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YOUNGER PRECAMBRIAN OF THE CANADIAN CORDILLERA

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ABSTRACT. Precambrian history of the Canadian Cordillera is recorded in two great, dominantly sedimentary sequences. The younger sequence, comprising the Windermere System and correlative strata can be observed in fairly wide belts throughout the full length of the Cordillera. The older sequence, comprising Purcell-Belt strata and presumed correlative rocks, is more restricted in outcrop, occurring in southern Rocky and adjacent Purcell Mountains, in northern Rocky Mountains, and in the core of Mackenzie Mountains.

In the southern Cordillera the Purcell and Windermere Systems are separated by a regional unconformity reflecting the East Kootenay Orogeny. In Mackenzie Mountains an angular unconformity, the result of the Racklan Orogeny, separates two thick sedimentary successions tentatively correlated with the type Purcell-Belt and Windermere.

The Purcell rocks, ranging from about 7000 feet (2150 m) to as much as 35,000 feet (11,000 m) in thickness, are characterized by fine-grained clastic and carbonate rocks of deep- to shallow-water marine origin. Andesitic flows and gabbroic dikes and sills are conspicuous locally. The overlying Windermere rocks, commonly more than 10,000 feet (3100 m) thick, consist dominantly of impure, gritty clastic sediments and local units of carbonate and coarse, poorly sorted conglomerate of probable shallow- and deep-water marine origin. Banded iron formation in Mackenzie Mountains is tentatively included within the Windermere System.

The general aspect of most of the Precambrian rocks suggest that they were deposited as continental terrace wedges along the western margin of the North American craton.

INTRODUCTION

The purpose of this paper is to outline some of the main elements of Precambrian history recorded in the Canadian Cordillera. The record is contained mainly in two thick sedimentary sequences comprising the classical Purcell and Windermere Systems[1] of the southern Cordillera and presumed correlative strata elsewhere. Additional information is provided by a study of the relationships between these two sequences and their relationships to older and younger rocks. No attempt is made to present a comprehensive review of the Precambrian stratigraphy. For detailed accounts of specific areas the reader is referred to papers by Green (in press) for Ogilvie Mountains, Gabrielse, Blusson, and Roddick, (in press) for southern Mackenzie Mountains, Bell (1968) for northern Rocky Mountains, Charlesworth and others (1957) and Slind and Perkins (1966) for Central Rocky Mountains, Price (1964, 1965) for southern Rocky Mountains, Gabrielse (1963) for Cassiar Mountains, Roots (1954) and Mansy (1972) for Omineca Mountains, Sutherland Brown (1963) (but see Douglas and others (1970) for reinterpretation) for Cariboo Mountains, Little (1960) for Selkirk Mountains, and Rice (1941) and Reesor (1957, in press) for Purcell Mountains. This report emphasizes only those aspects of Precambrian sedimentation, intrusive and

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[1] In Canada it has been traditional to refer to the Windermere and Purcell rocks as "Systems". Neither term is officially recognized as a period of geological time, however, and although the use of "Systems" is retained herein, it is clear that eventually the assemblages should be given "group" or "supergroup" status.

extrusive activity, metamorphism, and tectonism that seem to be of importance on a Cordillera-wide scale.

PURCELL (BELT) SYSTEM

Strata of the Purcell System and correlative rocks are exposed along the Yukon Territory-Alaska boundary and underlie fairly extensive areas in parts of Ogilvie, Wernecke, Mackenzie, and northern Rocky Mountains (see fig. 1; Canada Geol. Survey Map 1254A). In the southern Cordillera they comprise the core of Purcell Mountains, the type area, and form the well-known, ruggedly scenic terrain in southern Rocky Mountains including Waterton Lakes National Park. Representative stratigraphic columns are shown in figure 2. In many respects the rocks are similar in lithology and induration to Paleozoic strata exposed in Mackenzie and Rocky Mountains.

