Paleontology and carbonate petrology across the Marjumiid-Pterocephaliid biomere boundary southwestern Montana

Robert C. Thomas

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PALEONTOLOGY AND CARBONATE PETROLOGY
ACROSS THE
MARJUMIID-PTEROCEPHALIID BIOMERE BOUNDARY
SOUTHWESTERN MONTANA

by

Robert C. Thomas

B.A. Humboldt State University, 1985
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Approved by:

[Signatures]
Chairman, Board of Examiners
Dean, Graduate School

Date 6/26/87
The Upper Cambrian (Dresbachian) Marjumiid-Pterocephaliid trilobite biomere boundary occurs within the upper oolitic member of the Pilgrim Formation in the Bridger Range and Horseshoe Hills, southwestern Montana. Three stratigraphic sections collected at 10 cm intervals across the boundary show that Coosina, Coosella, Pemphigaspis, Tricrepicephalus, and Crepicephalus of the Crepicephalus Zone (Marjumiid biomere) are abruptly succeeded within 5 cm of uniform pelsparite by Glaphyraspis of the Aphelaspis Zone (Pterocephaliid biomere). Cheilocephalus and Aphelaspis, unrelated trilobites of the Aphelaspis Zone appear 40 cm above the boundary indicating that these genera are immigrants and did not originate on the shelf. Blountia nixonensis, an opportunistic species related to genera of the Crepicephalus Zone, appears in the section well above the extinction boundary and was apparently well adapted to the environmental changes that exterminated the remainder of the Crepicephalus Zone fauna.

The upper oolitic member of the Pilgrim Formation consists primarily of interbedded oolite and pelsparite. Digitate stromatolites occur at the top of the member at each locality. These lithologies record shallow water shoal, restricted platform and shallow subtidal to possibly lower intertidal deposition during a shallowing-upward sequence. The biomere boundary occurs within uniform pelsparite and does not coincide with any physical break in carbonate deposition at the boundary. The boundary does, however, occur within a shallowing-upward sequence that precedes a regionally recognized regression at the base of the overlying Dry Creek Shale. Changing environmental conditions during regression may have exterminated the Crepicephalus Zone fauna without leaving any record of the change in the sediments at the boundary.
ACKNOWLEDGMENTS

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Thanks to ranchers Jim Walma and Mark Cosier for access to collecting localities and to Don and Marlene Bastian for their hospitality throughout the summer field season. Field assistance provided by Dan Garcia and Anneliese Ripley added much to the effectiveness and accuracy of the field work. Their energy and interest helped me through the times of fatigue and frustration.

I most sincerely thank my parents for financial support during hard times and for persistent encouragement.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>vi</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>I.  INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>Biomeres</td>
<td>1</td>
</tr>
<tr>
<td>Purpose and Scope</td>
<td>10</td>
</tr>
<tr>
<td>Methods</td>
<td>11</td>
</tr>
<tr>
<td>Depositional Model and Interpretations</td>
<td>16</td>
</tr>
<tr>
<td>Regional Cambrian Stratigraphy</td>
<td>18</td>
</tr>
<tr>
<td>Dresbachian Biostratigraphy of Montana</td>
<td>23</td>
</tr>
<tr>
<td>II. DESCRIPTION AND INTERPRETATION OF ROCK TYPES</td>
<td>28</td>
</tr>
<tr>
<td>Oolitic Rock Type</td>
<td>28</td>
</tr>
<tr>
<td>Peloidal Rock Type</td>
<td>35</td>
</tr>
<tr>
<td>Intraclastic Rock type</td>
<td>44</td>
</tr>
<tr>
<td>Algal Rock Type</td>
<td>51</td>
</tr>
<tr>
<td>III. STRATIGRAPHIC CORRELATIONS</td>
<td>57</td>
</tr>
<tr>
<td>Lithostratigraphic Correlations</td>
<td>57</td>
</tr>
<tr>
<td>Biostratigraphic Correlations</td>
<td>60</td>
</tr>
<tr>
<td>IV. ENVIRONMENTAL SYNTHESIS</td>
<td>73</td>
</tr>
<tr>
<td>V.  MARJUMIID-PTEROCEPHALIID BIOMERE BOUNDARY</td>
<td>78</td>
</tr>
<tr>
<td>REFERENCES CITED</td>
<td>82</td>
</tr>
</tbody>
</table>
APPENDIX ......................................................... 93

