Carboniferous Megafaunal and Microfaunal Zonation in the Northern Cordillera of the United States

GEOLOGICAL SURVEY PROFESSIONAL PAPER 613-E

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By WILLIAM J. SANDO, BERNARD L. MAMET, *and* J. THOMAS DUTRO, JR.

CONTRIBUTIONS TO PALEONTOLOGY

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A comparison of a zonal scheme based on corals and brachiopods with foraminiferal zonation in the Mississippian rocks of Montana, Wyoming, Idaho, and Utah

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 75 cents (paper cover)

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By WILLIAM J. SANDO, BERNARD L. MAMET, and J. THOMAS DUTRO, JR.

ABSTRACT

omparison of a 12-zone biostratigraphic scheme based on ls and brachiopods with a 15-zone scheme based on forifers results in consistent chronostratigraphic correlations the Mississippian of the northern Cordilleran region both hin the Cordilleran basin and with the type Mississippian sere. Except for the Kinderhook (early Tournaisian) interval, resolution of the foraminiferal zones is as fine or finer than t of the megafaunal zones. A higher degree of cosmopolitanism the foraminiferal faunas makes them generally more useful r megafaunas for correlation with the type Mississippian standard Carboniferous sequences in western Europe.

e following correlations of northern Cordilleran formations ndicated by both megafaunal and foraminiferal faunas. (1) Lodgepole Limestone ranges in age from late Kinderhook to le Osage (pre-Burlington to earliest Keokuk). This age ge coincides approximately with the early and middle Toursian (upper part of Tn1–Tn2) of western Europe. (2) The sion Canyon Limestone ranges in age from middle Osage to l Meramec (early Keokuk to middle Salem). This interval pproximately equivalent to the late Tournaisian (Tn3) to l Viséan (V1) interval of western Europe. (3) A widespread tus with a minimum time span represented by the upper part the Salem Limestone (V2a of western Europe) separates t-Madison strata from the Madison Group. (4) The Little t Formation is of middle Meramec (early St. Louis) age correlates with a part of the middle Viséan (V2b and lowerst V3a) of western Europe. (5) The Monroe Canyon Lime-e ranges in age from middle Meramec (late St. Louis) ough most of the Chester. This interval includes the late éan and early Namurian (V3a–E2) of western Europe. (6) Amsden Formation of Wyoming ranges in age from Late sissippian to Pennsylvanian. The oldest fossils found in msden are of middle Chester age; late Chester fossils are present. (7) The Big Snowy Group of southwestern Montana contains faunas of middle and late Chester age.

INTRODUCTION

e lack of a practical comprehensive system of al zonation for the Mississippian[1] rocks of North America is a serious deterrent to precise time-stratigraphic analysis. Purely lithostratigraphic techniques, currently popular in this country, are not an adequate substitute for time-tested biostratigraphic methods. Because of the many diverse sedimentary environments represented in the Mississippian of North America, it seems unlikely that a single scheme of biostratigraphic zonation will ever prove to be satisfactory for the entire continent. Moreover, no single group of fossils seems to hold the key to temporal relationships in all parts of North America. A series of zonation schemes, each based on the distribution of many kinds of fossils in a particular sedimentary basin or province, is a logical alternate solution to the problem. Such an endeavor will take many years of careful study by teams of biostratigraphers.

Two of the authors of this report (Sando and Dutro) have devoted the better part of the past 10 years of their research to definition and testing of a zonation scheme based principally on corals and brachiopods for the Mississippian of the northern Cordilleran region, encompassing parts of Idaho, Montana, Wyoming, and Utah. The results of recent work by C. A. Sandberg and Gilbert Klapper on the distribution of conodonts in the uppermost Devonian and lowermost Mississippian strata in the same area have been incorporated in the zonation. Some of the zones have also been recognized and used by Helen Duncan and Mackenzie Gordon, Jr., in the Great Basin region of Utah.

Although the megafaunal zonation thus devised is useful in establishing relationships within the Cordilleran basin, important provincial differences in the faunas make it difficult to correlate them precisely with standard stratigraphic units in the type area of the Mississippian. Moreover, relationships between the

[1] e Mississippian System of American usage includes the Lower oniferous and the lower part of the Upper Carboniferous of Euro- usage. It extends from the lower part of the Tournaisian to a tion above the *Eumorphoceras* Zone of the Namurian. Opinion rding the position of the Devonian-Mississippian boundary in rica has fluctuated in a manner similar to that regarding the nian-Carboniferous boundary in Europe (Mamet, 1968a). The Mississippian-Pennsylvanian boundary was originally placed at an unconformity, and *Homoceras* Zone cephalopods have not been found in the United States (Gordon, 1964, p. 83). However, recent unpublished studies of Mississippian Foraminifera in south-central Idaho by Mamet indicate the presence of foraminiferal faunas equivalent to the *Homoceras* Zone faunas of Europe.

Cordilleran zones and the classic marine Lower Carboniferous sequences of England and western Europe can be established only in very broad terms. The results of studies of Carboniferous Foraminifera by Mamet offer a possible solution to the difficulties encountered in correlating the megafaunal zones outside the Cordilleran region. After having studied the Lower Carboniferous foraminiferal sequences in the classic Tournai and Visé areas of Belgium, Mamet extended his work during the past ten years to England, France, the U.S.S.R., and North Africa. Recently, he has been engaged in biostratigraphic studies in western Canada and in the area of the type Mississippian in the United States. The outcome of these studies is a scheme of 15 Lower Carboniferous foraminiferal zones which can be recognized in appropriate carbonate facies on a worldwide basis.

PURPOSE AND SCOPE

The purpose of this report is to present the results of a joint study of the zonation problem in the Mississippian of the northern Cordilleran region. Approximately 300 samples collected from stratigraphic sections zoned megafaunally by Sando and Dutro were searched for Foraminifera by Mamet by means of approximately 500 thin sections. These samples were taken from the matrix of specimens used in megafaunal zone determination. One hundred and five samples from 20 stratigraphic sections proved favorable for foraminiferal zone identification.

Locations of stratigraphic sections, shown in figure 1, are as follows:

1. Little Flat Canyon 2, NW¼ sec. 20 and S½ sec. 17, T. 7 S., R. 40 E., Bannock County, Idaho.
2. Little Flat Canyon 1, SE¼ sec. 20, T. 7 S., R. 40 E., Bannock County, Idaho.
3. East Canyon, NE¼ sec. 7, T. 9 N., R. 2 E., Cache County, Utah.
4. Old Laketown Canyon, W½ sec. 32, T. 13 N., R. 6 E., Rich County, Utah.
5. Sheep Creek, sec. 28 (approx.), T. 1 N., R. 45 E., Bonneville County, Idaho.
6. Black Mountain, SE¼ sec. 23 and W½ sec. 24, T. 3 N., R. 43 E., Bonneville County, Idaho.
7. Haystack Peak, sec. 19, T. 34 N., R. 117 W., Lincoln County, Wyo.
8. Covey Cut-off, sec. 27, T. 34 N., R. 117 W., Lincoln County, Wyo.
9. Hoback Canyon, sec. 3, T. 38 N., R. 115 W., Teton County, Wyo.
10. Baldy Mountain, secs. 26, 27 and 35, T. 7 S., R. 3 W., Madison County, Mont.
11. Logan, sec. 25, T. 2 N., R. 2 E., Gallatin County, Mont.

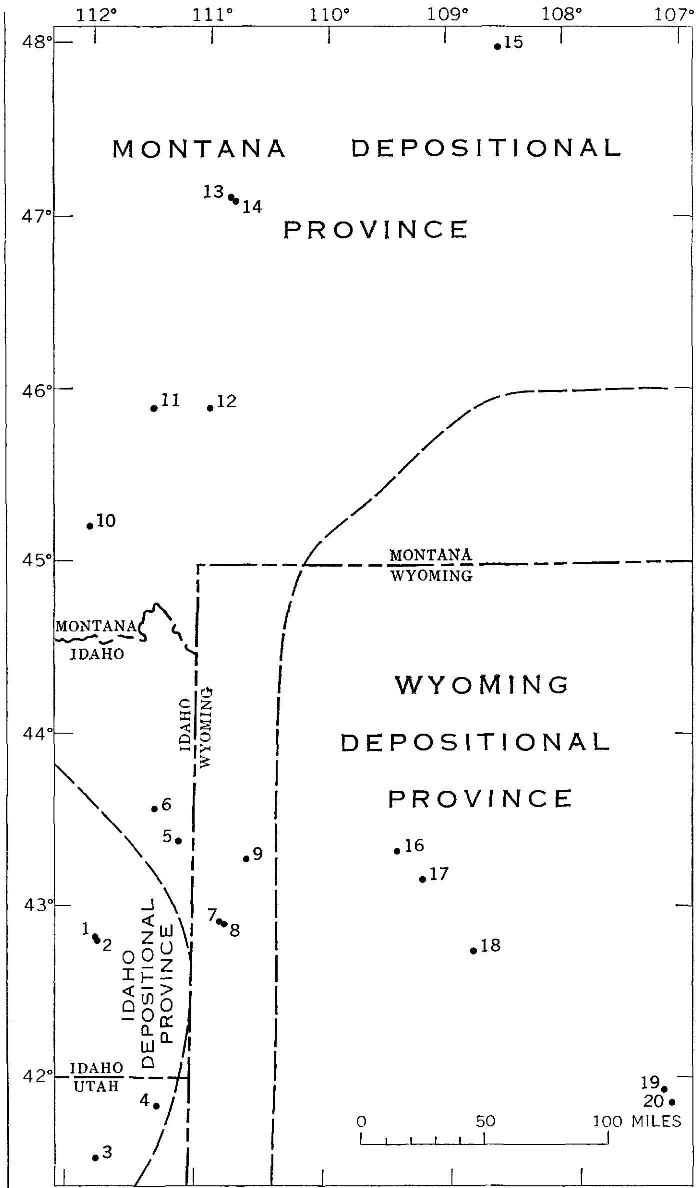


FIGURE 1.—Map of northern Cordilleran region, showing location of stratigraphic sections referred to in text and boundaries between Mississippian depositional provinces established by Sando (1967b).

12. Sacajawea Peak, N½ sec. 27, T. 2 N., R. 6 E., Gallatin County, Mont.
13. Monarch–U.S. 89, secs. 22 and 27, T. 16 N., R. 7 E., Cascade County, Mont.
14. Dry Fork, sec. 36, T. 16 N., R. 7 E., Cascade County, Mont.
15. Little Chief Canyon, secs. 19 and 30, T. 26 N., R. 25 E., Blaine County, Mont.
16. Dinwoody Canyon, NE¼ sec. 11, NW¼ sec. 12, S½ sec. 1, T. 4 N., R. 6 W., Fremont County, Wyo.
17. Bull Lake Creek, SE¼ sec. 3 and S½ sec. 2, T 2 N., R 4 W., Fremont County, Wyo.

18. Sinks Canyon (North), E½ sec. 18, T. 32 N., R. 100 W., Fremont County, Wyo.
19. Buck Spring, NW¼ sec. 33, T. 23 N., R. 88 W., Carbon County, Wyo.
20. Meadow Ranch, sec. 25, T. 22 N., R. 88 W., Carbon County, Wyo.

In table 1, the samples that form the basis of this study are listed by locality number; location of stratigraphic section, stratigraphic position, and zonal designations are provided for each sample. Plate 1 shows the positions of samples, each identified as to zonal designation, plotted to scale on a stratigraphic diagram.

The aims of this paper are (1) to summarize the coral-brachiopod zonation already established in the Mississippian sequences of Montana, Wyoming, Idaho, and Utah, (2) to establish equivalent Carboniferous foraminiferal zonation in the same area, (3) to compare the zonation schemes in order to test the internal validity of both approaches, and (4) to determine more precisely the ages of the zones in terms of the type Mississippian and standard sequences of the Carboniferous in western Europe.

