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DAVID BLOOM

Distribution of Fusulinaceans in the Western Canadian Cordillera

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Fusulinacean faunas in Upper Paleozoic lithological sequences containing volcanic rocks in the western Canadian Cordillera form two assemblages based on geographic association of genera. One assemblage, in Permian strata, is dominated by genera of the family Schwagerinidae and occupies belts in the eastern and western parts of the western Cordillera. This assemblage is associated with brachiopods, bryozoans, horn corals, and crinoids and is in limestones interbedded with clastic rocks and volcanic rocks of variable composition. The other Permian assemblage is dominated by genera of the family Verbeekinidae and occupies a central belt where it occurs with crinoid detritus and algae in thick, regionally extensive limestones associated with cherts, basalt, and ultramafic rocks. The less-well documented Pennsylvanian fusulinaceans appear to occupy similar belts. Because fossils of both assemblages are at least in part time equivalent, their distribution may well be due to differing local environments. In addition, or alternatively, this diversity may be brought about by major crustal movements juxtaposing originally isolated biogeographic provinces.

Introduction

This paper is a preliminary analysis of the distribution of fusulinaceans and their association with other organisms and lithologies in the western Canadian Cordillera and discusses some of the possible factors responsible for this distribution. The Upper Paleozoic fusulinaceans are in stratigraphic sequences containing volcanic rocks ("eugeosynclinal rocks") and occur west of the Rocky Mountain Trench and southwest of the more northerly Tintina Trench in the Yukon (Fig. 1). They contain many genera and species regarded as endemic to the Tethyan faunal realm and atypical of the southern and southwestern continental interior of North America. Upper Paleozoic faunas in non-volcanic stratigraphic sequences ("miogeosynclinal rocks") to the east in the Canadian Rocky Mountains and to the north in northern Yukon Territory have not been included.

In the western Canadian Cordillera fusulinaceans currently provide the most effective means of correlating Upper Paleozoic rocks. Rapid facies changes in these rocks commonly preclude rock–stratigraphic correlation even on a local basis and other fossil groups in this region are too poorly known to be of much value in precise correlation. Fusulinaceans are widely dispersed, are preserved even in many highly deformed rocks, and, because of their rapid evolutionary history, can be correlated readily with dated fusulinacean assemblages outside of the region. However, certain points need to be kept in mind when interpreting regional biostratigraphic relations and the relationship to fusulinacean faunal provinciality. At the species level fusulinaceans appear to be adapted to particular environmental conditions as inferred from associated lithologies (Ross 1961). Fusulinacean faunal data from the western Canadian Cordillera are compatible with, but are not proof of, the hypothesis that several originally semi-isolated biogeographic provinces have later been juxtaposed by major crustal movements.

Much data in this paper are based on preliminary reports prepared for correlation of samples collected during reconnaissance mapping for the Geological Survey of Canada. Several workers (*e.g.*, Thompson 1950; Thompson and Verville 1950; Pitcher 1960; Thompson 1965; and Ross 1969) have described fusulinaceans from parts of the western Canadian Cordillera. McGugan *et al.* (1964) briefly reviewed Permian rocks in the Cordillera. Danner (1965) made the suggestion that the differences between Tethyan and other Permian fusulinacean faunas in North America may be due largely to differences in environments. Bostwick and Nestell (1967) pointed out the existence of two fusulinacean faunas, identified by them as Tethyan and non-Tethyan, in the

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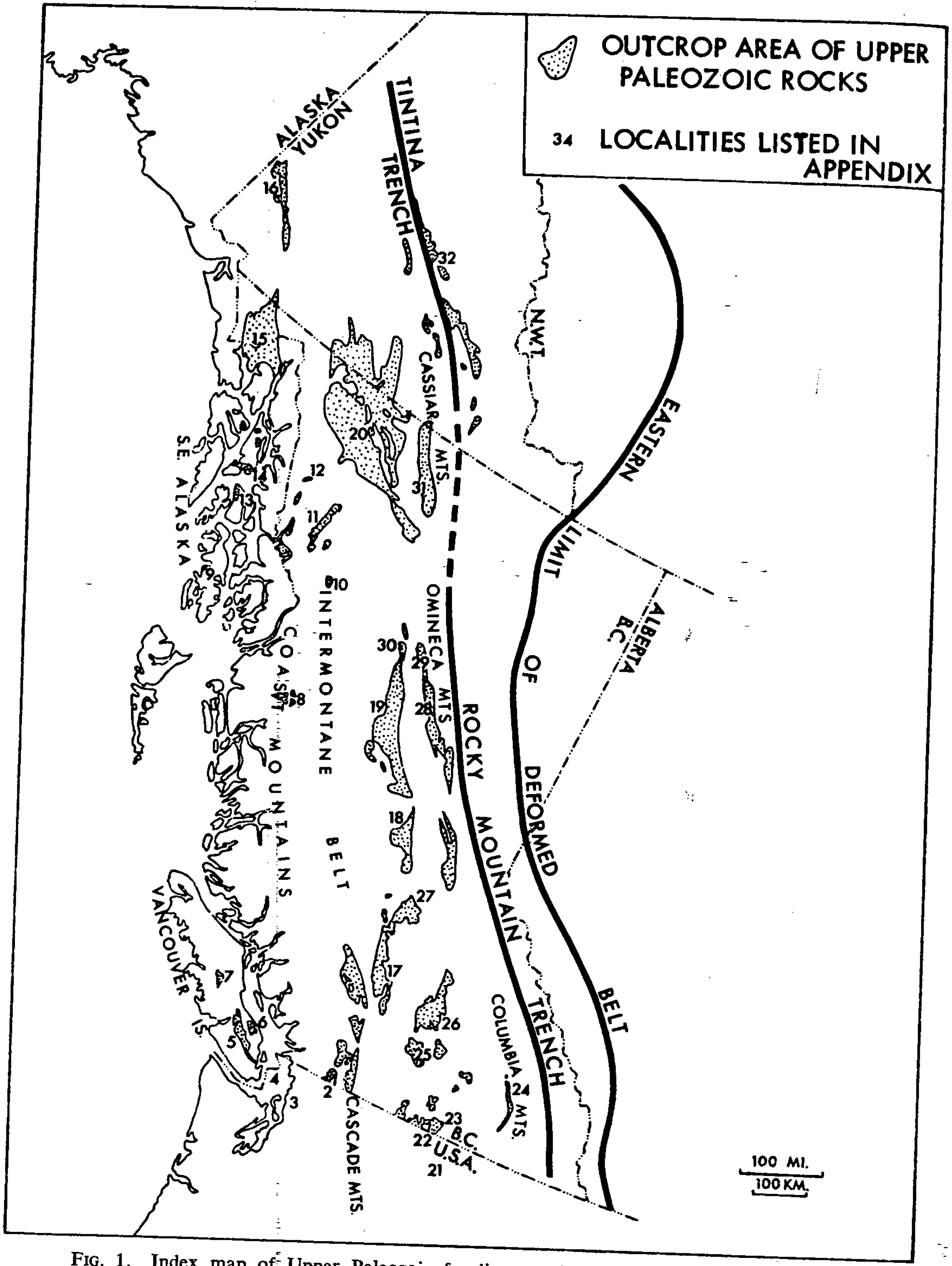

FIG. 1. Index map of Upper Paleozoic fusulinacean localities in the western Canadian Cordillera.

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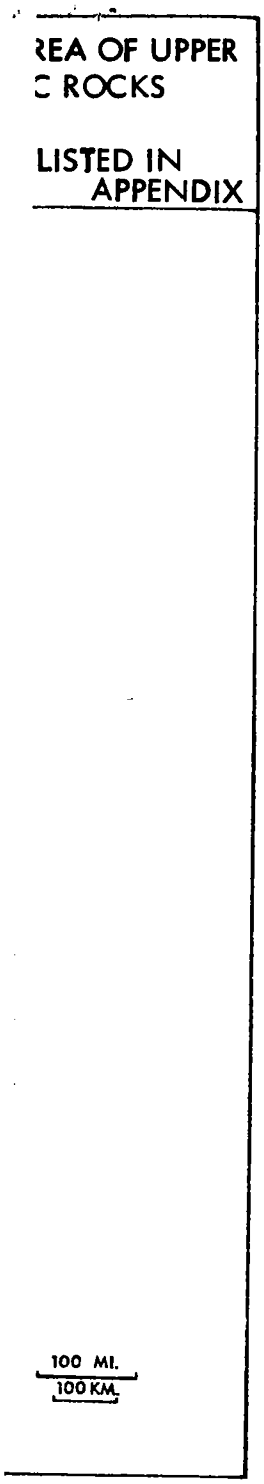


western Canadian

northwestern United States and they suggest that an abrupt faunal change between forms took place in mid-Permian time. More recently stratigraphic studies by Monger (1969, 1970) and a series of fusulinacean studies by Ross (Ross and Nassichuk, in press) have made additional data available and from this we are attempting a preliminary synthesis. The data support the suggestion by Ross (1967, p. 1353) that within the Tethyan faunal realm several distinctive faunal associations are related to differences in lithofacies and environment.

