Geosciences **2012**, *2*, 42-63; doi:10.3390/geosciences2020042

OPEN ACCESS

geosciences

ISSN 2076-3263

www.mdpi.com/journal/geosciences

Article

Distribution and Diversity of Carboniferous and Permian Colonial Rugose Coral Faunas in Western North America: Clues for Placement of Allochthonous Terranes

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Received: 3 April 2012; in revised form: 25 April 2012 / Accepted: 2 May 2012 / Published: 10 May 2012

Abstract: Colonial rugose corals are common in western cratonal North America and in some of the allochthonous terranes, now amalgamated against its western margin. Throughout the Late Paleozoic, the coral faunas in these two different settings were significantly different. Comparisons of these faunas suggest that during the Mississippian the Alexander terrane probably was southwest of Arctic Alaska and the Stikine terrane probably lay west of the southern part of the North American craton. The Cache Creek terrane lay far out in the Paleopacific Ocean. The Pennsylvanian faunas suggest that the Quesnellia and Eastern Klamath terranes were situated southwest of Arctic Alaska and the Alexander terrane was somewhat farther southwest and farther from cratonal North America. The Stikine terrane continued to be positioned west of the southern part of the North American craton. During the Early Permian, terranes with a cratonal faunal aspect may have lain 2000–3000 km west of cratonal North America and latitudinally generally southwest of their present positions. In the Middle Permian these terranes were carried southward relative to the North American craton. Simultaneously the Tethyan Realm expanded eastward.

Keywords: Carboniferous; Permian; colonial rugose corals; western North America; allochthonous terranes

1. Introduction

Western North America consists of a series of allochthonous crustal fragments, including the Alexander, Arctic Alaska, Cache Creek, Eastern Klamath, Quesnellia, Stikine, and Wrangellia terranes plastered against the North American craton, the margin of which is defined by the Sr87/Sr86 0.706 isotopic boundary, e.g., [1,2]. The geographic position of these terranes through time is a major question. Interpretations of these positions have been based on paleomagnetic data, e.g., [3], on detrital zircon analyses and other geologic data, e.g., [4], and on the distribution of fossils, e.g., [5]. Here I will consider the geographic position of terranes in the Carboniferous and Permian based on colonial rugose corals which occur both on cratonal North America and in several of the allochthonous terranes, with constraints based on paleomagnetic data.

Over all, Carboniferous and Permian colonial rugose coral faunas show periods of high diversity alternating with periods characterized by low diversity. Mississippian and Early Permian colonial coral faunas are large and well known, and have been studied extensively. Pennsylvanian and Middle Permian faunas, on the other hand, are meager and have received less attention.

Analyses of the distribution of colonial rugose corals throughout the Carboniferous and Permian show that these faunas fall into three groups: those of cratonal North America, those of most allochthonous terranes which have coral faunas related to those of cratonal North America, and those possessing a vastly different Tethyan fauna, e.g., [5]. The present locations of terranes, including Arctic Alaska which had been accreted to Laurentia by early Late Devonian time [4], are shown in Figure 1.

Placement of terranes through time based on faunal analyses must be speculative. The similarity of faunas appearing in different regions may be due to similar environments, long-distance dispersal by currents, or geographic proximity. Here, based primarily on the degrees of similarity of colonial rugose coral faunas among the terranes and with cratonal North America, the paleogeography is interpreted on the assumption that similarity or lack of it was due to distance between faunas compared.

Here I will first summarize knowledge on the colonial rugose coral faunas of the Mississippian, Pennsylvanian, Early Permian, and Middle Permian, and then use these data to interpret the location of the various terranes relative to one another and to the North American craton. Data on Carboniferous genera [6–10] are shown on Table 1 and distribution of Mississippian species is shown on Table 2. The present paper also includes information on the Late Paleozoic faunas of the North American craton [11] and that on three of the terranes, including the Stikine terrane [10] and the Eastern Klamath and Alexander terranes, the faunas of which are currently being studied. All of the Permian data have been shown on previously published tables [12].

Figure 1. Location of major terranes considered here and approximate western margin of the North American craton.

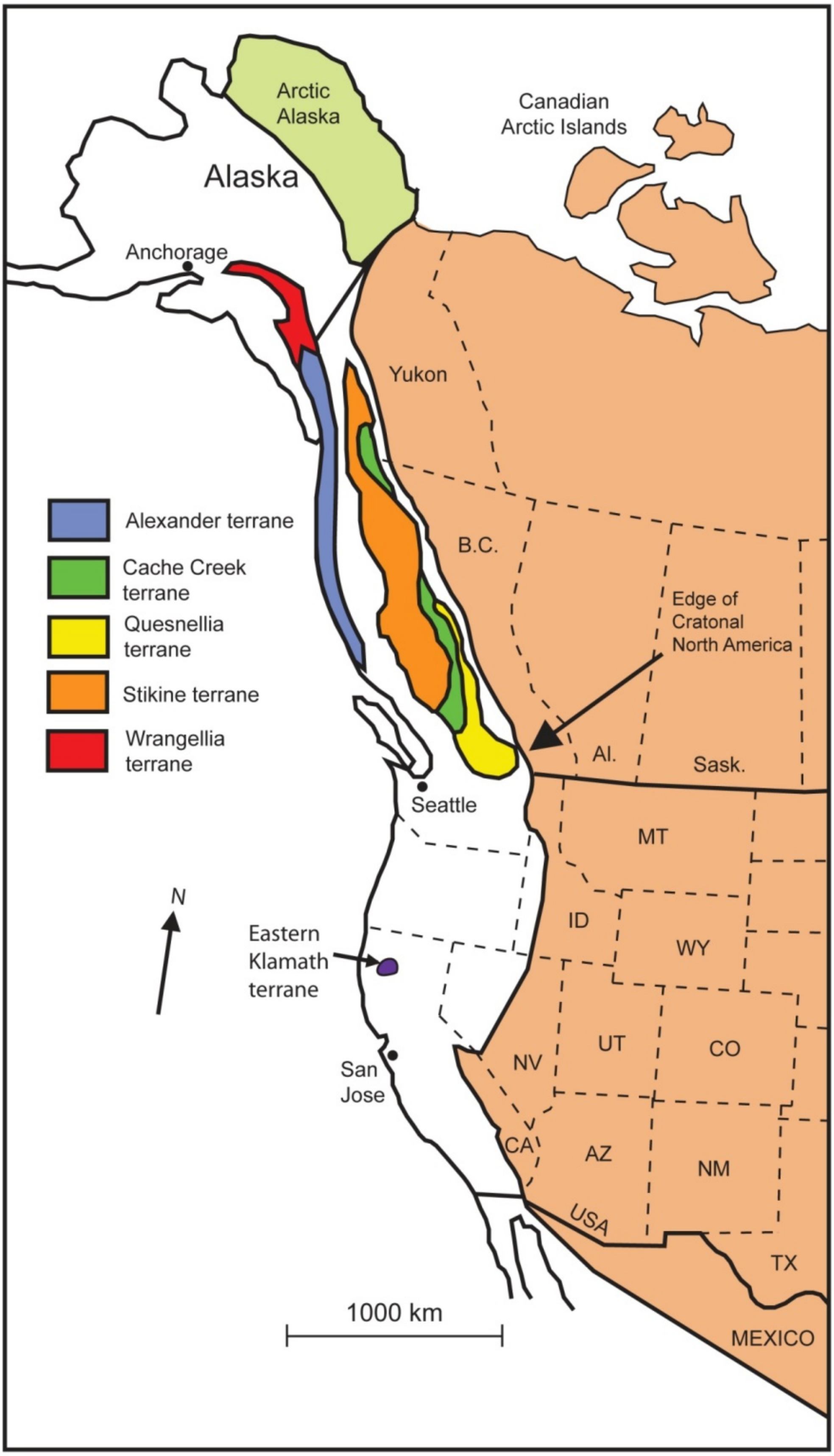


Table 1. Carboniferous Colonial Rugose Coral Genera. Cord = Cordilleran miogeocline; Arctic = Arctic Alaska; Alex = Alexander terrane; Stikine = Stikine terrane.