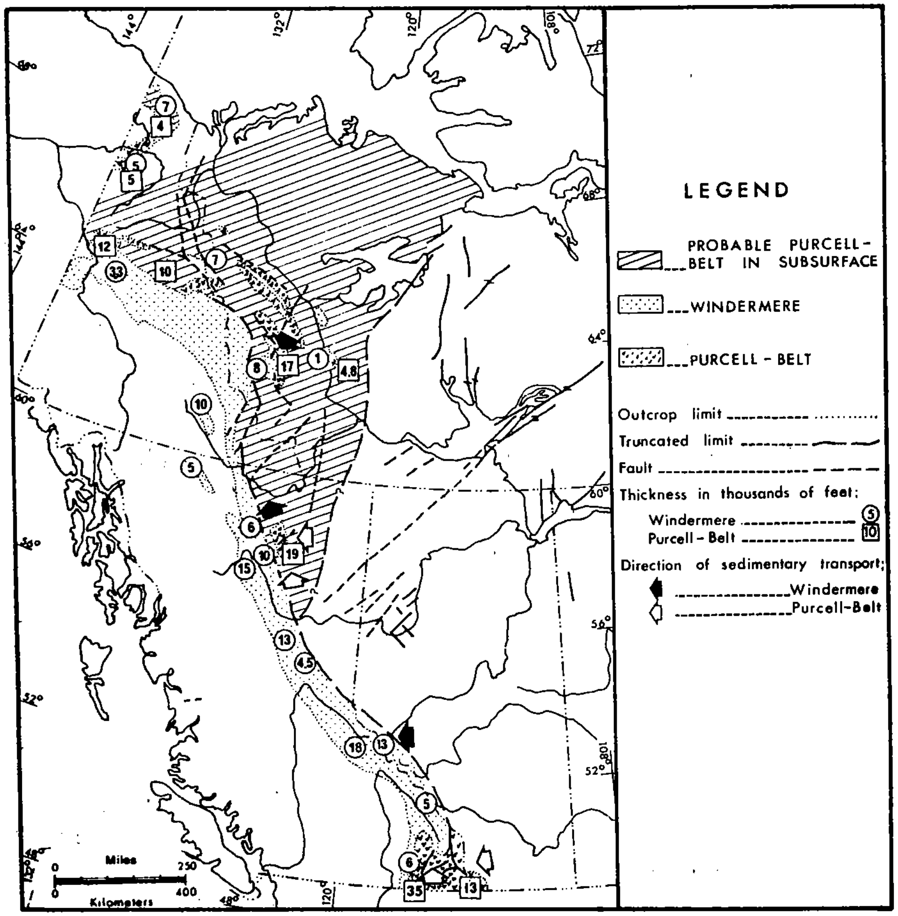

Fig. 1. Distribution and thickness of Upper Precambrian rocks in the Canadian Cordillera. Modified after Douglas and others, 1970.

Purcell rocks throughout the Cordillera display markedly similar characteristics. Except for easternmost facies the sequences are thick and nowhere is the base exposed. Clastic rocks are generally fine grained and well sorted; the bulk are argillite, siltite, and fine- to medium-grained quartzite. A thick, well-bedded, medium-grained quartzite in Mackenzie Mountains contrasts with a similar Lower Cambrian formation only in that it is remarkably even grained whereas the Cambrian clastics commonly display significant variations in grain size. Thick units of dark weathering mudstone, argillite, and siltstone form the lower parts of Purcell sequences in Ogilvie, Wernecke, and Purcell Mountains and the uppermost parts in northern Rocky Mountains.

Red-bed facies are conspicuous in southern Mackenzie Mountains and in southern Rocky Mountains. In Mackenzie Mountains pink-weathering siltstone and shale are intimately associated with, and are in

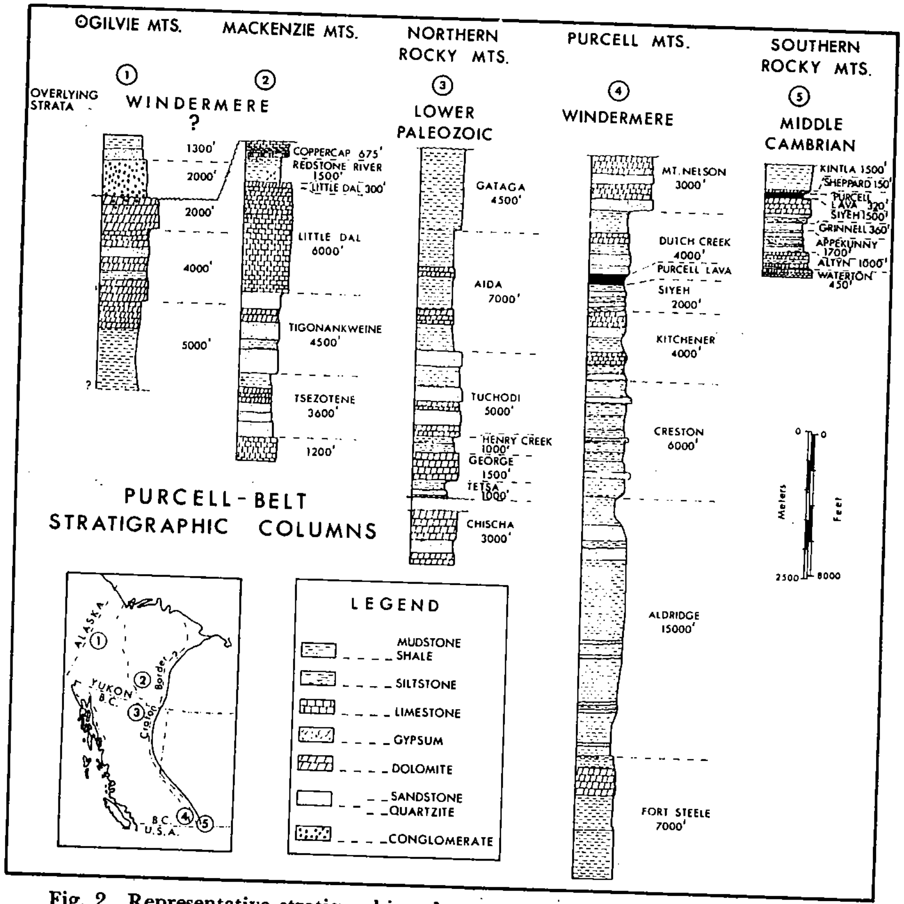

Fig. 2. Representative stratigraphic columns of Purcell (Belt) rocks. Main sources of data for columns are: 1. Green, in press; 2. Gabrielse, Blusson, and Roddick, in press; 3. Bell, 1968; 4. Rice, 1937, 1941; 5. Price, 1965.

part perhaps facies equivalent of, bedded gypsum which ranges in thickness from 100 to more than 1000 feet (30 to more than 300 m).

