THE UNIVERSITY OF ALBERTA

MINERALIZATION IN THE PURCELL SUPERGROUP, SOUTHWESTERN ALBERTA, SOUTHEASTERN BRITISH COLUMBIA

by

AMENTI ABRAHAM, B.Sc.

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ABSTRACT

The sedimentary rocks of the Purcell Supergroup in the North Kootenay Pass area, southwestern Alberta are shown to be shallow-water subtidal to supratidal arid zone deposits, with an eastern, predominantly gneissic, cratonic source area.

The Purcell lava, the only major igneous rock unit associated with the Purcell sedimentary rocks is of basic composition. Sills and dikes known as Moyie Intrusions present in Purcell rocks below the Purcell lava are slightly more basic in composition and may have acted in part as feeders to the Purcell lava. Moyie Intrusions above the Purcell lava are of intermediate composition. These compositional differences may have been brought about by differentiation of the source magma and may indicate that the Moyie Intrusions were intruded over a period both during and after deposition of the Purcell sedimentary rocks.

Sparse copper-lead-zinc mineralization present in the North Kootenay Pass area is thought to be sedimentary-diagenetic in origin. Differences in the geochemical mobility of copper as compared with lead and zinc led to precipitation of these metals in differing sedimentary environments: copper in a shallow-water littoral facies, lead and zinc in a deeper-water, slightly more alkaline, lagoonal facies.

Study of the facies relationships of the Purcell rocks of the southern Canadian Rocky Mountains indicates that lead-zinc mineralization, if present in these rocks, is to be expected mainly in the relatively deep-water carbonates of the Altyn Formation of southwestern Clark Range. Copper mineralization, if present, is to be expected in deposits of the shallower-water terrigenous Ravalli and Missoula Groups.

The generally weak concentration of copper, lead and zinc throughout rocks of the Belt-Purcell basin is due in part to an inferred arid climatic regime throughout the source areas, which led to the curtailment of migration of copper, lead and zinc in solution into the basin. Furthermore, the rocks of the source area may have been only slightly enriched in these metals.

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CHAPTER ONE

INTRODUCTION

General Statement

Anomalously high amounts of copper (100 or more ppm) are present in some of the rocks of the Purcell Supergroup, outcropping in southwestern Alberta and southeastern British Columbia, and in some of the rocks of the adjacent Belt Supergroup in the northwestern United States (HARRISON, 1972). Lead and zinc may be associated in lesser amount with the copper. Strata-bound copper sulfide deposits occur in a zone approximately 120 miles long and 40 miles wide that extends south-southeast from southern British Columbia, along the Idaho-Montana border, to near the Coeur d'Alene mining district, Idaho (CLARK, 1971).

This study was undertaken in order to elucidate the distribution and mode of origin of anomalous amounts of copper, lead and zinc in the sedimentary rocks of the Purcell Supergroup outcropping in the North Kootenay Pass area in southwestern Alberta (Fig. 1).

Location of study area

The North Kootenay Pass area lies within Flathead map-area, which covers 200 square miles in the south-central part of the Canadian Rocky Mountains (Fig. 2). The area itself, lying within Alberta

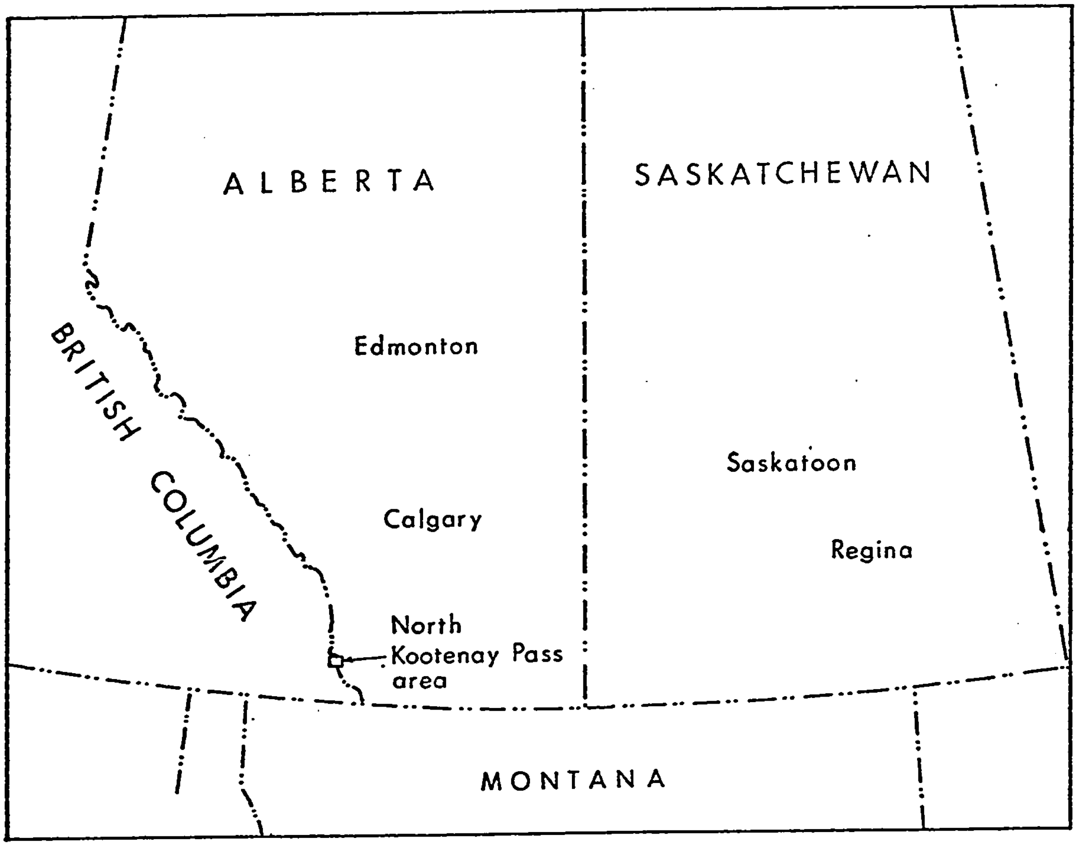


Fig. 1 Location of North Kootenay Pass area

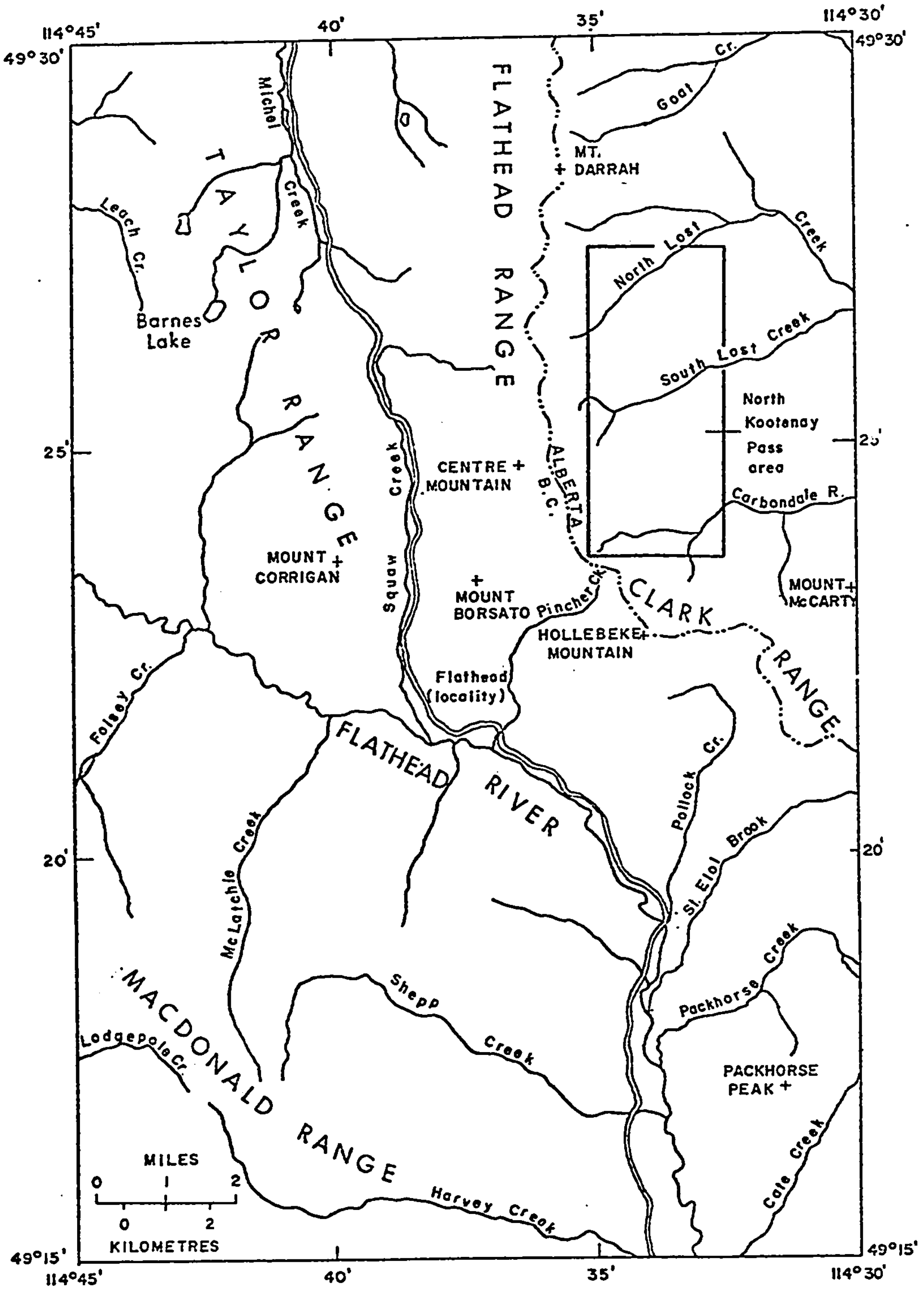


Fig. 2 Flathead map-area

adjacent to the Alberta-British Columbia provincial boundary, runs approximately 5 miles in a north-south direction by 2 miles in an east-west direction.

Access

The area is easily accessible by two logging roads, one following Carbondale River up to North Kootenay Pass, the other passing along South Lost Creek. These roads lead to Blairmore, just east of Crowsnest Pass.

Physiography

The North Kootenay Pass area lies along the border between the Front Ranges and Foothills subdivisions of the Canadian Rocky Mountains. These meet along the prominent east- and north-facing scarps of Flathead and Clark Ranges respectively. Clark Range terminates at North Kootenay Pass which separates it from Flathead Range.

Both Flathead and Clark Ranges are characterized by steep, rugged peaks, with a local relief of up to 4000 feet. Streams drain eastward from these ranges through the Foothills into the Interior Plains. The topographic detail in the area is thought to be due to the last phase of alpine glaciation (PRICE, 1965). The most conspicuous results of glaciation are well-developed cirques at the higher altitudes, specially in Flathead Range, and the typical glacial-trough character of the larger valleys. The floors and lower slopes of most valleys are covered by glacial drift and are vegetated. Outcrops are poor except in the case of resistant, cliff-forming rock units.

Previous work

The regional geology of Flathead map-area was comprehensively described in a terminal report by PRICE (1965). The succession and correlation of rocks of the Purcell System in Clark, Galton and Hughes Ranges in the southern Canadian Rocky Mountains and in the Purcell Mountains was also established by PRICE (1964).

GOBLE (1970) carried out a study of copper mineralization in the upper Appekunny, Grinnell and lower Siyeh Formations of the Purcell Supergroup in the Yarrow Creek-Spionkop Creek area lying approximately 30 miles to the southeast of the North Kootenay Pass area.

CHAPTER TWO

GENERAL GEOLOGY

Regional Geologic Setting

Stratigraphy

A tectono-stratigraphic sketch map of the southern Canadian Rocky Mountains and adjacent parts of the Columbia Mountains and Interior Plains is shown in Fig. 3a. The oldest rocks in this area are Helikian (middle Proterozoic) in age. These are overlain by Cambrian to Palaeocene rocks. Minor Eocene to Oligocene deposits are present in the southern part of the area, and Quaternary deposits in the west. The supracrustal rocks of this area are underlain by Aphebian (early Proterozoic) crystalline rocks that extend under the Interior Plains from the Churchill Province of the Canadian Shield (BURWASH et al., 1964).

Supracrustal rocks in the south-eastern Canadian Cordillera comprise two tectono-stratigraphic assemblages, an older miogeosynclinal-platform assemblage, and a younger assemblage of synorogenic clastic wedge deposits (PRICE et al., 1972). The older assemblage is a northeastward-tapering sedimentary wedge over 45,000 feet thick, and consists mostly of carbonate rocks, shales and mature sandstones. Terrigenous detritus was derived from the North American craton to the northeast. The accumulation of these sediments took place over more than 1100 million years from Helikian

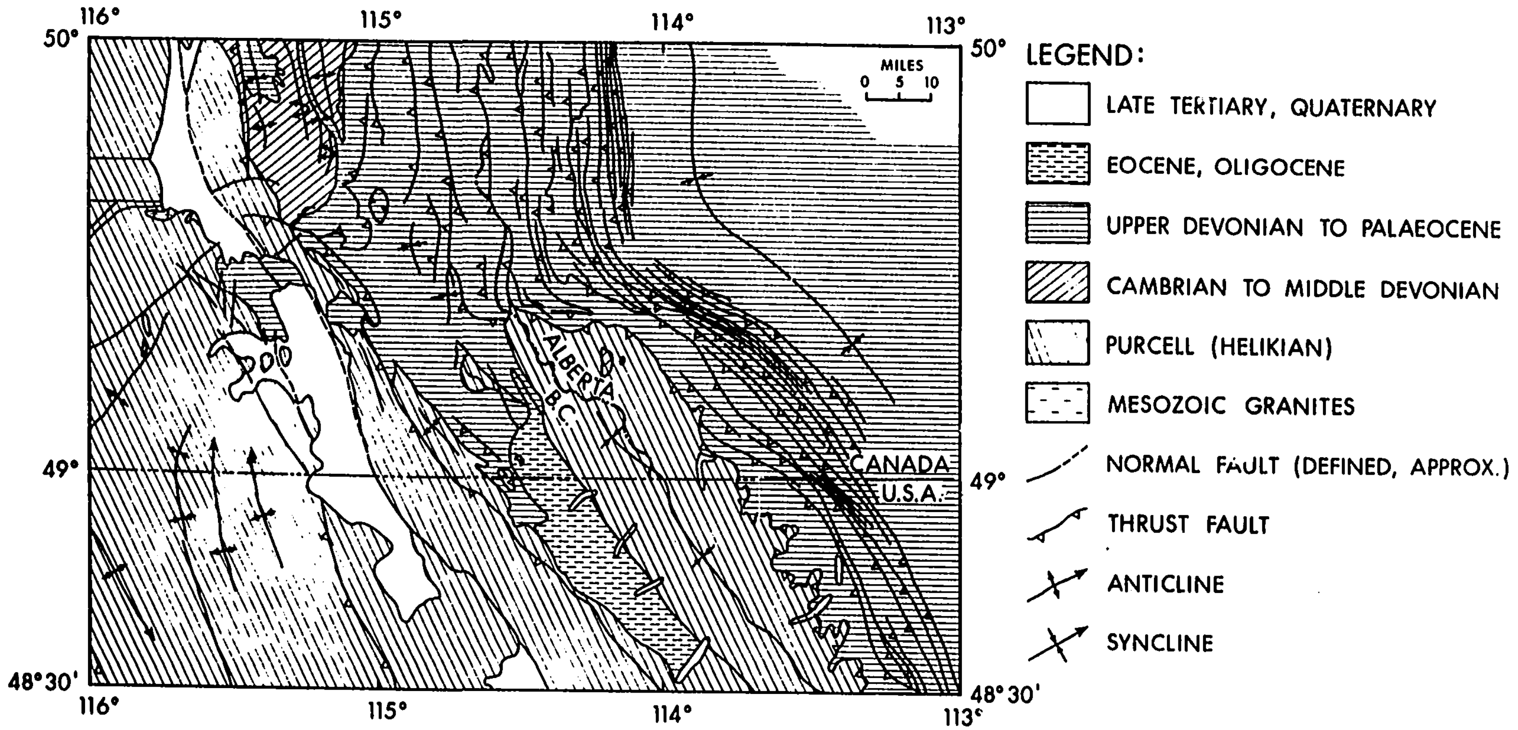


Fig. 3a Tectono-stratigraphic sketch map of the southern Canadian Rocky Mountains (modified after MONGER and PRETO, 1972)

to Late Jurassic as a continental terrace wedge prograded into an ocean basin. The younger assemblage, which is a similarly northeastward-tapering sedimentary wedge, is upto 20,000 feet thick, and consists almost exclusively of terrigenous material. The formation of this wedge took place in a 100 million year interval from Late Jurassic to early Tertiary, contemporaneously with orogeny to the west. Terrigenous detritus was derived from the west and transported out onto the craton flank.

Structure

A structure section from west to east across Fig. 3a is shown in Fig. 3b. The characteristic style of deformation in the southern Canadian Rocky Mountains is thrust faulting with associated concentric folding (WHEELER et al., 1972). Thrust-faults are southwest-dipping, concave upward and flatten with depth so that they do not cut the underlying basement. Deformation started in Late Jurassic, continuing to early Tertiary. The supracrustal sedimentary rocks have been thrust upto 125 miles northeastward relative to the basement, the stacking of thrust sheets thus caused having produced a surficial tectonic thickening of 5 miles above the passive basement. Block-faulting occurred after the thrusting. The resulting northwest-trending, southwest-dipping normal faults often pass into thrust-faults. They flatten with depth and do not cut the crystalline basement (BALLY et al., 1966). In the southeastern part of the region they are dated as Late Eocene to Early Oligocene (PRICE, 1962).

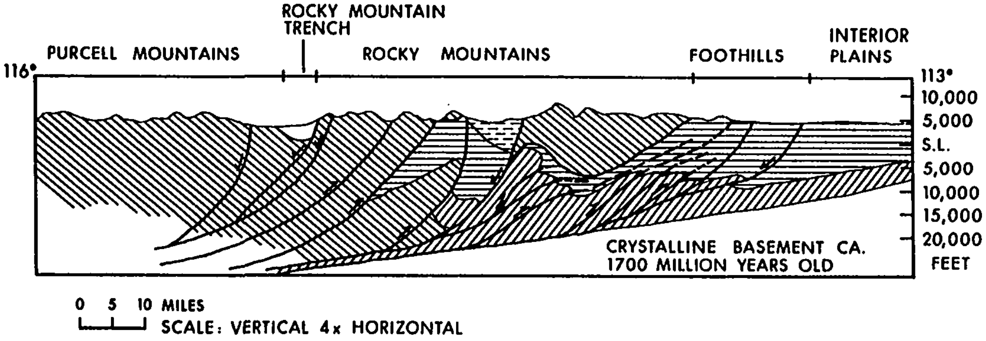


Fig. 3b Structural cross-section along N49° of Fig. 3a
(modified after MONGER and PRETO, 1972)

The Canadian Rocky Mountains are separated from the Purcell Mountains to the west by the Rocky Mountain Trench. The Purcell Mountains are underlain by the Helikian sedimentary rocks of the Purcell System, which have been deformed into the northwesterly-plunging Purcell anticlinorium. Deformation originated before and during the Hadrynian (late Proterozoic), but most of the deformation is younger (LEECH, 1962).

Belt-Purcell basin

Introduction

The oldest component of the miogeosynclinal-platform sequence in the southeastern Canadian Cordillera consists of the Helikian sedimentary rocks of the Purcell System. These rocks form the Purcell Supergroup which is equivalent to the Belt Supergroup of the northwestern United States.