Fusulinacean Assemblages

Permian Assemblages

Two well defined Permian fusulinacean assemblages are recognized by association of genera and their geographic distribution (Fig. 2, Table 1). One assemblage is dominated by genera of the family Schwagerinidae, particularly *Schwagerina*, *Parafusulina*, *Pseudofusulina*, and less commonly by *Pseudoschwagerina*, *Paraschwagerina*, *Rugosochwagerina*, *Monodiexodina*, and *Chusenella*. In Lower Permian strata this assemblage includes genera of the family Fusulinidae, particularly *Pseudofusulinella*, which in the eastern, western, and northern areas locally may be dominant in certain lithologies. This assemblage corresponds to the non-Tethyan fauna of Bostwick and Nestell (1967) and is usually associated with brachiopods, commonly productids, bryozoans, and solitary corals (Table 2). Geographically it occupies two belts, an eastern one mainly along the Cassiar – Omineca – Columbia Mountain belt, and a western one covering the Coast and Canadian Cascade Mountains, Vancouver Island, and southeastern Alaska (Fig. 2). The other fusulinacean assemblage is dominated by genera of the family Verbeekinidae including *Neoschwagerina*, *Yabeina*, *Verbeekina*, *Cancellina*, *Pseudodoliolina*, and *Kahlerina*. This second assemblage is associated with a large diversity of other fusulinaceans including several genera from each of the families *Ozawainellidae*, *Staffellidae*, *Fusulinidae*, *Schubertellidae*, and *Schwagerinidae*. This assemblage corresponds with the Tethyan fauna of Bostwick and Nestell (1967) and is commonly associated with crinoid debris and algae (as noted by Danner 1965, p. 121). Geographically this assemblage occupies part of the central Intermontane Belt of the Canadian Cordillera, and lies between the two belts occupied by the other assemblage (Fig. 2).

In many aspects these two fusulinacean facies assemblages, their zonation, lithologic association, and linear distribution are similar to those that have been reported from Japan where an "Inner zone" is characterized by schwagerinid faunas in dominantly clastic facies and an "Outer zone" is characterized by verbeekinid faunas in a massive carbonate facies.

Mississippian and Pennsylvanian Assemblages

In the western Canadian Cordillera the distribution of fusulinacean genera in Late Mississippian and Pennsylvanian strata is less well known than for the Permian, in part because much of the Pennsylvanian appears to be missing from the eastern and western belts (Table 1). However, the available data does suggest a similar, but not identical, distribution into at least two fusulinacean assemblages having separate geographic distributions (Fig. 3). The first poorly documented association consists mostly of *Millerella*, *Nakinella*, and a few genera in the family Fusulinidae, such as *Pseudostaffella*, *Fusulina*, *Beedeina*, *Fusulinella*, and locally *Wedekindellina*, in the western belt. This assemblage occurs elsewhere in the northern Yukon, Arctic, North America, Asia, and Europe. The second assemblage consists of additional genera in the family Fusulinidae, such as *Akiyoshiella* and *Fusiella*, which commonly are associated with the families Ozawainellidae, Schubertellidae, and Staffellidae in a central region where the species diversity within each of these families, although low, is significantly higher than in regions either to the east or west. This second assemblage reappears in the Prince of Wales Island area of southeastern Alaska (Douglass 1970).

The faunal distributional pattern for these Late Mississippian and Pennsylvanian fusulinid distributions indicates that a central belt contained a diverse fauna of Fusulinidae, Schubertellidae, and Ozawainellidae and that to the west faunal diversity was lower so that a few genera of the family Fusulinidae comprise the majority of the fusulinacean faunas with only an occasional genus from other families. To the east of this central belt, perhaps as far east

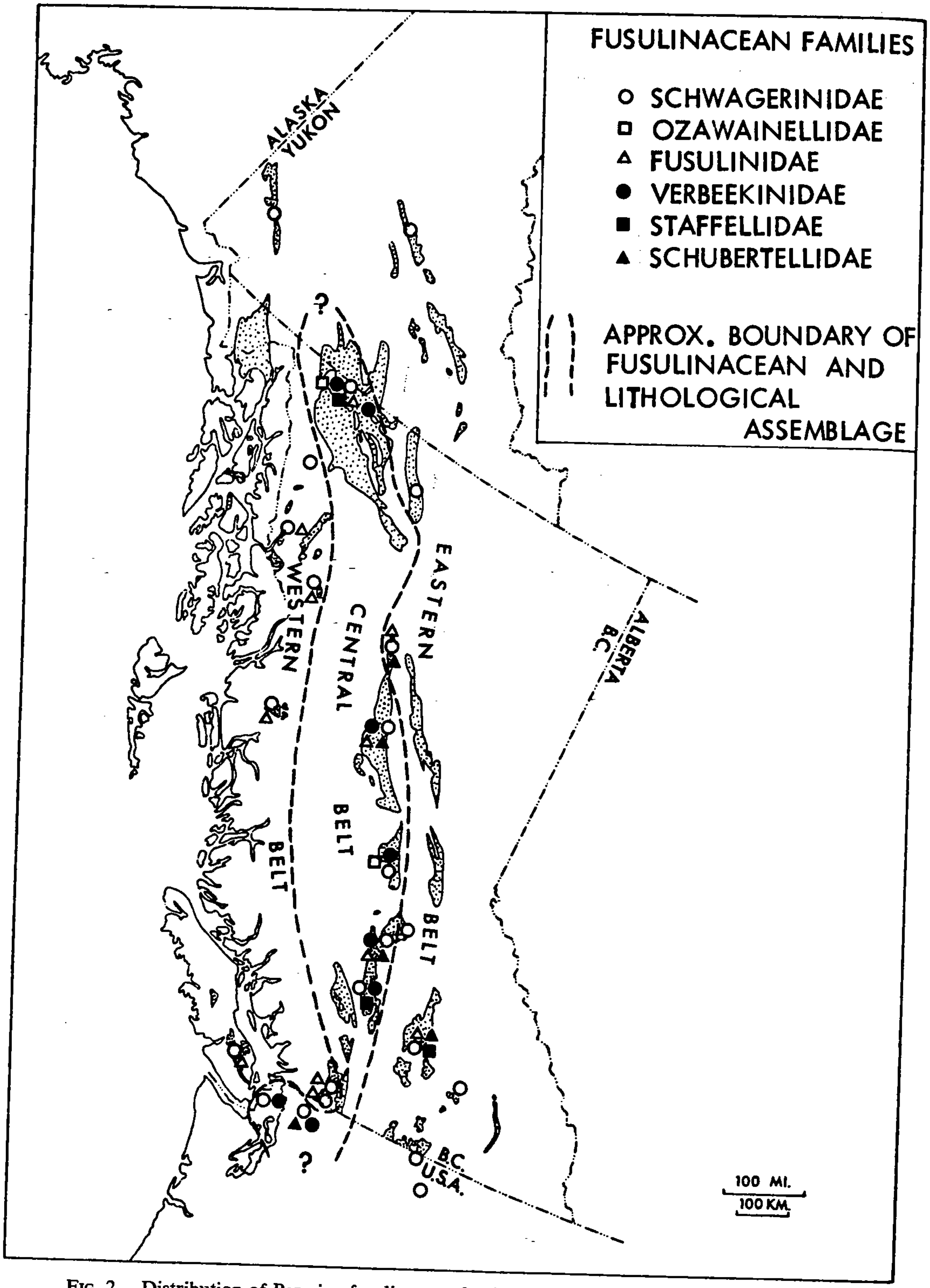
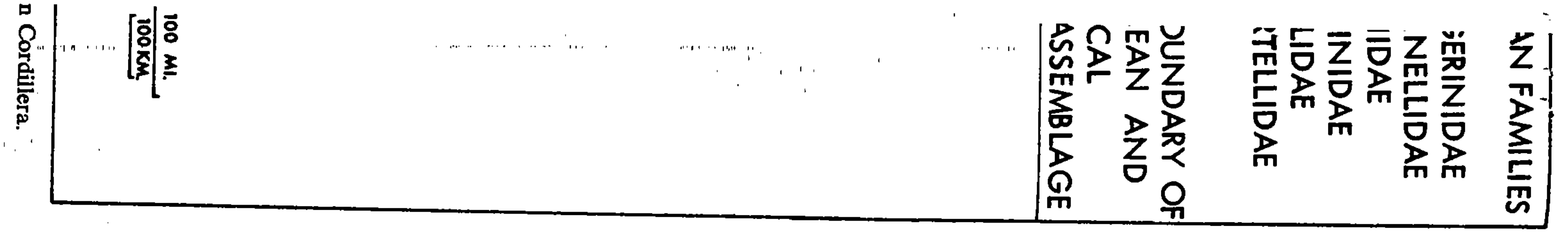


