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CONTENTS

Paleontology and Depositional Environments: Cambrian of Western North America

A symposium

Contributors of Papers

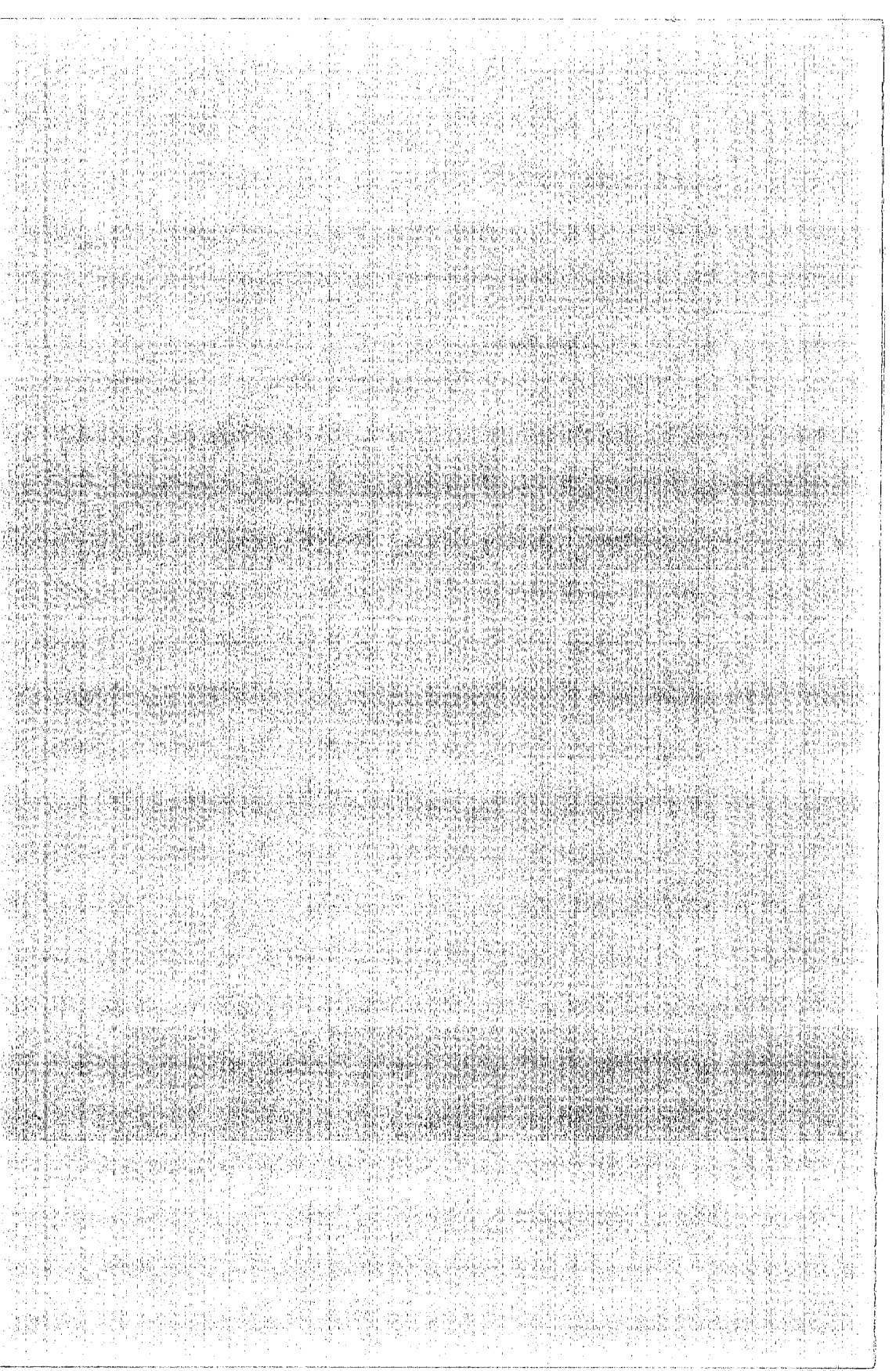
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Extended presentations of some papers presented at a Paleontological Society symposium held in Salt Lake City, Utah, on October 20, 1975.



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Contents

Trilobites in Utah folklore	M. E. Taylor and R. A. Robison	1
Lower Cambrian Stratigraphy, Mackenzie Mountains, Northwestern Canada	W. H. Fritz	7
Depositional Environments of the Lower Cambrian Poleta Formation and Its Stratigraphic Equivalents, California and Nevada	J. N. Moore	23
Biostratigraphic Implications of Trilobite Biofacies: <i>Albertella</i> Zone, Middle Cambrian, Western United States	A. R. Palmer and D. P. Campbell	39
Some Observations on Occurrences of Cambrian Porifera in Western North America and Their Evolution	J. K. Rigby	51
Biostratigraphy and Paleocology of Cambrian Echinoderms from the Rocky Mountains	James Sprinkle	61
Stratigraphic Relationships and Depositional Facies in a Portion of the Middle Cambrian of the Basin and Range Province	J. C. Kepper	75
Middle Cambrian Trilobite Biostratigraphy of the Great Basin	R. A. Robison	93
Lower Dresbachian (Upper Cambrian) Platform-to-Basin Transition in Eastern Nevada and Western Utah: An Evaluation through Lithologic Cycle Correlation	K. C. Lohmann	111
Depositional History of Upper Dresbachian-Lower Franconian Ptercephaliid Biome from West-Central Utah	R. B. Koepnick	123
Outer Shelf Communities and Trophic Groups in the Upper Cambrian of the Great Basin	D. J. McBride	139
An Upper Cambrian Subtidal Blanket Carbonate, Eastern Great Basin	M. J. Brady and A. J. Rowell	153
Brachiopods and Biomerer	A. J. Rowell and M. J. Brady	165
Continental Shelf and Slope Facies in the Upper Cambrian and Lowest Ordovician of Nevada	M. E. Taylor and H. E. Cook	181
Biostratigraphy of the Cambrian and Lowest Ordovician, Bighorn Mountains and Associated Uplifts in Wyoming and Montana	V. E. Kurtz	215

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Middle Cambrian Trilobite Biostratigraphy of the Great Basin