Age

The Aphebian crystalline rocks underlying the Purcell strata in the southeastern Canadian Cordillera formed 1800 to 1700 million years ago during the Hudsonian orogeny (BURWASH et al., 1964). The general age of crystalline terrane bordering Belt rocks in southwestern Montana is 1700 million years (GILETTI, 1966).

Purcell strata are overlain unconformably by the Hadrynian Windermere System in Canada. Windermere sedimentation occurred due to the East Kootenay orogeny, which is manifested by uplift, gentle folding, granitic intrusion and low-grade regional metamorphism, and is variously dated at 675 to 790 million years (DOUGLAS et al., 1970).

The Hellroaring Creek stock in southeastern British Columbia intrudes the Aldridge Formation, the oldest in the Purcell System, and is over 1300 million years old (RYAN and BLENKINSOP, 1971).

Thus Belt-Purcell rocks are between 1700 and 700 million years old. HARRISON (1972) concluded that deposition of Belt-Purcell sediments took place during the time interval between 1450 and 850 million years ago.

Extent

The outcrop area of Belt-Purcell rocks, which covers over 50,000 square miles, is shown in Fig. 4. These rocks are thrust onto Cambrian to Quaternary sedimentary rocks to the east, are overlapped by the younger Precambrian Windermere System on the northwest, and are buried under Columbia River Basalt to the west. Jurassic to Tertiary batholiths are intruded into the southern part of the basin.

Thickness

The thickest continuous sequence of Belt-Purcell rocks occurs in western Montana, and totals 67,000 feet with neither base nor top exposed. HARRISON (1972) stated that the average basin fill was at least 50,000 feet thick.

EXPLANATION

Tv
Tertiary volcanic rocks

TJi
Tertiary to Jurassic
intrusive rocks

QЄs
Quarternary to Cambrian
sedimentary rocks

pЄw
Precambrian rocks
(Windermere System of Canada)

pЄb
Precambrian Belt Supergroup
Stipple shows areas of high-
grade metamorphism; may
include some pre-Belt rocks

pЄo
Precambrian pre-Belt
metamorphic rocks

Contact

High-angle fault

Right-lateral fault

Thrust fault
Sawteeth on upper plate

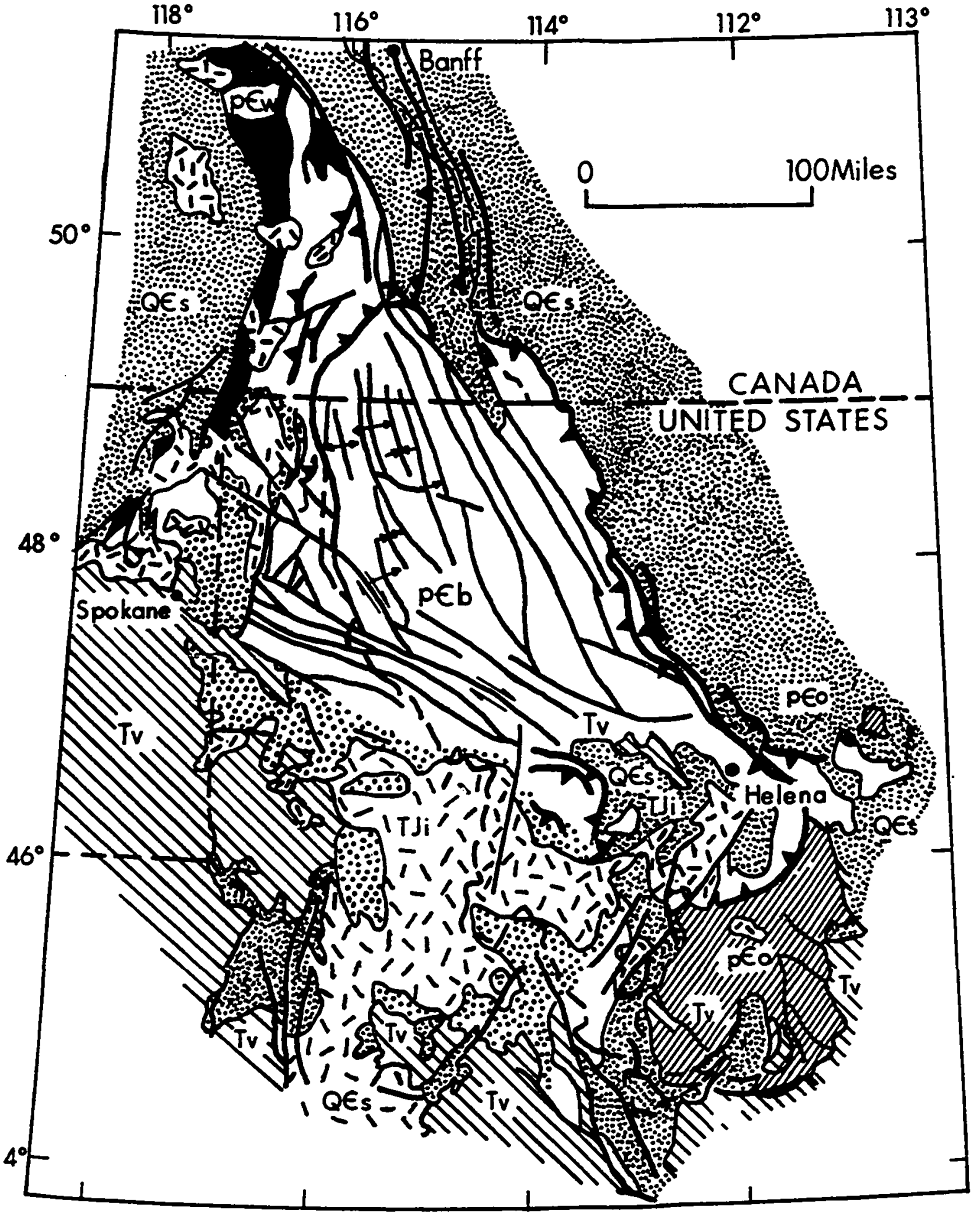


Fig. 4 Generalized geologic map of Belt terrane
(after HARRISON, 1972)

Sedimentation and Provenance

Both terrigenous and carbonate Belt-Purcell rocks are consistently fine-grained. Terrigenous rocks coarser than fine sand size are uncommon. Facies changes are very gradual except at the eastern edge of the basin. Disconformities are difficult to identify.

Cyclical sedimentation is well developed on all scales in the Belt-Purcell sequence. Two major cycles are recognized (SMITH and BARNES, 1966; HARRISON, 1972). The lower cycle comprises the Pre-Ravalli sequence and the overlying Ravalli Group. The finer fraction of the Pre-Ravalli sequence is characterized by black to grey, carbonaceous and/or carbonate-bearing, pyritic, commonly finely laminated strata, that of the Ravalli Group by red to green rocks of shallow water origin. The upper cycle consists of the Piegan and overlying Missoula Groups, which are lithologically similar to the Pre-Ravalli sequence and the Ravalli Group respectively.

The western part of the middle and upper Ravelli Group had a cratonic source to the south and southwest (HARRISON, 1972), whereas the eastern part had a Canadian Shield source. The clastic material of the Piegan Group was derived both from the southwest and the east. Carbonate deposits developed on the eastern shelf. Lower Missoula sediments similarly were derived from the southwest and the northeast. It appears that the Belt-Purcell basin was actually a re-entrant of a sea that extended along the western edge of the North American craton.

Metamorphism

Belt-Purcell rocks have undergone low-grade regional metamorphism. Metamorphic grade increases from northeast to southwest and with depth. Rocks in the upper part of the section in the eastern part of the basin are virtually unmetamorphosed. Metamorphism is due partly to burial at depth, partly to the effects of the East Kootenay orogeny and partly to the thermal effects of Mesozoic-Cenozoic intrusives in the basin (HARRISON, 1972).

Purcell System

The Purcell System is divisible into two main parts by the Purcell lava, an extensive basalt flow several hundred feet thick.

The lower Purcell comprises shallow-water sediments in its eastern facies in the Rocky Mountains. To the west in the Purcell Mountains, a deeper-water facies of northward-transported turbidites, represented by the Aldridge Formation, is overlain by shallow-water sediments similar to those in the Rocky Mountains (WHEELER et al., 1972).

The upper Purcell consists of shallow-water deposits.

The relationship between eastern and western Purcell outcrops is shown in Fig. 5.

Purcell sedimentation was terminated by the East Kootenay orogeny, as previously mentioned.

PRICE (1964) showed that the Purcell lava flowed out on an erosional surface that cuts down through the lower part of the Missoula Group and into carbonate rocks of the Piegan Group. The

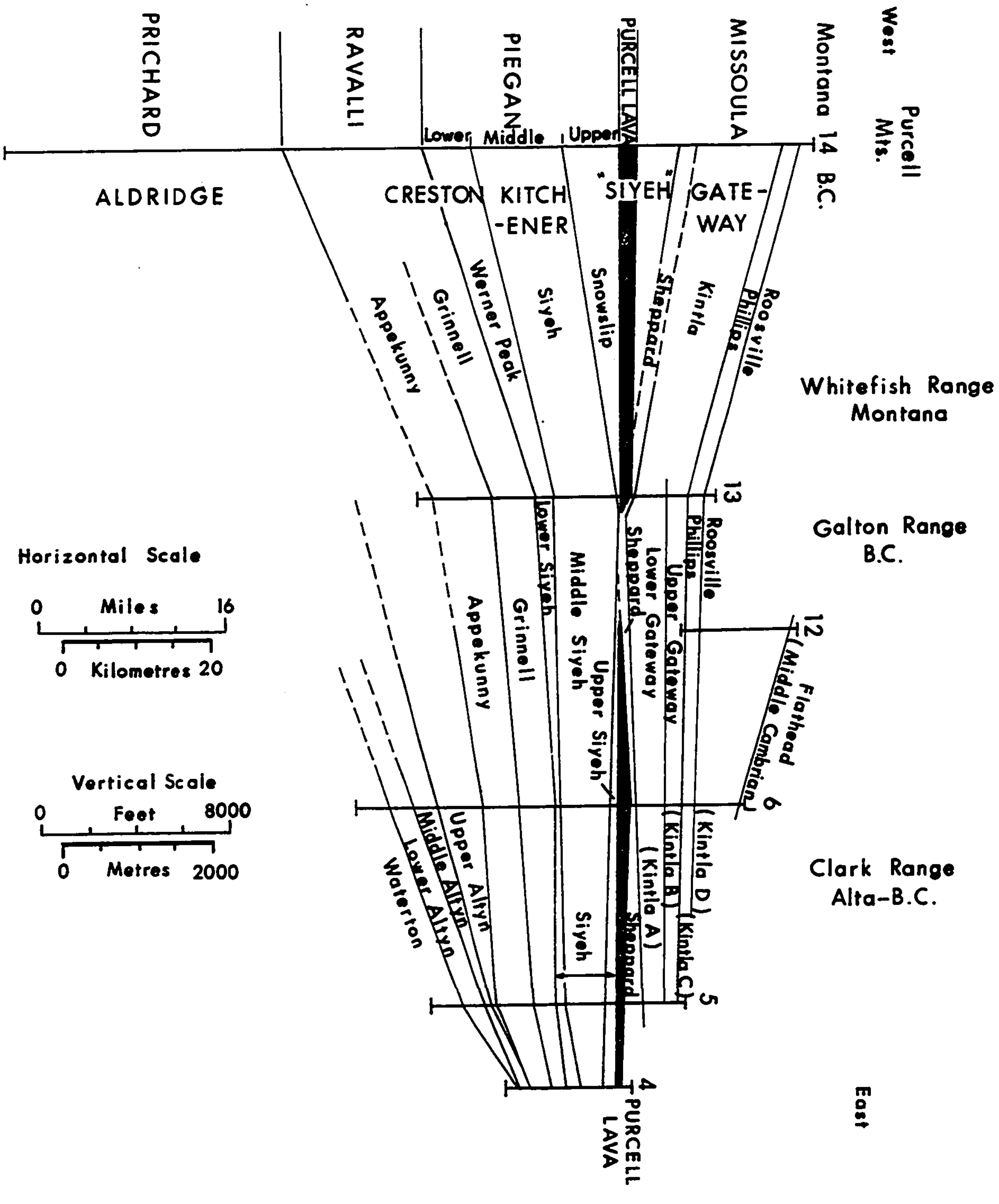


Fig. 5 Correlation of the Helikian (Purcell) rocks of the southern Canadian Rocky Mountains and eastern Purcell Mountains, Alberta and British Columbia (after PRICE, 1964)

Sheppard Formation lies unconformably on the Purcell lava. It was concluded that the Purcell sediments were deposited on and adjacent to the flood plain of a large, subsiding delta along the western margin of the North American craton under conditions analogous to those in the Gulf Coast geosyncline.

Geology of the North Kootenay Pass Area

A geologic sketch map of the North Kootenay Pass area is shown in Fig. 6. The Lewis Thrust, the most prominent structural feature in this area, lies subparallel to the overlying and underlying beds, having a general north-south strike and dipping west at 30° to 40°. A splay from the Lewis Thrust plane repeats the uppermost part of the Purcell section in the northern part of the area. The rocks above the Lewis Thrust plane form a homoclinal, generally west-dipping sequence of Purcell and Palaeozoic strata. These rocks have been thrust eastward onto Mesozoic strata. A few steeply west-dipping normal faults, trending generally N15°W, and with displacements from several inches upto 75 feet cut Purcell strata within the Lewis Thrust sheet.

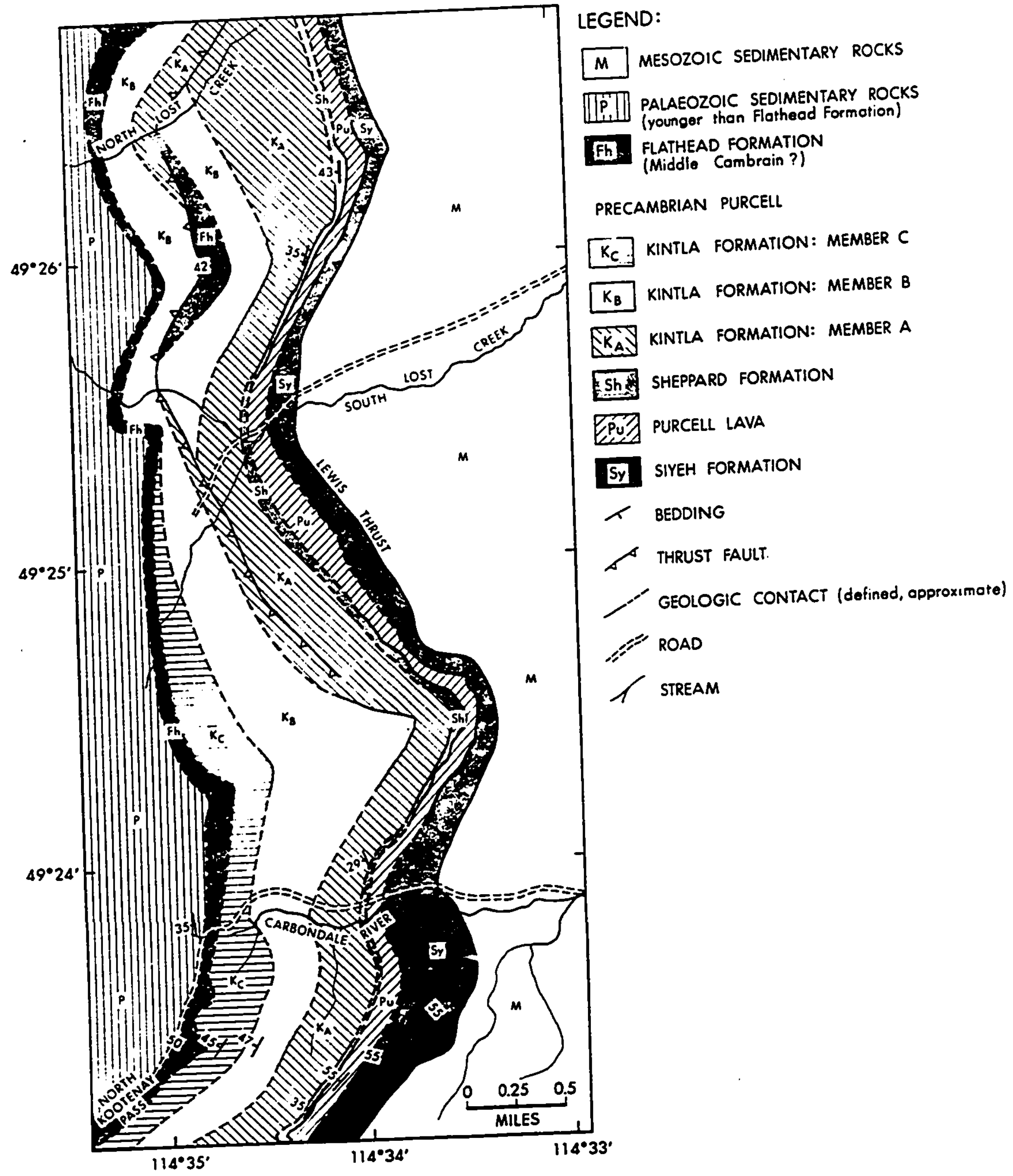


Fig. 6 Geologic sketch map of Purcell strata between North Kootenay Pass and North Lost Creek

CHAPTER THREE

STRATIGRAPHY

Introduction

In describing Flathead map-area, PRICE (1965) used the term "Purcell" as a provincial time and time-stratigraphic name of systemic value for Proterozoic rocks that are older than rocks of the Proterozoic Windermere System outcropping in the Hughes Range and the Purcell and Selkirk Mountains to the west. Purcell rocks within Flathead map-area are known as the "Lewis series", and are regarded as equivalent to the "Purcell series" of the Purcell Mountains (DALY, 1912; PRICE, 1965). The regional geology of the "Lewis series" is shown in Fig. 7.

A summary of the Purcell formations that comprise the "Lewis series" in Flathead map-area is given in Table 1. The oldest formation, the Waterton, is directly underlain by the Lewis Thrust Fault in Clark Range. The Lewis Thrust Fault rises in the stratigraphic succession towards the north, so that in the North Kootenay Pass area, which covers the extreme northern tip of Clark Range and the southern part of Flathead Range, the oldest Purcell beds lying directly above the thrust plane are those of the middle part of the Siyeh Formation.

A detailed stratigraphic description of the Siyeh through Sheppard Formations in the North Kootenay Pass area is given in Appendix A.