TABLE 1.—*Register of fossil localities*

USGS upper Paleozoic loc. No	Locality in fig. 1	Stratigraphic section	Stratigraphic position	Megafaunal zone	Foraminiferal zone
6965	8	Covey Cut-off	Amsden Formation, 250–260 ft above base	K	17–18(?)
16209	9	Hoback Canyon	Amsden Formation, 117.8–119.8 ft above base	K	18
16211	9	do	Amsden Formation, 197.3 ft above base	Pennsylvanian	post-18
16942	4	Old Laketown Canyon	Lodgepole Limestone, 400–600 ft above base	C_1	7
16943	4	do	Lodgepole Limestone, upper 2 ft	C_1	7
16950	4	do	Little Flat Formation, 39 ft below top	E	13
16951	4	do	Little Flat Formation, 12 ft below top	E	13
16953	4	do	Monroe Canyon Limestone, 6 ft above base	F	14
16954	4	do	Monroe Canyon Limestone, 23–30 ft above base	F	14
17360	11	Logan	Lodgepole Limestone, 256–266 ft above base	B	pre-7
17365	11	do	Lodgepole Limestone, 348.8 ft above base	C_1	7
17377	11	do	Mission Canyon Limestone, 19.7 ft above base	C_2	8
17378	11	do	Mission Canyon Limestone, 78.4 ft above base	C_2	8
17380	11	do	Mission Canyon Limestone, 269.2 ft above base	C_2	8
17381	11	do	Mission Canyon Limestone, 322.9 ft above base	C_2	8
17383	11	do	Mission Canyon Limestone, 523.8 ft above base	C_2	9
17494	10	Baldy Mountain	Big Snowy Group, 255–280 ft above base	K	17–18(?)
17496	10	do	Big Snowy Group, 367–379 ft above base	K	17–18(?)
17498	10	do	Big Snowy Group, 437–447 ft above base	K	17–18(?)
17848	7	Haystack Peak	Lodgepole Limestone, 6 ft above base	A	pre-7
17849	7	do	Lodgepole Limestone, 18–22 ft above base	A	pre-7
17855	7	do	Lodgepole Limestone, 159–163 ft above base	B	pre-7
17856	7	do	Lodgepole Limestone, 166–171 ft above base	B	pre-7
17859	7	do	Lodgepole Limestone, 178–183 ft above base	C_1	7
17860	7	do	Lodgepole Limestone, 183–188 ft above base	C_1	7
17879	7	do	Mission Canyon Limestone, 0–30 ft above base	C_2	8
17882	7	do	Mission Canyon Limestone, 96–100 ft above base	C_2	8
17902	7	do	Mission Canyon Limestone, 544–568 ft above base	D	10–11
17905	7	do	Amsden Formation, 177–178 ft above base	K	17
17906	7	do	Amsden Formation, 184–187 ft above base	K	17
17907	7	do	Amsden Formation, 199–209 ft above base	K	18
17929	10	Baldy Mountain	Lodgepole Limestone, 278.3 ft above base	C_1	7
17950	10	do	Lodgepole Limestone, 575.3–578.3 ft above base	C_1	7
17954	10	do	Lodgepole Limestone, 699.3 ft above base	C_1	7
17960	10	do	Mission Canyon Limestone, 348–368 ft above base	C_2	9
17964		do	Mission Canyon Limestone, 620.5–640.5 ft above base	D	11
18634	2	Little Flat Canyon 1	Lodgepole Limestone, lower 15 ft	A	pre-7
18637	2	do	Lodgepole Limestone, 13–23 ft above base	B	pre-7
18645	2	do	Lodgepole Limestone, 186–198 ft above base	C_1	7
18651	2	do	Little Flat Formation, 28–32 ft above base	pre-E	13–14
18655	2	do	Little Flat Formation, 488 ft above base	pre-E	13–14
18667	1	Little Flat Canyon 2	Little Flat Formation, 584 ft above base	E	13–14
18669	1	do	Little Flat Formation, 597 ft above base	E	13–14
18677	1	do	Little Flat Formation, 761.5 ft above base	E	13–14
18680	1	do	Little Flat Formation, 815 ft above base	E	13–14

TABLE 1.—*Register of fossil localities*—Continued

USGS upper Paleozoic loc. No.	Locality in fig. 1	Stratigraphic section	Stratigraphic position	Megafaunal zone	Foraminiferal zone
18689	1	Little Flat Canyon 2	Monroe Canyon Limestone, 225.5–245.5 ft above base	F	14
18699	1	do	Monroe Canyon Limestone, 407.5–412.5 ft above base	F	14–15
18700	1	do	Monroe Canyon Limestone, 418.5–422.5 ft above base	F	14–15
18702	1	do	Monroe Canyon Limestone, 460 ft above base	F	15
18703	1	do	Monroe Canyon Limestone, 468 ft above base	F	15
18704	1	do	Monroe Canyon Limestone, 488–508 ft above base	F	15
18705	1	do	Monroe Canyon Limestone, 588–600 ft above base	pre-K	16i
18706	1	do	Monroe Canyon Limestone, 613 ft above base	pre-K	16i
18707	1	do	Monroe Canyon Limestone, 628 ft above base	pre-K	16i
18708	1	do	Monroe Canyon Limestone, 638 ft above base	K	16i(?)–16s
18709	1	do	Monroe Canyon Limestone, 645–647 ft above base	K	16s
18710	1	do	Monroe Canyon Limestone, 661 ft above base	K	16s
18711	1	do	Monroe Canyon Limestone, 688 ft above base	K	16s–17
18715	1	do	Monroe Canyon Limestone, 805–825 ft above base	K	17–18
18720	1	do	Monroe Canyon Limestone, 905 ft above base	K	18
18721	1	do	Monroe Canyon Limestone, 919–923 ft above base	K	18
20047	3	East Canyon	Brazer Limestone (as used by Mullens and Izett, 1964), 50 ft below top.	K	17
20059	6	Black Mountain	Lodgepole Limestone, 227.5 ft above base	C_1	7
20064	6	do	Lodgepole Limestone, 340.5 ft above base	C_1	7
20065	6	do	Lodgepole Limestone, 355.5 ft above base	C_1	7
20067	6	do	Lodgepole Limestone, 402.5 ft above base	C_1	7
20068	6	do	Lodgepole Limestone, 404.5 ft above base	C_1	7
20070	6	do	Lodgepole Limestone, 415.5 ft above base	C_1	7
20079	6	do	Lodgepole Limestone, 612.5–617.5 ft above base	C_1	8
20085	6	do	Lodgepole Limestone, 668.5–673.5 ft above base	C_1	8
20088	6	do	Mission Canyon Limestone, 35–38 ft above base	C_2	8
20089	6	do	Mission Canyon Limestone, 44–47 ft above base	C_2	8
20100	6	do	Mission Canyon Limestone, 630–634 ft above base	C_2	9
20104	6	do	Mission Canyon Limestone, 825.5–845.5 ft above base	D	10–11
20107	5	Sheep Creek	Lodgepole Limestone, 196.5–200.5 ft below top	C_1	7
20106	5	do	Mission Canyon Limestone, 101–118 ft above base	C_2	8
20108	5	do	Mission Canyon Limestone, 38–48 ft above base	C_2	8
20647	12	Sacajawea Peak	Lodgepole Limestone, 251.5 ft above base	B	pre-7
20652	12	do	Lodgepole Limestone, 295.8–308.8 ft above base	C_1	7
20653	12	do	Lodgepole Limestone, 322.8–334.3 ft above base	C_1	7
20666	12	do	Lodgepole Limestone, 567.3 ft above base	C_1	7–8
20673	12	do	Mission Canyon Limestone, 51–52 ft above base	C_2	8
20675	12	do	Mission Canyon Limestone, 78–93 ft above base	C_2	8
20678	12	do	Mission Canyon Limestone, 240–242 ft above base	C_2	9
20701	15	Little Chief Canyon	Lodgepole Limestone, 5 ft above base	A	pre-7
20708	15	do	Lodgepole Limestone, 182–187 ft above base	C_1	7
20710	15	do	Lodgepole Limestone, 204–205 ft above base	C_1	7
20716	15	do	Lodgepole Limestone, 189–205 ft above base	C_1	7
20730	15	do	Lodgepole Limestone, 439.7–442.7 ft above base	C_1	7
20740	15	do	Mission Canyon Limestone, 30–35 ft above base	C_2	8
20743	15	do	Mission Canyon Limestone, 280 ft above base	C_2	8
20751	14	Dry Fork	Lodgepole Limestone, 1.5 ft above base	A	pre-7
20771	14	do	Lodgepole Limestone, 290.5–293.5 ft above base	C_1	7
20787	14	do	Lodgepole Limestone, 661–669.5 ft above base	C_1	7
20795	14	do	Mission Canyon Limestone, 70–75 ft above base	C_2	8
20798	13	Monarch–U.S. 89	Mission Canyon Limestone, 281.2–286.2 ft above base	C_2	9
20799	13	do	Mission Canyon Limestone, 309.2 ft above base	C_2	9
20804	13	do	Mission Canyon Limestone, 617.2 ft above base	D	10
20805	13	do	Mission Canyon Limestone, 695.2–696.2 ft above base	D	10
21647	18	Sinks Canyon (North)	Madison Limestone, 197–200 ft above base	C_2	9
21648	18	do	Madison Limestone, 242.5–250.5 ft above base	C_2	9
21677	17	Bull Lake Creek	Madison Limestone, 656.5–659.5 ft above base	D	10–11
21692	16	Dinwoody Canyon	Madison Limestone, 792.5–807.5 ft above base	D	10–11
21725	19	Buck Spring	Amsden Formation, 140.5–142.5 ft above base	Penn.?	post-18
21729	20	Meadow Ranch	Amsden Formation, 92.5–95.5 ft above base	Penn.	post-18

CORAL-BRACHIOPOD ZONATION

HISTORICAL DEVELOPMENT

The present scheme of megafaunal zonation had its origin in biostratigraphic studies of the Madison Group begun in 1954 by Sando and Dutro, who were assigned this research project in support of general geologic investigations by the U.S. Geological Survey in the northern Rocky Mountain region. Studies of nine stratigraphic sections in northeastern Utah, western Wyoming, and Montana led to the recognition of five coral zones (A, B, C_1, C_2, and D) for the Madison Group and Brazer Dolomite (Sando and Dutro, 1960; Sando, 1960) (fig. 2). The Madison coral zonation was subsequently applied to stratigraphic problems in northwestern Montana (Mudge and others, 1962) and central Wyoming (Sando, 1967a). This zonation concept has also been used extensively since 1960 in unpublished reports to Geological Survey field geologists on numerous collections from many localities in the northern Cordilleran region.

Study of the Mississippian sequence in the Chesterfield Range, southeastern Idaho, led to the recognition of three coral zones (E, F, and K) and four brachiopod zones in post-Madison Upper Mississippian strata (Dutro and Sando, 1963a). One of these coral zones and two of the brachiopod zones were also identified in beds of Late Mississippian age in western Wyoming and southwestern Montana (Dutro and Sando, 1963b). The coral zonation recognized in these areas is very similar to the scheme developed earlier by Parks (1951) for the Upper Mississippian sequence in northern Utah. The three coral zones have been tested subsequently in unpublished reports to Geological Survey geologists working in southeastern and south-central Idaho.

Studies by Mackenzie Gordon, Jr., and Helen Duncan (written commun., 1964) resulted in a zonation scheme, based on corals and brachiopods, for the Osage-Chester interval of the Great Basin area of Utah. In addition to the E (*Ekvasophyllum*,) F (*Faberophyllum*), and K (*Caninia*) Zones of the Chesterfield Range, this scheme included three zones in the Upper Mississippian interval beneath Zone E, a pre-*Caninia* Zone between Zones F and K, and a post-*Caninia* Zone of Chester age above Zone K. Subsequent unpublished studies by Gordon established the presence of the post-*Caninia* Zone in the lower part of the Amsden Formation of central Wyoming.

When the original Madison coral zonation was proposed (Sando and Dutro, 1960), noncoralliferous beds of earliest Mississippian age were included in the subjacent, predominantly Devonian formations. Subsequent detailed studies of these strata and their conodont faunas by C. A. Sandberg and Gilbert Klapper led to recognition of a conodont zonation (Klapper, 1966; Sandberg and Klapper, 1967) and inclusion of these beds in the Madison. It became apparent that the Lower *Siphonodella crenulata* Zone of Klapper (1966) and Sandberg and Klapper (1967) coincided with Zone A of Sando and Dutro (1960). The conodont work also resulted in definition of two zones, *Siphonodella sandbergi–S. duplicata* Zone and *S. sulcata* Zone, for the earliest Mississippian beds beneath Zone A.

In a synthesis of Mississippian stratigraphy in the northern Cordilleran region, Sando (1967b) presented a composite zonation of the entire Mississippian interval. A sequence of 12 megafaunal zones incorporated all the previous work discussed above. Two major cycles of sedimentation were recognized, Madison cycle and a later, post-Madison cycle, separated by a widespread episode of epeirogenic uplift. The Madison interval was divided into the five zones of Sando and Dutro (1960) plus a newly-recognized pre-A Zone at the base, proposed to include the *cu*I conodont fauna of Klapper (1966). The post-Madison interval included six zones that began with a newly recognized pre-E Zone followed by coral zones E and F of Dutro and Sando (1963a). A newly recognized pre-K Zone based on brachiopods was delineated above Zone F. Thence followed Zone K of Dutro and Sando (1963a), which was in turn overlain by a newly recognized post-K Zone based on brachiopods. This 12-zone megafaunal system is the one used in the present report.

DISTRIBUTION, COMPOSITION, AND CRITERIA FOR RECOGNITION

The zonation scheme embodies both assemblage zone and range zone concepts. With the exception of the pre–A Zone, which is based on conodonts, the zonal indices are genera and species of corals and brachiopods. The ranges of significant zonal fossils are shown in figures 3 and 4. The zones are identified by means of assemblages of these fossils in some occurrences and by means of individual taxa of restricted range in others.

The oldest unit recognized in the zonation scheme is the pre–A Zone, which includes the two *cu*I conodont zones (*Siphonodella sandbergi–S. duplicata* Zone and *S. sulcata* Zone) of Sandberg and Klapper (1967). The conodonts occur in the upper tongue of the Cottonwood Canyon Member of the Madison Limestone in central Wyoming and of the Lodgepole Limestone in southern Montana. (See Klapper, 1966, and Sandberg and Klapper, 1967, for detailed discussions of the conodonts and distribution of these beds.) The upper part of the pre–A Zone is characterized by the assemblage of *Siphonodella sandbergi*, *S. duplicata*, and *Pseudopoly-*

Parks (1951)	Sando and Dutro (1960); Sando (1960)	Mudge, Sando and Dutro (1962)	Dutro and Sando (1963a)	Dutro and Sando (1963b)	Gordon and Duncan (written commun., 1964)	Klapper (1966)	Sando (1967a)	Sandberg and Klapper (1967)	Sando (1967b)
Northern Utah	Montana, western Wyoming, and northern Utah	NW. Montana	SE. Idaho	SW. Montana and western Wyoming	Great Basin, Utah	SW. Montana, northern Wyoming, and western South Dakota	Central Wyoming	Montana and Wyoming	SE. Idaho western and central Wyoming, and northern Utah
	Not discussed	Not discussed	Not discussed	Not discussed	Post-*Caninia*	Not discussed	Not discussed	Not discussed	Post-K
Caninia			K; *Spirifer brazerianus*	K; *Spirifer brazerianus*	*Caninia*				K
Triplophyllites					Pre-*Caninia*				Pre-K
Lithostrotion whitneyi-F. leathamense; *Faberophyllum occultum-F. araneosum*			F; *Striatifera brazeriana*	*Striatifera brazeriana*; Not discussed	*Faberophyllum*				F
Ekvasophyllum inclinatum			E; *Echinoconchus* cf. *E. alternatus*		*Ekvasophyllum*				E
			Quadratia hirsutiformis		*Timania?*; *Rhopalolasma*; *Quadratia hirsutiformis*				Pre-E
Not discussed	D	D	Hiatus				D		D
	C_2	C			*Homalophyllites* *Vesiculophyllum*		C		C_2
	C_1		C_1				?		C_1
	B	B	B				A–B?		B
	A	A	A			Lower *Siphonodella crenulata*		Lower *Siphonodella crenulata*	A
	Not discussed	Not discussed	Not discussed			*cul* fauna	Not discussed	*Siphonodella sandbergi-S. duplicata*; *Siphonodella sulcata*	Pre-A

FIGURE 2.—Historical development of megafaunal zonation in the northern Cordillera.

