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Initial Deposits in the Cordilleran Geosyncline: Evidence of a Late Precambrian (<850 m.y.) Continental Separation

ABSTRACT

Upper Precambrian and Lower Cambrian strata in western North America are exposed in a narrow slightly sinuous belt extending from Alaska and northern Canada to northern Mexico, a distance of 2,500 mi. Within this belt, the strata thicken from 0 ft on the east to 15,000 to 25,000 ft in areas 100 to 300 mi to the west. The basal unit of this sequence is a diamictite (conglomeratic mudstone) which is widely distributed but discontinuous and is generally considered to be of glacial origin. Overlying sedimentary rocks consist predominantly of siltstone, shale, argillite, quartzite, and conglomerate. Tholeiitic basalt forms thick and widespread units near the base of the sequence but is sparse higher in the section.

The distribution pattern and lithologic characteristics of the upper Precambrian and Lower Cambrian sequence fit the recently developed concept that thick sedimentary sequences accumulate along stable continental margins subsequent to a time of continental separation. The depositional pattern of the sequence is unlike that of underlying rocks, a relation consistent with the idea of a continental separation cutting across the grain of previous structures. The pattern is, on the other hand, similar to that of overlying lower and middle Paleozoic rocks, suggesting that the diamictite and post-diamictite rocks were the initial deposits in the Cordilleran geosyncline. Thick units of volcanic rock near the bottom of the sedimentary sequence indicate volcanic activity related to the thinning and rifting of the crust during the continental separation.

INTRODUCTION

The oldest rocks exposed in western North America are metamorphic and plutonic rocks involved in the Kenoran (2,400 to 2,600 m.y.) and Hudsonian (1,640 to 1,860 m.y.) orogenies, overprinted in places by the Elsonian event (1,280 to 1,460 m.y.) (King, 1969b, Fig. 10, Table 3, p. 33–42). Overlying these metamorphic rocks are supracrustal rocks that consist of relatively unmetamorphosed sedimentary and volcanic rocks belonging to two major sequences, a lower sequence consisting of the Belt Supergroup and equivalent rocks (850 to 1,250 m.y.), and an upper sequence, consisting of the Windermere Group and equivalent rocks (<850 m.y.). These two great groups of supracrustal rocks commonly have been considered to be closely related in origin and have been grouped together as a major tectonic unit (Bayley and Muehlberger, 1968). The purpose of this article is to suggest that a change occurred in the tectonic framework of western North America after the deposition of the Belt Supergroup, and that this change marked the beginning of the Cordilleran geosyncline. In terms of plate tectonics theory, this change marks the time of a continental separation.

The plan of this paper is to describe the stratigraphy of the upper Precambrian (Windermere Group and equivalent rocks) along with the overlying lithologically similar Lower Cambrian strata and to compare this sequence of rocks with underlying and overlying rocks. The Precambrian Windermere and the Lower Cambrian rocks are considered together because they are closely related and cannot be consistently separated in western North America.

UPPER PRECAMBRIAN AND LOWER CAMBRIAN DETRITAL ROCKS

Upper Precambrian and Lower Cambrian rocks (Fig. 1) consisting of the Precambrian

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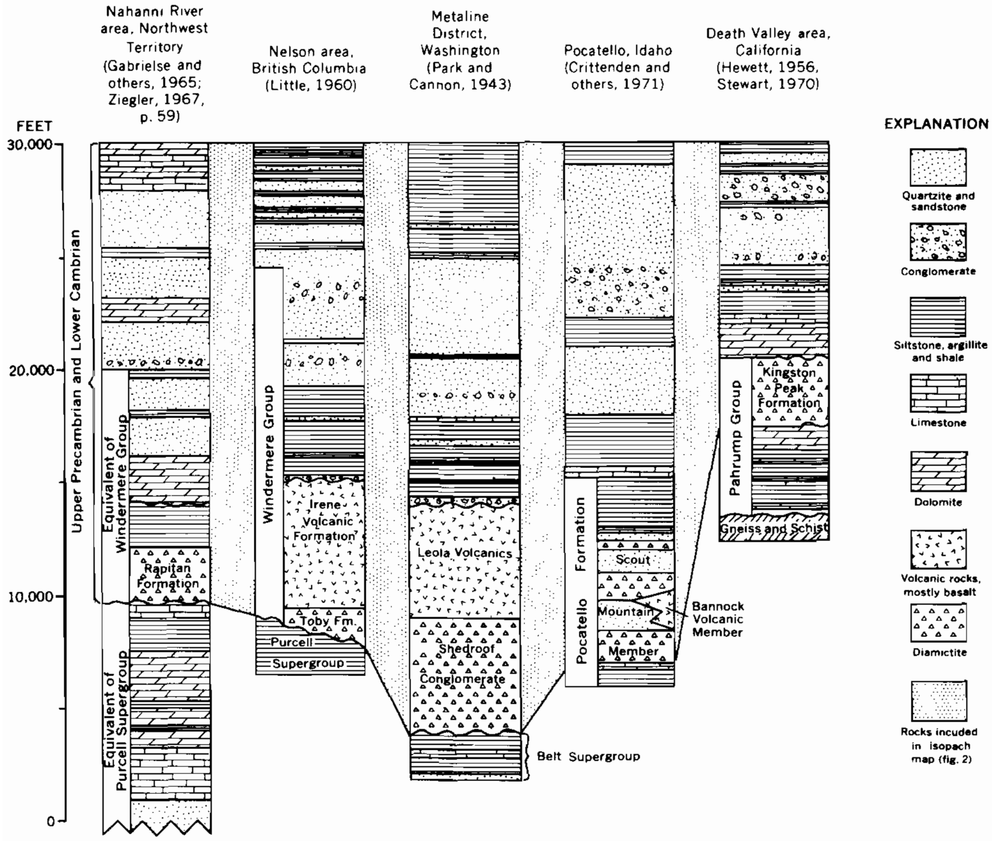


Figure 1. Precambrian and Lower Cambrian rocks in selected areas in western North America.

Windermere Group and equivalent rocks, and of overlying Lower Cambrian rocks, are composed predominantly of siltstone, argillite, shale, and of fine- to medium-grained, locally conglomeratic quartzite (Fig. 1). Siltstone, argillite, and shale are generally predominant in the lower half of the sequence and quartzite in the upper half. Limestone and dolomite form conspicuous units in some areas. The basal unit of these rocks is a widely distributed, but discontinuous, diamictite[1] (also called conglomeratic mudstone, conglomeratic subgraywacke, tillite, or tilloid). Volcanic rocks form thick units within or directly above the diamictite but are sparse higher in the upper Precambrian and Lower Cambrian sequence.