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ABSTRACT.—Trilobites are virtually the only fossils that have been used for zonation of the Middle Cambrian. A single zonal scheme has been gradually developed for most of North America, but that scheme disregards the existence of major biofacies. In the Great Basin two almost mutually exclusive marine biofacies are commonly encountered, and evidently faunal exchange was limited by shoal-water carbonate barriers. A restricted-shelf biofacies is characterized by sparse, low-diversity, endemic, polymeroid faunules, whereas an open-shelf biofacies has common to abundant, high-diversity, mixed endemic and cosmopolitan, polymeroid and agnostoid faunas. Sporadic and in places extensive displacement of Middle Cambrian environments caused intertonguing of lithofacies and associated biofacies, and therefore phyletically unrelated faunas succeed one another in vertical sections. Recent studies have shown that some index taxa have significantly longer stratigraphic ranges than formerly recorded, and agnostoids, which probably were pelagic, have distribution patterns different from those of most polymeroids, which probably were mostly benthic. To more realistically reflect the major faunal patterns and their relationships, three sets of coeval trilobite assemblage zones are proposed to accommodate most of the known Middle Cambrian trilobites of the Great Basin. The zonal sets are based on: 1) restricted-shelf polymeroid genera, 2) open-shelf polymeroid genera, and 3) open-shelf agnostoid species. A total of 13 assemblage-zones, one unnamed zone, and three barren interzones are considered. Correlation of restricted- and open-shelf faunas may be difficult even within the same mountain range in the Great Basin, but agnostoid assemblages of the open-shelf biofacies correlate well with faunas on other continents. Typical polymeroid biomere patterns are not evident in the Middle Cambrian of the Great Basin.

INTRODUCTION

Trilobites are virtually the only fossils that have been used for zonation of the Middle Cambrian. In North America a succession of zonal concepts has been proposed (e.g., Howell and others, 1944; Rasetti, 1951), and they reflect development of knowledge concerning Cambrian trilobites. However, in the establishment of zonal schemes, biostratigraphers have generally disregarded the existence of major intracontinental biofacies. A notable exception is the dual zonation by Lochman-Balk and Wilson (1958). Nevertheless, their set of "extracratonic" zones applies only to Acadian faunas that now, on the basis of plate-tectonic theory, may have been secondarily derived from a European source, and they included all other North American faunas within a single set of zones.

It is my ultimate purpose to define an alternative Middle Cambrian biostratigraphic scheme for the Great Basin that will contain a separate set of zones for each major trilobite biofacies. At this time, space limitations allow only a preliminary outline of three such zonal sets. Faunas are better known for some facies than others. Therefore, as new information becomes available, some of the less-studied units mentioned below may require modification or refinement.

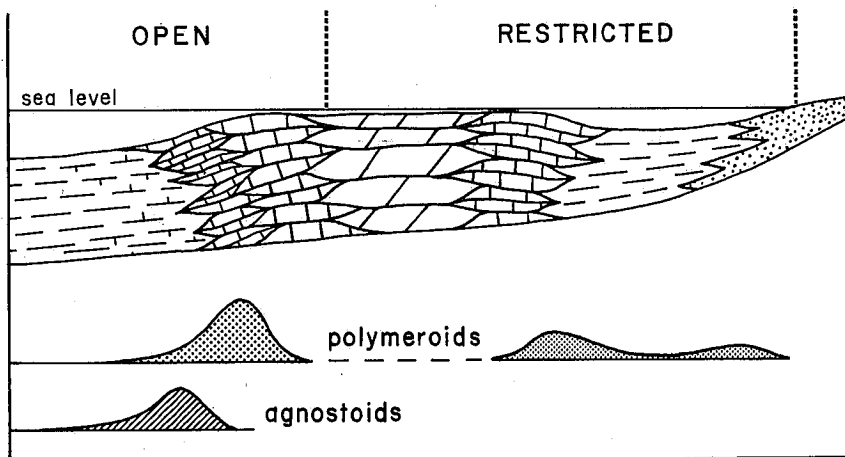
Traditionally the lower and upper boundaries of the Middle Cambrian in North America have been negatively defined by the highest occurrence of olenellid trilobites and by the lowest occurrence of representatives of the

Cedaria Zone. Intercontinental correlation of these boundaries is difficult, and working groups of the Cambrian Subcommittee of the International Stratigraphic Commission are currently evaluating possible boundary-stratotypes and correlation. Recently Daily and Jago (1975) presented evidence for correlating the top of the type Middle Cambrian of Europe (top of *Lejopyge laevigata* Zone) with a horizon well up in the *Cedaria* Zone in North America, and I have collected undescribed fossils from Nevada that tend to support their correlation. However, until a decision is reached by the Cambrian Subcommittee, for purposes of this paper, I continue to recognize the traditional lower and upper boundaries of the Middle Cambrian in North America.

LITHOFACIES AND BIOFACIES

Palmer (1973) has explained the global distribution of major Cambrian trilobite faunas in terms of restricted and unrestricted access to open oceans. The distribution of Middle Cambrian trilobites in the Great Basin is in accord with Palmer's interpretation.

Two almost mutually exclusive marine biofacies are commonly encountered in the Great Basin. Evidently faunal exchange between biotopes was limited by shoal-water carbonate barriers (Text-fig. 1) and changes in environmental parameters such as salinity and temperature. Lithofacies patterns usually show that a carbonate platform of variable extent was flanked by lagoonal muds and near-shore sands on one side, and by outer-shelf muds on the other side. An inner restricted-shelf biofacies is found in limestone and shale, and sometimes sand. Generally it is characterized by sparse, low-diversity, endemic, polymeroid faunules. An outer open-shelf biofacies also is found in limestone and shale, but is characterized by common to abundant, high-diversity, mixed endemic and cosmopolitan, polymeroid and agnostoid faunas. Trilobites tend to be most abundant near the seaward margin of the carbonate lithofacies (Text-fig. 1).



TEXT-FIGURE 1.—Generalized model for lithofacies of the Middle Cambrian shallow shelf, and relative abundance of polymeroid and agnostoid trilobites. Not drawn to scale.

Unnamed *Centropleura*-bearing strata in the Toiyabe Range of central Nevada (Stewart and Palmer, 1967) may contain a third and more seaward biofacies, which possibly represents the deeper shelf or a basinal environment. However, that biofacies is so poorly known in the Middle Cambrian of the Great Basin that it is not considered further at this time.

Sporadic and sometimes extensive displacement of Middle Cambrian environments caused intertonguing of lithofacies and associated biofacies. A cross sectional diagram (Text-fig. 2) from eastern Nevada to central Utah illustrates the intertonguing of lithofacies in western Utah, particularly in the House Range, which was often a boundary area and consequently has an excellent succession of Middle Cambrian faunas. Also, because of the intertonguing of biofacies, phylogenetically unrelated faunas commonly succeed one another in vertical sections.