FIG. 2. Distribution of Permian fusulinacean families in the western Canadian Cordillera.

TABLE 1. Correlation of fusulinacean assemblages at the generic level in the western Canadian Cordillera

A. Distribution of fusulinacean assemblages in western belt



n Cordillera.

TABLE 1. Correlation of fusulinacean assemblages at the generic level in the western Canadian Cordillera

A. Distribution of fusulinacean assemblages in western belt

				West side Cascade Mountains Loc. 1, 2	Vancouver Island Loc. 5, 6	Terrace, Oweegee Peaks, Telegraph Creek, Tatsamenie Lake Loc. 9, 10, 11, 12	Southeastern Alaska Loc. 9, 13, 14	Kluane Lake Loc. 16
Permian	Late	Ochoan						
		Guadalupian	Capitan					
			Word					
	Early	Leonardian		*Parafusulina* *Schwagerina*		*Parafusulina* *Schwagerina* *Pseudofusulinella*	*Monodiexodina*	*Parafusulina?*
		Wolfcampian		*Pseudofusulinella*	*Schwagerina ?* *Quasifusulina ?*	*Paraschwagerina* *Pseudoschwagerina* *Triticites*		
Pennsylvanian	Late							
	Middle				*Wedekindellina* *Eoschubertella*		*Fusulina* *Fusulinella* *Nankinella* *Millerella* *Pseudostaffella*	
	Early			*Eostaffella* *Ozawainella* *Millerella*			*Eostaffella*	
Mississippian	Late					*Endothyrid forams*	*Endothyrid forams*	
	Middle							

B. Distribution of fusulinacean assemblages in central belt

			Northwestern Washington west side Cascade Mountains Loc. 3, 4	Bonaparte River (west half) Loc. 17	Prince George Loc. 18	Fort St. James Loc. 19	Atlin-Dease Lake and Jennings River
Permian	Late	Ochoan					
		Guadalupian: Capitan Word	*Yabeina* *Neoschwagerina* *Codonofusiella* *Verbeekina*	*Yabeina* *Neoschwagerina* *Kahlerina* *Reichelina*	*Yabeina*	*Yabeina* ? *Neoschwagerina* *Parafusulina*	*Yabeina* *Reichelina* *Yangchenia* *Schwagerina*
	Early	Leonardian	*Schwagerina, Dunbarula* *Cancellina, Pseudodoliolina* *Boultonia, Schubertella* *Misellina, Parafusulina* ? *Schwagerina, Pseudofusulinella*	*Chusenella, Boultonia* *Schwagerina, Nankinella* *Parafusulina, Cancellina* *Pseudodoliolina*	*Coloniella* *Reichelina* *Schwagerina*	*Misellina* *Verbeekina* *Cancellina*	*Parafusulina, Kahlerina* *Chusenella, Staffella* *Monodiexodina, Neoschwagerina* *Pseudodoliolina, Pseudofusulina*
		Wolfcampian		*Pseudofusulina Pseudoschwagerina* *Pseudofusulinella, Quasifusulina* *Schubertella, Triticites* *Chalaroschwagerina, Schwagerina* *Nankinella*		*Pseudoschwagerina* *Oketaella* *Quasifusulina* *Schubertella, Triticites*	*Pseudoschwagerina* *Schubertella* *Triticites*
Pennsylvanian	Late						
	Middle					*Fusulina, Fusulinella* *Eoschubertella, Pseudostaffella* *Staffella, Akiyoshiella* *Nankinella*	*Fusulina, Fusulinella* *Fusiella, Pseudostaffella* *Eoschubertella, Ozawainella*
	Early			*Eostaffella*			*Eostaffella*
Mississippian	Late						**Endothyrid forams**
	Middle						**Endothyrid forams**

C. Distribution of fusulinacean assemblages in eastern belt

Northeastern

Part Kamloops

P	Early	*Eostaffella*	*Eostaffella*
Mississippian	Late		**Endothyrid forams**
	Middle		**Endothyrid forams**

C. Distribution of fusulinacean assemblages in eastern belt

				Northeastern Washington Loc. 21, 22	Vernon Loc. 25	Part Kamloops Bonaparte River area (east side) Loc. 26	Quesnel Loc. 27	McConnell Creek Loc. 30	McDame Loc. 31	Anvil Loc. 32
Permian	Late	Ochoan								
		Guadalupian	Capitan Word	*Parafusulina*		*Codonofusiella* *Parafusulina*	*Parafusulina*		*Parafusulina*	
	Early	Leonardian			*Parafusulina* *Schwagerina*	*Pseudofusulina*	*Schwagerina*	*Parafusulina* *Pseudofusulinella* *Rugosofusulina*		
		Wolfcampian		*Schwagerina* *Pseudofusulinella*	*Schwagerina, Triticites, Pseudoschwagerina, Paraschwagerina, Quasifusulinia, Schubertella*	*Pseudofusulinella* *Staffella*		*Schubertella* *Pseudoschwagerina* *Schwagerina* *Triticites*		*Schwagerina* *Triticites*
Pennsylvanian	Late				*Triticites*					*Thompsonella*
	Middle									
	Early									
Mississippian	Late								Endothyrid forams	
	Middle									

TABLE 2. Details of Upper Paleozoic localities shown on index map

Number of locality	Approximate location	Age(s)	Fossil groups*	Lithologies†	References
1	West side, Cascade Mountains (Chilliwack area)	Early Pennsylvanian (Morrow ?); Late Penn. ?-Early Permian; Early Permian (Wolfcamp).	EF, FU, RC, TC, BP, BZ, G, C, E, PL	lst, pel lst, pel, sst, cgl, py, bas, dac	Monger 1966
2	West side, Cascade Mountains (Black Mtn., Red Mtn. area)	Early Penn, (Morrow or e. Derry), Early Permian	F, FU, EF, A, RC, BP, BZ, P, G, PL	lst, pel lst, pel, sst, cgl	Danner 1966 Skinner and Wilde 1966
3	West side, Cascade Mountains (Granite Falls, Twin Lakes area)	mid-to Late Permian	A, FU, G, E	bas, cht, lst, sst	Thompson *et al.* 1950 Danner 1966
4	San Juan Islands	late Early Permian (Leonard), early Upper Permian (e. Guadalupe)	A, FU, BZ,	bas, py, cht, pel, sst, lst	Danner 1966 Skinner and Wilde 1966
5	Southern Vancouver Island	Early Permian	FU, BP	bas, py, sst, pel, lst	Fyles 1955
6	East coast, Vancouver Island (Balenas Islands)	Middle Pennsylvanian (Desmoines)	FU, RC, BP	sst, pel, lst	J. E. Muller‡
7	Central Vancouver Island	Early Permian	A, F, FU, RC, BP, BZ, G, P, O, PL	lst, py, pel	Yole 1963
8	Terrace area	Early to mid-Permian	FU, BP, BZ, E	lst, py, pel	J. K. Rigby‡
9	West side Prince of Wales Island	Middle Pennsylvanian Mississippian (Osage to Chester)	F, FU, RC, BP, BZ Fu ?, EF, RC	lst, sst lst	Buddington and Chapin 1929 Douglass, 1970 A. T. Ovenshine‡
10	Oweegee Peaks	Early to mid-Permian (Wolfcamp to lowest Guadalupe)	F, FU, PB, BZ, E, G, O	lst, py, and, rhy	J. K. Rigby‡
11	Telegraph Creek area	Late Mississippian Pennsylvanian Permian (Wolfcamp to Guadalupe)	EF, RC, BP, BZ, E PL	lst, pel lst, py pel, sst	J. K. Rigby‡ Pitcher 1960 Monger 1970 G. W. H. Norman‡
12	Tatsamenie Lake	Permian	FU	lst, gst	J. K. Rigby‡ Monger 1970
13	Saginaw Bay – Kuiu Island	Pennsylvanian	FU, BP, BZ, P, PL	lst, cht, pel, cgl, bas, and, rhy, py	Buddington and Chapin 1929
14	Pybus–Gambier area, Admiralty Island	Early Permian	R, BD, BZ	pel, sst, cgl, cht, lst, gst, py	Loney 1964 Lathram *et al.* 1965