GENERA	MISSISSIPPIAN				PENNSYLVANIAN				
	Cord.	Arctic	Alex.	Stikine	Cord.	Arctic	Alex.	Stikine	Klamath
Acrocyathus	+		+						
Actinocyathus	+		+						
Corwenia?						+			+
Cystolonsdaleia	+			+	+				
"Diphyphyllum"	+	+	+						
Dorlodotia?	+								
Durhamina					+				
Eastonastraea				+					
Fedorowskiella								+	
Fomichevella					+			+	
Heintzella				+	+			+	
Heritschioides						?	+		+
Lonsdaleia					+				
Lonsdaleoides				+					
Nemistium				+				+	
Paraheritschioides					+		+	+	
Pararachnastraea						?			+
Petalaxis	+				+				
"Pseudodorlodotia"	+								
Schoenophyllum	+								
Sciophyllum	+	+	+						
Siphonodendron	+	+	+						
Stelechophyllum	+	+	+						
"Thysanophyllum"	+	+	+						
2 new genera							+		

Table 2. Mississippian Colonial Rugose Coral Species. Canada = Canadian Cordillera; Arctic = Arctic Alaska; Alex = Alexander terrane.

Species	Canada	Arctic	Alex	Species	Canada	Arctic	Alex
Acrocyathus pennsylvanica	+		+	*Siphonodendron warreni*	+	+	+
Actinocyathus peratrovichensis			+	*Stelechophyllum banffensis*	+	+	+
"Diphyphyllum" klawockensis			+	*Stelechophyllum birdi*		+	+
"Diphyphyllum" venosum			+	*Stelechophyllum macouni*	?	+	
Sciophyllum alaskaensis		+	+	*Stelechophyllum mclareni*	+	+	
Sciophyllum lambarti	+	+		*"Thysanophyllum" astraeiforme*	+	+	+
Siphonodendron sinuosum	+	+		*"Thysanophyllum" orientale*	?	+	
Siphonodendron succinctus			+				

2. Mississippian Faunas

The greatest development of colonial rugose corals in the Mississippian of the western interior of North America (the Cordilleran miogeocline) was in the Meramecian (Viséan) [8]. For this paper the faunas of this age in the western Interior of Canada [8], Arctic Alaska [7], and the Alexander [6] and Stikine [10] terranes are compared. The Cache Creek terrane contains a completely different fauna [9].

2.1. Western Interior Province of Canada

The rich Mississippian coral faunas in the western interior of North America [8] have been summarized previously. That work [8] indicated the presence of species in the Canadian Interior belonging to the genera *Acrocyathus*, *Actinocyathus*, *Cystolonsdaleia*, "*Diphyphyllum*", *Dorlodotia*?, *Petalaxis*, "*Pseudodorlodotia*", *Schoenophyllum*, *Sciophyllum*, *Siphonodendron*, *Stelechophyllum*, and "*Thysanophyllum*" (Table 1). This fauna declined in richness from coral zone IV of late Meramecian age (late Viséan) into coral zone VI of late Chesterian (Serpukhovian) age [8]. Coral zone V in the lower and middle Chesterian (late Viséan and early Serpukhovian) still contained some colonial corals (two cerioid and two fasciculate forms), but in foraminiferal zone 18 (late Serpukhovian) only *Actinocyathus* and *Petalaxis* are recorded [8]. By coral zone VI only the cerioid genera *Petalaxis* [8] and *Cystolonsdaleia* [11], which continued into the Pennsylvanian, apparently are present.

2.2. Faunas of Allochthonous Terranes

A rich colonial coral fauna from the Peratrovich Formation in the Alexander terrane has already been studied [6]. This fauna contains 10 species of colonial corals, both fasciculate and cerioid, representing the genera *Acrocyathus*, *Actinocyathus*, "*Diphyphyllum*", *Sciophyllum*, *Siphonodendron*, *Stelechophyllum*, and "*Thysanophyllum*". These corals suggest a Meramecian (Serpukhovian) age.

Another Mississippian fauna was described from the Koguk Formation of Arctic Alaska [7]. This fauna contains 10 species representing the genera *Sciophyllum*, *Siphonodendron*, *Stelechophyllum*, and *Thysanophyllum*". "*Diphyphyllum*" is present elsewhere in Arctic Alaska [7]. This fauna in Arctic Alaska became exterminated in the latest Meramecian (Serpukhovian).

The fauna of the Stikine terrane consists of *Cystolonsdaleia*, *Eastonastraea*, *Heintzella*, *Lonsdaleoides* and *Nemistium* [10]. These corals occur in strata containing zone 18 foraminifera (late Serpukhovian).

A small colonial coral fauna of Serpukhovian age (foram Zone 18) from the Horsefeed Formation in the Cache Creek terrane has already been described [9]. It includes a species of *Siphonodendron* with well defined axial and periaxial zones within the tabularium, characteristics not previously described from North American species, and a compound coral belonging to the Family Pseudopavonidae, a family otherwise known only from Japan and one locality in China [13].

2.3. Faunal Relationships

Of the genera represented in the faunas of the Canadian Interior, Arctic Alaska, and the Alexander terrane five ("*Diphyphyllum*", *Sciophyllum*, *Siphonodendon*, *Stelechophyllum*, and "*Thysanophyllum*") occur in all three regions. *Acrocyathus* and *Actinocyathus* are not recorded from Arctic Alaska, and

Cystolonsdaleia, *Dorlodotia*?, *Petalaxis*, "*Pseudodorlodotia*", and *Schoenophyllum* are not recorded from either Arctic Alaska or the Alexander terrane. Thus, on the generic level, the faunas of the Canadian Interior, Arctic Alaska, and the Alexander terrane are similar although the Canadian Interior contains many genera not represented in either Arctic Alaska or the Alexander terrane. The fauna of the Alexander terrane is more similar to that of the Canadian Interior than to that of Arctic Alaska as it contains *Acrocyathus* and *Actinocyathus*, genera not present in Arctic Alaska.

On the specific level, all three areas (the Canadian Interior, Arctic Alaska, and the Alexander terrane) have three species in common. In addition, five species belonging to the genera *Sciophyllum*, *Siphonodendron*, *Stelechophyllum* (2 species) and "*Thysanophyllum*" are common to both Arctic Alaska and the Alexander terrane (Table 2). Arctic Alaska has between six and eight species in common with the Canadian Interior, and the Alexander terrane has five species in common with that part of Canada. Thus, the Alexander terrane has a similar number of species in common with both Arctic Alaska and the Canadian Interior, but it evidently has four endemic species whereas Arctic Alaska has none.

The fauna from the Stikine terrane does not compare closely with any of the other faunas in western North America. Although *Cystolonsdaleia* also occurs in both the Stikine terrane and the Canadian Interior, the Stikine fauna is much more diverse and contains a number of solitary and colonial coral genera of Mississippian age not present at a comparable time in cratonal North America. These genera (*Dibunophyllum*, *Heintzella*, *Nemistium*, and *Palaeosmilia*), however, occur in Euramerica and northwest Gondwana, including North Africa, where they occur at the same level [10].

The fauna of the Cache Creek terrane shows no affinity to any other fauna in North America.