Carbonate strata, mainly dolomitic and buff to orange weathering, are typically well bedded, locally laminated, clean, and in some localities abundantly stromatolitic. In places argillaceous, silty, or sandy dolomite weathers orange-brown, thus contributing to varicolored assemblages so distinctive of much of the Purcell strata as opposed to the general drab appearance of the younger Windermere strata.

Andesitic flows and gabbroic to dioritic dikes and sills are volumetrically minor but are widely distributed throughout the Purcell sequences. In the northern Cordillera conspicuous northerly trending diabasic dikes from 20 to as much as 250 feet (6-80 m), thick are most numerous in Purcell strata of northern Rocky Mountains (Taylor and Stott, 1971). Diorite sills that maintain their stratigraphic positions for many miles are characteristic of Mackenzie Mountains and seem to be particularly abundant in the oldest argillaceous unit of Ogilvie Mountains (Green, in press). In the southern Cordillera the Purcell Lava comprises a sequence of chloritized, andesitic volcanics several hundred feet (about 70-100 m) thick. The Moyie Intrusions of Purcell and southern Rocky Mountains are dioritic sills, possibly in part correlative with the Purcell Lava, but they may have been emplaced during a considerable range in time (Hunt, 1962; Ryan and Blenkinsop, 1971). Sills are concentrated in the middle and lower parts of the Aldridge Formation in Purcell Mountains and locally form a high proportion of stratigraphic successions (Reesor, 1958).

Precambrian strata are present in metamorphic complexes, gneiss domes, and regionally metamorphosed assemblages throughout the length of the Cordillera. Although Windermere rocks are definitely involved in the complexes, the presence of Purcell strata has not been demonstrated.

Sedimentary structures are abundant, and, although they have been studied in detail only locally, they provide useful preliminary data on the configuration and nature of the Purcell depositional basin(s). Well developed graded bedding, current markings, and slump structures indicative of turbidite deposition are present in the Aldridge Formation of Purcell Mountains and were interpreted by Bishop, Morris, and Edmunds (1970) to indicate deposition in relatively deep water. Farther east in southern Rocky Mountains correlative strata display crossbedding, ripple-marks, desiccation breccias, and salt-hopper markings indicative of tidal-flat and shallow-water deposition (Price, 1964). Strata younger than the Aldridge Formation in Purcell Mountains also display abundant structures formed in shallow water. "Molar-tooth", stromatolitic, and oölitic or pisolitic structures occur in carbonate rocks in many localities.

COMMENTS ON PURCELL SEDIMENTATION

Age.—The age of the Purcell System in the Canadian Cordillera is known only within broad limits. Basal strata along the eastern margin of preservation overlie crystalline basement having a minimum age of more than 1600 m.y. (Burwash, Baadsgaard, and Peterman, 1962). Minimum ages for the lower part of the Purcell System are suggested by a Rb–Sr age of about 1260 m.y. on a granodiorite stock intrusive into the Aldridge Formation in Purcell Mountains (Ryan and Blenkinsop, 1971); K–Ar ages of about 1100 m.y. on the Purcell Lava (Hunt, 1962); and a lead single-stage model age of about 1200 m.y. from the Sullivan Mine in the Aldridge Formation (Reynolds and Sinclair, 1971). The Purcell strata are overlain unconformably by the Windermere System, the basal beds of which are not closely dated. The character of Windermere rocks, however, suggests relatively rapid deposition probably encompassing less than 200 m.y. of latest Precambrian time. Thus the suggestion of Harrison and Peterman (1971) that Purcell-Belt sedimentation took place between about 850 and 1450 m.y. ago seems reasonable in view of limited data in the Canadian Cordillera.

Sedimentary environment.—The Purcell sedimentary rocks are regarded as representing a continental terrace wedge deposited along the western and southwestern margin of the North American craton (Price, 1964; Gabrielse 1967; see fig. 3). The most complete cross section of the wedge is available in the southern Cordillera (see fig. 4). There, contrasts in facies, thicknesses, and sedimentary structures indicate an easterly source for the miogeoclinal sediments. Current markings in the Aldridge

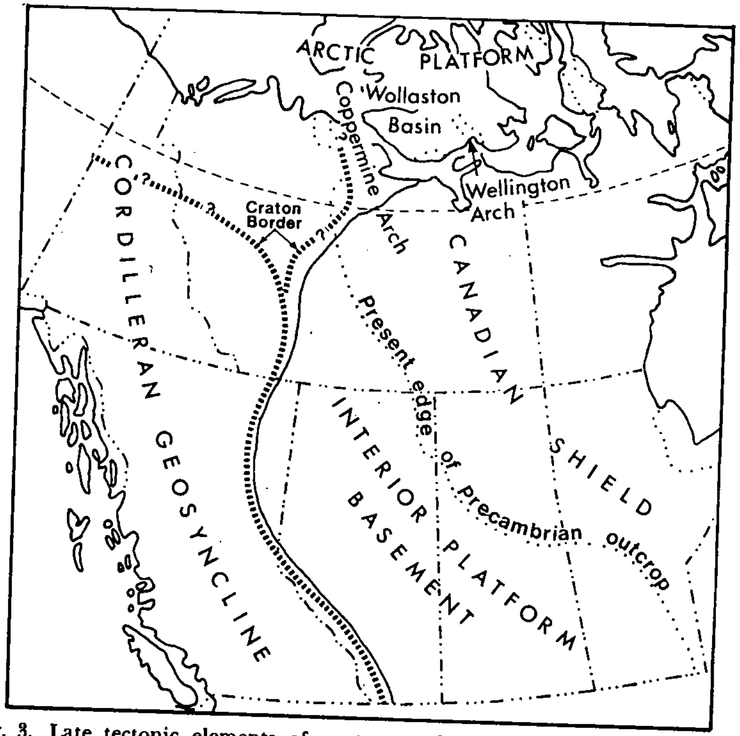

Fig. 3. Late tectonic elements of western and northern Canada. Modified after Douglas and others, 1970.