The general correlations of upper Precambrian and Lower Cambrian rocks shown in Figure 1 have been indicated by Gabrielse (1967) in Canada and by Crittenden and others (1971) in parts of the United States. These correlations throughout western North America have been described by Crittenden and others (1972). The similar stratigraphy and probable equivalence of the diamictite and associated volcanic rocks in British Columbia, in northern Washington, and near Pocatello, Idaho, have been suggested by Crittenden and others (1971) and in part by Yates (1968). The correlation of the diamictite from California to British Columbia was also shown in an illustration by Stewart (1970, Fig. 36), in which the top of the diamictite was used as a datum for an isopach map of upper Precambrian and Lower Cambrian strata in the western United States and parts of British Columbia. The possible equivalence of the diamictite has also been discussed by Cloud (1971).

The key unit in most of these correlations is the diamictite, which is commonly considered

[1] Diamictite: A nonsorted sedimentary rock consisting of sand and/or larger particles in a muddy matrix (Crittenden and others, 1971, *modified from* Flint and others, 1960).

to have a glacial origin (Hazzard, 1937; Johnson, 1957; Blackwelder, 1910; Hintze, 1913; Ludlum, 1942; Aalto, 1971; Little, 1960; Ziegler, 1959). The unit is lithologically unique in the Precambrian and Paleozoic sequence in western North America. It consists of rounded or subangular pebbles to boulders (some 5 to 8 ft across) of diverse rock types in a sandy or argillaceous matrix. In places, some of the diamictite or associated layers are graded (Condie, 1966, 1969; Troxel, 1967) and can be considered to be turbidites; elsewhere, isolated coarse fragments occur within thick, massive, argillaceous layers. Striated clasts of possible glacial origin have been noted in Utah (Crittenden and others, 1971). Troxel (1967), Crittenden and others (1971), and Aalto (1971) suggest that the diamictite unit may have had a complex origin; some parts may have been deposited directly from glaciers along the margins of a marine basin, other parts may have been dropped from ice rafts, and still other parts may be glacial material redeposited by turbidity currents.

The diamictite units are scattered throughout western North America (Fig. 2 and Table 1). They may be virtually synchronous units if they represent a time of widespread glaciation. Even if they are not glacial in origin, they may be correlative and perhaps even synchronous, judging from their uniqueness in the stratigraphic sequence.

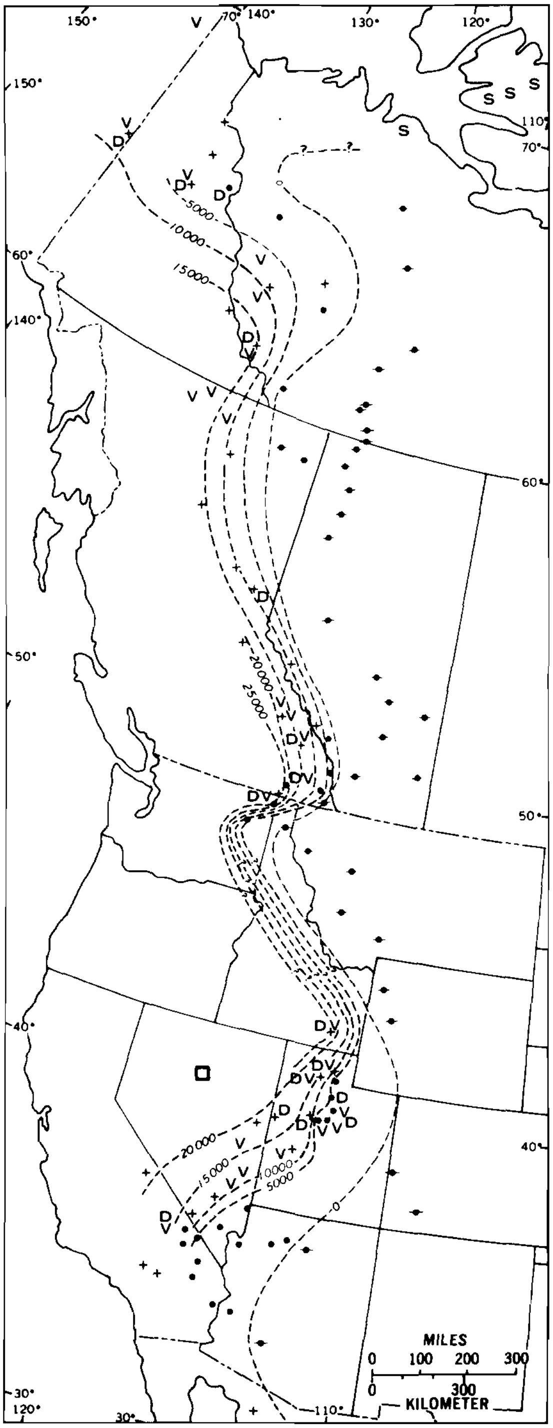
The upper Precambrian and Lower Cambrian rocks above the basal diamictite are divided into many local or semiregional map units. Some units can be traced for several hundred miles, but none is widespread enough to be useful in establishing correlations throughout the entire 2,500-mi length of the upper Precambrian and Lower Cambrian belt. Unconformities occur at various horizons within the upper Precambrian and Lower Cambrian sequence (North, 1966, Fig. 3–7; Crittenden and others, 1971, Fig. 8), but none can be traced for any great distance. The Lower Cambrian part of the sequence cannot be separated systematically from the Precambrian part throughout western North America because the two parts are lithologically similar and fossils are sparse.

Upper Precambrian and Lower Cambrian strata (Windermere Group and higher rocks) are widely distributed in western North America. They occur in a narrow slightly sinuous belt (Fig. 2) extending from Alaska and northern Canada to northern Mexico, a distance of 2,500 mi. Within this belt, the strata thicken from 0 ft in eastern areas to 15,000 to 25,000 ft in areas 100 to 300 mi to the west. The western thickening of these rocks seems well established in California and southern Nevada (Stewart, 1970), western Utah (Crittenden and others, 1971), and southern British Columbia (Okulitch, 1956, Fig. 4). Farther north in British Columbia and in the Yukon Territory, thickness trends are less well known and changes in the generalized isopachs given in Figure 2 will doubtless be made as more information becomes available. The isopach map is not shown on a palinspastic base and thus does not represent the exact original thickness distribution. Thrust faulting (Crittenden and others, 1971), strike-slip faulting and associated drag features (Albers, 1967; Stewart, 1967; Stewart and others, 1968), and large tectonic discontinuities (Yates, 1968) have affected various parts of the outcrop belt. In spite of these complications, the gross thickness trends shown on the isopach map seem well established.

The upper Precambrian and Lower Cambrian strata are considered to be predominantly marine deposits (Okulitch, 1956, p. 704–706; Stewart, 1970; Crittenden and others, 1971). The primary source area lay to the east as indicated by studies of current directions and facies changes (Ressor, 1957, p. 160–162; Mountjoy and Aitken, 1963; Seeland, 1968; Stewart, 1967 and 1970), although a western source has been suggested in parts of Canada (Gabrielse, 1967, p. 275). The strata were deposited predominantly in shallow water (Stewart, 1970). Tidal currents probably spread the sands that form the widespread quartzite units in the upper part of the sequence (Merifield and Lamar, 1968; Seeland, 1968; Stewart, 1970). Individual units of quartzite, carbonate rock, or siltstone commonly extend for several hundred miles along sedimentary strike, indicating a uniform tectonic and sedimentary environment (Stewart, 1970, p. 64), probably on a continental shelf (Fig. 3).

