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Foraminiferal zonation and carbonate facies of the Mississippian and Pennsylvanian Lisburne Group, central and eastern Brooks Range, Arctic Alaska.

by

Augustus K. Armstrong and others

U. S. Geological Survey.
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1. Foraminiferal zonation and carbonate facies of the Mississippian and Pennsylvanian Lisburne Group, central and eastern Brooks Range, Arctic Alaska, by Augustus K. Armstrong, Bernard L. Mamet, and J. Thomas Dutro, Jr. 26 p., 4 figs.

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FORAMINIFERAL ZONATION AND CARBONATE FACIES OF THE MISSISSIPPIAN AND PENNSYLVANIAN LISBURNE GROUP, CENTRAL AND EASTERN BROOKS RANGE, ARCTIC ALASKA

By

Augustus K. Armstrong, Bernard L. Mamet, and J. Thomas Dutro, Jr.

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Foraminiferal zonation and carbonate facies of the Mississippian and Pennsylvanian Lisburne Group, central and eastern Brooks Range, Arctic Alaska

By Augustus K. Armstrong[1], Bernard L. Mamet[2], and J. Thomas Dutro, Jr.[3]

ABSTRACT

The Lisburne Group carbonates of the central and eastern Brooks Range contain foraminiferal assemblages assigned to zones of Osage [late Tournaisian], Early Mississippian, to Atoka [early Moscovian], Middle Pennsylvanian age. Representatives of both Eurasiatic and American cratonic microfaunas permit correlation with the original Carboniferous type sections in western Europe as well as with the standard Mississippian and Pennsylvanian sequences in the Midcontinent region of North America. Correlation anomalies in the lower part of the sequence are discussed.

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The writers wish to express their appreciation to George Gryc for his suggestions and critical review of the manuscript.

Previous work

The nomenclatural history of the Lisburne group in the central Brooks Range is well described by Bowsher and Dutro (1957, p. 3):

> "Paleozoic rocks in this area were first described in 1902 by Frank C. Schrader (Fig. 3). Although the first name applied to the Carboniferous rocks was Fickett series, this term later was found to be inapplicable and was abandoned (Smith and Mertie, 1930, p. 149). Schrader (1902, p. 241-243) used the name Lisburne formation for a limestone unit exposed in the upper Anaktuvuk River valley. He noted here and later (1904, p. 62-66) that the Lisburne formation might be correlated with a similar limestone and shale section at Cape Lisburne, the geographic feature from which the name was taken. Although the limestone was first thought to be Devonian in age, critical evaluation by G. H. Girty of new fossil collections resulted in the assignment of a Mississippian age (Collier, 1906, p. 22-26). For more than 40 years the name Lisburne formation (later modified to Lisburne limestone) was applied, for all practical purposes, to any limestone of Mississippian age."

In the Shainin Lake area, Bowsher and Dutro (1957, p. 3, 4, 6) recognized two new formations within the Lisburne which they raised to group rank. The lower formation is the Wachsmuth Limestone, which includes four informal members and overlies the Kayak Shale (Fig. 4). The Alapah Limestone overlies the Wachsmuth Limestone and has nine informal members. The Alapah Limestone (p. 25) is covered by glacial gravel and alluvium at the top of the type section. They assigned the Wachsmuth to the Lower Mississippian, and the Alapah to the Upper Mississippian (p. 4).

Brosgé, Dutro, Mangus, and Reiser (1962) described the Paleozoic sequence in the eastern Brooks Range. In this region they recognized three formations within the Lisburne Group, the Wachsmuth and Alapah Limestones, and an overlying limestone which they named the Wahoo Limestone (p. 2187, 2190-2191). They assigned the Wahoo a Pennsylvanian(?) and Permian age (p. 2192).

Earlier biostratigraphic studies of the Lisburne Group were based on megafossil evidence. One of the more significant and important studies is that of Bowsher and Dutro (1957, p. 5, 6). They recognized two formations, the Wachsmuth and Alapah Limestones in the Shainin Lake area. There the Wachsmuth Limestone was considered to be Early Mississippian on the basis of echinoderms, brachiopods, and corals in the lower part, and brachiopods in the upper part and the Alapah Limestone was considered to be Late Mississippian on the basis of goniatites, brachiopods, corals, and gastropods.

Brosgé and coworkers (1962, p. 2191-2192) stated that the lower member (p. 2189, Fig. 6) of the Wahoo Limestone contained a "brachiopod-bryozoan assemblage of post-Mississippian, probably Pennsylvanian, age," and that at the Echooka River section, "the lower beds also contain colonial corals suggesting a post-Mississippian age." Brachiopods of Permian age in the upper beds of the upper member resemble the brachiopods in the lower beds of the Sadlerochit Formation. The authors believed that the Wahoo Limestone, "...in its most complete sections, may represent most of the Pennsylvanian and include part of the Lower Permian as well."

Gordon (1957) described and illustrated a number of Late Mississippian (Visean) goniatites collected from the upper middle part of the Alapah Limestone in the central Brooks Range.

Yochelson and Dutro (1960) described and illustrated a number of gastropods from the Lisburne Group. They also presented regional biostratigraphic relationships based on gastropods and other groups of megafossils.