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TABLE 2. Details of Upper Paleozoic localities shown on index map—*Continued*

Number of locality	Approximate location	Age(s)	Fossil groups*	Lithologies†	References
15	Squaw Creek – Rainy Hollow and Porcupine areas	Late Carboniferous	BP, E	lst, pel, lst, pel, gst	Watson 1948 Eakin 1919
16	Kluane–Kaskawulsh areas	Early Permian	FU, RC, TC, BP, BZ, C, G, E, PL	lst, pel lst, pel, sst, cgl, and, lat, py	Wheeler 1963 Muller 1967
17	Ashcroft and western Bonaparte River area (Marble Range)	Permian (Wolfcamp, Leonard and Guadalupe)	A, FU, RC, E	lst, cht, pel, gst, (bas ?)	Thompson *et al.* 1950 Duffell and McTaggart 1952 Trettin 1961 Trettin 1966
18	Prince George area	Late Permian	FU	cht, pel, bas ?, lst, um	Tipper 1961‡
19	Fort St. James (western belt)	Pennsylvanian (Desmoines) Lower Permian (Wolfcamp), mid and Late Permian (Leonard and Guadalupe)	FU, RC, BP, E, G	lst, cht, gst, um	Armstrong 1949 Thompson *et al.* 1953 Thompson 1965
20	Atlin area and Cassiar Mountains	Mississippian (Osage to Chester) Early Pennsylvanian (probably Morrow) Middle Pennsylvanian (Desmoines) Permian (Wolfcamp, Leonard, Guadalupian)	EF, RC, E FU A, R, EF, FU, RC, BP, C, E	cht, lst, bas, py, um, pel, sst	Aitken 1959 Wheeler 1961 Link 1965 Monger 1969*a* Monger 1969*b* Gabrielse 1969
21	Kettle Falls area	mid-to Late Permian	FU, BP, BZ, G, P, E, PL	and, py, pel, sst, lst	Mills and Davies 1962
22	Republic area	Early Permian (Leonard)	FU, BZ	lst, pel, ch, gst	Parker and Calkins 1964
23	Nelson area	Pennsylvanian	RC, TC, BP, BZ, E; PL	gst, lst, pel, cht, cgl	Little 1960
24	Kootenay Lake	Mississippian	RC, BP, BZ, E	pel, lst, cht, cgl	Walker and Bancroft 1929 Fyles and Eastwood 1962
25	Vernon area and part of Kamloops area	Permian Lower to Mid-Permian	FU, RC, BP, BZ, E	lst, qtz, pel and, py	Jones 1959 Nestell and Danner 1970
26	Part Kamloops area, part Bonaparte River area	Early Pennsylvanian (Morrowan) Permian (Wolfcamp, Leonard, Guadalupe)	FU, EF FU, RC, BP, BZ, E	pel, sst, and ?, py, lst	Campbell and Tipper 1969

References
Monger 1966
Danner 1966 Skinner and Wilde 1966
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Yole 1963
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J. K. Rigby‡ Monger 1970
Buddington and Chapin 1929
Loney 1964 Lathram *et al.* 1965

Table 2. Details of Upper Paleozoic localities shown on index map—*Concluded*

Number of locality	Approximate location	Age(s)	Fossil groups*	Lithologies†	References
27	Quesnel area	Mississippian Late Permian (Guadalupe)	RC	pel, cht, lst, gst sst, cgl	Tipper 1959 Campbell 1961
28	Fort St. James (eastern belt).	Mississippian ?	RC	pel, gst, py lst	Armstrong 1949
29	Aiken Lake area	Late Mississippian or Lower Permian Middle Pennsylvanian Atokan)	RC, BP, BZ, G FU	and, bas, py, pel, sst, cgl, cht, lst	Roots 1954 J. K. Rigby‡
30	McConnell Creek	Lower Permian Wolfcamp (Leonard ?)	FU, RC, BP, BZ	and, rhy, pel, cht, lst	Lord, 1948 J. K. Rigby‡
31	McDame area	Late Mississippian (Chester) Late Permian (e. Guadalupian)	A, EF, F CR, BP, BZ, E, O FU, CE	lst pel lst, py, gst, um	Mamet and Gabrielse 1969 Ross 1969
32	Anvil Range	mid ? Permian Late Penn. Early Permian	FU, E FU	lst pel, cht, lst, py, gst	Tempelman-Kluit, 1968‡

*Fossil groups: A, algae; R, radiolaria; F, foraminifera other than endothyrids or fusulinaceans; EF, endothyrid foraminifera; FU, fusulinaceans; RC, rugose corals; TC, tabulate corals; BP, brachiopods; BZ, bryozoans; G, gastropods; P, pelecypods; C, cephalopods; E, echinoderms (generally crinoid detritus); PL, terrestrial plants.

†Lithologies: lst, limestone; pel lst, pelitic limestone; pel, pelite; sst, sandstone; cgl, conglomerate; cht, chert; gst, greenstone; bas, basalt; and, andesite; dac, dacite; lat, latite; rhy, rhyolite; py, pyroclastic; um, ultramafic.

‡Personal communication.

as the Front Ranges of the Rockies, fusulinaceans of Pennsylvanian age are rare or lacking.

Factors Influencing Faunal Diversity and Geographic Distribution

The two apparent faunal assemblages located in a central belt and a western and an eastern belt in the Pennsylvanian and Permian may result from some combination of the following factors. Firstly, as suggested by Bostwick and Nestell (1967) the age of the various faunal assemblages may be significantly different so that the generic assemblages do not represent the same time interval. Secondly, many of the faunas in the different belts may be nearly contemporaneous but ecologically adapted to sharply differentiated environments. Thirdly, there is the possibility that isolated or semi-isolated biogeographic provinces were juxtaposed by major crustal movements. A further factor, impossible to evaluate at this time, is the distribution of the limited data available from this large region may have created a biased picture. From what is known, the writers feel that the second factor and possibly the third have had a considerable, probably overriding influence on the faunal diversity and distribution.

Age Relationships

The relative age relationships of the various collections are shown in Table 1. At several localities Visean and early Namurian (Middle to Late Mississippian) endothyrid foraminiferids have been reported but these have not been studied thoroughly. In the western and central belts a fauna characterized by *Eostaffella* (= *Paramillerella*) of Bashkirian (Early Pennsylvanian) age appears to be fairly widespread but has not been reported from the eastern belt. A Moscovian (Middle Pennsylvanian) fauna appears scattered along the length of the western and central belts. Those Moscovian faunal assemblages in the western belt contain a lower diversity of species and genera than those of the central belt and the collections represent several zones within the Moscovian.