UPPER PRECAMBRIAN AND LOWER CAMBRIAN VOLCANIC ROCKS

Basaltic volcanic rocks (Table 2) form thick and widespread units near the base of the upper Precambrian and Lower Cambrian sequence,



EXPLANATION

Upper Precambrian and Lower Cambrian rocks absent
Data from outcrop and drill-hole information

• Complete   + Incomplete

Stratigraphic section

Isopach
Contour interval 5,000 feet

D
Outcrop of diamictite unit

V
Outcrop of volcanic rock

Outcrop of eugeosynclinal
Scott Canyon Formation

S
Diabase and gabbro dikes and sills
dated as late Precambrian by K-Ar
methods (See table 2)

Figure 2. Generalized isopach map of upper Precambrian and Lower Cambrian strata in western North America showing distribution of diamictite and volcanic rocks.

TABLE 1. OCCURRENCES OF DIAMICTITE IN UPPER PRECAMBRIAN STRATA IN WESTERN NORTH AMERICA

Location	Stratigraphic unit	References
Eastern Alaska	Tindir Group (*in* "basalt and red beds unit" of Brabb and Churkin, 1969)	Cairnes, 1914, p. 91-93; Mertie, 1933, p. 369-392; E. E. Brabb, 1970, oral commun.
Yukon Territory, Canada	Part of Rapitan Formation	Ziegler, 1959, 1967, p. 48-51; Gabrielse, 1967, p. 274; Green and Goodwin, 1963, p. 15-16; Green and Roddick, 1962, p. 5.
Northwest Territory, Canada	Part of Rapitan Formation	Ziegler, 1967, p. 58-59; Gabrielse and others, 1965, p. 8.
British Columbia, Canada	Toby Formation and related rocks	Walker, 1926, p. 12; Evans, 1933, p. 117 A II; Rice, 1941, p. 14-15; Little, 1960, p. 14-16; Okulitch, 1956; Slind and Perkins, 1966, p. 449; Aalto, 1971.
Washington	Shedroof Conglomerate and Huckleberry Formation	Park and Cannon, 1943, p. 7-9; Bennett, 1941, p. 8; Becraft and Weis, 1963, p. 11-18 and Plate 2.
Idaho	Scout Mountain Member of the Pocatello Formation	Crittenden and others, 1971, p. 583; Ludlum, 1942, p. 89-93.
Utah	Mineral Fork tillite; Dutch Peak tillite; diamictites, in Huntsville, Great Salt Lake, and Deep Creek Range areas	Crittenden and others, 1971, Figure 8; Cohenour, 1959, p. 19-25; Crittenden and others, 1952; Bick, 1966, p. 17-18; Misch and Hazzard, 1962, p. 325; Eardley and Hatch, 1940, p. 800-807.
California	Kingston Peak Formation	Hewett, 1956, p. 27-28; Wright and Troxel, 1967, p. 938-943.

and are sparsely distributed higher in this sequence.

The thickest and probably most widespread of the volcanic units is the Irene Volcanic Formation in British Columbia and the correlative Leola Volcanics and Huckleberry Formation in northernmost Washington. These volcanic rocks crop out for about 90 mi in a generally northeasterly direction and locally are 5,000 to 6,000 ft thick (Park and Cannon, 1943; Little, 1960). They consist of altered and metamorphosed basalt (tholeiitic basalt according to F. K. Miller as quoted in Yates, 1970), some of which is amygdaloidal and some of which contains pillow structures (Park and Cannon, 1943). Minor amounts of agglomerate and flow breccia, and a few layers of phyllite and limestone (Little, 1960) are interstratified with the basalt. The Irene Volcanic Formation and correlative units directly overlie the diamictite (Toby Formation, Shedroof Conglomerate, Huckleberry Formation).

Mafic volcanic rocks interfinger with the diamictite or occur directly above it in Alaska, Yukon Territory, Northwest Territory, Idaho, Utah, and California (Table 2). In Idaho, the Bannock Volcanic Member of the Pocatello Formation forms a wedge of volcanic rock at least 1000 ft thick that interfingers with the diamictite (Crittenden and others, 1971).

Volcanic rocks that are not within or directly above the diamictite unit are relatively sparse. They occur in Lower Cambrian strata in British Columbia (Evans, 1933; Wheeler, 1965) in the Lower Cambrian Prospect Mountain Quartzite and the Lower and Middle Cambrian Tintic Quartzite in Utah and Nevada (Abbott, 1951; Morris and Lovering, 1961; Kellogg, 1963). These volcanic rocks consist (for the most part) of amygdaloidal mafic flows less than 100 ft thick.

The petrographic and chemical characteristics of the upper Precambrian and Lower Cambrian volcanic rocks are poorly known. These rocks have not been studied much, and in many places their original textures and compositions have been destroyed by alteration and metamorphism. In general, the rocks appear to be highly altered, porphyritic, subophitic mafic lava with altered plagioclase (mostly labradorite) phenocrysts (Daly, 1912; Park and Cannon, 1943; Abbott, 1951; Morris and Lovering, 1961). Much of the rock is a "confused, felted mass of uralite, chlorite, epidote, quartz, calcite, limonite, sericite, saussurite, and often biotite, with which pyrite, magnetite, and ilmenite (generally altered to leucoxene) regularly form accessories in variable amounts" (Daly, 1912, p. 145). Augite has been reported in some rocks (Abbott, 1951; Little, 1960) and an actinolitic amphibole in others (Little, 1960). Most of this mineralogy reflects alteration and metamorphism, rather than the original character of the rock.

A few chemical analyses of these rocks are presented in Table 3. The unusually high H_2O and CO_2 contents are due to alteration and metamorphism (in sample 4, the total H_2O

