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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

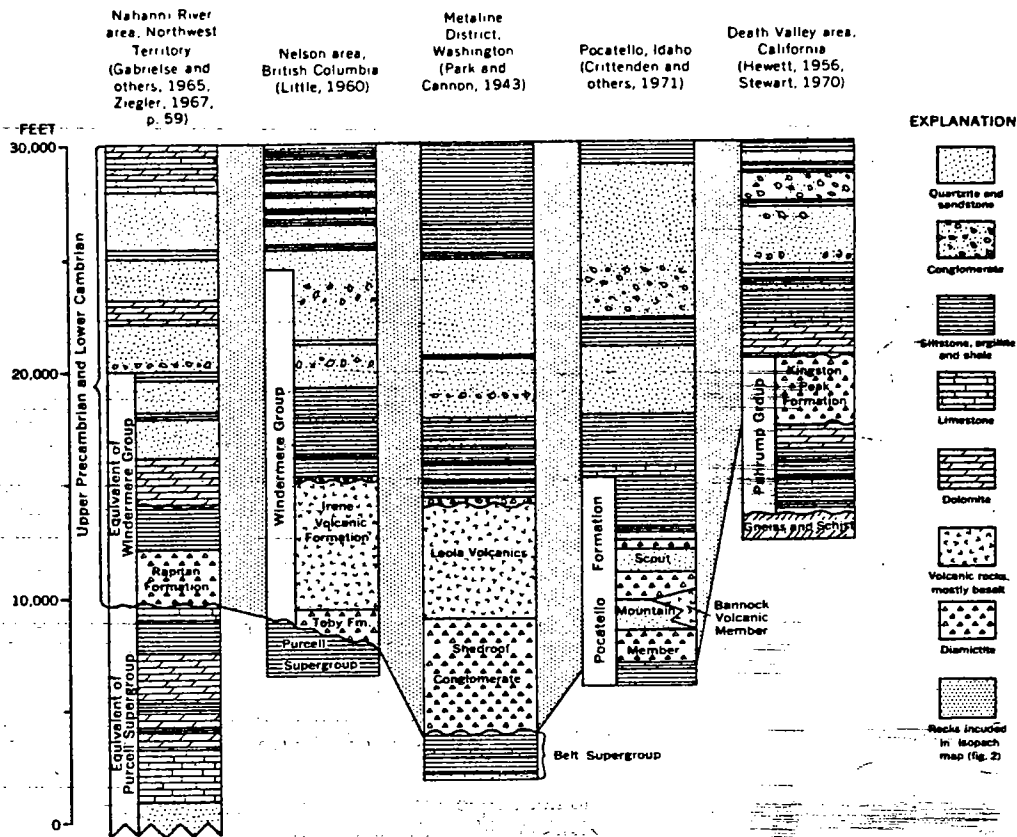


Figure 1. Precambrian and Lower Cambrian rocks in selected areas in western North America.

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, diamictite¹ (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

¹Diamictite: 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).

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

to have a glacial origin (Ludlum, 1957; Ziegler, 1955) in the Precambrian of western North America or subanguliform (ft across) of argillaceous diamictite (Condie, 1969) considered to be coarse fragments of argillaceous glacial origin. Crittenden and others (1972) suggest that the complex of deposited diamictites at the margins of a basin may be partly turbidity currents.

The diamictite is widespread in western North America (Fig. 1). They may be if they represent a common event. Even may be of the same age, but stratigraphically distinct.

The upper Precambrian rock sequence is divided into units. Some of these units are several hundred meters thick and may be useful in correlating out the upper Precambrian. The diamictite conformities in the upper sequence (Crittenden and others, 1971) and other units may be traced for several hundred miles. Cambrian strata separated from the upper part through cause the fossils are not preserved.

Upper Cambrian strata (Werner, 1960) are widely distributed in North America. The Cambrian is a sinuous belt

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 (Merfield 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,

Area
1956,
1970)

EXPLANATION

-  Quartzite and sandstone
-  Conglomerate
-  Siltstone, argillite and shale
-  Limestone
-  Dolomite
-  Volcanic rocks, mostly basalt
-  Diamictite
-  Rocks included in isopach map (Fig. 2)

North America.

indicated by Gabrielse Crittenden and others United States. These western North America by Crittenden and similar stratigraphy and of the diamictite and in British Columbia, and near Pocatello, ed by Crittenden and by Yates (1968). The tite from California to o shown in an illustration (Fig. 36), in which the s used as a datum for per Precambrian and in the western United itish Columbia. The he diamictite has also (1971). of these correlations is commonly considered

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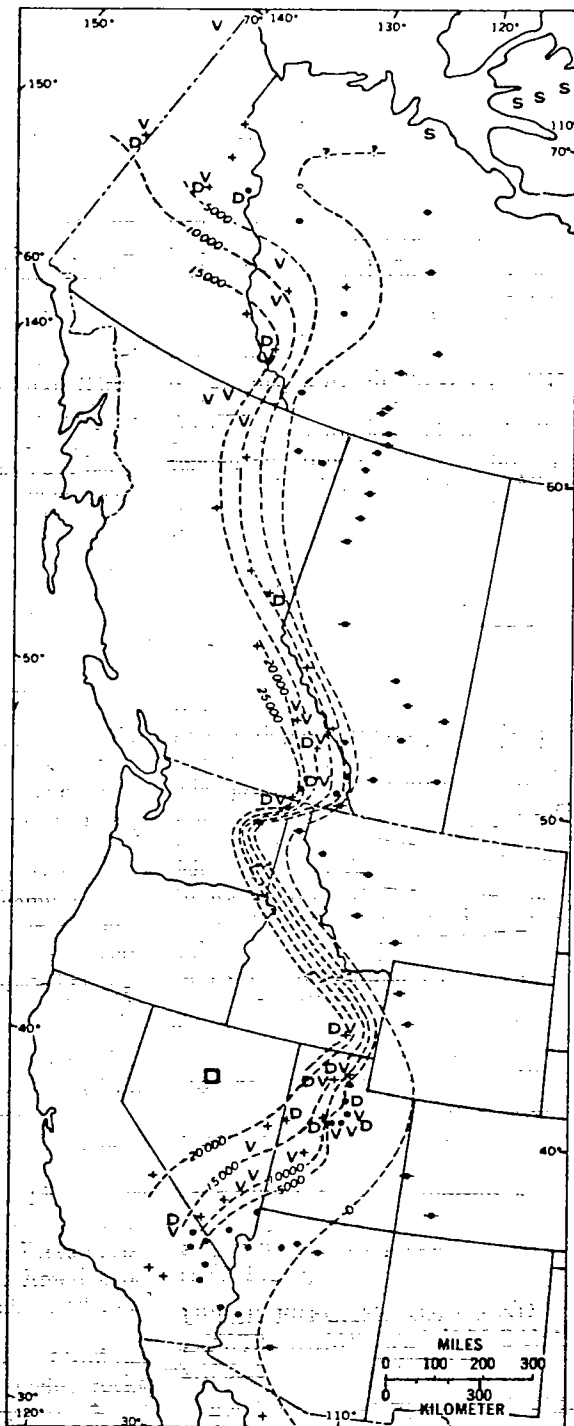