This study of the Lisburne Group microfossils supports the general age assignments previously based on megafossils, with two important exceptions: The microfossils indicate that the upper part of the Wachsmuth Limestone at Shainin Lake is early Meramec (early Late Mississippian) in age (fig. 3) and thus slightly younger than the Early Mississippian age indicated by Bowsher and Dutro (1957, p. 4), and that the Wahoo Limestone in the sections studied is no younger than Atoka (Middle Pennsylvanian) in age and, in the area of this study, is considered to be Early and Middle Pennsylvanian.

Method of study

The material on which this study is based consists of carefully measured stratigraphic sections from which lithologic and foraminiferal samples were collected at intervals of 5 to 10 feet. Thin sections were cut from these samples in order to determine the microfossil assemblage and the carbonate petrography and microfacies. Concurrent with the collecting of carbonate rock samples, extensive collections of rugose corals were made.

The sequences in northeastern Alaska, in the Sadlerochit and Franklin Mountains, were collected by Armstrong in 1968.

The sequences in the Endicott Range were collected by Stanley F. Schindler, Sigmund Snelson, and Robert R. Smith of Shell Oil Company in 1959 and 1960 and were re-examined and re-collected by Schindler and Armstrong in 1964.

Bowsher and Dutro's (1957) descriptions and illustrations of type sections facilitated re-collection of microfossil material from all significant stratigraphic levels. The Shell Oil Company lithologic samples from Shainin Lake were carefully keyed to the beds within the informal members of the type sections of the Wachsmuth and Alapah Limestones.

The lithologic and microfossil material from the Echooka River section was collected from a structurally complex terrain in 1960 by John Lawrence and Alan H. Coogan of Shell Oil Company.

Dunham's (1962) carbonate classification is used in this report.

Geologic setting

The structural geology of the Brooks Range is complex. As a result, the stratigraphic sequences in the central Brooks Range were measured on allochthonous thrust sheets, whereas those in the Franklin and Sadlerochit Mountains are in autochthonous rocks (Fig. 1).

For a regional introduction to the geology of the central and eastern Brooks Range, the reader is referred to the studies of Bowsher and Dutro (1957); Brosgé, Dutro, Mangus, and Reiser (1962); Brosgé, Reiser, Patton, and Mangus (1960); Porter (1966); Reed (1968); and Reiser and Tailleur (1969).

Fig. 1 near here.

Foraminiferal biostratigraphy of the central and eastern Brooks Range

The study of Foraminifera of the Brooks Range carbonate succession is generally difficult; indeed, bryozoan-echinoderm wackestones and packstones, very common in the Carboniferous systems of Alaska, form a very unfavorable environment for Protozoa. Moreover, dolomitization and stress-reorientation of the calcite often obliterate the original texture of the sediments and makes identification of the foraminiferal ghosts hazardous.