Formation representing the oldest exposed westerly facies of the sedimentary prism reveal sediment transport by turbidity currents flowing from south to north (Bishop, Morris, and Edmunds, 1970). The direction of transport may reflect a paleoslope related to a reentrant of the Purcell miogeocline in the northwestern United States (Harrison and Peterman, 1971) or perhaps simply flow parallel with the axial part of the depositional trough, a phenomenon well documented in a number of flysch basins. The mode of deposition is envisaged (Bishop, Morris, and Edmunds, 1970) as simple infilling of a basin with deep-water conditions in the early stages changing to shallow-water conditions during Creston deposition time. During the remainder of Purcell time sedimentation kept pace with subsidence, and shallow-water conditions prevailed generally.

An easterly source is suggested by the distribution of facies and thicknesses of Purcell rocks in the northern Rocky Mountains (Bell, 1968). There also, however, fine-grained clastic rocks, represented by the Aida and Gataga Formations, the uppermost units of the Purcell rocks, have sedimentary structures suggesting a northwesterly direction of transport along the axis of a linear trough or troughs parallel with the margin of the cration.

The distribution of Purcell rocks in Mackenzie Mountains poses a problem concerning the craton margin. Insufficient data are available to allow detailed comparison of the sequences in western and eastern Mackenzie Mountains. One significant difference is the presence of a thick assemblage of argillite with numerous sills in the lower part of the westtern Mackenzie sequence. These rocks appear to be much like those of the Aldridge Formation in Purcell Mountains, interpreted as having been deposited mainly in deep water. If so, they could represent a distal facies of Purcell rocks correlative with carbonates that are the oldest exposed strata in northeastern Mackenzie Mountains. In general, however, the gross characteristics of Purcell strata in western and northeastern Mackenzie Mountains appear similar. This indicates a shelf area lay to the north of northern Mackenzie Mountains and that the margin of the craton trended east-west as shown by the present trend of Mackenzie Mountains. The writer prefers this interpretation and therefore supports a contention implied by Jeletzky (1961, 1962) that Precambrian basement north of Mackenzie Mountains probably was cratonic and a westerly extension of the Canadian Shield. An alternative possibility (fig. 3) shows the margin of the craton during Purcell time trending northerly along a flexure to the west of which the Precambrian sedimentary rocks thicken markedly (see Douglas and others, 1970).

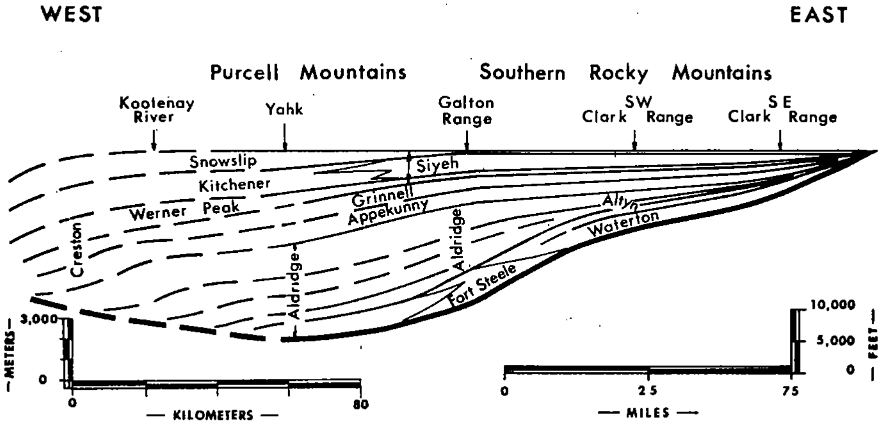

Fig. 4. Restored section showing postulated configuration of miogeocline during early Purcell time. Data mainly from Price, 1964.

Thicknesses of Purcell rocks.—As evident from figure 2 most sequences of Purcell rocks are very thick. Maximum thicknesses of about 45,000 feet (14,000 m) are reported for strata in Purcell Mountains (Rice, 1937 and 1941; Reesor, 1957). It is evident, however, that very thick sequences, greatly exceeding the relief of a region, must be measured over a considerable horizontal distance. Thus there is no assurance that the measured strata were ever disposed, with the reported thicknesses, in a single vertical stratigraphic column. Indeed, if the model of a continental terrace wedge for Purcell strata has validity, then it seems unlikely that stratigraphic columns in any area would greatly exceed 45,000 feet (14,000 m). This thickness is about a maximum for modern analogues such as the continental shelf along the eastern margin of North America (Drake, Ewing, and Sutton, 1959) and the Gulf Coast geosyncline (Ewing, Edgar, and Antoine, 1970; Hales, Helsey, and Nation, 1970) and is presumed to be controlled by depth of water and amount of downwarping or downfaulting of the ocean floor in compensation for the sedimentary load. Assuming that the sediment load caused downwarping, it may be considered that the proximal part of the miogeoclinal wedge was progressively tilted basinward. In this environment sedimentation kept pace with subsidence, and structures indicative of shallow water were formed. Presumably, in distal parts of the sedimentary prism deeper water prevailed for longer periods. Such a mechanism accounts for proximal sediments (those most commonly observed in regions such as the Gulf Coast) being essentially of shallow-water origin throughout much of the history of deposition.