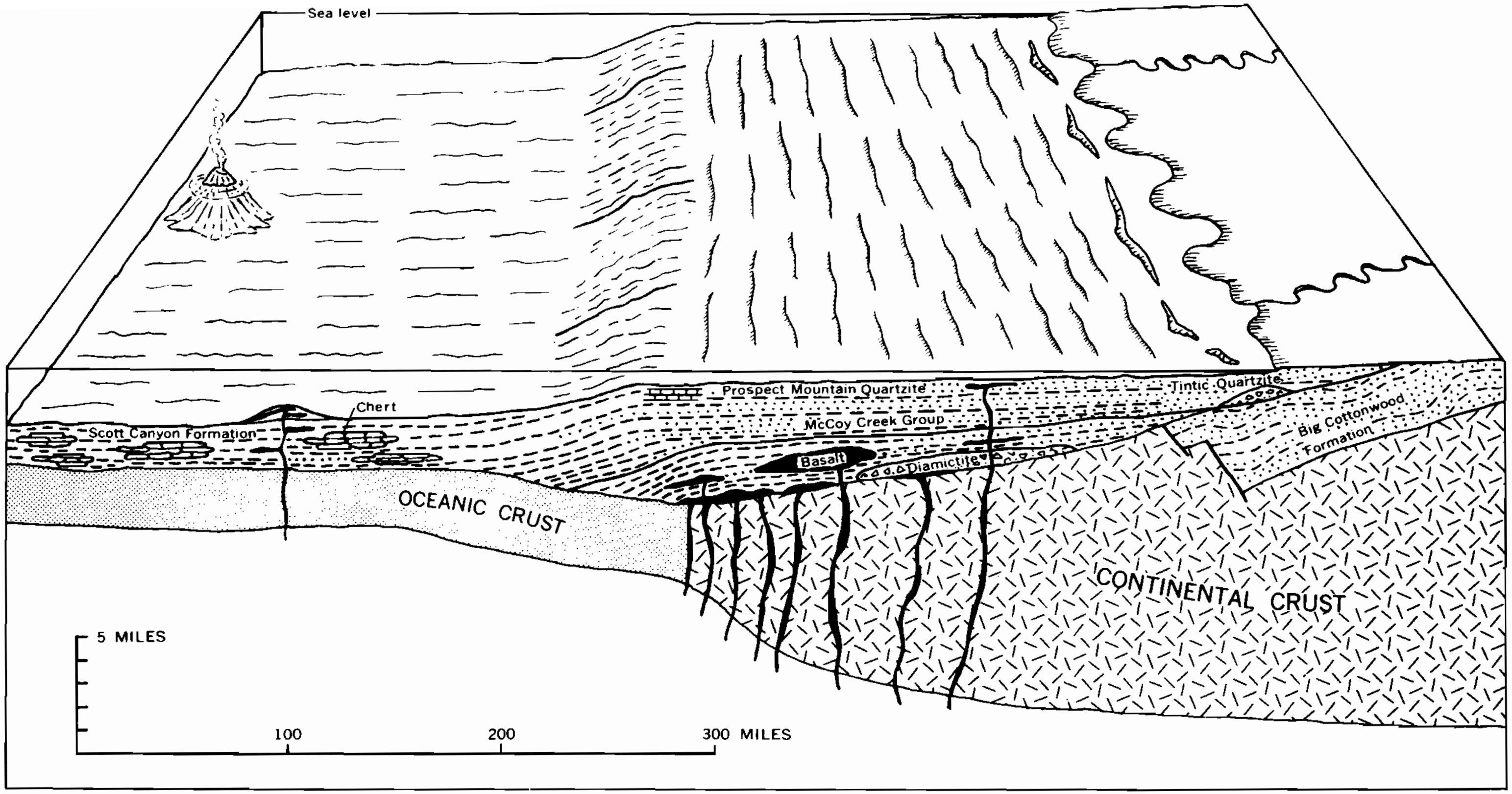


Figure 3. Diagrammatic cross section showing upper Precambrian and Lower Cambrian rocks in the northern Great Basin, Nevada and Utah.

TABLE 2. PARTIAL LIST OF OCCURRENCES OF VOLCANIC ROCKS IN THE UPPER PRECAMBRIAN AND LOWER CAMBRIAN SEQUENCE AND HYPABYSSAL ROCKS OF POSSIBLE LATE PRECAMBRIAN AGE IN WESTERN NORTH AMERICA

Location	Description	References
Alaska	Basalt, greenstone, and basaltic tuff in basalt and red beds unit* of Brabb and Churkin (1969), Tindir Group (Precambrian)	Brabb and Churkin, 1969; Mertie, 1933, p. 369-392.
Yukon Territory, Canada	Amygdaloidal andesitic or basaltic flows and tuffaceous sediments in Rapitan Formation* (Precambrian)	Gabrielse, 1967, Fig. 3 and p. 274; Green and Goodwin, 1963, p. 15-16; Green and Roddick, 1962, p. 5.
Northwest Territory, Canada	Mafic volcanic rocks in Rapitan Formation* as used by Ziegler (1967, p. 58-59) (Precambrian)	Gabrielse and others, 1965, p. 8.
	Diabase and gabbro dikes and sills on Victoria Island and eastern part of the northern Interior Plains. Dated by K-Ar methods as 635 and 640 m.y. on Victoria Island and 705 and 770 m.y. in the eastern part of the northern Interior Plains	Thorsteinsson and Tozer, 1962, p. 38-39, and Map 1135 A; Yorath and others, 1969, p. 8.
British Columbia, Canada	Irene Volcanic Formation (Precambrian)* and various amygdaloidal and pillow greenstones of both late Precambrian and Early Cambrian age	Daly, 1912, p. 144-147; Evans, 1933, p. 122A II and 117A II; Little, 1960, p. 16-18; Rice, 1941, p. 15-17; Wheeler, 1963, p. 3 and 6; Wheeler, 1965, p. 10; Gabrielse, 1967, Fig. 3.
Washington	Leola Volcanics* and Huckleberry Formation* (Precambrian)	Park and Cannon, 1943, p. 9-11; Bennett, 1941, p. 8-9; Becraft and Weis, 1963, p. 11-18 and Pl. 2.
Idaho	Bannock Volcanic Member* of Pocatello Formation (Precambrian)	Crittenden and others, 1971, p. 583-584; Ludlum, 1942, p. 88.
Utah	Basalt member of Browns Hole Formation (Precambrian)	Crittenden and others, 1971, p. 592.
	Mafic flows in Great Salt Lake area (Precambrian)	Eardley and Hatch, 1940, p. 800-807; Olson, 1956, p. 42-44.
	Amygdaloidal and pillow basalt flow in Tintic Quartzite (Lower Cambrian)	Abbott, 1951; Morris and Lovering, 1961, p. 15; D. M. Lemmon, 1966, written commun.
Nevada	Basalt flow, locally amygdaloidal, in Prospect Mountain Quartzite (Lower Cambrian)	Kellogg, 1963, p. 687-688; J. H. Stewart, this paper.
California	Pillow basalt* in Kingston Peak Formation	A. L. Albee, 1965, oral commun.

Volcanic unit either intercalated with the diamictite or lying directly on top of it.

and CO_2 content is 12.8 percent). An average of the 8 samples (Table 4, column 1), H_2O and CO_2 free, indicates the general similarity of these upper Precambrian and Lower Cambrian volcanic rocks to tholeiitic basalt. Particularly indicative is the low total alkali and the low Fe_3O_2/FeO ratio (Engel and others, 1965). The amount of K_2O is greater than in most oceanic tholeiites but is much less than is found in alkali basalt. The chemistry is similar to the basalt of the Upper Triassic Newark Group of the eastern United States (Table 4, column 5).

An unusual occurrence of volcanic rock of Early or Middle Cambrian age is in the Scott Canyon Formation in north-central Nevada (Roberts, 1964, p. A14–A17). This formation consists of chert, argillite, and greenstone (altered basaltic lava and pyroclastic rocks), with some limestone, quartzite, sandstone, and limy sandstone. It appears to be more than 5,000 ft thick, but the structural setting is complex and the thickness difficult to estimate precisely. The abundance of chert in this formation and its similarity to other lower Paleozoic siliceous and volcanic assemblage rocks suggest that it was deposited in a eugeosynclinal environment to the west of the continental margin (Fig. 3).