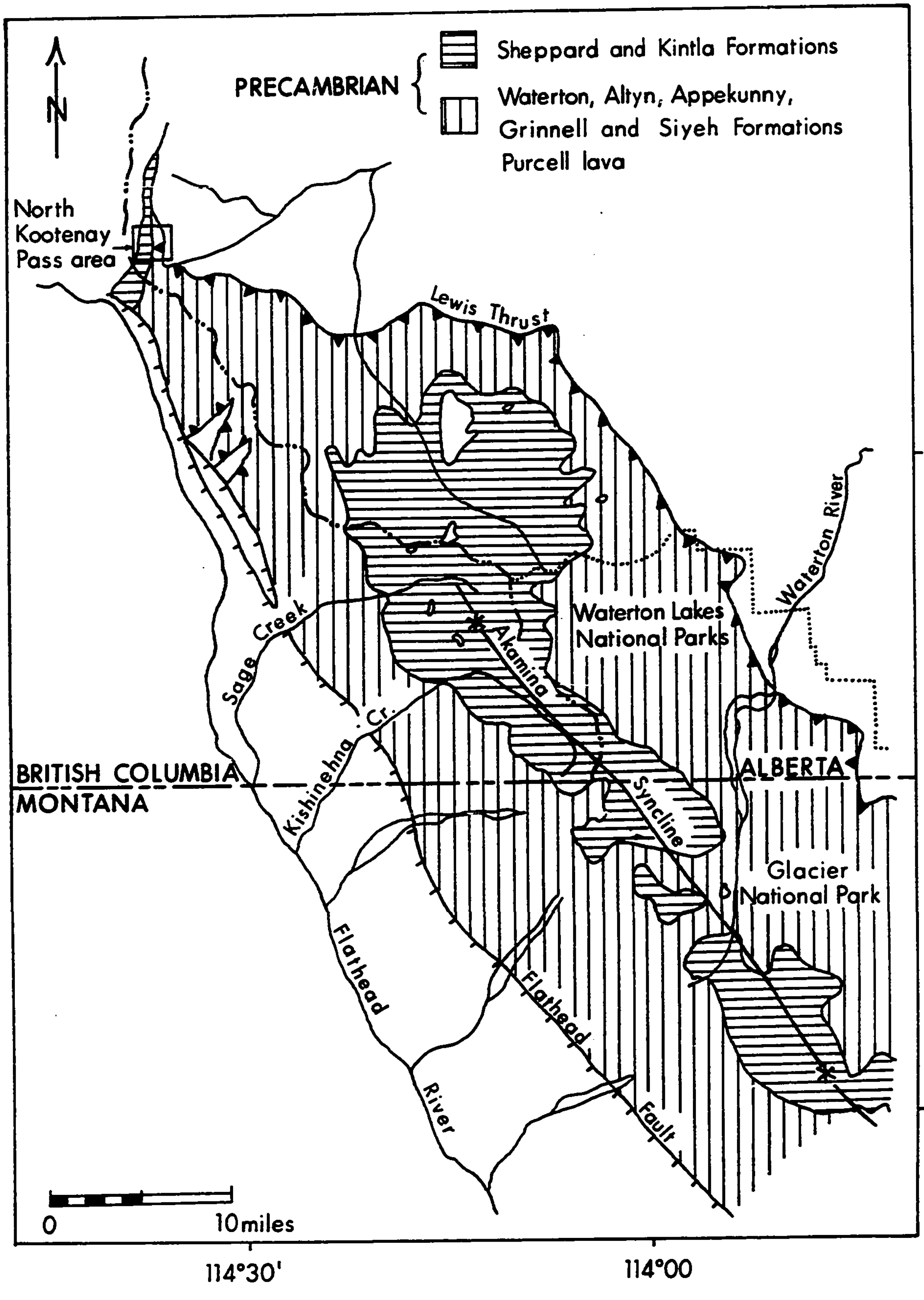


Fig. 7 Regional geology of the "Lewis series" (after PRICE, 1965)

TABLE 1

PURCELL FORMATIONS, FLATHEAD MAP-AREA

(after PRICE, 1965)

Era	Period	Formation	Lithology	Thickness (feet)
PRECAMBRIAN	Purcell?	Moyie Intrusions	Diorite sills	
	PURCELL	Kintla Formation	Red quartzite, sandstone, siltstone, argillite; green argillite, dolomitic argillite	600-1600
		Sheppard Formation	Dolomite, quartzite, siltstone, argillite	150
		Purcell lava	Chloritized, amygdaloidal andesite; pillow andesite	320
		Siyeh Formation	Grey, fine-crystalline dolomite; green, red and black argillite	1130
		Grinnell Formation	Red argillite; white, green and red quartzite; red siltstone	350
		Appekuny Formation	Green argillite; white, grey and green quartzite; sandy, argillaceous dolomite and dolomitic argillite	1700
		Altyn Formation	Grey, argillaceous limestone and dolomite; black argillite; sandy dolomite	1250
		Waterton Formation	Banded and streaked limestone and dolomite; green argillite; red argillaceous dolomite; white limestone	450

Siyeh Formation

In Flathead map-area the Siyeh Formation is divided into three litho-stratigraphic units, a lower terrigenous unit, a middle carbonate-rich unit, and an upper terrigenous unit. Directly south of the North Kootenay Pass area these units are respectively 30, 1000 and 100 feet thick (PRICE, 1965). Within the North Kootenay Pass area, due to truncation by the Lewis Thrust Fault, the lower unit and part of the middle unit are missing; thus the preserved thickness is 650 feet of the middle unit and 100 feet of the upper unit.

Middle Siyeh Formation

The middle unit of the Siyeh Formation within the North Kootenay Pass area consists of light to medium grey, rusty-weathering dolomite-rich rocks, and is thin-bedded throughout. It is divisible into several subunits on the basis of slightly differing lithologies and stromatolite types (Table 2). A basal covered zone is present directly above the Lewis Thrust Fault.

LOGAN et al. (1964) classified algal stromatolites according to their geometric forms. Basic geometric units are hemispheroids and spheroids, which combine in different ways to give three main geometric arrangements:

(1) laterally linked hemispheroids, type - LLH

(2) discrete, vertically stacked hemispheroids, type - SH

(3) discrete spheroidal structures, type - SS

These types are shown schematically in Fig. 8.

TABLE 2

Lithostratigraphic subunits within the middle Siyeh Formation, North Kootenay Pass area.

Subunit	Lithology	Thickness (feet)
(iv)	Silty dolomite and dolomitic siltstone; type - LLH stromatolites dominant	130
(iii)	Silty and sandy dolomite	63
(ii)	Silty dolomite and dolomitic siltstone; type - LLH stromatolites dominant, grading to type - SH at top	160
(i)	Covered interval, directly above Lewis Thrust Fault	300 (estimated)

Type - LLH stromatolites are associated with protected intertidal mudflats, type - SH stromatolites with exposed intertidal mudflats, and type - SS stromatolites with low intertidal area. Type - LLH stromatolites indicate the lowest energy environment, type - SS stromatolites the highest.

Stromatolites in the middle Siyeh Formation are predominantly of type - LLH in Subunit (ii), with an increase in type - SH towards the top of this subunit. Type - LLH stromatolites are dominant in Subunit (iv).

Subunit (ii) rocks consist of very finely to finely crystalline hypidiotopic dolomite, with varying proportions of admixed medium silt. Grain size increases slightly towards the top of the subunit. Graded

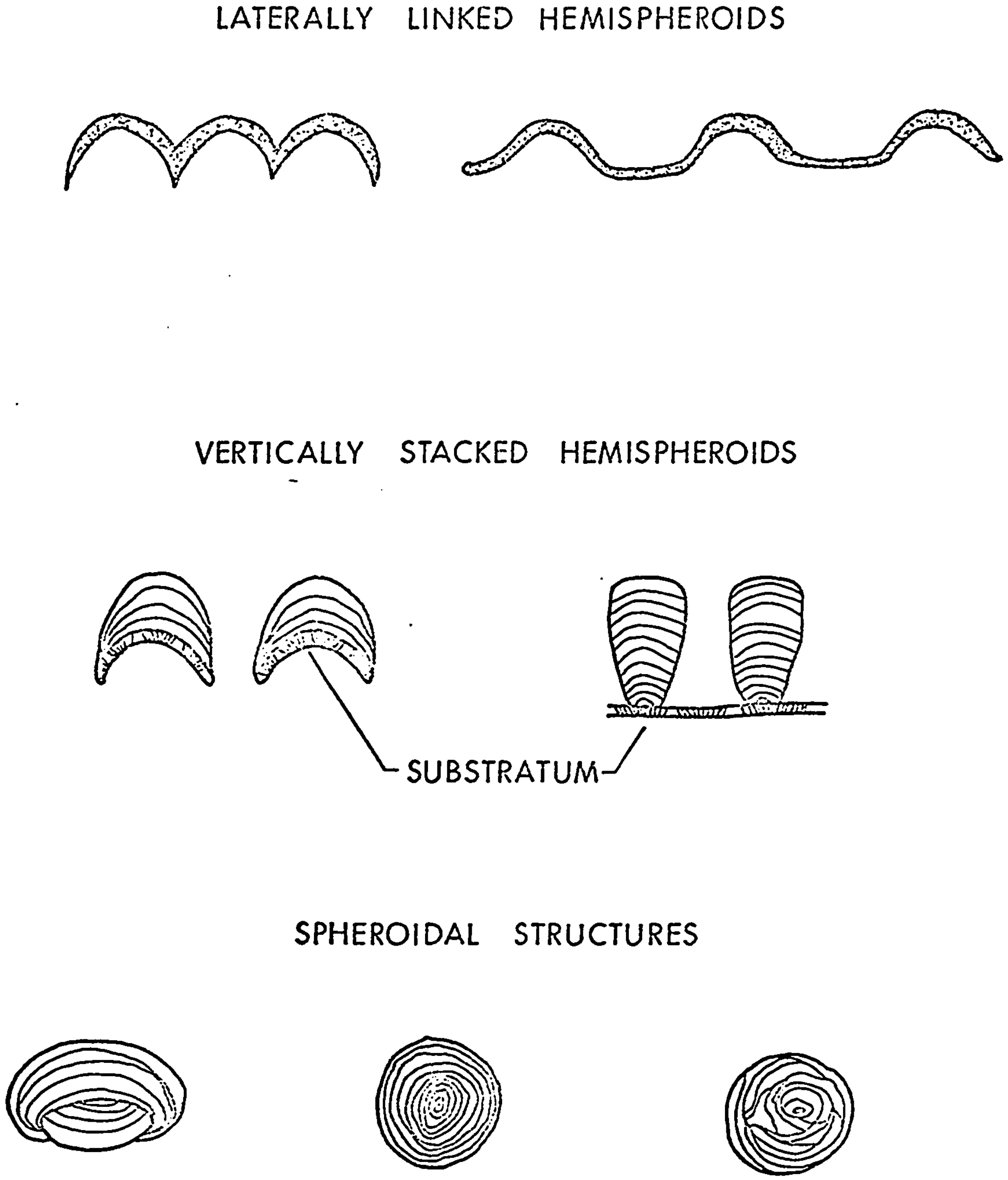


Fig. 8 Schematic representation of algal stromatolite types (after LOGAN et al., 1964)

bedding, with siltier bases grading upward to purer dolomite, is common (Plate 1-A). Dolomitic intramicrites occur in the uppermost beds of this subunit.

Subunit (iii) consists mainly of silty to sandy, intramicritic, medium dolarenites. Both intraclasts and surrounding matrix consist of very finely crystalline dolomite, the intraclasts being spherical to ellipsoidal in shape. Admixed sand grains are invariably slightly larger on average than the associated carbonate intraclasts.

Subunit (iv) is petrographically very similar to Subunit (ii).

Rare, aggrading recrystallization to medium crystalline dolomite occurs in these middle Siyeh Formation rocks.

White calcite segregations are present in the rocks of Subunits (ii) and (iv). In thin section, these appear as contorted veinlets generally perpendicular to the bedding (Plate 1-B). The calcite is medium to coarsely crystalline. These segregations represent calcite-filled shrinkage fractures.

Organic material of stromatolitic origin is present in rocks throughout the middle Siyeh Formation. It commonly takes the form of extremely thin laminae spaced 15 microns apart in the purer dolomites. Wider spacings are common in the siltier dolomites. In a few cases the laminae form an interwoven net, with carbonate infillings of the pores (Plate 1-C).

In a few thin sections of rocks from Subunit (iii), films of organic matter enclosing a mosaic of rounded, ellipsoidal intraclasts flattened parallel to bedding are present (Plate 1-D, E, F). SHEARMAN and FULLER (1969) described such fabrics as "chicken-wire" structure, and ascribed them to compaction of anhydrite nodules retained within algal mats. It was stated that such nodules characteristically developed in carbonate mud and carbonate sand sediments of the capillary zone, above the rest-level of ground water in supratidal areas of arid zones, and that they were early diagenetic in origin.

No anhydrite was observed in the rocks of the middle Siyeh Formation, the flattened intraclasts consisting of medium crystalline dolomite. Intraclasts in layers adjacent to the "chicken-wire" structure layers consist of medium crystalline dolomite, with dolomite crystals transecting the borders of the intraclasts, indicating a replacement origin. The dolomite of "chicken-wire" structure layers probably is also of replacement origin.

ADSHEAD (1963), in a study of a complete section of the Siyeh Formation in the Lewis Thrust sheet exposed approximately twenty-five miles southeast of the study area, described nodular sheets within the carbonate sequence of the Siyeh termed "growth segregations". The nodules, in two dimensions, consisted of ellipsoidal masses one-half to several inches long flattened in the bedding plane. Three dimensionally, individual nodules were connected laterally by thin apophyses to form extensive, unbroken sheets, with constant upper and lower limits. It was shown that nodule growth commenced within a few millimetres of the sediment surface while the groundmass was still plastic, and was completed after only very slight burial. These nodular sheets were observed throughout the middle and upper parts of the middle Siyeh Formation, with the greatest concentration in the upper part. No explanation of the genesis of these structures was given. It is probable that these nodular sheets and the "chicken-wire" structure layers in the middle Siyeh Formation of the North Kootenay Pass area represent supratidal sabkha facies sediments. Any evaporitic minerals, such as anhydrite and gypsum, that may originally have been present when these sediments formed in the middle Proterozoic have probably been removed in solution and replaced by carbonate, mostly dolomite.

Upper Siyeh Formation

The middle Siyeh Formation grades by sharp decrease in carbonate content to the upper Siyeh Formation. The upper Siyeh Formation is a cyclic sequence of very thinly to thinly interbedded, red and green, medium to coarse siltstones, with minor very fine to fine sandstones. Rare dolomite occurs. Over half the upper Siyeh Formation is calcareous, calcite appearing in thin section as medium to coarse crystalline, anhedral, poikilotopic crystals.

Purcell lava

The Purcell lava in Flathead map-area lies conformably on the Siyeh Formation, and is about 300 feet thick (PRICE, 1965). In the North Kootenay Pass area, a basal 65-foot zone of altered, green, amygdaloidal, porphyritic, fine-grained lava is overlain by approximately 230 feet of altered, brownish purple, amygdaloidal, fine-to medium-grained lava. PRICE (1965) described pillows occurring in the basal zone of this area as averaging 18 inches in diameter, with dark red interiors, light green peripheries and breccia-filled interstices between the pillows. Breccia fragments consisted of material similar to that of the pillow peripheries, and were assumed to have been derived from them by surface spalling.

The brownish purple lava accumulation overlying the basal pillowed unit consists of fourteen flows ranging from 3 to 45 feet in thickness. The flows are usually separated from each other by two- to three-inch zones of reddish-green tachylyte, representing the rapidly chilled bases of successive, extruded flows. Centres of thick flows are usually of slightly coarser grain than the peripheries. Upper parts of flows are often amygdaloidal with irregular, ropy surfaces.

Thin section studies show that the lava is holocrystalline to hypocrystalline, exhibiting intersertal to relict hyalopilitic texture. Interstitial glass is always altered to haematitized variolitic plagioclase (Plate 1-G), chlorite, calcite, iron ore or cryptocrystalline material. Pseudoperlitic texture is common, with rectilinear iron ore-filled cracks (Plate 1-H). Amygdales are mostly chloritic, sometimes with calcite and chalcedonic quartz cores. Amygdaloidal pyrite and chalcopyrite occur rarely (Plate 2-A). The dominant phenocrystal phase in porphyritic rocks is plagioclase, with subordinate olivine and pyroxene, and very rare altered amphibole.

The Purcell lava is altered throughout, the greatest degree of alteration having taken place with respect to ferromagnesian minerals. Olivine is mainly altered to chlorite-goethite intergrowths, sometimes to chlorite or iddingsite. Zoned pseudomorphs are common (Plate 2-B). Pyroxene is altered to chlorite, sometimes to iron ore. Patchy replacement of plagioclase by chlorite, and to a lesser extent by sericite, calcite and ocellar albite is common. In some cases, large well-formed plagioclase crystals are completely replaced in a zoned manner, with chlorite-quartz centres and distinct calcite rims (Plate 2-C). Magnetite is the main opaque mineral, with minor ilmenite. Leucoxene pseudomorphs after magnetite are common, indicating that the original mineral was Ti-rich (Plate 2-D). Hematite is the main alteration product of both magnetite and ilmenite.

Interflow tachylyte consists of amygdaloidal, devitrified glass. The devitrified material consists of extremely fine, cryptocrystalline, greyish green granules, set in a brownish white isotropic matrix. Amygdales are chlorite-filled. Adjacent to these amygdales the tachylyte is bleached free of the greyish green granules, indicating that the chlorite of the amygdales is derived from breakdown of the granules (Plate 2-E). Sparse, altered olivine crystals are present throughout the devitrified groundmass (Plate 2-F).

TABLE 3

Modal composition (volume percent) of Purcell lava, North Kootenay Pass area

	Plagioclase	Chlorite	Iron ore	Calcite	Accessories
Basal green lava flow	24	66	6	3	1
Overlying brownish purple flows	52	15	25	4	4

The modal composition of the Purcell lava is given in Table 3. The composition given for the brownish purple flows is the average for five samples from different flows. Most of the iron ore of the basal green zone is pseudomorphed by leucoxene. The basal green flow is chlorite-rich and iron ore-poor as compared with the overlying flows.

The plagioclase of the lavas is sodic andesine. TURNER and VERHOOGEN (1960) stated that alkaline olivine basalts can be differentiated petrographically from tholeiitic basalts by the presence of strong zoning in olivines; only one pyroxene, titan-augitic in composition, is present. In tholeiitic basalts olivine is unzoned, and two types of pyroxene are present. Chlorite pseudomorphs of olivine in the Purcell lava often show very distinct zoning. Altered pyroxenes generally appear to be of a single type. Thus the Purcell lava petrographically is a sodic andesine-rich alkaline olivine basalt. HUNT (1961) has chemically classified the Purcell lava of the "Lewis series" as trachybasaltic.

Sheppard Formation

Within Flathead map-area, strata lying between the Purcell lava and the Kintla Formation are placed in the Sheppard Formation (PRICE, 1965).

Within the North Kootenay Pass area, the Sheppard Formation lies with sharp contact on the Purcell lava, and is in gradational contact with the overlying Kintla Formation.

The Sheppard Formation is approximately 160 feet thick and consists of a cyclic sequence of thin-bedded, red and green, carbonate-rich, medium to coarse siltstones and very fine sandstones, with minor claystone and dolomite. It is divisible into four subunits based on rock type and colour, as shown in Table 4.

TABLE 4

Lithostratigraphic subunits within the Sheppard Formation, North Kootenay Pass area

Subunit	Lithology	Thickness (feet)
(iv)	Red siltstone and claystone, grading into Kintla Formation	4.5
(iii)	Green to grey siltstone and dolomite, minor sandstone and claystone, with interbedded 2-foot thick lava flow	61.5
(ii)	Red sandstone and siltstone, minor claystone and dolomite	72.0
(i)	Green to grey siltstone, minor sandstone and dolomite	23.5

Oscillation ripple marks, mud cracks and intraformational mud-chip conglomerates are common. Sandstones and coarse siltstones in Subunit (ii) and the lower part of Subunit (iii) are usually parallel- to cross-laminated. Type - SH stromatolites occur in the dolomites of Subunit (i), with type - LLH stromatolites present in the overlying subunits.

Terrigenous beds within Subunit (i) are calcareous. Carbonate in terrigenous beds of the overlying subunits is dolomite.

Kintla Formation

The Kintla Formation is separated into four lithostratigraphic subdivisions, designated Members A, B, C and D (HAGE, 1943). Members A, B and C are present in Flathead map-area (PRICE, 1965), Member D having been removed by pre-Palaeozoic erosion.

PRICE (1964) stated that Hage's nomenclature is a duplication of an earlier one proposed by DALY (1912), and should therefore be discarded, but continued to use it for Flathead map-area. The term Kintla is therefore used here for Purcell strata overlying the Sheppard Formation in the North Kootenay Pass area, rather than Daly's equivalent terms. Daly's nomenclature is shown in Table 5.