Figure 2. Generalized isopach map of upper Precambrian and Lower Cambrian strata in western North America showing distribution of diamictite and volcanic rocks.

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

DV
Outcrop of eugeosynclinal
Scott Canyon Formation

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

Location
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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. 683; 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 uraltite, 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 H₂O and CO₂ contents are due to alteration and metamorphism (in sample 4, the total H₂O

ACCORDANT EARLY STAGE OF RIFTING

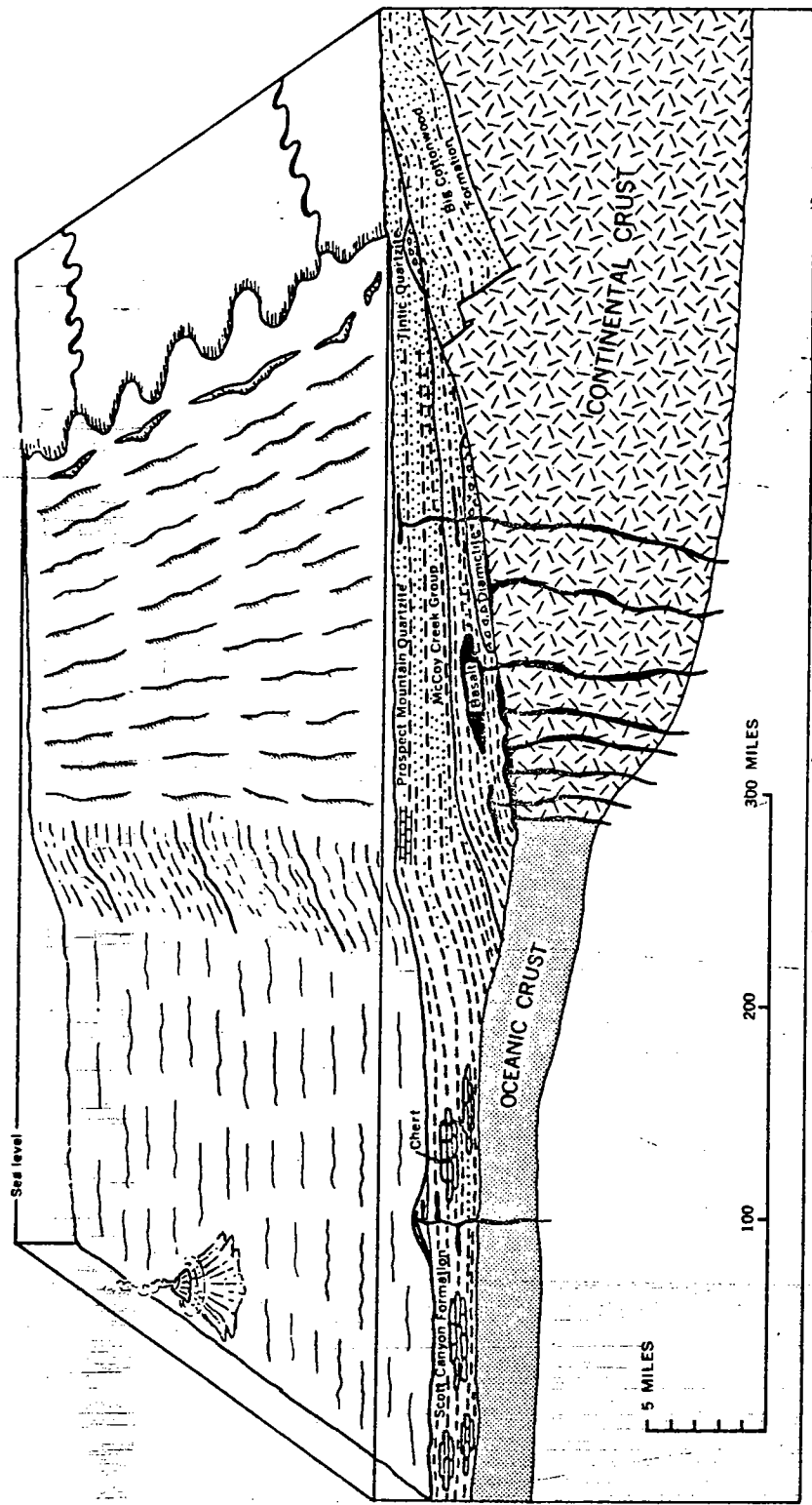


Figure 3. Diagrammatic cross section showing upper Precambrian and Lower Cambrian rocks in the northern Great Basin, Nevada and Utah.