A. Measured Sections ....................................... 93

B. Systematic Paleontology .............................. 110

C. Fossil Illustrations (Plates) ......................... 135
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stitt's four stages of a biomere</td>
<td>2</td>
</tr>
<tr>
<td>2. Palmer's original conceptualization of a biomere</td>
<td>4</td>
</tr>
<tr>
<td>3. Documented biomeres</td>
<td>6</td>
</tr>
<tr>
<td>4. Well documented biomere localities</td>
<td>7</td>
</tr>
<tr>
<td>5. Biomere boundary revisions</td>
<td>9</td>
</tr>
<tr>
<td>6. Location map of study area and measured sections</td>
<td>12</td>
</tr>
<tr>
<td>7. Cambrian stratigraphy in Montana</td>
<td>20</td>
</tr>
<tr>
<td>8. Relationship of the three Upper Cambrian biomeres to Cambrian strata in Montana</td>
<td>22</td>
</tr>
<tr>
<td>9. Proposed strato-type stages based on biomeres</td>
<td>25</td>
</tr>
<tr>
<td>10. Stratigraphic ranges for Dresbachian trilobites in Montana</td>
<td>27</td>
</tr>
<tr>
<td>11. Legend for stratigraphic columns</td>
<td>58</td>
</tr>
<tr>
<td>12. Lithostratigraphic correlations</td>
<td>59</td>
</tr>
<tr>
<td>13. Correlation of the biomere boundary between Logan and Nixon Gulch</td>
<td>61</td>
</tr>
<tr>
<td>14. Stratigraphic ranges for trilobites at Logan</td>
<td>63</td>
</tr>
<tr>
<td>15. Stratigraphic ranges for trilobites at Nixon Gulch</td>
<td>66</td>
</tr>
<tr>
<td>16. Stratigraphic ranges for trilobites at Sacajawea Peak</td>
<td>70</td>
</tr>
</tbody>
</table>
17. Block diagram of the environments of deposition ........................................ 74
18. Legend for measured sections .................. 94
19. Stratigraphic ranges for trilobites, brachiopods and gastropods at each section ........................................ 111

PLATE

1. Figure 1 - field photo of the Logan section ............................................... 13
2. Figure 1 - field photo of the Nixon Gulch section ................................ 14
3. Figure 1 - field photo of the Sacajawea Peak section .................................. 15
4. Figure 1 - field photo of the oolitic rock type ........................................ 29
5. Figure 1 - radial pattern in a ooid .......... 32
6. Figure 1 - field photo of the peloidal rock type .................................... 36
7. Figure 1 - photomicrograph of the dolomitic partings .......................... 37
8. Figure 1 - field photo of the intraclastic rock type ............................. 45
9. Figure 1 - photomicrograph of the intraclastic rock type ........................ 47
9. Figure 2 - photomicrograph of the intraclastic rock type ........................ 47

vii
10. Figure 1 - photomicrograph of vadose silt ........................................... 49

10. Figure 2 - photomicrograph of radiaxial fibrous calcite ........................................... 49

11. Figure 1 - field photo of the algal rock type .................................................. 52

11. Figure 2 - photomicrograph of the algal rock type .................................................. 52

12. Figure 1 - field photo of biomere boundary at Logan ........................................... 64

13. Figure 1 - polished slab photo of the biomere boundary at Logan .......................... 65

14. Figure 1 - field photo of biomere boundary at Nixon Gulch .................................. 68

15. Figure 1 - polished slab photo of the biomere boundary at Nixon Gulch .................. 69

16. Aphelaspis Zone trilobites .......................................................... 137

17. Aphelaspis Zone trilobites .......................................................... 139

18. Aphelaspis Zone trilobites .......................................................... 141

19. Aphelaspis Zone and Crepicephalus Zone trilobites ............................................ 143

20. Crepicephalus Zone trilobites .......................................................... 145

21. Crepicephalus Zone trilobites .......................................................... 147
CHAPTER I
INTRODUCTION

BIOMERES

The Late Cambrian trilobite sequence in North America is punctuated by three mass extinction events that define three extinction-bounded biostratigraphic units called biomeres (Palmer, 1965). Allison R. Palmer (1965) first described biomeres from the non-agnostid trilobite sequences in Cambrian shallow water shelf limestones of the Great Basin. A biomere is a sharply bounded biostratigraphic unit representing immigration of trilobite stocks, progressive evolutionary development and diversification of those stocks ending with abrupt extinction (Palmer, 1965). At many localities, these extinctions are not accompanied by apparent physical discontinuities in the sedimentary record, and they may be diachronous (Palmer, 1984).

James Stitt (1971, 1975 and 1977) recognized a repeating pattern of evolution of the non-agnostid trilobite populations of the Pterocephaliid and Ptychaspid biomeres, and established a four-stage evolutionary sequence for each biomere (Fig. 1). Stage 1 trilobites are immigrants characterized by low faunal diversity, wide intraspecific variation and short stratigraphic ranges. Low faunal diversity persists into stage 2, but intraspecific variation
STITT'S FOUR BIOMERE STAGES (1977)

Figure 1. (Modified from Stitt, 1977)

Stage 1: Immigrants (generalists) with low faunal diversity and wide intraspecific variation.

Stage 2: Low faunal diversity continues but intraspecific variation is reduced.

Stage 3: High faunal diversity, low intraspecific variation. Stratigraphic ranges of species are long.