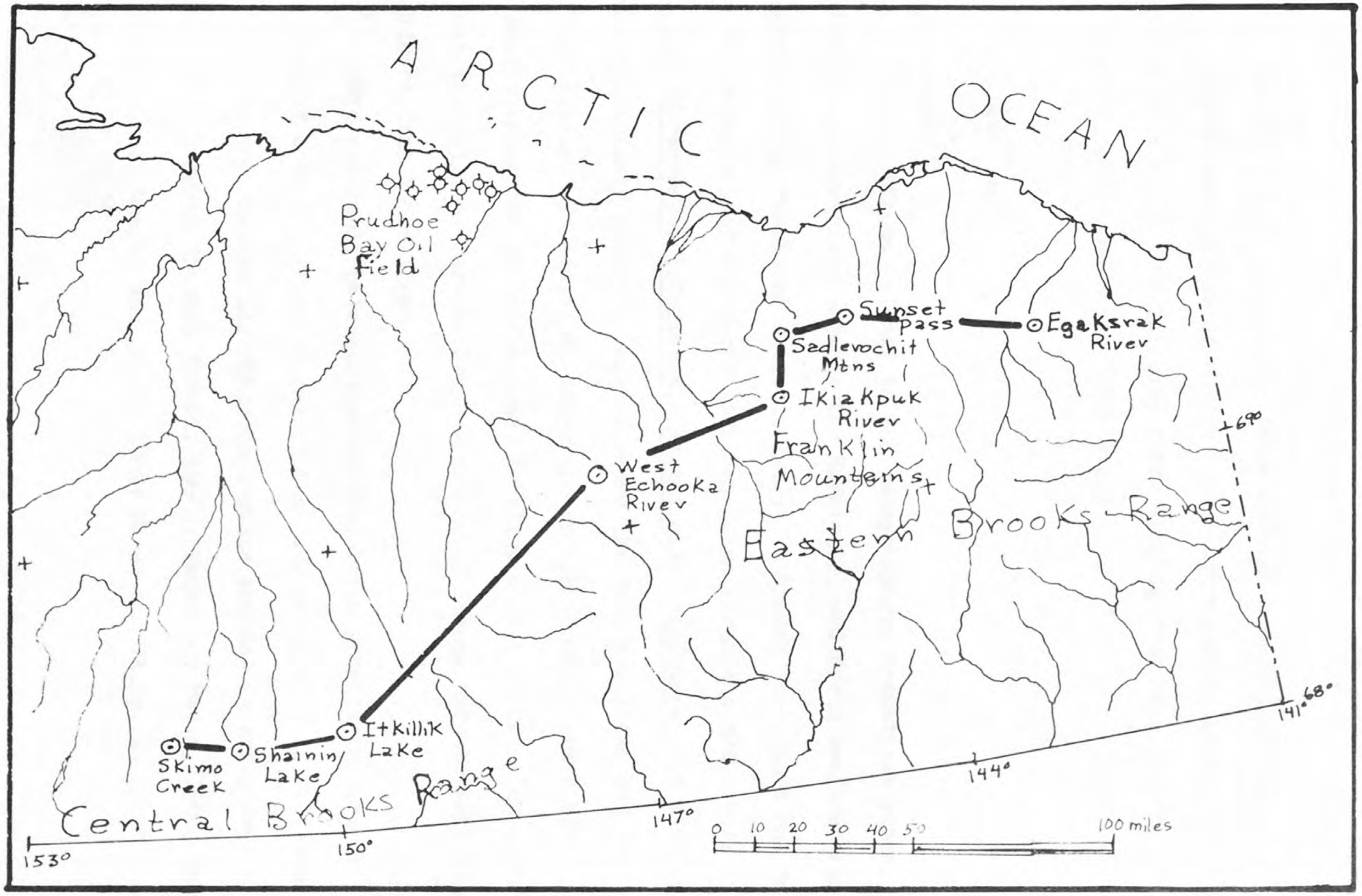

Figure 1 - Index map of northern Alaska showing location of area studied in this report.

Despite these hindrances, foraminiferal assemblages have been observed at many levels of the sections investigated, permitting recognition of a dozen foraminiferal zones ranging from late Tournaisian (Osage) to early Moscovian (Atoka) age (Fig. 2).

Fig. 2 near here.

The microfauna belongs to the Taimyr-Alaska transition realm, which is intermediate between the Eurasiatic and North American realms (Mamet, 1962; Mamet and Belford, 1968). Although this fauna has many representatives of the North American fauna (abundant and diversified *Eoendothyranopsis*, *Eoforschia*, "*Eostaffella*" *discoidea*), it also contains many Eurasiatic elements, mostly among the Tournayellidae and the Endothyridae. In addition, there are enough "cosmopolitan" elements (mostly among the Archaediscidae) to allow direct correlation with both the original Carboniferous zonation of Europe and the American Midcontinent succession.

This favorable paleobiological dispersion permits the use in Alaska of a foraminiferal zonation that was originally established in Europe by the Russian micropaleontologists and has recently been extended to North America (Mamet, 1968a; Mamet and Mason, 1968; Mamet, 1968b; Sando, Mamet, and Dutro, 1969; Mamet and Skipp, in press).