Location	Alaska
	Yukon Territory, Canada
	Northwest Territory, Canada
	British Columbia, Canada
	Washington
	Idaho
	Utah
	Nevada
	California
	*Volcanic

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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. Lawson, 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 diamicrite or lying directly on top of it.

and CO₂ content is 12.8 percent). An average of the 8 samples (Table 4, column 1), H₂O and CO₂ 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 Fe₂O₃/FeO ratio (Engel and others, 1965). The amount of K₂O 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

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

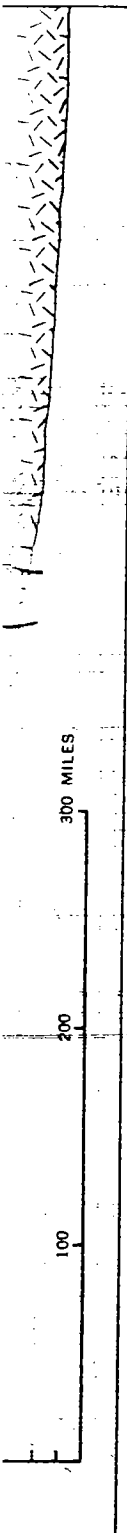


TABLE 3. CHEMICAL ANALYSES OF UPPER PRECAMBRIAN AND LOWER CAMBRIAN VOLCANIC ROCKS IN WESTERN NORTH AMERICA

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 ₂ O ₃	13.8	14.5	13.6	15.4	15.1	12.7	12.0	13.2
Fe ₂ O 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 ₂ O	2.5	1.2	5.1	2.2	1.4	1.9	.95	2.8
K ₂ O	.76	1.1	.00	.77	.82	.59	.28	.85
H ₂ O+	3.2	3.3	2.6	5.8	1.7	5.0	5.7	4.3
H ₂ O-	.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 ₂ O 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, Buckleberry 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 (H₂O AND CO₂ FREE)

	1	2	3	4	5
SiO ₂	51.7	49.94	49.84	48.16	51.86
Al ₂ O ₃	15.0	17.25	14.09	18.31	14.62
Fe ₂ O 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 ₂ O	2.5	2.76	2.15	4.05	2.99
K ₂ O	.71	.16	.38	1.69	0.74
TiO ₂	2.0	1.51	2.52	2.91	1.33
P ₂ O ₅	.40	.16	.26	.93	0.17
MnO	.18	.17	.16	.16	0.12

1. Average (H₂O and CO₂ 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 volcanic islands of the eastern Pacific Ocean (Engel and others, 1965, Table 3).

5. Average of 8 samples of Triassic basalt from New Jersey (Washington, 1933, p. 297, Table 6, col. 3).

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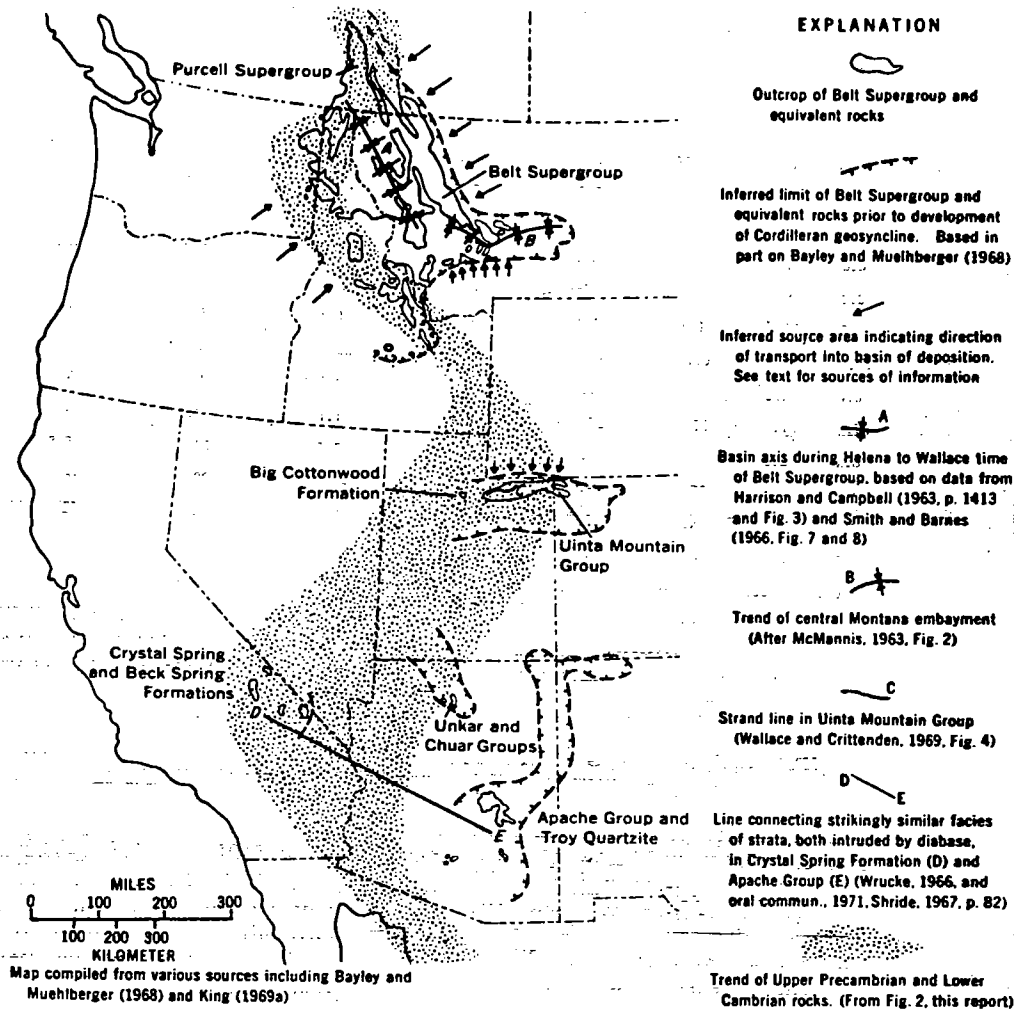


Figure 4. Comparison of distribution of upper Precambrian and Lower Cambrian strata with underlying supracrustal rocks.

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 Group². 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 ap-

²The 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.

pear 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.