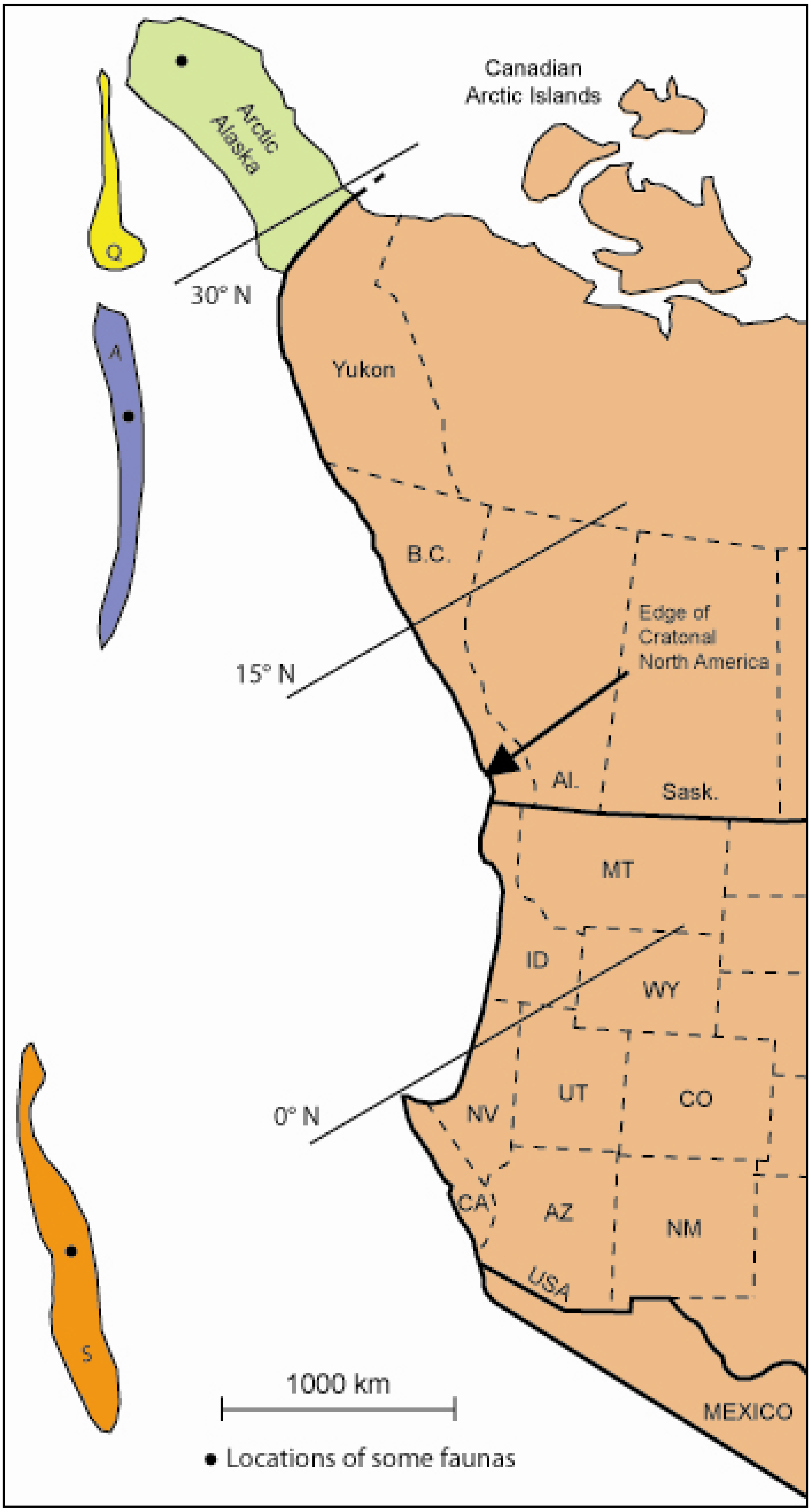
The rich coral faunas of the Viséan began to be depleted in the latter part of that Stage with few genera persisting into the Serpukhovian and only two or three continuing into the Pennsylvanian. This widespread decimation of colonial coral faunas may have been triggered by glaciations [14].

2.4. Interpretation of Terrane Placement

The faunas of the Alexander terrane and those of Arctic Alaska and the Canadian Interior are similar at the specific level. The presence in the Alexander terrane of *Acrocyathus* and *Actinocyathus*, genera not present in Arctic Alaska, suggests a position farther to the south. The lack of five genera in the Alexander terrane present in the Canadian Interior, however, suggests that this terrane may have been located near the northern limit of the faunas of the Canadian Interior. The similarities between the fauna of the Alexander terrane and those of the Canadian Interior and Arctic Alaska also suggest that that terrane was not far removed from cratonal North America, as shown in Figure 2.

The Stikine terrane is characterized by Euramerican and North African genera, indicating an exchange of faunas along the southern margin of Euramerica during the late Serpukhovian, probably driven by an east-to-west-flowing warm-water current [10]. This tends to suggest that the Stikine terrane lay at a latitude of about the southern part of the North American craton, substantially south of the Alexander terrane. The lack of this fauna on cratonal North America also may suggest that this terrane lay a substantial distance to the west. A possible placement of the Stikine terrane is shown on Figure 2.

Figure 2. Interpreted Mississippian position of allochthonous terranes. A = Alexander; Q = Quesnellia; S = Stikine terranes. Paleolatitudes for cratonal North America are from Scotese and McKerrow [15].



The Cache Creek terrane is interpreted to have been located far out in the Paleopacific Ocean. It may be one of several dispersed fragments of a terrane, most of which are now in Japan and one of which is now in China [13].

The Quesnellia terrane is shown here because it may be Serpukhovian in age, but as the single colonial coral known from that terrane is closely related to corals elsewhere known to be Bashkirian, that coral is here considered early Bashkirian. Therefore, the fauna of this terrane is described along with other Pennsylvanian faunas.

3. Pennsylvanian Faunas

Pennsylvanian faunas are known from cratonal North America, Arctic Alaska, and a number of allochthonous crustal fragments along the western margin of the craton, including the Alexander, Eastern Klamath, Quesnellia, and Stikine terranes.

3.1. Faunas of Cratonal North America

Pennsylvanian colonial rugose corals are uncommon on the North American craton. South of the Arctic only two genera of cerioid corals are known: *Petalaxis* from the Viséan-Kasimovian or Gzhelian of Canada [11] and one specimen from Desmoinesian (Moscovian) rocks in the Death Valley area of eastern California [16], and *Cystolonsdaleia* from the middle Viséan-Kasimovian or -early Gzhelian in Canada [11].

A number of fasciculate corals appeared in the cratonal faunas beginning with the introduction of a few new genera in the Bashkirian: the genus *Heintzella* from the Bashkirian-Gzhelian in north-central USA and *Paraheritschioides* from Bashkirian-Moscovian in Arctic Canada [11]. In addition, *Lonsdaleia* is present in Arctic Canada [17] (personal communication). Later, in the Moscovian, *Fomichevella* appeared in the Canadian Arctic [11] and even later a species of *Durhamina* appeared in the Gzhelian of Nevada [18].

3.2. Faunas of Allochthonous Terranes and Arctic Alaska

Several colonial rugose coral faunas of Pennsylvanian age totally different from those in cratonal North America are now known from Arctic Alaska, the Alexander terrane, the Eastern Klamath terrane, the Quesnellia terrane, and the Stikine terrane. Three of the five areas contain both cerioid and fasciculate forms.

The Arctic Alaska fauna [19] contains the fasciculate coral *Corwenia*? *jagoensis* Armstrong, which may include more than one species, and a cerioid coral referred to as *Lithostrotionella wahooensis* which could belong in the genus *Pararachnastraea*. *Heritschioides* also may be present. The age of this fauna was considered [19] to be Atokan (Bashkirian).

The fauna from the Alexander terrane, currently being described, is moderately diverse. It contains fasciculate corals including three species of *Heritschioides* and one of *Paraheritschioides*, and two new cerioid genera. These corals were collected from units dated as Bashkirian and Moscovian in age [20] (personal communication).