TABLE 5

Nomenclature of Purcell strata overlying the Sheppard Formation

DALY (1912)	HAGE (1943)
	Kintla Formation
Roosville Formation	Member D
Phillips Formation	Member C
Gateway Formation	Member B
	Member A

The Kintla Formation in the North Kootenay Pass area is composed overwhelmingly of terrigenous material. Members A and C are red bed sequences, Member B being composed of similar but green to grey rocks.

The sedimentary sequence systematically coarsens upwards. Member C of the Kintla Formation is incomplete, as indicated by a two-foot thick weathered zone developed on a diorite sill topping the sedimentary sequence. This member is unconformably overlain by the basal unit of the Palaeozoic sequence - the quartzites of the Flathead Formation. Descriptive summaries of each member of the Kintla Formation are given in Table 6.

TABLE 6

Description of the Kintla Formation, North Kootenay Pass area

MEMBER	LITHOLOGY	THICKNESS (feet)
C	Very thin-bedded, red to purple, very fine to fine sandstone, with less resistant talus-covered (siltstone?) interbeds averaging 3 feet thick. Oscillation ripple-marked and parallel-laminated; rare thin zones of intraformational mud-chip conglomerate.	400
B	Very thin-bedded, green to gey, dolomitic, coarse siltstone and very fine sandstone, with minor silty dolomite. Oscillation ripple marks and parallel lamination common.	570
A	Laminated to thick-bedded, red, clayey, medium siltstone and silty claystone, with minor very fine sandstone. Oscillation ripple marks, mud-cracks and intraformational mud-chip conglomerates common. Abundant cubic casts of halite crystals developed on bedding planes in lower horizons.	660

Moyie Intrusions

Dykes and sills of basic to intermediate composition intrude Purcell strata throughout Flathead map-area (PRICE, 1965). In the North Kootenay Pass area, sills ranging from 2 to 30 feet thick occur in the middle Siyeh Formation, and in Members A, B and C of the Kintla Formation. Sills below the Purcell lava are gabbroic, whereas those occurring in the upper Purcell strata are dioritic in composition.

Sill outcrops are resistant, massive, jointed and grey to black. Baked contacts are poorly developed, and are limited to widths upto 2 feet. Amygdaloidal texture in some sills indicates emplacement at shallow depths.

The intrusives are holocrystalline, fine to medium-grained. Gabbroic sills show a subophitic texture, the main original constituents being sodic labradorite, augite and skeletal ilmenite, with minor rhombohedral magnetite (Plate 2-G).. Alteration is usually extensive, feldspar being replaced by sericite and calcite, augite by serpentine, and iron ore being rimmed by phlogopite.

Dioritic sills consist of medium-grained feldspar laths and acicular, altered amphibole crystals, interstitial material consisting of chlorite, iron ore (mainly magnetite), micropegmatite (quartz-orthoclase intergrowths) and quartz (Plate 2-H). Plagioclase is normal-zoned, the average composition being sodic andesine. Alteration commonly occurs to chlorite, sericite and epidote. Amphibole is almost completely replaced by chlorite.

The mineralogic compositions of an altered gabbroic sill and an altered dioritic sill are given below:

Altered gabbro, middle Siyeh Formation:

	%
Plagioclase	48
Iron ore	11
Phlogopite	11
Serpentine	10
Sericite	9
Augite	7
Calcite	4

Altered diorite, Member C, Kintla Formation:

	%
Plagioclase	29
Chlorite	29
Sericite	9
Quartz	8
Magnetite	8
Micropegmatite	8
Epidote	6
Others	3

The sills in the North Kootenay Pass area are extensively altered. Moyie intrusives throughout the "Lewis series" are similarly altered (HUNT, 1958). According to Hunt, the main types of alteration are saussuritization and granophyric alteration, both of which have been observed in the above described sills. The alteration is thought to be due to autometamorphism by late magmatic, deuteric fluids.

In the North Kootenay Pass area, intrusives in the Siyeh Formation below the Purcell lava are of gabbroic composition, plagioclase being labradoritic. The Purcell lava is a sodic andesine basalt, whereas intrusives in the overlying Purcell strata are sodic andesine-rich microdiorites.

PRICE (1965) stated that the Moyie Intrusions are Precambrian in age, but post-Kintla Formation. Intrusives below the Purcell lava, in the Grinnell and Siyeh Formations of the Lewis Thrust sheet are dated at 1050 to 1100 million years (HUNT, 1961). GOBLE (1970) was of the opinion that these intrusives were contemporaneous with the Purcell lava. Possibly some of these basic intrusives acted as feeders to the overlying basaltic Purcell lava. With continuing differentiation of the source magma, dioritic sills were later intruded into the upper Purcell strata. In this case, the Moyie Intrusions would not be all post-Kintla Formation as postulated by Price.

CHAPTER FOUR

ENVIRONMENT OF DEPOSITION

Siyeh Formation

Middle Siyeh Formation

The carbonate sequence of the middle Siyeh Formation formed in an intertidal to supratidal depositional zone. In Subunit (ii), type - LLH stromatolites are dominant, indicating that depositional conditions were those of a protected, intertidal, carbonate mud flat. Graded bedding due to variation in silt content indicates recurrent cycles of greater and lesser influx of terrigenous material. Towards the top of this subunit, dolomitic intramicrites are associated with a change to type - SH stromatolites, indicating a change to a higher energy, exposed, intertidal, carbonate mud flat environment. Most of the intramicrites probably formed by reworking of dessicated carbonate crusts.

Dolomitic intramicrites are best developed in Subunit (iii). Silt is replaced by sand, possibly of windblown origin. "Chicken-wire" structure layers representative of sabkha facies sediments are present. Subunit (iii) thus represents deposits of an exposed intertidal to supratidal environment.

Subunit (iv), which closely resembles Subunit (ii), indicates that there was a return to the lower energy, protected, intertidal, carbonate mud flat environment.

Upper Siyeh Formation

A sharply increased influx of terrigenous sediment led to deposition of the red to green upper Siyeh Formation siltstones. Common mud cracks and small-scale oscillation ripple marks indicate a subaerial to very shallow water environment. The upper Siyeh Formation siltstones encroached on the underlying carbonates from the east (PRICE, 1964).

VAN HOUTEN (1961) classified red beds as those occurring in mobile belts and on cratons. Craton red beds were of two types, the piedmont-valley flat type, and the coastal plain-tidal flat type. The upper Siyeh Formation red beds are of the latter type. According to Van Houten, such red beds consist of well-bedded, well-sorted, quartzose to feldspathic, red to orange-red sandstone, siltstone and shale. Sediment accumulation took place in a warm to hot, semi-arid to arid climate on broad, featureless flood and coastal plains, on wide tidal flats and in restricted, shallow seas. Due to the very low gradient, minor topographic changes effected extensive advances and retreats of the sea, leading to the formation of cyclic sedimentational sequences.

Such cyclic sequences have been discussed by SANDERS and FRIEDMAN (1967). They stated that at the margin of an evaporite basin, a sequence from base upwards consisting of green shale, oolite, dolostone, gypsum and red shale indicates an approach of the shore zone to an originally offshore position; the reverse sequence represents a retreat of the shoreline. Rapid transgression and regression lead to the formation of incomplete sequences, so that, for example, the offshore green shale may rest directly on the marginal red shale.

This was undoubtedly the case during the deposition of the upper Siyeh Formation, since red and green beds are superposed; dolomite beds are few and oolitic limestones absent, only disseminated calcite being present.

Purcell lava

The Purcell lava was extruded onto the upper Siyeh Formation tidal flat sediments either subaerially or as submarine flows. The basal lava flow has a distinct green appearance in comparison with the overlying flows, principally due to a much greater chlorite content. Pillows are present in this basal lava flow, and HUNT (1961) mentioned sediment assimilation by the lava at the lower contact.

The basal flow may have been extruded under water leading to early large-scale chloritization, with the overlying flows later extruded subaerially. Lesser chloritization in these flows probably occurred during subsequent burial and propylitization.

Sheppard Formation

The cyclic accumulation of shallow water sediments that forms the Sheppard Formation was deposited under conditions similar to those which existed during deposition of the upper Siyeh Formation.

The green to grey, calcareous siltstones of the lowermost Sheppard Formation are of subtidal origin. Dolomites bearing type - SH stromatolites interbedded with these siltstones attest to intermittent periods of intertidal carbonate deposition.

The overlying red sandstones and siltstones of Subunit (ii) originated under subaerial, tidal flat depositional conditions. A second subtidal, probably lagoonal, phase is represented by the dolomitic, terrigenous beds of Subunit (iii), and this grades into the red, subaerial tidal flat deposits that comprise Member A of the Kintla Formation. LLH - type stromatolites in the interbedded dolomites of Subunits (ii) and (iii) indicate a generally slightly more protected environment than that of Subunit (i).

Kintla Formation

The red beds of Member A of the Kintla Formation are a thick accumulation of coastal plain-tidal flat muds. Hypersaline conditions were common during the earlier period of deposition of this member, as evidenced by abundant halite casts in the lower horizons.

The green strata of Member B of the Kintla Formation differ from Member A in being slightly coarser-grained and more dolomitic; sedimentary structures indicating subaerial exposure and dessication are less well developed. Member B was deposited subtidally during continuing deltaic progradation.

Member C of the Kintla Formation indicates a return to tidal flat sedimentation. The coarser grain size and reduced carbonate content of Member C beds indicate that they were farthest removed from the shore line of the terrigenous Purcell sedimentary rocks in the North Kootenay Pass area.

Summary

The Purcell sedimentary rocks of the North Kootenay Pass area are arid zone deposits. The oldest of these are the intertidal to supratidal silty dolomites and dolomitic siltstones of the middle Siyeh Formation.

Carbonate sedimentation was terminated at the end of middle Siyeh time, the upper Siyeh Formation consisting of a cyclic sequence of siltstones. These siltstones were deposited in a coastal plain-tidal flat environment as the littoral facies of a prograding delta.

Progradation was probably due to epeirogenic movements affecting the adjacent craton. Associated basaltic magmatism led to the submarine to subaerial extrusion of the Purcell lava onto the Siyeh Formation. Gabbroic sills were intruded into the Siyeh Formation.

The Sheppard Formation, a cyclic series of very shallow marine to tidal flat sediments, was deposited on top of the Purcell lava.

Continuing deltaic progradation led to deposition of the Kintla Formation, an upward coarsening accumulation of subtidal to intertidal silty claystones to fine sandstones. Dioritic sills were intruded into the Purcell strata deposited above the Purcell lava.

CHAPTER FIVE

PETROLOGY

Introduction

Most of the Purcell sedimentary rocks in the North Kootenay Pass area are fine grained. Rocks consisting of subequal portions of admixed carbonate and terrigenous sediment or predominantly of carbonate are usually finer than sand size. Aside from Member C of the Kintla Formation, predominantly terrigenous rocks are of silt size.

The general fine grain of Purcell rocks inhibits microscopic modal analysis. Quartz is generally not easily distinguishable from feldspar. Differentiation by staining was not found to be satisfactory, specially with regard to plagioclase feldspar.

Belt-Purcell sedimentary rocks throughout the Belt depositional basin contain a simple mineral suite (HARRISON and GRIMES, 1970). Quartz, feldspar, calcite, dolomite, chlorite and mica are the only common minerals. Mica includes muscovite, sericite, illite and biotite. Muscovite occurs as flakes easily visible under the microscope. Sericite occurs as very fine grained, highly birefringent, interstitial material. In claystones illite is cryptocrystalline, and usually stained red, green or grey. Biotite is common only in rocks that have undergone slight regional metamorphism.

The simple Belt-Purcell mineral suite allows the use of X-ray diffraction to obtain quantitative, mineralogic data on these rocks. An analytical technique designed for unmetamorphosed and very slightly metamorphosed Belt-Purcell rocks was used to obtain the modal compositions of a number of samples. The results are given in Table 7. A description of the technique used is given in Appendix B.

Classification of sedimentary rocks.

Rocks with 50 percent or more carbonate are classified as dolomites (or limestones). Carbonate rocks with over 10 percent terrigenous material are qualified as sandy, silty or clayey (FOLK, 1968). Terrigenous rocks are divided texturally into sandstones, siltstones and claystones. Such rocks with over 10 percent carbonate are qualified as dolomitic or calcareous, according to the dominant carbonate.

The terms argillite, siltite and quartzite, commonly used in description of Belt-Purcell rocks, are not used here because of the absence of recognizable regional metamorphic effects.

Discussion of quantitative data

With the exception of Member C of the Kintla Formation, carbonate occurs abundantly in the Purcell rocks of the North Kootenay Pass area. Dolomite is predominant, calcite occurring only in the upper Siyeh Formation and the basal part of the Sheppard Formation. These two minerals exhibit an antipathetic relationship, occurring

TABLE 7

Average modes, in volume percent, of Purcell rocks, North Kootenay Pass area

Rock Type	Number of Samples	Quartz	Potassium Feldspar	Plagio-Clase	Dolo-mite	Calcite	Chlorite	Illite-sericite-muscovite
KINTLA FORMATION - MEMBER C								
Sandstone	5	66	13	15	1	-	-	5
KINTLA FORMATION - MEMBER B								
Dolomitic sandstone	2	47	9	22	9	3	10	-
Dolomitic siltstone	1	31	14	17	26	-	7	5
Silty to sandy dolomite	1	15	5	17	55	-	4	4
KINTLA FORMATION - MEMBER A								
Clayey siltstone	5	46	20	11	5	2	6	9
SHEPPARD FORMATION								
Sandstone	4	54	19	9	9	-	6	3
Dolomitic sandstone	2	42	11	13	28	-	4	2
Dolomitic siltstone	6	39	14	7	17	5	10	8
Calcareous siltstone	2	26	18	3	3	39	6	5
Claystone	3	50	18	9	4	-	9	10
Dolomitic claystone	1	30	8	7	32	-	8	15
Dolomite	1	7	-	-	93	-	-	-
Silty dolomite	3	17	7	3	55	9	5	4
UPPER SIYEH FORMATION								
Calcareous sandstone	3	40	11	5	2	34	7	1
Siltstone	8	49	12	11	2	6	12	8
Calcareous siltstone	3	40	14	8	1	24	11	2
MIDDLE SIYEH FORMATION								
Dolomitic siltstone	4	37	7	5	42	3	6	-
Dolomite	1	2	-	-	98	-	-	-
Silty dolomite	3	31	3	2	57	2	5	-

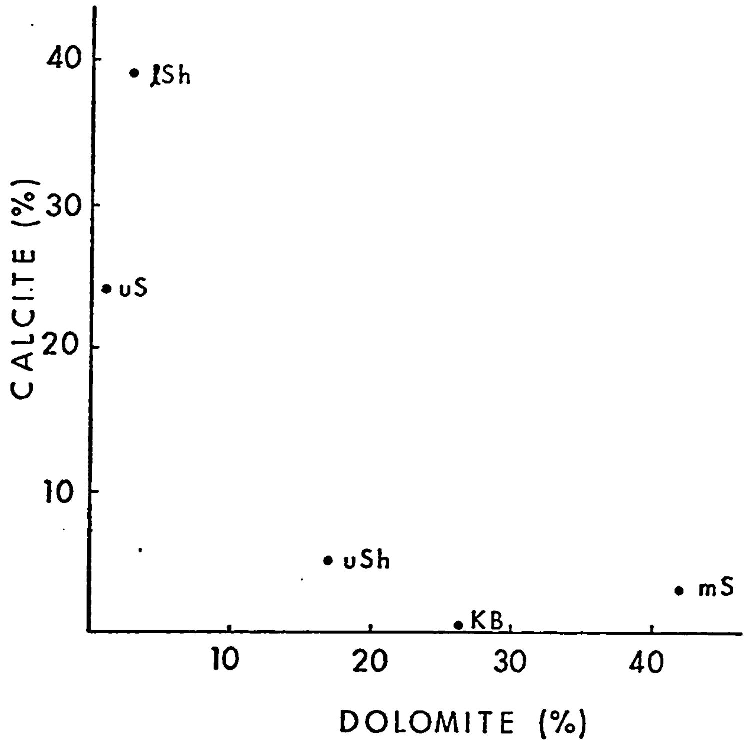
exclusively of each other both in terrigenous and carbonate rock units. This relationship is shown for siltstones in Fig. 9.

Fig. 10 shows that the terrigenous Purcell rocks of the study area are of a relatively uniform composition. Variations in carbonate content are imposed on a constant quartz-feldspar-phyllosilicate ratio. Quartz is the dominant component, with lesser feldspar and a minor phyllosilicate content.

Claystone, in general, is uncommon in the North Kootenay Pass area, shaly and slaty rocks proving usually to be fine siltstones in thin section. The only clay mineral present is illite. Smectite and kaolinite that may originally have been present have probably been altered to illite during burial (GRIM, 1968).

Ratios between quartz, potassium feldspar and plagioclase among the Purcell formations are similar. Fig. 11 shows clearly a decreasing quartz content from the middle Siyeh Formation upto Member B of the Kintla Formation. The increased quartz proportion in Member C of the Kintla Formation may reflect partly a relatively increased quartz supply, partly a difficulty in sampling less resistant, presumably finer-grained and quartz-poor, covered interbeds. The general increase in feldspar proportion upwards in the sedimentary succession is accompanied by a decrease in carbonate content, and a seaward shift of depositional zones, reflecting increased tectonism in the source area.