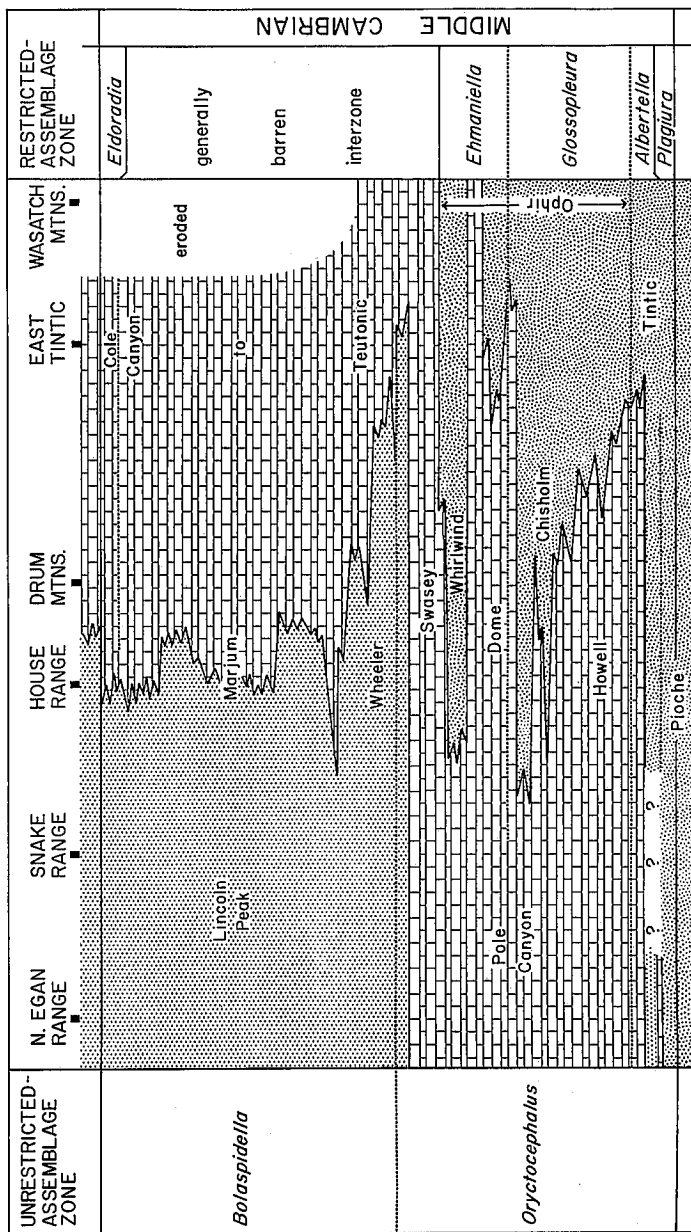
BIOSTRATIGRAPHY

The observed ranges of selected genera that are commonly encountered in the shallow restricted- and open-shelf biofacies of the Great Basin are illustrated in Text-figures 3 and 4. These figures also include supplementary information on reported generic ranges of trilobites from the Canadian Rocky Mountains. The selection of genera is subjective, but an effort has been made to include those forms most likely to be encountered by field geologists. As they become better documented, other genera may need to be added to the charts.

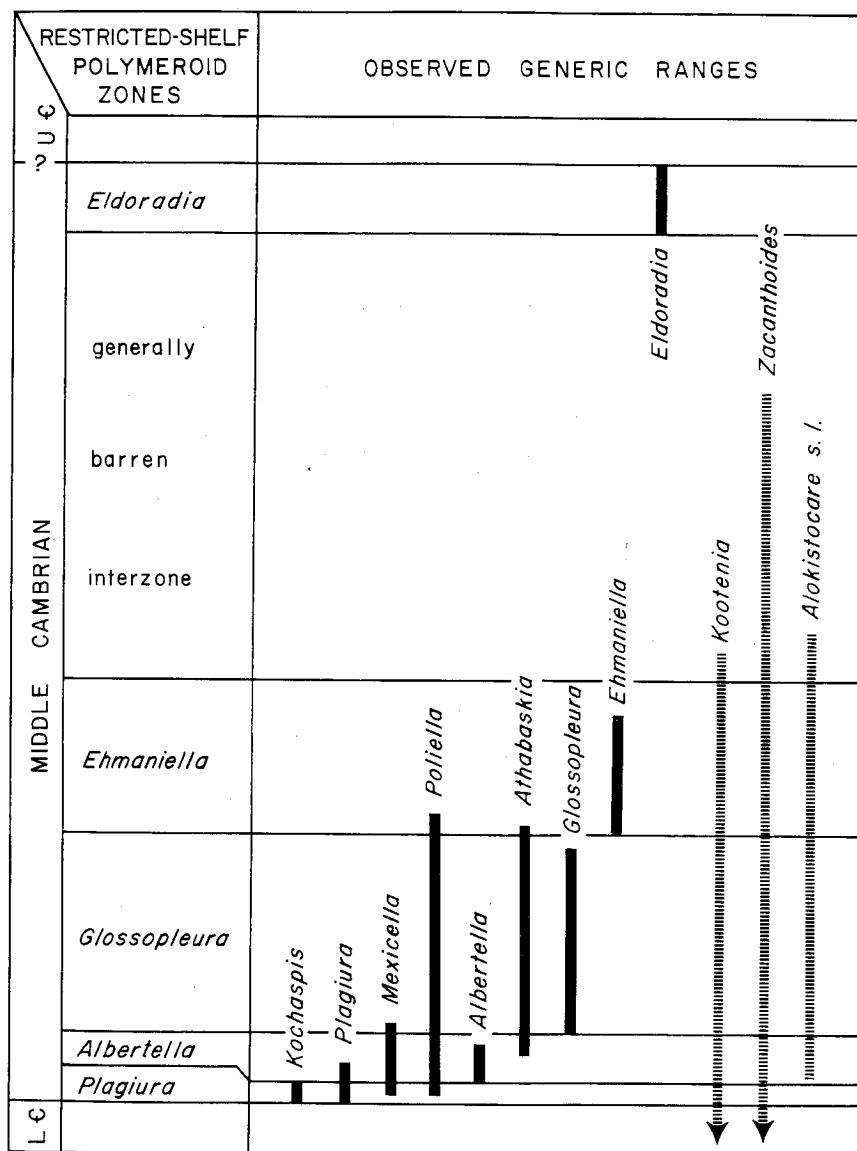
Alokistocare s.l., *Kootenia* and *Zacanthoides* are long ranging and evidently eurytopic. They tend to be most common in the restricted-shelf biofacies, but certain species may be locally abundant in the open-shelf biofacies. For economy of space, the stratigraphic ranges of these three genera are plotted only on Text-figure 3.