A fauna from the Baird Formation in the Eastern Klamath terrane [21] contains the fasciculate corals *Corwenia? jagoensis* Armstrong? and a new species of *Heritschioides*, and three species of the cerioid genus *Pararachnastraea.* This fauna occurs with foraminifera indicating an early Atokan (Bashkirian) age.

The fauna of the Quesnellia terrane is poorly known. However, the type species of *Heritschioides* of late Serpukhovian, or more likely early Bashkirian age [11], occurs in this fauna.

The Pennsylvanian (Bashkirian) fauna in the Stikine terrane [10] consists of *Fedorowskiella*, *Fomichevella*, *Heintzella*, *Nemistium*, and *Paraheritschioides*. This fauna is associated with foraminiferal zone 20 (Bashkirian).

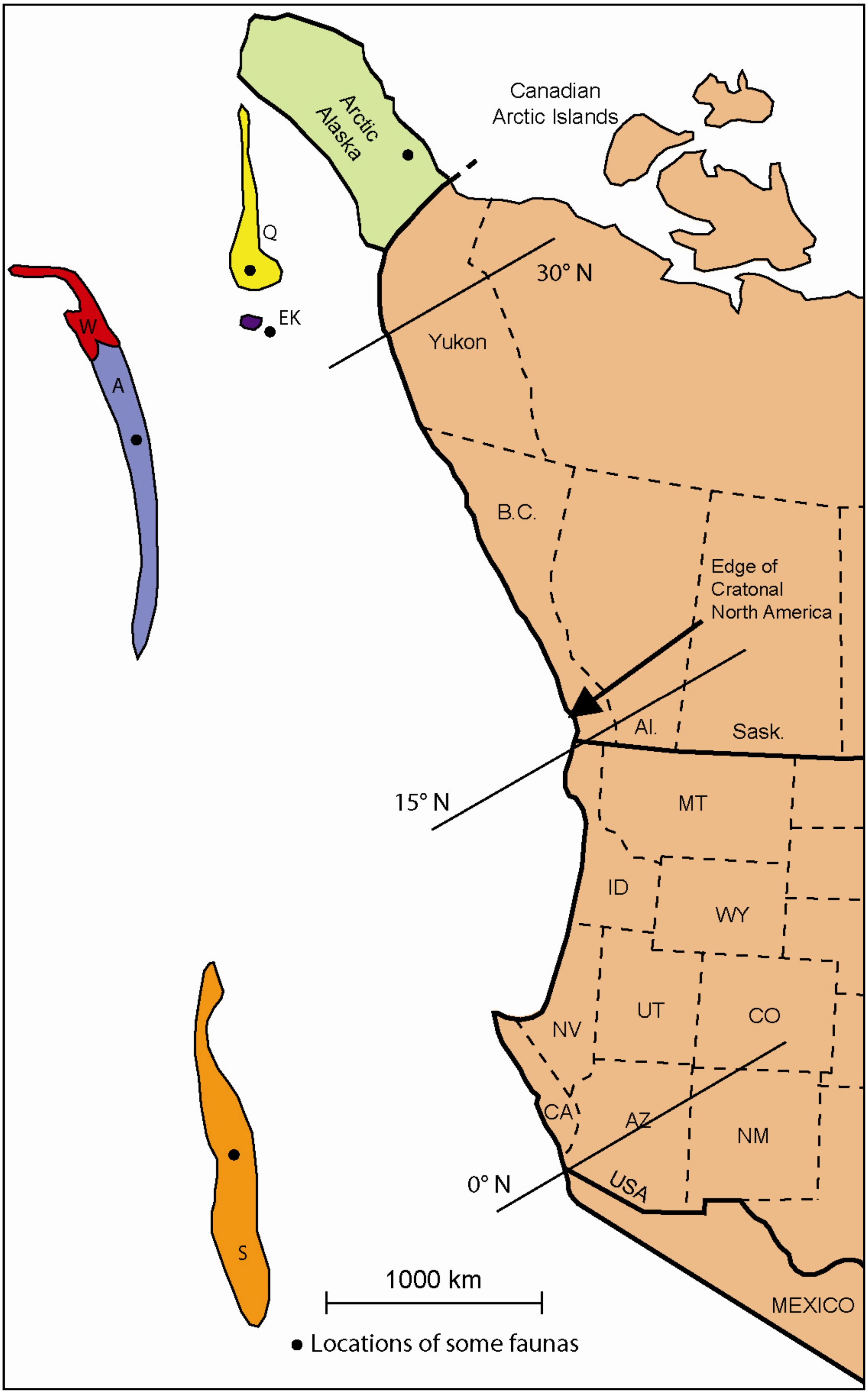
3.3. Faunal Relationships

In the early part of the Pennsylvanian the colonial coral fauna of the North American craton was completely different from that of the terranes. Among several terranes, however, there are some similarities. The Quesnellia terrane is not known to contain any cerioid forms, but it does contain the fasciculate genus *Heritschioides* which also is present in the Alexander terrane, the Eastern Klamath terrane, and perhaps Arctic Alaska. The Eastern Klamath terrane fauna also contains the Arctic Alaska species *C.* ? *jagoensis* and cerioid species, here considered to belong to *Pararachnastraea*, resembling a form from Arctic Alaska. The Alexander terrane fauna is highly endemic with two previously unrecognized cerioid genera. Several genera (*Fomichevella*, *Heintzella*, and *Paraheritschioides)* occur in both the Stikine terrane and on the North American craton, although the first of these genera appeared in cratonal North America later. The Stikine fauna also differs from that of cratonal North America in containing *Nemistium* and *Fedorowskiella. Paraheritschioides* occurs in the Alexander terrane, as well as in the Stikine terrane, but the other members of those faunas are very different.

3.4. Interpretation of Terrane Placements in the Pennsylvanian

The colonial rugose coral fauna of the Eastern Klamath terrane, which contains a species of *Heritschioides*, is similar to that of the Arctic Alaska but quite different from that of the central part of the North American miogeocline suggesting a position in the vicinity of Arctic Alaska. On Figure 3 it is placed southwest of Arctic Alaska. The Quesnellia terrane, which also contains *Heritschioides*, probably was also located in the general vicinity. During the Late Paleozoic the Alexander and Wrangellia terranes were amalgamated [22, 23], as shown here (Figure 3). The presence of *Heritschioides* in the Alexander terrane allies it to the Eastern Klamath terrane, the Quesnellia terrane, and perhaps Arctic Alaska. However as the Alexander terrane also contains two endemic cerioid genera, it is shown here to be located farther out in the Paleopacific Ocean southwest of the Eastern Klamath and Quesnellia terranes. The Stikine terrane has a colonial coral fauna containing one typical Euramerican and northern Gondwanan genus (*Nemistium*), one endemic genus (*Fedorowskiella*), and three cratonal North American genera which, except for *Paraheritschioides* and possibly *Heintzella*, did not appear on the craton until later [10]. This may imply that this terrane possibly still lay offshore at the latitude of the southern part of the North American craton.

Figure 3. Interpreted Pennsylvanian position of allochthonous terranes. A = Alexander; EK = Eastern Klamath; Q = Quesnellia; S = Stikine; W = Wrangellia terranes. Paleolatitudes for cratonal North America are from Scotese and McKerrow [15].



4. Early Permian Faunas

In the Early Permian colonial coral faunas originating in the Uralian region dispersed in at least two waves along the margin of cratonal North America and to many of the terranes [24]. Terranes containing Early Permian colonial rugose corals include the Eastern Klamath, Quesnellia, and Stikine terranes, which constitute the McCloud Belt [25], and the Wrangellia terrane. All of these faunas, as well as those on the northern and western margins of Pangaea, stretching from the Ural Mountains to South America, are related and have been referred to as the Cordilleran-Arctic-Ural (CAU) Realm [11].