Volcanism.—Basic rocks of volcanic affinity are common in Purcell strata and indicate the presence of deep-seated fractures. Similar conditions appear to have prevailed until Silurian time reflecting general or recurring tensional environments possibly resulting from oceanward tilting of the sedimentary prism.

Metal content.—The Aldridge Formation, the oldest formation recognized in Purcell Mountains, is the host rock for one of the world's great base-metal deposits — the Sullivan Mine at Kimberley, B. C. Elsewhere, however, copper is the most common metal (see Harrison and Peterman, 1971). Stratiform copper deposits in Mackenzie Mountains occur in the upper part of a pink-weathering siltstone (Redstone River

Formation). In northern Rocky Mountains copper deposits are spatially related to diabase dikes in Purcell strata, and it is possible that intrusion of the dikes facilitated concentration of copper already present in the sediments.

EAST KOOTENAY AND RACKLAN OROGENIES

Purcell sedimentation was separated from Windermere sedimentation by a period of uplift, folding, faulting, and regional metamorphism. These events are attributed to the East Kootenay Orogeny in the southern Cordillera (White, 1959; Leech and Wanless, 1962) and the Racklan Orogeny in the northern Cordillera (Gabrielse, 1967).

Deformation in the south appears to have been mild, and uplift is recorded mainly in a regional unconformity beneath the Windermere System. The role of plutonic activity and regional metamorphism at this time is not clear. K–Ar ages on biotite and muscovite from regionally metamorphosed Aldridge rocks are as old as 985 m.y. but show considerable scatter (Leech, *in* Wanless and others, 1967). Muscovites from two granodiorite stocks intrusive into the Aldridge Formation have given K–Ar ages of 705 and 745 m.y. (Lowdon, 1961) and 769 m.y. (Hunt, 1962). These ages may reflect times of metamorphism or regional uplift because a Rb–Sr isochron on one of the stocks approximates 1260 m.y. (Ryan and Blenkinsop, 1971). Studies by Obradovich and Peterman on the Belt Supergroup (1968) indicate that the youngest Belt (Purcell) sediments may be as young as 850 m.y. Also, if the dating of the Purcell Lava, at about 1100 m.y., by Hunt (1962) is meaningful, it is clear that granitic intrusion noted above considerably predated the close of Purcell sedimentation. Leech (1962) stated that one of the granodiorite stocks (Hellroaring Creek Stock) was intruded into an anticline, thus suggesting some deformation of the host rocks at about, or earlier than, 1260 m.y. In summary, events that can be specifically related to the East Kootenay Orogeny are limited and not clearly differentiated from earlier events that affected Purcell rocks. In terms of significance in Precambrian history, however, the East Kootenay Orogeny is regarded as an episode of regional uplift accompanied by regional metamorphism and perhaps minor folding (Ryan and Blenkinsop, 1971) that terminated the long period of Purcell sedimentation in the southern Cordillera at about 800 m.y. ago.

In the northern Cordillera uplift, folding, and faulting attributed to the Racklan Orogeny resulted in a spectacular unconformity at the base of presumed Windermere rocks (Rapitan Group) and younger strata (Gabrielse, 1967). Deformation produced tight, north-northeasterly trending folds in northern Selwyn Mountains and block faulting accompanied by tilting farther east in Mackenzie Mountains. Tight east-west folds northwest of Wernecke Mountains and north of Ogilvie Mountains and low-grade regional metamorphism in Wernecke, Ogilvie, and Richardson Mountains took place before Cambrian time and are probably also related to the Racklan Orogeny. Folding in northern Rocky Mountains predated Cambrian sedimentation (Taylor and Stott, 1971), but more precise dating of deformation awaits future work. Nowhere in the northern Cordillera area have Purcell and Windermere strata, other than those of the Rapitan Group, been observed in contact. A well-developed system of northerly, northwesterly, and northeasterly fractures, emphasized by basic dikes, was impressed on Purcell rocks in northern Rocky Mountains before Early Cambrian time. Again, the relationship of these structures to Windermere sedimentation is unknown. Clasts of the dikes are present in Lower Cambrian conglomerates.

Where Purcell rocks are exposed Windermere strata are commonly absent, and Paleozoic rocks are generally present in condensed sequences with many unconformities. Thus, following the Racklan and East Kootenay orogenies the Purcell System behaved essentially as basement or pseudo-basement over large areas.