Stage 4: Low faunal diversity, short stratigraphic ranges and coquinoid abundances of one or two species. Stage 4 ends with total extinction of the pre-existing fauna.
is reduced and stratigraphic ranges of individual species are longer than the previous stage. Stage 3 is characterized by high species diversity and low intraspecific variation. The stratigraphic ranges of individual species are long, and new species evolved only as minor adjustments to well adapted trilobite stocks. Stage 4 is characterized by low species diversity, short stratigraphic ranges and coquinoid abundances of one or two species that are members of the established families of the biomere. The end of stage 4 is marked by the total extinction of the pre-existing fauna. This evolutionary sequence is repeated in each biomere and records an iterative pattern of invasion, evolution and extinction. The morphological similarity of successive invaders in stage 1 of each biomere suggests that the immigrants came from similar, slowly evolving lineages, but no record of where the invading trilobites of these lineages came from has been preserved.

Palmer (1965) proposed that the immigrants came from a slowly evolving stock of oceanic trilobites that appeared on the shallow shelf only after the extinction of the established shelf fauna (Fig. 2). Stitt (1975) elaborated on this idea, suggesting that a rapid rise in the thermocline and subsequent temperature drop of the Late
Figure 2. Palmer's (1965) original conceptualization of a biomere. (Modified from Palmer, 1984)
Cambrian epicontinental seas might have killed the highly specialized shelf faunas and instigated a migration of oceanic trilobites adapted to cooler waters. He (1975) argued that in this fashion, the extinction would be slightly diachronous and would leave no recognizable imprint within the sedimentary record. Ludvigsen (1982), on the other hand, argued that biomere extinctions are a response to environmental shifts that brought outer shelf environments over inner shelf environments and therefore coincide with lithological changes in the sedimentary record. In addition, Lochman-Balk (1974) proposed that the extinctions were caused by widespread cooling events that coincide with global regressions at each biomere boundary. Palmer (1982) has even suggested that extraterrestrial impacts may have caused the extinctions.

Since the introduction of the biomere concept, three Late Cambrian biomeres have been recognized and well documented: (1) the Marjumiid biomere, (2) the Pterocephaliid biomere and (3) the Ptychaspid biomere (Fig. 3). At well documented biomere boundaries (Fig. 4), relatively rich assemblages of trilobites, including genera and species of several families, are abruptly overlain by assemblages of new trilobites belonging to different families. These faunal changes rarely coincide with
### DOCUMENTED BIOMERES

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>ZONE</th>
<th>BIOMERE</th>
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</thead>
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<td>Upper</td>
<td>Trempealeauan</td>
<td>Saukia</td>
<td>Ptychaspid Biomere</td>
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<tr>
<td>Cambrian</td>
<td>Franconian</td>
<td>Saratogia</td>
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<td></td>
<td></td>
<td>Taenicephalus</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Elvinia</td>
<td></td>
</tr>
<tr>
<td>Cambrian</td>
<td>Dresbachian</td>
<td>Dunderbergia</td>
<td>Pterocephaliid Biomere</td>
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<td></td>
<td></td>
<td>Aphelaspis</td>
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<td></td>
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<td>Crepicephalus</td>
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<tr>
<td></td>
<td></td>
<td>Cedaria</td>
<td>Marjumiid Biomere</td>
</tr>
<tr>
<td></td>
<td>Middle Camb.</td>
<td>Bolaspidella</td>
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<tr>
<td></td>
<td></td>
<td>Bathyuris.-Elrath.</td>
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</table>

Figure 3. Well documented biomeres and their relationship to Cambrian stages and faunal zones. (Compiled from Sepkoski, 1977 and Palmer, 1984)
Figure 4.

physical discontinuities in the sedimentary record.

Palmer (1979), in an attempt to document the sharpness of a biomere boundary, recollected across the Marjumiid-Pterocephaliid biomere boundary at several localities across the Great Basin. The added detail narrowed the boundary interval to a few centimeters at several localities and brought about a revision in the biostratigraphic placement of the boundary (Fig. 5). According to Palmer (1979), a 10-20 centimeter interval exists where opportunists from the pre-existing fauna occur together with generalists of the new fauna. Palmer interprets this "zone of mixing" as a time of crisis when opportunists from the earlier fauna attempt to adjust to new environmental conditions, while competing with the incoming, more generalized trilobites. He (1979) concluded that the emphasis should be placed on the crisis aspect of biomere boundaries and shifted the base of each biomere downward to include the opportunists Corbinia apopsis, Irvingella major and Coosella perplexa (Fig. 5). The revision redefines Stitt's terminal declining stage (stage 4) as the initial developmental stage of a biomere (stage 1) and makes the trilobite extinctions consistent with major changes in the inarticulate brachiopod and conodont faunas (Rowell and Brady, 1976; Miller, 1978).