RELATION OF UPPER PRECAMBRIAN AND LOWER CAMBRIAN SEQUENCE TO UNDERLYING ROCKS

The upper Precambrian and Lower Cambrian sequence (Windermere Group and younger rocks) was deposited after a major late Precambrian orogenic event in some regions of western North America. In British Columbia, rocks of the Purcell Supergroup were uplifted and mildly folded during the East Kootenay orogeny (White, 1959) before deposition of the Windermere Group. A similar orogeny, the Racklan (Gabrielse, 1967), occurred in the Yukon Territory before rocks equivalent to the Windermere were deposited. Here Purcell-like rocks were uplifted, tightly folded, and block faulted, forming "one of the most spectacular unconformities in the northern Cordillera" (Gabrielse, 1967, p. 274). An unconformity also separates rocks of the Belt Supergroup (equivalent to the Purcell Supergroup) from overlying Windermere-equivalent rocks

TABLE 3. CHEMICAL ANALYSES OF UPPER PRECAMBRIAN AND LOWER CAMBRIAN VOLCANIC ROCKS IN WESTERN NORTH AMERICA

Lab. and Field Nos.	1* M108934 W JS-69-7	2† 163648 62ABa2813	3† 163649 60ABa363	4† 163650 63ABa3625	5† 163652 63ABa3372	6‡ 165200 95	7‡ 165201 96	8‡ 165202 98
SiO_2	49.6	56.0	51.5	41.0	50.1	42.6	43.8	44.8
Al_2O_3	13.8	14.5	13.6	15.4	15.1	12.7	12.0	13.2
Fe_2O_3	4.9	2.4	6.0	1.9	1.4	.95	1.6	1.0
FeO	8.8	3.9	6.8	8.2	3.7	13.5	12.2	11.5
MgO	5.0	5.7	5.7	8.5	5.8	7.3	7.1	6.3
CaO	8.0	8.0	5.2	8.5	14.3	5.0	7.8	6.6
Na_2O	2.5	1.2	5.1	2.2	1.4	1.9	.95	2.8
K_2O	.76	1.1	.00	.77	.82	.59	.28	.85
H_2O+	3.2	3.3	2.6	5.8	1.7	5.0	5.7	4.3
H_2O-	.24	1.0	1.1	1.0	.70	.14	.15	.18
TiO_2	2.3	.53	1.5	.47	.47	3.5	3.2	2.8
P_2O_5	.31	.26	.24	.17	.24	.72	.54	.45
MnO	.21	.06	.21	.09	.15	.20	.21	.21
CO_2	<.05	1.3	.10	6.0	3.2	5.5	4.3	4.8
Total	100	99	100	100	99	100	100	100

*Vesicular basalt, Prospect Mountain Quartzite (Lower Cambrian), Delamar district, Lincoln County, Nevada. Rapid rock analysis by Leonard Shapiro (project leader), P. Elmore, H. Smith, L. Artis, G. Chloe, J. Kelsey, and J. Glenn. Methods used are those described by Shapiro and Brannock (1962), supplemented by atomic absorption.

†Mafic volcanic rocks, "basalt and red beds unit" of Tindir Group (Precambrian) (Brabb and Churkin, 1969), Charlie River quadrangle, easternmost Alaska. Rapid rock analysis by Leonard Shapiro (project leader), P. Elmore, S. Botts, and Lowell Artis. Samples analyzed by x-ray fluorescence supplemented by methods described by Shapiro and Brannock (1962). Data supplied by E. E. Brabb.

‡Basalt flows, Huckleberry Formation (Precambrian), Chewelah No. 1 quadrangle, Stevens County, Washington. Rapid rock analysis by Leonard Shapiro (project leader), P. Elmore, S. Botts, and L. Artis. Samples were analyzed by x-ray fluorescence supplemented by methods described by Shapiro and Brannock (1962). Data supplied by F. K. Miller.

in Washington (Park and Cannon, 1943; Smith and Barnes, 1966, Fig. 9). In Utah, Nevada, and California, the diamictite unit, which is considered to be correlative with the basal Windermere, rests on older rocks unconformably in some areas (Crittenden and others, 1952) but conformably in others (Hewett, 1956; Cohenour, 1959; Crittenden and others, 1971, Figs. 7 and 8). A significant unconformity may not have been detected below the diamictite in Utah, Nevada, and California, but locally deposition of the upper Precambrian and Lower Cambrian sequence possibly may have started before, and been continuous up to, deposition of the diamictite (Crittenden and others, 1971, Figs. 7 and 8).

The rather simple depositional pattern of the upper Precambrian and Lower Cambrian sequence contrasts with an irregular pattern in underlying rocks (Fig. 4). Rocks of the Belt Supergroup (850 to 1250 m.y., Obradovich and Peterman, 1968; ages recalculated by Ryan and Blenkinsop, 1971, Fig. 2) in Montana, Idaho, and Washington occur mostly east of the

TABLE 4. COMPARISON OF UPPER PRECAMBRIAN AND LOWER CAMBRIAN BASALT AND MAFIC VOLCANIC ROCKS WITH OCEANIC THOLEIITIC BASALT, HAWAIIAN BASALT, ALKALI BASALT, AND TRIASSIC BASALT FROM NEW JERSEY (H_2O AND CO_2 FREE)

	1	2	3	4	5
SiO_2	51.7	49.94	49.84	48.16	51.86
Al_2O_3	15.0	17.25	14.09	18.31	14.62
Fe_2O_3	2.7	2.01	3.06	4.24	3.49
FeO	9.3	6.90	8.61	5.89	8.79
MgO	7.1	7.28	8.52	4.87	7.08
CaO	8.6	11.86	10.41	8.79	8.80
Na_2O	2.5	2.76	2.15	4.05	2.99
K_2O	.71	.16	.38	1.69	0.74
TiO_2	2.0	1.51	2.52	2.91	1.33
P_2O_5	.40	.16	.26	.93	0.17
MnO	.18	.17	.16	.16	0.12

1. Average (H_2O and CO_2 free) of 8 samples of upper Precambrian and Lower Cambrian basalt and mafic volcanic rocks shown in Table 3.
2. Average of 10 samples of oceanic tholeiite dredged from the Atlantic and Pacific Oceans (Engel and others, 1965, Table 3).
3. Average of 181 samples of tholeiite and olivine tholeiite from the Hawaiian Islands (MacDonald and Katsura, 1964, Table 9, col. 8, p. 124).
4. Average of 10 samples of alkali basalt from submarine volcanos and islands of the eastern Pacific Ocean (Engel and others, 1965, Table 3).
5. Average of 8 samples of Triassic basalt from New Jersey (Washington, 1922, p. 797, Table 8, col. 5).

