrite deformed by fracturing. Individual ore shoots are found as isolated or overlapping en echelon, flattened, or pipe-like lenses. These have been illustrated on Figure 22 to show approximate relationships; plunge directions are uniformly steep to the west.

**Genesis:** The following facts are significant in the present interpretation of the Silbak Premier ore deposit. Spatial relations indicate that this deposit has been localized in metasomatized cataclasites related to the Middle Jurassic Texas Creek pluton. This transformation process, termed ground preparation by Park and McDiarmid (1964, pp. 58, 59), tended to make the Silbak Premier zone brittle compared to the surrounding rocks. Later fracturing in this brittle zone localized deposition of vein quartz, carbonate, barite, and sulphide.
Silver-gold ratios in the vein system show gold concentrated in the lower depths and silver in the upper sections. This suggests a changing ore fluid pH from alkaline to more acid and also a possible temperature gradient decreasing from depth toward the surface (Fig. 23). The ratio values also support the field evidence that gold was more abundant in the early phases of mineral deposition than in the later. It appears likely that the late silver-rich mineral assemblages were deposited closer to the surface (lower pressure) than the gold-rich assemblages. These results are comparable to those Nolan (1935) obtained at Tonapah, Nevada, that is, they suggest a telescoped, hydrothermal deposit (Borchert, 1951) formed at shallow depth where changes in temperature and pressure are rapid.

Taylor’s (1970) experimental studies of phase relations in the silver-iron-sulphur system show the importance of the silver sulphidization curve for interpreting silver-pyrite assemblages. He indicated that native silver, particularly in silver-pyrite assemblages, does not result from the breakdown of silver-bearing minerals (for example, argentite). Instead, he suggested that the invariant reaction argentite (Ag$_2$S) + monoclinic pyrrhotite (m-po) yields silver (Ag) + pyrite (py), in the presence of vapor (S), at 248 degrees Celsius, was important in certain massive sulphide deposits. At the silver-bearing Kidd Creek zinc deposit in the Timmins, Ontario area, where much of the silver occurs as stringers, veinlets, and blebs in pyrite, the assemblage Ag + py formed below 248 degrees Celsius, at a sulphur fugacity of less than 10$^{-14}$ atmospheres (Taylor, op. cit.). The phase relationships in the silver-iron-sulphur system and the above reaction explain the apparent worldwide absence of the assemblage argentite + pyrrhotite in nature. At Silbak Premier argentite, pyrite, and native silver are concentrated in the near surface bonanza lenses, and pyrite and associated native silver extend from surface to a known depth of 360 metres. Pyrrhotite is present in minor amounts in the pyrite-galena-sphalerite assemblage in the deep sub-ore sections but has never been recognized in the upper native silver-argentite-pyrite assemblages. Taylor’s (op. cit.) phase diagrams and mineral assemblage
data suggest that the Silbak Premier bonanza ore shoots formed below 248 degrees Celsius.

Indirect evidence by analogy with other comparable silver-gold deposits also suggests a low temperature and pressure of formation for the Silbak Premier ore. Nishiwaki, et al. (1971, p. 412) have outlined a classification of Neogene silver-gold ores in Japan on the basis of mineral assemblages. The Silbak Premier ores compare to Nishiwaki's (op. cit., pp. 413–415) combined Type 3 argentite ore and Type 5 high silver sulphosalt ore as characterized by the Seigoshi deposit. The preceding authors suggested that the temperature of formation of the combined Type 3-Type 5 deposits was near 200 degrees Celsius and that the depth of formation was as shallow as a few hundred metres. Shilo, et al. (1971) have indicated that mineral assemblages in silver-gold deposits in the northeast USSR were deposited at temperatures of 230 degrees to 300 degrees Celsius and at depths at 0.5 to 1.5 kilometres.

The evidence of mineral zoning, metal zoning, mineral assemblages, and the near surface concentration of the bonanza ores at Silbak Premier points to a rapid change in temperature and pressure during the ore-forming process which in part reflects a physical or structural control. An important structural feature recognized near Premier is that the Lower Jurassic rocks in which the Silbak Premier deposit occurs are overlain unconformably by Middle Jurassic sediments. These sediments occur as structural remnants just to the east of Premier at Bear River Ridge and just to the west at Salmon Glacier (Grove, 1971, Fig. 3). Reconstruction of the geological sections (Grove, op. cit., Fig. 4) suggests that Middle Jurassic strata overlay the Premier area at a height of about 150 to 300 metres. This estimate, plus the fact that the glory hole ore is truncated by the present erosion surface, suggests that some bonanza ore once extended above the present level and has been eroded. Like the ore deposits in Japan and the USSR, the Silbak Premier ore was probably deposited near the surface.

Shilo, et al. (op. cit.) suggested that certain silver-gold ores in the northeast Russia were genetically related to postmagmatic volcanic processes. The Silbak Premier ores appear to be early Middle Jurassic in age and related to the adjacent Texas Creek pluton. The Middle Jurassic Monitor Lake rhyolite has also been related to this intrusion and diatreme-like breccia zones occur near Premier. Spatial and temporal relations suggest a complex plutonic-volcanic association with the Silbak Premier ore deposits. Red bed strata described near the base of the Middle Jurassic Betty Creek sequence are also spatially related to the mineral deposit and may have been a factor in controlling deposition of this complex ore. The general conclusion is that the Silbak Premier deposit represents a telescoped, low-temperature deposit and that most of the native silver is primary, not secondary as suggested in the old literature.

Syntectonic deformation, which induced destructive deformation along irregular zones now marked by abundant cataclasites, was probably accompanied by explosive acid volcanism. Later during the actual penetration of these zones the plutons partially granitized local physically and/or chemically favourable areas of the wallrocks. Petrographic studies in marginal zones of the Texas Creek granodiorite show lower silica content than in the main batholith; this outer zone of dioritic material thus represents an area of chemical depletion. The mobile constituents, possibly including some of the metals which were released by the granitizing process during an early stage, permeated through the country rocks and migrated along fissures to produce the initial alteration zones. Metoeic waters enriched with iron-rich complexes from the Betty Creek red beds percolated toward the fractured thermal area, mixed with the diffusing mobile elements and participated in the complex physical-chemical processes which led to deposition of the oxide-sulphide vein systems in physically favourable sites. Phases of mobilization led to formation of mineral deposits in traps in the prepared ground. Younger dyke swarm intrusions in the same altered horizons have themselves been mineralized by smaller but chemically similar
mineral deposits giving a total of at least four very similar mineralizing episodes. Such apparent repetition would be unusual unless the genetic process occurred throughout more or less constant conditions.

**STRATIFORM MASSIVE SULPHIDE DEPOSITS**

**GEOLOGY OF THE ANYOX DEPOSITS**

Massive sulphide deposits in the Anyox area (Fig. 24) include at least twelve compact mineral lenses. These consist principally of pyrite, pyrrhotite, and chalcopyrite, with minor sphalerite, and gangue minerals which include mainly quartz, calcite, biotite, and sericite. These deposits are largely confined to volcanic strata; they form stratiform or bed-like bodies characterized by a low length to width ratio which sets them apart from sedimentary deposits (Dunham, 1971).

The Anyox massive sulphide deposits occur mainly within a volcanic sequence, which is overlain by generally conformable marine sedimentary strata. The major northerly trending Hidden Creek syncline has sulphide lenses near the volcanic-sedimentary contact on both limbs along a known length of 10 kilometres.

**Production Record:** Mineral production from the Anyox area has been mainly from the Hidden Creek and Bonanza mines (Fig. 24) which operated during the period 1914 to 1935. Total ore production from these deposits was approximately 22.4 million tonnes which contained 336 million kilograms of copper, about 218 million grams of silver, and 3.86 million grams of gold. Ore from the major Hidden Creek mine averaged 1.5 per cent copper, 1.7 grams per tonne gold, 9.25 grams per tonne silver, and contained less than 0.5 per cent combined lead and zinc. The nearby Bonanza mine, consisting of a single massive sulphide lens, averaged 2.2 per cent copper, 1.0 gram per tonne gold, 13.4 grams per tonne silver, about 1 per cent zinc, and negligible lead. Selenium was produced at the Anyox smelter as a byproduct of the massive sulphide ores.

**Geologic Setting:** The main rock types underlying the Anyox area (Figs. 2C, 24) include a thick succession of Middle Jurassic pillow lavas and thin-bedded marine siltstones. These rocks form part of a large pendant that is entirely isolated within the Tertiary Hyder pluton at the eastern margin of the Coast Plutonic Complex. Comparable pillow volcanic-siltstone sequences have also been mapped at Treaty Glacier and Alice Arm, but in these areas the pillow lava units are relatively minor in extent compared to those in the Anyox area and no stratiform massive sulphide deposits have been found.