The mixed zone is now recognized at many localities in
# PROPOSED BOUNDARY REVISIONS

**North American Assemblage Zones**

<table>
<thead>
<tr>
<th>Missisquoia Zone</th>
<th>Stitt, 1975</th>
<th>Palmer, 1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corbinia apopsis</td>
<td>stage 4</td>
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<tr>
<td>Saukia Zone</td>
<td>stage 3</td>
<td>stage 4</td>
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<tr>
<td>Ellipsocephaloides Zone</td>
<td>stage 2</td>
<td>stage 3</td>
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<tr>
<td></td>
<td><strong>Ptychaspid Biomere</strong></td>
<td><strong>Ptychaspid Biomere</strong></td>
</tr>
<tr>
<td>Saratogia Zone</td>
<td>stage 1</td>
<td>stage 2</td>
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<tr>
<td>Taenicephalus Zone</td>
<td>stage 4</td>
<td>stage 1</td>
</tr>
<tr>
<td>Irvingella major</td>
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<td>Dunderbergia Zone</td>
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<tr>
<td>Prehousia Zone</td>
<td>stage 2</td>
<td>stage 3</td>
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<tr>
<td>Dicanthopyge Zone</td>
<td>stage 3</td>
<td>stage 3</td>
</tr>
<tr>
<td>Aphelaspis Zone</td>
<td>stage 1</td>
<td>stage 2</td>
</tr>
<tr>
<td>Coosella perplexa</td>
<td>stage 2</td>
<td>stage 1</td>
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<tr>
<td>Crepicephalus Zone</td>
<td>Marjumiid Biomere</td>
<td>Marjumiid Biomere</td>
</tr>
</tbody>
</table>

Figure 5. Palmer's (1979) proposed boundary revisions.
North America, including sections across the Marjumiid-Pterocephaliid biomere boundary within the Pilgrim Formation in southwestern Montana (Bonem, 1972). However, previous collections across the boundary in Montana have been very widely spaced and the details, on a centimeter scale, are still unknown.

PURPOSE AND SCOPE

The objectives of this study are to: (1) describe the Marjumiid-Pterocephaliid biomere boundary in southwestern Montana from detailed collections of trilobites, (2) determine if the faunal change coincides with any physical discontinuities or subtle changes in carbonate deposition and (3) evaluate Palmer's (1979) boundary revisions.

Petrography of the carbonate sedimentation and subsequent diagenesis across the boundary, especially with tight biostratigraphic control, was analyzed to determine if the faunal change occurs at a physical discontinuity or subtle change in carbonate sedimentation. The validity of Palmer's boundary revisions was evaluated by determining the extent of the mixed interval at the base of the Aphelaspis Zone in southwestern Montana.
METHODS

Three stratigraphic sections across the Marjumiid-Pterocephaliid biomere boundary were measured in the Bridger Range and Horseshoe Hills in southwestern Montana. The sections are named: (1) Logan, (2) Nixon Gulch and (3) Sacajawea Peak (Fig. 6). Field photographs of each section are illustrated in Plates 1, 2 and 3. Each section was measured and described at 10 cm intervals across the boundary, ending each section at the overlying Dry Creek Shale. Trilobites and hand samples for petrographic analysis were collected both vertically and laterally from each 10 cm interval, but trilobite collections tend to be more widely spaced because of unfossiliferous intervals. Lithostratigraphic and biostratigraphic intervals were correlated between each measured section, noting any lateral and/or vertical change in petrography across the boundary.

Large (2" X 3" and 3" X 4") thin sections of the carbonate rocks were prepared, and the primary and diagenetic fabrics were described and interpreted. Trilobites were identified from published descriptions to species level when possible, and many identifications were reviewed and confirmed by Dr. A. R. Palmer. Many trilobites were exhumed by heating and quenching of fossiliferous samples as suggested by Palmer (Palmer, personal
Figure 6. Location map of study area and measured sections.

1 - Logan
2 - Nixon Gulch
3 - Sacajawea Peak
Figure 1. Field photo of the Logan section.
Figure 1. Field photo of the Nixon Gulch section.
Figure 1. Field photo of the Sacajawea Peak section.
communication, 1986), and several samples were treated with formic acid for brachiopods, although very few brachiopods or other fossils were found.

DEPOSITIONAL MODEL AND INTERPRETATIONS

The upper oolitic member of the Pilgrim Formation represents shallow water shoal, restricted platform and shallow subtidal to possibly lower intertidal deposition along the eastward margin of a stable shelf environment.

Interbedded oolite and pelsparite at the base of each section grades upsection to predominantly pelsparite. A thick sequence of digitate stromatolites occurs at the top of each section and is abruptly overlain by the Dry Creek Shale Member of the Snowy Range Formation.

Oolites probably represent platform-edge shoals similar to those along the western edge of the Great Bahama Bank (Newell et al., 1960; Ball, 1967). Overlying pelsparite intervals were deposited on a moderately restricted platform cratonward of the distal margins of the ooid shoals and thin oolitic interbeds within pelsparites probably represent lobate ooid spillover sheets deposited by migrating shoals. The increase in pelsparite upsection and the abrupt appearance of digitate stromatolites at the top of each section is interpreted to record continued shallowing
upsection to the base of the overlying Dry Creek Shale.