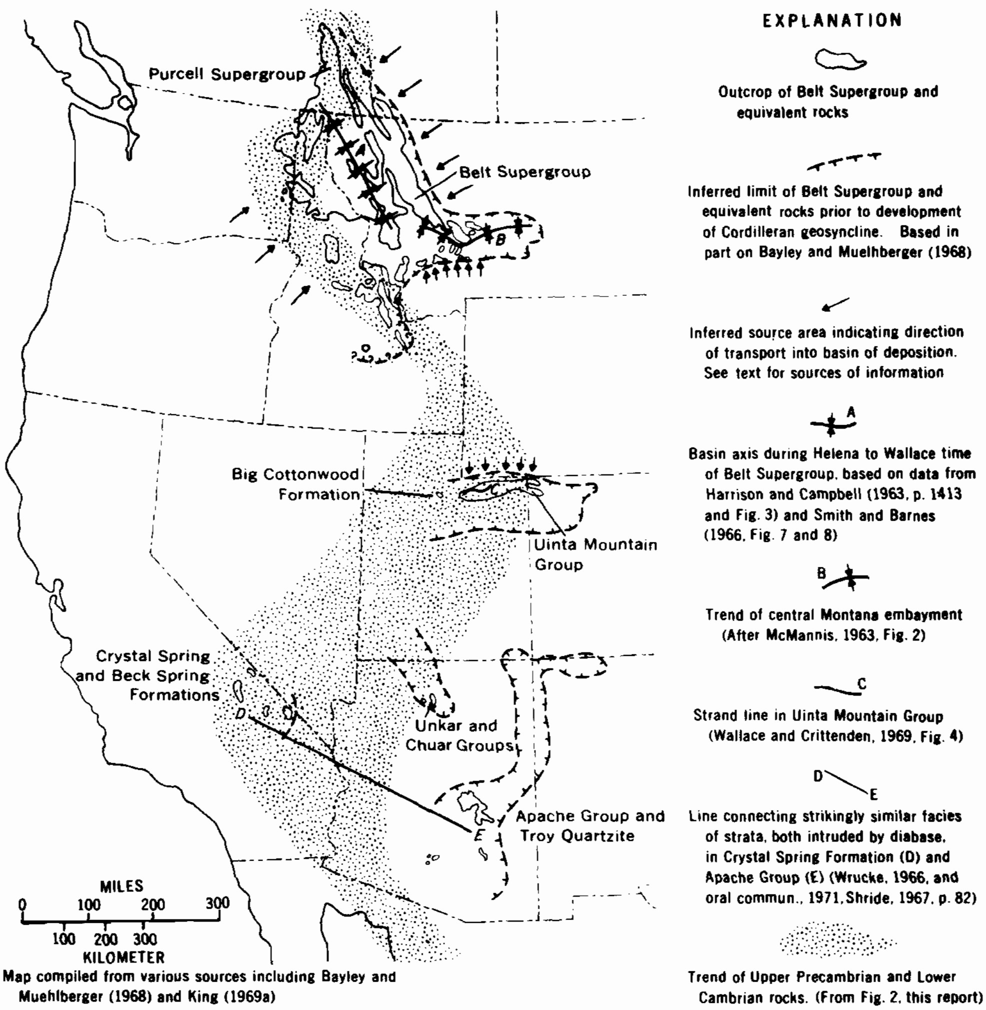


Figure 4. Comparison of distribution of upper Precambrian and Lower Cambrian strata with underlying supracrustal rocks.

upper Precambrian and Lower Cambrian strata (Fig. 3). They are locally more than 40,000 ft thick (Harrison and Campbell, 1963) and were deposited in a trough that trended west-northwest during part of lower Belt time and northwest (Fig. 4) during part of upper Belt time (Harrison, 1971). The sediments were derived from a cratonic source terrane to the south or southwest and from the Canadian Shield to the northeast (Price, 1964; Harrison, 1971). Near-source boulder conglomerate occurs in the Belt Supergroup along the southern margin of the east-trending central Montana embayment (Fig. 3) (McMannis, 1963). The northwest-trending trough of the Belt Supergroup (Fig. 4) intersects the depositional wedge of the upper Precambrian (Windermere Group) and Lower Cambrian sedimentary rocks at a high angle near the international boundary, suggesting a marked difference in the tectonic setting of the Belt Supergroup and the upper Precambrian and Lower Cambrian strata. The east-west trend of the central Montana embayment, which is probably controlled at least in part by east-west faulting along its margins, contrasts with the general north-south trend of the upper Precambrian and Lower Cambrian rocks (Fig. 4).

In Utah, rocks underlying the upper Precambrian and Lower Cambrian sequence consist mainly of the Big Cottonwood Formation and the Uinta Mountain Group[2]. The Big Cottonwood Formation is 16,000 ft thick (Crittenden and others, 1952), and the Uinta Mountain Group appears to be at least 24,000 ft thick locally (Hansen, 1965, p. 33). These rocks crop out in an east-west belt (Fig. 4) that seems to represent at least in part the original depositional trough (Wallace and Crittenden, 1969, p. 140). Much of the sediment was derived from source areas to the north (Wallace and Crittenden, 1969; Hansen, 1965, p. 36–37). An east-west–trending strand line (Fig. 4) has been identified in the Uinta Mountain Group (Wallace and Crittenden, 1969, Figs. 4 and 5). The east-west trends of the Big Cottonwood Formation and the Uinta Mountain Group intersect the general north-south trends of the upper Precambrian and Lower Cambrian sequence at a high angle.

In California, rocks underlying the upper Precambrian and Lower Cambrian sequence consist of the Crystal Spring Formation and the Beck Spring Dolomite. The Crystal Spring Formation is strikingly similar lithologically (Wrucke, 1966, and 1971, oral commun.; Shride, 1967) to the Apache Group in southern Arizona (formed sometime during the interval 1,200 to 1,400 m.y.; Shride, 1967; Livingston and Damon, 1968), and both units are intruded by Precambrian diabase. Although outcrops of the Crystal Spring Formation and the Apache Group are about 300 mi apart, they both may have been deposited in a northwest-trending basin, a basin that would intersect the general north-south trend of the upper Precambrian and Lower Cambrian sequence at a high angle (Fig. 4).

Rocks below the upper Precambrian and Lower Cambrian sequence, therefore, were deposited in several basins or troughs which appear to be unrelated to the general north-south trend of the upper Precambrian and Lower Cambrian rocks. This suggests that the tectonic setting of western North America changed before deposition of the upper Precambrian and Lower Cambrian sequence.

[2] The correlation of the Big Cottonwood Formation and Uinta Mountain Group has been questioned by C. A. Wallace (1971, written commun. and *in* Crittenden and others, 1972). The Big Cottonwood Formation is a pre-diamictite unit (Crittenden and others, 1971), whereas the Uinta Mountain Group is lithologically similar, according to Wallace, to post-diamictite rocks in southeastern Idaho. M. D. Crittenden, Jr. (1971, oral commun. and *in* Crittenden and others, 1972), however, on the basis of broad depositional patterns, considers the Uinta Mountain Group to be a part of the pre-diamictite sequence, an interpretation followed here.