The lavas at Anyox, which have been correlated to the Betty Creek Formation lavas at Treaty Glacier, consist mainly of altered, green, closely packed pillows (Plate VI). In thin section the pillow lavas consist of very fine-grained felted masses of acicular amphibole, scattered blebs of epidote, and some fresh, fine-grained biotite. The lavas are basaltic but pervasive alteration of these rocks throughout the area precludes determination of their original petrography. Five samples of relatively unaltered compact pillow lava were taken from the flows between Dam Lake and the Hidden Creek mine for chemical analysis. The results shown in Table 6 suggest that the sequence includes mainly metamorphosed tholeiitic basalt. The upper 600 to 750 metres of the pillow lava sequence include a variety of altered pillow breccias (Plate VII) which are localized in and traditional with the closely packed pillow lavas. The pillow breccia zones are used to outline the structure of the pillow succession. The pillow breccias form discrete lenses from a few metres to several metres thick which are traceable over hundreds of metres. The transition from closely packed pillow to pillow breccia takes place within a few metres, and the vertical limits are marked by sharply conformable contacts. This pillow lava sequence is largely conformably overlain by a thick sequence of thin-bedded marine siltstones that correlate with the Middle Jurassic Salmon River Formation.
The nature of the contact between the pillow lavas and the siltstones varies along the length of the Bonanza syncline. In the axial zone, near the south end of the syncline, the contact is gradational through a 3 to 6-metre-thick zone of thinly banded quartzite which in turn grades into the overlying calcareous siltstone sequence (Plate VIII). Along both limbs of the syncline the contact is obscured by local deformation. In the Bonanza Creek area the contact consists of a series of thin carbonate, chert, and siltstone lenses that are intercalated with pillow lavas underlying the main siltstone sequence. At the mouth of
TABLE 6. CHEMICAL ANALYSES, ANYOX PILLOW LAVAS

<table>
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<td></td>
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<td>14820M</td>
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Locations: 1 — Dam Lake, No. 1 dam.  
2 — No. 2 dam.  
3 — Eden 1.  
4 — Double Ed 1.  
5 — Bonanza 1.

Analyses by the Analytical Laboratory, Geological Survey Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources.

Bonanza Creek on the east limb, pillow lavas underlying the siltstone are intensely flattened and have commonly been misidentified as thin-bedded sediments. At Hidden Creek near the orebodies the contact between the pillow lava and overlying siltstones is sharp and conformable, but it has been complexly folded and faulted.

The overlying siltstones include abundant small limestone concretions, minor cherty lenses, and graphite zones. Disseminated fine-grained pyrite and pyrrhotite are ubiquitous within the calcareous siltstones that immediately overlie the pillow lavas. The siltstones are mainly thinly bedded, and buff to black with intercalated silty greywackes, calcarenites, and silty argillites. The siltstones are characterized by a blocky to splintery habit and weather reddish. Within the body of the Bonanza syncline, they are moderately fresh and exhibit a typical grey and black striping. Planar banding is the major primary feature, although enterolithic structures have been noted. Foliation is rare and generally limited to the margins of dykes. At contacts with the Hyder pluton the siltstones are indurated and typically display tremolite needles or clumps of needles. Elsewhere altered andalusite and fine-grained brown biotite occur as random clusters within the lower 300 to 450 metres of the siltstone sequence. Near the Hyder pluton, limestone concretions in the lower part of the succession have been altered to aggregates of calcite, quartz, epidote, and grossularite.

The extensive alteration of the pillow lavas is assumed to represent autometasomatism (Bonatti, 1967), whereas development of andalusite is interpreted to indicate Middle Jurassic lower amphibolite grade regional metamorphism. The tremolite hornfels zones are obviously related to Tertiary plutons.

The major geological structure in the Anyox area is the Bonanza syncline. This feature trends northerly and is asymmetric. Shear zones, assumed to be related to the same tectonic event, are localized within the pillow lava sequence near the intrusive contact zone south of Bonanza Creek and also along the margins of the massive sulphide deposits.
Detailed structural studies at the Hidden Creek mine have shown that the complexly folded siltstone sequence overlies the massive sulphide bodies, forming what has locally been called a structural 'nose' in the older literature (Nelson, 1948). This local feature has generally been interpreted to represent the major structural control for the localization of the massive sulphide lenses (Fig. 25). Mapping of the Bonanza, Double Ed, and Redwing properties (Fig. 24) has shown that these deposits lie entirely within the pillow lavas, but their structural situation in relation to the overlying siltstone is complicated by folding. The No. 6 orebody at Hidden Creek (Fig. 23) also lies entirely within the pillow lavas and is overlain by relatively undeformed siltstones. The folding of the Hidden Creek syncline postdates massive sulphide deposition and is assumed to be related to Middle Jurassic tectonism.

Orebodies at the Hidden Creek Mine: The principal orebodies in the Anyox area are those of the Hidden Creek mine. The Hidden Creek orebodies are pipe-like to sheet-like lenses that consist mainly of pyrite, pyrrhotite, chalcopyrite, and sphalerite with minor arsenopyrite, galena, and magnetite. The gangue minerals are principally quartz, calcite, and sericite with minor epidote and garnet. Eight separate ore lenses are known of which the largest has a length of at least 500 metres, a width of from 250 to 300 metres, and a thickness up to 100 metres. The smaller lenses are nonuniform in thickness along their length. All of the lenses at the Hidden Creek mine are nearly vertical and six major ore lenses were mined by underground and glory hole methods. Prior to closing the operation in 1935 mining procedures were attempted which resulted in extensive damage to the mine system. Access is now restricted to surface exposures in the glory holes and to limited mine workings.

The orebodies at Hidden Creek lie mainly within the pillow lava sequence at different stratigraphic levels below the siltstone contact. This general relationship is illustrated on the geological plan (Fig. 25) and on the composite geological section (Fig. 26). The contact orebodies, Nos. 1, 4, 5, and 6, exhibit complex relationships to the enclosing country rocks and, as indicated by the geological plan and section, appear to lie partly within the siltstone. The keel sections as well as the margins of these four lenses are entirely within the altered pillow lavas, but the upper, complexly deformed segment of 1-5 ore zone exhibits possible replacement of the thin-bedded siltstones. This siltstone-sulphide contact has been deformed along much of the 1-5 zone, but certain segments, particularly in the No. 5 orebody, suggest a continuity of mineral banding in the ore with apparent bedding in the siltstones. The sulphide ore in these segments is irregular and appears to transect the sediments. Elsewhere apparent replacement of siltstones by sulphides is a result of localized shearing and sulphide remobilization.

The general mineralogy of these lenses is simple. The footwall zone of the Nos. 1, 4, and 5 orebodies (Fig. 25) comprises a 230-metre-thick zone of fine-grained granular quartz and sericite characterized by a vuggy or spongy texture and very fine-grained framboidal pyrite encrusted within the cavities. In polished sections this pyrite displays radial shrinkage cracks but is otherwise textureless. The 1, 4, and 5 orebodies themselves, as compared to the footwall zone, consist almost entirely of medium-grained, massive pyrite in which chalcopyrite is present as blebs and streaks along discrete fractures. The minor amount of gangue consists of disseminated and lens-like fine-grained quartz and calcite.

The 6 orebody, one of the contact lenses, is marked by well-defined centimetre-scale mineral banding defined by pyrite, pyrrhotite, and quartz-sericite gangue (Plate XXI). In hand specimen the chalcopyrite and pyrrhotite occur as veinlets and streaks cutting the banding in the pyrite gangue as a response to late-stage deformation.

The narrow footwall of the 2 and 3 orebodies, which are entirely enclosed in the pillow lavas, is uniquely characterized by the presence of very fine-grained epidote and grossularite garnet as specks and streaks in the sulphide matrix. These orebodies comprise principally medium to coarse-grained pyrite, pyrrhotite, and chalcopyrite, with
Figure 25. Plan of orebodies, Hidden Creek mine, Anyox.
minor magnetite and quartz. In the 2-3 ore zone, chalcopyrite is associated with pyrrhotite, which is localized within the central part of the ore lenses. The 7 and 8 orebodies, also confined to the pillow lavas, consist almost entirely of granular pyrite and pyrrhotite, disseminated chalcopyrite, and fine-grained quartz. These two orebodies have not been completely studied and are known only from exploration drill-core data.

The chemical compositions of the major orebodies at Hidden Creek have been calculated from the smelter records and are shown in Table 7.

In summary, the sulphide orebodies at the Hidden Creek mine consist primarily of pyrite, pyrrhotite, and chalcopyrite with minor sphalerite, magnetite, galena, and arsenopyrite. The principal gangue minerals include quartz, calcite, and sericite with some epidote and garnet. The orebodies can be characterized as conformable massive sulphide deposits in the terminology of Dunham (1971).

On the basis of the observed mineralogy, mineral zoning, and bulk chemical composition, the individual orebodies can be divided into three distinct groups:

(A) The contact orebodies, represented by 1, 4, 5, and 6, which are primarily pyrite masses with associated pyrrhotite, chalcopyrite, quartz, calcite, and sericite.

(B) Orebodies 2 and 3, which lie entirely within the pillow lava sequence, consist of pyrite and pyrrhotite, with chalcopyrite entirely confined to the central pyrrhotite zone; the gangue includes calc-silicates, quartz, and minor sericite, but is notably deficient in calcite.

(C) Sub-ore masses such as the 7 and 8 lenses which are spatially intermediate between groups A and B and are relatively deficient in chalcopyrite.