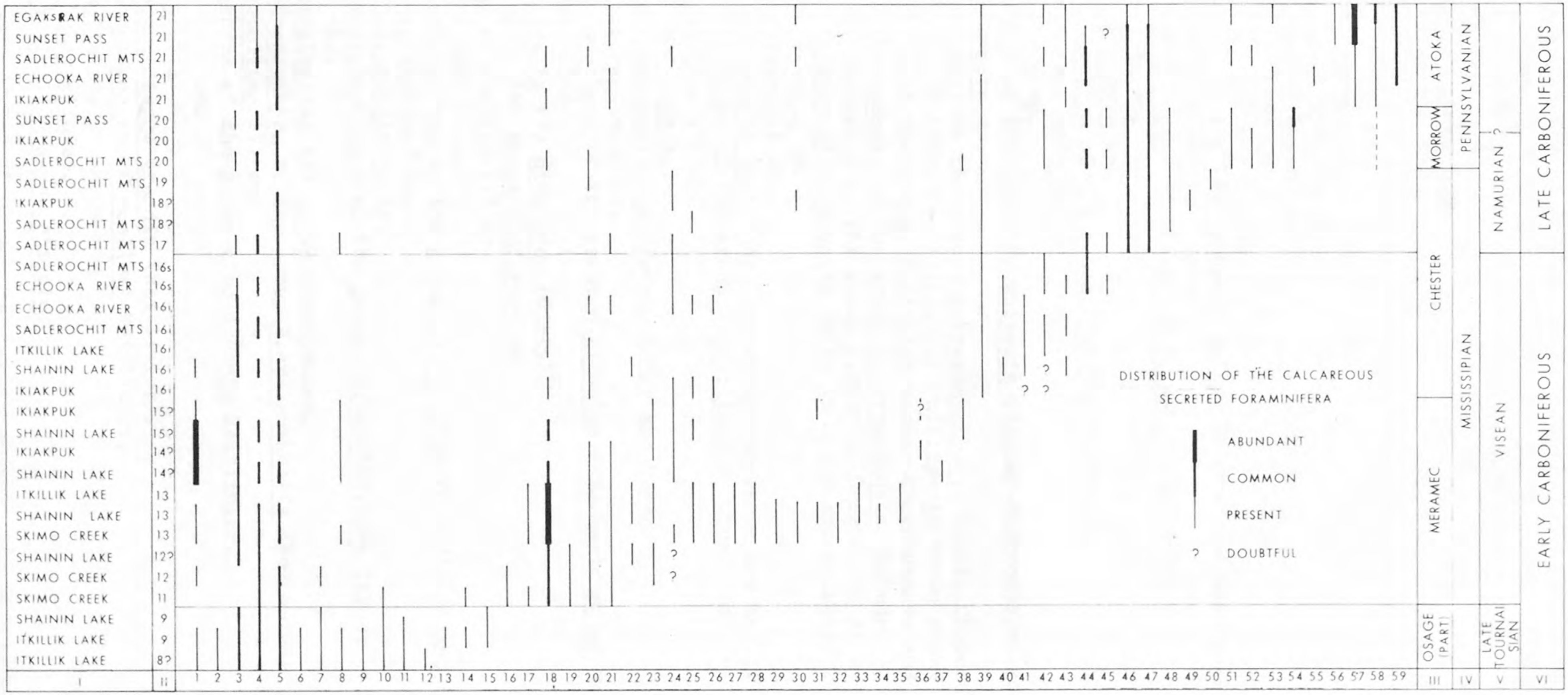

Figure 2 - Selected samples showing stratigraphic distribution of microfossils in the Lisburne Group, central and eastern Brooks Range, Alaska. (I) Measured stratigraphic sections; (II) Microfaunal assemblage Zone; (III) Midcontinent Series; (IV) System; (V) European Stage; (VI) European System.

1) Brunsia sp.
2) Brunsiina sp.
3) Calcisphaera sp.
4) Earlandia sp.
5) "Endothyra" sensu lato.
6) Glomospiranella sp.
7) Latiendothyra sp.
8) Parathurammina sp.
9) Septabrunsiina sp.
10) Septaglomospiranella sp.
11) Septatournayella sp.
12) Tuberendothyra sp.
13) Endothyra inflata Lipina.
14) Septatournayella (?) henbesti Skipp, Holcomb and Gutschik.
15) Tournayella døiscoidea Dain.
16) Eoendothyranopsis of the group E. spiroides (Zeller).
17) Eoforschia sp.
18) Globoendothyra sp.
19) Globoendothyra of the group. G.baileyi (Hall).
20) Stacheia sp. and Stacheoides sp.
21) Tetrataxis sp.
22) Earlandia of the group E. vulgaris (Rauzer-Chernoussova and Reitlinger).
23) Koninckopora sp.
24) Archaediscus of the group. A.krestovnikovi. Rauzer-Chernoussova.
25) Endothyra of the group E. bowmani Phillips in Brown emend Brady.
26) Endothyra of the group. E.similis Rauzer-Chernoussova and Reitlinger.
27) Eoendothyranopsis of the group E. ermakiensis (Lebedeva).
28) Eoendothyranopsis of the group E.pressa (Grozdilova in Lebedeva).
29) Eoendothyranopsis? redwalli Skipp in McKee and Gutschick.
30) Endothyranella sp.
31) Endothyranopsis sp.
32) Endothyranopsis compressa (Rauzer-Chernoussova and Reitlinger).
33) Globoendothyra of the group G.tomiliensis (Grozdilova in Lebedeva).
34) Irregularina (?) sp.
35) Propermodiscus sp.
36) Eoendothyranopsis? banffensis McKay and Green.
37) Planoarchaediscus sp.
38) Globoendothyra of the group G.globulus d'Eichwald emend von Möller.
39) Apterinellids.
40) Eostaffella (?) discoidea (Girty).
41) cf. primitive Neoarchaediscus sp.
42) Pseudoglomospira (?) sp.
43) Tre?peilopsis sp.
44) Neoarchaediscus of the group. N.incertus (Grozdilova and Lebedeva).
45) Planospirodiscus sp.
46) Asteroarchaediscus sp.
47) Asteroarchaediscus of the group. A.baschkiricus (Krestovnikov and Teodorovitch).
48) Globivalvulina (?) parva Chernysheva.
49) Pseudoendothyra of the group P.kremenskensis (Rozovskaia).
50) Eosigmoilina (?) sp.
51) Endothyra of the group E.mosquensis Reitlinger.
52) Lipinella sp.
53) Millerella
54) Neoarchaediscus grandis (Reitlinger).
55) Climacammina cf. C.moelleri Reitlinger.
56) Dvinella sp.
57) Eoschubertella sp.
58) Globivalvulina sensu stricto.
59) Pseudostaffella sp.

In this zonation, the Tournaisian and Visean Stages are divided respectively into four and eight zones, established on Endothyridae and Tournayellidae for the Tournaisian and on Endothyridae, Archaediscidae, Eostaffellidae, and Pseudoendothyridae for the Visean (Fig. 3).

Fig. 3 near here.

Late Tournaisian (middle and late Osage) foraminiferal faunas

The late Tournaisian Zones 8? and 9 have been encountered only in the basal part of the Shainin Lake and Itkillik Lake sections. They are characterized by the acme of the Tournayellidae, represented by *Glomospiranella*, *Septabrunsiina*, *Septatournayella*, and *Tournayella discoidae*. The spinose endothyrida *Tuberendothyra* and *Spinoendothyra*, usually abundant at that level in the southern part of the American Cordillera, are here very scarce.