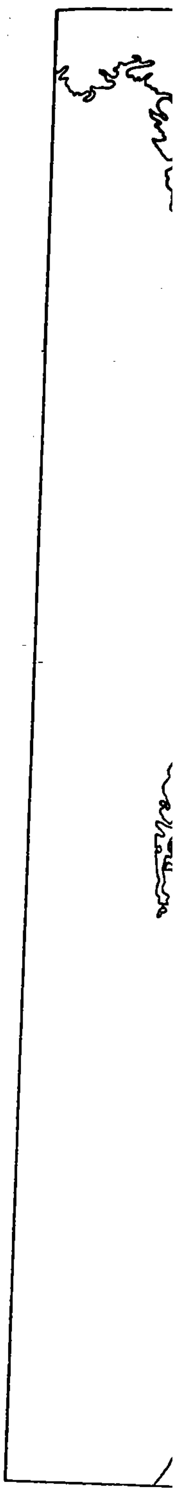

Fig. 3.
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References
Tipper 1959 Campbell 1961
Armstrong 1949
Roots 1954 J. K. Rigby‡
Lord, 1948 J. K. Rigby‡
Mamet and Gabrielse 1969 Ross 1969
Tempelman-Kluit, 1968‡

lothyrid foraminifera; FU, fusu-
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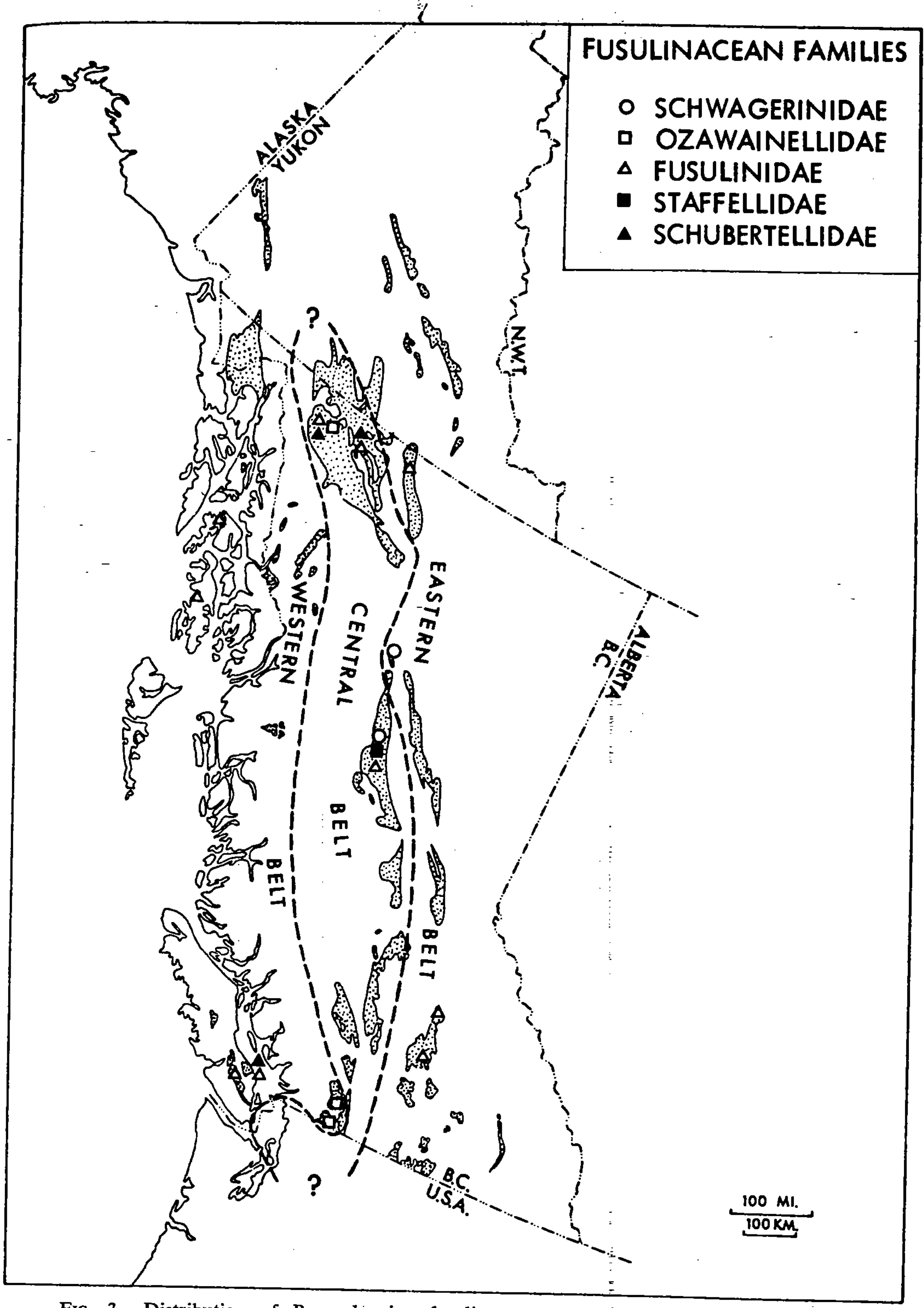

FIG. 3. Distribution of Pennsylvanian fusulinacean families in the western Canadian Cordillera.

Fusulinacean faunas of Late Pennsylvanian age are almost entirely missing in the western Canadian Cordillera and have been recorded at only two localities (Loc. 26 and 32) where they appear to represent local marine deposition associated with the beginning of the major marine depositional pattern of the Early Permian.

Early Permian fusulinaceans are widespread in the central, eastern, and western belts and several zones are recognizable. The oldest of these includes *Triticites*, *Schwagerina*, *Paraschwagerina*, *Pseudoschwagerina*, *Schubertella*, and *Pseudofusulinella* in various associations with one another and other genera. The species of this zone are similar to those species from the Russian Asselian and lower part of the Sakmarian Stages (Wolfcampian). This widespread faunal zone forms a distinctive unit, but its diversity is greater in the central belt and its composition differs considerably from the eastern and western belts.

Above this lowest Permian zone, two other zones are recognizable; one of late Sakmarian (early to middle Leonardian) and a higher zone of Artinskian (middle to late Leonardian or late Nebeyaman) age. The late Sakmarian faunas are readily divisible into a non-verbeekinid facies containing *Schwagerina*, primitive species of *Parafusulina*, *Pseudofusulina*, and advanced species of *Pseudofusulinella* and *Monodiexodina*, which is found in the eastern and western belts, and a verbeekinid facies including, in addition to the schwagerinids listed above, *Verbeekina*, *Misellina*, *Cancellina*, *Schubertella*, *Boultonia*, and *Kahlerina*. In the western Canadian Cordillera species closely similar to *Schwagerina guembeli*, a zonal guide to the lower part of the Leonardian Series, are locally common in the western belt (Monger 1966; Pitcher 1960) and in Washington and Oregon (Mills and Davies 1962) in the eastern belt. In Japan, Toriyama (1967) reported a similar species from the upper Nabeyaman Series. The Artinskian faunal zone is also readily divisible into two or more facies associations. One association is characterized by simple species of *Parafusulina* and rare species of *Schwagerina*, *Pseudofusulina*, and *Monodiexodina* and is located in the eastern and western belts. A diverse verbeekinid faunal association containing elements of the other facies, also includes *Misellina*, *Verbeekina*, *Cancellina*, *Neoschwagerina*, *Nankinella*, *Chusenella*, *Boultonia*, and *Schubertella* and is located in the central belt. This association is similar to the faunas of the lower part of the Akasakan Stage of Japan.

At least two late Permian fusulinacean zones are recognizable in the western Canadian Cordillera. The lower zone includes *Schwagerina* and a primitive species of *Yabeina* (Ross and Nassichuk 1970; Ross, in press) associated with the ammonoids *Waagenoceras*, *Stacheoceras*, *Agathiceras*, and *Hyattoceras* indicating a correlation with the Wordian Stage of the Guadalupian Series. Also included in this zone are *Neoschwagerina*, *Yangchenia*, *Kahlerina*, and *Verbeekina* so that this zone is correlated with the upper part of the Akasakan Stage of Japan. In the eastern belt large polymorphic species of *Parafusulina* mark a zone that is approximately equivalent and can be correlated with the upper part of the Wordian Stage. In the western belt an equivalent zone appears to be lacking. The highest fusulinacean zone occurs only in the central belt, includes a great diversity of genera and species, and is characterized by the appearance of *Codonofusiella* and more advanced species of *Yabeina* together with many genera which range upward from the zone below. This zone is most readily correlated with the Kuman Stage of Japan and is probably time equivalent to much of the Capitanian Stage of the Guadalupian Series.

Lithologic Relationships and Environmental Differences

In detail the lithologies in which the different faunal associations occur are very dissimilar, suggesting that the basic differences in faunal composition are mainly the result of environmental differences. The fusulinacean faunas of the eastern and western belts occur in regionally discontinuous, commonly local limestones, in many places argillaceous, associated with argillites, sandstones, pyroclastic rocks, and volcanic flow rocks of variable composition. The fusulinacean faunas of the central belt occur in thick, extensive limestones, characteristically associated with ribbon cherts, basic volcanic rocks, and ultramafics. Argillite is commonly present in this assemblage but is rarely a major component.