On the basis of available biostratigraphic data, both published and unpublished, I propose three coeval sets of zones to accommodate most of the known Middle Cambrian trilobite faunas of the Great Basin. One set of zones is applied to the shallow restricted-shelf biofacies and includes only polymeroid assemblages, which are usually separated in space from other trilobite assemblages. The other two sets of zones are applied to the shallow open-shelf biofacies and are based on polymeroid and agnostoid trilobites. Most polymeroids were probably benthic or nekto-benthic whereas the agnostoids were probably pelagic (Robison, 1972b). Major differences in structure of the hypostoma suggest strong divergence in the food and feeding habits of polymeroids and members of the Agnostina (Robison, 1972a). The two groups also differ markedly in distribution patterns. Geographically, polymeroid genera tend to be provincial whereas many agnostoid genera and species have global distribution within oceanic and open-shelf biofacies. Stratigraphically, except for one eodiscid (*Pagetia*), agnostoid genera were unaffected by factors that caused major replacement in open-shelf polymeroid genera during the middle Middle Cambrian in western North America (Text-fig. 4). For these reasons, the polymeroids and agnostoids are treated with separate zonal nomenclature even though they are commonly associated in the same rocks.

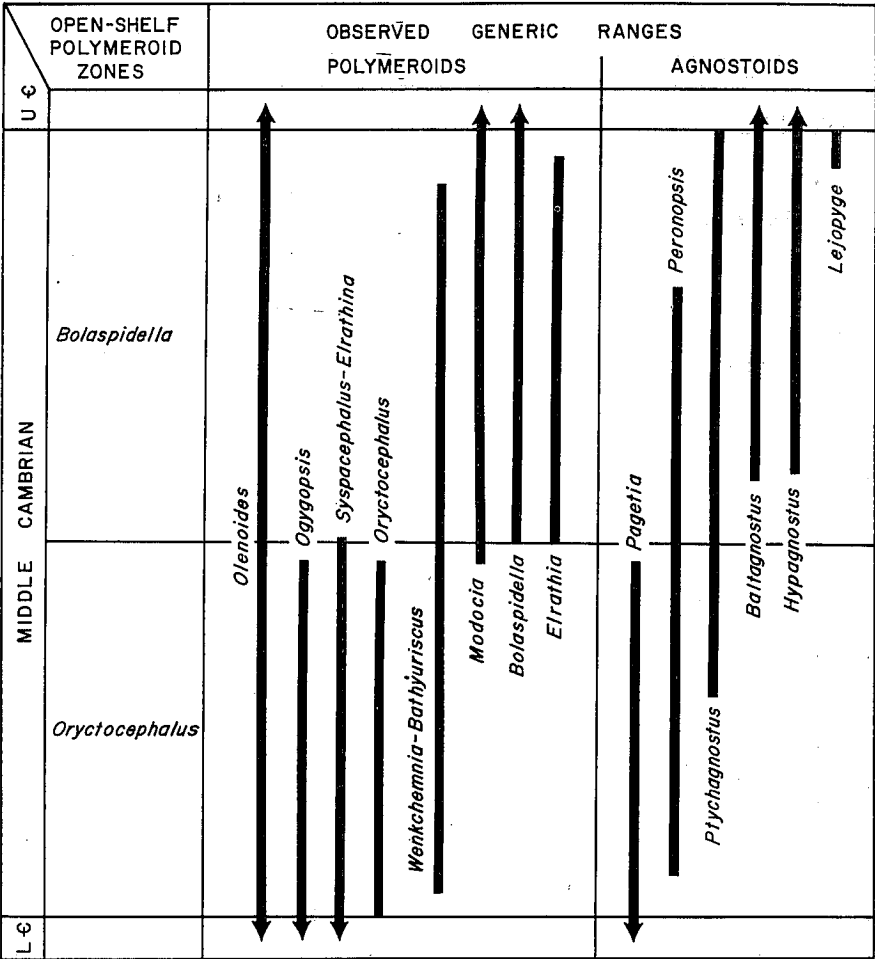
Each zone is characterized by an assemblage of trilobite taxa that has been repeatedly encountered in the same homotaxial position during regional study. The base of each zone is defined by the first appearance of either the taxon for which the zone is named or by an assemblage of fossils characteristic of the zone. Usually the top of each zone is defined by the first appearance of fossils char-



TEXT-FIGURE 2.—Cross-sectional diagram from eastern Nevada (left) to central Utah (right) illustrating the distribution of major Middle Cambrian lithofacies and polymeroid trilobite zones. Inferred time planes are horizontal. Actual Middle Cambrian rock thickness ranges from about 650 m in the east to over 1200 m in the west.



TEXT-FIGURE 3.—Zonation and observed stratigraphic ranges of common polymeroid genera. Solid lines indicate restricted-shelf genera. Broken lines indicate eurytopic genera with composite ranges from restricted- and open-shelf biofacies; known occurrences between *Ehmaniella* and *Eldoradia* zones are mostly from the open-shelf biofacies.



TEXT-FIGURE 4.—Polymeroid zonation and observed stratigraphic ranges of common open-shelf trilobites (see Text-fig. 3 for eurytopic genera).

acteristic of the next overlying zone. However, in accord with the *International Stratigraphic Guide* (International Subcommittee on Stratigraphic Classification, 1976, p. 49), thick barren intervals are designated as "barren interzones."

Restricted-Shelf Assemblage-Zones

In western North America the restricted-shelf biofacies is best known from the Great Basin and the Canadian Rocky Mountains. Within this biofacies the assemblage-zones are generally characterized by a succession of disjunct, low-diversity, endemic, polymeroid faunules. It is common for highly fossiliferous individual beds to be randomly distributed in mostly unfossiliferous sections. Trilobites are rarely articulated and sclerites are commonly broken.

Brief summaries of the restricted-shelf assemblage-zones follow. The relationship of polymeroid zones and major lithofaciés is illustrated by Text-figure 2, and observed generic ranges are plotted on Text-figure 3.

Plagiura Assemblage Zone.—Deiss (1939, p. 1000) apparently was the first to designate a *Plagiura* Zone, and although olenellid trilobites were absent, he considered the unit to be the highest zone of the Lower Cambrian. Following the conclusions by Rasetti (1951, p. 86), and in accord with subsequent usage, I provisionally include the *Plagiura* Assemblage-Zone in the Middle Cambrian. The unit is a synonym of the *Plagiura-Kochaspis* Zone of Rasetti (1951, p. 90-93) and the *Plagiura-Poliella* Faunizone of Lochman-Balk and Wilson (1958, p. 320).

The *Plagiura* Assemblage-Zone is characterized by *Plagiura* and *Kochaspis*. Additional common to rare genera in the Great Basin are *Fieldaspis*, *Mexicella*, *Onchocephalus*, *Poliella*, and *Schistometopus*. Except for *Mexicella*, the same genera have been reported from this interval in the Canadian Rockies (Rasetti, 1951, p. 90-93; 1957). Although *Kootenia* and *Zacanthoides* range from the upper Lower Cambrian to at least the middle Middle Cambrian, they are unknown from this zone. *Alokestocare* s. l. (= *Amecephalus* is part of the *Plagiura* assemblage in Canada.