The Marjumiid-Pterocephaliid biomere boundary occurs within uniform pelsparite and does not coincide with any physical discontinuity or subtle change in carbonate deposition. At the boundary, trilobites of the Crepicephalus Zone (Coosina, Coosella, Pemphigaspis, Tricrepicephalus and Crepicephalus) are abruptly overlain by trilobites of the Aphelaspis Zone (Glaphyraspis, Aphelaspis and Cheilocephalus). Coosella perplexa, an opportunistic species related to genera of the Crepicephalus Zone, is mixed with Glaphyraspis of the Aphelaspis Zone for approximately 30 cm above the boundary. Another opportunist, Blountia nixonensis, appears several meters above the boundary and is confined to the algal rock type at each locality. Blountia's persistence into the Aphelaspis Zone well after the extinction indicates that it was well adapted to the environmental changes that exterminated the remainder of the Crepicephalus Zone fauna. The extension of Blountia well into the Aphelaspis Zone, and therefore the extension of the "mixed" or "crisis" interval well into the Aphelaspis Zone, suggests that Palmer's (1979) boundary revisions are valid. Without the revisions, the biomere boundary would be placed nearly 9.0 m above the extinction of most of the Crepicephalus Zone fauna and a long period of
adaptation and diversification of the new fauna would wrongly be included in Stitt's (1975) terminal declining stage 4.

Although the extinction of the *Crepicephalus* Zone fauna does not precisely coincide with a discontinuity surface, the extinction does occur within a shallowing upward sequence within the upper part of the Pilgrim Formation that precedes the regionally recognized Dresbachian-Franconian regression at the base of the overlying Dry Creek Shale (Lochman-Balk, 1970). Changing environmental conditions during regression may have exterminated the *Crepicephalus* Zone fauna without leaving any record of the change in the sediments at the boundary.

REGIONAL CAMBRIAN STRATIGRAPHY

A westward thickening sequence of Middle Cambrian through Upper Cambrian platform carbonates and shales record eastward transgression of the Cambrian epicontinental sea on the subsiding, early Paleozoic, trailing continental margin. Cyclic sedimentary patterns similar to those described by Aitken (1966, 1978, 1981) characterize the Cambrian sequence. Each cycle consists of a lower, shaly half-cycle gradationally overlain by a thick carbonate half-cycle. These cycles are produced by lateral shifts of the inner
detrital, middle carbonate and outer detrital belts (Palmer, 1960) during eustatic sea level fluctuations or changes in the rate of carbonate production (Aitken, 1966).

In western Montana near Philipsburg, the Cambrian reaches a maximum thickness of 2200 ft. (Hanson, 1952) and thins to approximately 900 ft. to the east in the Little Rocky Mountains. Cambrian positive cratonic features include "Montania" in northwestern Montana and "The Skull Canyon Uplift" along the Idaho-Montana border west of Yellowstone Park. Sepkoski (1977) suggests that "The Skull Canyon Uplift" may have influenced deposition of the upper oolitic member of the Pilgrim Formation through Dresbachian uplift, erosion and deposition of thick quartz sands near the top of the Pilgrim Formation in southwestern Montana. He (1977) also attributes the appearance of stromatolites at the top of the Pilgrim Formation in southwestern Montana to Dresbachian uplift and the establishment of intertidal flats.

Middle and Upper Cambrian platform carbonates and shales conformably overlie the lower Middle Cambrian Flathead Sandstone in southwestern Montana (Fig. 7). Cambrian strata above the Flathead Sandstone consists of alternating shales (Wolsey Shale, Park Shale and Dry Creek Shale Member of the Snowy Range Formation) and limestones
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Figure 7. Cambrian stratigraphy in Montana. (Modified from Hanson, 1952)
(Meagher Formation, Pilgrim Formation and Snowy Range Formation). The Marjumiid-Pterocephaliid biomere boundary occurs within the Pilgrim Formation in southwestern Montana. The relationship of the three Upper Cambrian biomeres to Cambrian strata in southwestern Montana is illustrated in Figure 8.

The Pilgrim Formation and its stratigraphic equivalents (Hasmark Formation to the west and Dunoir Formation in western Wyoming) vary in both thickness and lithology. Variations in thickness reflect a possible intra-Cambrian unconformity produced by "The Skull Canyon Uplift" and post-Cambrian-pre-Upper Devonian erosion produced by the Central Montana Uplift (Lochman and Duncan, 1944; Sepkoski, 1977).

The Pilgrim Formation consists primarily of oolitic limestone, laminated pelsparite, shale, various stromatolitic carbonates and intra-formational conglomerate beds. These dominantly carbonate lithologies pass laterally to massive dolomite to the north (Devils Glen Dolomite) and west (Hasmark Formation) and flat-laminated quartz siltstone and peloidal limestone to the southeast (Gros Ventre Formation) in Wyoming (Sepkoski, 1977).

Within the study area, the Pilgrim Formation consists of three well-defined informal members: (1) the lower oolitic member, (2) the middle member and (3) the upper
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Figure 8. Relationship of the three Upper Cambrian biomeres to Cambrian strata in southwestern Montana. (Compiled from Grant, 1965 and Sepkoski, 1977)
oolitic member (Sepkoski, 1977). The lower oolitic member is a thick-bedded limestone (3 to 15 m thick) composed primarily of oosparite with a few non-oolitic interbeds. The middle member is a less resistant unit, 30 to 60 m thick, composed of laminated limestone or dolomite interbedded with quartz siltstone in the west and intercalated shale, limestone and flat-pebble conglomerate in the east. The upper oolitic member is a thick-bedded to massive limestone (0 to 75 m thick), composed primarily of oolite that is interbedded with pelsparite and intrasparite near the top of the member. The member is capped by a thick (2 to 8 m) sequence of digitate stromatolites at several localities in southwestern Montana, and the Marjumiid-Pterocephaliid biomere boundary occurs within the upper part of this member.