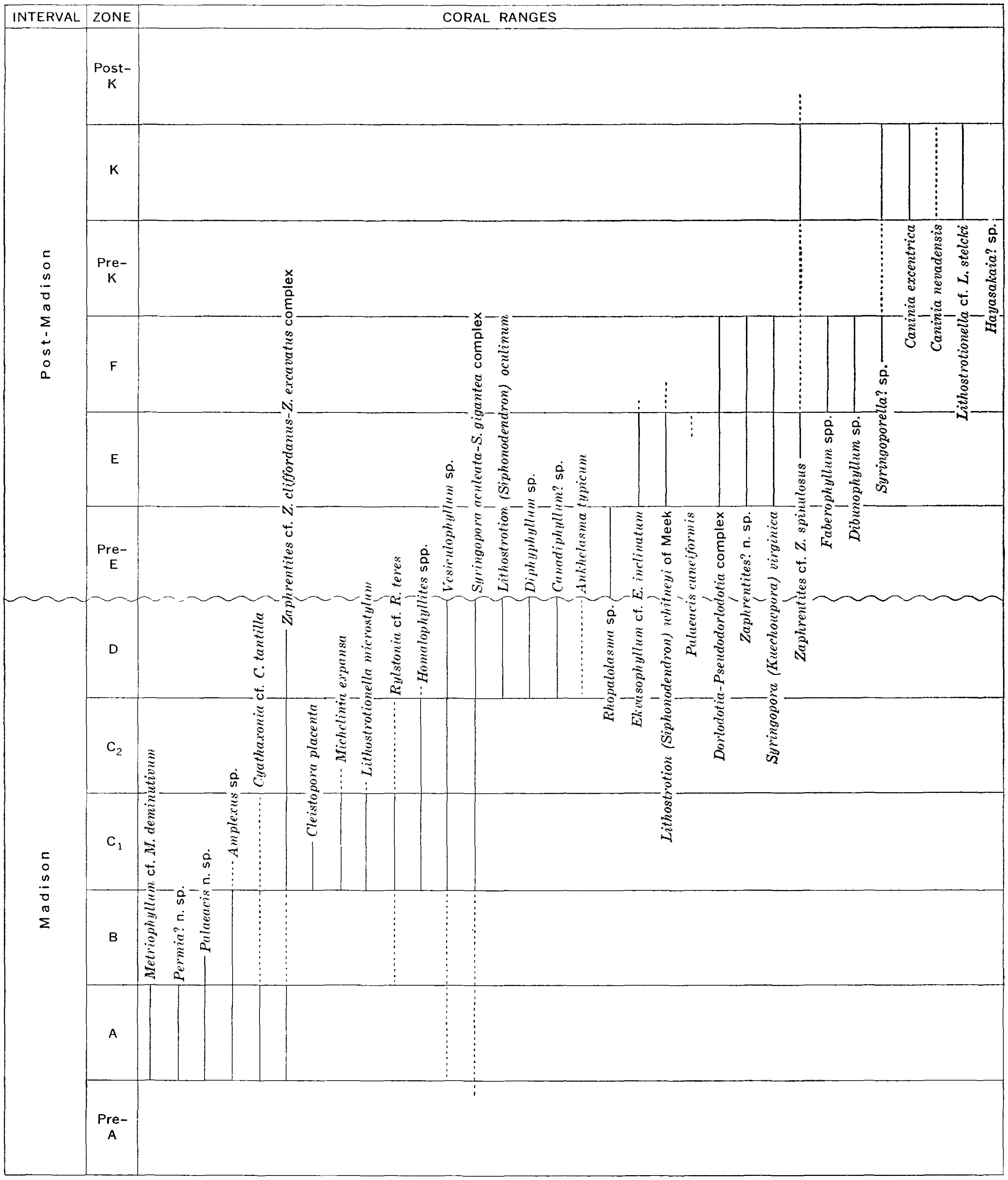


FIGURE 3.—Ranges of significant coral taxa in megafaunal zones of the Mississippian in the northern Cordillera. Solid range lines indicate common to abundant occurrences; dashed lines denote rare occurrences.

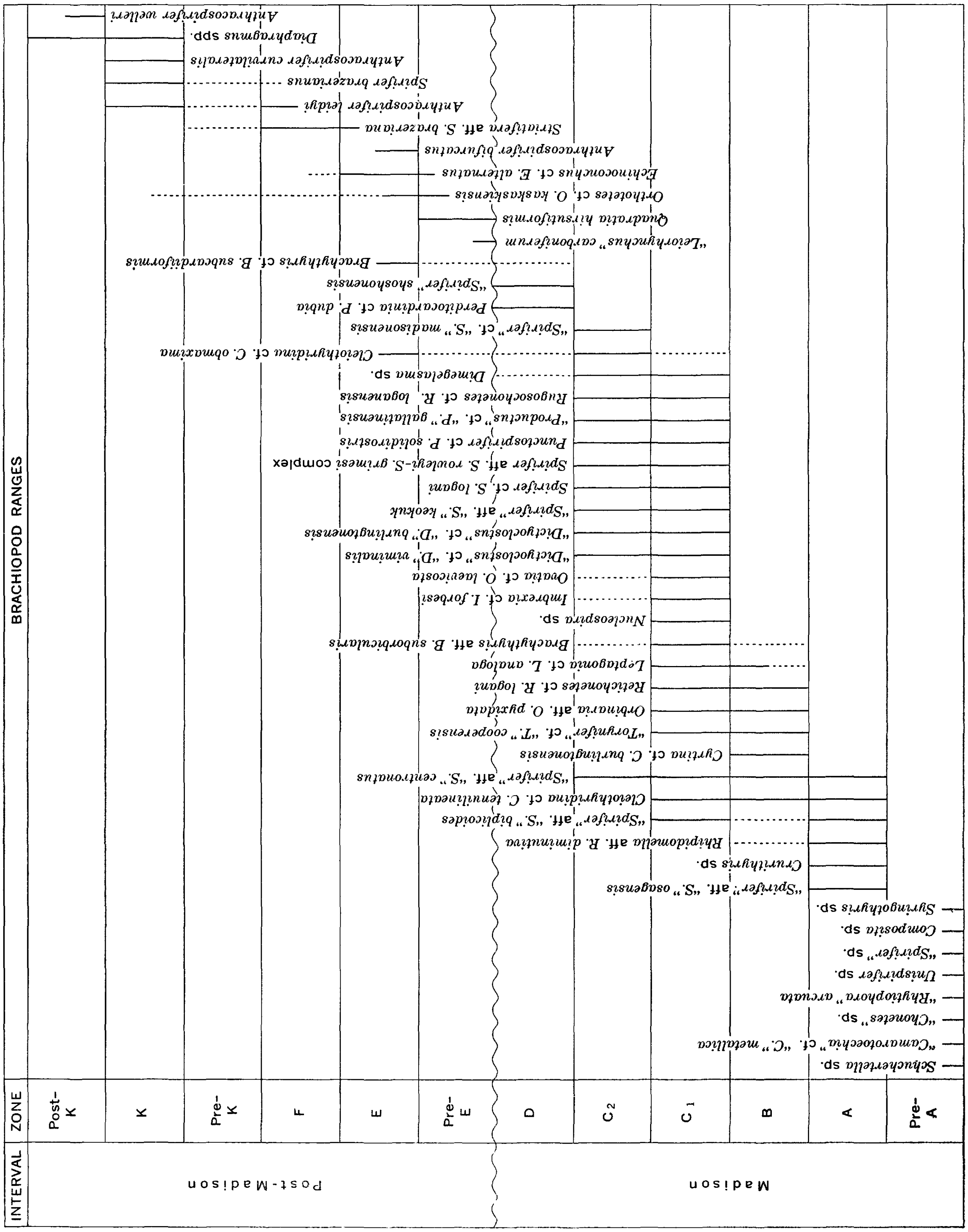


FIGURE 4.—Ranges of significant brachiopod taxa in megafaunal zones of the Mississippian in the northern Cordillera. Solid range lines indicate common to abundant occurrences; dashed lines denote rare occurrences.

gnathus dentilineata. The lower part, known only from Windy Gap in west-central Wyoming, is characterized by *Siphonodella sulcata.* No brachiopods have been found in the Cottonwood Canyon Member, but *Syringpora* occurs in the upper part at a few localities in central Wyoming.

Brachiopods from the upper part of the Sappington Member of the Three Forks Formation of southwestern Montana also are included in the pre–A Zone. Despite recent detailed work on the biostratigraphy of the Sappington (Rodriquez and Gutschick, 1967; Gutschick and Rodriquez, 1967), the age and correlation of parts of this unit remain controversial. Evaluation of the Sappington fauna involves not only comparison of this fauna to Mississippi Valley faunas but also the question of whether the Louisiana Limestone is of Carboniferous or Devonian age, a problem that has not been resolved to the satisfaction of all paleontologists who have worked on the Louisiana Limestone faunas. Although a detailed discussion of the age and correlation of the Sappington is beyond the scope of this paper, we provisionally believe that the Louisiana Limestone is of Devonian age and that the Carboniferous part of the Sappington includes units F, G, and H of Gutschick and Rodriquez (1967, p. 601, fig. 1). Unit I of Gutschick and Rodriguez is regarded as an extension of the upper tongue of the Cottonwood Canyon Member of the Lodgepole Limestone. Consequently, the principal elements of the brachiopod fauna that we include in the pre–A Zone largely consist of undescribed species of *Schuchertella*, "*Camarotoechia*," "*Chonetes*," "*Rhytiophora*," "*Unispirifer*," "*Spirifer*," *Composita*, and *Syringothyris.*

Zone A includes an assemblage of diminutive corals and brachiopods together with conodonts of the Lower *Siphonodella crenulata* assemblage of Klapper (1966) and Sandberg and Klapper (1967). Among the corals, *Metriophyllum* cf. *M. deminutivum* Easton and an undescribed species provisionally referred to *Permia* are restricted to this zone, and *Cyathaxonia* cf. *C. tantilla* (Miller) and undescribed species of *Palaeacis*, *Amplexus*, and *Zaphrentites* range into overlying beds. *Vesiculophyllum* occurs rarely in the zone in central Wyoming. Brachiopods restricted to the zone include "*Spirifer*" aff. "*S.*" *osagensis* Swallow and a small species of *Crurithyris.* Other common Zone A brachiopods are *Rhipidomella* aff. *R. diminutiva* Rowley, "*Spirifer*" aff. "*S.*" *biplicoides* Weller, *Cleiothyridina* cf. *C. tenuilineata* (Rowley), and "*Spirifer*" aff. "*S.*" *centronatus* Winchell. Cephalopods are extremely rare in this assemblage; *Pericyclus* (*Caenocyclus*) sp., *Pericyclus* (*Rotopericyclus*) sp., and *Gattendorfia* sp. have been found at one locality, the Little Chief Canyon section in Montana (Mackenzie Gordon, Jr., oral commun., 1967). Zone A characterizes the lower 10–50 feet of the Paine Shale Member of the Lodgepole Limestone over a broad area in Montana, western Wyoming, southeastern Idaho, and northeastern Utah. At most localities, this interval is characterized by glauconitic crinoidal limestone. The zone has also been provisionally identified in dolomitic beds above the Cottonwood Canyon Member of the Madison Limestone in central Wyoming.

In Zone B *Amplexus* is the most common coral, and *Cyathaxonia*, *Zaphrentites*, and *Palaeacis* are rare, Among the brachiopods are *Rhipidomella* aff. R. *diminutiva* Rowley, "*Spirifer*" aff. "*S.*" *biplicoides* Weller, *Cleiothyridina* cf. *C. tenuilineata* (Rowley), and "*Spirifer*" aff. "*S.*" *centronatus* Winchell, which continue into Zone B from subjacent strata. New elements in the brachiopod fauna include *Cyrtina* cf. *burlingtonensis* Rowley, which is seemingly restricted to the zone, and "*Torynifer*" cf. "*T.*" *cooperensis* (Swallow), *Orbinaria* aff. *O. pyxidata* (Hall), *Retichonetes* cf. *R. logani* (Norwood and Praten), *Leptagonia* cf. *L. analoga* (Phillips), and *Brachythyris* aff. *B. suborbicularis* (Hall), which continue into superjacent beds. Zone B corresponds approximately to the upper part of the Paine Shale Member of the Lodgepole Limestone, which consists of poorly fossiliferous thin-bedded silty and argillaceous limestone. The zone has been recognized throughout the outcrop area of the Lodgepole Limestone and is also present in the Allan Mountain Limestone of northwestern Montana.