WINDERMERE SYSTEM

Strata of the Windermere System, unlike those of the Purcell System, are almost continuously exposed the full length of the Cordillera (fig. 1). They comprise a tremendous volume of impure clastic sediments, the lower part of which consists dominantly of phyllite, slate, siltstone, and sandstone (fig. 5). The distinctive rocks, however, are gritty, feldspathic sandstone with opalescent bluish quartz grains and feldspathic pebble conglomerate. Locally, extremely coarse, poorly sorted conglomerate (diamictite) such as the Toby Conglomerate in the southern Cordillera occurs at or near the base of the Windermere System. A great variety of lithologies are represented in clasts of the conglomerates. Fine-grained green quartzite is very common but carbonate, chert, diabase, gneissic dioritic, and granitic rocks may predominate locally. Lenticular bodies of conglomerate in sequences overlying the Toby Conglomerate contain clasts mainly of quartz and quartzite with minor slate, feldspar, and granitic rock. A thick sequence of andesitic volcanics overlies the Toby Conglomerate in southern Selkirk Mountains (Little, 1960), and similar units are present near the British Columbia-Yukon border (Gabrielse, 1969) and in southern Ogilvie Mountains (Green, in press). Eastern facies of the lower Windermere System are generally coarser than those farther west, and sedimentary structures are better developed. Although bedding is conspicuous in western facies, small-scale sedimentary structures are scarce.

The upper part of the system is much more calcareous than the lower (see fig. 5) and much more variable in lithology. It includes thick formations of well-bedded to massive limestone in western facies and dolomite farther east, argillaceous limestone and calcareous phyllite, and conspicuous maroon and green weathering slate and phyllite. Although thicknesses vary considerably, the stratigraphic succession of Windermere rocks, with the exception of the Rapitan Group discussed in the following paragraphs, is remarkably similar throughout the length of the Cordillera.

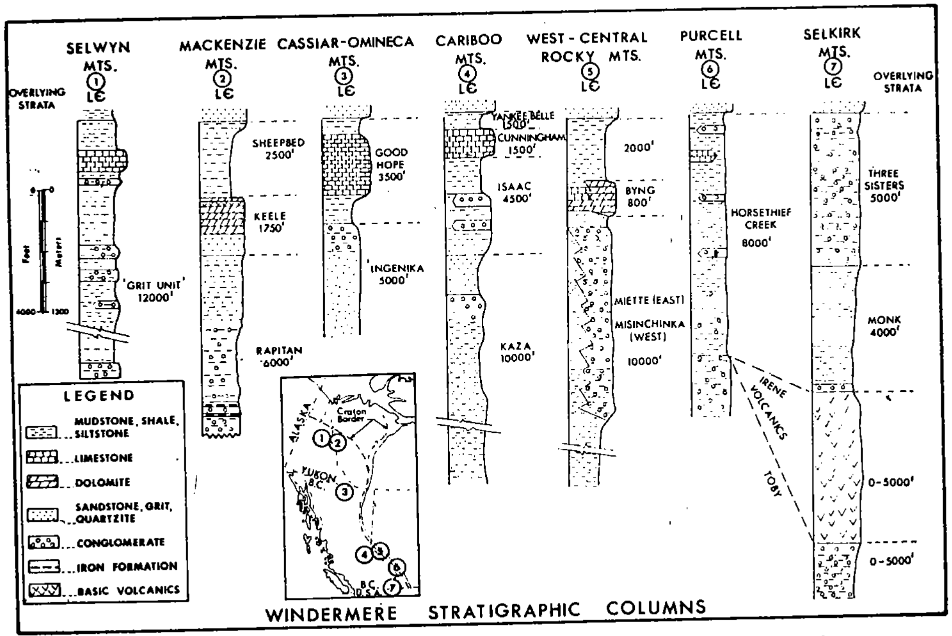

Fig. 5. Representative stratigraphic columns of Windermere rocks. Main sources of data for columns are: 1 and 2. Gabrielse, Blusson, and Roddick, in press; 3. Gabrielse, 1963; Roots, 1954; Mansy, 1972; 4. Sutherland Brown, 1963; 5. Slind and Perkins, 1966; Charlesworth and others, 1967; 6. Reesor, 1957; 7. Little, 1960.

The Rapitan Group in Mackenzie Mountains is an unique assemblage of sedimentary rocks tentatively correlated with Windermere strata although nowhere have the two assemblages been observed in contact (Gabrielse, 1967). The group includes three distinct formations with an aggregate thickness of as much as 6000 feet (1800 m), separated by unconformities (Upitis, ms). A lower formation comprises conglomeratic mudstone, siltstone, slate, impure sandstone, and bedded chert-hematite iron formation. In places the iron formation is as much as 500 feet (150 m) thick. It lies with marked angular unconformity on Purcell strata. The middle unit consists dominantly of conglomeratic mudstone and the upper unit of shale, siltstone, and arkosic sandstone.

Two contrasting kinds of sedimentation appear to be juxtaposed in the jasper-hematite iron formation. The well-banded iron formation probably represents a chemical precipitate in an environment receiving little influx of clastic material. Well-defined slump structures are present locally. Into this environment were deposited coarse, poorly sorted conglomerate, in places deposited in deep channels in the iron formation, along with fine-grained mud and siltstone. Some exotic boulders have the characteristics of "dropstones" in that the beds beneath them are bent sharply downward whereas the overlying beds pass without flexure directly above the clasts. Reddish brown to maroon mudstone, perhaps the most abundant lithology, displays small-scale ripple-marks and thin laminations. Where thin conglomeratic or sandy lithologies are present, graded bedding is common.

Thick bedding is present in the middle formation of coarse conglomerate and diamictite, but few other structures are evident. Some of the clasts are striated.

The upper part of the Rapitan Group displays well-developed thin bedding with an abundance of crossbedding and ripple-marks, load casts, and slump structures.