DRESBACHIAN BIOSTRATIGRAPHY OF MONTANA

Upper Cambrian strata of North America is currently divided into three stages and eight biostratigraphic zones (refer to Fig. 3). The boundaries of the three Upper Cambrian stages coincide with established zonal boundaries, but do not coincide with major faunal extinctions (biomeres) recognized throughout North America. This inconsistency has
recently prompted Ludvigsen and Westrop (1985, 1987) to propose a succession of new strato-type defined stages based on biomeres (Fig. 9). Opposition to the proposed stages has been strong (Geology Forum, 1985) and the problem is currently unresolved. In this study, the traditional Upper Cambrian stages are used and biomeres are treated as unique biostratigraphic units that are not synonymous with stages.

The Dresbachian stage consists of three faunal zones in southwestern Montana: (1) Cedaria, (2) Crepicephalus and (3) Aphelaspis Zones (refer to Fig. 3). The Dunderbergia Zone has been recognized only in the outer middle carbonate belt of the Great Basin (Palmer, 1960) and is apparently absent in southwestern Montana and elsewhere (Grant, 1965; Bonem, 1972; Lochman-Balk, 1974). Traditionally, the absence of the Dunderbergia Zone has been explained by nondeposition or erosion during a Late Dresbachian regression (Lochman-Balk and Wilson, 1958). Sepkoski (1977), however, proposed that the Dunderbergia Zone may be a biofacies restricted to the margins of the craton rather than a regional faunal assemblage. He based the proposal on the discovery of Aphelaspis Zone trilobites in the lower Dry Creek Shale in southwestern Montana (Shaw, 1956; Grant, 1965) and noted that an unconformity does not exist at or near the last appearance of trilobites of the Aphelaspis
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Figure 9. Strato-type stages proposed by Ludvigsen and Westrop (1985). (Modified from Ludvigsen and Westrop, 1985)
The Cedaria, Crepicephalus and Aphelaspis Zones occur in the Pilgrim Formation in southwestern Montana (Lochman and Duncan, 1944; Bonem, 1972). The stratigraphic ranges for Dresbachian trilobites in the Pilgrim Formation in southwestern Montana (Fig. 10) shows that the transition between the Cedaria and Crepicephalus Zones is gradational while the Crepicephalus-Aphelaspis boundary is sharp. The abrupt change in fauna at the Crepicephalus-Aphelaspis boundary reflects the extinction of most of the Crepicephalus Zone fauna at the Marjumiid-Pterocephaliid biomere boundary. Mixed faunas consisting of Aphelaspis and species related to genera of the Crepicephalus Zone occur near the base of the Aphelaspis Zone in southwestern Montana (Bonem, 1972). These mixed faunas are similar to those described by Palmer (1954) from Texas and by Rasetti (1965) from Tennessee.
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Figure 10. Stratigraphic ranges for Dresbachian trilobites in the Pilgrim Formation in Montana. (Compiled from Lochman and Duncan, 1944; Lochman and Hu, 1962; Lochman, 1950, and Sepkoski, 1977)
CHAPTER II
DESCRIPTION AND INTERPRETATION OF ROCK TYPES

The primary rock types in the upper oolitic member of the Pilgrim Formation are: (1) the oolitic rock type, (2) the peloidal rock type, (3) the intraclastic rock type and (4) the algal rock type.

Rock type descriptions are based on field observations and petrographic analysis of 151 thin sections. The descriptions include composition, morphology, and distribution of grains, cements and diagenetic fabrics. Folk's (1959) classification for carbonate rocks is used in preference to Dunham's (1962) classification because I feel Folk's classification focuses more on grain composition. Rock types are based on descriptions of primary fabrics and diagenesis while interpretations are based on stratigraphic relationships, analogies with modern carbonate environments and comparisons to similar paleoenvironments.

OOLITIC ROCK TYPE
Description:

Primary Fabrics. The oolitic rock type (Plate 4) consists of well-sorted, grain supported, mottled oosparite in tabular beds .50 to 1.0 m thick. Ooids are spherical and
Figure 1. Field photo of the oolitic rock type.

Figure 2. Photomicrograph of the oolitic rock type.
range from .30 to .50 mm in diameter. The nuclei of well preserved ooids are composed of fine-grained micritic peloids, trilobite and eocrinoid bioclasts and broken ooids. Ooids with bioclastic cores are commonly kidney-shaped. Quartz grains, which constitute less than 3% of this rock type, never act as nuclei.