4.1. Faunas of cratonal North America

Colonial rugose corals have been tabulated [12] for four areas on the craton (Texas, Cordilleran miogeocline in California and Nevada, western Canada, and Canadian Arctic Islands), the major terranes of the McCloud Belt (Stikine and Eastern Klamath terranes), and the Wrangellia terrane. Additional data not included in that report also have been published [17,26], respectively. A Tethyan coral of this age is known only from pebbles in a Triassic conglomerate in Oregon [27].

On the North American craton highly diverse faunas of colonial rugose corals of Early Permian age are known only from the Cordilleran miogeocline in California and Nevada and the Canadian Arctic [12]. In the Cordilleran miogeocline species of *Protowentzelella* and *Durhamina* dominate followed by species of *Sandolasma*, *Permastraea*, and *Paraheritschioides*, with a moderate representation of *Petalaxis*, *Kleopatrina*, *Fomichevella*, *Shastalasma*, and *Heintzella.* Two genera (*Shastalasma* and *Petalaxis*) are not reported from elsewhere on cratonal North America, whereas *Sandolasma* and *Wilsonastraea* are known elsewhere on the craton only in Texas.

The Canadian Arctic fauna is quite different from that of California and Nevada, being dominated by *Protowentzelella* followed by *Permastraea* and *Kleopatrina*. Other moderately important genera in this region are *Fomichevella*, *Paraheritschioides*, and *Protolonsdaleiastraea*, a genus unknown elsewhere on the craton. In the western Canadian fauna only *Protowentzelella* and *Kleopatrina* are represented by more than one species and this fauna differs from that in the Canadian Arctic in being generically much less diverse, containing the genus *Durhamina*, which is common along the cratonal margin to the south, and lacking *Protolonsdaleiastraea.*

Only six genera, most represented by only one species and all of which also occur in the Cordilleran miogeocline, are present in Texas. No Permian colonial corals are known from Arizona or western New Mexico.

Thus, on the basis of the above observations, four Early Permian cratonal coral faunal assemblages, those in Texas, Cordilleran miogeocline of Nevada and California, western Canada, and Arctic Canada, are relatively distinct.

4.2. Faunas of the Terranes

Among the terranes only the Stikine and the Eastern Klamath terranes contain relatively diverse colonial coral faunas [12]; very few corals are known from the Quesnellia terrane, which has not been well studied, and the Wrangellia terrane [26]. The faunas in the Stikine and Eastern Klamath terranes are similar in some respects, but are quite different in detail. In the Eastern Klamath terrane species of

Petalaxis are the most numerous followed by those of *Durhamina*, *Pararachnastraea*, *Wilsonastraea*, *Shastalasma*, and *Kleopatrina.* Among the most diverse genera in the Stikine terrane, *Lytvophyllum*, *Iskutella*, *Fomichevella* and *Cystolonsdaleia* replace *Durhamina*, *Pararachnastraea*, *Shastalasma* and *Kleopatrina* in the Eastern Klamath terrane in importance.

The few corals reported from the Quesnellia terrane are similar to those in other parts of the McCloud Belt. The fauna of the Wrangellia terrane is slightly less sparse than that of Quesnellia, with eight genera represented by one species each. All genera in this terrane also are present in the McCloud Belt. Thus, although there are differences between the faunas of these four terranes (Eastern Klamath, Quesnellia, Stikine and Wrangellia), there are also important similarities (e.g., the presence of *Lytvophyllum*, which is unknown on the North American craton, but which appears in all of these terranes).

4.3. Faunal Relationships

Early Permian faunas on the craton are considerably different from those in the terranes. Four genera (*Sandolasma*, *Cordillerastraea*, *Tschussovskenia*, and *Permastraea*) are restricted to the craton. Another four genera (*Iskutella*, *Langenheimia*, *Lytvophyllum*, *and Cystolonsdaleia*) are restricted to the terranes. Of the genera restricted to the terranes, all four occur in both the Eastern Klamath and Stikine terranes, and two of the four are recorded from both the Quesnellia and Wrangellia terranes. Thus, faunas of these terranes are somewhat similar.

The Early Permian faunas on the craton span about 40° of latitude from Texas to the Canadian Arctic. As latitude imposes important constraints on the distribution of animals of all types, attempts have been made to ascertain the importance of latitude in controlling the distribution of colonial rugose corals by comparing those occurring at different latitudinal positions on the craton [12].

As shown by the distribution of genera of colonial rugose corals on the craton [12], some are cosmopolitan, whereas others are restricted to specific latitudes, probably because of differences in the water temperatures. Diverse faunas represented in the southern part of the Cordilleran miogeocline lived at low paleolatitudes (about 8°–15°), whereas those of the Canadian Arctic were located at relatively high paleolatitudes (35°–40°). Here these two faunal assemblages are used as a starting point for consideration of the significance of latitude in controlling distribution of Early Permian colonial coral genera. Data [12] show that in the miogeocline in California and Nevada, five genera (*Durhamina*, *Sandolasma*, *Wilsonastraea*, *Shastalasma*, and *Petalaxis*) do not occur in the Canadian Arctic, whereas *Protolonsdaleiastraea*, which is known from the Canadian Arctic, is not present elsewhere on the craton. These genera, therefore, appear to be latitudinally restricted and are here referred to as miogeocline-indicative and Arctic-indicative genera.

Further comparisons show that one genus in the miogeocline in California and Nevada (*Sandolasma*) occurs elsewhere only in Texas. This genus therefore apparently was confined to the most southerly parts of the craton. Two other genera (*Petalaxis* and *Shastalasma*), both missing from the Canadian Arctic, western Canada, and Texas, occur in the miogeocline of Nevada and California. Thus, they evidently are restricted to higher latitudes than Texas and lower latitudes than western Canada. As mentioned previously *Protolonsdaleiastraea* is confined to the high latitudes of the Canadian Arctic. Thus, four belts defined by colonial rugose corals can be recognized: an equatorial belt including Texas and the southern part of the miogeocline, extending to about 10° north of the paleoequator, a central miogeoclinal belt including most of Nevada and California and extending from about 10°–20° N, a northern miogeoclinal belt including western Canada and extending from about 20°–30° N, and an Arctic belt extending from 30°–40° N.

Using this information on temperature-sensitive genera, the latitudinal placement of the terranes during the Early Permian can be interpreted. The Eastern Klamath terrane contains four of the five miogeocline-indicative coral genera, lacking only *Sandolasma*, which also occurs in the equatorial belt, and it lacks *Protolonsdaleiastraea*, the Arctic-indicative genus. Thus, this fauna is allied to that of the central miogeocline.

The poorly studied Quesnellia terrane has yielded only two miogeocline-indicative genera (*Wilsonastraea* and *Petalaxis*), and it apparently lacks *Protolonsdaleiastraea*. The Stikine terrane has three miogeocline-indicative coral genera (*Durhamina*, *Wilsonastraea*, and *Petalaxis*), but it also contains *Protolonsdaleiastraea*. The Wrangellia terrane, which also contains *Protolonsdaleiastraea*, has only two miogeocline-indicative genera (*Durhamina* and *Wilsonastraea*). The progressive decrease in miogeocline-indicative genera from the Eastern Klamath terrane, through the Quesnellia and Stikine terranes, to the Wrangellia terrane, and the appearance of *Protolonsdaleiastraea* in the two latter terranes suggest increasingly higher paleolatitudes.