The bulk chemical composition of the Hidden Creek orebodies (Table 7) has been presented to complement the mineralogical variations outlined and to characterize the
Alteration in the Hidden Creek Mine Area: The Hidden Creek orebodies are enveloped in a thin, film-like zone of quartz-sericite schist which varies in thickness from a few metres to tens of metres, where the alteration is gradational with the footwall vuggy quartz framboidal pyrite zone. The pillow volcanics outside the schist zone exhibit the widespread amphibole alteration previously described, but apart from local iron staining, they show no apparent alteration that is spatially related to the massive sulphide lenses. Similarly, the overlying siltstones exhibit no significant alteration near the massive sulphide lenses that is related to the sulphide lenses alone. Locally silicification and secondary brown biotite appear to be more prominent near the orebodies than along the nonproductive contact in the siltstones but this may merely reflect rock exposure, regional metamorphism, or personal bias.

Several extensive quartz, carbonate, and magnetite alteration zones have been outlined along the pillow lava-siltstone contact south of the Hidden Creek mine. Extensive exploration diamond drilling of these areas has not led to discovery of any significant massive sulphide or disseminated sulphide mineralization. These zones, like the many barren quartz veins in the Anyox area, are probably of Tertiary age.
TABLE 7. CHEMICAL COMPOSITION, HIDDEN CREEK OREBODIES

(Per Cent)

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Other Massive Sulphide Deposits: Three other stratiform massive sulphide deposits, the Double Ed, Redwing, and Bonanza, occur near the contact between the pillow lavas and the siltstones south of the Hidden Creek mine. The first two occur on the west limb of the Hidden Creek syncline, while the Bonanza deposit is the only known occurrence on the east limb (Fig. 24). All three deposits are within the pillow lavas and are enveloped in a narrow, variably chloritic, quartz biotite schist zone. These deposits are minerallogically similar to the group 1 contact zone orebodies. They are characterized by medium to coarse-grained, frequently granular pyrite, streaky pyrrhotite lenses, scattered chalcopyrite, and prominent bands of dark brown sphalerite (Plate XXII).

The Bonanza deposit consists of a flattened, pipe-like lens that plunges at a shallow angle to the north below the pillow lava-siltstone contact near the axis of the Hidden Creek syncline. The known length of this lens is about 750 metres; it has a thickness of up to 40 metres and width of up to 120 metres. The grades and mineralogy are comparable to the contact lenses at the Hidden Creek mine. The Bonanza deposit is cut by several dyke swarms and intruded by Tertiary intrusives near the north end.

The Redwing and Double Ed deposits, also localized within chloritic biotite schist envelopes within the pillow lavas, are similar in grade and mineralogy to the Bonanza and Hidden Creek deposits. Both the Redwing and Double Ed deposits were slightly deformed, probably during the regional tectonic episode (Fig. 18). These deposits exhibit flattened, pipe-like forms and plunge steeply within the pillow lava sequence; like all these deposits they are essentially parallel to the pillow lava-siltstone contact.

Exploration west of the contact revealed several siliceous massive pyrrhotite-chalcopyrite replacement zones. These are confined to pillow breccia and broken pillow breccia zones. Surface work and diamond drilling indicate these zones are about 100 metres in diameter and steeply inclined; they are not related to any simple fracture system or to plutons.

The fact that the stratiform massive sulphide and sulphide breccia deposits in the Anyox area are associated in every instance with lavas is evidence of a genetic relationship (Dunham, 1971, p. 169). The fact, that the length to width ratios of these sulphide lenses are lower than almost all known sedimentary deposits, also argues for a volcanogenic association. Detailed studies at Anyox have not revealed plutons spatially related to the sulphide deposits. On the basis of chemical composition of the eight sulphide lenses at the Hidden Creek mine and lithostructural and mineralogical similarity at the other sulphide deposits, the sulphide lenses are probably volcanogenic, but hydrothermal processes may have been involved.

The bulk of the hydrothermal vein deposits in the Stewart Complex suggests a similarity of process indicated by large amounts of quartz and carbonate gangue compared to relatively minor sulphide content. A calculation based on the Silbak Premier deposit indicates that the overall ratio of gangue material to sulphide in the vein system is about 700:1. A general study of the vein deposits suggests that the minimum gangue to sulphide ratio is greater than 500:1. In contrast the Anyox volcanogenic massive sulphide deposits are characterized by a low volume of gangue mineral which at Anyox forms less than half the material in the lenses, so that the ratio is less than 1:1 (Table 7).
Plate XXI. Mineral banding in massive sulphide ore, No. 6 orebody, Hidden Creek mine.

Plate XXII. Mineral banding in massive sulphide ore, Bonanza mine.
The massive sulphide deposits at Anyox appear to form part of a continuous volcanic sequence deposited during the late stages of submarine activity prior to regional, shallow marine sedimentation.

Clark (1971), Hutchinson and Searle (1971), and others have reviewed the geological setting of the cupriferous massive sulphide deposits of Cyprus. The various workers have generally concluded that these ore deposits have formed periodically related to subaqueous exhalations or effusions, followed by distinctive iron oxide, silica-rich chemical sedimentation. They have also suggested that the precipitation and accumulation of colloidal sulphide in sea floor depressions occurred in a reducing environment. Hutchinson and Searle (op. cit.) concluded that the water, metals, and sulphur in the volcanic emanations were derived from a mantle source in accord with the character of the Troodos Complex as a whole.

The general relationships of the Anyox massive sulphide deposits, including age, size, shape, composition and texture, timing, and in part the sedimentation record, correspond closely to the Cyprus deposits. By analogy, the similarity between the extensively altered pillow lavas, the presence of mineralized volcanic breccias, plus the possible colloidal nature of part of the Anyox deposits as expressed by the frambooidal pyrite and vuggy quartz zones suggests a comparable ore-forming process.

Because of deformation and folding few of the Anyox massive sulphide lenses are readily accessible. Reconstruction and unfolding of the deposits suggest a partly preserved centrifugal pattern for the sulphide bodies radiating from the Hidden Creek area. To the writer this pattern suggests a common vent source for sulphide flows controlled by submarine canyons which may have first been distorted by caldera collapse and later by regional deformation.

On the basis of the geological evidence and the comparability of the Anyox and Cyprus sulphide orebodies, it is suggested that the Anyox massive sulphide deposits formed principally by subaqueous fumarolic and syngenic processes related to Middle Jurassic plutonic-volcanic activity. In the Anyox area in particular and the Stewart Complex in general, widespread Tertiary plutonism has erased evidence of any Middle Jurassic pillow lava-ophiolite affiliation, if it ever existed. More importantly Tertiary plutonism may have destroyed, or even recycled, other Anyox-type massive sulphide deposits.

CONCORDANT MASSIVE SULPHIDE DEPOSITS

GEOLOGY OF THE GRANDUC DEPOSIT

The only representative of this class of mineral deposit in the Stewart Complex is the Granduc property located at Granduc Mountain 40 kilometres northeast of Stewart. This large deposit was discovered in 1951 when ablation of the South Leduc Glacier revealed a small area of mineralization at the 1100-metre elevation (Fig. 4). Published ore reserves indicated 49 million tonnes of ore with a grade of about 1.55 per cent copper and 6.9 grams per tonne silver, with minor gold, lead, and zinc. The deposit represents the largest concordant massive sulphide deposit in the Canadian Cordillera (Dunham, 1971).

The Granduc ore deposit lies near a conspicuous reentrant in the eastern margin of the Coast Plutonic Complex (Fig. 13). The sulphide lenses comprising the ore deposit are entirely confined to a 120-metre-wide zone located near the easterly margin of the South Unuk cataclasite zone. The zone is locally bounded on the west by northerly trending mixed granodiorite gneisses and on the east by variably deformed epiclastic volcanic conglomerates and indurated, altered pillow volcanics. South of Granduc Mountain the country rocks, including the ore-bearing cataclasites, are cut by Tertiary plutons. Because strata in the Granduc Mountain area are deformed, the original nature of the ore-bearing strata and enclosing wallrocks is based on study of the least deformed rock units in the area.
general mine area. Away from the ore lenses the country rocks include a complex volcanic-sedimentary sequence dated by fossils as Pliensbachian, and referred to in this study as part of the middle member of the Unuk River Formation (Fig. 9).

Extensive, thick, andesitic volcanics east of the Granduc orebodies form part of a northerly trending zone of shallow marine, closely packed pillow lavas intercalated within graphitic siltstones, thin-bedded lithic and crystal tuffs, and volcanic sandstones. This sequence is overlain by a sequence of strata, including the ore zone, which includes graphitic siltstones, thin-bedded lenticular gypsum-bearing limestones, quartz pebble and quartz cobble conglomerate lenses, banded volcanic tuffs, quartzites, and cherts. Strata north of the ore zone at North Leduc Glacier are intruded by a variety of Lower Jurassic plutons previously described as the Unuk River Intrusions. Several of these small plutons as well as the country rocks have been deformed and form part of the South Unuk cataclasite zone. In addition to cataclasis the mine area underwent several periods of later deformation, intrusion, alteration, faulting, and erosion culminating in Tertiary time with Hyder plutonism.