Other common carbonate grains include compound ooids, oolitic grapestone aggregates and intraclasts of cemented oosparite. The oosparite intraclasts range from .20 to 4.0 cm in length and are generally ellipsoidal with well rounded margins. Oosparite intraclasts are restricted to the oolitic rock type. Asymmetric and broken ooids are abundant near the top of the Pilgrim Formation at each locality.

Trilobites and eocrinoids are the dominant skeletal grains in oosparite, but rarely constitute more than 20% of the allochems. Most of the bioclasts are broken and randomly dispersed.

Rare burrows, .30 to .70 mm in diameter, occur in small patches of micrite within the oosparite. The burrows have compaction rims of micrite, and carbonate grains at the bases of the burrows are loosely packed and overlain by sparry calcite, producing geopetal structures.

**Diagenesis.** Ooids display a variety of alteration fabrics ranging from ooids with well preserved lamellae to
oolids with no preserved internal structure. This alteration imparts a distinctive mottling to the oolite beds, typical of the upper oolitic member in the region (Peale, 1893; Brown, 1959 and Sepkoski, 1977).

Well preserved ooids have distinct internal lamellae with superimposed patterns of radial fibrous calcite crystals (Plate 5). The radial fibrous pattern is probably acquired early, since radial fibrous cement surrounding the ooids is optically continuous with the pattern (Wilkinson and Landing, 1978). The nuclei are usually preserved, although scattered nuclei are neomorphosed to single calcite crystals or clusters of micron-sized calcite spar. Radial fibrous cement, composed of stubby calcite crystals, radiates perpendicular from the surfaces of ooids. The cement surrounds ooids in all stages of alteration and is commonly neomorphosed to granular calcite spar.

Aggrading neomorphism produced ooids composed of nonequigranular mosaics of calcite spar and ooids composed entirely of one or two crystals of coarse calcite spar. The outlines of the ooids remain as amber-colored rims of microspar.

Other types of alteration include replacement of ooids by circular clusters of idiotopic dolomite rhombs and less frequently, microcrystalline quartz and pyrite. Styolites
Figure 1. Radial pattern in a ooid.
are also common, exhibiting amplitudes of up to 3 mm. Styolitization appears to post-date all other diagenetic features since styolites cut all alteration fabrics.

**Stratigraphic Setting.** Much of the upper oolitic member in the study area consists of thin (less than one meter) intervals of oosparite interbedded with thick (greater than one meter) intervals of pelsparite. Some intervals of oosparite pinch-out laterally to the east into intervals of pelsparite. Internal sedimentary structures are difficult to see in the field because of neomorphic alteration of the oolite.

**Interpretation:**

The oolitic rock type is interpreted to represent subtidal, platform-edge sand belts analogous to ooid sand bars along the western edge of the Great Bahama Bank (Newell et al., 1960; Ball, 1967, Halley, Harris and Hine, 1983). Open ocean circulation and tidal flow from the west controlled formation of ooids, and storms transported the ooids bankward (east) in the form of lobate spillover sheets.

The thin oosparite intervals that pinch-out to the east probably represent spillover sheets that were driven landward by storms over a platform of peloidal carbonates (pelsparite). In a similar fashion, modern ooids are
transported bankward from the leeward side of the ooid shoals of the Great Bahama Bank (Ball, 1967; Halley, Harris, Hine, 1983). On the leeward side of the Bahamian shoals where turbulence is reduced, asymmetric ooids and oolitic grapestone aggregates are common in the grapestone lithofacies (Illing, 1954; Freeman, 1962; Purdy, 1963; Bathurst, 1975). Similarly, the oolitic grapestone aggregates and asymmetric ooids in some intervals of oosparite in the Pilgrim Formation may also indicate deposition on the leeward margin of the shoal where turbulence was reduced. Abundant broken ooids with early radial fabrics in oolite near the top of the section at Nixon Gulch, may even indicate that water behind the shoal was slightly hypersaline. Robert B. Halley (1974, 1977) showed that syndepositionally developed radial calcite crystals in ooids formed in hypersaline conditions are weaker than tangential aragonite needles formed in normal marine waters, resulting in a high percentage of broken ooids. Similarly, a change in normal marine salinity near the top of the Pilgrim Formation may have resulted in an unusually high percentage of broken ooids.

The radial fibrous calcite cement surrounding individual ooids indicates they were cemented early in a submarine environment (Bathurst, 1975; Sandberg, 1985). The
radial fibrous calcite may be the inversion product of original aragonite cement (Cotter, 1966; Mathews, 1967), although primary radial fibrous calcite cement has been reported (Friedman, 1964; Wilkinson et al. 1982). Early radial fibrous aragonite cement around ooids in stabilized portions of the Great Bahama Bank is strong enough to form oolitic intraclasts (Ball, 1967). Similar intraclasts in the oolitic rock type of the Pilgrim Formation supports the interpretation that oolites were cemented early, probably in the submarine environment.

Alteration fabrics also support restriction of oolites to subaqueous environments since the fabrics produced resulted from neomorphism rather than vadose dissolution (Bathurst, 1975).