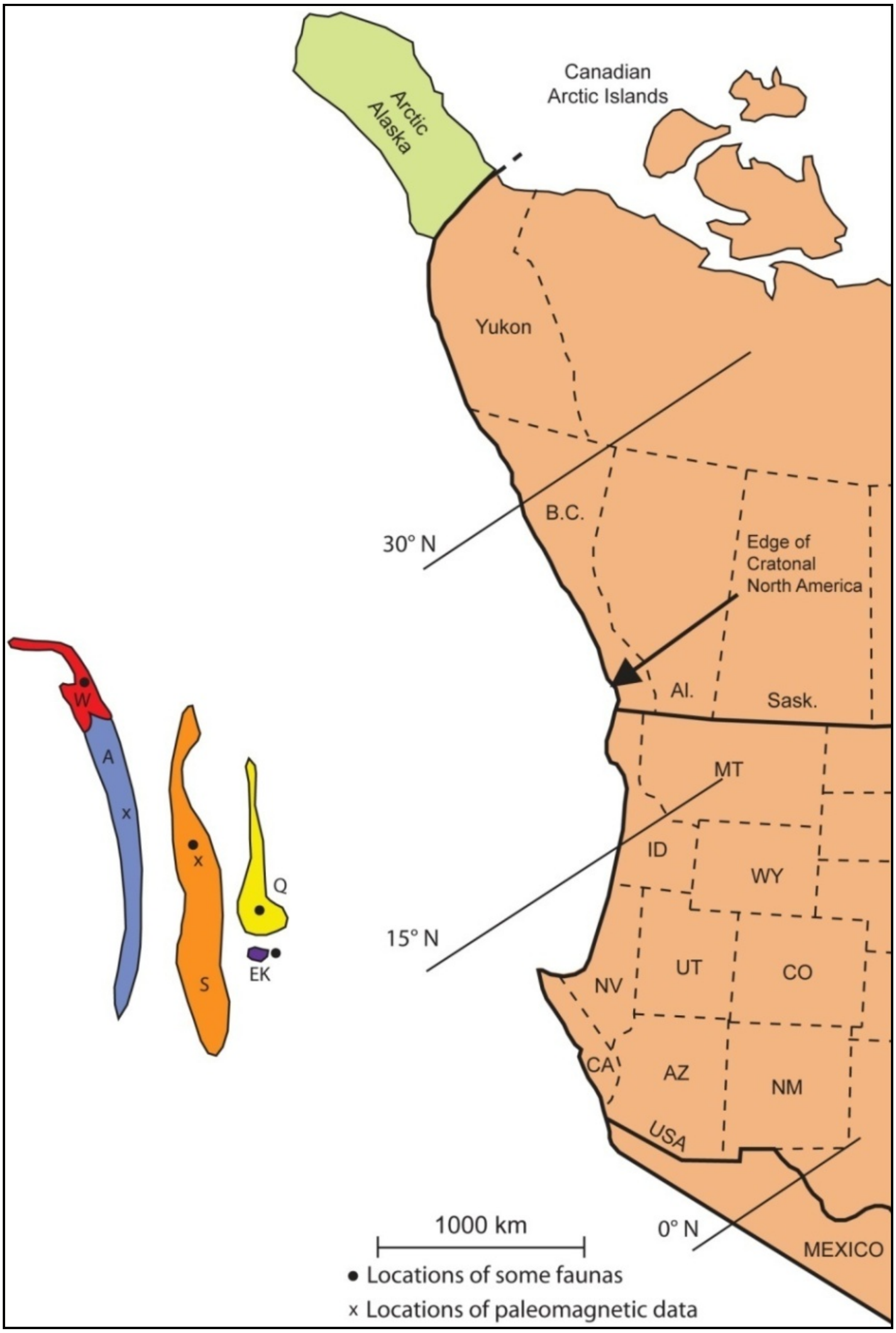
The only known Early Permian Tethyan colonial rugose coral in western North America, which occurs in pebbles in a Triassic conglomerate in central Oregon [27], belongs to a family (the Waagenophyllidae) not represented in the CAU Realm. This coral, however, is similar to species of the Tethyan genus *Yokoyamaella*, thus suggesting an origin from a Tethyan terrane, which originally was far removed from cratonal North America and the non-Tethyan terranes in the Early Permian.

4.4. Interpretation of Terrane Placements in the Early Permian

The terranes under consideration can be placed latitudinally on the basis of the coral faunas present, assuming that water temperatures, which almost surely decreased northward, played a significant role in determining the faunas present. The placement of these terranes is shown on Figure 4. A moderately high latitudinal position for the central Stikine terrane (see location on Figure 4) is suggested by the presence of three miogeocline-indicative colonial coral genera and the Arctic-indicative coral genus *Protolonsdaleiastraea*. This position is compatible with the paleomagnetic data which show that the central part of the Stikine terrane was at a position of about 23° N [28] in the Early Permian. Thus, the available data suggest placement of the central part of the Stikine terrane at a little higher paleolatitude than the Canada-USA border.

The Eastern Klamath terrane has a higher diversity of colonial corals than the Stikine terrane, has more miogeocline-indicative colonial coral genera, and lacks the Arctic-indicative coral *Protolonsdaleiastraea.* Therefore, it should be placed south of the central part of the Stikine terrane. Although the coral fauna of the Eastern Klamath terrane is rather closely allied to that of the Cordilleran miogeocline, it lacks *Sandolasma* (an equatorial coral). Therefore, this terrane is placed at a higher paleolatitude than that of the miogeocline in Nevada. A position at the paleolatitude of Oregon seems most reasonable.

Figure 4. Interpreted Early Permian position of allochthonous terranes. For abbreviations see caption for Figure 3. Paleolatitudes for cratonal North America are from Scotese and McKerrow [15].



The fauna of the Quesnellia terrane is not well known. It contains only two of the miogeocline-indicative coral genera, and it lacks *Protolonsdaleiastraea*. Therefore, based on these meager data, and presence of an important Middle Permian coral fauna from this terrane (see later), the Quesnellia terrane is tentatively placed latitudinally between the central part of the Stikine terrane and the Eastern Klamath terrane**.** The Wrangellia terrane in Alaska has an apparent lower diversity of coral genera than the Stikine terrane. It contains only two miogeocline-indicative coral genera rather than three as in the Stikine terrane, and it also contains *Protolonsdaleiastraea*. Therefore, this part of the Wrangellia terrane belongs north of the Stikine terrane. The presence of two miogeocline-indicative colonial corals, however, also suggests placement of the Wrangellia terrane well south of the Canadian Arctic. Paleomagnetic data from the central Alexander terrane, with which the Wrangellia terrane evidently had been amalgamated, indicate a paleolatitude of 25°–30° N [29]. This then places that part of the Wrangellia terrane now located in mainland Alaska at 33° N, at about the paleolatitude of the British Columbia-Yukon Territory boundary. This position north of the Stikine terrane is compatible with the data on the colonial corals. Of the genera restricted to the non-Tethyan terranes, *Iskutella* and *Lytvophyllum* occur in both the McCloud Belt and the Wrangellia terrane. Two other genera, *Langenheimia* and *Cystolonsdaleia*, however, are restricted to the McCloud Belt. This tends to suggest some separation between the McCloud Belt and the Wrangellia terrane during the Early Permian.

Longitudinal placement of the terranes is much more speculative than latitudinal placement. Four genera, *Sandolasma*, *Cordillerastraea*, *Tschussovskenia*, and *Permastraea*, are restricted to the craton, whereas four others, *Iskutella*, *Langenheimia*, *Lytvophyllum*, and *Cystolonsdaleia*, are restricted to the non-Tethyan terranes suggesting some degree of separation. Otsuka similarity coefficients used to compare the coral faunas of eastern California and the Eastern Klamath terrane suggest a separation on the order of 2,000–3,000 km [27].