In the American Cordillera, similar zones are known in the Shunda Formation of the Fort St. John region of southern Alberta. They are also observed in the Livingstone Formation of southwestern Alberta, in the lower part of the Mission Canyon Limestone of Montana and western Wyoming, and in the upper part of the Madison Limestone of central Wyoming (Sando, Mamet, and Dutro, 1969). They are present in the Keokuk Limestone of the American Midcontinent, in particular, in its type section.

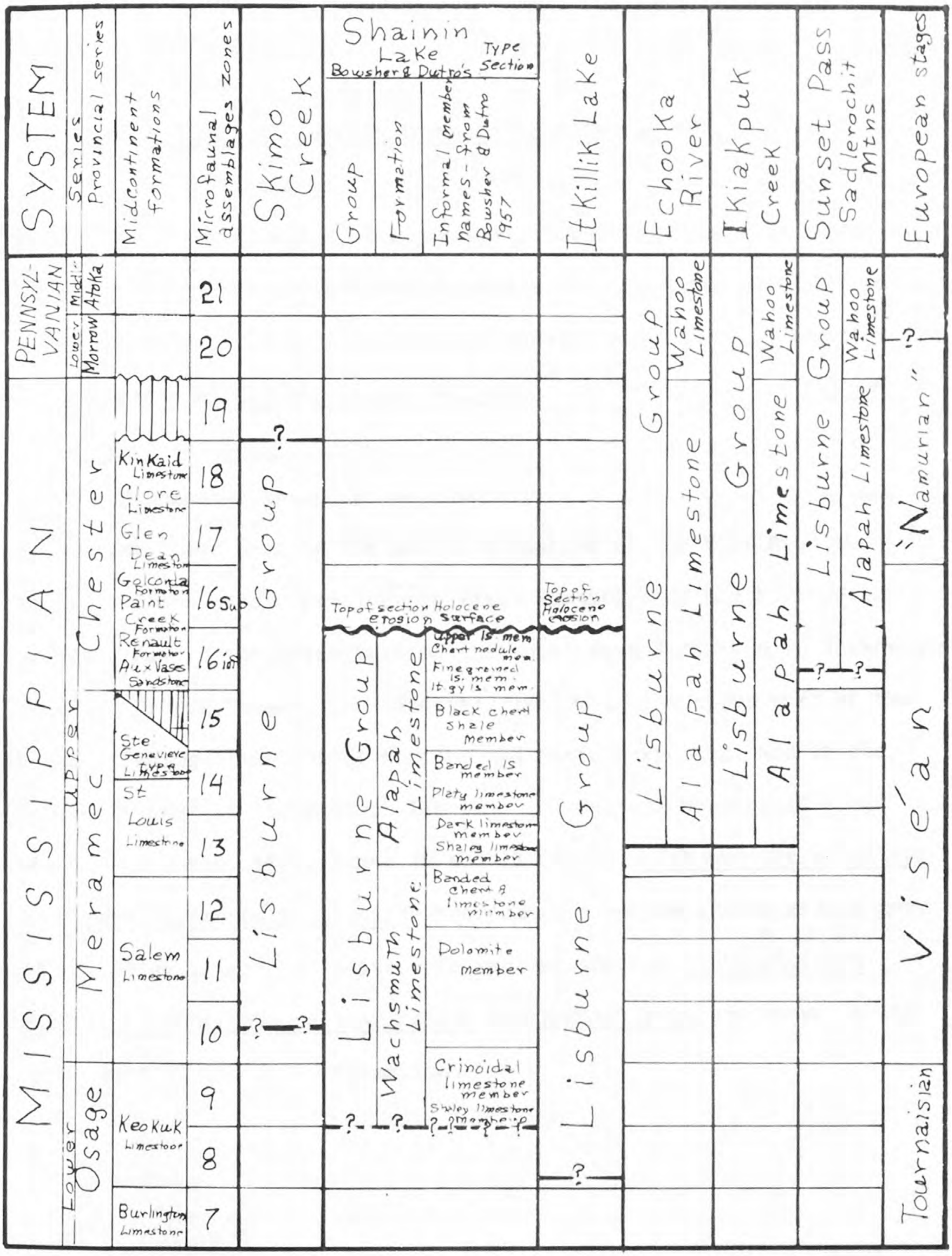

Figure 7 Biostratigraphic age and regional relationship of selected measured sections of Lisburne Group carbonates. Age is determined by microfaunal assemblages.

Early and early middle Visean foraminiferal faunas

No characteristic microfauna of the earliest Visean Zone 10 is known in the Brooks Range, the passage between the Tournaisian-Visean being either barren or in a nondiagnostic Earlandia facies. The late early Visean Zone 11 and early middle Visean faunal Zone 12 are characterized by Globoendothyra baileyi, numerous species of Stacheia-Stacheoides and Eoendothyranopsis, and, in zone 12, Koninckopora. Similar faunas are known in the middle part of the Prophet Formation and in the lower part of the Debolt Formation of the Fort St. John region; in the middle part of the Flett Formation of the Northwest Territories; in the lower part of the Mount Head Formation in southwestern Alberta (Petryk, Mamet, and Macqueen, 1969); in the upper part of the Mission Canyon Limestone of Montana and western Wyoming; and in the uppermost part of the Madison Limestone of central Wyoming (Sando, Mamet, and Dutro, 1969, Zones 10 and 11 only). Globoendothyra baileyi and Eoendothyranopsis spiroides are common elements of the middle part of the Salem Limestone in its type region, whereas Globoendothyra baileyi-Eoendothyranopsis spiroides and Koninckopora are known in the upper part of the Salem Formation.