In Zone C_1, the principal coral indices are *Cleistopora placenta* (White), *Michelinia expansa* White, *Lithostrotionella microstylum* (White), and *Rylstonia* cf. *R. teres* (Girty). *Cleistopora* appears to be restricted to the zone, and the other elements occur only rarely above it. *Homalophyllites* and *Zaphrentites excavatus* (Girty) begin their ranges at the base of the zone, and *Vesiculophyllum* becomes abundant for the first time. Brachiopods that range into the zone from below but do not occur above it are "*Spirifer*" aff. "*S.*" *biplicoides* Weller, *Cleiothyridina* cf. *C. tenuilineata* (Rowley), "*Torynifer*" cf. "*T.*" *cooperensis* (Swallow), *Orbinaria* aff. *O. pyxidata* (Hall), *Retichonetes* cf. *R. logani* (Norwood and Pratten), and *Leptagonia* cf. *L. analoga* (Phillips). *Brachythyris* aff. *B. suborbicularis* (Hall) is known in subjacent and superjacent beds but is most common in Zone C_1. The ubiquitous and long-ranging "*Spirifer*" aff. "*S.*" *centronatus* Winchell is also present. A species of *Nucleospira* seems to be restricted to the zone. The zone is also characterized by a large assemblage of brachiopod species that appear for the first time and continue to the top of Zone C_2. Among these are *Imbrexia* cf. *I. forbesi* (Norwood and Pratten), *Ovatia* cf. *O. laevicosta* (White), "*Dictyoclostus*" cf. "*D.*" *viminalis* (White), "*D.*" cf. "*D.*" *burlingtonensis* (Hall), "*Spirifer*" aff. "*S.*" *keokuk* Hall, *Spirifer* cf. *S. logani* Hall, the *Spirifer* aff. *S. rowleyi–S. grimesi* complex, *Punctospirifer* cf. *P. solidirostris* (White), "*Productus*" *cf.* "*P.*" *gallatinensis* Girty, and *Rugosochonetes* cf. *R. loganensis* (Hall and Whitfield). Other longer ranging elements are *Dimegelasma* sp. and *Cleiothyridina* cf. *C. obmaxima* (McChesney). Zone C_1 corresponds approximately to the Woodhurst Limestone Member of the Lodgepole Limestone. This zone has been identified in the upper part of the Lodgepole wherever the Lodgepole has been studied. Elements of the zone are also present in the Allan Mountain Limestone of northwestern Montana and in the lower part of the Madison Limestone of central Wyoming.

The principal corals of Zone C_2 are *Zaphrentites excavatus* (Girty), *Homalophyllites*, *Vesiculophyllum*, and several species of *Syringopora*. The brachiopod assemblage of this zone is dominated by the Zone C_1 species of spiriferids and productids previously mentioned. "*Spirifer*" cf. "*S.*" *madisonensis* Girty seems to be the only brachiopod species restricted to the zone. Zone C_2 includes approximately the lower half of the Mission Canyon Limestone at all localities where the Mission Canyon faunas have been studied. Elements of this zone also have been identified in the lower part of the Castle Reef Dolomite of northwestern Montana, in the lower half of the Brazer Dolomite of northeastern Utah, and in the upper half of the Madison Limestone of central Wyoming.

Zone D is characterized by the lowest occurrence of fasciculate lithostrotionid corals, including *Lithostrotion* (*Siphonodendron*) *oculinum* Sando and *Diphyphyllum* sp. Other characteristic coral elements are *Canadiphyllum?*, *Ankhelasma*, *Zaphrentites*, *Vesiculophyllum*, and *Syringopora*. *Homalophyllites* has been found in basal beds of Zone D at a few localities but is characteristically a pre-Zone D index. Brachiopods are generally rare, but *Perditocardinia* cf. *P. dubia* (Hall), "*Spirifer*" *shoshonensis* Branson and Greger, and *Brachythyris* cf. *B. subcardiiformis* (Hall) are found at some localities. Zone D is the highest biostratigraphic unit recognized in the Madison Group and equivalent strata. It is present in the upper half of the Mission Canyon Limestone of Montana and western Wyoming, the Charles Formation of northeastern Montana, the uppermost part of the Sun River Member of the Castle Reef Dolomite of northwestern Montana, the upper part of the Madison Limestone of central Wyoming, and the upper half of the Brazer Dolomite of northeastern Utah.

Zone pre-E is characterized by the restricted occurrence of the brachiopods *Quadratia hirsutiformis* (Walcott) and "*Leiorhynchus*" *carboniferum* Girty. *Auloprotonia*, *Rhipidomella arkansana* Girty, and *Echinoconchus* cf. *E. alternatus* (Norwood and Pratten) also occur in the upper half of the zone. Although corals are generally very rare in this zone, a species of *Rhopalolasma* has been found at several localities. Zone pre-E has been identified at several localities in southeastern Idaho and northeastern Utah in the lower part of the Deep Creek and Little Flat Formations.

In Zone E the principal index fossil is the coral genus *Ekvasophyllum*, which appears to be restricted to this zone at some localities but may range into the lower part of the overlying Zone F. Other common corals in Zone E are the species of *Lithostrotion* (*Siphonodendron*) called *Lithostrotion whitneyi* by Meek, species of the *Dorlodotia-Pseudodorlodotia* complex, *Zaphrentites* cf. *Z. spinulosus* (Milne-Edwards and Haime), a small undescribed solitary coral provisionally referred to *Zaphrentites*, and the tabulate coral *Syringopora virginica* Butts, which may actually belong in the genus *Kuechowpora*. *Palaeacis cuneiformis* Haime occurs rarely in the upper half of the zone. The principal brachiopods in Zone E are *Echinoconchus* cf. *E. alternatus* (Norwood and Pratten) and *Orthotetes* cf. *O. kaskaskiensis* (McChesney), which range into the lower half of the zone from below, and *Anthracospirifer bifurcatus* (Hall), which appears to be restricted to the lower half. Other common brachiopods in the lower half are *Brachythyris* cf. *B. subcardiiformis* (Hall) and *Cleiothyridina* cf. *C. obmaxima* (McChesney), which are the only Madison fossils known to occur in the post-Madison interval. *Striatifera* aff. *S. brazeriana* (Girty), a characteristic Zone F brachiopod, occurs in the uppermost part of Zone E in northeastern Utah. Zone E is established on fossils that occur in the upper part of the Little Flat Formation and the lowermost part of the Monroe Canyon Limestone of southeastern Idaho and northeastern Utah and has also been identified in the White Knob Limestone in south-central Idaho.

Zone F is named from the coral genus *Faberophyllum*, whose range defines the limits of the zone. Other common coral elements are species of the *Dorlodotia-Pseudodorlodotia* complex, *Zaphrentites?* n. sp., and *Syringopora virginica* Butts, which range into the zone from below. Species of *Dibunophyllum* and odd syringoporoids questionably referred to *Syringoporella* are also common. *Ekvasophyllum* cf. *E. inclinatum* Parks and *Lithostrotion* (*Siphonodendron*) *whitneyi* of Meek may occur rarely in the lower part. *Striatifera* aff. *S. brazeriana* (Girty), which ranges into Zone F from below, is the principal brachiopod index. *Anthracospirifer leidyi* (Norwood and Pratten) is common in the upper half, whereas *Spirifer brazerianus* Girty is rare. Zone F is known principally from the lower part of the Great Blue Limestone and Monroe Canyon Limestone of southeastern Idaho and northeastern Utah and the White Knob Limestone of south-central Idaho. It has also been identified in beds referred to the Amsden Formation by Klepper (Klepper and others, 1957) in southwestern Montana.

Zone pre-K is a poorly fossiliferous interval that has been identified near the middle of the Great Blue Limestone and Monroe Canyon Limestone of southeastern Idaho. The limits of this zone are defined on criteria that determine the top of the underlying F Zone and the bottom of the overlying K Zone. A few solitary corals, possibly belonging to *Zaphrentites*, and the brachiopods *Anthracospirifer leidyi* (Norwood and Pratten), *Spirifer brazerianus* Girty, and *Striatifera* aff. *S. brazeriana* (Girty) are the only fossils now known from this zone.

In Zone K, the principal index fossil is the coral species *Caninia excentrica* (Meek). Other common coral taxa are *Zaphrentites* cf. *Z. spinulosus* (Milne-Edwards and Haime), *Lithostrotionella* cf. *L. stelcki* Nelson, and the syringoporoids *Syringoporella*? and *Hayasakaia*? *Caninia nevadensis* (Meek) is also found in this zone at some localities. Zone K is also characterized by a large assemblage of brachiopods. The principal brachiopod elements are *Spirifer brazerianus* Girty, *Anthracospirifer leidyi* (Norwood and Pratten), certain species of *Diaphragmus*, and *Anthracospirifer curvilateralis* (Easton). Other brachiopod species found in the Zone K assemblage will probably prove useful when more is known about their precise distribution. Zone K is a widely distributed biostratigraphic unit that has been identified at the top of the Great Blue Limestone and Monroe Canyon Limestone of southeastern Idaho, in the White Knob Limestone of south-central Idaho, in the Amsden Formation of western Wyoming, and in the Big Snowy Group of southwestern Montana.

The highest Mississippian zone recognized in this paper is the post-K Zone based on unpublished brachiopod studies by Mackenzie Gordon, Jr. The zone is presently recognized on the occurrence of *Anthracospirifer welleri* (Branson and Greger) and an undescribed species of *Diaphragmus*. Other potentially useful elements of the brachiopod assemblage remain to be described. This zone has been identified in the Manning Canyon Shale of southeastern Idaho and the Amsden Formation of central Wyoming.

LIMITATIONS

The zonation scheme outlined above is by no means intended as the final solution to biostratigraphic problems in the Mississippian of the Cordilleran region. There are many limitations to the usefulness of the zonation as it is presently understood, and much work remains to be done to perfect the system. Some of the problems are summarized below.

Incomplete taxonomy.—Most of the faunas upon which the zonation is based have been treated only superficially from a taxonomic standpoint. Many decisions remain to be made concerning the limits of species and genera. The zones can be no more precise than the discrimination of zonal indices. More detailed systematic studies are necessary to sharpen the tools of biostratigraphic discrimination.

Composite superposition.—There is no single locality where all the megafaunal zones can be seen in superposition. This circumstance has arisen because of a complicated history of sedimentation and epeirogenesis during Mississippian time in the northern Rocky Mountain region (Sando, 1967b). The complete zonal succession, though necessarily composite, was established after examination of many sequences of Mississipian rocks, some of which provided key overlaps in various parts of the Mississippian time interval. Nevertheless, the ultimate test of this zonation requires that it be compared with a suitable independent biostratigraphic standard.

Difficulties in identifying zone boundaries.—Because the horizontal distribution of zonal indices is not uniform, the precise positions of zone boundaries are commonly difficult to determine in any given stratigraphic section. The lack of a continuous sequence of significant fossils at some localities may result in local uncertainties involving tens or hundreds of feet of section. At these localities, arbitrary boundaries are recognized. A common example is the boundary between Zones C_1 andC_2, which is difficult to place precisely at many localities but which can be conveniently approximated by the contact between the Lodgepole and Mission Canyon Limestones. Boundary indentification can be improved only by additional collecting in the poorly fossiliferous intervals and by discovery of new fossils useful for identifying the zones.

Facies influences.—Although environmental sensitivity of the organisms used in zonation has not proved to be as important a factor as originally anticipated, recognition of some of the zones in certain parts of the area studied has been made difficult because of facies changes. A good example is the lower part of the Madison Limestone of central Wyoming (Wyoming province of Sando, 1967b), where corals and brachiopods characteristic of Zones A, B, and C_1 of the Lodgepole Limestone are greatly reduced in variety and numbers so that precise determination of zone boundaries has not been possible on the basis of available evidence. Similar difficulties have been experienced in attempting to analyze the Madison Group in subsurface sections in and near the depositional center of the Williston basin of Montana and North Dakota. Although some of the problems may prove to be insurmountable, additional collecting in these poorly fossiliferous areas should resolve many of the questions.

Difficulties in correlation with the type Mississippian.—It became apparent early in the work on zonation that many of the key fossils in the Cordilleran region either were absent or had different vertical ranges in the Mississippi Valley area. This is particularly striking in the coral faunas but is less apparent among the brachiopods. This provincialism has evoked a relunctance on our part to apply standard Mississippian time-stratigraphic designations to the Cordilleran sections. Broad faunal similarities, particularly in the brachiopod faunas, led to the following tentative correlations: Zones pre-A, A, and B are approximately equivalent to the Mississippion part of the Kinderhook Series; Zones C_1 and C_2 equate approximately with the Osage Series; Zones D, pre-E, E, and F represent approximately the Meramec Series; and Zones pre-K, K, and post-K are approximately equivalent to the Chester Series. Identification of parts of the standard series in the Cordilleran region was based largely on arbitrary division of the Cordilleran equivalents rather than on precise comparisons of parts of the faunal successions. For example, because the Zone D–Zone F interval equals the Meramec, Zone D is called early Meramec, Zone pre-E and E are middle Meramec, and Zone F is late Meramec. More precise calibration of the megafaunal zones in terms of the type Mississippian sequence requires checking these conclusions against a system based on less provincial organisms than the ones used thus far.

Difficulties in correlation with Carboniferous standards.—Although Hill (1948, 1957) and Moore (1948) recognized European stages (Tournaisian, Viséan, and Namurian) in the North American faunal succession largely on the basis of corals, subsequent work in Europe and America has not produced a sharpening of the resolution of these biostratigraphic tools. It is too soon to pass judgment on the ultimate utility of corals and brachiopods for intercontinental correlation because much work remains to be done on these groups of fossils. However, available information does not permit the same level of biostratigraphic discrimination attained by means of cephalopods, conodonts, and foraminifers.

FORAMINIFERAL ZONATION

HISTORICAL DEVELOPMENT

Although Lower Carboniferous foraminiferal zonation has been the subject of much study and discussion in the U.S.S.R. and western Europe since publication of an important symposium by Rauzer-Chernoussova and others 1948, considerably less interest in this field has been shown by North American paleontologists. American attempts at zonation began with the pioneer study of Zeller (1950), who demonstrated that various parts of the Mississippian sequence in its type area could be identified by means of evolutionary changes in the endothyroid faunas. Subsequently, Zeller (1957) published a study of 12 endothyroid sequences of Mississippian age in the Cordilleran region in which he recognized four widespread zones. Zeller found a close similarity between Cordilleran faunas and Mississippi Valley faunas in the Upper Mississippian, but experienced difficulty in correlating the lower Mississippian rocks of the two areas.