COMMENTS ON WINDERMERE SEDIMENTATION

General.—Conditions of sedimentation similar to those of the Windermere System seem to have existed in many late Precambrian depositional basins around the world. Well-known examples of assemblages that include thick clastic sequences, locally characterized by diamictite, are outlined in papers by Harland (1964) and Schwarzbach (1963). Thus, the problems of Windermere sedimentation are not only important in terms of evolution of the Cordilleran geosyncline but are part of a much larger picture involving worldwide glaciation, high continental relief, or both.

Age.—The age of basal Windermere strata was discussed above. In westernmost exposures the top of the system appears to be generally conformable with overlying Lower Cambrian rocks, whereas to the east a regional unconformity marks the base of Cambrian strata. Therefore, on a regional basis, no great hiatus need be postulated for the interval between Windermere and Cambrian Sedimentation. Probably the Windermere System was deposited during the interval of approximately 800 to 600 m.y.

Sedimentary environment.—The Windermere System was deposited mainly west and southwest of the exposed Purcell sediments. Thicknesses, lithologies, and facies changes indicate an easterly derivation. The eastern facies are commonly coarser, and their lithologies commonly suggest a crystalline shield source. Granitic and/or metamorphic terrains must have provided the abundant feldspar, including potash feldspar and plagioclase, and the distinctive bluish opalescent quartz, most common in granulites (Duffel, personal commun., 1971). Sedimentary clasts were probably derived from Purcell rocks, and where very thick sections of conglomerate are present, as in central Rocky Mountains (Slind and Perkins, 1966), the lack of Purcell strata may be explained by erosion during Windermere time. The source of Windermere strata in the northernmost Cordillera remains a problem, but it may have been a westward extension of the craton parallel with northern Mackenzie Mountains rather than a more westerly or southwesterly sialic terrain as suggested previously (Gabrielse, 1967).

The bulk of the Windermere assemblage is considered to represent a continental-terrace wedge deposited west and southwest (outboard) of the Purcell sedimentary prism. Regardless of the exact position of the craton margin during Purcell sedimentation, it is clear that Purcell sediments served essentially as pseudocraton during Windermere time. Thus the approximate margin of the Windermere depositional basin closely follows the trend of Rocky and Mackenzie Mountains. Near-shore facies are represented by strata displaying numerous shallow-water features including desiccation cracks, ripple-marks, cross-laminae, and desiccation breccias (Charlesworth and others, 1967). These rocks are generally coarser grained than those farther from the craton. Much of the westerly facies may be of turbidite origin. Except for graded bedding, a general lack of sedimentary structures in the interbedded slate and gritty sandstone is common with proximal turbidite facies (Eisbacher, personal commun., 1971).

Few studies have been made of directions of transport determined from sedimentary structures (see fig. 1). Average current directions in the Jasper area of central Rocky Mountains indicate a southwesterly current movement (Charlesworth and others, 1967; Mountjoy and Aitken, 1963). Bell (1968) noted a northwesterly direction of transport by paleocurrents, parallel with the margin of the craton, in northwestern Rocky Mountains.

The poorly sorted conglomerate or diamictite such as the Toby Conglomerate has been attributed to subaqueous mud flows possibly associated with widespread late Proterozoic glaciation (Ziegler, 1959; Gabrielse, 1967; Aalto, 1971). Aalto suggested that the deposits may represent postglacial mass flow of slumped tills and deltaic deposits. This hypothesis is attractive in that it could provide an abundant source of poorly sorted clastic material near the margin of the depositional basin. On the other hand perhaps a coastline of considerable relief could provide the same phenomena (Walker, 1926). Diamictite must be common along the present west coast of British Columbia where streams of high gradient are building local fans of coarse, well-rounded pebbles, cobbles, and boulders along margins of deep basins. Presumably these fans slump into the basins from time to time thus mixing with the normal fine-grained sediments to form diamictite. This mechanism might or might not be independent of glaciation.

Windermere seas transgressed easterly, and, as time progressed, relief probably became lower in the source areas. Eventually, as the sedimentary prism built up to wave base, shallow-water carbonate formed in sites formerly characterized by turbidite deposition.

Rapitan Group.—Correlation of the Rapitan Group with at least part of the Windermere System is based mainly on their similar stratigraphic position relative to Purcell and Lower Cambrian rock. In addition the two sequences have several unique characteristics in common, including the presence of thick diamictite and probable turbidite assemblages.

Problems concerning the origin of Rapitan diamictite are similar to those for the Toby Conglomerate. Ziegler (1959) proposed a glacial marine origin for these strata, but again it can be proposed that considerable relief was an important factor. The origin of the iron formation is obviously of great significance in view of models proposed for crustal evolution (Cloud and Gibor, 1970). The writer favors an hypothesis proposed by Gross (1965) that ascribes the derivation of hematite and silica to volcanic exhalations. Supporting evidence for volcanic activity is provided by large amounts of fresh ash and tuff associated with the iron formation. Greenstone clasts are particularly prominent in the middle part of the Rapitan Group. Also, in one locality in southern Mackenzie Mountains, fractures in underlying Purcell rocks are locally coated with specular hematite.

Clastic material that occurs with iron formation appears to have been emplaced as conglomeratic mud flows and turbid flows that disrupted the quiescent conditions of chemical precipitation on the sea floor. It may be postulated that such conditions existed in basins at least partly bounded by faults. The faults may have provided channel ways for volcanic exhalations, the relief necessary to form deep basins, and proximal highlands that were a source of coarse clastic material.