Late middle and early late Visean foraminiferal faunas

In Alaska, Zone 13 is usually displayed among facies favorable to calcareous forams, such as pseudo-oolitic packstones, grainstones, or algal wackestones and packstones; hence, the assemblages of *Globoendothyra-Eoendothyranopsis*, *Endothyranopsis*, and *Archaediscus* of the group *A. krestovnikovi* are usually rich and diversified. *Eoendothyranopsis* of the group *E. pressa* (*E. scitula* Toomey) is present.

In contrast, Zones 14-15 (St. Louis and Ste. Genevieve Limestones) are difficult to identify, as the "*Brunsia*-facies," indicative of abnormal salinity, eliminates most of the characteristic normal marine representations of *Eoendothyranopsis* and *Endothyranopsis*.

The *Eoendothyranopsis pressa* fauna (Zones 13-15) is known in the upper part of the Debolt Formation (Macauley, 1958, p. 298) of Fort St. John, in the upper part of the Mount Head Formation of southwestern Alberta (Lummus, Marston, Carnarvon, and Opal Members) (Petryk, Mamet, and Macqueen, 1969), in the Middle Canyon and in the basal part of the Scott Peak Formations of Huh (1967) of southwestern Idaho, and in the Little Flat Formation and lower part of Monroe Canyon Limestone of the Idaho depositional province (Sando, Mamet, and Dutro, 1969). It is also well displayed in the St. Louis and Ste. Genevieve Limestones of Missouri.

The "*Brunsia-facies*" is found as far south as northeastern British Columbia and the Yukon Territory.

Late Visean foraminiferal faunas (early Chester)

Zone 16_{inf} and 16_{sup} are recognizable mainly on Archaediscidae and Endothyridae; Meramecian elements, such as *Eoendothyranopsis* or *Eoforschia* are eliminated, and the *Neoarchaediscus*-"*Eostaffella*" *discoidea* fauna progressively becomes a prominent feature; the base of Zone 16_{sup} is drawn at the base of the acme of *Neoarchaediscus* *incertus* mixed with *Planospirodiscus*.

Both zones are known in the basal part of the Nizi Formation of British Columbia (Mamet and Gabrielse, 1969), in the lower Etherington Formation of southwestern Alberta (Mamet, 1968a), in the upper part of the Scott Peak Formation and in the South Creek Formation of Huh (1967) in the Lost River Range, Idaho, and in the middle part of the Monroe Canyon Limestone of the Idaho depositional province (Sando, Mamet, and Dutro, 1969). The zones are also present from the Aux Vases Sandstones to the Golconda Formation of the Chester type region.

Namurian foraminiferal faunas (middle to upper Chester and Morrow)

The Eumorphoceras foraminiferal equivalents (Zones 17 and 18) are recognized on the successive outbursts of Asteroarchaediscus baschkiricus and Globivalvulina(?) parva. These assemblages are known in an "unnamed recessive interval succession" of Northern Yukon; in the Calico Bluff Formation, Yukon River, east-central Alaska; in the middle and upper part of the Nizi Formation in northern British Columbia; in Mississippian rocks on the Prince of Wales Island, southeastern Alaska; in the middle and upper parts of the Etherington Formation of southeastern British Columbia (Mamet, 1968a); in the Surrett Canyon Formation of Huh (1967) in the Lost River Range, Idaho; in the upper part of the Monroe Canyon Limestone of the Idaho depositional province (Sando, Mamet, and Dutro, 1969); and in the middle part of the Amsden Formation in the Wyoming depositional province. In the Midcontinent region, these zones are observed from the Glen Dean to the Kinkaid Limestones.

Zone 19, the Homoceras foraminiferal partial equivalent (Eosigmoilina?), is known in the Sadlerochit Mountains section and is the probable equivalent of the basal Baschkirian of the Russian Platform. Homoceras equivalents appear to be scarce in North America, although the Eosigmoilina? fauna has been identified in the upper part of the Surrett Canyon Formation of Huh (1967) in Idaho, in the upper part of the Indian Springs Formation of Rich (1963) in Nevada, and in scattered localities in the Great Basin. The zone is missing by hiatus in the American Midcontinent.

Zone 20, characterized by the appearance of Lipinella-Millerella sensu stricto assemblage, could be partially equivalent to part of the late Baschkirian of the Russian Platform. Should this be correct, the zone would straddle the Namurian-Westphalian boundary (Gordon, 1964). However, the upper part of the late Baschkirian contains Profusulinella, whereas in Zone 22 this fusulinid is only known in the Cordillera. The assemblage is known in the basal part of the Pennsylvanian System of Idaho and in the upper part of the Amsden Formation in central and western Wyoming. Zone 20 corresponds to the Morrow Series in the Midcontinent.

Undetermined late Carboniferous foraminiferal faunas

The highest Carboniferous zone identified in this report is Zone 21, recognized by the outburst of Eoschubertella-Pseudostaffella associated with Globivalvulina sensu stricto. The zone is known in the basal part of the lower limestone unit in Yukon and in the upper part of the Amsden Formation of the Wyoming depositional province. It is present in the basal Atoka Series (Middle Pennsylvanian) of the American Midcontinent.