The ore deposit at Granduc Mountain lies along part of the deformed, overturned, west limb of a pre-Middle Jurassic, possibly Aalenian, northerly trending anticlinal fold. The west limb of this fold is crossed at a low angle by the South Unuk cataclasite zone. In the cataclasite zone, structure at Granduc Mountain is outlined by lenses of deformed recrystallized limestone, thick lenticular ultramylonite sheets, and mineral banding in the mylonites and phyllonites. Both the petrology and structure of this cataclasite zone in the mine area have been described in previous chapters. South of the ore zone at South Leduc Glacier the country rocks are weakly deformed and consist of thick-bedded andesitic volcanic conglomerates with minor fine-grained sediments.

Orebodies: All known ore-grade mineralization at Granduc is confined to a 120-metre-wide, vertical zone within the northerly trending South Unuk cataclasite zone. The relationship of the various ore zones within the mylonite-phyllonite sequence is shown on Figure 28. Each ore zone includes several lenses of massive sulphides separated mainly by barren cataclasite or by country rock cut by stockwork-like sulphide stringer zones. Ore zones comprise pancake-like, overlapping, and commonly merging lenses which are known to extend vertically from about 450 to 1200 metres elevation and extend laterally for at least 1200 metres. The massive sulphide lenses have been assigned letters A through F to partially systematize the complex pattern (Fig. 28 and Fig. 4).

In detail individual ore zones consist of massive lenses, irregular streaks and blebs, and veinlets of sulphide with rapidly changing outlines. Breccia texture in the massive sulphide, largely represented by rotated blocks of mylonite and also abundant evidence of chalcopyrite and pyrrhotite remobilization as veins, indicates pervasive sulphide deformation at several periods. As a result of repeated deformation the massive sulphide lenses and orebodies have an irregular, feathery nature and have been called stringer lodes by the mine geologists (Norman and McCue, 1966).

The Granduc orebodies consist principally of pyrite, chalcopyrite, pyrrhotite, sphalerite, and galena in order of relative abundance. Arsenopyrite is ubiquitous and cobaltite has been identified in the upper part of the 'A' zone. Magnetite is a common constituent in both the ore zones and wallrocks but appears to be more abundant along the western limit of the ore horizon. In the massive sulphide lenses, gangue includes blocks of brecciated country rock, quartz as lenses, stringers and blebs, and moderately abundant recrystallized coarse-grained calcite as lenses and stringers.

In each orebody the massive sulphide lenses are concordant with the thinly banded wallrocks. The major ore zones (Fig. 28) consist of numerous massive sulphide lenses, each up to a few tens of metres thick, which extend laterally up to hundreds of metres within the confining cataclasites. Wallrocks intercalated with the massive sulphide lenses
contain a multitude of concordant millimetre-scale sulphide lenticles as well as a reticulated stockwork of fine sulphide veins and veinlets that consist mainly of chalcopyrite. These veinlets generally extend outward from the massive sulphide lenses into and across the country rock for distances of a few tens of metres; locally they transect other massive sulphide lenses within the ore zones. Chalcopyrite and, to a lesser extent, pyrrhotite comprising these veinlets are assumed to have been remobilized (Mookherjee, 1970) by local post-cataclastic deformation. As a result, locally wallrock between sulphide lenses in the ore zones has been mined.

In the massive sulphide lenses galena and sphalerite are concentrated with quartzose material and occur as irregular augen throughout the lenses. In contrast to the fine-grained pyrite, chalcopyrite, and pyrrhotite in these lenses, galena and sphalerite are coarse-grained and exhibit little evidence of deformation. The galena, sphalerite, and host quartz are also veined by chalcopyrite and pyrrhotite veinlets. Contrary to experimental evidence (J. E. Gill, personal communication), chalcopyrite and pyrrhotite appear to have been remobilized in preference to galena. However, the galena and sphalerite may have been protected by their close association with quartz lenses.

Crude mineral banding and flow-like structures occur rotated around country rock inclusions in the massive sulphide bodies (Plate XXIII). Pyrite in the lenses is coarse grained; it consists of irregular, angular fragments, and also forms pods or streaks (Plate XXIV) surrounded and veined by chalcopyrite and pyrrhotite. Complex bands of magnetite occur throughout the ore lenses. Both the chalcopyrite and pyrrhotite are generally fine-grained, show recrystallization and segregation, and form the matrix for the angular ore and gangue materials. The protoclastic textures of the ore and gangue minerals indicate that the massive sulphide lenses, like the country rocks, were subjected to deformation. This is expressed by the cataclastic textures, mineral differentiation, and irregular mineral recrystallization.

As Stanton (1959, 1960, 1964) and others have suggested, textures in deformed sulphide ores are not evidence of a normal paragenetic sequence. Instead the textures reflect the intensity of the deformational event and can commonly be expressed as a crystalloblastic series. In the Granduc ore, because of unusual conditions, chalcopyrite and pyrrhotite have also been remobilized and recrystallized at a late stage in preference to the normally more mobile galena.

The mobility of the chalcopyrite has been an important factor in determining commercial ore limits at Granduc. McDonald (1967) cited experimental and physical evidence for the mobility of chalcopyrite and for the associated preferential enrichment of wallrocks by veining as a result of differential movement. At Granduc, chalcopyrite and to a lesser
Plate XXIII. Massive sulphide ore from the Ch zone, Granduc mine, showing related country rock inclusions.

Plate XXIV. Massive sulphide ore from the C zone, Granduc mine, with fragmented pyrite and magnetite as streaks.
Vokes (1969) noted that ores healed by fine-grained products of deformed sulphide are very commonly found in the greenschist facies environment of the Norwegian Cal- edonides. Composition, particularly the presence of abundant chalcopyrite, appears to partly control mineral textures in massive sulphide deposits deformed under such a low-grade regime. Thus the Granduc ores are massive and compact in contrast to the sandy pyritic deposits at Anyox and Cyprus. As Vokes and many others have pointed out, a banded structure common to most sulphide ores is generally oriented parallel to bedding or country rock stratification and is characteristic of metamorphosed ‘kieslagerstatten’ ore deposits.

Alteration: There is no apparent macroscopic or microscopic alteration related to the massive sulphide lenses at Granduc. Calc-silicate lenses are found within the ore as well as throughout the cataclasite zone at the Granduc property. Tourmaline is found as clasts in the mineralized areas as well as in the footwall phyllonite unit but, like the widespread calc-silicate minerals, has no direct spatial relationship to ore. Brecciated remnants of dykes and small plutons occur in the ore horizon but these appear to be spatially restricted and unrelated to ore zones, calc-silicates, and tourmalinized wallrock. The apparent absence of an alteration halo may be a result of cataclastic deformation in the ore horizon but it may also be a function of ore genesis.

Genesis: The Granduc ore deposit comprises a series of concordant massive sulphide lenses localized within a complex sequence of volcanic-sedimentary rocks that have been deformed by cataclasis. Norman and McCue (1966) suggested that the orebodies occur in a folded metasedimentary sequence and formed when mineralizing fluids were channeled along a swarm of andesitic dykes. They concluded that the introduction of chalcopyrite was preceded by the formation of abundant magnetite, epidote, actinolite, small amounts of garnet, and tourmaline. Also the presence of biotite in the phyllonites has been interpreted as an alteration halo possibly related to migrating solutions associated with nearby dioritic plutons. Norman and McCue (op. cit.) have classified the Granduc deposit as a pyrometasomatic stringer lode while others (Ney, 1966; White, 1966) referred to it as a sulphide lode or lode deposit. Because of extensive destructional deformation along the South Unuk cataclasite zone, original structures and textures, and relationships between the ore and the country rocks are obscured. As a result, any genetic interpretation regarding the Granduc orebodies must rely on indirect evidence.

The intimate association of apatite, magnetite, calcite, and calc-silicate minerals in the ore horizon and in the country rocks suggests an indirect relationship. The normal range of apatite in igneous rocks is from 0.1 to 1.0 per cent by volume (Grobler and Whitfield, 1970). They indicated that in olivine-apatite-magnetite bands in the Villa Nora deposit in the Bushveld Igneous Complex magnetite averaged 20 per cent and apatite 22 per cent by volume. Philpotts (1967) summarized literature on magnetite-ilmenite-apatite occurrences; they appear to be restricted to certain alkaline complexes and to rocks of the anorthosite suite. He concluded that these minerals resulted from fractional crystallization, and formed at minimum temperatures of 850 degrees to 1 000 degrees centigrade. Magnetite-apatite deposits are also well known in the Palabora area of northeast Transvaal, where they occur as veins and disseminated deposits in pyroxenite and syenite, and near carbonatite complexes (Schwellnus, 1938; Haughton, 1969). Naldrett (1970) reports widespread occurrences of magnetite-apatite-hypersthene cumulus layers within oxide-rich gabbro in the Sudbury irruptive.
At the Granduc property, the magnetite-apatite-calcite mineral assemblage occurs as thinly banded layers intercalated with calc-silicates, limestone bands up to 6 metres thick, graphitic quartzofeldspathic cataclasites, and the massive sulphide lenses. Thin section studies show that apatite comprises up to 25 per cent by volume in the calc-silicate layers and averages about 10 per cent in most of the rocks. Bulk analyses of country rocks outside the ore zone indicate an average composition of about 4.4 per cent total iron, 2.42 per cent $\text{Ca(PO}_4\text{)}_2$, 0.02 per cent copper, 0.008 per cent lead, and 0.005 per cent zinc.