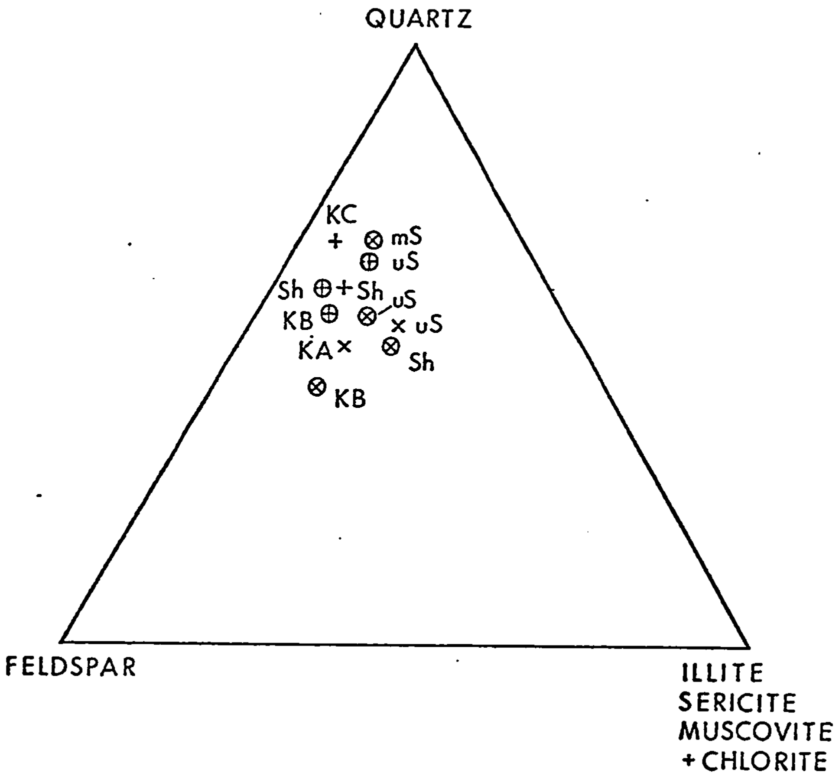
Members B and C of the Kintla Formation are richer in plagioclase than in potassium feldspar. HARRISON and GRIMES (1970) reported rocks similarly enriched in plagioclase from the eastern Belt basin in Montana. FOLK (1968) stated that plagioclase generally occurs in



LEGEND

		No.of samples
KB	Kintla Formation, Member B	1
uSh	Sheppard Formation, Subunits (ii)–(iv)	6
ℓSh	Sheppard Formation, Subunit (i)	2
uS	Upper Siyeh Formation	3
mS	Middle Siyeh Formation	4

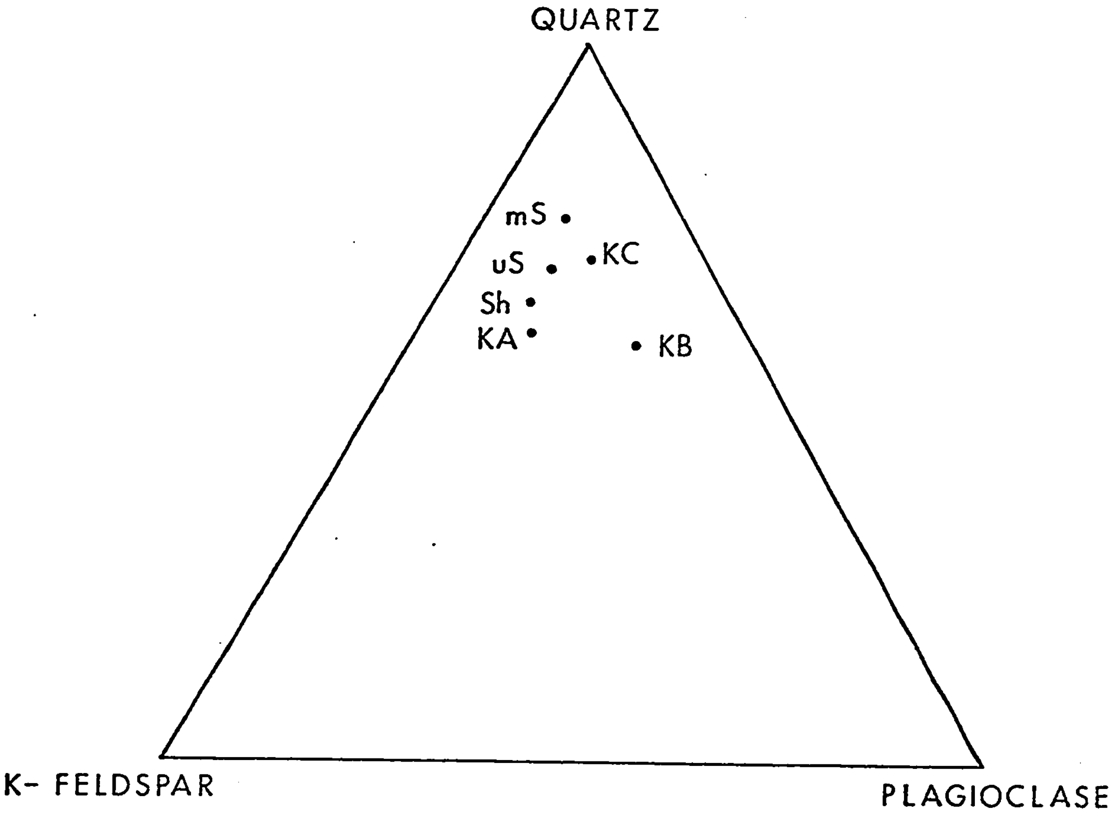
Fig. 9 Carbonate distribution in carbonate-rich siltstones of Purcell strata, North Kootenay Pass area



LEGEND		No. of samples
KC	Kintla Formation, Member C	5
KB	Kintla Formation, Member B	3
KA	Kintla Formation, Member A	5
Sh	Sheppard Formation	14
uS	Upper Siyeh Formation	14
mS	Middle Siyeh Formation	4

+	Sandstone
⊕	Carbonate - rich sandstone
×	Siltstone
⊗	Carbonate - rich siltstone

Fig. 10 Average mode (volume percent) of Purcell sandstones and siltstones, North Kootenay Pass area (recalculated to exclude carbonate)



LEGEND		No. of samples
KC	Kintla Formation, Member C	5
KB	Kintla Formation, Member B	3
KA	Kintla Formation, Member A	5
Sh	Sheppard Formation	18
uS	Upper Siyeh Formation	15
mS	Middle Siyeh Formation	4

Fig. 11 Ratio among quartz, potassium feldspar and plagioclase (volume percent) in sandstones, siltstones and claystones of Purcell strata, North Kootenay Pass area

lesser amount than potassium feldspar in sedimentary rocks, abundant plagioclase indicating a volcanic source terrane. No volcanic rock fragments were observed in the sandstones of Members B and C of the Kintla Formation. The Precambrian basement underlying the western Canada sedimentary basin to the east of the study area is thought to be mostly gneissic (BURWASH et al., 1964). PETTIJOHN (1970) stated that sodic granitic rocks are common in the Canadian Shield. Thus, the increased plagioclase content of the upper members of the Kintla Formation may be due to their derivation from albitized gneisses.

The Purcell sandstones and siltstones of the North Kootenay Pass area are quartz-rich arkoses (Fig. 12), being immature to submature in the Sheppard Formation and Member A of the Kintla Formation, and submature to mature in Members B and C of the Kintla Formation. Rock fragments constitute not more than 4 percent of the sandstones and coarse siltstones of these formations. Scarcity of rock fragments is undoubtedly associated with the fine grain size of these rocks. Volcanic rock fragments of medium sand size are present locally in coarse sandstone lenses in the Sheppard Formation. These volcanic rock fragments are very similar petrographically to the underlying Purcell lava, and are undoubtedly derived therefrom (Plate 3-A).

The most common rock fragment types are sericite schist and quartz-sericite schist (Plate 3-B, C). Chert is less common and is possibly in part authigenic (Plate 3-D). Medium to very coarse sand size calc-silicate rock fragments were observed in several horizons towards the top of Member C, Kintla Formation (Plate 3-E). These

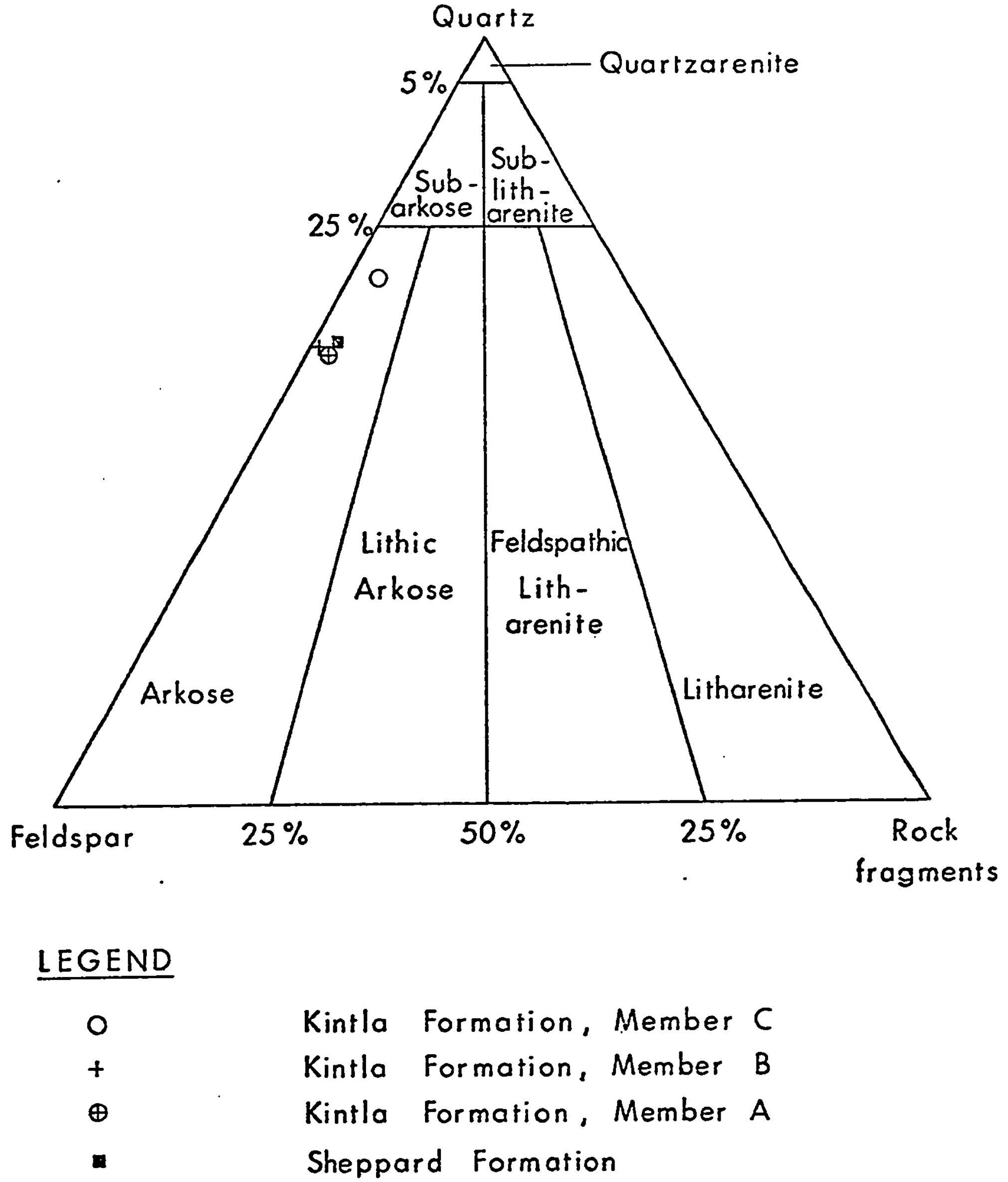


Fig. 12 Classification of Purcell sandstones and coarse siltstones, North Kootenay Pass area (after FOLK, 1968)

fragments are ellipsoidal, with their elongate axes aligned parallel to bedding, and are composed of an extremely fine intergrowth of carbonate and silicate minerals.

Quartz occurs predominantly as single crystal units with straight to slightly undulose extinction.

BURWASH et al. (1964) stated that the basement underlying the western Canada sedimentary basin in southern Alberta is a predominantly gneissic terrane (90 percent), with minor associated sedimentary and metasedimentary rocks (10 percent). Thus, the greater proportion of the sedimentary material comprising the Purcell strata of the study area must have been derived from this gneissic terrane. That minor associated sedimentary and metasedimentary rocks were present is indicated by the derived rock fragments present in these Purcell strata.

Pigmentation

Terrigenous beds of the Purcell strata in the North Kootenay Pass area are mostly either red or green.

The red colour is due to the presence of hematite, in some cases with minor goethite. Hematite is present in red beds as a stain on detrital grains, as a thin rim surrounding these grains, and interstitially. Rim and interstitial hematite is usually earthy. Micaceous hematite occurs aligned parallel to bedding. Hematite grains distributed along cross-beds and parallel to bedding are common.

According to STRAKHOV (1969), the main bulk of authigenic iron minerals in sediments form during diagenesis from iron introduced into the basin in mechanical suspension. The chief mineralogical form of suspended iron is hydro-goethite in various stages of hydration. Lesser sources of introduced iron are silicates, aluminosilicates, magnetite, titanomagnetite, pyrite (STRAKHOV, 1967). VAN HOUTEN (1961) postulated that hydrated iron oxides rapidly deposited in an oxidizing environment are preserved and converted with burial to hematite. Thus, possibly, most of the earthy rim and interstitial hematite in the Purcell red beds was derived diagenetically from iron oxides introduced into the basin in suspended form.

In green to grey beds chlorite is the dominant cement. Authigenic sphene is ubiquitous in these beds, detrital hematite grains being scarce.

Iron-rich ilmenite commonly alters to hematite + rutile; ilmenite exsolves from titanomagnetite, forming magnetite-ilmenite intergrowths (RAMDOHR, 1969). Rutile and ilmenite so formed further break down into titanium compounds. Thus, the original source of the titanium in the sphene of drab beds was probably detrital magnetite and ilmenite. Iron released by alteration of these minerals probably contributed to the formation of the chlorite of these beds. Similarly, it is likely that hematite grains arranged parallel to bedding and along cross-beds in Purcell red beds are replacement products of detrital magnetite and ilmenite grains. The hematite was preserved because of deposition in an oxidizing environment.

Cementation

Hematite is the primary cement in the Purcell red beds, usually occurring as rims on detrital grains. Where abundant it occurs interstitially as well. Chlorite is often developed on hematite-rimmed grains. This chlorite must have formed in these sediments after their removal by burial from the oxidizing environment in which they were deposited. Sericite is a common cement in rocks of the Kintla Formation. Where developed it postdates hematite and invariably precedes chlorite. Quartz is the final cement, occluding pores. Purcell rocks thus are of low porosity.

In green to grey beds hematite is absent, or present as very thin stains on detrital grains. Chlorite is developed both as rims and interstitially, with quartz as the final pore-filling cement. Sericite, when present, precedes chlorite.

CHAPTER SIX

COPPER-LEAD-ZINC MINERALIZATION

Introduction

Copper, lead and zinc mineralization in the North Kootenay Pass area is very sparse, being present mostly in the Sheppard Formation.

In order to study the distribution of these metals, 21 rock samples from the various Purcell formations were analyzed. Of these 13 were sedimentary, 5 were from the Purcell lava, and 3 were from sills intruded into the sedimentary rocks. The analytical method used is described in Appendix C. The results are shown in Table 8.

Discussion

The concentrations of Cu, Pb and Zn in most of the samples are close to the average concentrations in basaltic, dioritic and sedimentary rocks as given by VINOGRADOV (1962), TUREKIAN and WEDEPOHL (1961), GRAF (1960) and KRAUSKOPF (1955).

Cu in the Purcell lava

The five basalt lava samples analyzed show anomalous Cu values as compared to the average for basalts of 87 ppm (TUREKIAN and WEDEPOHL, 1961). Samples 94, 108 and 113 show positive anomalies

TABLE 8

Concentration of Cu, Pb, Zn (in ppm) in Purcell rocks, North Kootenay Pass area

Formation	Sample Number	Rock Type	Cu	Pb	Zn
Kintla	14	Microdiorite	37.5	8.5	160.5
	23	Microdiorite	36.0	7.5	118.0
Sheppard	37	Dolomite	13.5	9.0	25.5
	46	Dolomitic sandstone	7.5	4.0	10.5
	50	Sandstone	16.5	5.0	45.5
	51	Claystone	7.5	8.5	53.0
	128	Dolomite	16.5	10.0	45.5
	129	Dolomitic sandstone	136.0	3.5	15.5
	130	Dolomitic siltstone	201.0	8.0	108.0
	132	Silty dolomite	24.5	5.5	72.0
	134	Dolomitic sandstone	466.0	11.5	28.0
	149	Silty dolomite	18.5	760.0	505.5
Purcell lava	94	Altered basalt	153.5	7.5	114.5
	105	Altered basalt	10.0	1.5	153.0
	108	Altered basalt	366.0	9.0	155.5
	113	Altered basalt	231.0	9.5	138.0
	114	Altered basalt	17.5	4.5	233.0
Siyeh	66	Silty dolomite	21.5	12.5	15.5
	91	Calcareous siltstone	6.0	3.0	23.0
	124	Gabbro	20.0	15.0	143.0
	125	Silty dolomite	7.5	4.5	13.0

clearly related to the concentration of Cu in the form of chalcopyrite in vesicles in the lava. These lava samples are highly altered. ELLIS (1968) has shown that hot, highly saline, sulfide-poor, aqueous solutions are capable of removing Cu almost completely from rocks of andesitic composition in a relatively short period of time. Solutions of this type may have effected the propylitization of the Purcell lava, at the same time leaching out Cu and redepositing it in vesicles. However, such chalcopyrite-filled vesicles are present in only a few thin and restricted layers in the Purcell lava. One such layer is a pillowed zone at the top of the basal lava flow. Possibly, voids among the pillows allowed easier passage of Cu-bearing solutions, leading to the localization of Cu deposition.

Two non-mineralized samples of the Purcell lava (Samples 105 and 114), which are more representative of the Purcell lava as a whole, show very low values for copper. It may be that most of the Cu in these lavas was removed during propylitization, with chalcopyrite being redeposited in vesicles only infrequently.

Cu-Pb-Zn in the Purcell sedimentary rocks

(a) Cu, distribution and environment of deposition

Two sandstone samples and a siltstone (Samples 129, 130 and 134) from the Sheppard Formation show high Cu values as compared with the average concentration of 10-40 ppm in sandstones (KRAUSKOPF, 1955). These rocks are typical terrigenous members of the suite of red to greyish green, shallow-water deposits that characterize the Sheppard Formation. Cu mineralization occurs in the form of sparse, interstitial chalcopyrite disseminations, usually not exceeding 1 mm in diameter (Plate 3-F). The chalcopyrite may be randomly distributed, or may be aligned parallel to bedding. Limonitization of the chalcopyrite is common.

(b) Pb-Zn, distribution and environment of deposition

An anomalous concentration of Pb and Zn occurs in a dark grey to black, finely crystalline, silty dolomite (Sample 149). According to GRAF (1960), Pb concentration in carbonates averages 8 ppm, and Zn 26 ppm. Sample 149 shows a concentration of 760 ppm Pb and over 505 ppm Zn. In polished section, this sample shows anhedral galena occurring interstitially among silt grains in a dolomite matrix, with very minor chalcopyrite occurring as disseminated blebs (Plate 3-G). No zinc ore mineral was observed, indicating that the zinc present occurs isomorphously in the carbonate (STRAKHOV, 1970). Disseminated authigenic pyrite occurs throughout the rock (Plate 3-H). A few of the pyrite grains are rounded, indicating that they may be of detrital origin.

The above-mentioned silty dolomite is the only dark coloured sedimentary rock to be observed in the Purcell sequence in the North Kootenay Pass area. All other Purcell rocks vary in colour from red to green to greyish white. In hand specimen, apart from its dark grey to black colour, the most striking characteristic of the rock is a very fine, even lamination throughout most of the rock.

FRIEDMAN and SANDERS (1967) stated that the two main processes responsible for dolomite formation are "capillary concentration" and "refluxion". In "capillary concentration", interstitial waters in sediments transpire upward through porous sea-marginal sediments and evaporate at the sediment-air interface. By concentration, this process leads to dolomite formation in supratidal and intertidal environments on broad shallow shelves. Under warm, arid conditions gypsum and anhydrite may develop. These dolomites typically display shallow-water sedimentary structures.

In "refluxion", evaporation increases the concentration and density of the water in a restricted basin. This produces a brine that sinks and migrates to the lowest possible topographic depressions where it may seep slowly through the underlying sediments, which are progressively dolomitized. Alternately, dolomite may form directly from the brine, with the deposition of layered dolomite mud at the bottom of the basin. In order for dolomite to precipitate from such a brine, it was stated that the Mg/Ca ratio of the brine had to be increased from that of sea water to a ratio larger than that which would be in equilibrium with both calcite and dolomite. This could be brought about by the removal of gypsum or aragonite. Gypsum is preserved only in shallow water which is amply oxygenated, it being degraded to H_2S and iron sulfide by bacteria in deeper water.

It is probable that the black, galena-bearing, silty dolomite (Sample 149) formed by "refluxion" at a time when a heavy influx of water led to deepening of the basin. Gypsum formed was degraded to H_2S and iron sulfide, and organic matter preserved due to the reducing environment, leading to the black coloration of the sediment. This dolomite occurs as a 10-foot thick bed, with outcrop restricted to the northern part of the North Kootenay Pass area, indicating that deepening of the basin was local and of limited duration.

The great majority of the dolomitic rocks of the Purcell sequence in the North Kootenay Pass area are of shallow-water type formed by "capillary concentration". A few of these dolomites may have formed through progressive dolomitization due to seepage through buried sediments of concentrated brines formed by "refluxion". Thus it becomes evident that the black, galena-bearing, silty dolomite is a deeper-water deposit, probably lagoonal, unique among shallow-water deposits.