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Near the northern end of the central belt in the Atlin area, northwestern British Columbia (Locality 20), massive limestone of Late Mississippian to Permian age extends along the regional strike in a belt 100 miles (160 km) long and up to 20 miles (32 km) wide and reaches a maximum thickness of 6000 ft (1830 m) (Monger 1969). In the Fort St. James area, central British Columbia (Locality 19), the main limestone (Pennsylvanian to Permian in age) extends for at least 100 miles (160 km) and is up to 5 miles (8 km) wide with a thickness of up to 5000 ft (1525 m) (Armstrong 1948). In the Marble Range, south-central British Columbia (Locality 17), the Permian limestone extends for a distance of at least 50 miles (80 km), is up to 10 miles (16 km) wide and reaches 6000 ft (1830 m) (Duffel and McTaggart 1952), although Trettin (1965) considers the stratigraphic thickness to be less than this because the limestone is tightly and isoclinally folded. These thicknesses, although estimates, give some measure of the tremendous volume of limestone that occurs as highly deformed yet continuous limestone bodies.

In the central belt limestones are massive, dense, porcellaneous, light in color and very pure. Rarely bedding may be apparent from a distance but generally is obscure from a few feet away. The most characteristic lithology is crinoidal and/or foraminiferal calcarenite or calcarenitic limestone (classification of Powers 1962) with some oolitic limestone, breccia and relatively rare, dark, aphanitic algalminate beds. Crinoid detritus, fusulinaceans and algae are abundant whereas all other invertebrate groups are rare with the local exception of corals (Table 2). These rocks appear to have been deposited mainly as limestone banks, reefs, and tidal flats in fairly shallow clear water. They are perhaps analogous to the modern Bahama Banks in areal extent, lithology and even in a somewhat similar overall rate of subsidence (64 ft/m.y. in northern British Columbia, versus about 85 ft/m.y. in the Bahamas–Florida keys region, according to Lynts 1970). They differ from rocks of the Bahama Banks in that locally these carbonates are interbedded with basic volcanic rocks and cherts.

Limestone beds in the eastern and western belts are much thinner and appear to be restricted to a single system or part of a system in contrast to those in the central belt. Some of the thickest limestones are in Telegraph Creek area (Locality 11) where upper (?) Mississippian limestone more than 2000 ft (610 m) thick is unconformably overlain by Permian limestone at least 1000 ft (305 m) thick (J. K. Rigby[1]; Monger 1970). These limestones may originally have been of regional extent, the ones in Telegraph Creek area having been correlated by Rigby[1] with limestone 200 miles (320 km) to the south in the Terrace area (Locality 8), but nowhere do they form the continuous masses similar to those now exposed in the central belt.

Lithologically, these limestones are well-bedded and in many places are argillaceous or tuffaceous. There are exceptions, such as the Pennsylvanian Soda Bay Formation in southeastern Alaska and the upper part of the Permian limestone in the Telegraph Creek area, where the limestone is massive, pure, and texturally similar to limestone in the central belt. However, the fusulinid faunas in the latter locality are not the same as those in the central belt (Table 1). Texturally these carbonates typically consist of micritic matrix containing variable quantities of crinoidal detritus, fusulinaceans, bryozoans, and rarely algae. Other fossils such as horn corals, brachiopods, and gastropods also are locally very abundant (Table 2). In general these rocks appear to have been deposited in a lower energy environment than those of the central belt, perhaps in an apron below wave base or in protected bays and lagoons. Their impure composition in many localities suggests that the water was probably turbid.

Data on the primary composition of the Upper Paleozoic volcanic rocks is limited because these rocks are generally strongly altered and the chemical analyses required for their precise compositional definition have been made in only a few areas. Consequently, the generalizations made below by extrapolation from the few known areas are provisional. The volcanic rocks in the central belt are basic flows with little pyroclastic material. Chemical analyses of this type of rock, from northern

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[1] Personal communication.

British Columbia (Locality 20) show that they are altered tholeiitic basalts, but no information is available from the rest of the region. In contrast, many volcanic rocks in the eastern and western belts are intermediate or acidic rocks and the sections of these contain much pyroclastic material. In the Telegraph Creek area (Locality 11) and on Vancouver Island (Locality 5), much of the volcanic rock appears to be andesitic tuff and agglomerate. In the Chilliwack area (Locality 1) basalt occurs with dacite tuff (Monger 1966). Other acidic rocks that have been reported are latite from Kluane map-area (Locality 15) (Muller 1967), rhyolite from McConnell Creek map-area (Locality 30) (Lord 1948), and Cry Lake area (south end of Locality 20) (H. Gabrielse[1]). The ecological significance of this distribution is that the intermediate and acidic volcanic rocks are more likely to contribute pyroclastic detritus to the depositional basin, thus make the water turbid and blanket the substratum. The significance of the distribution of volcanic rocks in terms of possible large-scale crustal movement is discussed below.

Chert, commonly well-bedded ("ribbon chert") and radiolarian-rich, is only abundant in the central belt. Armstrong (1949, p. 32) pointed out that in the Fort St. James area (Locality 19), ribbon cherts are not present in the eastern belt although they are abundant in the central belt. In the Atlin area (Locality 20) the areal extent of ribbon cherts and small amount of associated pelite and graywacke is about twice that of the volcanic rock and limestone combined, and contrasts markedly with the absence of chert (except as nodules in limestone) about 50 miles (80 km) to the south in the Telegraph Creek area (Locality 11, Monger 1970). The ecological significance of these cherts is that they indicate conditions of little clastic inflow and hence clear water. Their depth significance is not known. Although radiolarian chert commonly has been regarded as a deep water deposit (*e.g.* Carozzi 1960, p. 312), Danner (1967) has suggested that the chert in this region is of shallow water origin because locally it is interbedded with algal-bearing limestones. Possibly the bulk of the chert is of deep water origin with these interbedded cherts marginal to the main site of deposition.

Clastic rocks are abundant in both the eastern and western belts, where they are pelites, sandstones, and conglomerates. In the central belt they are far less common and are mainly pelites. These rocks are formed by material contributed by pyroclastic activity associated with the intermediate to acid volcanic rocks in the eastern and western belts (volcaniclastic rocks) and also by erosion accompanying regional uplift and local building-up above sea level by volcanic activity (epiclastic rocks). Evidence for uplift and erosion is well shown in the western belt and inferred in the eastern belt. In northwestern British Columbia (Locality 11), Lower Permian rocks unconformably overlie Mississippian rocks (J. K. Rigby[1]; Monger 1970) and in the southwestern part of the region (Localities 1 and 2) Lower Permian rocks lie disconformably on the Lower Pennsylvanian (Monger 1966). The general absence of Pennsylvanian rocks in the eastern belt is difficult to evaluate in terms of uplift and may merely indicate the absence of dateable Pennsylvanian rocks in the region. Conglomerates with rounded clasts of sedimentary and volcanic rocks in the western and southern part of the eastern belt (Localities 1, 2, 13, 14, 16, 23, 24, 27, and 29) and terrigenous plant fossils (Localities 1, 2, 7, 11, 13, 16, 21, and 23) suggest the presence of land masses, perhaps volcanic islands, in the western belt and southern part of the eastern belt.

These lithologies and their relationships suggest several ecological factors that may be partly responsible for the differences in fusulinacean distribution. Water turbidity may be important and was likely high in the eastern and western belts in comparison to the central belt because of the distribution of clastic material. A second factor may be water depth, as limestone of the central belt contains abundant algae and probably formed in shallow water. Algae are relatively rare in the eastern and western belts, possibly implying greater water depths, although here the increased turbidity, in so far as it affects the depth of the photic zone, may play a part. On a more speculative basis, salinity variation may be important. Possible fresh water run-off from land areas could make lagoons, bays, and estuaries more brackish at least locally along the eastern and western belts. By contrast there is some reason to be-

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lieve (see below) that limestone of the central belt was adjacent to open ocean and thus was deposited under conditions of normal salinity. Perhaps the tremendous bioclastic limestone accumulation in this central belt reflects a rich nutrient supply which stimulated the development of an abundant biota.