The initial evidence from the Granduc rocks suggests that the magnetite-apatite-calcite zones are random within the local sequence and have not been concentrated as veins related to alkaline, carbonatite, or basic intrusives. This lack of relationship to intrusives indicates the possibility of a sedimentary origin with concentration of iron and phosphorous-rich material in close association with organic-rich sediments and carbonates.

A hydrothermal origin for Granduc mineralization has had a few proponents but direct evidence is lacking. Granduc ore, like Anyox ore, has a gangue to sulphide ratio of approximately 1:1, even including country rock breccia. Hydrothermal veins in the study area have a minimum gangue to ore ratio of 500:1, and the Silbak Premier system, which is known in detail, has a gangue to sulphide ratio of 700:1. The possibility of metamorphic dispersal of the gangue from the sulphide has been considered but this appears to be unlikely. The mobility of both sulphide and gangue material is very limited under low-grade metamorphic conditions, and there are no significant quartz or quartz-carbonate veins in the Granduc area.

After considering various theories for the origin of massive sulphides at Granduc, a volcanogenic-sedimentary origin is preferred. As Krauskopf (1971) noted the association of massive sulphide deposits with volcanogenic-sedimentary processes eliminates the enrichment stage generally related to hydrothermal and other processes, and also provides a metal source directly in magma. Clues to possible genesis of the Granduc mineralization can be found in the local stratigraphic sequence and in the wallrocks. The strata comprise a variety of gypsiferous grey limestone lenses, graphitic marine siltstones, volcanic sandstones, lithic and crystal tuffs, cherts, quartz conglomerates, and volcanic conglomerates. This sequence overlies thick pillow lavas, rhyolite flows, cherts, quartz conglomerates, and volcanic conglomerates. This sequence overlies thick pillow lavas, rhyolite flows, cherts, and various volcanic sediments. To the north and south this complex stratigraphic sequence grades rapidly into thick epiclastic volcanic conglomerates and marine sediments. The Granduc massive sulphide lenses occur in a sequence of shallow water marine, possibly brackish, near shore or restricted basinal deposits. The original rock assemblage is assumed to have included primary calcite, organic matter, iron oxides, gypsum, and phosphate. It is likely that significant acid volcanism was active during deposition of the sedimentary assemblage.

On the basis of the stability field diagram for iron oxides (Krumbein and Garrels, 1952), the writer assumes that the lithologic assemblage at Granduc was deposited in a restricted, shallow marine environment marked by a low negative Eh and a pH about 7.8. Apparent cyclic deposition in this basin, which is evidenced by alternating apatite-magnetite, calc-silicate, limestone, and quartzofeldspathic rocks, possibly represents fluctuations in the acidity of the basin (Sakamoto, 1950). There were periodic incursions of volcanic ash. The massive sulphide lenses at Granduc are present within a 230-metre-thick sequence as a series of overlapping lenses separated by originally unmineralized basinal sediments suggesting that these widely separated sulphide layers formed periodically. The evidence at Granduc suggests a sedimentary-volcanogenic origin analogous to other well-known deposits.

The relatively unmetamorphosed Kuroko-type deposits of Japan provide a model for bedded sedimentary sulphides related to submarine volcanic processes. Kuroko-type deposits formed under conditions of nearly neutral pH and low Eh (Horikoshi, 1965). A comparison of the chalcopyrite-rich sulphide lenses at Granduc to Japanese deposits indicates a similarity to the yellow, massive cupferiferous iron sulphide Oko ores (Mat-
sukuma, et al., 1970). The Oko ores are apparently transitional between siliceous breccia ores and the sphalerite and galena-rich Kuroko ores. This distinction is not as readily made at Granduc, although galena and sphalerite are mainly concentrated in the A and Ch zones which stratigraphically lie at the top of the ore horizon. The B and F footwall zones at Granduc, like Kuroko deposits, include a higher proportion of pyrite and siliceous material than the overlying zones. Matsukuma, et al., (op. cit.) have also noted that gypsum deposits, which are spatially related to Oko ores, have never been found directly adjacent to acidic volcanics but are generally associated with small lenses of silicified rocks. Apparently, these rocks have commonly been mistaken for rhyolite, but actually represent silicified pyroclastic zones. At Granduc siliceous ultramylonite lenses are intimately related with the massive sulphide lenses and are comparable in size and extent to siliceous zones related to Oko ores.

The Granduc ore horizon lies within a sequence marked by abundant graphite and carbonate. There are no known occurrences of graphite associated with Kuroko deposits and no carbonate minerals in Kuroko ores (Kajiwara, 1970). Calcite is a common minor gangue mineral in the Granduc sulphide lenses and graphite is characteristic of the footwall phyllonite country rocks. It appears that, although the general ore environment at Granduc compares to certain Kuroko features, there are significant variations which imply a somewhat different ore-forming process.

Lambert and Bubela (1970) studied the processes leading to formation of banded sedimentary sulphide ores. In these experiments (Bubela and McDonald, 1969; Lambert and Bubela, op. cit.), the pH of the suspension was held between 7 and 8, and the aqueous sodium sulphide solution was inoculated with the sulphate-reducing organism Desulfotomaculum nigrificans. The sulphate-fixing bacterium requires nutrients in order to promote cell growth; both nitrogen and phosphorus are essential to organic growth and to the activity and regeneration of these organisms. Nitrogen is generally available as the \( \text{NH}_4^+ \) ion, and phosphorus, which supports the primary function of storing and transferring energy, is supplied by phosphate. At Granduc, phosphate is now represented by abundant apatite in both the ore horizon and the country rocks; it appears to have been present in more than adequate amounts to promote bacterial growth and perpetuate the bacterial sulphate-fixing cycle in the sedimentary-volcanic sequence.

The writer concludes that the concordant Granduc massive sulphide deposits represent deformed syngenetic sulphide. These deposits were probably formed in a restricted, shallow marine, sedimentary-volcanic environment where sedimentation was accompanied by hydrothermal or fumarolic enrichment of metal, where biogenic sulphur was available and where phosphorus was supplied by upwelling currents.

**PORPHYRY DEPOSITS**

**PORPHYRY MOLYBDENUM DEPOSITS**

The Tertiary Lime Creek quartz monzonite stock is one of the Alice Arm Intrusions, all of which bear a close petrological resemblance and all of which have accessory molybdenite. The Alice Arm Intrusions are part of an extensive belt of Tertiary quartz monzonite stocks that parallel the eastern margin of the Coast Plutonic Belt. G. Pouliot (personal communication) studied producing mines in this belt of Tertiary stocks from Alice Arm to Montana, and has been impressed with their similar petrogenic characteristics. In northwestern British Columbia the age of these stocks has been determined by K-Ar methods as about 50 to 52 Ma.

**PORPHYRY COPPER-MOLYBDENUM DEPOSITS**

These deposits are characterized by their large size, complex geological environment, and the presence of both copper, molybdenite, and accessory silver mineralization. A low-grade disseminated mineral zone in the Stewart Complex is the Mitchell-Sulphurets
property north of the Granduc mine (Fig. 2A). The deposit is a chalcopyrite-pyrite-bornite and molybdenite replacement feature spatially related to a differentiated syenodiorite stock and dyke complex. Major features indicating large-scale replacement are alteration haloes of porphyroblastic microcline, pyrite, quartz, and sericite in the country rocks enveloping the stock (Kirkham, 1968). The country rocks include preferentially altered and replaced Lower Jurassic volcanic conglomerates and less altered volcanic breccias and sandstones. Both the mineralized zone and the intrusives are deformed and eroded. The mineralized zone is unconformably overlain by part of the Middle Jurassic Betty Creek Formation, which in turn has been faulted and eroded, and is disconformably overlain by the Middle Jurassic Salmon River Formation.

The secondary potash feldspar represents an early widespread hydrothermal alteration phase. Subsequent sericite and quartz alteration is restricted to the northeast margin of the zone, where country rocks were pervasively altered to a sericitic quartz stockwork. Quartz veins are common along the east margin of the zone. Extensive massive quartz emplacement at the north side of Mitchell Glacier suggests a major hydrothermal event. Talc schists along parts of the eastern hydrothermal aureole appear to have developed as a result of local deformation related to plutonism.

METALLOGENIC EPOCHS IN THE STEWART COMPLEX

The complexity of the tectonic evolution of the Stewart Complex, as well as the great abundance of mineral deposits in the area, has hindered the development of a metallogenic model for the region. The metallogenic epochs presented below are directly applicable to the Stewart Complex but could be adapted to an overall metallogenic hypothesis for the Western Cordillera.

(2) Epoch 2: Lower Jurassic — copper, molybdenum, gold, silver.
(3) Epoch 3: Middle Jurassic — copper, gold, silver, lead, zinc.
(4) Epoch 4: Late Jurassic-Cretaceous — copper, lead, zinc, gold, silver, antimony, arsenic.