(c) Geochemistry of Cu-Pb-Zn

Cu, Pb and Zn in arid zones migrate in the dissolved state (STRAKHOV, 1970). These elements, where occurring combined with sulfur as sulfides in source rocks, migrate initially as the sulfates $CuSO_4$, $PbSO_4$ and $ZnSO_4$. Cu and Pb sulfates are unstable, hydrolyzing at pH values greater than 6.63 and 7 respectively, and changing in the presence of carbonate into the basic carbonates which being insoluble are precipitated. Zn sulfate, the most stable sulfate of this group, hydrolyzes at a pH greater than 7.5, forming the carbonate which has a solubility of 10-40 mg/litre.

The waters of arid regions, both in streams and in basins, are characterized by the abundance of dissolved carbonates (mostly $CaCO_3$, $MgCO_3$) and by high pH. They are thus good precipitants of Cu, Pb and Zn from sulfate solutions. By contrast, the waters of humid zones are generally poor in dissolved carbonates and rich in dissolved organic matter, with neutral to slightly acid pH, making them poor precipitants of Cu, Pb and Zn.

Because of the differing stabilities and solubilities of the sulfates and carbonates of Cu, Pb and Zn, the first of these metals to be precipitated from waters entering an arid zone marine basin is Cu, followed by Pb and finally Zn. Thus Cu would be expected to be sedimented at the shore or very close to shore. Pb and Zn would be sedimented farther out from shore, in slightly deeper water. Since the degree of differentiation of these metals during sedimentation is not complete, some Pb and Zn would occur with Cu inshore, and some Cu with Pb and Zn farther away from shore.

(d) Causes of concentration of Cu-Pb-Zn

From the above description of the geochemical behaviour of Cu, Pb and Zn, the reason for the slight concentration of Cu in several sandstones and siltstones of the Sheppard Formation becomes apparent. As discussed previously, these sandstones and siltstones are intertidal deposits, and Cu would be expected to be sedimented in sediments of this facies.

The black, galena-bearing, silty dolomite, though formed among intertidal deposits, was probably deposited in a reducing environment due to the generation of H_2S by degradation of gypsum. Pb and Zn sulfates were therefore hydrolyzed and then precipitated in this environment.

The basic carbonates of Cu, Pb and Zn deposited during sedimentation are converted during diagenesis to the sulfide form (STRAKHOV, 1970), so that it is this form that is now present in the

Purcell rocks.

According to STRAKHOV (1967), sedimentary ore formation is influenced by at least five factors:

a) the intensity of chemico-biogenic precipitation of the ore component, due at times to locally sharp increase in supply of the component from the shore, at others to increased withdrawal from the reserves of the component in the water of the basin;

b) the effect of the hydrodynamic conditions and the palaeogeography of the region of increased precipitation of the ore component;

c) the diluting effect of clastic material brought in from the shore;

d) the secondary concentration effect of redistribution of material during diagenesis of the ore sediments;

e) the reworking of the ore bed with removal of finely dispersed clastic material from it.

Ore deposits develop when all five factors act together in a favourable, accumulative direction.

The meagre development of Cu, Pb and Zn mineralization in the Purcell rocks of the North Kootenay Pass area is most probably due to the absence of an increased supply of ore components. In the case of the black, silty dolomite of the Sheppard Formation, favourable palaeogeographic as well as geochemical conditions led to the increase in Pb and Zn concentrations observed.

Relationship between sedimentary facies and Cu-Pb-Zn mineralization in the Purcell System

The North Kootenay Pass area lies at the eastern depositional edge of the Belt-Purcell basin (HARRISON, 1972). Throughout most of Belt-Purcell terrane facies changes are subtle and occur over tens to hundreds of miles. Noticeable facies changes occur, however, in an east-west direction along the eastern edge of the basin.

SMITH and BARNES (1966) noted that the Altyn Formation of the lower Purcell Supergroup in northeast Clark Range, Alberta-British Columbia is thin and consists predominantly of light grey, dolomitic limestones, frequently containing oolites together with granules of quartz, feldspar and chert. Stromatolites, calcareous mud-chip conglomerate and mud crack casts were observed to be common, indicating that these sediments were deposited in a well-aerated, shallow-water, near-shore environment where they were frequently exposed to subaerial dessication. By contrast, the thicker Altyn Formation of southwest Clark Range was observed to consist of very finely and evenly laminated, black to grey argillaceous dolomite and limestone. No mud cracks, stromatolites or coarse-grained detritus are present, and pyrite occurs in some intervals. It was concluded that the depositional environment was poorly aerated and highly reducing, with greater water depth and restricted circulation as compared with the eastern facies. Still further to the west, the Aldridge Formation of Canada, correlative of the Prichard Formation south of the international border, was deposited in a similar environment, but with reduced or no carbonate sedimentation.

In the case of the middle Belt-Purcell Supergroup, SMITH and BARNES (1966) using variations in calcite/dolomite ratios and the distribution of stromatolites and "molar tooth" structures (post-burial, pre-lithification slump fractures, ADSHEAD, 1963) showed that the facies belts within the Piegan Group and its Purcell equivalent, the Siyeh Formation, appear to be symmetrically disposed about a northwest-trending axis (Fig. 13). A central calcite-rich zone grades northeastward into a zone in which dolomite predominates. To the southwest, a less well established dolomitic zone indicates a shallowing of the depositional basin and an approach to a shoreline on the southwest.

A completely carbonate-free but carbonaceous equivalent of the Siyeh Formation has nowhere been observed in the middle Belt-Purcell Supergroup. On the other hand mud cracks are reported to occur in most sections of the Siyeh, indicating a generally very shallow-water sedimentational regime.

The only carbonate-rich formation of the upper Belt-Purcell Supergroup, the Sheppard Formation and its correlatives, wherever described is predominantly dolomitic, stromatolite-bearing, mud cracked and bears intraformational mud-chip conglomerates and, more rarely, "molar tooth" structures. Depositional conditions were clearly of the very shallow-water type (SMITH and BARNES, 1966).

The above described facies relationships indicate that in the Purcell rocks of the "Lewis series" in the southern Canadian Rocky Mountains, sedimentary Pb-Zn mineralization, if present, is to be

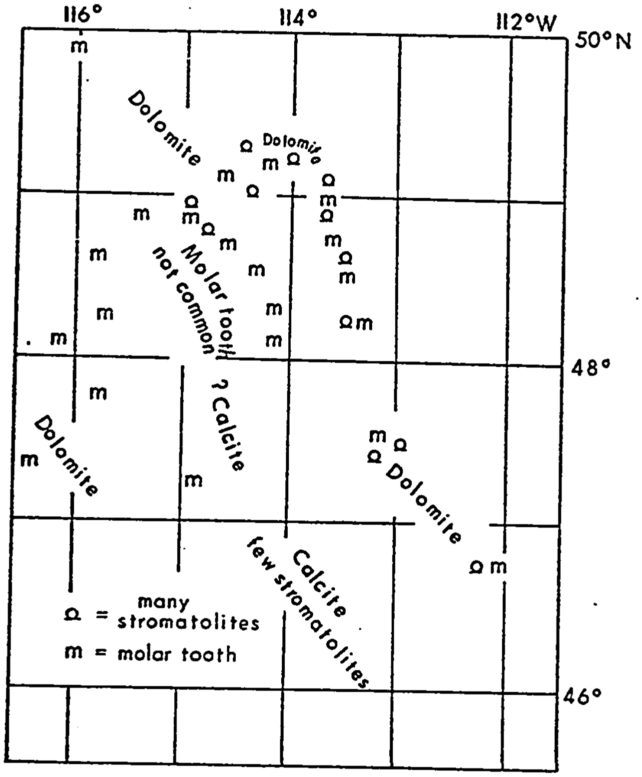


Fig. 13 Distribution of carbonate, "molar tooth" structures and abundant stromatolites in the Piegan Group and Purcell equivalent

expected mainly in the relatively deep-water, black to grey, argillaceous dolomites and limestones of the Altyn Formation in southwestern Clark Range.

The shallow-water, intertidal to supratidal Siyeh and Sheppard Formations did not form in an environment favourable to the sedimentation of either Pb or Zn. These metals would be concentrated in these deposits only in local, isolated, deep-water, lagoonal facies sediments, as is the case in the North Kootenay Pass area.

Cu mineralization in the Purcell rocks of the "Lewis series", if present, would be expected in the deposits of the terrigenous Ravalli and Missoula Groups. Such mineralization occurs extensively in the Grinnell Formation of the Ravalli Group (GOBLE, 1970).

Conclusion

STRAKHOV (1970) noted that cupriferous sandstones in the geologic column have formed immediately after major orogenic epochs, and are situated within fold zones or in immediately adjacent parts of platforms. In other words, cupriferous strata have formed against a background of marked tectonic activity. It was also noted that epochs of sedimentary Pb-Zn mineralization are mostly very close to, or identical with, those of Cu accumulation.

Considerable topographic relief due to tectonic activity would result in a certain degree of vertical climatic zoning, with drainage areas being more humid than zones of sedimentation.

In arid zones, chemical weathering, curtailed because of lack of water, is replaced by mechanical weathering. The initial movement of Cu, Pb and Zn into the dissolved state thus must take place in the humid drainage zones. Under these conditions, provided there was primary Cu-Pb-Zn enrichment of source rocks, and assuming favourable sedimentational conditions, sedimentary ore deposits of these metals would be able to develop.

The Belt-Purcell basin shows little evidence of major tectonic activity. Many slight tectonic adjustments are identifiable in the basin, but even the largest of these, a dome formed in early Missoula time, was but a relatively gentle warp (HARRISON, 1972). Slow, gentle, generally downward warping was the habit of the basin. Terrane adjacent to the Belt-Purcell basin was low-lying, with low-gradient streams contributing fine sediment to it. Thus, these surrounding source areas probably had a climatic regime as arid as that of the basin. Even assuming metal enrichment in the rocks of the source area, such climatic conditions would not have favoured Cu-Pb-Zn removal leading to subsequent concentration in the Belt-Purcell basin. Hence the weak concentration of Cu, Pb and Zn throughout rocks of the Belt-Purcell basin, and the scarcity of ore bodies of sedimentary origin.

PLATE 1

A: Graded dolomite beds, darker and silty at base, lighter and purer towards top (top at left), Siyeh Formation. Plane polarized light. x40

B: Calcite-filled shrinkage fracture cutting through graded dolomite bed (top at left), Siyeh Formation. Plane polarized light. x40

C: Net of organic laminae of stromatolitic origin in dolomite, Siyeh Formation. Plane polarized light. x155

D,E,F: "Chicken-wire" structure in Siyeh Formation dolomites. Intraclasts retained between organic laminae are flattened parallel to bedding. White sand grains are mostly quartz. Plane polarized light. x40

G: Variolitic plagioclase in groundmass, Purcell lava. Crossed nicols. x390

H: Pseudoperlitic texture in Purcell lava, cracks being iron-ore filled. Plane polarized light. x155

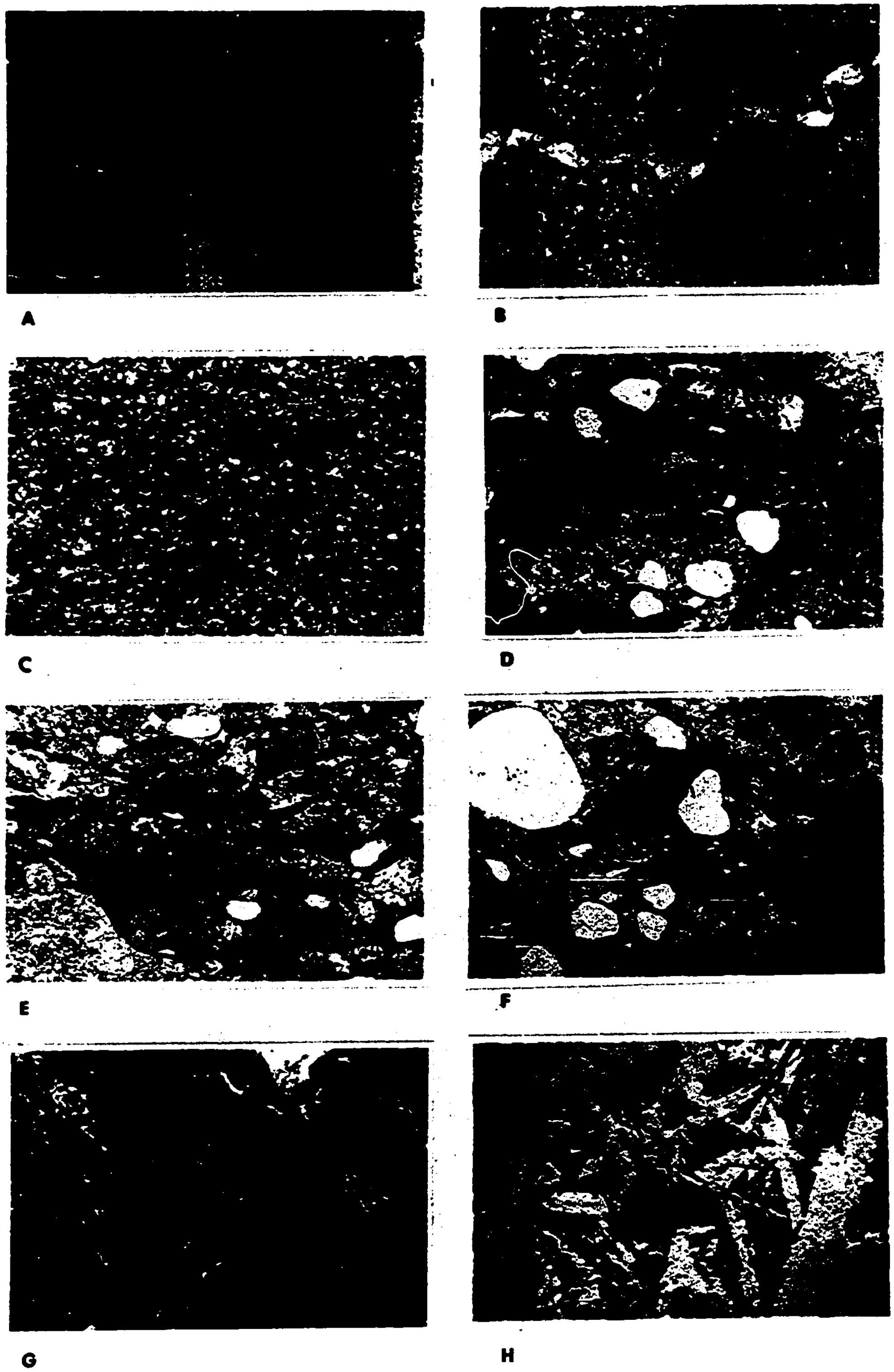


PLATE 1

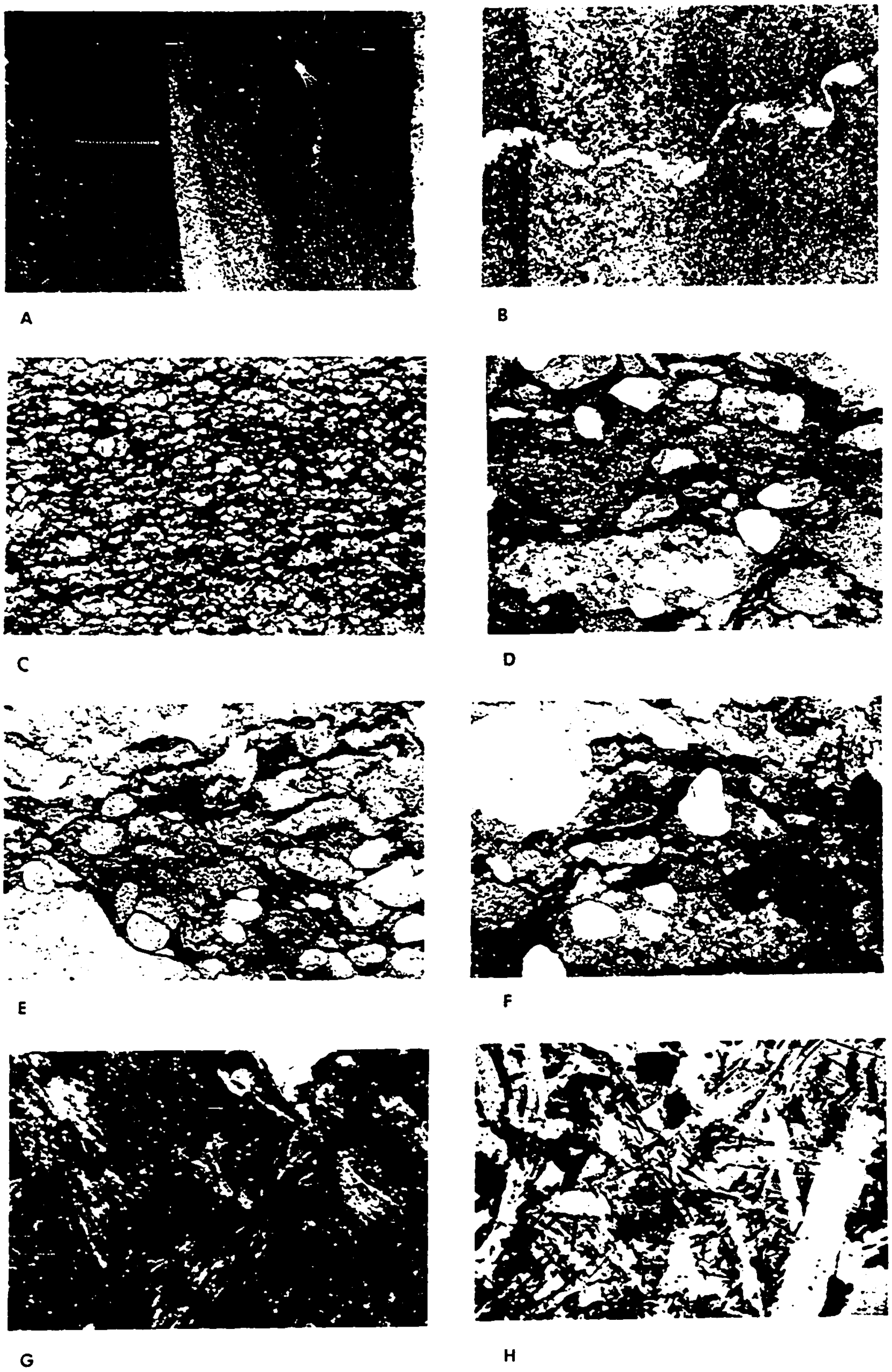


PLATE 1

PLATE 2

A: Part of amygdale in Purcell lava, showing pyrite surrounded by chalcopyrite, with grey hematite reaction rim in between. Black is outer chlorite rim of amygdale. Plane polarized light. x62.5

B: Pseudomorph of zoned olivine crystal (centre of photo). White central layer is sericite, other layers are chlorite. Purcell lava. Crossed nicols. x155

C: Altered plagioclase crystal in Purcell lava showing chalcedonic quartz-chlorite core with white calcite rim. Crossed nicols. x40

D: Leucoxene pseudomorphs of magnetite, Purcell lava. Plane polarized light. x155

E: Altered tachylyte. Note chlorite amygdales surrounded by bleached borders. Purcell lava. Plane polarized light. x40

F: Altered zoned olivine crystal in tachylyte, Purcell lava. Crossed nicols. x155

G: Altered gabbroic sill intruded into Siyeh Formation. Main original constituents are labradorite, augite and ilmenite. Plane polarized light. x40

H: Altered dioritic sill intruded into Kintla Formation. Main original constituents are andesine and amphibole. Crossed nicols. x40