Woodland (1958) recognized three zones and one subzone in the Mississippian of central Utah. Woodland's zonation scheme was similar to Zeller's in the Osage-Meramec interval, but he also recognized a zone of Chester age not found by Zeller. Like Zeller, Woodland was able to correlate readily the late Mississippian faunas with the Mississippi Valley area but was uncertain about correlations in the Lower Mississippian. Armstrong (1958, 1967) found that endothyroid faunas are useful in differentiating rocks of Early Mississippian age from rocks of Late Mississippian age in northern and central New Mexico.

Mamet (1962), having studied the Carboniferous Foraminifera of western Europe (Tournaisian, Viséan, and Namurian type sections), was struck by the great similarities among formaminiferal families observed in Europe and North America. He suggested that (1) phylogenetic development of all the families is identical in Eurasia and North America, (2) there is no true provincialism in the northern hemisphere, and free communication persisted during most of the Lower Carboniferous, (3) a number of widespread taxa can be traced all around the northern hemisphere, (4) precise correlation can be made between Eurasia and North America, (5) the Kinderhook is approximately of early Tournaisian age, the Osage is middle to late Tournaisian, the Meramec is early to middle Viséan, and the Chester is late Viséan to early Namurian.

McKay and Green (1963) recognized four main successive range zones, two concurrent range zones, and one assemblage zone in the Mississippian rocks of Alberta and attempted to correlate these rocks with the type Mississippian and sections in the Western United States by means of endothyroid faunas. They also pointed out that non-endothyroid genera were present and might be useful as zone fossils. Studies of the distribution of foramanifers in the Redwall Limestone of

Arizona by Skipp (1963, 1964, 1969) led to the recognition of six zones based on endothyroids and tournayellids and ranging in age from Kinderhook to late Meramec. Skipp, Holcomb, and Gutschick (1966) summarized the known distribution of tournayellids in the Mississippian of North America.

Mamet and Skipp (1969) presented a comprehensive outline of foraminiferal zonation of the Mississippian of North America. The distribution of all Early Carboniferous genera known in North America was recorded, 14 assemblage zones were established, and the standard units of the type Mississippian were correlated with their counterparts in the standard western European sections of the Lower Carboniferous. Mamet and Skipp's paper formed the foundation for the present work, which treats the occurrence of the foraminiferal zones in the northern Cordilleran region in more detail and compares the foraminiferal zonation with the megafaunal scheme established for that area.

DISTRIBUTION, COMPOSITION, AND CRITERIA FOR RECOGNITION

The foraminiferal zones recognized in this study are part of a 19-zone system originally established on European and Asiatic faunal successions (Mamet, 1965; Mamet, Mortelmans, and Sartenaer, 1965; Legrand, Mamet and Mortelmans, 1966; Mamet and Reitlinger, 1969). Zones 1 through 5 in this scheme are Upper Devonian (upper Famennian) and will not be discussed here. The earliest Tournaisian zone in the type locality of the Tournaisian is Zone 6 (Legrand, Mamet, and Mortelmans, 1966). The Tournaisian-Viséan boundary is between Zones 9 and 10, and the top of the Viséan is the top of Zone 16s. Zones 17, 18, and 19 are Namurian; only the lower part of the Namurian was observed in the present study.

Mamet and Skipp (1969) have already summarized the distribution of 107 taxa used in distinguishing zones in the Mississippian of North America and have set forth the principles upon which the zonation is based. The following remarks are confined to a brief characterization of the composition and distribution of these zones in the northern Cordillera. The ranges of significant foraminiferal taxa are shown in figure 5.

Zone pre-7 includes a meager assemblage of plurilocular foraminifers, mostly tournayellids (*Septaglomospiranella* and *Septabrunsiina*) or endothyroids (*Latiendothyra*). Abundant unilocular forms and forms of uncertain taxonomic position include *Earlandia* (E. *minima* (*Birina*)), *Paracaligella*, *Tuberitina*, *Calcisphaera*, *Vicinesphaera*, *Bisphaera*, and "*Radiosphaera*." The scarcity of plurilocular forms does not permit reliable identification of Zone 6 of Mamet and Skipp (1969). This assemblage is found in the Paine Shale Member of the Lodgepole Limestone in southeastern Idaho, western Wyoming, and Montana.

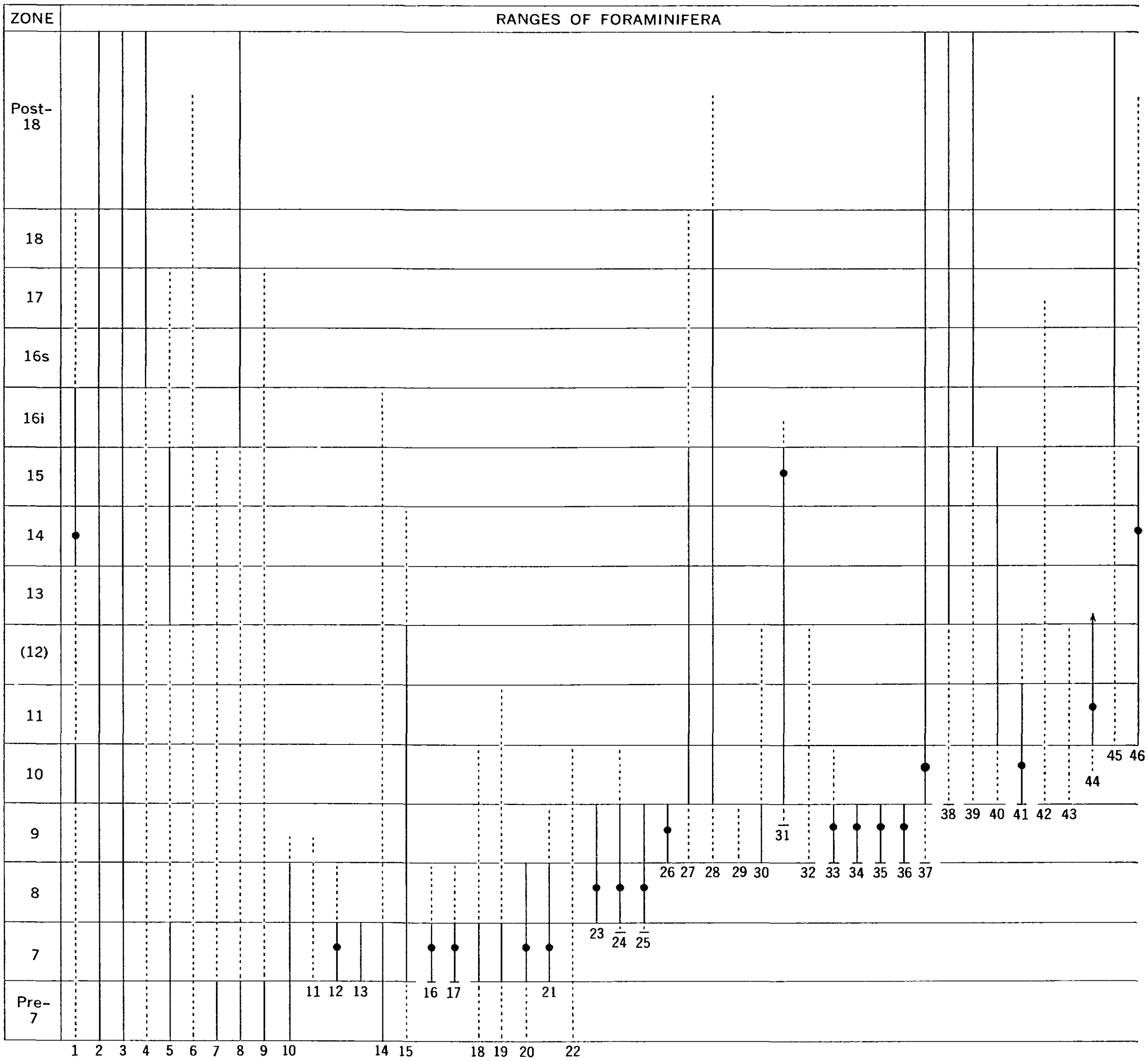
Zone 7 is characterized by the acme of *Septaglomospiranella primaeva* (Rauzer-Chernoussova, in Chernysheva), *S. dainae* Lipina, and *Rectoseptaglomospiranella*. *Chernyshinella* (*C. tumulosa* Lipina), *Septabrunsiina*, *Palaeospiroplectammina*, and *Latiendothyra* are other, less abundant, elements. This assemblage is found in the Woodhurst Limestone Member of the Lodgepole Limestone in southeastern Idaho, northeastern Utah, western Wyoming, and Montana.

Zone 8 is recognized by the outburst of *Tuberendothyra tuberculata* (Lipina) and by abundant *Septaglomospiranella primaeva* (Rauzer-Chernoussova, in Chernysheva), *Septabrunsiina parakrainica* Skipp, Holocomb, and Gutschick, *Calcisphaera laevis* Williamson, and *Latiendothyra*. It is also characterized by the decline of *Chernyshinella* and *Rectoseptaglomospiranella*. This assemblage occurs mostly in the lower third of the Mission Canyon Limestone in southeastern Idaho, western Wyoming, and Montana.

Zone 9 is characterized by numerous *Tuberendothyra* (*T. tuberculata* (Lipina)) and by the acmes of *Spinoendothyra spinosa* (Chernysheva), *S. paracostifera* (Lipina, in Lebedeva and Grozdilova), *S. bellicosta* (Malakhova), and *Carbonella*. *Tournayella*, *Septatournayella*, *Septaglomospiranella*, and *Septabrunsiina* are also present. *Eoforschia*, *Tetrataxis*, *Endothyra* of the group E.? *nordvikensis* Lipina, *Latiendothyra latispiralis* (Lipina), and *Endothyra* of the group E.? *prisca* Rauzer-Chernoussova and Reitlinger appear for the first time. "*Endothyra*"(?) *trachida* Zeller is common. The zone also marks the appearance of *Calcisphaera pachysphaerica* (Pronina). This assemblage is found near the middle of the Mission Canyon Limestone in southeastern Idaho and Montana and near the middle of the Madison Limestone of central Wyoming.

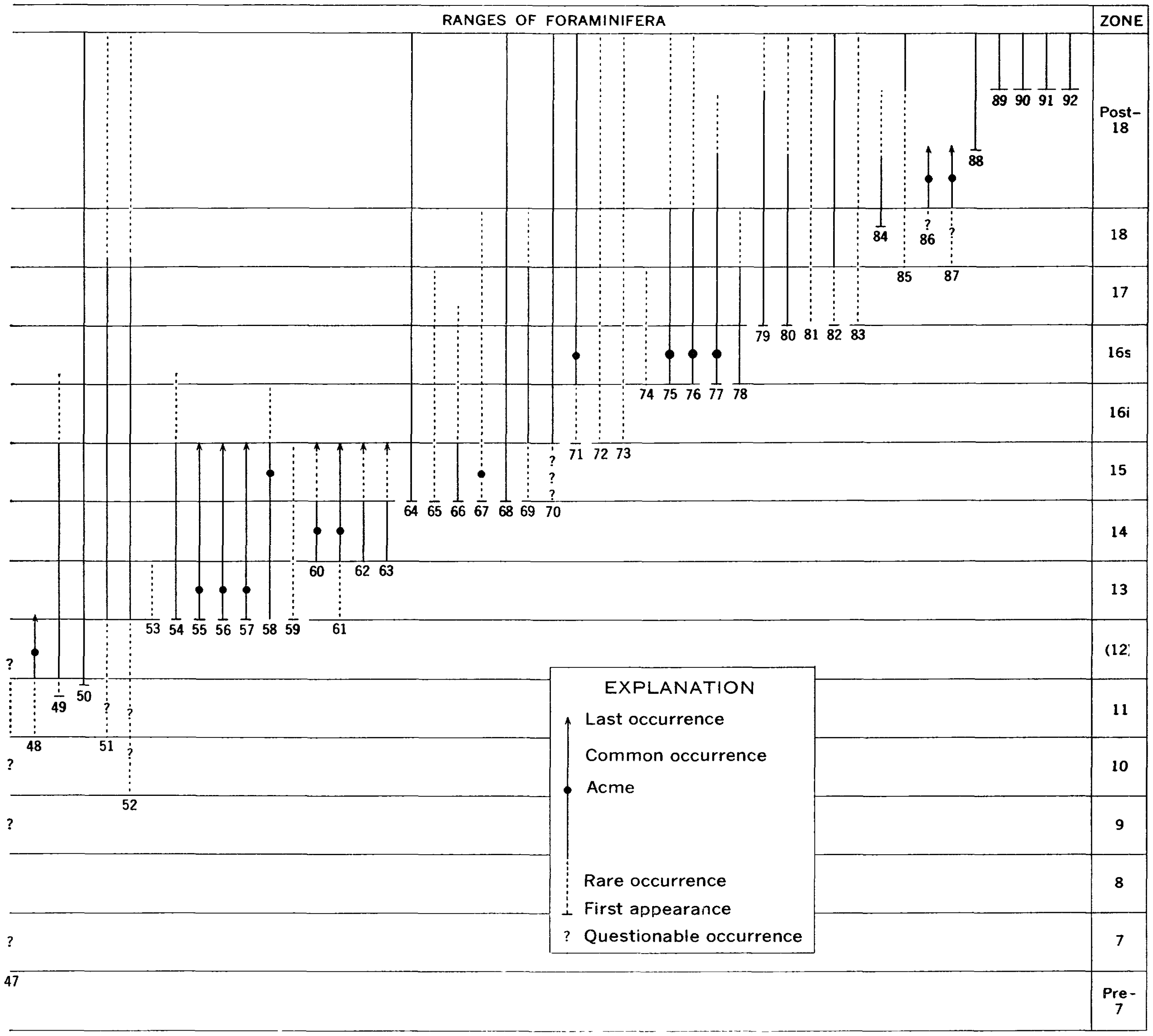
Zone 10 is marked by an outburst of *Globoendothyra*[2] (*G. baileyi* (Hall)), *Eoforschia*, and the Tetrataxidae. *Haplophragmella*, the Archaediscidae, and Eostaffellidae appear for the first time. *Brunsia* is abundant, along with *Calcisphaera laevis* Williamson and *C. pachysphaerica* (Pronina). The base of the zone is also characterized by the marked decline of *Tuberendothyra* and *Spinoendothyra* and the extinction of *Carbonella*. This assemblage occurs in the upper third of the Mission

[2] The genus *Globoendothyra* Reitlinger 1954 is used conditionally. It is probably synonymous with *Plectogyra* Zeller 1950, which has priority. However, the wall structure cannot be determined on Zeller's type material owing to recrystallization. Moreover, *Plectogyra* has been used by its original author to include about 10 different endothyroid genera.