Effect of Major Crustal Displacements

If the fusulinacean faunas in the western Canadian Cordillera are in essentially the same relative geographic position today as they have always been, apart from a few tens of miles of crustal shortening during Mesozoic mountain-building, then it seems likely that the different fusulinacean faunas are largely the result of local environmental differences such as those noted above. However, much evidence is accumulating that the crust of the earth is highly mobile laterally and that parts of it can be displaced thousands of miles relative to other parts. This being so, the possibility exists that faunas living in widely separated regions subsequently may have been transported bodily for considerable distances and brought into contact with one another. In this case both genetic isolation and climatic factors such as length of season and possibly differing water temperatures (for the same water depth), in addition to the local environmental factors above, may have had an important influence on the observed faunal diversity. This point needs to be considered carefully, because the rocks of late Paleozoic age more than any others in the Canadian Cordillera display features considered to be characteristic of rocks involved in large-scale crustal movements. However, it is to be noted that we have yet to establish positive proof of such movements and the faunas themselves do not support or refute a mobilistic picture, although they may place certain constraints on any Upper Paleozoic distribution of crust in this region.

The current model of major crustal displacements known as the plate tectonic hypothesis is briefly (*see* Menard 1969) that the surface of the earth consists of about seven rigid but mobile plates of oceanic and/or continental crust that interact in various ways. When the plates move apart, new crust composed of basalt is generated between and added to them. Such crust is exposed along the oceanic ridges and forms the floor of the ocean below the sedimentary cover. Assuming that the surface area of the earth is constant, the addition of this new crust must be compensated for by the destruction of older crust elsewhere. This takes place at the margins of plates, commonly by one plate passing beneath the other and becoming consumed. The surface expression of such a contact is an oceanic trench in some places, and in others a mountain chain. In response to the physical and chemical disequilibria caused by the descending plate, high-pressure, low-temperature metamorphism (producing blueschist metamorphic rocks) occurs at the contact between plates and andesitic magma is generated which forms island arcs or strato-volcanoes on the upper plate, near the plate margin. Island arcs imply disappearance of crust and are thus of considerable significance when part of a geological record as in the western Canadian Cordillera.

In trying to determine the nature of plates that are no longer active and the possible type of movement that may have occurred between them, the following criteria are sought (*see* Hamilton 1969, pp. 2409–2412). Basalt alone or in many places associated with ultramafic rocks indicates crustal spreading and where associated with sediments such as bedded chert, argillite, or turbidite sequences, characterizes old oceanic crust. Volcanic rocks of variable composition, ideally andesite but ranging from basalt to dacite, volcaniclastic and epiclastic sediments derived from these rocks, and limestones that may have formed fringing reefs to volcanic islands, characterize island arcs. The contact zone between plates may be delineated by metamorphic rocks belonging to the blueschist metamorphic facies.

Applying these criteria to Upper Paleozoic rocks of British Columbia, both oceanic and arc-type rocks seem to be present. Andesitic and mixed volcanics of Mississippian and Permian age are known in the western belt as are abundant clastics, some containing plant fossils that indicate a subaerial source area, and limestones. The eastern belt contains known Permian acidic volcanic rocks, abundant clastic rock, and limestones. By contrast the central belt contains basalt (where details of chemistry are known), ultramafic rocks, and bedded chert and is separated from the eastern belt by local

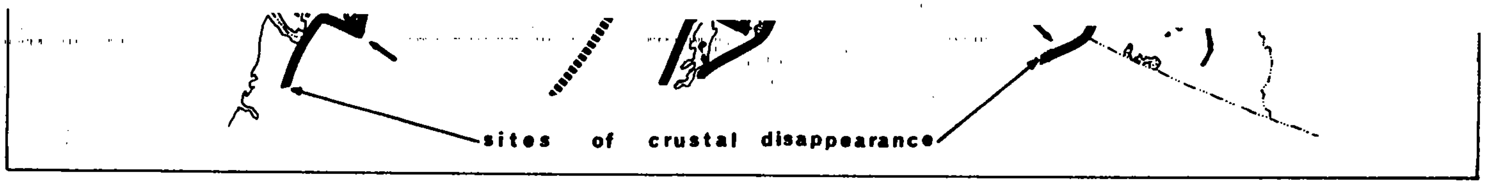

FIG. 4. Schematic diagram showing the possible distribution of crustal segments in a simple plate tectonic model of the Canadian Cordillera in late Paleozoic time.

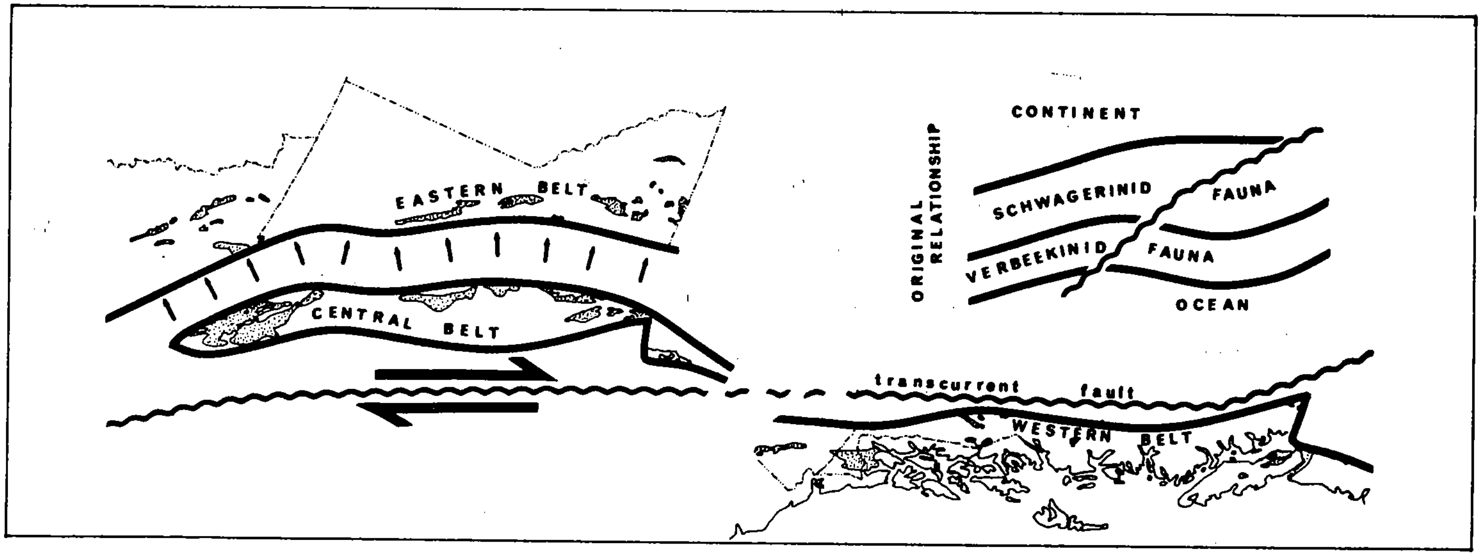

FIG. 5. Schematic diagram showing the possible distribution of crustal segments in a plate tectonic model involving major transcurrent faulting in the Canadian Cordillera in post-late Paleozoic time.