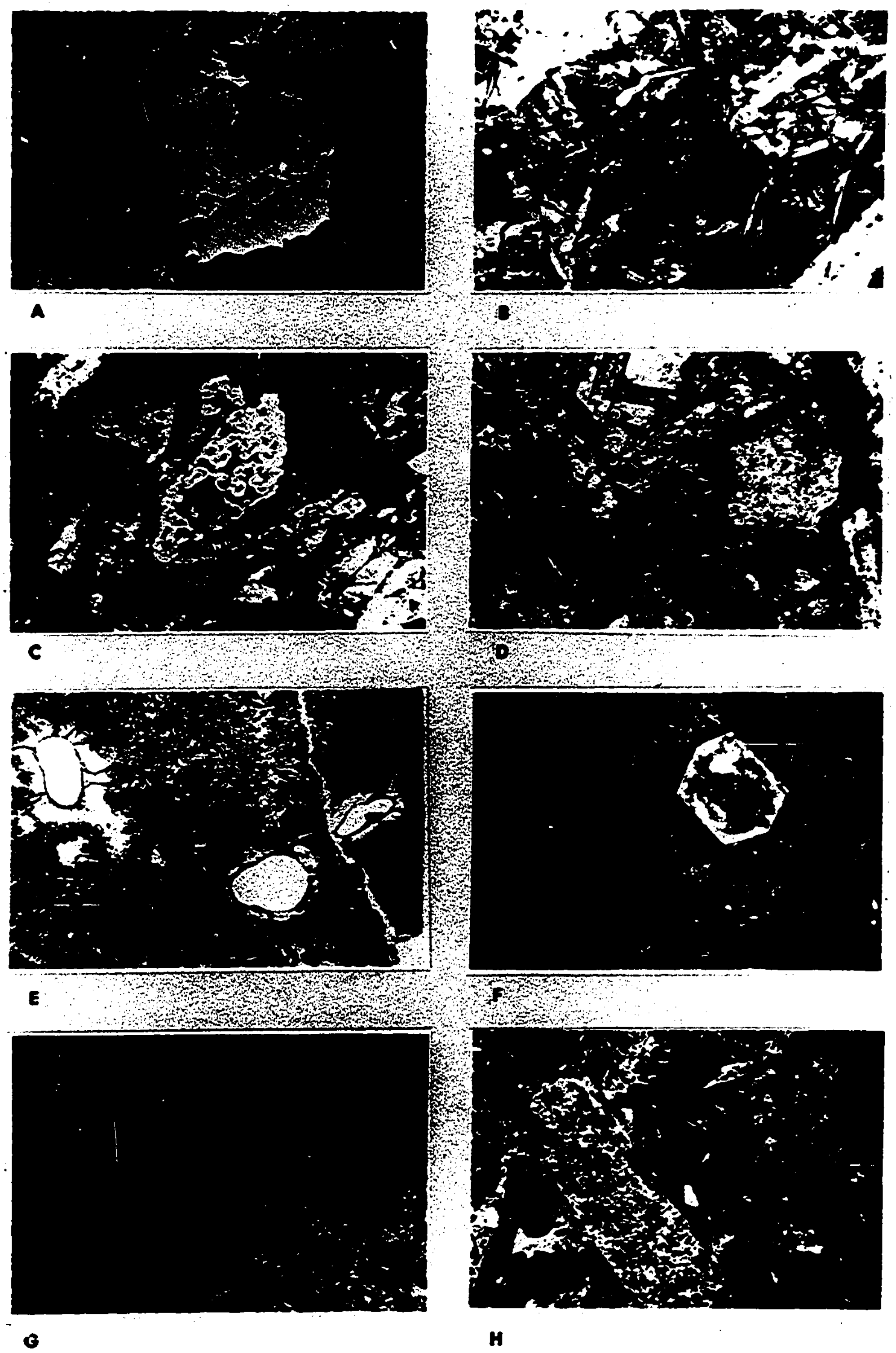


PLATE 2

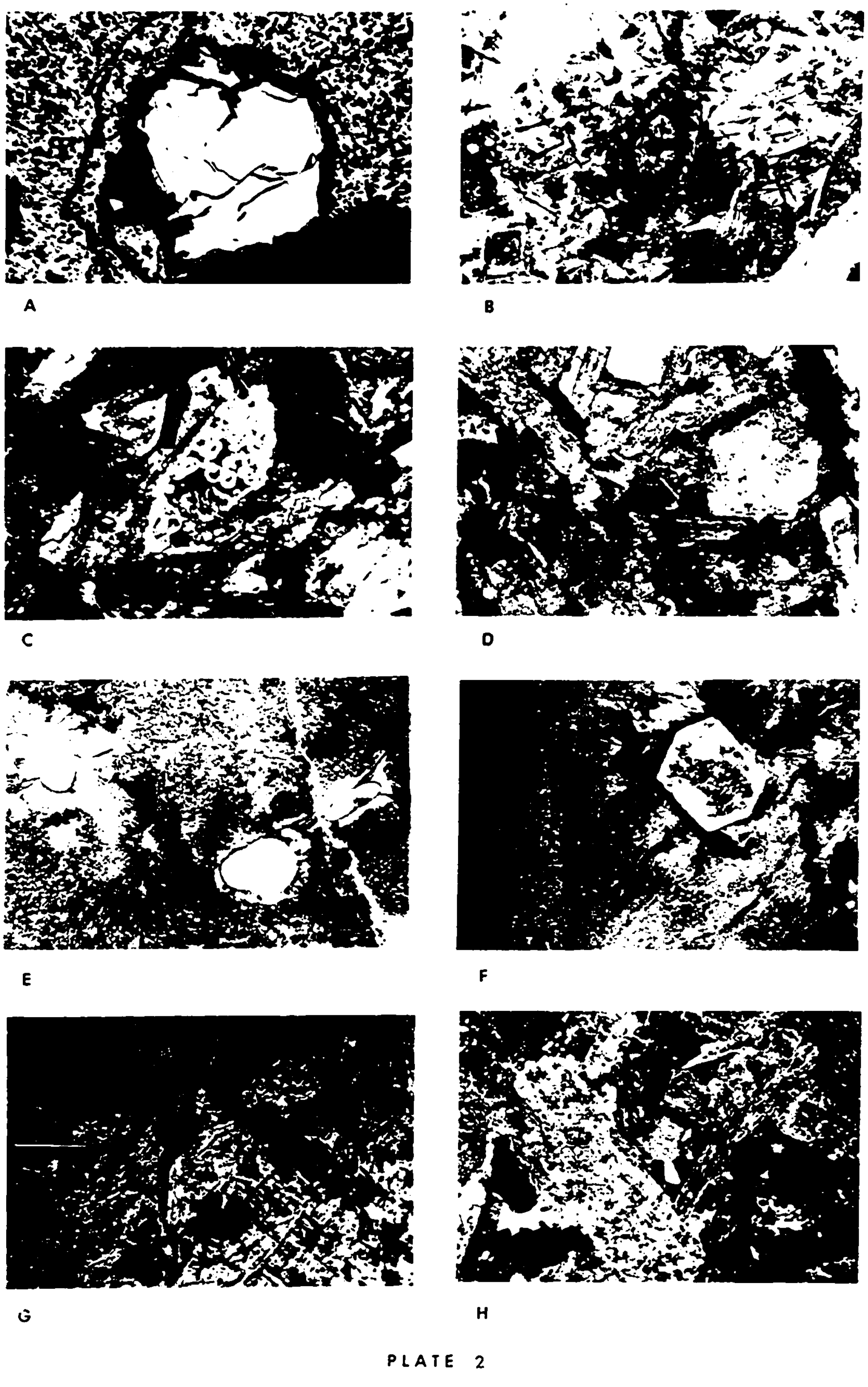


PLATE 2

PLATE 3

A: Purcell lava rock fragments in overlying Sheppard Formation. Crossed nicols. x40

B,C,D: Sericite schist, quartz-sericite schist and chert rock fragments respectively, typical of Purcell rocks of North Kootenay Pass area. Crossed nicols. x 390

E: Coarse calc-silicate rock fragments aligned parallel to bedding, Kintla Formation. Crossed nicols. x40

F: Interstitial chalcopyrite (light) dissemination in sandy siltstone, Sheppard Formation. Reflected plane polarized light. x250

G: Interstitial galena (light) in black, silty dolomite, Sheppard Formation. Reflected plane polarized light. x250

H: Disseminated authigenic pyrite (same sample as G). Reflected plane polarized light. x625

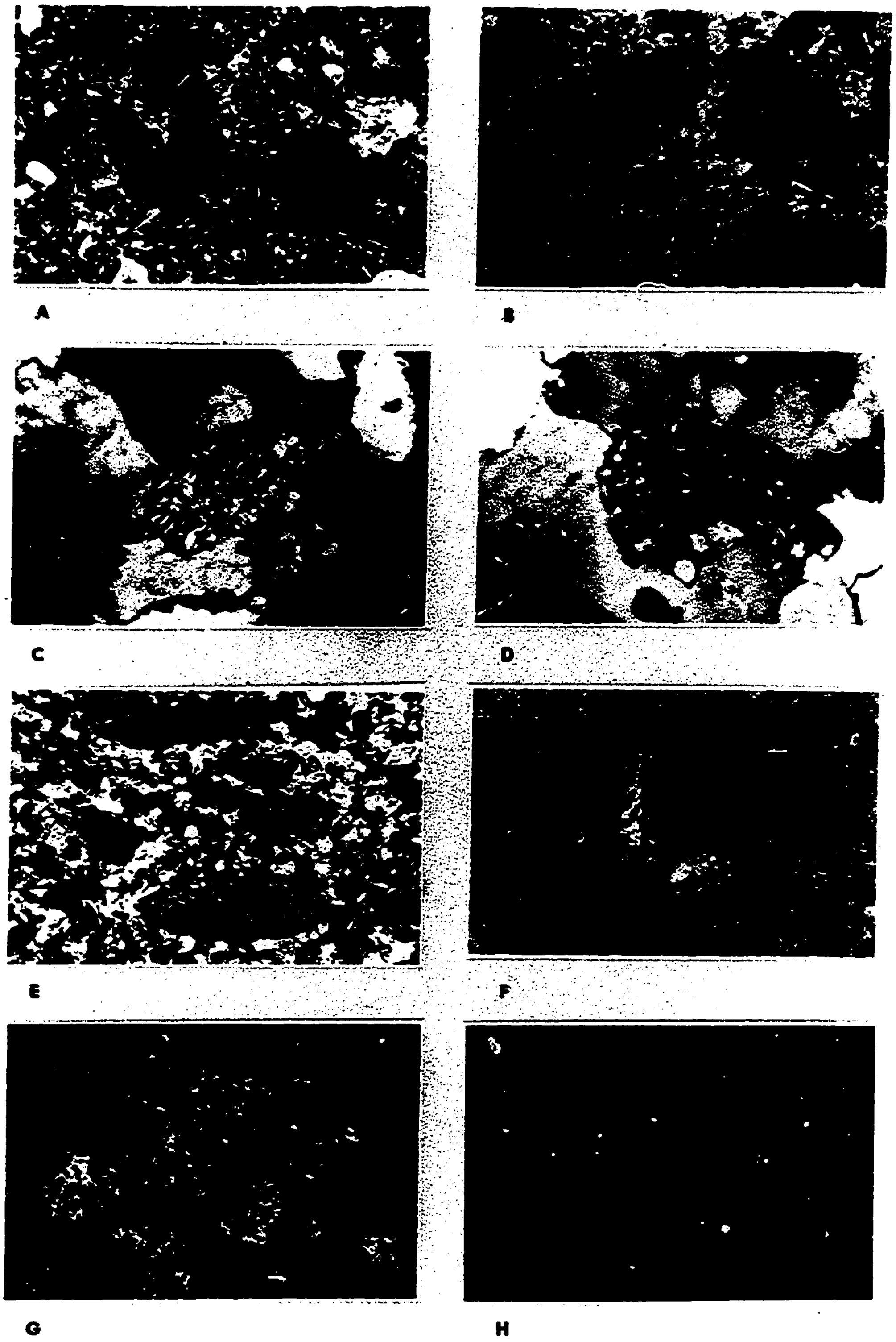


PLATE 3

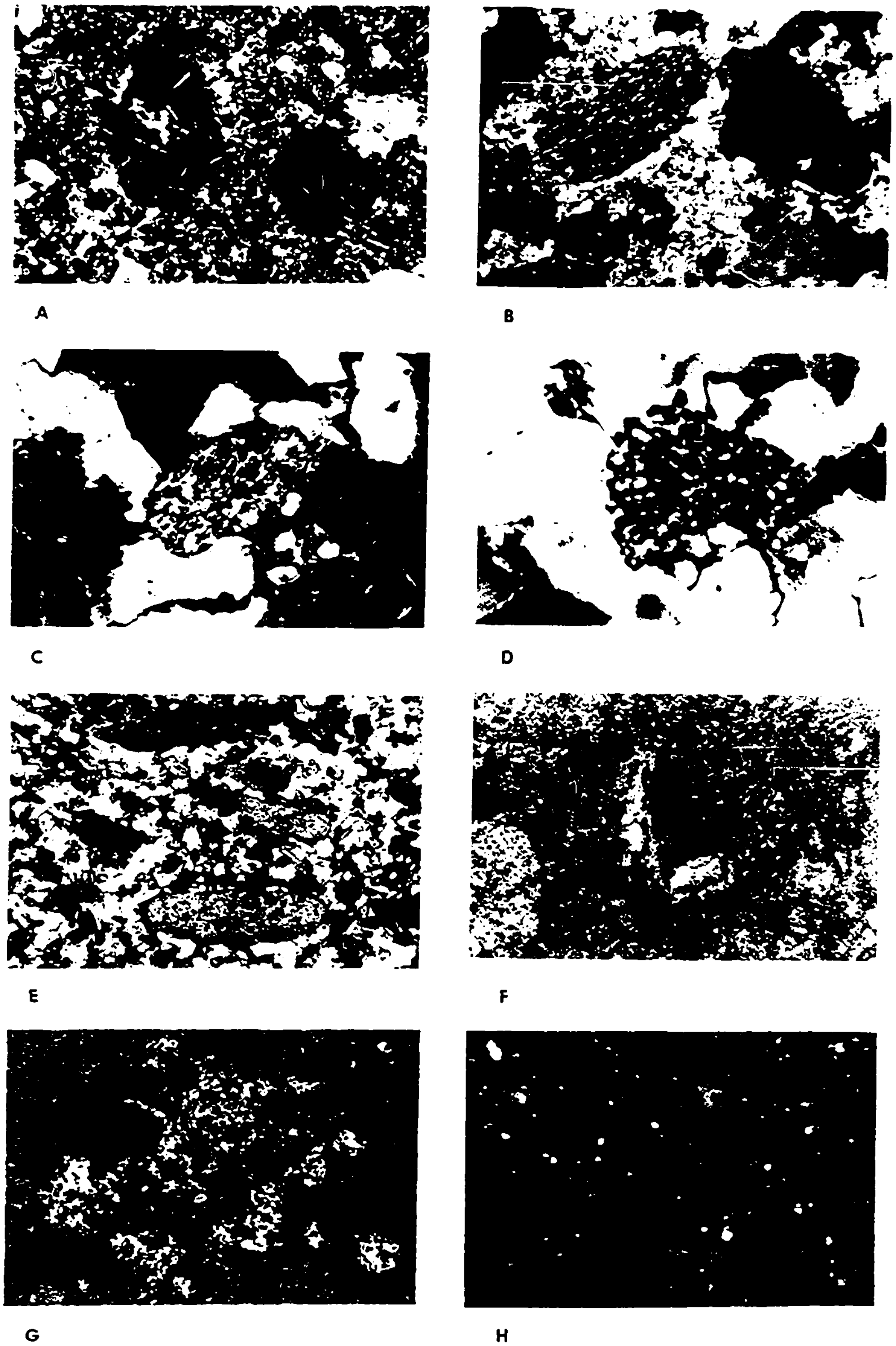


PLATE 3

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APPENDIX A

STRATIGRAPHIC SECTION, SIYEH FORMATION, PURCELL LAVA SHEPPARD FORMATION, NORTH KOOTENAY PASS AREA

Section was measured along the provincial boundary south of North Kootenay Pass. Overlain by Kintla Formation.

Terminology for stratification after McKEE and WEIR (1953). Grain size terminology after FOLK (1968).

Unit	Description	Thickness in feet Unit	 Total from base
	SHEPPARD FORMATION		
48	Siltstone, dolomitic, red to grey, interbedded with red to grey dolomitic claystone; intercalated zones of purple, medium to coarse grained sandstone upto 1 inch thick; oscillation ripple-marked; shaly, weathers greyish red	4.5	1210.5
47	Siltstone, dolomitic, green, interbedded with red, finely crystalline dolomite; oscillation ripple-marked; flaggy, weathers yellowish brown.	6.0	1206.0
46	Siltstone, dolomitic, grey; type - LLH stromatolites; blocky, weathers yellowish brown.	3.0	1200.0

Unit	Description	Thickness in feet	
		Unit	Total from base
	SHEPPARD FORMATION - continued		
45	Siltstone, dolomitic, green, with associated red claystone laminae; intercalated zones of pinkish green, medium to very coarse grained sandstone upto 0.5 inch thick; grades upward into green, dolomitic siltstone; oscillation ripple-marked; platy, weathers greyish green.	10.5	1197.0
44	Siltstone, dolomitic, greenish pink exhibits soft-sediment slumping; platy, weathers greyish brown.	3.5	1186.5
43	Dolomite, silty, grey, finely crystalline; type - LLH stromatolites; blocky, weathers yellowish brown.	6.5	1183.0
42	Siltstone, grey; very thinly cross-bedded; flaggy, weathers greyish brown	12.0	1176.5
41	Dolomite, grey, finely crystalline; abundant sand-size lava grains; blocky, weathers grey.	4.5	1164.5

Unit	Description	Thickness in feet Unit	Total from base
	SHEPPARD FORMATION - continued		
40	Basalt lava, altered, greyish green, medium grained; many calcite amygdules, some bearing limonitized pyrite	2.0	1160.0
39	Claystone, green, grading upward into green siltstone; flaggy, weathers greenish grey	2.5	1158.0
38	Siltstone, sandy, greyish green, with basal 4-inch bed of coarse grained, dolomitic, silty sandstone; parallel-laminated, very thinly cross-bedded; pyritic; slabby, weathers yellowish brown	4.0	1155.5
37	Claystone, micaceous, green, interbedded with green, micaceous siltstone; oscillation ripple-marked; shaly, weathers greyish green	7.0	1151.5
36	Sandstone, red to green, very fine to medium grained, interbedded with red to green siltstone; interbeds upto 18 inches thick; parallel-laminated, oscillation ripple marked; shaly to flaggy, weathers greyish brown	21.5	1144.5

Unit	Description	Thickness in feet	
		Unit	Total from base
	SHEPPARD FORMATION - continued		
35	Dolomite, light yellowish brown, finely crystalline; type - LLH stromatolites; slabby, weathers dark yellowish brown	4.0	1123.0
34	Sandstone, dolomitic, light greyish purple, very fine grained; oscillation ripple-marked; slabby, weathers greyish brown	5.0	1119.0
33	Sandstone, dolomitic, greyish purple, very fine grained, interbedded with reddish purple claystone; thinly cross-laminated, mud cracked, exhibiting sandstone clasts upto 8 inches in diameter embedded in shale; shaly to flaggy, weathers reddish grey	5.5	1114.0
32	Sandstone, reddish purple, medium grained, with two 8-inch interbeds of green, very fine grained, dolomitic sandstone; cross-laminated; locally conglomeratic at base; blocky, weathers dark yellowish brown	11.5	1108.5
31	Sandstone, purplish green, very fine grained; blocky, weathers brownish red	6.0	1097.0