Epoch 1: One type of mineral deposit characterizes the Upper Triassic mineralization in the Stewart Complex. This is a massive magnetite-chalcopyrite occurrence on the north side of McQuillan Ridge in the Unuk River area. The Max deposit has not been studied in detail but ore appears to be confined to the anticlinal crest of a folded granular limestone sequence which has been intruded and weakly deformed by Late Triassic quartz diorite. Physically the Max deposit is a conformable, stratabound, massive oxide-sulphide deposit. The writer suggests that this has been formed by syngenetic sedimentary-volcanogenic processes, rather than contact metamorphic processes.

Epoch 2: Lower Jurassic deposits in the Stewart Complex include simple fissure veins which exhibit high gold-low silver ratios, hydrothermal replacement porphyry-type copper-molybdenum deposits, and the conformable cupriferous massive sulphide deposits at Granduc Mountain. Structural and stratigraphic evidence indicates that these deposits formed during the Hettangian to Toarcian stages prior to Aalenian or Early Bajocian orogeny.

Epoch 3: Characteristic Middle Jurassic mineral deposits include gold-silver fissure veins, vein-replacement mineralization, characterized by the Silbak Premier deposits, and stratiform cupriferous pyritic deposits localized in the Anyox area. The simple fissure vein and transitional vein-replacement deposits are characterized by low silver-gold ratios and have been correlated with a spatially related Middle Jurassic granitic intrusion and acid volcanism.
Epoch 4: These deposits are generally fissure vein or replacement deposits spatially related to the margins of minor intrusions. None of these deposits has produced a significant tonnage of ore.

Epoch 5: This epoch is characterized by high silver-low gold fissure and vein-replacement deposits, porphyry deposits, and minor contact skarn deposits. The B.C. Molybdenum mine at Lime Creek characterizes the Tertiary porphyry deposits. Significantly, there are no known major mineral deposits found in the local Hyder pluton, in the large satellite granitic bodies, or in the gneissic segment of the Coast Plutonic Complex.

Discussion: The metallogenic sequence developed for the Stewart Complex indicates that mineralization from the Late Triassic to Tertiary periods has an overall similarity as a result of comparable genetic processes but is marked by certain distinct features. One feature which readily separates the groups of deposits is the silver-gold ratio in the ores. The Stewart Complex exhibits broad metal zoning (Fig. 17) which can be directly related to metallogenesis. The Upper Triassic and Lower Jurassic vein deposits have high gold-low silver ratios, the Middle Jurassic vein deposits low silver-gold ratios of about 30:1, and the younger Jura-Cretaceous and Tertiary deposits high silver to gold ratios. At the Torbrit deposit, for example, the silver-gold ratio is about 100 000:1, and the Dolly Varden ratio is about 1 400 000:1.

As a general rule, vein deposits in the Stewart Complex have high gangue to sulphide ratios; at Silbak the ratio was about 700:1; it is even higher in the less productive fissure vein systems. The various massive sulphide deposits are characterized by gangue to sulphide ratios of 1:1 or less which appears to be indicative of a syngenetic volcanic-sedimentary environment. The silver-gold ratios of the volcanogenic massive sulphide ores range from about 30:1 to 60:1 which is approximately the same as the values calculated for the vein-replacement deposits (for example, Silbak Premier) related to a plutonic-volcanic environment.

The evolution of the Stewart Complex has been characterized by repeated cycles of volcanism, sedimentation, plutonism, uplift, and erosion. Within this orogenic cycle, metallogenesis, related to volcanic, sedimentary, and plutonic processes during each major tectonic phase, has produced broad mineral zoning and a large array of mineral deposits, which characterize this portion of the Western Cordillera.
APPENDICES

APPENDIX I — STRATIGRAPHIC SECTIONS

SECTION 1
UNUK RIVER FORMATION (MAP UNIT 12)
UPPER MEMBER

Section was measured at Tim Williams Glacier (Unuk River map sheet). It is exposed on the northeast limb of a broad northerly trending anticline. The uppermost beds are unconformably overlain by sedimentary beds of the Salmon River Formation. The lower contact with the middle member of the Unuk River Formation is obscured by permanent ice and snow.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (metres)</th>
<th>Total From Base</th>
</tr>
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<tbody>
<tr>
<td>SALMON RIVER FORMATION</td>
<td>7</td>
<td>Shale, silty shale, and siltstone: monotonous succession, thinly laminated; interbedded with stringers of very fine-grained sandstone and silty argillite; 60 per cent shale, 20 per cent silty shale, 15 per cent sandstone, and 5 per cent argillite; sandstone and argillite beds less than 30 centimetres thick throughout sequence; silty shale, olive-green, weathers grey, angular blocky fragments, limonitic stain general; abundant fossil fragments.</td>
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<tr>
<td></td>
<td>6</td>
<td>Greywacke, with intercalated subgreywackes, siltstone, and silty argillite: light to medium salt and peppy grey, medium grained, medium to light greenish grey, weathers darker grey with limonitic stain; blocky fragments, fissile argillite weathers to platy blocks; abundant fossil fragments form coquina with greywacke beds.</td>
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<td>5</td>
<td>Andesitic to dacitic lapilli and lithic tuffs, olive-green, maroon, and light grey, well bedded, locally 0.5 metre in thickness, mainly lack distinct units; covered for most part by andesitic debris and shows as isolated outcrops; bedding down to 1 centimetre in thickness where exposed; generally siliceous alteration, some pyrite.</td>
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<td>4</td>
<td>Volcanic breccia and agglomerate interbedded with tuffaceous greywacke, medium dark grey, composed of lithic fragments, mainly andesitic; clasts dark green to grey, fine-grained amygdaloidal andesite, angular to subrounded, 1 to 10 centimetres in diameter, poorly sorted, with obscure bedding, generally massive and structureless; matrix, tuffaceous andesite with interbedded fine-grained lithic tuffs forming beds locally 30 to 60 centimetres thick.</td>
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<td>3</td>
<td>Interbedded tuffaceous greywacke and quartz granite conglomerate; partly covered, intermittent outcrops, 15-centimetre to 1-metre beds with flat, regular bedding planes and no obvious partings; weather dark grey; 75 per cent greywacke, 25 per cent pebble conglomerate; quartz pebble conglomerate prominent near base, very well sorted having a mean of 2.5 centimetres and rarely over 3 centimetres or under 2 centimetres across.</td>
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<td></td>
<td>2</td>
<td>Interbedded tuffaceous greywacke and quartz pebble conglomerate, partly covered limonitic stained outcrop, well bedded, 15 centimetre to 1.2-metre beds with flat, regular bedding planes, no obvious partings; blocky, dark weathering, 50 per cent greywacke, 50 per cent quartz pebble conglomerate; pebble conglomerate well sorted, quartz pebbles well rounded; fossil fragments locally abundant; matrix quartz-rich near base, decreasing upward and replaced by medium-grained greywacke.</td>
</tr>
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<td></td>
<td>1</td>
<td>Polymictic conglomerate, well-rounded boulders and cobbles of hornblende granodiorite, with andesitic and basaltic pebbles, thick bedded, sandy dark greywacke as matrix; coarse-grained, thick-bedded dark greywacke intercalated within predominantly conglomeratic sequence; 1 to 2-metre beds; gradational into overlying conglomerates; abundant moderately well-preserved fossil fragments.</td>
</tr>
</tbody>
</table>

UNCONFORMITY
SECTION 2
UNUK RIVER FORMATION (MAP UNITS 11 AND 12)
MIDDLE MEMBER

The composite section was measured in the Twin John Peaks-Mount Madge and Mount Einar Kvale-Mount George Pearson areas. The succession is partly obscured by permanent ice and snow. These rocks are unconformably overlain by the upper member in the Tim Williams Glacier area as well as by members of the Betty Creek and Salmon River Formations in the Unuk River area. The base of the section is exposed at Twin John Peaks where it unconformably overlies the lower member of the Unuk River Formation.

<table>
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<tr>
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<td>13</td>
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<td>4</td>
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</tbody>
</table>

**UNCONFORMITY**

13 Interbedded volcanic sandstone, limestone, tuffaceous greywacke, lithic and crystal tuff, quartz pebble conglomerate, chert, and rhyolite; unit marked by its diversity and by discontinuity of the individual members; sandstones about 60 per cent of the thickness, typically greyish green, salt and pepper appearance in thin to medium beds which often exhibit channeling; limestone, medium grained, granular white to bluish grey, forming discrete lenses a few centimetres to several metres thick; tuffs, greenish grey, rarely red or maroon, graded 5 to 25-centimetre beds, generally andesitic and intercalated with grey planar-bedded tuffaceous greywacke; chert and rhyolite, thinly banded grey with intercalated quartz sandstone, forming beds 5 centimetres to 75 centimetres thick; argillaceous siltstone forms thin shaly partings within the various members throughout the unit; incipient schistosity is general and hornfelses developed adjacent to plutons; graphite, pyrite, and ankerite typical alteration minerals and limestone stain widespread; fossil fragments rare.