RELATION OF UPPER PRECAMBRIAN AND LOWER CAMBRIAN SEQUENCE TO OVERLYING ROCKS

The upper Precambrian and Lower Cambrian detrital and volcanic rocks are conformably overlain by a thick sequence of lower Paleozoic carbonate and shale rocks. This change from predominantly argillite, shale, siltstone, conglomerate, and quartzite below to carbonate and shale above, is striking.

The depositional pattern of the upper Precambrian and Lower Cambrian rocks is very like that of overlying lower and middle Paleozoic strata of the Cordilleran geosyncline. This similarity can be seen by comparing an isopach map of the upper Precambrian and Lower Cambrian rocks with an isopach map of Cambrian, Ordovician, and Silurian rocks (Fig. 5), and also by comparing Figure 2 of this report with Plates 3 and 4 of Kay (1951). The "Wasatch line" of Utah, across which Paleozoic and Mesozoic strata thicken greatly, coincides with the position of the wedge of upper Precambrian and Lower Cambrian sedimentary strata. The diamictite appears to be the oldest unit whose depositional pattern follows closely that of lower and middle Paleozoic rocks and thus may represent the earliest deposit in the Cordilleran geosyncline.

LATE PRECAMBRIAN (<850 M.Y.) CONTINENTAL SEPARATION

The concepts of ocean-floor spreading and plate tectonics have led to the development of new ideas concerning the origin of geosynclines (Dewey, 1969; Dewey and Horsfield, 1970; Dewey and Bird, 1970; Dickinson, 1970a and 1970b; Coney, 1970; Bird and Dewey, 1970). According to these theories, after continents separate, thick linear belts of sediment form along their trailing edges. In its simplest form, this concept is illustrated by Figure 6, which shows a continental mass splitting in two and the two sections drifting apart. The initial phases of a continental separation are marked by extrusion of tholeiitic basalt in areas where thinning and rifting of the crust tap magma sources in the mantle. The volcanism and sedi-

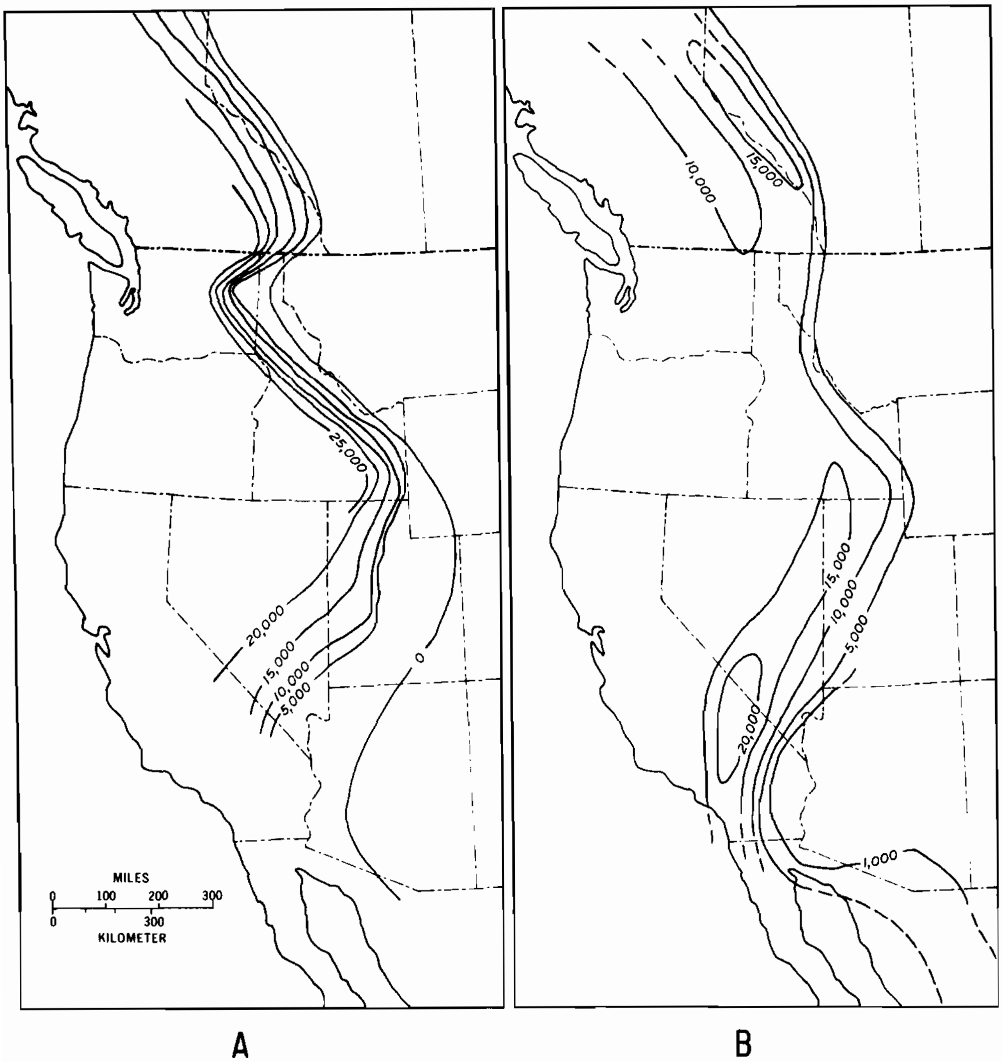


Figure 5. Comparison of isopach map (A) of Precambrian and Lower Cambrian rocks (*from* Fig. 2, this report) with isopach map (B) of Cambrian, Ordovician, and Silurian rocks (*after* Eardley, 1951, Pl. 2). Thickness in feet.

mentation that occur along the trailing edges of continents that are separating, differ markedly from those related to a subduction zone at the leading edge of a continent (such as the Andean type). Along a subduction zone, frictional melting at the top of the descending lithospheric plate generates massive volumes of andesitic and basaltic magma, and sediments consist primarily of structurally contorted graywacke and chert (Dewey, 1969; Dickinson, 1970a).

The present-day continental margin off the east coast of the North American continent is considered (Dewey, 1969; Bird and Dewey, 1970) to be a typical example of a stable continental margin containing a thick linear belt of sedimentary rock (Drake and others, 1959). This margin developed when the North American plate was separated from the Eurasian and African continental plates during the breakup of the Pangaean continental mass in the early Mesozoic (Dietz and Holden, 1970). The initial phases of this separation produced the Triassic grabens and basalt masses of the eastern United States.