Faunas of the *Plagiura* Zone are poorly documented in the Great Basin. I have collected undescribed fossils from an interval 15 to 25 m below the top of the "Brigham Quartzite" in Two Mile Canyon near Malad, Idaho, and D. P. Campbell has collected undescribed fossils from the basal two metres of the Tatow Member of the Pioche Formation in the House Range of western Utah. Elements of the assemblage also are known from the Susan Duster Member of the Pioche Shale in the Pioche district, Nevada (Palmer, 1964, p. 26-27), and in the Carrara Formation in southern Nevada and adjacent California (Palmer, 1971, p. 13; Palmer and Halley, in press).

Albertella Assemblage-Zone.—As a name, first for a distinctive fauna (Burling, 1914) and later for a zone (e.g., Deiss, 1939; Howell and others, 1944), *Albertella* has been in common use for over 60 years. In the Great Basin the zone is characterized by *Albertella* and *Mexicella*, as well as new genera being described by Palmer (Palmer and Halley, in press). During the mid-*Albertella* Chronozone, carbonate deposition was greatly reduced, and was even absent from parts of the Great Basin region. Autochthonous associations within single beds indicate that the elimination of carbonate barriers allowed restricted- and open-ocean faunas to intermingle, and may partly account for the unusually high taxonomic diversity that is encountered at some localities (cf., Resser, 1939b; Fritz, 1968; Campbell, 1974).

Albertella faunas are known from the Twin Knobs Formation of southern Idaho and the uppermost Brigham Quartzite and lower to middle Naomi Peak Member of the Twin Knobs Formation in northern Utah (Campbell, 1974). Undescribed representatives are present in the upper half of the Tatow Member of the Pioche Formation at several localities in western Utah (Hintze and Robison, 1975, p. 882-84). Fritz (1968) has described an *Albertella* fauna from the Pioche Shale of eastern Nevada, and Palmer (1971; Palmer and Halley, in press) has documented other occurrences in the Pioche and Carrara formations of southern Nevada and adjacent California.

Glossopleura Assemblage-Zone.—This is one of the most widely distributed zones in the Middle Cambrian of North America, and at many localities in the

eastern Great Basin the fauna consists predominantly or entirely of *Glossopleura*. Where other trilobite genera are associated, the most common of these are *Alokistocare*, *Athabaskia*, *Kootenia*, and *Zacanthoides*. A detailed biostratigraphic analysis of the *Glossopleura* Zone has not been published for any section in the Great Basin; however, unpublished investigations have been made by Oldroyd (1973) and Campbell (1974).

Ehmaniella Assemblage-Zone.—This unit is represented throughout most of the eastern Great Basin and is usually characterized by low species diversity, commonly one species per bed, but great abundance of disarticulated individuals. Fossiliferous beds are usually sparse and irregularly distributed. The total fauna is largely undescribed, but appears to be dominated by species of *Ehmaniella*. A few collections contain *Kootenia*, undetermined simple ptychoparioids, and lingulide brachiopods. One of the most diverse faunas, which has been collected from oolitic beds in the lower Dome Limestone of the House Range, contains *Ehmaniella*, *Kootenia*, *Poliella*, *Spencella*?, two undetermined ptychoparioid genera, the molluscs *Helcionella* and *Scenella*, and rare articulate and inarticulate brachiopods.

In 1939, Deiss (p. 1005) tentatively designated an *Ehmaniella* Zone in the upper Stephen Formation of the Canadian Rockies, and based on numerical analysis Schwimmer (1975) named an *Ehmaniella* Zone in Montana and Wyoming. Neither author discussed boundaries or characters of their zones, and therefore the zonal concept presented here is essentially new. The lowest observed occurrences of *Ehmaniella*, which define the base of the *Ehmaniella* Assemblage-Zone in the Great Basin, are in the basal beds of the Ute Formation of northern Utah (Campbell, 1974) and about 25 m above the base of the Dome Limestone of the House Range in western Utah (Oldroyd, 1973). *Ehmaniella* faunules tend to be most prevalent in the following formations in the eastern Great Basin: Ute, upper shale member of the Ophir, Whirlwind, and Burnt Canyon Member of the Highland Peak. Previous reports of *Ehmaniella* in the Spence Shale. (Resser, 1939a) and "*Ptarmigania strata*" (Resser, 1939b) appear to be in error.

Although *Ehmaniella* is known only from restricted-shelf facies in the Great Basin, two species have been reported from what are here interpreted to be open-shelf facies in the Canadian Rockies. Rasetti (1951, p. 103-5) indicated that *E. burgessensis* and *E. waptaensis* are rare elements in his *Pagetia bootes* faunule in the lower Stephen Formation (=Burgess Shale), and the former species provides the name for his *E. burgessensis* fauna from high in the Stephen. Additional stratigraphic data on these species has been provided by Fritz (1971).

Ehmaniella to Eldoradia barren interzone.—This interval includes most of the upper half of the Middle Cambrian in the eastern Great Basin (cf. Text-figs. 2 and 3). It consists of 600 to 700 m of predominantly limestone and dolomite, and generally lacks metazoan body fossils. Kepper (1975) concluded that many of these carbonate rocks are of algal origin and were formed in a broad region of peritidal to subtidal environments. Unstable or unfavorable levels of salinity and temperature may account for the general lack of trilobites and other metazoa.

Eldoradia Assemblage-Zone.—This is a new zone that is mainly represented in the eastern Great Basin, particularly in the Fish Springs Member of the Trippe Limestone, but it also is present in the Eureka district of central Nevada (Hintze and Robison, 1975, p. 889). The fauna is usually found in shaly

limestone interbedded with algal boundstone and flat-pebble limestone conglomerate. These rock types, in combination with desiccation cracks, small channel-fill deposits and other features, suggest broad tidal-flat environments. Generally only a single species, *Eldoradia prospectensis*, is encountered. It occurs sporadically, but disarticulated sclerites may be concentrated in small lenses and channel-fill deposits.

The fauna of the *Eldoradia* Zone is mostly undescribed, and in addition to *Eldoradia prospectensis* it rarely includes species of *Asaphiscus*, *Blainia*, *Bolaspidella*, and *Modocia*. These additional genera are more typical of the open-shelf biofacies in the Great Basin and are generally associated with *Eldoradia* only in the more seaward or transitional parts of the restricted biofacies. However, in other areas such as Montana, Arizona, and Texas, *Bolaspidella* and *Modocia* are found in rocks that may prove to represent restricted-shelf environments.

Regional facies relations, trace fossils, and sedimentary criteria together indicate that the habitat of *Eldoradia* in the Clarks Spring Member of the Secret Canyon Shale near Eureka, Nevada, may have been in an unusual area of local shoaling on the outer part of the Cambrian shelf.