12 Gracey Creek limestone member, medium to coarse grained, mottled buff to blue-grey, massive, rare shale partings, no evidence of fossil debris, grey weathering.

11 Volcanic sandstone, andesitic tuff, argillaceous graphitic siltstone, limestone, chert, and rhyolite with sandstone comprising up to 40 per cent of this complexly interbedded unit; limestone as recrystallized, gypsiferous lenses a few centimetres to several metres thick, up to 30 per cent of the unit; thinly banded, altered rhyolite and grey chert lenses, 20 per cent of the unit; thinly laminated andesitic crystal and lithic tuff and dark siltstone form partings throughout the sequence; deformation produced incipient schistosity; most members recrystallized, generally altered, and variably hornfelsed; fossil fragments rare.

10 Pillow lava, extensively altered, variably hornfelsed, generally andesitic; cherty quartz sandstone, siltstone, and limestone, lens-like partings a few centimetres to approximately a metre thick form less than 10 per cent of this generally massive unit; generally dark green in colour, weathering medium green.

9 Volcanic conglomerate, clasts subangular to subrounded; 90 per cent andesite, 5 per cent volcanic sandstone, and 5 per cent volcanic siltstone as partings; massive, medium to light green, weathering dark green; variably schistose, hornfelsed, and marked by irregular mineralization, including scattered magnetite-rich zones.

8 Volcanic sandstone, siltstone, conglomerate, and some breccia interlayered, in about equal amounts; light to dark green, massive, locally marked by shale partings, generally structureless; clasts and matrix generally andesitic, variably schistose and hornfelsed.

7 Pillow lava, variably altered, generally massive, andesitic with rare chert, quartz sandstone, and siltstone partings; dark green, weathers medium green; pillows outlined by altered rims.

6 Siltstone, medium olive-green to grey-brown on surface, mainly thin bedded, weathers to chips, slope-forming unit; weakly schistose or hornfelsed.

5 Pillow lava, olive-green, weathers medium green, massive, rare chert partings, generally altered, probably andesitic; hornfelsed and indurated near intrusive contacts.

4 Volcanic conglomerate and greywacke interbedded, conglomerate clasts subangular to subrounded, comprise 90 per cent andesite, 10 per cent greywacke and siltstone; conglomerate matrix poorly sorted andesite clasts; medium green, weathering grey to brown; variably schistose and irregularly altered and hornfelsed.
### SECTION 3

**UNUK RIVER FORMATION (MAP UNIT 12)**

**LOWER MEMBER**

Section was measured along the axial zone of a major anticline between Treaty Creek and Jack Glacier, and from West McTagg Glacier to Twin John Peaks. Base of the section is obscured by ice and snow and the section is overlain unconformably by the middle member of the Unuk River Formation.

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### Thickness (metres)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness From Base</th>
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<tbody>
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<tr>
<td>14</td>
<td>7 940</td>
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<td>8</td>
<td>91</td>
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<td>Unit</td>
<td>Thickness (metres)</td>
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</tr>
<tr>
<td>7</td>
<td>Greywacke, siltstone, argillite, interbedded; grey-black; some indistinct layering; flaggy weathering siltstone and argillite, blocky greywacke; thin bedded from 15 centimetres to 3 metres thick with argillite partings.</td>
</tr>
<tr>
<td>6</td>
<td>Volcanic breccia, sandstone interbedded with lesser amounts of andesitic lava, minor thin basalt lenses; clasts angular, dark green fine-grained andesite; 1 centimetre to 60 centimetres poorly sorted, crudely stratified, thick beds, poorly defined, generally massive appearance; sandstone green, medium grained, angular, mainly andesite with 10 to 15 per cent augite; lava dark green, black, generally porphyritic, massive, limonite stained.</td>
</tr>
<tr>
<td>5</td>
<td>Volcanic sandstone, greywacke, and siltstone interbedded; greenish grey; thin alteration of beds throughout unit; clasts mainly andesite; fossil fragments.</td>
</tr>
<tr>
<td>4</td>
<td>Volcanic breccia, 1 centimetre to 60 centimetres, angular to subangular clasts, greenish andesite in andesitic matrix; massive, structureless.</td>
</tr>
<tr>
<td>3</td>
<td>Interbedded monotonous succession of volcanic sandstone, siltstone, shale, and minor breccia and rare limestone; general grey-green aspect; well bedded; 15 centimetres to several metres, rhythmic sequence marked by shaly partings; planar bedding typical, structures rare; fossiliferous at top and base.</td>
</tr>
<tr>
<td>2</td>
<td>Volcanic conglomerate, sandstone; gradational with overlying sandstone succession; massive appearance, thick bedded, shaly partings; grey-green to olive-green, brown weathering; blocky, cliff forming; limonite stained, pyritic, altered.</td>
</tr>
<tr>
<td>1</td>
<td>Volcanic flows, breccia, interbedded; massive thick-layered porphyritic and amygdaloidal andesitic flows; dark green, grey weathering, limonite stained, pyritic; breccia as intercalations, clasts to 1 metre, andesitic with andesitic matrix.</td>
</tr>
</tbody>
</table>

BASE OF FORMATION NOT EXPOSED.

SECTION 4
BETTY CREEK FORMATION (MAP UNIT 13)

Section measured at Betty Creek, on the south side, west of Betty Glacier. The uppermost beds are conformably to disconformably overlain by sedimentary rocks of the Salmon River Formation and underlain unconformably by units of the upper member of the Unuk River Formation. Part of the succession is obscured by snow and talus.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Thickness (metres)</th>
<th>Total</th>
<th>From Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Interbedded volcanic conglomerate and sandstone; dominantly brick red to maroon, mottled green to grey; clasts entirely greenish to olive-green, fine-grained to porphyritic andesite, angular to subrounded, 1 centimetre to 10 centimetres across; poorly sorted, moderately well stratified, crossbedding and oscillation ripples well developed in fine-grained members; sandstone about 50 per cent of succession, 95 per cent medium-grained angular andesite clasts; coloration impacted by iron oxide-rich matrix in both conglomerate and sandstone; generally massive in overall aspect.</td>
<td>122</td>
<td>823</td>
</tr>
<tr>
<td>3</td>
<td>Interbedded volcanic sandstone and conglomerate; dominantly dark olive-green to almost black; massive; apparently moderately indurated and variably hornfelsed; bedding indistinct; clasts mainly dark green andesite, with 1 to 5-centimetre angular fragments dominant; sedimentary structures other than planar laminations rare; scattered fossil fragments.</td>
<td>274</td>
<td>701</td>
</tr>
<tr>
<td>2</td>
<td>Interbedded volcanic sandstone and conglomerate; alternating red and green laminations, bedding planar; crossbedding and oscillation ripples common; clasts 1 to 10 centimetres, mainly andesite, up to 10 per cent granitic fragments, thin red shaly</td>
<td></td>
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</tr>
<tr>
<td>Unit</td>
<td>Thickness (metres)</td>
<td>Total From</td>
<td>Base</td>
</tr>
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<td>------</td>
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</tr>
<tr>
<td>1</td>
<td>80 per cent red volcanic sandstone, 20 per cent conglomerate; massive, beds approximately 1 metre to 2 metres thick; crossbedding frequent; clasts dominantly dark green andesite, matrix andesitic with abundant oxide which imparts overall colour.</td>
<td>335</td>
<td>427</td>
</tr>
<tr>
<td>92</td>
<td>92</td>
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</tr>
</tbody>
</table>
APPENDIX II

FOSSIL LOCALITIES

TAKLA GROUP
(Identifications by E. T. Tozer)


GSC locality 44414; elevation 1 520 metres; west side of Harrymel Creek; latitude 56° 34', longitude 130° 37'.
  *Aulacoceras* sp.
  Age: Late Triassic, probably Karnian

GSC locality 44417; elevation 1 370 metres; east slope of McQuillan Ridge; latitude 56° 24', longitude 130° 32'.
  *Halobia?* sp.
  Age: Triassic, probably Late Triassic

GSC locality 44418; elevation 1 370 metres; east slope of McQuillan Ridge; latitude 56° 24', longitude 130° 32'.
  *Halobia* sp.
  Crushed ammonite indet.
  Age: Late Triassic

UNUK RIVER FORMATION

GSC locality 44416; elevation 1 690 metres; on ridge 3.2 kilometres south of toe of Treaty Glacier; latitude 56° 36', longitude 130° 20' (determination by E. T. Tozer).
  *Psiloceras canadense* Frebold
  *Weyla* sp.
  *Pleuromya?* sp.
  Gastropods
  Age: Hettangian

Field No. 67-F-7; elevation 1 690 metres; on ridge 2.9 kilometres south of toe of Treaty Glacier; latitude 56° 36', longitude 130° 20' (determination by W. R. Danner).
  Indeterminate ammonite
  *Weyla* sp.
  Indeterminate gastropod
  *Pleuromya* sp.
  Large pecten
  *Lima* sp.?
  *Entolium* sp.?
  *Oxytoma* sp.?
  *Psiloceras canadense*
  Horn corals, one form resembles *Kraterostrobihs bathys* Crickmay
  Age: Early Jurassic (collection similar to localities near Ashcroft)

GSC locality 44413; elevation 1 340 metres; west side of Jack Glacier; latitude 56° 35', longitude 130° 21' (determination by E. T. Tozer).
  *Weyla* sp. indet.
  Age: Early Jurassic

GSC locality 44412; elevation 1 310 metres; west side of Jack Glacier; latitude 56° 37', longitude 130° 20' (determination by E. T. Tozer).
  Belemnoid fragments indet.
  *Pecten* sp. indet.
  Age: Probably Early Jurassic

GSC locality 86264; elevation 1 950 metres; west side of Twin John Peaks; latitude 56° 33', longitude 130° 25' (determination by H. Frebold).
  Pelecypods
  *Weyla* sp.
  *?Cardinia* sp. indet.
  Age: The genus *Weyla* is only known from Lower Jurassic beds. Identification of the species would probably enable a more precise age determination. The material will be sent to H. W. Tipper who is a Weyla expert. The author suggests a Hettangian or Sinemurian age.
GSC locality 44419; elevation 1 890 metres; west side of Twin John Peaks; latitude 56° 34', longitude 130° 25' (determination by H. Frebold).