A continental separation appears to be a

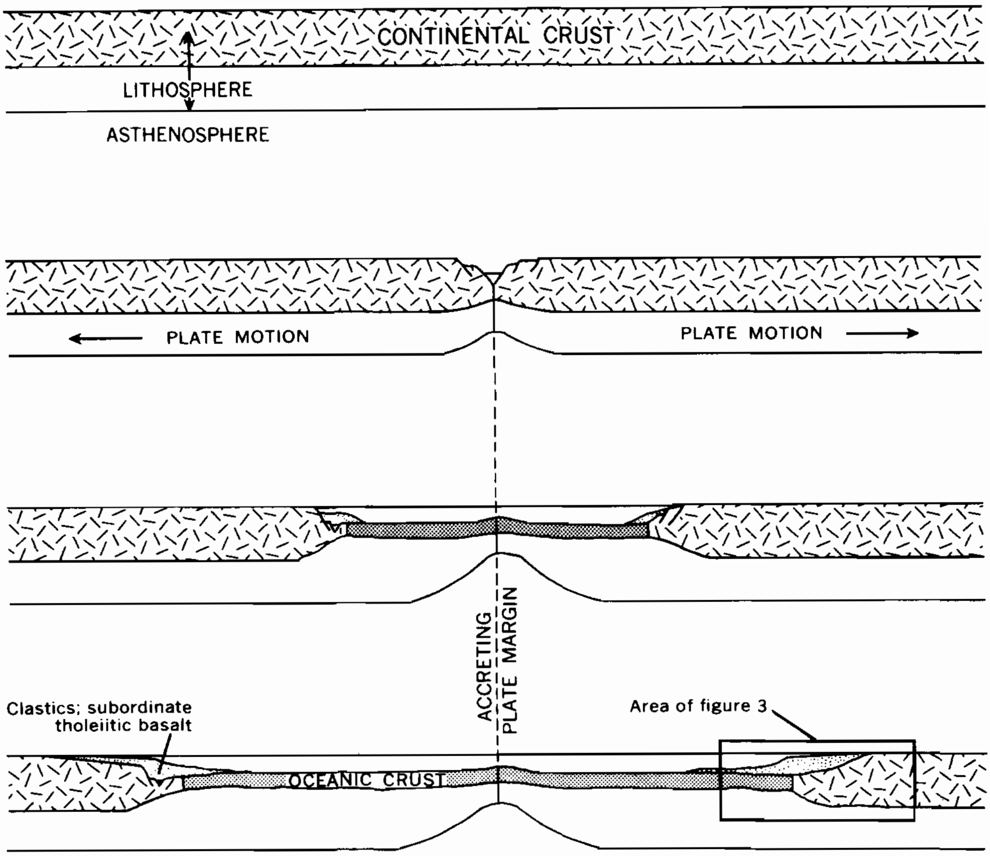


Figure 6. Diagram showing late Precambrian continental separation and deposition of the upper Precambrian and Lower Cambrian sequence. Rectangle in lower right of diagram shows position of Figure 3.

likely explanation for the origin of the Cordilleran geosyncline in western North America. The general north-south trend of the upper Precambrian and Lower Cambrian strata cuts across the trends of several sedimentary troughs in underlying rocks, suggesting a continental separation across the grain of previous structures. The occurrence of significant amounts of tholeiitic basalt near the bottom of the sedimentary sequence suggests volcanic activity related to the thinning and rifting of the crust during the separation. The chemical composition of the basalt is very similar to that of Triassic basalt of the eastern United States, which has been interpreted to be related to a continental separation. The linear belt of westward-thickening detrital rocks deposited subsequent to the volcanic activity indicates an accumulation along a stable continental margin (Fig. 3) that is perhaps similar in setting and character to the thick sedimentary accumulation (Drake and others, 1959; Dietz and Holden, 1967) off the east coast of the North American continent.

The upper Precambrian and Lower Cambrian rocks exposed in western North America are inferred to lie mostly on the continental crust (Fig. 3). Rocks of the Belt Supergroup and related strata which underlie the upper Precambrian and Lower Cambrian sequence in many parts of western North America are considered to be part of this continental block. Nowhere in western North America do the upper Precambrian and Lower Cambrian rocks (Windermere and younger rocks) rest on ultramafic rock which could be considered to be oceanic crust. Such oceanic crust, if the interpretations presented here are correct, must be buried under later Phanerozic rock. The plutonic and metamorphic rocks of the Yukon-Tanana Complex and of the Shuswap Complex (King, 1969a) of Canada and Alaska appear to lie west of the inferred zone of separation and thus, following the interpretations presented here, should not contain pre-Windermere cratonic sequences indigenous to the North American continent. Geologists in early studies in these regions assigned rocks of these complexes to the Archean (*see* discussion by King, 1969b, p. 49 and 68), but most radiometric dates are Mesozoic and much of this terrain is now considered to be composed mostly of metamorphosed Paleozoic or Mesozoic rock (King, 1969b; Gabrielse, 1967, Fig. 15 and p. 287–288), although a Precambrian age for some rocks cannot be entirely ruled out (King, 1969b; Ross, 1968).

The time of the inferred late Precambrian separation is not well known. It postdates the youngest rocks of the Belt Supergroup, which are about 850 m.y. old (Obradovich and Peterman, 1968; ages recalculated by Ryan and Blenkinsop, 1971, Fig. 2). I have suggested previously (Stewart, 1971) that the separation might be younger than 750 m.y., on the basis of K-Ar dating of the Hellroaring Creek stock, which intrudes Purcell Supergroup rocks, and K-Ar dating of a metamorphic event of about the same age. (These data are summarized briefly by Burwash and others, 1966.) More recent work (Ryan and Blenkinsop, 1971) including Rb-Sr isotope measurements, indicates that the age of the Hellroaring Creek stock is approximately 1,260 m.y. According to Ryan and Blenkinsop (1971), the K-Ar ages may have been reset by a pre-Windermere event and further reduced by post-Cambrian to Mesozoic deformation. With present data, the inferred separation can perhaps only be dated as younger than about 850 m.y. (the age of the youngest rocks of the Belt Supergroup) and older than about 570 m.y. (the age of the oldest Cambrian; Geol. Soc. London, 1964).

SUMMARY

The relatively unmetamorphosed Precambrian supracrustal sedimentary rocks of western North America can be divided into two main sequences: (1) the Belt Supergroup and equivalent rocks (850 to 1,250 m.y.)—the lower sequence; and (2) the Windermere Group and equivalent rocks (<850 m.y.)—the upper sequence. Rocks belonging to the Windermere Group or correlative units cannot be consistently separated from Lower Cambrian strata in western North America. Considered together, the upper Precambrian (Windermere and equivalents) and Lower Cambrian strata are exposed in a narrow slightly sinuous belt extending from Alaska and northern Canada to northern Mexico, and they thicken from 0 ft on the east to 15,000 to 25,000 ft in areas 100 to 300 mi to the west. The general north-south trend of the upper Precambrian and Lower Cambrian sequence cuts across the grain of several sedimentary troughs in underlying rocks (Belt and equivalent rocks), indicating that the tectonic setting of western North America changed before this sequence was deposited. In distribution and thickness pattern, the upper Precambrian and Lower Cambrian rocks are very similar to overlying strata of the Cordilleran geosyncline. These rocks therefore must have been the initial deposits in the geosyncline. Continental separation cutting across trends of underlying sedimentary rocks seems a likely mechanism for the initial development of the Cordilleran geosyncline.

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