1. *Brunsia* emended
2. *Calcisphaera laevis* Williamson
3. *Earlandia* sp.
4. *Glomospira* sp.
5. *Paracaligella* sp. and *Irregularina* sp.
6. *Parathurammina* sp.
7. *"Radiosphaera"* sp.
8. *Tuberitina* sp. and *Eotuberitina* sp.
9. *Vicinesphaera* sp.
10. *Bisphaera* sp.
11. *Brunsiina* sp.
12. *Chernyshinella* sp.
13. *C. tumulosa* Lipina
14. *Earlandia minima* (Birina)
15. *Latiendothyra* sp.
16. *Palaeospiroplectammina tchernyshinensis* (Lipina)
17. *Rectoseptaglomospiranella* sp.
18. *Septabrunsiina* sp.
19. *Septaglomospiranella* sp.
20. *S. primaeva* (Rauzer-Chernoussova, in Chernysheva)
21. *S. dainae* Lipina
22. *Septatournayella* sp.
23. *Septabrunsiina parakrainica* Skipp, Holcomb, and Gutschick
24. *Tuberendothyra* sp.
25. *T. tuberculata* (Lipina)
26. *Carbonella* sp.
27. *Calcisphaera pachysphaerica* (Pronina)
28. *Endothyra* of the group *E.*? *prisca* Rauzer-Chernoussova and Reitlinger
29. *Endothyra* of the group *E.*? *nordvikensis* Lipina
30. *"Endothyra"*(?) *trachida* Zeller
31. *Eoforschia* sp.
32. *Latiendothyra* of the group *L. latispiralis* (Lipina)
33. *Spinoendothyra* sp.
34. *S. bellicosta* (Malakhova)
35. *S. paracostifera* (Lipina, in Lebedeva and Grozdilova)
36. *S. spinosa* (Chernysheva)
37. *Tetrataxis* sp.
38. Archaediscidae
39. *Cornuspira* sp.
40. *Eoendothyranopsis* sp.
41. *Globoendothyra baileyi* (Hall)
42. *Haplophragmella* sp.
43. *Septatournayella*(?) *henbesti* Skipp, Holcomb and Gutschick
44. *Eoendothyranopsis spiroides* (Zeller)
45. keeled *Eostaffella* sp.
46. *Stacheia* and *Stacheoides* sp.
47. *Tournayella* sp.
48. *Eoendothyranopsis* of the group *E. spiroides* (Zeller)
49. *Koninckopora* sp.
50. *Palaeotextularia* sp.

FIGURE 5.—Ranges of significant Cordilleran foraminiferal taxa in Mamet Carboniferous zonation scheme. Zone 12



51. *Archaediscus* of the group *A. chernoussovensis* Mamet
52. *Archaediscus* of the group *A. krestovnikovi* Rauzer-Chernoussova
53. *Cribrospira*? sp.
54. *Endothyranopsis compressa* (Rauzer-Chernoussova and Reitlinger)
55. *Eoendothyranopsis pressa* (Grozdilova, in Lebedeva)
56. *E. rara* (Grozdilova, in Lebedeva)
57. *E. scitula* (Toomey)
58. *Globoendothyra* of the group *G. tomiliensis* (Grozdilova)
59. *Omphalotis* sp.
60. "*Eoendothyranopsis*"(?) *banffensis* (McKay and Green)
61. *Eoendothyranopsis* of the group *E. ermakiensis* (Grozdilova, in Lebedeva)
62. *E. macra* (Zeller)
63. *E. utahensis* (Zeller)
64. bilayered *Climacammina* sp.
65. bilayered *Cribrostomum* sp.
66. *Endothyranopsis crassa* (Brady)
67. *Globoendothyra* of the group *G. globulus* (d'Eichwald)
68. *Palaeotextularia* of the group *P. longiseptata* Lipina
69. "*Eostaffella*" *discoidea* (Girty)
70. *Hedraites* sp.
71. *Neoarchaediscus* sp.
72. *Palaeonubecularia* sp.
73. *Trepeilopsis* sp.
74. *Helicospirina* sp.
75. *Neoarchaediscus incertus* (Grozdilova and Lebedeva)
76. *N. gregorii* Dain, in Grozdilova
77. *Planospirodiscus* sp.
78. *Pseudoendothyra* of the group *P. kemenskensis* Rozovskaia
79. *Asteroarchaediscus* sp.
80. *A. baschkiricus* (Krestovnikov and Teodorovitch)
81. *A. rugosus* (Rauzer-Chernoussova)
82. *Globivalvulina* sp.
83. *Ammovertella*? sp.
84. *Eostaffellina* sp.
85. *Millerella* sp.
86. *Eosigmoilina* sp.
87. *Hemiarchaediscus* sp.
88. *Lipinella* sp.
89. *Bradyina* of the group *B. cribrostomata* Rauzer-Chernoussova and Reitlinger
90. *Eoschubertella* sp.
91. *Eostaffella* of the group *E. acutissima* Kireeva
92. *Pseudostaffella* sp.

fauna not known in the area of this report. Zones 19–21 undifferentiated in this report and included in Zone post-18.

Canyon Limestone in southeastern Idaho, western Wyoming, and Montana and in the Bull Ridge Member (Sando, 1968) of the Madison Limestone of central Wyoming.

Zone 11 is characterized by the acme of *Eoendothyranopsis spiroides* (Zeller) and abundant *Globoendothyra* and *Eoforschia*. The first keeled *Eostaffella* appears here, and *Stacheia* and *Stacheoides* are also present. *Tournayella* s.s. is rare. This assemblage occurs in the upper third of the Mission Canyon Limestone in southeastern Idaho, western Wyoming, and Montana and in the Bull Ridge Member of the Madison Limestone in central Wyoming.

Zone 12 includes a fauna similar to that of Zone 11 but can be distinguished by the outburst of a new species of *Eoendothyranopsis* of the group *E. spiroides* (Zeller) and the abundance of *Koninckopora* and monolayered *Palaeotextularia*. The Zone 12 assemblage was not encountered in this study; it is present in the Salter Member of the Mount Head Formation of Alberta, where it occupies a stratigraphic position that coincides with part of the post-Madison hiatus which characterizes the northern Cordilleran region in the United States.

Zone 13 is marked by the extinction of *Eoendothyranopsis spiroides* (Zeller) after a short concurrent interval with *Eoendothyranopsis pressa* (Grozdilova, in Lebedeva), *E. rara* (Grozdilova, in Lebedeva), *E. scitula* (Toomey), and *Endothyranopsis compressa* (Rauzer-Chernoussova and Reitlinger). *Propermodiscus* is also present. There is an outburst of *Archaediscus* (*A. krestovnikovi* Rauzer-Chernoussova and *A. chernoussovensis* Mamet groups). *Cribrospira*? and *Omphalotis* appear for the first time. This assemblage occurs in the Little Flat Formation in southeastern Idaho and northeastern Utah.

Zone 14 is recognized on the acme of *Eoendothyranopsis* of the group *E. ermakiensis* (Grozdilova, in Lebedeva), represented by *E. macra* (Zeller) and *E. utahensis* (Zeller), and abundant *Stacheia* and *Stacheoides*. *Brunsia* is commonly abundant (*Brunsia* facies) and "*Eoendothyranopsis*"? *banffensis* (McKay and Green) is normally present. This assemblage is found in the Little Flat Formation and the lower third of the Monroe Canyon Limestone in southeastern Idaho and northeastern Utah.

Zone 15 includes the acme of *Eoendothyranopsis* and is marked by the appearance of *Endothyranopsis crassa* (Brady) mixed with *E. compressa* (Rauzer-Chernoussova and Reitlinger). It is characterized by the acme of *Globoendothyra* of the groups *G. globulus* (d'Eichwald) and *G. tomiliensis* (Grozdilova). Bilayered *Palaeotextularia*, *Cribrostomum*, and *Climacammina* appear for the first time. This assemblage is poorly represented in samples from near the middle of the Monroe Canyon Limestone in southeastern Idaho but is well-represented in the Upper Mississippian of south-central Idaho and Alberta.

Zone 16i is marked by the first appearance of *Neoarchaediscus*, rarefaction of *Endothyranopsis*, and extinction of *Eoendothyranopsis*. It is also characterized by keeled *Eostaffella* and "*Eostaffella*" *discoidea* Girty. "*Glomospira*," *Hedraites*, *Trepeilopsis*, *Palaeonubecularia*, and numerous *Endothyra* s.s. are also present. *Globoendothyra* is rare. Like Zone 15, this assemblage is poorly represented near the middle of the Monroe Canyon Limestone in southeastern Idaho but is well-represented in the Upper Mississippian of south-central Idaho and Alberta.

Zone 16s is characterized by the coexistence of *Archaediscus* of the groups *A. krestovnikovi* Rauzer-Chernoussova and *A. chernoussovensis* Mamet and abundant *Neoarchaediscus* (*N. gregorii* Dain, in Grozdilova and *N. incertus* Grozdilova and Lebedeva)). *Planospirodiscus* becomes an important and characteristic faunal marker. *Endothyra* ss. is abundant. There is an outburst of *Pseudoendothyra* of the group *P. kemenskensis* Rozovskaia. *Helicospirina*, the ancestor of *Globivalvulina*, is also present. *Koninckopora* becomes extinct and *Endothyranopsis crassa* (Brady) practically disappears. This assemblage occurs near the middle of the Monroe Canyon Limestone of southeast Idaho.

Zone 17 is marked by an outburst of *Asteroarchaediscus* (*A. baschkiricus* (Krestovnikov and Teodorovitch) and *A. rugosus* (Rauzer-Chernoussova)) mixed with numerous *Neoarchaediscus*. *Globivalvulina* s.s. appears for the first time. This assemblage is found in the upper third of the Monroe Canyon Limestone of southeastern Idaho, near the top of the Brazer Limestone (as used by Mullens and Izett, 1964) of northern Utah, in the Amsden Formation of western Wyoming, and in the Big Snowy Group of southwestern Montana.

Zone 18 includes Archaediscidae similar to those in Zone 17 but is marked by the outburst of *Globivalvulina* and the first appearance of *Eostaffellina*. This assemblage occurs near the top of the Monroe Canyon Limestone of southeastern Idaho, in the Amsden Formation of western Wyoming, and in the Big Snowy Group of southwestern Montana.

Zone post-18 includes Zones 19, 20 and 21 of Mamet (1968b), which are not differentiated in this report. It includes the Namurian *Eosigmoilina-Hemiarchaediscus*, *Lipinella-Millerella*, and *Eoschubertella-Pseudostaffella-Bradyina cribrostomata* assemblages. The position of Zone 19 is uncertain with respect to the Mississippian-Pennsylvanian boundary as defined in the midcontinent region. Zone 19 is certainly younger than the highest formation of the Chester Series (Grove Church Formation of Swann, 1963) in Illinois and the Pitkin Limestone in Arkansas. There is an apparent hiatus between these formations and the overlying Pennsylvanian, which begins with Zone 20. Zone 19 could be regarded either as uppermost Mississippian or as lowermost Pennsylvanian. Recent discovery of a continuous sequence of foraminiferal faunas across this boundary in south-central Idaho may provide a solution to this problem. We currently favor regarding Zone 19 as uppermost Mississippian because of the greater similarity of Zone 19 faunas to Zone 18 faunas. Zone post-18 has been identified in the Amsden Formation of western and south-central Wyoming.

LIMITATIONS

Available evidence indicates that the distribution of Foraminifera permits a more precise correlation of the Lower Carboniferous than megafaunal groups on a continent-wide or intercontinental scale. Although this may be partly due to more detailed study of the Foraminifera in a global perspective in recent years, it also seems to reflect the fundamentally more cosmopolitan aspect of Early Carboniferous Forminifera. Endemism is quite evident in some Early Carboniferous foraminiferal faunas, but there are still many more widely distributed genera and species than are known among the corals and brachiopods. Despite this advantage, the foraminifers are subject to the following limitations. (See also discussion by Mamet and Skipp, 1969.)

Influence of environment of deposition

Microfacies found particularly suitable for foraminiferal study are biosparite and biomicrite containing a minimum of terrigenous debris. Moderately shallow water, indicated by association with girvanellid and dasycladacean algae, is also a favorable factor. The influence of depositional environment is particularly evident in the Lower Mississippian (Tournaisian), where foraminiferal correlations are commonly difficult. An example in the present study is the difficulty in precise correlation of the lower part of the Lodgepole Limestone (Paine Shale Member). Foraminifers are generally rare in this facies, apparently because of high terrigenous sediment content and perhaps also because of greater depth. Another example is the difficulty in recognizing a Mississippian-Pennsylvanian boundary because of the scarcity of foraminifers in lowermost Pennsylvanian terrigenous rocks of the midcontinent region. Such hindrances make detailed correlation of these beds difficult on the basis of foraminiferal evidence.

Postdepositional changes

Recrystallization associated with extensive dolomitization is the principal hindrance to precise taxonomic determination of foraminifers. When wall structures are severely altered, determination becomes hazardous, even on a generic basis. All samples determined in this study are of slightly recrystallized limestone. Postdepositional changes are responsible for the lack of foraminiferal determinations in the Brazer Dolomite and the scarcity of determinable samples in the Madison Limestone of central Wyoming. Age determinations on these strata and other similar facies must depend on fossils less susceptible to destruction by recrystallization. Corals are usually the most lasting of these.