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-

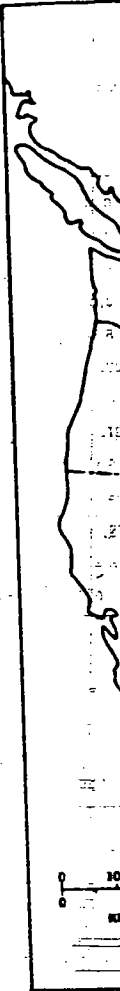


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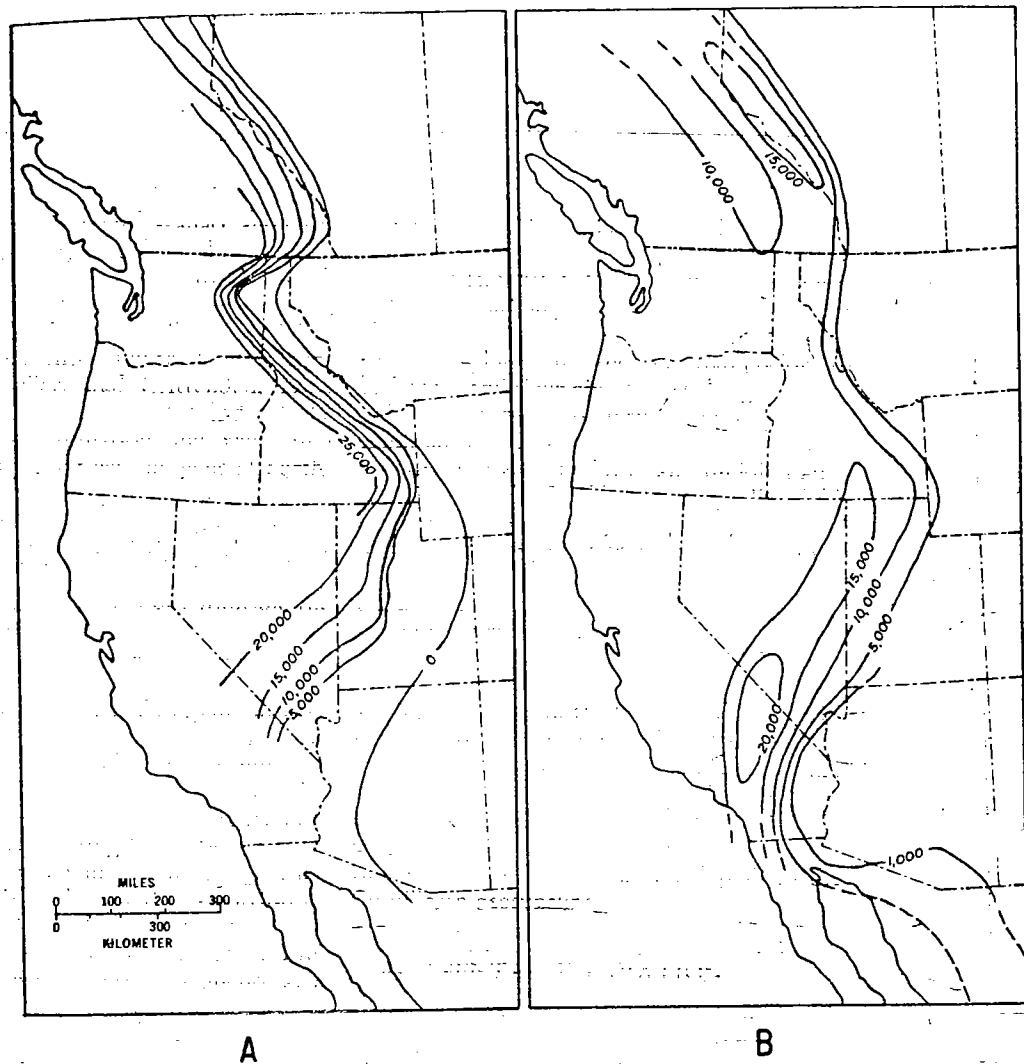


Figure 5. Comparison of isopach map (A) of Precambrian and Lower Cambrian rocks (from Fig. 2, this report) with isopach map (B) of Cambrian, Ordovician, and Silurian rocks (after Eardley, 1951, Pl. 2). Thickness in feet.

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 Pangaeon 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