On the basis of the substantial difference between the corals and fusulinids of Tethyan affinity from Oregon [27] and the Cache Creek terrane [30], respectively, and those of the Cordilleran-Arctic-Ural (CAU) Realm, including the McCloud Belt and the Wrangellia terrane, all Tethyan terranes are interpreted to have been situated far out in the equatorial Paleopacific Ocean far from cratonal North America and the other terranes in the Early Permian [12].

At the end of the Early Permian colonial rugose corals of the (CAU) Realm became extinct, the extinction progressing from north to south along the cratonal margin [11]. These major faunal changes have been interpreted as due to a cooling of the climate beginning in the latter part of the Early Permian. This event is especially well illustrated in the rocks in northwestern Pangaea [31]. Those writers [31] found that in the Asselian and Sakmarian (early Early Permian), a succession of limestones bearing calcareous algae and foraminifera, interpreted as recording warm-water environments, were deposited. This was followed in the Artinskian (middle Early Permian) by carbonates bearing bryozoans and echinoderms, interpreted to represent cool to locally warm-water environments. Later, in the Kungurian (late Early Permian) and later, the waters became progressively colder and chert was deposited. A similar change in faunas also is recorded in the miogeocline in Nevada where Lower Permian rocks bearing colonial rugose corals and fusulinids were succeeded by Middle Permian units bearing bryozoan and brachiopod faunas [32].

5. Middle Permian Faunas

No Middle to Late Permian colonial rugose corals have been found in cratonal North America and they are very rare in the allochthonous terranes.

5.1. Faunas in Terranes

Two colonial corals have been recovered from the McCloud Belt, both waagenophyllids of Tethyan affinity. They include a species of *Miyagiella* associated with several fusulinids of Tethyan affinity from the Quesnellia terrane [33], and *Waagenophyllum klamathensis*, which was described from the Eastern Klamath terrane [34]. The latter species also occurs in blocks in the western Klamath Mountains where it is associated with Tethyan fusulinids [34]. Other waagenophyllid colonial corals of Tethyan affinity from the northern part of the Cache Creek terrane also have been mentioned [35].

5.2. Interpretation of Terrane Placement in the Middle Permian

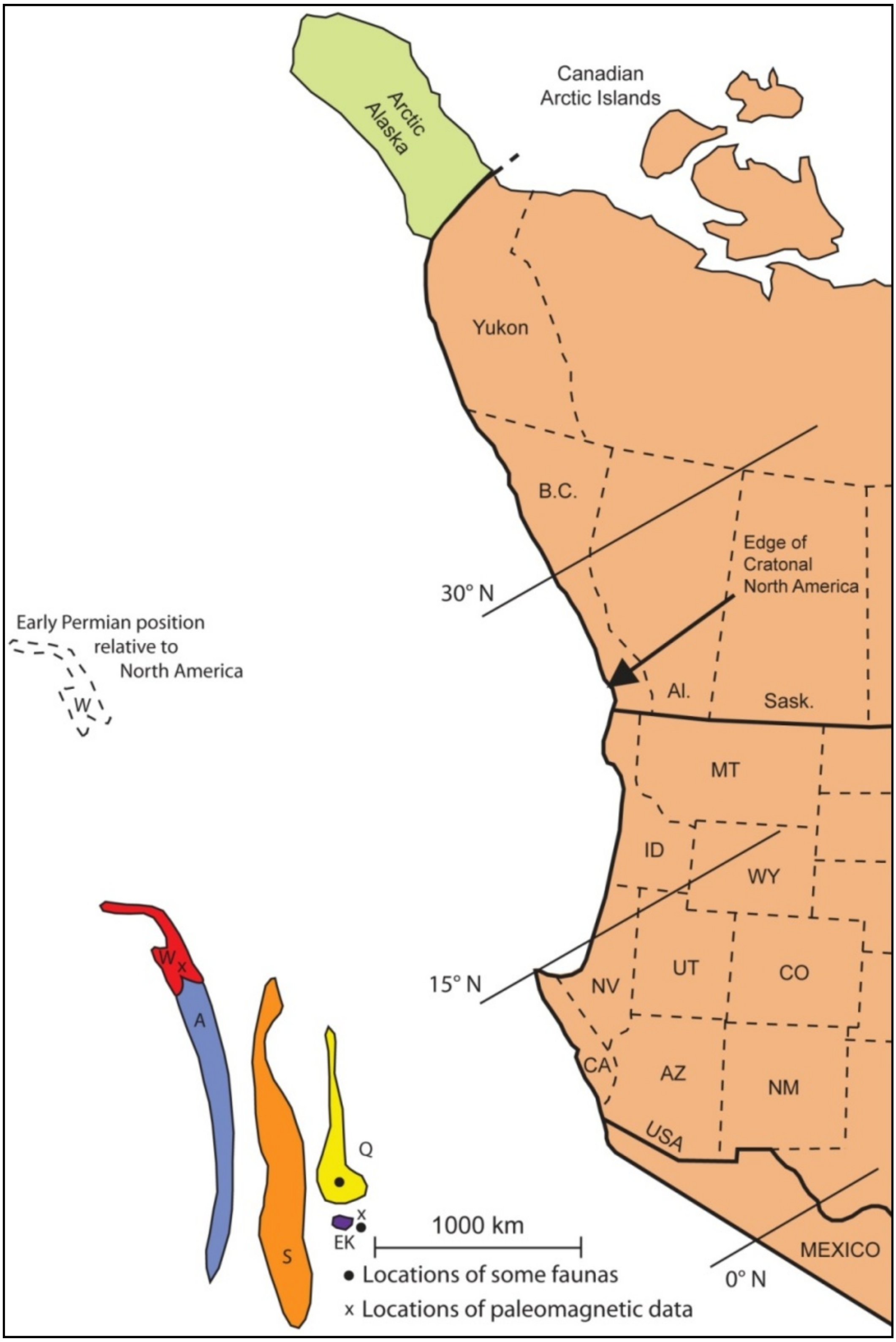
The lack of both colonial corals and fusulinids on cratonal North America north of the latitude of Texas is interpreted to be the result of waters too cold for survival of those taxa. The presence of rare colonial corals with warm-water Tethyan affinities in the Quesnellia and the Eastern Klamath terranes, therefore, presents a problem; if these terranes had not moved from the latitudes of Oregon to southern British Columbia since the Early Permian, they would have been bathed by cool water and should not contain colonial corals and fusulinids. Therefore, we suggest that at least parts of the McCloud Belt (Eastern Klamath and Quesnellia terranes) were located south of the Cordilleran miogeocline in the Middle Permian where the waters were warmer. Figure 5 shows the interpreted placement of the terranes in the Middle Permian. This interpretation of the change of terrane positions relative to North America between the mid-Artinskian and mid-Wordian requires a quite reasonable displacement rate of about 9cm/yr.

Sparse paleomagnetic data for Middle to Late Permian rocks, suggesting a more southerly location of the non- Tethyan terranes, are consistent with the interpretation of placement of terranes based on these coral and fusulinid faunas. Paleomagnetic data from the Eastern Klamath terrane [3] suggest that this terrane was situated at a paleolatitude of 8° to 28° N in the Middle to Late Permian.

On the basis of the presence of fusulinids and one species of colonial coral, I have elected to place the Eastern Klamath terrane at about 9° N, at about the paleolatitude of northern Baja California, which is within the margin of error for the paleomagnetic data. The fusulinids and the colonial coral in the Quesnellia terrane also require us to place that terrane south of the Nevada part of the Cordilleran miogeocline in the Middle Permian.