COMPARISON OF ZONATION SCHEMES

One of the principal reasons for undertaking this study was to check the internal consistency of the megafaunal zones already established in the northern Cordilleran region by means of an independent biostratigraphic system. Among the questions posed are: (1) Is the composite superposition of megafaunal zones erected on widely separated sequences verified by foraminiferal determinations on the same samples? (2) Do foraminiferal determinations confirm the identification of megafaunal zones in various parts of the northern Cordilleran region, particularly in different depositional provinces? (3) Are the boundaries of the megafaunal zones coincident with the boundaries of foraminiferal zones? (4) Do foraminiferal determinations confirm the hiatus between Madison and post-Madison strata inferred from megafaunal distribution? (5) Are there any gaps in the record that have not been recognized by megafossils? We believe that this study has given reasonable answers to most of these questions. Pertinent data for comparison of the two zonal schemes are given in figure 6, which shows the megafaunal and microfaunal zone identifications of 105 samples from 20 stratigraphic sections.

INTEGRITY OF SUPERPOSITION

Without exception, foraminiferal analysis reveals the same order of superposition established on the basis of megafaunal zonation of the same samples. Although there are overlaps in zone boundaries, no reversals in the expected sequence of zones are found. The following equations between the two zonal schemes are established.

1. Unzoned beds of Pennsylvanian age equal Zone post-18.
2. Zone post-K equals Zone unknown (no foraminifers found).
3. Zone K equals Zones 16s–18.

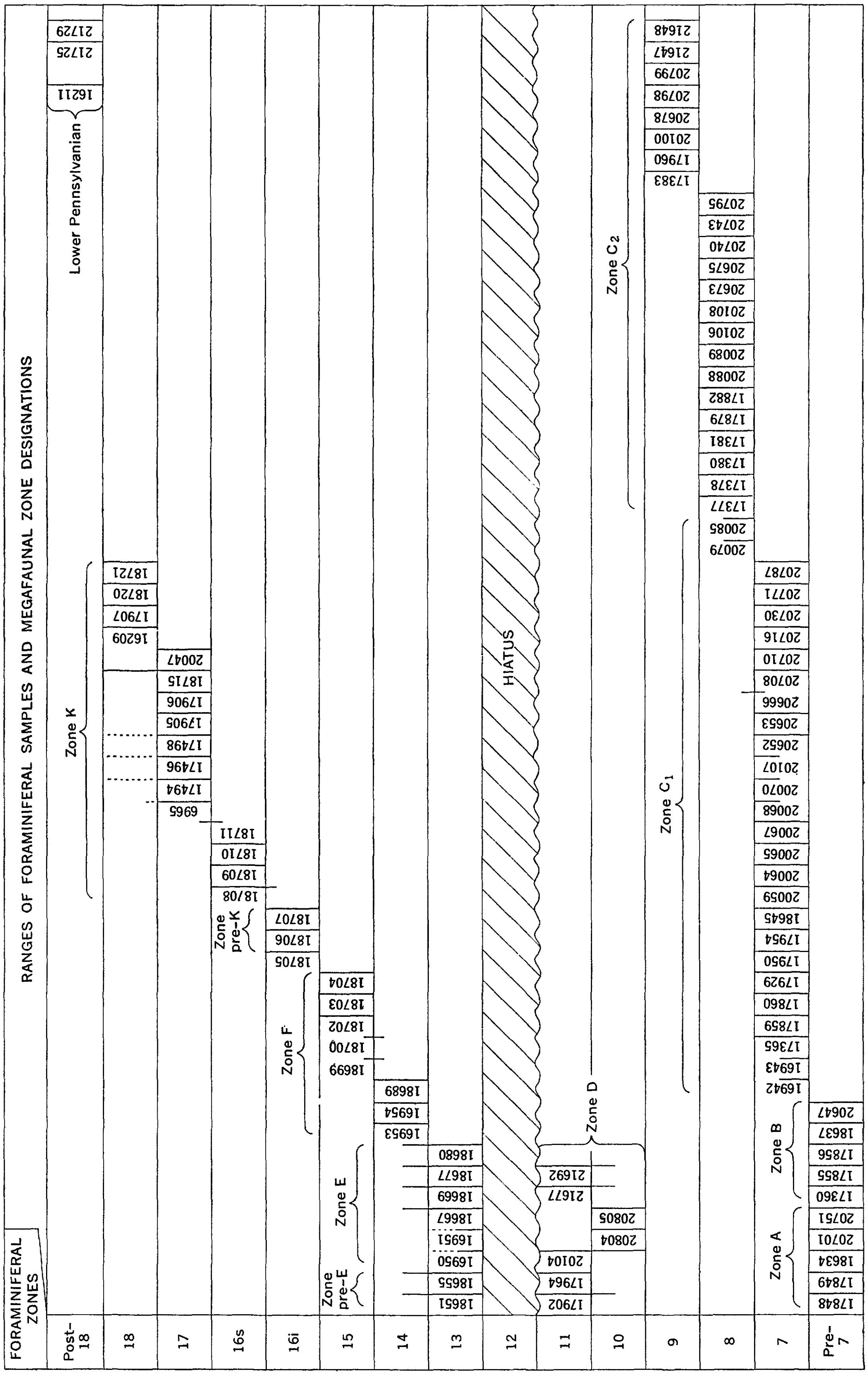


FIGURE 6.—Ranges of northern Cordilleran foraminiferal samples in the Mamet zonation scheme for the Lower Carboniferous compared with megafaunal zone designations for the same samples. Sample numbers are USGS upper Paleozoic localities listed in table 1. Possible range of sample indicated by solid line; dashed where questionable.

4. Zone F equals upper part of Zone 14 and Zone 15.
5. Zone E equals Zone 13 and lower part of 14.
6. Zone pre-E equals Zone 13 and lower part of 14.
7. Zone D equals Zones 10 and 11.
8. Zone C_2 equals Zones 8 and 9.
9. Zone C_1 equals Zone 7 and lowermost part of 8.
10. Zones A and B equal Zone pre-7.
11. Zone pre-A equals Zone unknown (no foraminifers found).

IDENTIFICATION IN DIFFERENT DEPOSITIONAL PROVINCES

Megafaunal studies summarized by Sando (1967b) indicate that there was a marked differentiation of the northern Cordilleran region into cratonic and miogeosynclinal areas during Late Mississippian time. Correlations established on the basis of megafaunas indicate that the upper part of the Monroe Canyon Limestone of the migeosynclinal Idaho province is the temporal equivalent of part of the cratonic Amsden Formation of western Wymoing and the Big Snowy Group of southwestern Montana. The discovery of Zone 17 and 18 foraminiferal assemblages in each of these units confirms the previous identifications of Zone K. Although the Amsden and Big Snowy are generally poor facies for foraminifers, additional collecting might prove even more rewarding for establishing relationships with sequences in the Idaho province.

Another noteworthy example of interprovincial correlation corroborated by the foraminiferal studies is the confirmation of Zone D in the Bull Ridge Member (Sando, 1968) of the Madison Limestone of the Wyoming province by discovery of Zone 10 and 11 assemblages there. Also, the presence of Zone C_2 has been confirmed in the lower part of the Madison Limestone at Sinks Canyon on the basis of a Zone 9 foraminiferal assemblage.

CORRELATION OF ZONE BOUNDARIES

None of the megafaunal zones is precisely equivalent to one foraminiferal zone. If the boundaries between megafaunal zones were coincident with boundaries between foraminiferal zones, one might suspect numerous hiatuses in the sequence. In the Kinderhook Series (lower part of the Lodgepole Limestone and lower part of the Madison Limestone), foraminifers are too rare and evolved too slowly for precise zonation, so the entire interval is included in a single zone (Zone pre-7). Corals, brachiopods, and conodonts evolved more rapidly, permitting recognition of three zones (pre-A, A, and B) in the same interval.

The upper part of the Lodgepole is generally characterized by Zone C_1 and Zone 7 assemblages, but evidence from the Black Mountain and Sacajawea Peak sections indicates that there is an overlap in the lower boundaries of these zones (pl. 1 and fig. 6). Samples 20079 and 20085 from the upper part of Zone C_1 contain a rich *Tuberendothyra tuberculata* faunule (Zone 8), which is normally found in beds assigned to Zone C_2. A similar situation is found in sample 20666 from the uppermost part of Zone C_1 at Sacajawea Peak, where determinable foraminifers do not indicate whether the faunule belongs to Zone 7 or to Zone 8.

More rapid evolution of the Foraminifera permit the recognition of two distinct zones (8 and 9) in the megafaunal Zone C_2 interval of the lower part of the Mission Canyon Limestone. Two foraminiferal zones (10 and 11) can also be recognized in Zone D (upper part of Mission Canyon Limestone), but these zones are not clearly separable in about half of the samples from this interval.

Poor microfacies for foraminifers in the Little Flat Formation make it difficult to draw a precise boundary between Zones 13 and 14. Samples identified megafaunally as Zone pre-E and Zone E contain similar foraminiferal assemblages. The base of Zone 14 appears to occur in the upper part of Zone E, but many of the samples from Zone F of the Monroe Canyon Limestone contain good Zone 14 foraminiferal assemblages. Zone F also clearly includes all of Zone 15.

Zone pre-K of the Monroe Canyon Limestone yielded a meager assemblage of foraminifers identified as Zone 16i, which is much better represented in samples from south-central Idaho and Alberta than in the samples examined in the present study. More work is necessary to establish precise zonal boundaries on both megafaunas and microfaunas in this part of the section.

The outburst of many foraminiferal taxa in middle and late Chester time makes it possible to recognize three zones (16s, 17, and 18) corresponding to megafaunal Zone K of the Monroe Canyon Limestone, Amsden Formation, and Big Snowy Group. The base of Zone K coincides with the base of Zone 16s in all but one sample (18708), which may include an equivalent to the upper part of Zone 16i. The top of Zone K appears to coincide with the top of Zone 18, but the lack of foraminiferal control in Zone post-K prohibits a final judgment.

Zone post-K is so poorly represented in the area studied that few samples are available, and the samples that were examined contained no determinable foraminifers. This zone is provisionally correlated with Zone post-18 on the basis of its position above the Zone 18 assemblage. Zone post-18 also includes samples (16211, 21725, 21729) that are dated as Early Pennsylvanian on the basis of brachiopods.

POST-MADISON HIATUS

Dutro and Sando (1963a, fig. 6) postulated the existence of a significant hiatus between the Lodgepole Limestone and the overlying Little Flat Formation in southeastern Idaho and northeastern Utah. Sando (1967b) presented evidence that this hiatus was due to a widespread episode of post-Madison epeirogenic emergence in the northern Cordilleran region. The main basis for this interpretation in the Idaho province (southeastern Idaho and northeastern Utah) is the absence of Zones D, C_2, and possibly a part of C_1 from stratigraphic sections in the Deep Creek Mountains, the Chesterfield Range, and Old Laketown Canyon, where Zone pre-E rests on Zone C_1. In the Montana and Wyoming provinces, the interpretation rests on the presence of widespread karst features at the top of the Madison Group and the absence of Zone pre-E and E assemblages.

Foraminiferal data compiled in the present study not only confirm the interpretation made on megafaunal evidence but also permit a more precise evaluation of the time span of the erosional interval in the Idaho province. At Little Flat Canyon in the Chesterfield Range, five foraminiferal zones are missing from the sequence between the Lodgepole Limestone and the Little Flat Formation. At Old Laketown Canyon, no control was obtained on the lower part of the Little Flat Formation, but the highest Lodgepole beds there were identified as Zone 7, the same interval recognized in the upper part of the Lodgepole at Little Flat Canyon. Correlation of these missing zones with the type Mississippian indicates that the hiatus represents all of Keokuk, Warsaw, and Salem time.

Evaluation of the timespan of the post-Madison hiatus is more difficult in the Montana and Wyoming provinces. In the Sweetgrass arch area of north-central Montana and in the Sawtooth Range of northwestern Montana, the Madison is overlain disconformably by Mesozoic rocks. Elsewhere in the Montana province the Madison is overlain disconformably by rocks of Late Mississippian age included in the Big Snowy Group or Amsden Formation or by the Pennsylvanian part of the Amsden. In the Wyoming province, the Madison is overlain disconformably by rocks of Late Mississippian age in the Amsden Formation or by the Casper Formation of Pennsylvanian and Permian age. Inasmuch as the lowest beds of the Amsden Formation (Darwin Sandstone Member) and Big Snowy Group (Kibbey Sandstone) are unfossiliferous, the age of the oldest post-Madison Mississippian strata has been estimated by means of lithostratigraphic correlation with beds dated by fossils in the Idaho province (Sando, 1967b). Foraminiferal data compiled in this study do not contribute significantly to more precise determination of the maximum timespan of the post-Madison hiatus in the Montana and Wyoming provinces. However, the universal absence of foraminiferal Zone 12 indicates that the minimum timespan of the hiatus is the Late Mississippian interval equivalent to the upper part of the Salem Limestone in the type Mississippian sequence.

ABSENCE OF OTHER GAPS IN THE RECORD

Aside from the foraminiferal zones missing between the Madison and post-Madison intervals, no other hiatuses were detected in the sequence, a conclusion reached previously by megafaunal analysis. This conclusion must, of course, be qualified according to the resolving power of the zonation scheme. Francis and Woodland (1964, table 1) estimated that the Mississippian spanned approximately 25 million years which were about equally divided between Early Mississippian (Kinderhook and Osage) and Late Mississippian (Meramec and Chester) divisions. Inasmuch as four foraminiferal zones are recognized in the Early Mississippian interval, the average timespan of a zone during that interval is approximately 3 million years. In the Late Mississippian interval, more rapid evolution of the Foraminifera permits recognition of 10 zones. Here the average timespan of a zone is decreased to slightly more than 1 million years. Consequently, gaps of less than 3-million-years duration in the early Mississippian or less than 1-million-years duration in the late Mississippian could not be detected by the zonation scheme.