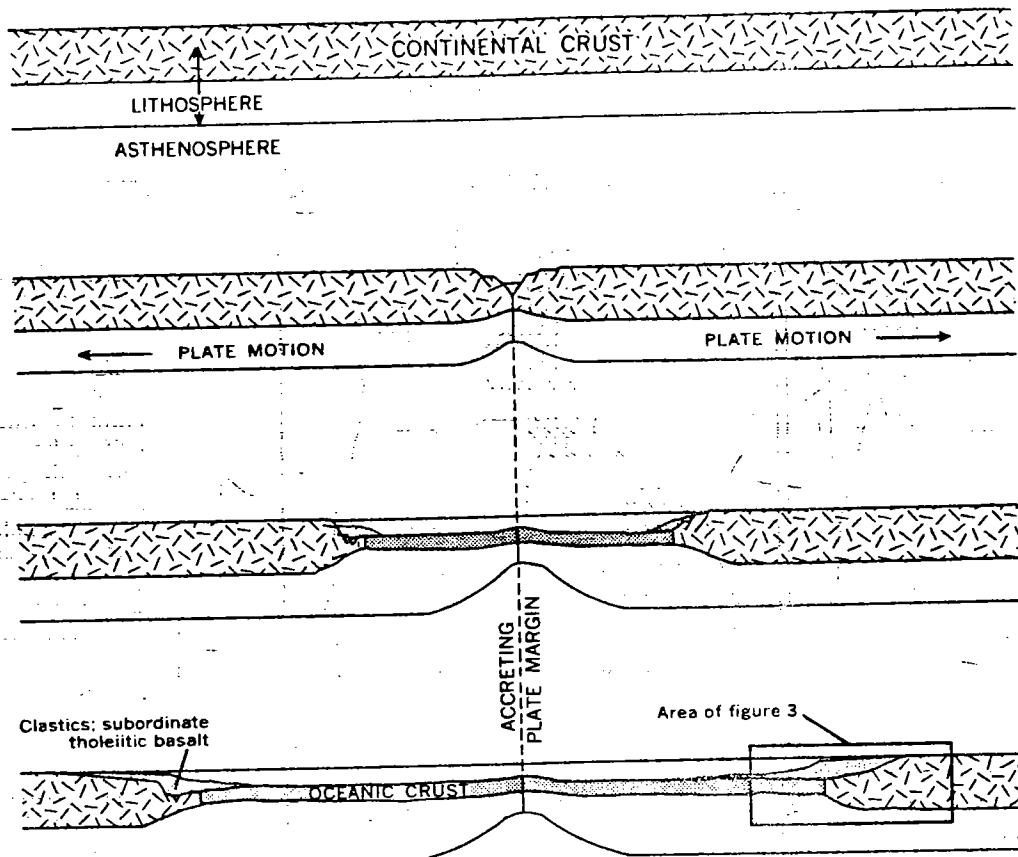


Figure 6. Diagram showing late Precambrian continental separation and deposition of the upper Precambrian and Lower Cambrian sequence. Rectangle in lower right of diagram shows position of Figure 3.

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 accumula-

tion (Drake and others, 1959; Dietz and Holden, 1967) off the east coast of the North American continent.

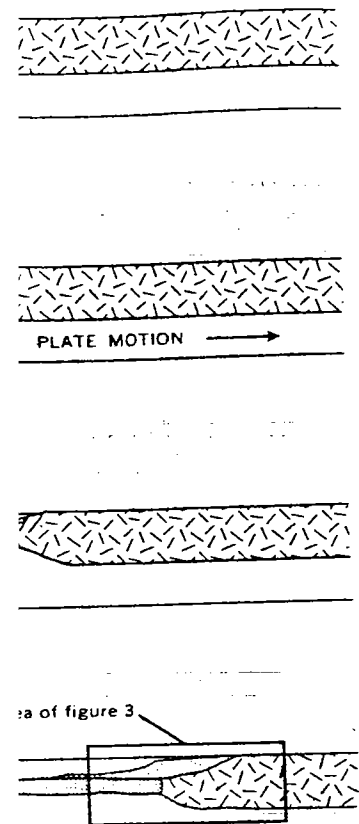
The upper Precambrian and Lower Cambrian rocks exposed in western North America are inferred to lie mostly on the continental crust (Fig. 3). Rocks of the Belt Supergroup and related strata which underlie the upper Precambrian and Lower Cambrian sequence in many parts of western North America are considered 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 Phanerozoic rock. The plutonic and metamorphic rocks of the Yukon-Tanana Complex and of the Shuswap Complex (King, 1969a) of Canada and Alaska appear to

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SUMMARY

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Lower Cambrian sequence. Rectangle in diagram shows position of Figure 3.

and others, 1959; Dietz and) off the east coast of the North continent.

Precambrian and Lower Cambrian sequence composed in western North America to lie mostly on the continental block. Rocks of the Belt Supergroup strata which underlie the upper and Lower Cambrian sequences of western North America are part of this continental block. In western North America do the Cambrian and Lower Cambrian rocks and younger rocks) rest on ultramafic crust which could be considered to be oceanic crust, if the interested here are correct, must be later Phanerozoic rock. The plutonic rocks of the Yukon Complex and of the Shuswap Complex) 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.

ACKNOWLEDGMENTS

The concept of a late Precambrian continental separation was first brought to my attention by W. R. Dickinson of Stanford University, who briefly mentioned the idea in talk he gave during early 1970. I appreciate his help, not only for the original idea, but also for subsequent interest and encouragement. I would also like to acknowledge the invaluable help of my colleagues at the Geological Survey including, in particular, E. E. Brabb, W. P. Brosgé, Michael Churkin, M. D. Crittenden, Jr., F. K. Miller, R. J. Roberts, C. T. Wrucke, and R. G. Yates, although not all of them agree entirely with the conclusions of this paper. Unpublished chemical analyses were kindly supplied by E. E. Brabb and F. K. Miller. The manuscript was improved by helpful suggestion from M. D. Crittenden, Jr., E. H. Bailey, K. C. McTaggart, and William Barnes.

REFERENCES CITED

- Aalto, K. R., 1971, Glacial marine sedimentation and stratigraphy of the Toby Conglomerate (upper Proterozoic) southeastern British Columbia, northwestern Idaho and northeastern Washington: *Canadian Jour. Earth Sci.*, v. 8, no. 7, p. 753-787.
 Abbott, W. O., 1951, Cambrian diabase flow in central Utah: *Compass*, v. 29, no. 1, p. 5-10.