In much of central and western Utah the *Eldoradia* Zone is succeeded by a thick barren interzone below a fairly widespread *Crepicephalus* fauna in the Upper Cambrian. Therefore, as noted by Hintze (1974), the shaly *Eldoradia*-bearing Fish Springs Member, which has an average thickness of about 30 m, is an important marker unit near the middle of an approximately 1000-metre interval of mostly barren carbonates.

Open-Shelf Polymeroid Assemblage-Zones

The open-shelf biofacies is generally characterized by a succession of more continuously fossiliferous strata than is the restricted-shelf biofacies. A shallower, higher energy subfacies, near the seaward margin of the carbonate platform, tends to have high taxonomic diversity, and the trilobites are usually disarticulated and are commonly preserved in biosparites. A deeper, lower energy, more seaward subfacies tends to have lower taxonomic diversity, and the trilobites may be articulated and are commonly preserved in laminated fine-grained rocks. Palmer and Campbell (1975, also see paper in this volume) have described the relations of trilobite faunas in these two subfacies, which they refer to as the "zacanthoidid and *Ogygopsis* biofacies," in an interval that temporally correlates with the *Albertella* Assemblage-Zone of the restricted-shelf facies.

On the average, trilobite genera that are common in the open-shelf biofacies have longer temporal ranges than genera that are common in the restricted-shelf biofacies (cf. Text-figs. 3 and 4), and this may reflect the influence of more stable environments and trophic resources on the open shelf. The polymeroids fall naturally into two generic assemblages. For the oldest group I propose the new name *Oryctocephalus* Assemblage-Zone, and the youngest group fits a modified concept of the previously defined *Bolaspidella* Assemblage-Zone (Robison, 1964a, c).

Oryctocephalus Assemblage-Zone.—Many genera previously assigned to the *Bathyriscus-Elrathina* Assemblage-Zone are included in this new zone, which is erected because of taxonomic problems with both *Bathyriscus* and *Elrathina*, and because of significant modification of concept from that previously applied

to the *Bathyriscus-Elrathina* Zone. *Wenckhemnia* and *Bathyriscus* appear to represent opposite ends of an evolutionary continuum and *Bathyriscus* probably should be regarded as a senior synonym of *Wenckhemnia*. If that synonymy is accepted, *Bathyriscus* has an observed range through most of the Middle Cambrian. Furthermore, because it is at least as common, if not more common, in the overlying *Bolaspidella* Zone, it is not appropriate to continue to use the name *Bathyriscus* in zonal nomenclature. *Elrathina* probably should be regarded as a junior synonym of *Syspacephalus*, which has been previously used to designate an upper Lower Cambrian zone (Howell and others, 1944). In view of these problems, which I intend to discuss in more detail in a separate paper, *Bathyriscus-Elrathina* is abandoned as a zone name and *Oryctocephalus* is proposed as a partial substitute that includes a greater geologic interval but is restricted to shallow outer-shelf biofacies.

Among polymeroids commonly encountered in the *Oryctocephalus* Zone are *Alokistocare*, *Bathyriscus* (= *Wenckhemnia*), *Kootenia*, *Ogygopsis*, *Olenoides*, *Oryctocephalus*, *Syspacephalus* (= *Elrathina*), and *Zacanthoides*. Although *Kootenia*, *Ogygopsis*, *Olenoides*, *Syspacephalus*, and *Zacanthoides* all range from the Lower Cambrian into the *Oryctocephalus* Zone, the assemblage of lower Middle Cambrian genera differs markedly from older faunas by the absence of *Bonnia* and olenellids and by the appearance of *Alokistocare*, *Bathyriscus*, and *Oryctocephalus*. A large number of additional genera are found in the *Oryctocephalus* Zone, but available data is inadequate for meaningful analysis of ranges at this time. However, with more information, I expect that many of these genera and their species will prove to be useful biostratigraphic indices and a much more refined zonation will be possible.

A single section with a continuous succession of *Oryctocephalus* faunas is not known. Nevertheless, a fairly complete sequence can be pieced together from the Great Basin and the Canadian Rockies. The oldest representatives are in the middle Carrara Formation of southern Nevada (Palmer and Halley, in press) and in the lower and middle Mount Whyte Formation in Canada (Rasetti, 1951, p. 87-90). A slightly younger fauna is rather widespread in southern Idaho and northern Utah (uppermost Twin Knobs Formation and Spence Tongue of Lead Bell Shale; Campbell, 1974), western Utah (undifferentiated unit in the lower Abercrombie Formation in Deep Creek Range), eastern Nevada (undifferentiated unit in Pioche Shale of Fritz, 1968), and in southern Nevada and adjacent California (parts of Carrara Formation of Palmer and Halley, in press). An intermediate fauna (*Ogygopsis klotzi* and *Pagetia bootes* faunules of Rasetti, 1951, p. 101-104) is found in the Stephen Formation in Canada, and the uppermost faunas, known from many undescribed collections, are rather widely distributed in central and eastern Nevada (upper 1-2 m of Pole Canyon Limestone and basal Geddes Formation) and western Utah (upper 1-2 m of Swasey Limestone and basal one-fifth of Wheeler Formation). These uppermost faunas in the Drum Mountains of western Utah have been described in unpublished studies by Randolph (1973) and White (1973).

The agnostoids *Pagetia* and *Peronopsis* are commonly associated with all but about the lowermost one-fifth of the *Oryctocephalus* fauna.

Bolaspidella Assemblage-Zone.—The concept of this zone, which has been previously discussed (Robison, 1964a, b), is here modified to exclude agnostoid trilobites. The zone is well developed in the central part of the Great

Basin and extends through approximately the upper half of the Middle Cambrian. Representative faunas commence about 27 m above the base of the Wheeler Shale and range into the basal Weeks Formation in the House Range of western Utah (Robison, 1964a, 1971). Characteristic genera are *Bath-yuriscus*, *Bolaspidea*, *Elrathia*, *Modocia*, and *Olenoides*. Less common polymeroids are *Asaphiscus*, *Brachyaspion*, *Semisphaerocephalus*, and *Spencella*. Several other genera are more rarely encountered, and associated agnostoids tend to be common to abundant.

Three subzones were defined in the House Range (Robison, 1964a), but subsequent study has shown that only the *Lejopyge calva* Subzone can be recognized on a regional scale, and the characteristic taxa of that unit here are transferred to the agnostoid zonation.

Open-Shelf Agnostoid Assemblage-Zones

Many agnostoid species have distinctive morphology, cosmopolitan distribution, and relatively short stratigraphic ranges. Therefore, the zones of this set are based on assemblages of species rather than assemblages of genera as in the zonal sets for polymeroids.