INTRACONTINENTAL AND INTERCONTINENTAL CORRELATIONS

The foraminiferal zones recognized in the northern Cordilleran region have been identified by Mamet in the type Mississippian, the Mississippian of western Canada, and in standard Carboniferous sequences in Europe. Mamet and Skipp (1969) have summarized the temporal significance of the foraminiferal zones as applied to correlation of the North American Mississippian with western European Carboniferous standards. However, the present study deals in more detail with specific formations in the northern Cordilleran region. Consequently, it is desirable to discuss briefly the correlations of these units with the type Mississippian and with European time-stratigraphic divisions. The essential conclusions of the following discussion are summarized in figure 7.

LODGEPOLE LIMESTONE

Two foraminiferal assemblages are recognizable in the Lodgepole Limestone, the Zone pre-7 assemblage

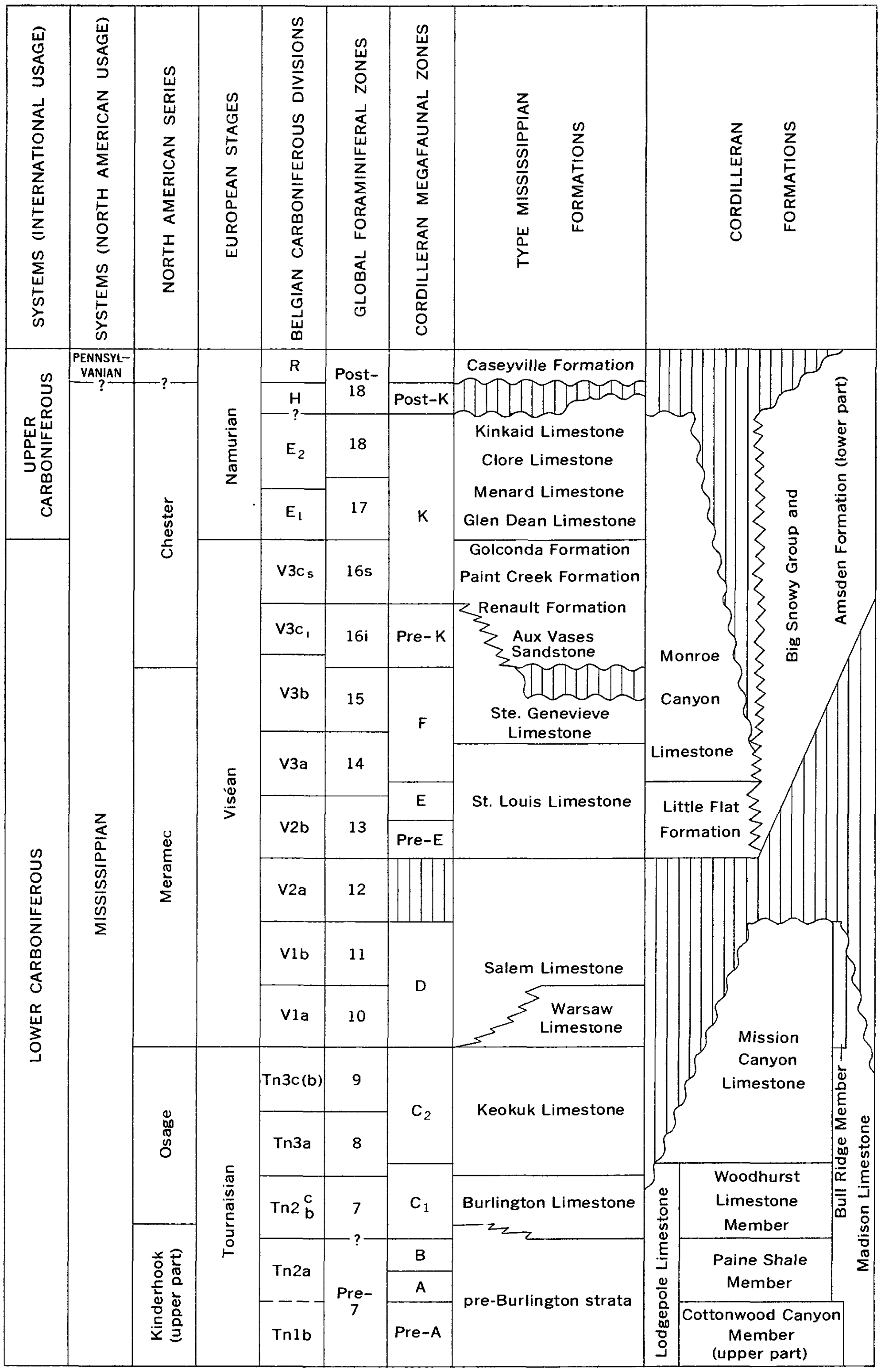


FIGURE 7.—Correlation chart showing inferred relationships of faunal zones, principal European and American time-stratigraphic divisions, and Cordilleran and type Mississippian formations.

found in the Paine Shale Member and the Zone 7 assemblage of the Woodhurst Limestone Member. Scarcity of foraminifers in the Paine Shale Member makes comparison with other foraminiferal sequences difficult. However, a similarly poor microfacies, in which only calispherids and *Bisphaera* are common, is also found in the type Kinderhook Series and in the Banff Formation of Alberta. An early Tournaisian, pre-Burlington age is indicated, but the foraminifers are here of no value in identifying the base of the Lower Carboniferous. Identification of this datum in the Lodgepole depends mainly on interpretation of conodont faunas in the Cottonwood Canyon Member.

The foraminiferal assemblage (Zone 7) of the Woodhurst Limestone Member is characteristic of the uppermost Kinderhook and the Burlington Limestone of the type Mississippian and of the upper part of the Banff Formation and lowermost part of the Livingstone and Pekisko Formations of Alberta. This assemblage is encountered in the U.S.S.R. above the *Bisphaera* beds and constitutes the *Chernyshinella glomiformis—Palaeospiroplectammina tchernyshinensis* assemblage zone of Russian authors. Zone 7 is also known in the type section of the Tournaisian (Legrand and others, 1966) and in the Calcaire de Landelies (Tn2b) of Belgium. The presence of a Zone 8 assemblage in the upper part of the Woodhurst Limestone Member at some localities suggests that a lowermost Keokuk equivalent could also be present near the top of the Lodgepole.

MISSION CANYON LIMESTONE

Four foraminiferal assemblages can be distinguished in the Mission Canyon Limestone, the Zone 8 and 9 assemblages in the lower part, and the Zone 10 and 11 assemblages in the upper part. The Osage-Meramec boundary, which correlates with the Tournaisian-Viséan boundary, occurs between Zones 9 and 10.

The lower Mission Canyon assemblages (Zones 8 and 9), characterized by "spinose" endothyroids, are poorly developed in the Keokuk Limestone of the midcontinent region but are well developed in the Shunda Formation and part of the Turner Valley Formation of Alberta. These assemblages are also characteristic of the Chikman-Kizel interval in the U.S.S.R. Although these zones are poorly exposed in the type locality of the Tournaisian, they are present in the Calcaire d'Yvoir (Tn3a) and the Calcaire de Leffe (Tn3c) in the Dinant synclinorium of Belgium.

The upper Mission Canyon assemblages (Zones 10 and 11), also found in the Bull Ridge Member of the Madison Limestone of central Wyoming, have been observed in the Salem Limestone of the midcontinent region. In particular, the Warsaw Limestone, Harrodsburg Limestone (restricted) of Stockdale (1939), and the lower and middle parts of the Salem Limestone in Illinois are characterized by the outburst of *Globoendothyra* and *Endothyranopsis*, evolved Tetrataxinae, and the first Archaediscidae, which mark these assemblages. This radical change in the foraminiferal faunas is conspicuous at the lowermost level of the Viséan in Belgium in the "Marbre noir de Dinant" (V1a) and "Dolomie de Sovet" (V1b) (Mamet, 1965).

Foraminiferal Zone 12, which corresponds to the upper part of the Salem Limestone, has not been found in any of the samples studied. Evidently, the timespan of this zone coincides with at least a part of the period of post-Madison uplift that occurred throughout most of the northern Cordilleran region. This zone, represented in Alberta (Salter Member of the Mount Head Formation in its type locality), is of early middle Viséan (V2a) age.

LITTLE FLAT FORMATION

Although most of the beds in the Little Flat Formation are not particularly good microfacies for foraminifers, elements of two assemblages (Zones 13 and lower part of Zone 14) have been found. These assemblages, particularly characterized by abundant *Endothyranopsis* and *Koninckopora*, occur in the St. Louis Limestone of the midcontinent region and are also known in the Loomis and Marston Members of the Mount Head Formation in Alberta. Zone 13 is well represented in the Calcaire de Lives and in the Bancs Inferieurs d'Anhee of Belgium, where the outburst of *Endothyranopsis compressus* is conspicuous. Zone 14 is poorly known in the Belgian sequences, but it is well displayed in the Bristol area of England (upper part of S_2).

MONROE CANYON LIMESTONE

The Monroe Canyon Limstone represents a considerable interval of Late Mississippian time. Its foraminiferal sequence can be divided into six zones that range in age from late Meramec through most of the Chester.

The lowest beds of the Monroe Canyon Limestone are characterized by a continuation of the Zone 14 assemblage found in the upper part of the Little Flat Formation. This lowermost Monroe Canyon is correlated with the upper part of the St. Louis Limestone and the lowermost part of the Ste. Genevieve Limestone (of the type section in Missouri).

The Zone 15 assemblage, found near the middle of the Monroe Canyon, represents the highest beds of Meramec age in the formation. This assemblage occurs in the upper part of the type Ste. Genevieve (Missouri) and extends into beds assigned to the Ste. Genevieve in Illinois and Kentucky. The upper part of the Ste. Genevieve of Illinois and Kentucky contains elements of the Zone 16i assemblage and therefore extends across the Meramec-Chester boundary, which is placed at the top of Zone 15. Zones 15 and 16i are represented in the upper Viséan (V3b and lower part of V3c) of Belgium. The Zone 15 assemblage is well developed in the Carnavon Member of the Mount Head Formation of Alberta.

The upper third of the Monroe Canyon Limestone contains three zones of Chester age and straddles the Viséan-Namurian boundary. The abundance of *Neoarchaediscus* and occurrence of *Planospirodiscus* in Zone 16s indicates equivalence with the Paint Creek–Golconda interval of the midcontinent region and the middle part of the Etherington Formation of Alberta. Zone 16s is also found in the uppermost Viséan of Belgium (upper part of V3c) and England (upper P2) (Mamet, Hottinger, and Choubert, 1967). Zones 17 and 18 are characterized by the outburst of *Asteroarchaediscus*, *Globivalvulina* s.s., and *Eostaffellina*. Such early Namurian fossils are observed in the Glen Dean–lower Kinkaid interval of the midcontinent region and are also present in the upper part of the Etherington Formation of Alberta. Zone 17, which coincides with the lower *Eumorphoceras* Zone (E_1 and lower E_2) of western Europe, is often called uppermost Viséan in the U.S.S.R. There are few modifications at that level in the Eostaffellidae and Pseudoendothyridae; the first outburst of *Eostaffellina protvae* occurs above Zone 17 in the upper part of E_2 in the Protva Formation of the U.S.S.R.

AMSDEN FORMATION

Although the determinable foraminiferal samples from the Amsden Formation are rather limited both in number and in geographic distribution, several significant conclusions can be derived from them. The Amsden samples clearly indicate a Late Mississippian age for the lower part of the formation in western Wyoming and suggest a means for distinguishing the Mississippian-Pennsylvanian boundary on the basis of foraminiferal assemblages.

Five of the Amsden samples are from the middle or the lower half of the formation associated with megafossils determined as Zone K (pl. 1). These samples contain foraminiferal Zone 17 and Zone 18 assemblages, which are found in the upper Chester (Glen Dean–Kinkaid) of the midcontinent region.

Three samples are from beds near the middle of the formation that have been determined as Pennsylvanian on the basis of megafossils. These samples are all referred to forminiferal Zone post–18. These findings suggest that in sections where the post-K Zone is missing, the Mississippian-Pennsylvanian boundary can be drawn between Zones 18 and post–18 of the foraminiferal scheme.

BIG SNOWY GROUP

The only determinable foraminiferal samples from the Big Snowy Group are from beds near the middle of this unit in the Baldy Mountain section of southwestern Montana (pl. 1). These samples are associated with megafossils determined as Zone K. The foraminiferal assemblages are characteristic of Zones 17 and 18, indicating a Chester (Glen Dean–Kinkaid) age for this part of the Big Snowy.

CONCLUSIONS

It has been said that corals and brachiopods are too facies sensitive to be practical for chronostratigraphy even within a basin of deposition. This viewpoint is probably too pessimistic, at least in regard to correlations within the shelly carbonate facies. Comparison of the coral-brachiopod zonation scheme established for the Mississippian of the northern Cordillera with a foraminiferal scheme that has been tested on a global basis results in remarkably consistent answers with regard to intra- and extra-basinal correlations.

Time correlations based on foraminiferal faunas confirm the broad chronostratigraphic relationships established between the northern Cordillera and the type Mississippian on the basis of megafaunas. Moreover, a higher degree of cosmopolitanism in the foraminiferal faunas permits more precise correlations with the type Mississippian and with standard Carboniferous sequences in western Europe.

Although the resolution of the foraminiferal zones is generally finer than that of the megafaunal zones tested, corals and brachiopods evolved more rapidly than the foraminifers in some parts of the Lower Carboniferous and, hence, are locally more useful for zonation. The greater susceptibility of the foraminifers to alteration or destruction by recrystallization leaves no alternative but to use megafaunas in some rock sequences. Mutual calibration of the two zonal schemes enhances the value of both for biostratigraphic studies.

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