- Albers, J. P., 1967, Belt of sigmoidal folding and right-lateral faulting in western Great Basin: *Geol. Soc. America Bull.*, v. 78, p. 143-156.
- Bayley, R. W., and Muehlberger, W. R., compilers, 1968, Basement rock map of the United States, exclusive of Alaska and Hawaii: U.S. Geol. Survey, 2 sheets, scale 1:2,500,000.
- Becraft, G. E., and Weis, P. L., 1963, Geology and mineral deposits of the Turtle Lake quadrangle, Washington: U.S. Geol. Survey Bull. 1131, 73 p.
- Bennett, W.A.G., 1941, Preliminary report on magnesite deposits of Stevens County, Washington: Washington Div. Mines and Geology Rept. Inv. 5, 25 p.
- Bick, K. F., 1966, Geology of the Deep Creek Mountains, Tooele and Juab Counties, Utah: Utah Geol. and Mineralog. Survey Bull. 77, 120 p.
- Bird, J. M., and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: *Geol. Soc. America Bull.*, v. 81, p. 1031-1060.
- Blackwelder, Eliot, 1910, New light on the geology of the Wasatch Mountains, Utah: *Geol. Soc. America Bull.*, v. 21, p. 517-542, 767.
- Brabb, E. E., and Churkin, Michael, Jr., 1969, Geology of the Charley River quadrangle, east-central Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-573.
- Burwash, R. A., Baadsgaard, H., Peterman, Z. E., and Hunt, G. H., 1966, Precambrian, chap. 2, in R. G. McCrossan and R. P. Glaister, eds., *Geological history of western Canada*: Calgary, Alberta Soc. Petroleum Geologists, p. 20-28.
- Cairnes, D. D., 1914, The Yukon-Alaska international boundary, between Porcupine and Yukon Rivers: Canada Dept. Mines Mem. 67, 161 p.
- Cloud, Preston, 1971, Precambrian of North America: *Geotimes*, v. 16, no. 3, p. 13-18.
- Cohenour, R. E., 1959, Sheeprock Mountains, Tooele and Juab Counties: Utah Geol. and Mineralog. Survey Bull. 63, 201 p.
- Condie, K. C., 1966, Late Precambrian rocks of the northeastern Great Basin and vicinity: *Jour. Geology*, v. 74, no. 5, pt. 1, p. 631-636.
- 1969, Geologic evolution of the Precambrian rocks in northern Utah and adjacent areas: Utah Geol. and Mineralog. Survey Bull. 82, p. 71-95.
- Coney, P. J., 1970, Geotectonic cycle and the new global tectonics: *Geol. Soc. America Bull.*, v. 81, p. 739-748.
- Crittenden, M. D., Jr., Schaeffer, F. E., Trimble, D. E., and Woodward, L. A., 1971, Nomenclature and correlation of some upper Precambrian and basal Cambrian sequences in western Utah and southeastern Idaho: *Geol. Soc. America Bull.*, v. 82, p. 581-602.
- Crittenden, M. D., Jr., Sharp, B. J., and Calkins, F. C., 1952, Geology of the Wasatch Mountains east of Salt Lake City, Parleys Canyon to Traverse Range, in Marsell, R. E., ed., *Geology of the central Wasatch Mountains, Utah*: Utah Geol. Soc. Guidebook, no. 8, p. 1-37.
- Crittenden, M. D., Jr., Stewart, J. H., and Wallace, C. A., 1972, Regional correlation of upper Precambrian strata in western North America: *Internat. Geol. Cong.*, 24th, Montreal, Canada (in press).
- Daly, R. A., 1912, North American Cordillera, forty-ninth parallel: Canada Geol. Survey Mem. 38, pt. 1, p. 144-147.
- Dewey, J. F., 1969, Continental margins—a model for conversion of Atlantic type to Andean type: *Earth and Planetary Sci. Letters*, v. 6, no. 3, p. 189-197.
- Dewey, J. F., and Bird, J. M., 1970, Mountain belts and the new global tectonics: *Jour. Geophys. Research*, v. 75, p. 2625-2647.
- Dewey, J. F., and Hørsfield, Brenda, 1970, Plate tectonics, orogeny and continental growth: *Nature*, v. 225, p. 521-525.
- Dickinson, W. R., 1970a, Global tectonics: *Science*, v. 168, p. 1250-1259.
- 1970b, The new global tectonics: *Geotimes*, v. 15, no. 4, p. 18-22.
- Dietz, R. S., and Holden, J. C., 1967, Miogeoclines in space and time: *Jour. Geology*, v. 65, p. 566-583.
- 1970, The breakup of Pangaea: *Sci. American*, v. 223, no. 4, p. 30-41.
- Drake, C. L., Ewing, W. M., and Sutton, G. H., 1959, Continental margins and geosynclines—the east coast of North America north of Cape Hatteras, in Ahrens, L. H., and others, eds., *Physics and chemistry of the earth*, Vol. 3: New York, Pergamon Press, p. 110-198.
- Eardley, A. J., 1951, *Structural geology of North America*: New York, Harper and Bros., 624 p.
- Eardley, A. J., and Hatch, R. A., 1940, Proterozoic(?) rocks in Utah: *Geol. Soc. America Bull.*, v. 51, p. 795-844.
- Engel, A.E.J., Engel, C. G., and Havens, R. G., 1965, Chemical characteristics of oceanic basalts and the upper mantle: *Geol. Soc. America Bull.*, v. 76, p. 719-734.
- Evans, C. S., 1933, Brisco-Dogtooth map area, British Columbia: Canada Geol. Survey Summ. Rept., 1932, pt. A II, p. 106-176.
- Flint, R. F., Sanders, J. F., and Rogers, J., 1960, Diamicite, a substitute term for symmictite: *Geol. Soc. America Bull.*, v. 71, p. 1809.
- Gabrielse, H., 1967, Tectonic evolution of the northern Canadian Cordillera: *Canadian Jour. Earth Sci.*, v. 4, p. 271-298.
- Gabrielse, H., Roddick, J. A., and Blusson, S. L., 1965, Flat River, Glacier Lake, and Wrigley Lake, district of Mackenzie and Yukon Territory: Canada Geol. Survey Paper 64-52, 30 p.
- Geological Society of London, 1964, *The Phanero-*