Unit	Description	Thickness in feet	
		Unit	Total from base
	SHEPPARD FORMATION - continued		
30	Siltstone, sandy, purple; shaly, weathers brownish red	1.0	1091.0
29	Sandstone, dolomitic, ligh reddish purple, very fine grained; parallel- and cross-laminated; flaggy, weathers light greyish pink	2.0	1090.0
28	Dolomite, sandy, white; slabby, weathers yellowish brown	3.5	1088.0
27	Sandstone, dolomitic, red, very fine grained; parallel- to cross-laminated; massive, weathers greyish pink	12.0	1084.5
26	Siltstone, calcareous, medium greyish green; wavy laminations; flaggy, weathers dark greyish green	4.5	1072.5
25	Siltstone, medium to dark green; thinly cross-laminated; flaggy, weathers light greyish green	3.5	1068.0
24	Dolomite, silty, greyish brown, finely crystalline; type - SH stromatolites; flaggy, weathers dark yellowish brown	0.5	1064.5

Unit	Description	Thickness in feet	
		Unit	Total from base
	SHEPPARD FORMATION - continued		
23	Siltstone, calcareous, medium grey; slabby, weathers dark grey	3.5	1064.0
22	Siltstone, micaceous, green; thinly cross-laminated; flaggy, weathers pinkish brown	2.5	1060.5
21	Dolomite, silty, grey, finely crystalline; slabby, weathers dark brown	5.0	1058.0
20	Siltstone, calcareous, green; slabby, weathers dark greyish brown	3.5	1053.0
19	Sandstone, calcareous, light greyish green, medium grained; flaggy, weathers dark greyish brown	0.5	1049.5
	Total thickness of Sheppard Formation	161.5	
	PURCELL LAVA		
18	Basalt lava, altered, brownish purple, fine to medium grained; constitutes fourteen flows ranging from 3 to 45 feet in thickness; tachylyte layers upto 6 inches thick common at bases of flows; amygdaloidal throughout		

Unit	Description	Thickness in feet	
		Unit	Total from base
	PURCELL LAVA - continued		
	(chlorite, calcite, quartz amygdales upto 0.4 inch in diameter); less commonly porphyritic (plagioclase phenocrysts upto 2.5 inches long)	231.5	1049.0
17	Basalt lava, altered, greyish green, fine grained; constitutes one flow, indistinct pillow structure at base; chlorite, calcite, quartz amygdales upto 0.3 inch in diameter; plagioclase phenocrysts 0.3 to 0.5 inch long	65.0	817.5
	Total thickness of Purcell Lava	231.5	
	SIYEH FORMATION		
	Upper Part		
16	Siltstone, calcareous, green; weathers greyish green	1.0	752.5
15	Sandstone, calcareous, red, very fine grained; platy to flaggy, weathers greyish red	2.5	751.5
14	Siltstone, red; slabby, weathers greyish red	2.5	749.0

Unit	Description	Thickness in feet Unit	Total from base
	SIYEH FORMATION - continued		
13	Siltstone, green to red, interbedded with green to grey claystone; shaly to flaggy, weathers greyish green	4.5	746.5
12	Siltstone, clayey, calcareous, predominantly red with a few green interbeds; exhibits isolated small scale ripple marks, mud cracked; flaggy to slabby, weathers greyish red	7.0	742.0
11	Siltstone, clayey, red; shaly, weathers greyish red	6.0	735.0
10	Siltstone, 3-inch red and green interbeds; slabby, weathers greyish red	12.0	729.0
9	Siltstone, calcareous, greyish green, interbedded with minor red, calcareous, fine-grained sandstone; slabby to blocky, weathers dirty yellowish green	12.0	717.0
8	Siltstone, green; shaly, weathers light green	12.0	705.0
7	Siltstone, calcareous, green to reddish green; sparsely pyritized; platy, weathers light green	10.0	693.0

Unit	Description	Thickness in feet Unit	Total from base
	SIYEH FORMATION - continued		
6	Dolomite, sandy, silty, greyish red, finely crystalline, grading upward into red, fine-grained, calcareous sandstone; intraformational slumping in dolomite, sandstone thinly cross-laminated; flaggy to slabby, weathers reddish grey	8.0	683.0
5	Siltstone, sandy, calcareous, grey, grading upward into green, calcareous siltstone; shaly to slabby, weathers light green	22.0	675.0
	Thickness of upper part	99.5	
	Middle Part		
4	Dolomite, silty, light to medium grey, finely crystalline, interbedded with medium grey, dolomitic siltstone; beds 1 inch to 3 feet thick; type - LLH stromatolites; papery to slabby, weathers to light brownish yellow	130.0	653.0
3	Dolomite, silty to sandy, light to medium grey, finely crystalline; beds averaging 2 feet thick; shaly to slabby, weathers light brownish yellow	63.0	523.0

Unit	Description	Thickness in feet Unit	Thickness in feet Total from base
	SIYEH FORMATION - continued		
2	Dolomite, silty, light to medium grey, finely crystalline; beds 1 to 2 feet thick; interbedded with medium grey, dolomitic siltstone, beds 3 to 6 inches thick; type - LLH stromatolites dominant in lower horizons, gradational to type - SH stromatolites towards top; shaly to slabby, weathers light brownish yellow	160.0	460.0
1	Covered interval, directly above Lewis Thrust plane; thickness estimated	300.0	300.0
	Thickness of middle part	653.0	
	Total thickness of Siyeh Formation	752.5	

APPENDIX B

X-RAY DIFFRACTION ANALYSIS OF BELT-PURCELL ROCKS

Purcell sedimentary rocks of the North Kootenay Pass area were analyzed by X-ray diffraction using a technique designed specifically for Belt-Purcell rocks (HARRISON and GRIMES, 1970).

Each sample was crushed and ground in a Bleuler rotary mill for 25 to 30 seconds.

The procedure used for mounting the sample powder was one that minimizes preferred orientation and at the same time produces a plane surface (TATLOCK, 1966). An aluminum slotted powder holder is placed on a clean glass slide and held in place with masking tape. The powder is dumped into the cavity, tamped down with a spatula blade, and the back covered across the width of the aluminum holder with masking tape reinforced on the sticky side with a piece of file card. This backing is pressed firmly, further compressing the powder. The holder is picked up and the glass face plate removed, the mount being now ready for use.

Each sample was run on a Phillips Norelco X-ray diffractometer from 4° to 34° at 2° 2θ per minute, using Cu $K\alpha$ radiation. Chart speed was 0.5 inch per minute.

The following peak heights above background on the diffractometer trace were then measured: the 10 Å peak for mica (illite-sericite-muscovite), the 7 Å peak for chlorite, the 3.35 Å peak for potassium feldspar, the 3.2 Å peak for plagioclase, the 3.05 Å peak for calcite and the 2.9 Å peak for dolomite. General formulas for relating peak heights to mineralogy are given in Table 9.

HARRISON and GRIMES (1970) devised these formulas by comparing X-ray diffractometer data with chemical analyses of Belt-Purcell rocks. Standard chemical formulas for each mineral were used to compute chemical content from rock mineralogy. Chlorite was assumed to be iron-rich. Plagioclase was assumed to be albite-oligoclase and to contain essentially all the sodium in these rocks.

These simplified formulas were justified because of the relatively simple mineralogy involved, and because of the limited interference between principal and secondary peaks of the minerals.

Excessive biotite totally disrupts the mica formula. However, in the Purcell rocks of the North Kootenay Pass area biotite is virtually absent.

HARRISON and GRIMES (1970) stated that X-ray mineralogy of samples checked against chemical analyses agreed within 10 percent. Replicate X-ray diffraction analyses of various rock types commonly fell within 5 percent of each other, and were always within 10 percent. Replicate X-ray diffraction analyses of several rocks from the North Kootenay Pass area similarly always were within 10 percent of each other.

TABLE 9

General formulas for relating X-ray diffractometer trace peak heights to mineralogy of Belt-Purcell rocks

Mineral	Formula
Quartz*	$\frac{3.35\ \text{Å} - \frac{1}{2}\,(10\ \text{Å})}{4}$
Potassium feldspar	$\frac{3.25\ \text{Å}}{3}$
Plagioclase	$\frac{3.20\ \text{Å}}{3}$
Dolomite	$\frac{2.9\ \text{Å}}{3}$
Calcite	$\frac{3.05\ \text{Å}}{2}$
Chlorite	$\frac{7\ \text{Å}}{2}$
Mica	$\frac{2\,(10\ \text{Å})}{3}$

* Subtraction required because of interference between main quartz peak and secondary mica peak

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APPENDIX C

SPECTROPHOTOMETRIC ANALYSIS FOR CU, PB, ZN

Rock samples were analyzed for Cu, Pb and Zn using a Beckman Model B spectrophotometer.

The analytical technique used was that of SANDELL (1950) for the simultaneous determination of Cu, Pb and Zn in silicate rocks. The carbamate method was used in the determination of Cu, the dithizone method in the determination of Pb and Zn. The standard curves used in the determination of these metals are shown in Figs. 14, 15 and 16.

U.S. Geological Survey silicate rock standard GSP-1, a granodiorite, was used as a check on the accuracy of the determinations. Values obtained were for Cu 30 ppm, for Pb 55 ppm and for Zn 86 ppm. FLANAGAN (1967) gives values for Cu of 34-66 ppm, for Pb of 50-90 ppm and for Zn of less than 600 ppm.

Replicate analyses carried out on two samples were within 20% of each other.

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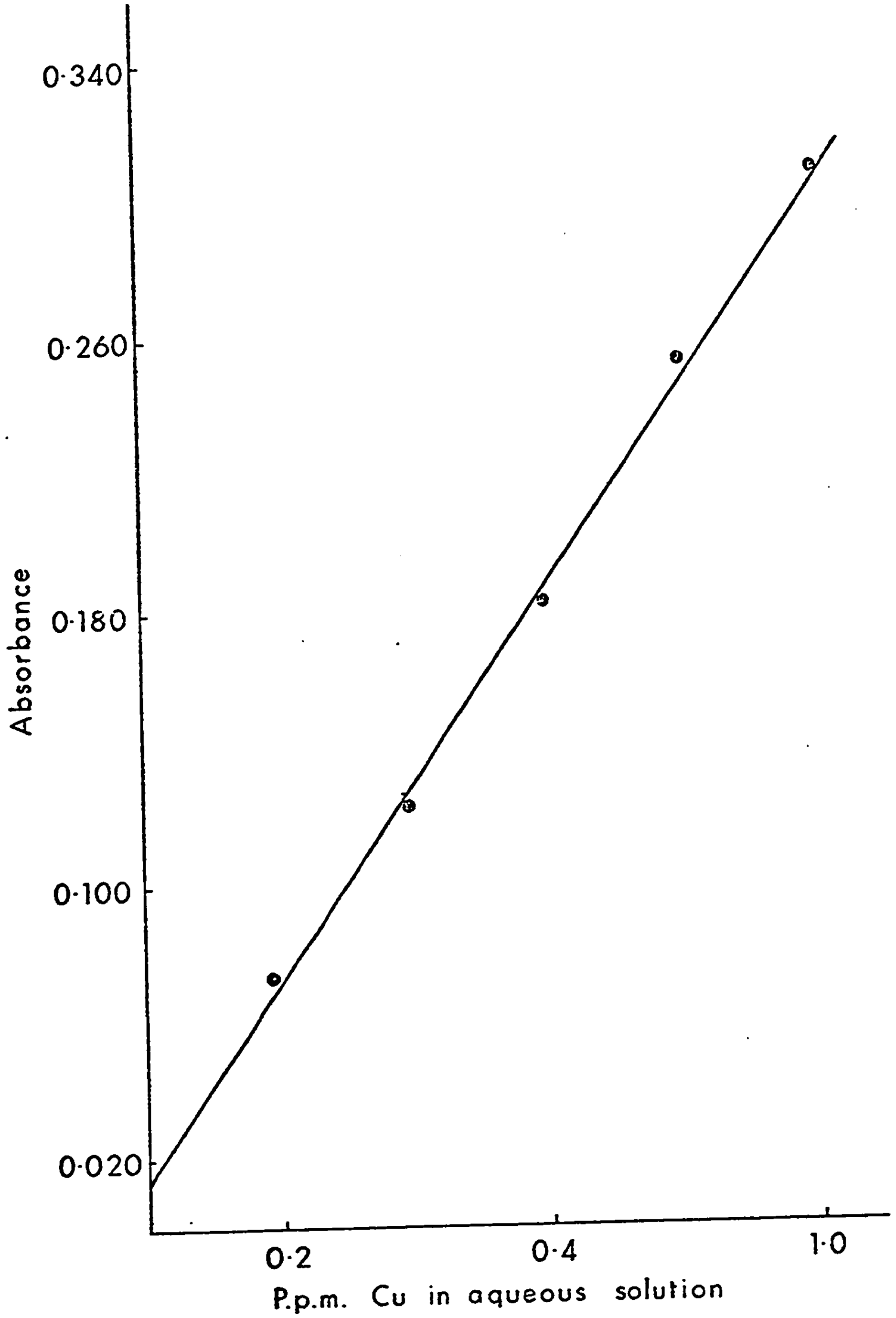

Fig. 14 Standard curve for spectrophotometric determination of Cu

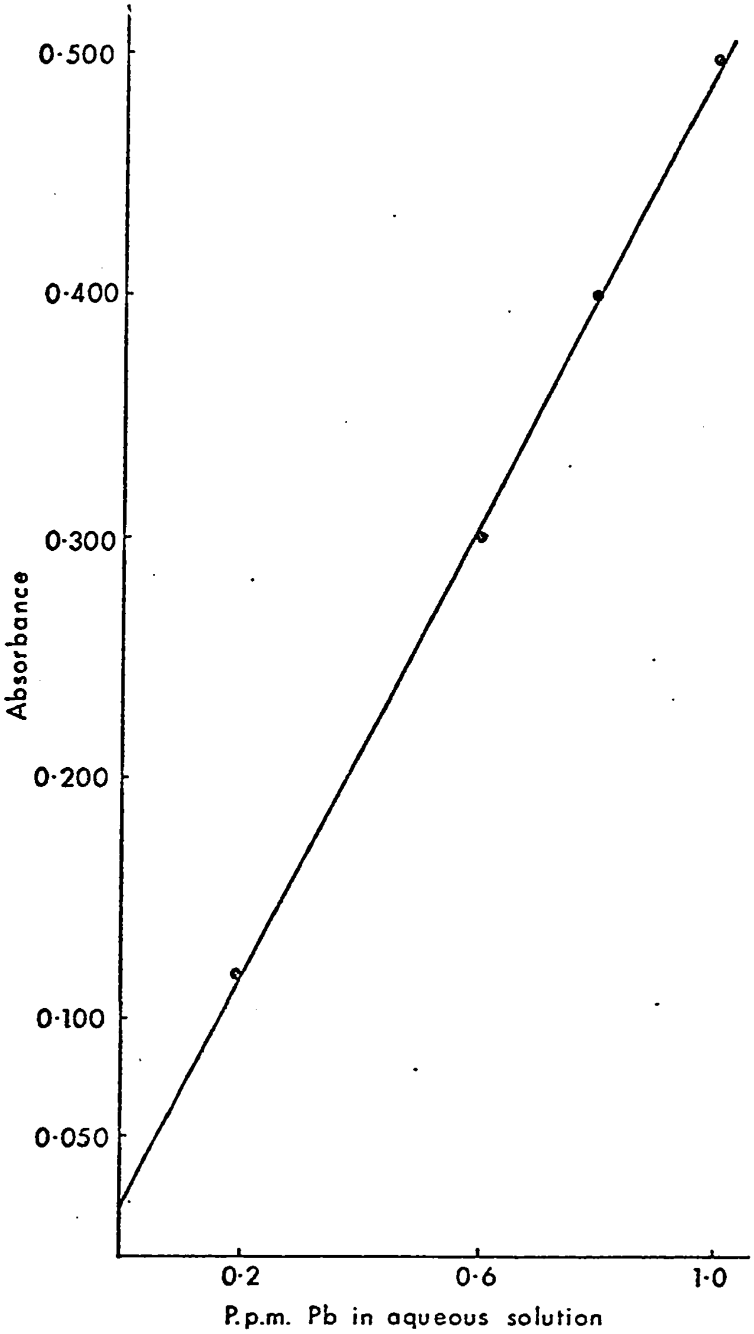

Fig. 15 Standard curve for spectrophotometric determination of Pb

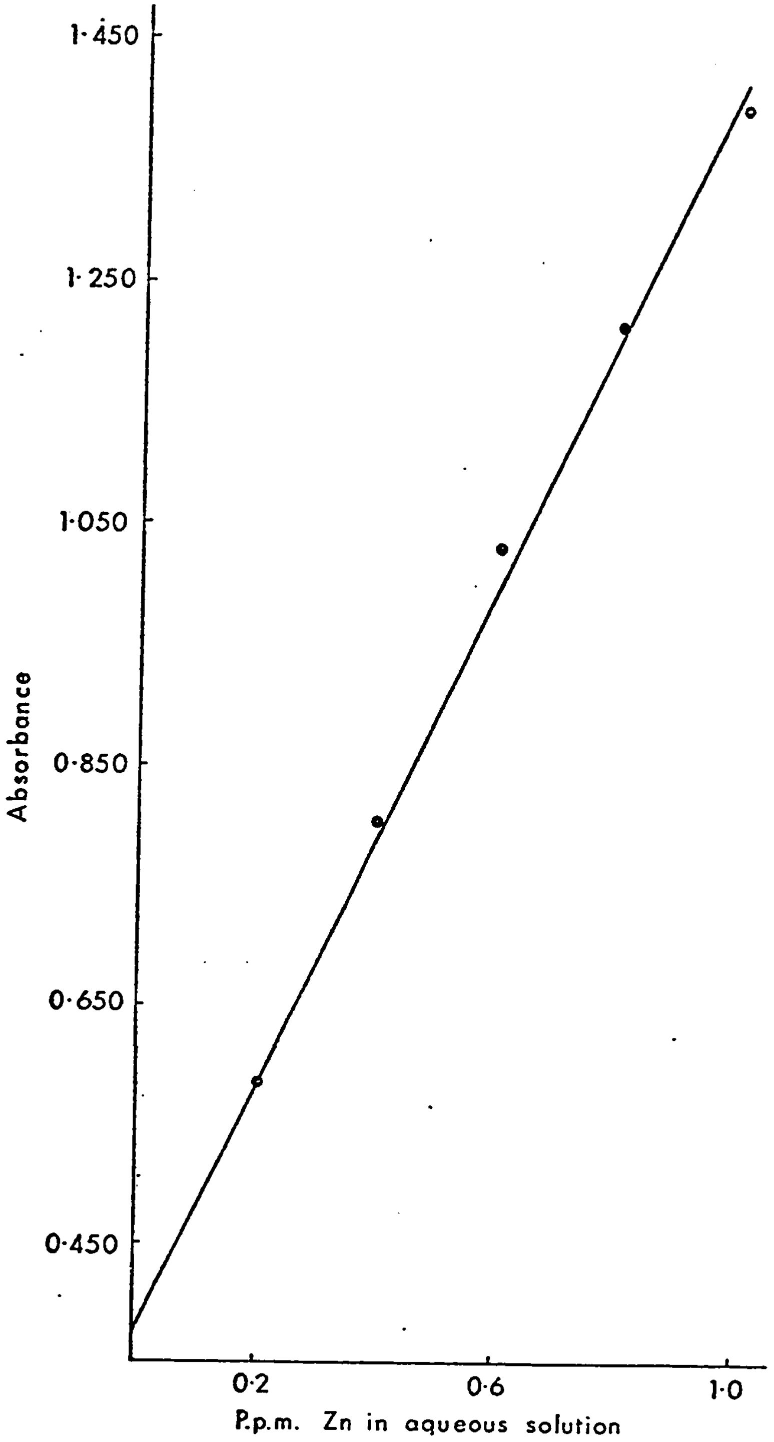

Fig. 16 Standard curve for spectrophotometric determination of Zn

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