Paleomagnetic data from Lower Permian rocks in the central part of the Alexander terrane indicate a position of 25° to 30° N in the Early Permian, but 10° to 20° N in the Late Triassic [29], indicating a significant displacement of this terrane and the attached Wrangellia terrane during the intervening time. Placement of the Wrangellia terrane at 8° ± 6° N for Upper Permian rocks [36] suggests that displacement occurred in about Middle Permian time. Thus, it appears possible that the composite Wrangellia-Alexander terrane was displaced southward, along with the terranes of the McCloud Belt, during late Early or early Middle Permian time. On the assumption that the Wrangellia-Alexander terrane moved with the McCloud Belt, the central part of the Alexander terrane falls at about 16° N. This is within the limits of the data on Upper Triassic rocks [29]. This placement of the Alexander terrane requires the Wrangellia terrane to be placed about 27° N, however, considerably farther north of the limits indicated for Upper Permian rocks [36]. Thus, the composite Wrangellia-Alexander terrane could be placed farther south than is shown on Figure 5.

Figure 5. Interpreted Middle Permian position of allochthonous terranes. For abbreviations see caption for Figure 3. Paleolatitudes for cratonal North America are from Scotese and McKerrow [15].



The occurrence of the same coral species, *W. klamathensis*, in both the Eastern Klamath terrane and in Tethyan blocks in the western Klamath Mountains, and the presence of fusulinids and a coral with Tethyan affinities in the Quesnellia terrane suggest that the Tethyan Realm expanded eastward in the Middle Permian. The presence of fusulinids of Tethyan affinity on the craton in Texas [37] also points to this possibility.

6. Comparison of Terrane Placement with Previous Interpretations

A series of paleogeographic maps covering the Silurian to the Triassic have been published [4]. In the Early Devonian those authors showed Arctic Alaska essentially in place with the Alexander terrane located to the east of it and the Yreka terrane (which includes the Eastern Klamath terrane) immediately to the south. The location of the Alexander terrane in Late Devonian to Early Mississippian time was shown as north of Arctic Alaska and the Yreka terrane was shown as essentially in place in northern California [4]. By Pennsylvanian to Early Permian time the Wrangellia-Alexander composite terrane was placed at about 30° N and far removed from North American craton, with the McCloud Belt (including the Eastern Klamath, Quesnellia, and Stikine terranes) closer to the North American craton and lined up more or less opposite where they are today [4]. In Late Permian to Early Triassic the McCloud Belt was shown as very close to North America at their approximate present position with the Wrangellia-Alexander terrane still far out in the Paleopacific Ocean. In contrast, other writers [38] placed the Arctic Alaska-Chukotka terrane north of Baltica in the Devonian to Mississippian, much farther east than placed by other writers [4]. They also suggested that the margin of Pangaea was rifted during Devonian to Mississippian time, but that at that time the terranes were not necessarily laterally displaced.

Interpretations made here based on occurrences of colonial coral faunas from western North America mostly agree with the locations previously suggested [4]. In the Mississippian, at least by the Viséan, however, I suggest that the Alexander terrane was southwest of Arctic Alaska rather than north of it. In the Pennsylvanian I place the Eastern Klamath terrane closer to Arctic Alaska, considerably farther north than the position previously shown [4]. This placement would be more in line with a position implied by other authors [38]. At that time the Alexander terrane probably was in the Paleopacific Ocean somewhat southwest of Arctic Alaska similar to the position shown by Colpron and Nelson [4]. By Early Permian I place the terranes of the McCloud Belt more or less where they have been placed previously [4], but the Wrangellia-Alexander terrane is here placed closer to the McCloud Belt. In the Middle Permian the McCloud Belt and the Wrangellia-Alexander terrane are here interpreted to have been farther south than previously [4] shown for Late Permian to Early Triassic time.

7. Conclusions

The colonial coral faunas expanded and contracted twice during the Carboniferous and Permian. They became diverse during the Mississippian, but were highly restricted during the entire Pennsylvanian. In the Early Permian the colonial rugose coral faunas again became highly diverse but by the end of the Early Permian all of the CAU coral lineages became extinct. A few species representing the Tethyan Realm and confined to the terranes are the only colonial corals known in the Middle Permian in the former CAU Realm.

On the basis of colonial coral faunas I suggest that during the Mississippian the Alexander terrane was close to Arctic Alaska and the Stikine terrane lay offshore from southwestern cratonal North America. An ecological crisis occurred during the latter part of the Mississippian affecting not only the faunas on cratonal North America, but also the Alexander terrane. Apparently all previous genera of colonial rugose corals except *Petalaxis* and *Cystolonsdaleia* were eliminated except in the Stikine terrane where the genera *Heintzella* and *Nemistium* persisted into the Pennsylvanian. Near the end of the Pennsylvanian the genera *Durhamina* and *Paraheritschioides* were introduced onto cratonal North America.

On the basis of the known faunas from the North American craton, Arctic Alaska, and the Eastern Klamath, Stikine, Alexander, and Cache Creek terranes, I suggest that in the Pennsylvanian the Eastern Klamath terrane probably lay somewhat south of Arctic Alaska, and the Alexander terrane was somewhat removed from it out in the Paleopacific Ocean. The Stikine terrane probably still lay west of the southern part of the North American craton. The Cache Creek terrane lay much farther west out in the Paleopacific Ocean at relatively low latitudes.

The faunas of the Early Permian, evidently mostly introduced from the Uralian Province, e.g., [24], are widespread and diverse allowing a more complete analysis of the paleogeography at that time. Various comparisons of the Early Permian colonial rugose coral faunas and statistical tests based on these faunas indicate that the McCloud Belt and the Wrangellia-Alexander terrane lay somewhat offshore from cratonal North America, perhaps on the order of 2000–3000 km [27]. These faunas also suggest that the Eastern Klamath terrane was at the paleolatitude of Oregon at that time. The colonial rugose corals, as well as the paleomagnetic data from the central part of the Stikine and Alexander terranes [28,29], indicate that the Stikine terrane lay north of the Eastern Klamath terrane and that the Wrangellia-Alexander terrane was situated even farther north, perhaps at the paleolatitude of northern British Columbia. The meager data from the Quesnellia terrane suggest that this terrane probably lay latitudinally between the Stikine and Eastern Klamath terranes. At this time the Tethyan terranes were located far out in the Paleopacific Ocean at relatively low latitudes.

The rather abrupt cooling of the oceans beginning in the latter part of the Early Permian evidently resulted in extinction of the colonial corals of the Cordilleran-Arctic-Uralian Realm [11].

After or during this cooling event near the end of the Early Permian, the terranes of the McCloud Belt and the composite Wrangellia-Alexander terrane moved 12°–13° southward relative to cratonal North America so that Quesnellia and Eastern Klamath terranes lay at least as far south as the paleolatitude of southern California or northern Baja California by the Middle Permian.

While the McCloud Belt and the Wrangellia-Alexander terrane were moving southward and perhaps closer to cratonal North America, the Tethyan Realm apparently was expanding eastward, perhaps due to movement of some of the Tethyan terranes closer to North America. This allowed a few members of that colonial rugose coral fauna to disperse into two terranes of the McCloud Belt (Eastern Klamath and Quesnellia). In Texas on the North American craton several Tethyan fusulinids also appear at about the same time, e.g., [37].

Later, during the Mesozoic, all of the terranes considered here were amalgamated to cratonal North America and smeared out northward along the cratonal margin with some terranes and blocks bearing warm-water faunas being carried to high latitudes. This is especially well shown by the great latitudinal spread of species of the fusulinid *Parafusulina* having gigantic microspheric forms. These species which lived during the cool Wordian Epoch occur in cratonal rocks in Texas as well as in the McCloud Belt and some other non-Tethyan terranes stretching from Coahuila and Sonora, Mexico through northern California, Washington, and British Columbia to Alaska [39], a distribution of about 50° of latitude.

Acknowledgments

I am grateful to Paul Belasky for his collaboration on many projects and participation in collecting data for Permian faunas, and to Jerzy Fedorowski and Wayne Bamber for their continued advice and interest in understanding Carboniferous and Permian colonial rugose coral faunas. Joe Petsche provided the art work.

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