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 Hill, R. E., ed.,
 Wasatch Mountains,
 Guidebook, no. 8.
- H., and Wallace,
 Correlation of upper
 Precambrian North America:
 24th, Montreal,
- American Cordillera,
 Canada Geol. Survey
- Continental margins—a
 Atlantic type to
 Planetary Sci. Letters,
 1970, Mountain
 tectonics: Jour.
 2625-2647.
- Brenda, 1970, Plate
 continental growth:
 tectonics: Science,
 tectonics: Geotimes,
- C., 1967, Miogeo-
 Jour. Geology, v. 65,
- area: Sci. American,
 and Sutton, G. H.,
 and geosynclines—
 America north of Cape
 and others, eds.,
 the earth, Vol. 3:
 p. 110-198.
- geology of North
 and Bros., 624 p.
- A., 1940, Proter-
 Geol. Soc. America
- and Havens, R. G.,
 Characteristics of oceanic
 mantle: Geol. Soc.
 734.
- Logtooth map area,
 Canada Geol. Survey
 II, p. 106-176.
- and Rogers, J., 1960,
 term for symmetite:
 v. 71, p. 1809.
- evolution of the
 era: Canadian Jour.
- and Blusson, S. L.,
 Lake, and Wrigley
 and Yukon Ter-
 Survey Paper 64-52,
- 1964, The Phanero-
- zoic time-scale; a symposium: Geol. Soc. Lon-
 don Quart. Jour., v. 120, supp., p. 260-262.
- Green, L. H., and Goodwin, C. I., 1963, Mineral
 industry of Yukon Territory and southwestern
 district of Mackenzie: Canada Geol. Survey
 Paper 63-38, 71 p.
- Green, L. H., and Roddick, J. A., 1962, Dawson,
 Larsen Creek, and Nash Creek map areas,
 Yukon Territory (116B and CE½, 116A and
 106D): Canada Geol. Survey Paper 62-7, 20 p.
- Hansen, W. R., 1965, Geology of the Flaming
 Gorge area, Utah-Colorado-Wyoming: U.S.
 Geol. Survey Prof. Paper 490, 196 p.
- Harrison, J. E., 1971, Relation among geometry,
 sedimentation, and copper occurrences in the
 Precambrian Belt basin in Montana, Idaho,
 and Washington—a working hypothesis: Geol.
 Soc. America, Abs. with Programs (Rocky
 Mountain Sec.), v. 3, no. 6, p. 386.
- Harrison, J. E., and Campbell, A. B., 1963, Cor-
 relations and problems in Belt Series stratig-
 raphy, northern Idaho and western Montana:
 Geol. Soc. America Bull., v. 74, p. 1413-1428.
- Hazzard, J. C., 1937, Possibility of pre-Cambrian
 glaciation in southeastern California [abs.]:
 Internat. Geol. Cong., 17th, Moscow and
 Leningrad, 1937, p. 215-216.
- Hewett, D. F., 1956, Geology and mineral re-
 sources of the Ivanpah quadrangle, California
 and Nevada: U.S. Geol. Survey Prof. Paper
 275, 172 p.
- Hintze, F. F., Jr., 1913, A contribution to the
 geology of the Wasatch Mountains, Utah: New
 York Acad. Sci. Annals, v. 23, p. 85-143.
- Johnson, B. K., 1957, Geology of a part of the
 Manly Peak quadrangle, southern Panamint
 Range, California: California Univ. Pubs.
 Geol. Sci., v. 30, no. 5, p. 353-423.
- Kay, Marshall, 1951, North American geosynclines:
 Geol. Soc. America Mem. 48, 143 p.
- Kellogg, H. E., 1963, Paleozoic stratigraphy of the
 southern Egan Range, Nevada: Geol. Soc.
 America Bull., v. 74, p. 685-708.
- King, P. B., 1969a, Tectonic map of North Amer-
 ica: U.S. Geol. Survey.
- King, P. B., 1969b, The tectonics of North Amer-
 ica—a discussion to accompany the tectonic
 map of North America, scale 1:5,000,000: U.S.
 Geol. Survey Prof. Paper 628, 95 p.
- Little, H. W., 1960, Nelson map-area, west half,
 British Columbia, Canada: Geol. Survey
 Canada Mem. 308, 205 p.
- Livingston, D. E., and Damon, P. E., 1968, The
 ages of stratified Precambrian sequences in
 central Arizona and northern Sonora: Canadian
 Jour. Earth Sci., v. 5, no. 3, pt. 2, p. 763-772.
- Ludlum, J. C., 1942, Pre-Cambrian formations of
 Pocatello, Idaho: Jour. Geology, v. 50, no. 1,
 p. 85-95.
- MacDonald, G. A., and Katsura, T., 1964, Chemi-
 cal composition of Hawaiian lavas: Jour.
 Petrology, v. 5, p. 82-133.
- McMannis, W. J., 1963, LaHood Formation—a
 coarse facies of the Belt Series in southwestern
 Montana: Geol. Soc. America Bull., v. 74, p.
 407-436.
- Merifield, P. M., and Lamar, D. L., 1968, Sand
 waves and early earth-moon history: Jour.
 Geophys. Research, v. 73, no. 14, p. 4767-
 4774.
- Mertie, J. B., Jr., 1933, The Tatonduk-Nation
 district: U.S. Geol. Survey Bull. 836-E, p.
 347-443.
- Misch, Peter, and Hazzard, J. C., 1962, Stratig-
 raphy and metamorphism of Late Precambrian
 rocks in central northeastern Nevada and ad-
 jacent Utah: Am. Assoc. Petroleum Geologists
 Bull., v. 46, p. 289-343.
- Morris, H. T., and Löwering, T. S., 1961, Stratig-
 raphy of the East Tintic Mountains, Utah,
 with a section on Quaternary deposits by H. D.
 Goode: U.S. Geol. Survey Prof. Paper 361,
 145 p.
- Mountjoy, E. W., and Aitken, J. D., 1963, Early
 Cambrian and late Precambrian paleocurrents,
 Banff and Jasper National Parks: Canadian
 Petroleum Geologists Bull., v. 11, p. 160-168.
- North, F. K., 1966, [Cambrian] Cordillera, Chap. 3,
 part II, in McCrossan, R. G., and Glaister,
 R. P., eds., Geological history of western
 Canada: Calgary, Alberta Soc. Petroleum
 Geologists, p. 29-33.
- Obradovich, J. D., and Peterman, Z. E., 1968,
 Geochronology of the Belt Series, Montana:
 Canadian Jour. Earth Sci., v. 5, no. 3, pt. 2, p.
 737-747.
- Okulitch, V. J., 1956, The Lower Cambrian of
 western Canada and Alaska, in Rodgers, J.,
 ed., El Sistema Cambrico su paleogeografía y
 el problema de su base: Internat. Geol. Cong.,
 20th, Mexico City, Mexico, v. 2, p. 701-734.
- Olson, R. H., 1956, Geology of the Promontory
 Range: Utah Geol. Soc. Guidebook 11, p.
 41-75.
- Park, C. F., Jr., and Cannon, R. S., Jr., 1943,
 Geology and ore deposits of the Metaline
 quadrangle, Washington: U.S. Geol. Survey
 Prof. Paper 202, 81 p.
- Price, R. A., 1964, The Precambrian Purcell Sys-
 tem in the Rocky Mountains of southern Al-
 berta and British Columbia: Canadian Petro-
 leum Geologists Bull., v. 12 (special issue in
 Special Guide Book Issue, Flathead Valley,
 14th Ann. Field Conf., published by Alberta
 Soc. Petroleum Geologists), p. 399-426.
- Ressor, J. E., 1957, The Proterozoic of the Cordil-
 lera in southeastern British Columbia and
 southwestern Alberta: Royal Soc. Canada
 Spec. Pub. 2, p. 150-177.
- Rice, H.M.A., 1941, Nelson map area, east-half,
 British Columbia: Canada Geol. Survey Mem.
 228, 86 p.
- Roberts, R. J., 1964, Stratigraphy and structure of
 the Antler Peak quadrangle, Humboldt and