The environment proposed above is perhaps not too different from that in which the diabase dikes were emplaced in northern Rocky Mountains in post-Purcell time. There no Windermere strata have been positively recognized, although the writer has observed thick diamictite locally that could be of Windermere age.

Stewart (1971) has suggested that Windermere diamictite and overlying rocks were the initial deposits of a Cordilleran geosyncline that originated with continental separation less than 750 m.y. ago. He cited as evidence the thick sedimentary sequences interpreted, as in this paper, as continental-terrace wedge deposits, and the occurrence of thick units of volcanic rock near the base of the sedimentary sequence, interpreted as evidence for thinning and rifting of the crust during continental separation. The environment of deposition proposed herein for the Rapitan Group would fit nicely with Stewart's hypothesis.

The composition of Windermere volcanics (tholeiitic basalt mainly) is, however, not that expected in relation to initial rifting of continental crust (see Gilluly, 1971). If the Rhine graben or East African rift valleys are valid examples of initial stages of crustal separation, then one would expect much more alkalic lavas. In addition the Windermere volcanics are not unique. Similar, and in places much more abundant, volcanics occur in miogeoclinal Lower Cambrian and Middle Ordovician strata in Mackenzie Mountains. Thus the presence of volcanics is thought to indicate a continuing or recurring extensional environment within the sedimentary prism perhaps related to continued basinward tilting throughout late Proterozoic and early Paleozoic time.

No evidence has been obtained in the Canadian Cordillera in support of a concept that the Purcell sedimentary basin closed to the west. Structural trends of Purcell rocks, except for one region in northern Selwyn Mountains, are roughly parallel with those of Windermere strata. These criteria, along with facies and thickness distributions of Purcell strata and their sharp contrast in structural style and degree of metamorphism to crystalline basement to the east indicate that the earliest record of the Cordilleran geosyncline is contained in Purcell and not Windermere sedimentation. Deformation, uplift, and erosion of the older assemblage during the Racklan and East Kootenay Orogenies have resulted in its discontinuous outcrop distribution.

CONCLUSIONS

The Precambrian Purcell and Windermere assemblages of the Canadian Cordillera are believed to have been deposited along the western margin of the North American craton during an interval perhaps extending from about 1600 to 600 m.y. ago. The Racklan Orogeny in the north and the East Kootenay Orogeny in the south terminated Purcell sedimentation, but the dating of these episodes and, indeed, their correlation is uncertain. Available evidence, however, suggests that the Windermere rocks were deposited within a considerably shorter interval than those of the Purcell and possibly represent only the last 200 m.y. or so of Precambrian history.

Many of the characteristics of Precambrian sedimentation in the Cordillera are related to processes postulated for the building of a continental terrace wedge including turbidite deposition and downbuckling of the ocean floor under the sedimentary load with concomitant extensional faulting and basinward tilting of the wedge.

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A WORKING MODEL OF THE PRIMITIVE EARTH*

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ABSTRACT. Knowledge of the sedimentary and biological record of pre-Paleozoic time, scanty though it still is, suggests a working model of early Earth history consisting of four successive modes (or Eons) punctuated by "events" in which surface conditions on the Earth changed relatively rapidly. The four modes are:

1. An interval (Hadean) for which no certain record has been discovered on Earth, though it has on the moon — ended 3.6 to 3.5 aeons ago by a world-wide thermal event, possibly cosmic as the moon may also have been affected.

2. An interval (Archean) characterized by rocks mainly or entirely of the greenstone–graywacke–granodiorite suite, relatively low in potassium and little differentiated, by the earliest suggestions of life, and by thin crust and no large continental cratons —ended about 2.6 aeons ago by the beginning of extensive cratonization.

3. An interval (Proterophytic) characterized by the formation of large continental cratons and upon them a gamut of differentiated sedimentary and igneous rock types, and by the oxidation of vast amounts of iron by photo-autotrophic procaryotic microorganisms, although the atmosphere remained reducing. This terminated around 1.9 aeons ago with the development of advanced oxygen-mediating enzymes that permitted the evasion of oxygen to the atmosphere and probably led quickly to the development of eucaryotes, mitosis, and sex.

4. An interval (Proterozoic in a restricted sense) characterized by an increasingly oxidizing atmosphere and oxidized sediments, especially red beds, and by an abundance of unicellular eucaryotes, but without differentiated multicellular animal life (Metazoa) —ended about 0.68 aeons ago by the appearance of an ozone layer in the atmosphere, by the onset of Metazoa, and perhaps by a climax of continental glaciation.

INTRODUCTION

Recent advances in geochronology, geochemistry, biogeology, microbiology, electron microscopy, and sedimentology converge with the increasingly genetic focus of pre-Paleozoic geology to illuminate the evolution of the primitive Earth with growing clarity. Scanty though it still is, we now have a presumptive record of life going back to the oldest sedimentary rocks, and one that we can unequivocally relate to known living organisms for at least the last 2 aeons (years × 10^9). Broad trends in crustal evolution are now also clear, and some of these can be related to biospheric and atmospheric evolution. The larger need is for a consistent working model that will integrate present knowledge and well-reasoned inference about the interdependent variables so as to focus on the central problems and predict future directions of advance. Such a model, under study for some years now, is here outlined—not with any thought of finality, but as a framework for discussion and a focus for observation.

RATIONALE

Because time is continuous and without natural subdivisions, it becomes necessary in all historical science to identify events or broad

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