The eodiscids currently are classified with the Agnostida (e.g., Harrington and others, 1959), but may deserve recognition as a separate order. In features such as hypostomal structure, lack of basal lobes, and retention of an articulating half ring on the anterior thoracic segment, the Eodiscina show greater similarity to polymeroids than to members of the Agnostina. It is perhaps significant that *Pagetia*, which is the only eodiscid known from the Middle Cambrian of western North America, disappeared near the *Oryctocephalus-Bolaspidea* boundary along with several polymeroid genera (Text-fig. 4). Because of insufficient study and probable differences in mode of life, species of *Pagetia* are not used as guide fossils in this zonal scheme. However, further investigation may well demonstrate a significant biostratigraphic value for these species in the lower half of the Middle Cambrian in the Great Basin.

Since Westergård's (1946) monographic study, the Middle Cambrian of Scandinavia has been mostly zoned with agnostoid species, and has come to be recognized as a standard for world reference. Some of the same agnostoid zones can be recognized in the Great Basin. A few species have longer relative stratigraphic ranges in the Great Basin than in Scandinavia, but thus far no evidence has been found that indicates a lack of homotaxial succession for those species common to both provinces. The few polymeroids previously used for zonation in Scandinavia are unknown in North America, and the zonal scheme used in this section differs from Westergård's because it is based entirely on assemblages of agnostoid species. Furthermore, Westergård's concept of zones is not explicitly described and the boundaries of his zones are not necessarily based on first appearances of species. The sequence of agnostoid zones for the Great Basin is given in Text-figure 5 and descriptions follow below. Where appropriate, previously defined or revised zonal names are used, and two new zonal names, *Peronopsis bonnerensis* and *Ptychagnostus praecurrens*, are proposed.

Peronopsis bonnerensis Assemblage-Zone.—In this new zone *P. bonnerensis* (= *P. lautus*) is commonly associated with *Peronopsis brighamensis* and various species of *Pagetia*. The zone is present in northern Idaho (Lakeview Limestone), southern Idaho and northern Utah (uppermost Twin Knobs Formation and

	Lochman-Balk & Wilson 1958	PROPOSED ZONES - GREAT BASIN		
		Restricted-shelf polymeroids	Open-shelf	
			polymeroids	agnostoids
MIDDLE CAMBRIAN	<i>Bolaspidella</i>	<i>Eldoradia</i>	<i>Bolaspidella</i>	<i>Lejopyge calva</i>
		barren interzone		unnamed
				<i>Ptychagnostus punctuosus</i>
	<i>Bathyriscus-Elrathina</i>	<i>Ehmaniella</i>	<i>Oryctocephalus</i>	<i>Ptychagnostus atavus</i>
				<i>Ptych. gibbus</i>
	<i>Glossopleura</i>	<i>Glossopleura</i>		barren interzone
<i>Albertella</i>	<i>Albertella</i> →	<i>Ptych. praecur.</i>		
<i>Plagiura-Poliella</i>	<i>Plagiura</i> ←	barren interzone		
			<i>Peronopsis bonnerensis</i>	

TEXT-FIGURE 5.—Inferred chronocorrelation of zones from Lochman-Balk and Wilson (1958) and this paper. *Ptychagnostus praecurrens* Zone is presently known only from the Canadian Rocky Mountains.

Spence Tongue of Lead Bell Shale), western Utah (lower Abercrombie Formation), and southern Nevada (Carrara Formation; Palmer and Halley, in press).

P. bonnerensis is the oldest known representative of the Agnostina in western North America. However, older species of *Peronopsis* have been described from the upper Lower Cambrian in the eastern United States (Rasetti and Theokritoff, 1967).

Peronopsis bonnerensis to *Ptychagnostus praecurrens barren interzone*.—The open-shelf agnostoid biofacies is unknown in the Great Basin in an interval that corresponds to the middle and upper *Glossopleura* Zone of the restricted-shelf facies. This is apparently the result of regional expansion of restricted-shelf environments at the expense of open-shelf environments.

Ptychagnostus praecurrens Assemblage-Zone.—The species for which this new zone is named has been reported from Sweden, Siberia, British Columbia, and may be present in Norway and England. The open-shelf facies is unknown from this interval in the Great Basin. However, *P. praecurrens* (= *Triplagnostus burgessensis*), which is the ancestral species of *Ptychagnostus*, is present in the Burgess Shale Member of the Stephen Formation in British Columbia (Rasetti, 1951, p. 136-37), and is the basis for recognition of this zone in western North America. It is associated with *Peronopsis montis* and *Peronopsis columbiensis* (Fritz, 1971, fig. 5).

The *P. praecurrens* Zone in Canada correlates with the *Paradoxides pinus* Zone of Westergård (1946) in Sweden. *P. praecurrens* first appears and is most common in the *P. pinus* Zone and ranges upward into the *Ptychagnostus gibbus* Zone in Sweden, but it is not known to occur in the *P. gibbus* Zone of North America.

Ptychagnostus praecurrens to *Ptychagnostus gibbus barren interzone*.—Regional expansion of carbonate lithofacies is indicated in an interval that includes the Dome through Swasey Formations and some equivalent units in the Great Basin (see Text-fig. 2). A few, either biostratigraphically nondiagnostic or new agnostoids, have been collected from the uppermost metre of the Swasey Limestone at a few localities in western Utah, but otherwise the interval appears to be barren of agnostoids.

Ptychagnostus gibbus Assemblage-Zone.—Westergård (1946) developed the concept of this zone in Sweden, and its nominate species is cosmopolitan. In addition to Scandinavia, *P. gibbus* has been reported from Australia, England, Poland, Siberia, and North America (New York, Nevada, Utah). In the open-shelf facies of the Great Basin, *P. gibbus* may be common to abundant in the basal beds of the Geddes, Lincoln Peak, Wheeler, and some correlative units. Other agnostoids commonly associated with *P. gibbus* in the Great Basin are *Ptychagnostus intermedius*, *Ptychagnostus seminula*, *Peronopsis fallax*, and *Peronopsis* cf. *P. matthewi*. Less common associates are *Euagnostus opimus*, *Peronopsis gaspensis*, *Peronopsis montis*, and a new species of *Peronopsis* similar to *P. depressa*.

Faunas with *Ptychagnostus intermedius* and *Peronopsis montis* occur in the "black band" of the Eldon Formation in British Columbia (Aitken and others, 1972, p. 14) and the lower Meagher Formation in Montana, and represent the *Ptychagnostus gibbus* Zone in those regions.