No post-Atoka microfauna is reported here from the Wahoo Limestone, but no samples from the upper member of the formation have been studied. The upper member is present in the upper 230 feet or so of the Echooka River sequence; it thickens southeastward to Wahoo Lake, where it is more than 500 feet thick (Brosgé and others, 1962). It is possible that more detailed geologic studies will reveal younger Pennsylvanian faunas in these thicker sequences of the Wahoo Limestone.

Summary of foraminiferal zonation

The study of the Carboniferous foraminiferal succession in Alaska is of particular importance as it ties the Eurasiatic Carboniferous zonation to the American Midcontinent standard succession. Such zonation, although still based on insufficient data, appears to be fairly consistent along the Cordilleran axis and is easily integrated with the Siberian and Russian zonations (Mamet, 1968b).

In contrast, serious discrepancies are encountered when comparing these results with conodont zonation. For instance, Austin (1968) has recently suggested that the Burlington Limestone of the Midcontinent would extend as high as the early Visean Zone 11 of Europe, and that the top of the Burlington, the Keokuk Limestone, the Salem Limestone, and the basal part of the St. Louis Limestone should only be equivalent to one and a half standard Carboniferous zones (upper Zone 11 and Zone 12). This correlation is not substantiated by foraminifers, which indicate that the top of the Burlington belongs to the top of the middle Tournaisian Zone 7 (Mamet and Skipp, in press), one stage below that indicated by conodonts.

The foraminiferal succession of Zones 7 to 12 appears to be consistent in the Eurasiatic realm and, from Alaska, can be extended all along the Cordilleran axis to the Midcontinent without observing either condensation or inversion. Hence there is not sufficient evidence for parallel heterochronism of the appearance of five foraminiferal families--Biseriamminidae, Tetrataxidae, Archaediscidae, Eostaffellidae, Pseudoendothyridae--and 18 genera that would be much older in Europe than in America appears unwarranted.

Carbonate lithostratigraphy

Carbonates of the Lisburne Group in the Skimo Creek, Shainin Lake, and Itkillik Lake sections in the Endicott Range and the Echooka River section in the Phillip Smith Mountains are predominately open-marine echinoderm-bryozoan wackestones and packstones. Within these sequences there are subordinate amounts of grainstones, lime mudstones, and dolomites (Fig. 4).

Fig. 4 near here.

The basic rock type, echinoderm-bryozoan wackestone and packstone, commonly has large bryozoan fronts and articulated crinoid stems. Murray and Lucia (1967, p. 34) suggest that this kind of rock was deposited essentially where the animals died and is indicative of deposits little influenced by currents.

Bryozoan-echinoderm to echinoderm grainstones, less common in these sections, are composed of well-rounded and sorted fossil fragments. These would suggest carbonates deposited after considerable current reworking.

Fig. 4. Regional biostratigraphic correlation chart and carbonate facies for the Lisburne Group, from Skimo Creek in the central Brooks Range to Egaksrak River in the eastern Brooks Range.

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The dark limestone member of the lower part of the Alapah Limestone (Zone 13) at Shainin Lake and equivalent horizons at Itkillik Lake includes well-developed ooids, algae, echinoderms, and Foraminifera in crossbedded grainstone. The widespread geographic distribution of these oolitic beds within Zone 13 probably reflects the development of a fairly large area of shoaling water and carbonate sands in the central Brooks Range during Meramec time.

Dolomites, also common in these sections, are well developed in the upper part (Zones 14 and 15) of the Skimo Creek and Itkillik Lake sections and at the Shainin Lake section in the dolomite member of the Wachsmuth Limestone (Bowsher and Dutro, 1957; Krynine, Folk, and Rosenfeld, 1950).

Thin-section studies of the dolomites indicate that they were formed by the dolomitization of echinoderm wackestones, packstones, and lime mudstones. Some have good visible porosity (Krynine et al., 1950, pl. 6, Fig. A, B, D).

Field and thin-section studies of the three sequences in the Endicott Range and the Echooka River sequence indicate that the Lisburne Group was deposited in an open marine environment on a subsiding shelf on which carbonate deposition and subsidence were near equilibrium. Similar environments and conditions of carbonate deposition are reported for the Mississippian Kogruk Formation in the DeLong Mountains, western Brooks Range, by Armstrong and Dutro (1969, p. 704).

The Alapah Limestone (Fig. 4), of Meramec and Chester age (Zones 13?, 14 through 19), at the Ikiakpuk Creek, Franklin Mountains section (68A-1) is composed of echinoderm-bryozoan packstone, lime mudstone, and fine-grained dolomite. Within the Alapah Limestone at Ikiakpuk Creek there is a noticeably higher percentage of lime mud than in the Alapah Limestone of the Endicott Mountains. Furthermore, in the Ikiakpuk River section some 1,200 feet above its base (Zones 17, 18), stromatolitic-like structures may indicate deposition in an intertidal environment. Fine-grained dolomites and dolomitic lime mudstones are associated with, and lie below, this zone.