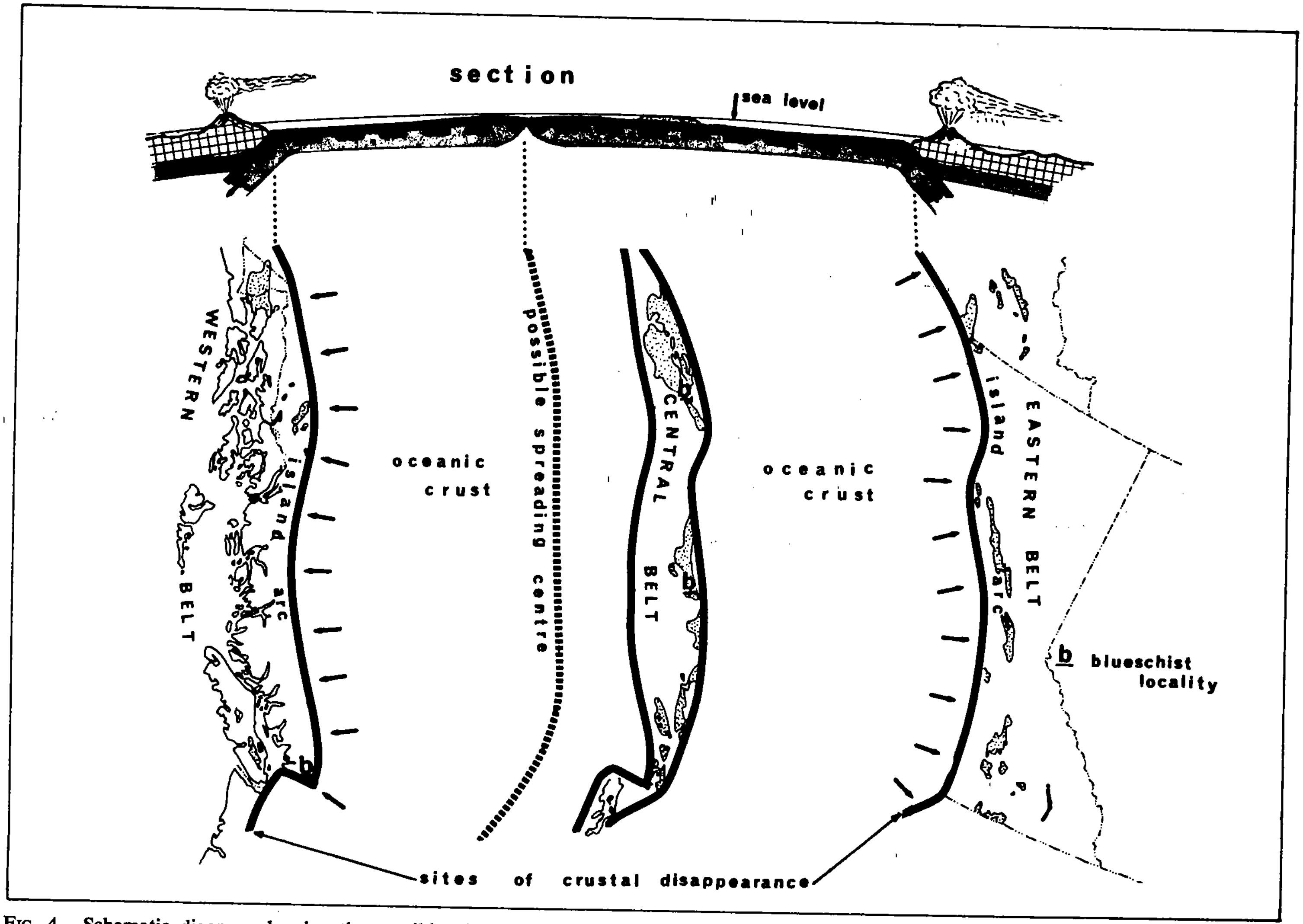

FIG. 4. Schematic diagram showing the possible distribution of crustal segments in a simple plate tectonic model of the Canadian Cordillera in late Paleozoic time.

blueschist metamorphism (Localities 20, 19, and 1). An anomaly in this belt, which because of isostasy should belong to the deep ocean, is the regionally extensive shallow water limestone locally intercalated with chert and basaltic flows. This can only be interpreted as some kind of barrier reef on to oceanic crust. A possible analogy is Cretaceous carbonate in the Bahama Banks that is in close proximity to Cretaceous basic volcanics and ultramafics of Cuba (Khudoley 1967). A further problem is the presence of probable Mississippian basaltic rocks and ultramafics that are east of the eastern belt, overlie older non-volcanic (miogeosynclinal) rocks, and are in proximity to non-volcanic rocks of the same age (part of Locality 31 and the outcrop area east of Locality 18). It has been suggested by J. Dercourt[1] that these rocks are allochthonous ocean floor material that has been thrust eastwards over continental crust.

From this study it is possible to construct several simple plate models on the assumption that the eastern and western belts are island arcs and the central belt old oceanic crust. The simplest would be a model (in part analogous to the modern Red Sea), whereby the central zone became the site of basaltic generation and spreading and the eastern and western belts (because of their andesitic volcanism) sites of crustal disappearance. This model implies no great separation and if valid suggests that local environmental conditions control the distribution of fusulinaceans. A second model (Fig. 4) is more conventional in terms of plate tectonic theory and has the three belts separated by unknown distances, so that genetic isolation and climatic factors (water temperature, season length) could have been important. However, the faunas themselves are in conflict with this model as some Permian faunas in both eastern and western belts are very similar, thus arguing against great separation of the eastern and western belts. For example the same three genera (*Parafusulina*, *Schwagerina*, and *Pseudofusulinella*) comprise the bulk of the fusulinacean faunas in some localities in both eastern and western belts (Localities 1, 11, and 21). A third compromise model that allows faunas in the eastern and western belts to have been in relatively close relationship in Paleozoic time, yet adheres to the concept of major crustal movements, is shown in Fig. 5. In this model the western belt is merely the continuation of the eastern belt transposed, presumably in Mesozoic time, by right lateral faulting, in a situation analogous to the modern San Andreas fault. This presents a simple picture of an oceanward belt of basic rocks flanked by a barrier reef and separated by an unknown distance from a landward arc.

These models point out some of the possibilities for explaining the distribution of fusulinaceans that have to be considered once crustal mobility is accepted. Before the fusulinaceans or any other faunal group can be used for any sort of regional paleogeographic reconstruction or, more likely, to place constraints on any proposed model, detailed comparative studies at species level will need to be made with other areas such as the Canadian Arctic, the Interior of the United States, and Japan or Indonesia. At present we do not have the information from this region to make such comparisons.

Conclusions

In the western Canadian Cordillera the distribution of fusulinacean genera into two assemblages, one having considerable diversity and restricted to a lithologically distinctive central belt and the other having less diversity and dominant in an eastern and western belt, presents several perplexing problems in interpreting the biogeographic and the tectonic history of the region. Various models are proposed and include: (1) an ecological model in which strongly differentiated local environments are populated by highly selective fusulinaceans; (2) a simple plate tectonic model in which originally widely separate segments of crustal material are brought together and; (3) a transcurrent plate tectonic model in which an original single pair of ecological belts has been broken and juxtaposed by major right lateral movement. The available data is only suggestive that the first or third model may have more supporting evidence.

Acknowledgments

Members of the Cordilleran Section, Geological Survey of Canada, made available both material for one of us (C. A. Ross) to study and also unpu
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and also unpublished data. Detailed stratigraphic studies by J. K. Rigby in 1959 for Amoco Canada Petroleum Company (then Pan-American) on upper Paleozoic rocks in northern B.C. gave the writers information on several little-known localities. The writers are grateful to Dr. Rigby and Amoco Canada for making this information available for publication. A. T. Ovenshine, U.S. Geological Survey, guided one of us (J. W. H. Monger) over the Paleozoic section in southern southeastern Alaska. Finally, G. W. H. Norman, Newmont Mining Corporation, informed us of the occurrence of a late Paleozoic (Pennsylvanian ?) plant fossil locality in northwestern British Columbia.

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The Stratigraphy and Morphology of Para-
South-central British Col

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Alluvial fan construction within the interior valleys of
dependent upon temporary conditions resulting from deglaci
by streams and mudflows to form fans whose composition
the drift supply and the hydrologic character of the parent bas
Stratigraphic evidence suggests that fan building commence
ice-free, continued during post-glacial aggradation by major
wards. Most recently, fans were built upon degradational riv
within fans indicates that their construction continued until a
tion ceased many fans were dissected either as local base-leve
of degrading major rivers or by fan-head trenching initiate
Where fan building persisted during degradation, multi-level f

Introduction

Alluvial fans are common in glaciated mountains where valley aggradation commenced during deglaciation. Fans in south-central British Columbia are products of an environment in the process of transition from predominantly glacial to dominantly fluvial conditions. It is suggested that such fans—referred to as "paraglacial" fans—differ in this respect from the more commonly studied fans of arid environments (Bull 1963; Lustig 1965; Melton 1965; Denny 1967; Hooke 1967).

Alluvial fans in formerly glaciated areas have received very little specific attention in North American literature (Anderson and Hussey 1962; Legget *et al.* 1966) although their presence as an element of the post-glacial landscape is commonly noted. From Europe only one recent investigation of post-glacial fan development has been published (Hoppe and Ekman 1964) although several earlier descriptive studies were carried out in the Alps (Solch 1949). Fans have received greater attention in New Zealand; Cotton (1958), Suggate (1963), Carryer (1966) and others discussed fan construction as a consequence of glaciation.

For study of such fans in south-central Brit-

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