Ptychagnostus atavus Assemblage-Zone.—Westergård (1946) designated a "zone of *Tomagnostus fissus* and *Ptychagnostus atavus*" in Sweden. *P. atavus* is cosmopolitan (Scandinavia, England, Newfoundland, western U. S., Australia, China, U. S. S. R.), but except for eastern Newfoundland, *Tomagnostus* is unknown from North America. Therefore, the revised name, *Ptychagnostus atavus* Assemblage-Zone, is proposed for the Great Basin.

In Nevada and Utah *P. atavus* may be common to abundant in the upper four-fifths of the Wheeler, basal Marjum, and correlative units of the open-shelf facies. It is commonly associated with *Peronopsis interstricta* and *Peronopsis fallax* and less commonly with *Peronopsis ferox*, *Peronopsis segmenta*, *Baltagnostus eurypyx*, and *Hypagnostus parvifrons*.

Ptychagnostus punctuosus Assemblage-Zone.—As used here, the base of the *P. punctuosus* Zone is defined on the first appearance of *P. punctuosus affinis*, which in the House Range is about 15 m above the base of the Marjum Formation. This revised zone is probably equivalent to Westergård's (1946) zones of *Hypagnostus parvifrons* and *Ptychagnostus punctuosus*. The former name is abandoned because *H. parvifrons* first appears well down in the *P. atavus* Zone as used in both Scandinavia and the Great Basin. Furthermore, in Utah *H. parvifrons* is known to range through most of the upper half of the Middle Cambrian, and in Scandinavia the zone apparently does not include a distinctive biostratigraphic assemblage.

Both subspecies of *P. punctuosus*, *P. p. affinis* and *P. p. punctuosus* are present in the Great Basin, but are relatively rare. Only a few specimens have been collected in the House Range, Utah, and the northern Egan Range and Eureka district in Nevada. Several other agnostoid species are present in this zone in the Great Basin, but occurrences tend to be sporadic and relative stratigraphic ranges are inadequately known. Some of the more significant species are *Ptychagnostus richmondensis*, *Ptychagnostus hybridus* and *Ptychagnostus nanus*, *Ptychagnostus atavus* ranges 115 m into the base of the *P. punctuosus* Zone in the House Range.

Unnamed zone.—An interval in the upper Marjum Formation and some equivalent units of the Great Basin has a relatively rare agnostoid fauna with mostly long-ranging species such as *Hypagnostus parvifrons* and *Baltagnostus eurypyx*. The interval probably correlates closely with the "Zone of *Ptychagnostus lundgreni* and *Goniagnostus nathorsti*" of Westergård (1946) in Sweden. However, with the exception of *Ptychagnostus nanus* (= *P. lundgreni nanus* of Westergård), none of the species reported from the *P. lundgreni*-*G. nathorsti* Zone of Sweden have been discovered in the Great Basin. I have collected *P. nanus* from isolated outcrops in the House Range, Utah, and in the Eureka district, Nevada, but unfortunately in both instances the stratigraphic position is uncertain. Nevertheless, in the Eureka district *P. nanus* is associated with *P. punctuosus punctuosus*, whereas in Sweden the ranges of those two species are not known to overlap (Westergård, 1946, p. 100). Until more information is available on the faunas of this interval, I prefer to leave the zone unnamed.

Lejopyge calva Assemblage-Zone.—This unit was originally defined as a subzone of the *Bolaspidella* Assemblage-Zone (Robison, 1964a), but is here elevated to zonal rank. *L. calva* has been found in considerable abundance at many localities in the central Great Basin, and Palmer (1968) has recorded its presence in Alaska. In the House Range it has an observed range through the upper 16 m of the Marjum Formation and the lower 28 m of the Weeks Formation. Rarely *L. calva* has been found in association with *Ptychagnostus aculeatus*, *Utagnostus trispinulus* and new species of *Lejopyge*, *Ptychagnostus* and *Hypagnostus*.

Because *P. aculeatus* is cosmopolitan whereas *L. calva* is only known from western North America, *P. aculeatus* might be a preferable name for this zone. However, reports indicate that *P. aculeatus*, although it is a distinctive cosmopolitan species, is a relatively rare faunal element at practically all localities. In the Great Basin only a few specimens have been found in two collections from 1.5 and 3.0 m above the base of member B of the Emigrant Springs Limestone at Patterson Pass, Nevada. Therefore, because of its regional abundance, and also because of its restricted stratigraphic range, *L. calva* is retained as the nominate species for this zone.

CORRELATION

Chronocorrelation of Great Basin trilobite faunas is somewhat of a paradox. On one hand, the cosmopolitan distribution and rapid evolution of many Middle Cambrian agnostoid species allows reasonably confident correlation of faunas from the open-shelf facies of the Great Basin with certain faunas in Australia, Asia and Europe. On the other hand, it may be difficult to correlate faunas of the restricted- and open-shelf facies even within the same mountain range in the Great Basin. For example, *Lejopyge* and *Eldoradia* faunas are

separated in the central and northern House Range by less than 30 km, but their temporal relations have only been approximately determined because of facies changes and the lack of adequate physical and biological bases for precise correlation.

Inferred chronocorrelation of the three proposed zonal sets is illustrated in Text-figure 5. Faunas from some intervals are not well documented and further refinement probably will be possible. Dashed lines indicate an uncertain position for some boundaries, and the arrows indicate some mixing of restricted- and open-shelf faunas during the *Albertella* Chronozone.

The extensive eastward shift of lithofacies in the middle Middle Cambrian (base of *Ptychagnostus gibbus* Zone) coincides with a major change in biofacies patterns in much of the Great Basin (Text-fig. 2). Rather abrupt lithofacies changes can be recognized in other parts of the world at the base of the *P. gibbus* Zone (for example, base of Exsulans Limestone or *Acrothele* Conglomerate in Sweden, base of "black band" of the Eldon Formation in the Canadian Rocky Mountains), and may have resulted from a eustatic rise in sea level. Whatever the cause, pervasive effects of a physical event coupled with the appearance of *P. gibbus* provide an exceptional datum horizon for intercontinental correlation of Cambrian rocks and fossils, and I anticipate that it will prove to be one of the best chronohorizons in the Cambrian System.

BIOMERES

The extensive middle Middle Cambrian shift of lithotopes in the Great Basin was accompanied by immigration of facies faunas of the upper *Oryctocephalus* Zone and was followed by major extinction and replacement of polymeroid genera near the base of the *Bolaspidella* Zone. This faunal change is somewhat similar to that on which biomere boundaries are defined in the Upper Cambrian, and perhaps the factors that caused abrupt and near total discontinuity of polymeroid genera and families in shelf areas during the Late Cambrian were beginning to have effect as early as the middle Middle Cambrian. Nevertheless, several polymeroid genera range into younger rocks, and although only common genera are included in the range charts of Text-figures 3 and 4, they are adequate to demonstrate the absence of typical biomere patterns in the Middle Cambrian of the Great Basin.

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