The Alapah Limestone of Chester age (Zones 16 through 19), in the Sadlerochit Mountains as displayed by the Sadlerochit Mountains (68A-3) and Sunset Pass (68A-4) sequences, is typified by carbonate rocks that have a higher percentage of lime mud, dolomitic lime mudstone, and fine-grained dolomite. Such rocks are also generally found together with and below a horizon of stromatolitic-like and birdseye sedimentary structures (Fig. 4).

The Alapah Limestone in the Franklin and Sadlerochit Mountains probably was deposited in a shallow, partly restricted marine environment, as compared with the deeper, more open marine environment of biostratigraphically comparable beds in the Endicott Mountains.

Field and micropaleontologic studies indicate that carbonate sedimentation in the eastern Brooks Range continued from latest Chester (latest Mississippian) into Morrow (Early Pennsylvanian) time. The beds of latest Chester age (Zone 19) are bryozoan, echinoderm wackestone and packstone, as are the Morrow age (Zone 20) Pennsylvanian carbonates. These younger wackestones and packstones suggest a return to more normal marine circulation.

The carbonate rocks, of Atoka age (Zone 21), range from echinoderm-bryozoan packstones to foraminiferal oolitic grainstones over an extensive area from the Franklin Mountains north across the Sadlerochit Mountains and east to the Egaksrak River (Fig. 4). Apparently this region in Atoka time was covered by a shoaling sea with the development of extensive oolitic carbonate sands. In the sequences that include carbonates of Atoka age, they are overlain disconformably by quartz sandstone of the Sadlerochit Formation.

Correlation anomalies

The foraminiferal zonation provides a highly useful tool for correlation in the Mississippian of northern Alaska. The consistent vertical distribution of assemblage zones parallels similar patterns in the Rocky Mountains of Canada and the northern United States. However, when several fossil groups are used to attempt correlations with the standard American Midcontinent sequence or the type region in western Europe, certain anomalies become evident.

The main divergence of opinion relates to the Wachsmuth Limestone. All lines of biostratigraphic evidence are in essential agreement for the Alapah and Wahoo Limestones. Megafossil assemblages in the lower two members of the Wachsmuth Limestone are more like those of the Burlington Limestone than any other formation in the Midcontinent. According to the foraminiferal zonation worked out by Mamet, such beds should yield a Zone 7 microfauna. Instead, Zones 8 and 9 are identified from the lower part of the Wachsmuth in the Shainin Lake and Itkillik Lake sequences of the central Brooks Range.

Similarly, megafossils from the upper member of the Wachsmuth appear most like those of the Keokuk Limestone of the American Midcontinent standard. These faunas are like those of the Montana-Wyoming region that occur in Zone C_2, which has yielded a Zone 9 microfauna (Sando, Mamet, and Dutro, 1969). However, microfaunas from the upper Wachsmuth are herein assigned to Zone 12 and, possibly, zone 13.

It could be inferred that the predominantly benthonic megafaunas would be more strongly influenced by facies variations and thus might be less reliable as time indicators. Care must be taken in leaping to such a conclusion, however, because most of the early Carboniferous Foraminifera also were probably benthonic organisms. Moreover, serious discrepancies are encountered when comparing foraminiferal conclusions with conodont zonations. For example, Rhodes, Austin, and Druce (1969) have suggested that the Burlington Limestone of the Midcontinent may represent $Tn3_b$ of the Belgian sequence; this unit yields foraminiferal Zone 9. Thus Zones 10-12 may represent all the beds from the basal Keokuk Limestone through the Salem Limestone. This implies that the base of the Visean in Belgium is approximately equivalent to the base of the Keokuk of the Midcontinent sequence. This view is more nearly compatible with the correlations suggested from studies of the Alaskan megafaunas, but raises some questions in the western Cordillera. Clearly, much research into the vertical and geographic ranges of several phyla must yet be undertaken in order to resolve these seemingly irreconcilable points of view.

Location of measured sections, Figure 4

(1) Skimo Creek section. At Simo Creek, central Brooks Range; long 151°57' W., lat 68°17' N.

(2) Shainin Lake section. Along line of traverse for the Lisburne Group, shown by Bowsher and Dutro (1957, pl. 1). Traverse is from North Ridge down and across Sugarloaf Hill.

(3) Itkillik Lake section. Southeast of Itkillik Lake, from crest of mountain to base of section in the Kayak Shale; long 149°57' W., lat 68°20' N.

(4) Echooka River section. Near front of eastern Brooks Range, on the west side of Echooka River; long 147°25' W., lat 69°13' N.

(5) Ikiakpuk Creek section. Franklin Mountains, eastern Brooks Range. U.S. Geological Survey section 68A-1 was measured in the creek bed and banks in sec. 22, T. 1 S., R. 26 E.

(6) Sadlerochit Mountains section. U.S. Geological Survey section 68A-3 was measured along the crest of a ridge in sec. 13, 24, T. 3 N., R. 27 E.

(7) Sunset Pass section. Western end of Sadlerochit Mountains. U.S. Geological Survey section 68A-4 was measured on the crest of a slope which slopes to the north, sec. 7, T. 3 N., R. 32 E.

(8) Egaksrak River section. Along the crest of a ridge sloping south on Aichilik Ridge. U.S. Geological Survey section 68A-5 is in sec. 17, T. 2 N., R. 38 E.

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