- Lander Counties, Nevada: U.S. Geol. Survey Prof. Paper 459-A, 93 p.
- Ross, J. V., 1968, Structural relations at the eastern margin of the Shuswap Complex, near Revelstake, southeastern British Columbia: *Canadian Jour. Earth Sci.*, v. 5, p. 841-849.
- Ryan, B. D., and Blenkinsop, J., 1971, Geology and geochronology of the Hellroaring Creek stock, British Columbia: *Canadian Jour. Earth Sci.*, v. 8, p. 85-95.
- Seeland, D. A., 1968, Paleocurrents of the late Precambrian to Early Ordovician (basal Sauk) transgressive clastics of the western and northern United States with a review of the stratigraphy [Ph.D. thesis]: Salt Lake City, Utah Univ., 276 p.
- Shapiro, Leonard, and Brannock, W. W., 1962, Rapid analysis of silicate, carbonate, and phosphate rocks: U.S. Geol. Survey Bull. 1144-A, p. A1-A56.
- Shride, A. F., 1967, Younger Precambrian geology in southern Arizona: U.S. Geol. Survey Prof. Paper 566, 89 p.
- Slind, O. L., and Perkins, G. D., 1966, Lower Paleozoic and Proterozoic sediments of the Rocky Mountains between Jasper, Alberta, and Pine River, British Columbia: *Canadian Petroleum Geologists Bull.*, v. 14, no. 4, p. 442-468.
- Smith, A. G., and Barnes, W. C., 1966, Correlation of and facies changes in the carbonaceous, calcareous, and dolomitic formations of the Precambrian Belt-Purcell Supergroup: *Geol. Soc. America Bull.*, v. 77, p. 1399-1426.
- Stewart, J. H., 1967, Possible large right-lateral displacement along fault and shear zones in the Death Valley-Las Vegas area, California and Nevada: *Geol. Soc. America Bull.*, v. 78, p. 131-142.
- 1970, Upper Precambrian and Lower Cambrian strata in the southern Great Basin, California and Nevada: U.S. Geol. Survey, Prof. Paper 620, 206 p.
- 1971, Late Precambrian (<750 m.y.) continental separation in western North America—possible evidence from sedimentary and volcanic rocks: *Geol. Soc. America Abs. with Programs (Cordilleran Sec.)*, v. 3, no. 2, p. 201.
- Stewart, J. H., Albers, J. P., and Poole, F. G., 1968, Summary of regional evidence for right-lateral displacement in the western Great Basin: *Geol. Soc. America Bull.*, v. 79, p. 1407-1414.
- Thorsteinsson, R., and Tozer, E. T., 1962, Banks, Victoria, and Stefansson Islands, Arctic archipelago: *Canada Geol. Survey Mem.* 330, 85 p.
- Troxel, B. W., 1967, Sedimentary rocks of late Precambrian and Cambrian age in the southern Salt Springs Hills, southeastern Death Valley, California: *California Div. Mines and Geology Spec. Rept.* 92, p. 33-41.
- Walker, J. F., 1926, Geology and mineral deposits of Windermere map-area, British Columbia: *Canada Geol. Survey Mem.* 148, 69 p.
- Wallace, C. A., and Crittenden, M. D., Jr., 1969, The stratigraphy, depositional environment and correlation of the Precambrian Uinta Mountain Group, western Uinta Mountains, Utah, in Lindsay, J. B., ed., *Geologic guidebook of the Uinta Mountains, Utah's maverick range*: *Intermt. Assoc. Petroleum Geologists 16th Ann. Field Conf.*, p. 127-141.
- Washington, H. S., 1922, Deccan traps and other plateau basalts: *Geol. Soc. America Bull.*, v. 33, p. 765-804.
- Wheeler, J. O., 1963, Rogers Pass map-area, British Columbia and Alberta (82N W $\frac{1}{2}$): *Canada Geol. Survey Paper* 62-32, 32 p.
- 1965, Big Bend map-area, British Columbia, 82M (east half): *Canada Geol. Survey Paper* 64-32, 37 p.
- White, W. H., 1959, Cordilleran tectonics in British Columbia: *Am. Assoc. Petroleum Geologists Bull.*, v. 43, p. 60-100.
- Wright, L. A., and Troxel, B. W., 1967, Limitations on right-lateral, strike-slip displacement, Death Valley and Furnace Creek fault zones, California: *Geol. Soc. America Bull.*, v. 78, p. 933-950.
- Wrucke, C. T., Jr., 1966, Precambrian and Permian rocks in the vicinity of Warm Spring Canyon, Panamint Range, California [Ph.D. thesis]: Stanford, California, Stanford Univ., 215 p.
- Yates, R. G., 1968, The Trans-Idaho discontinuity, a major tectonic feature in northwestern United States [abs.]: *Internat. Geol. Cong.*, 23d, Prague, Czechoslovakia, 1968, p. 38.
- 1970, Geologic background of the Metaline and Northport mining districts, Washington: *Washington Div. Mines and Geology Bull.* 61, p. 17-39.
- Yorath, C. J., Balkwill, H. R., and Klassen, R. W., 1969, Geology of the eastern part of the northern interior and arctic coastal plains, Northwest Territories: *Canada Geol. Survey Paper* 68-27, 29 p.
- Ziegler, P. A., 1959, Frühpaläozoische tillite im östlichen Yukon-Territorium (Kanada): *Eclogae Geol. Helvetiae*, v. 52, no. 2, p. 735-741.
- 1967, Guidebook for Canadian cordillera field trip, *Internat. Symposium on the Devonian System*: Alberta Soc. Petroleum Geologists.

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