Poorly preserved ammonites, Arieticeras? in shale
Weyla sp. and other poorly preserved pelecypods in limestone
Age: Early Jurassic, probably younger than GSC locality 44416

GSC locality 86265; elevation 1 340 metres; southwest slope of Twin John Peaks; latitude 56° 31', longitude 130° 28' (determination by H. Frebold).

Pelecypods — very poorly preserved
?Weyla sp. — referred to H. W. Tipper
Age: Probably Early Jurassic

GSC locality 87061; elevation 1 450 metres; east side of small unnamed glacier 7.2 kilometres south of Treaty Creek (determination by H. Frebold).

Ammonoids
Dactylioceras sp. (fine ribbed)
Age: Not Cretaceous; the genus Dactylioceras is mainly characteristic of the Toarcian but some species occur already in the Upper Pliensbachian (also in British Columbia). As there are no other guide ammonoids in this collection the exact age cannot be determined at present — Late Pliensbachian or Toarcian.

GSC locality 44411; elevation 1 520 metres; on ridge 2.4 kilometres east of King Creek; latitude 56° 31', longitude 130° 42' (determination by H. Frebold).

Belemnoid and pelecypod fragments indet
Age: Probably Early Jurassic

GSC locality 86261; elevation 1 580 metres; on ridge 2.6 kilometres east of King Creek; latitude 56° 31', longitude 130° 41' (determination by H. Frebold).

Pelecypods — numerous but very poorly preserved specimens; no species can be identified
Age: Possibly Middle Jurassic

GSC locality 86273; elevation 1 705 metres; on west ridge of Nickel Mountain; latitude 56° 44', longitude 130° 35' 30" (determination by H. Frebold).

Ammonoids
Imprints and flattened specimens of Hildocerataceae in shale: some specimens somewhat similar to Haugia and related genera but no safe identification of genus can be made; better material requested
Age: Possibly Toarcian

BETTY CREEK FORMATION
(Determinations by H. Frebold)

GSC locality 86283; elevation 1 740 metres; north side of Mitchell Glacier; latitude 56° 33', longitude 130° 13'.

Ammonoids
Sonninia sp.
?Sonninia sp. indet.
Subfamily Graphoceratinae Buckman; few more or less unsatisfactorily preserved specimens somewhat similar to Graphoceras
Belemnoids — according to J. A. Jeletzky — undeterminable
Pelecypods
Ostrea sp.
Pleuromya sp.
?Trigonia sp. Other poorly preserved fragments of pelecypods
Gastropods — undeterminable
Age: Upper part of Early or Middle Bajocian

SALMON RIVER FORMATION
(Determinations by J. A. Jeletzky and H. Frebold)

GSC locality 69404; elevation 1 050 metres; Divide Lake, east shore; latitude 56° 11', longitude 129° 58'.

Generically indeterminate representatives of Trigoniidae of general Jurassic or Cretaceous affinities
Age and Correlation: According to E. T. Tozer (personal communication) these generically indeterminate trigoniids could hardly be Triassic in age. They must therefore be of a general Jurassic or Cretaceous age — cannot be dated any closer

GSC locality 69405; elevation 1 310 metres; on Bear River Ridge, east of Long Lake; latitude 56° 07', 129° 58'.

Indeterminate belemnite-like Coleoidea
Indeterminate pelecypods
Age and Correlation: Presumably Mesozoic — cannot be dated any closer

150
GSC locality 69403; elevation 1520 metres; west slope of Mount Dillworth; latitude 56° 09', longitude 130° 02'.

Cylindroteuthis (Cylindroteuthis?) sp. indet.
Trigonia (Haidaia?) sp. indet.
Pelecypods, genus and species indet.
Solitary corals, genus and species indet.

Age and Correlation: Presumably of the Middle (Bajocian or Bathonian) to Early Oxfordian) Jurassic age but cannot be dated definitively because of extremely poor preservation of all fossils available.

GSC locality 86260; elevation 1580 metres; west slope of Mount Dillworth; latitude 56° 09', longitude 130° 02' 30'.
Pelecypods
Ctenostreon gikshanensis McLearn (fragment)
Trigonia aff. T. guhsani McLearn
Pecten sp. indet.
Other pelecypods too poorly preserved to warrant safe identification
Belemnoids — referred to J. A. Jeletzky
Age: Probably Middle Bajocian.

GSC locality 86259; elevation 1400 metres; east side of Bruce Glacier; latitude 56° 36', longitude 130° 17' 20'.
Ammonoids
?Sonninia sp. indet.
Belemnoids — undeterminable
Pelecypods
Trigonia sp. aff. T. guhsani McLearn — similar to some of the Trigonia in 86267
?Ctenostreon aff. C. gikshanensis McLearn
Gastropods — undeterminable
Age: Probably Middle Jurassic.

GSC locality 86267; elevation 1280 metres; between Bruce and Jack Glaciers; latitude 56° 37', longitude 130° 21'.
Ammonoids — one fragment of a larger ammonoid, undeterminable
Belemnoids — according to J. A. Jeletzky, undeterminable
Pelecypods
Trigonia sp. — large specimens, poorly preserved
Age: Probably Middle Jurassic.

GSC locality 86268; elevation 1070 metres; on south slope of ridge 2.4 kilometres northeast of Tom MacKay Lake; latitude 56° 40', longitude 103° 25'.
Ammonoids — poorly preserved imprints, deformed, undeterminable
Pelecypods
Inoceramus sp. indet.
Age: Jurassic.

GSC locality 86266; elevation 1110 metres; south end of Tom MacKay Lake; latitude 56° 36', longitude 130° 31'.
Ammonoids — squashed and deformed specimens possibly belonging to the genus Kheraiceras Spath; as far as a comparison is possible these fragments seem to be similar to Kheraiceras species from the Smithers area.
Age: Early Callovian.

NASS FORMATION
(Identifications by H. Frebold)

GSC locality 69406; elevation 485 metres; at Meziadin Lake, northwest side, along road; latitude 56° 07', longitude 129° 22'.

Buchia concentrica Sowerby
(? = Buchia bronni Rouillier)
Large perisphinctid (?) ammonites — referred to H. Frebold
Cylindroteuthis (Cylindroteuthis) sp. indet.
Age and Correlation: Buchia concentrica zone, Upper Oxfordian or Lower Kimmeridgian in terms of the international standard stages; in western British Columbia this zone occurs on the west coast of Vancouver Island in the upper part of Division A of J. A. Jeletzky (Geol. Surv. Canada, Paper 50-37), in the lower part of the so-called Eldorado Group in Taseko Lakes map-area (920), and in the unnamed Upper Jurassic rocks in Tatlayoko Lakes map-area.

GSC locality 86269; Snowslide Range, west of Bell-Irving River; latitude 56° 38', longitude 120° 46'.
Ammonoids — one poor imprint of a small ammonoid, undeterminable belemnoids — referred to J. A. Jeletzky
Age: Probably Oxfordian.
GSC locality 86270; Snowslide Range, west of Bell-Irving River; latitude 56° 38' 30", longitude 129° 46' 25".
Ammonoids
Subfamily Cardioceratinae Siemiradzki — small fragments of Cardioceras? sensu lato or Amoeboceras? sensu lato
Belemnoids — fragments to J. A. Jeletzky
Age: Oxfordian

GSC locality 86271; Snowslide Range, west of Bell-Irving River; latitude 56° 38' 30", longitude 129° 45' 30'.
Belemnoids — referred to J. A. Jeletzky
Pelecypods
Pecten sp.
Age: ?Oxfordian

GSC locality 86272; Snowslide Range, west of Bell-Irving River; latitude 56° 39', longitude 129° 46' 30'.
Ammonoids
Subfamily Cardioceratinae Siemiradzki; very poorly preserved, numerous small specimens, probably belonging to the genus Amoeboceras Hyatt or some of its subgenera; some specimens resemble also Plasmatoceras Buckman, a subgenus of Cardioceras
Age: Oxfordian

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