PELOIDAL ROCK TYPE

Description:

Primary Fabrics. The peloidal rock type (Plate 6) consists of very well sorted, grain supported, flat-laminated pelsparite in slightly irregular beds 2.0 to 8.0 cm thick. These beds are separated by .50 to 1.0 cm thick quartz and glauconite-rich, dolomitic partings (Plate 7). Peloids are well rounded, spherical to elliptical in shape and range from .05 to .10 mm in diameter. Well preserved
Figure 1. Field photo of the peloidal rock type.

Figure 2. Photomicrograph of the peloidal rock type.
Figure 1. Photomicrograph of the dolomitic partings.
peloids are composed of micrite and constitute up to 98% of the allochems in this rock type.

Scattered intraclasts of flat-laminated pelsparite are the most common non-peloidal allochems. These intraclasts range from 0.50 to 2.0 cm in length and are ellipsoidal with rounded margins. They are identical in grain and cement composition to the enclosing peloidal groundmass. Other allochems include ooids and peloids with radial fibrous oolitic coatings.

Skeletal fragments are rare in most pelsparite and are absent from the dolomitic partings. The dominant bioclasts include calcareous sponge spicules, silt-sized, macerated trilobite fragments and eocrinoid fragments that are all oriented parallel to the flat laminations. Glauconite and quartz silt grains form from 5 to 8% of this rock type.

Rare small (0.50 to 1.0 mm) burrows have thin (0.10 to 0.50 mm) compaction rims of compressed and homogenized peloids. Most burrows are filled with radial fibrous calcite, while others are partially filled with peloids producing geopetal structures.

Pelsparite is mostly flat-laminated and less commonly, cross-laminated. The cross-laminations consist of low angle cross-beds approximately 1 to 2 cm wide. Differences in peloid packing densities produce the internal flat-
laminations which range from .50 to 2.0 mm in thickness.

**Diagenesis.** In the first stage of neomorphism, micritic peloids are neomorphosed to coarse (10 to 15 microns) microspar. Neomorphism also obliterates the original cement fabric, leaving the cement a slightly coarser microspar than the neomorphosed peloids. Continued neomorphism produces amber-colored peloid ghosts that appear to float in a matrix of coarse calcite spar.

The dolomitic partings consist of limonite-coated, euhedral to subhedral dolomite rhombs averaging 20 to 100 microns wide. The partings are normally flat to wavy, but are extremely disrupted at the Logan section. Moderate amounts of clay, glauconite and quartz concentrated within the partings suggests that dissolution of the carbonate grains results in concentration of insoluble residues.

Diffuse styolites occur along the boundaries between the pelsparite and the dolomitic partings, and well defined styolites, with amplitudes less than 3 mm, occur within the pelsparite and cut all other alteration fabrics.

**Stratigraphic Setting.** On a regional scale, the thickness and frequency of pelsparite intervals greatly increase from west to east as the proportion of oolite declines (Sepkoski, 1977). Further east and southeast, pelsparite intervals gradually decrease, passing laterally
to the shale, siltstone and conglomerate facies of the Gros Ventre Formation. Sepkoski (1977) interprets the shale, siltstone and conglomerate facies of the Gros Ventre Formation to represent a subtidal lagoon located between the peloidal sands to the west and the nearshore clastics of the Deadwood Formation to the east.

Interpretation:

The peloidal rock type is interpreted to represent deposition on a shallow subtidal, semi-restricted platform on the leeward side (east) of the ooid sand belts. Extremely low faunal diversity within the pelsparite indicates deposition in a restricted environment. The well sorted, silt-sized fragments of trilobites and eocrinoids indicate that the bioclasts were transported into the depositional environment, probably from the seaward side of the ooid sand shoals.

The similar shape and fine size of both the peloids and the bioclasts indicates that the peloids are also allochthonous and were transported into the depositional environment with the bioclastic debris. The well sorted peloids may be fecal pellets and/or small micrite intraclasts that originated on the seaward side of the ooid shoals and were transported through channels in the shoals by flood tides and storms. The lack of burrows in the
pelsparite supports the interpretation that the fecal pellets are allochthonous, since few fecal pellet producing animals lived in the environment of deposition. The small size and loose packing of the peloids indicates that they were transported by suspended load rather than traction load, settling out landward of the shoals on the platform where turbulence was reduced. In modern carbonate environments, peloidal sand is common on the leeward margins of ooid shoals, but is mixed with abundant carbonate mud that is interpreted to have formed insitu through the breakdown of calcareous algae (Shinn et al., 1969; Taylor and Illing, 1969 and Bathurst, 1975). For example, Stockman et al., (1967), demonstrated the codiacean alga Penicillus was totally responsible for the accumulation of mud in Florida bay. Neumann and Land (1969) also demonstrated the importance of algae-produced mud off Great Abaco in the Bahamas. The absence of carbonate mud producers like Penicillus in the Cambrian, may be responsible for the lack of insitu carbonate mud matrix in the pelsparite of the peloidal rock type. Carbonate mud produced by abrasion of shell fragments and/or direct precipitation on the deeper marine shelf west of the study area, would be transported as peloidal clasts and pellets through the ooid shoals and deposited as loosely packed peloidal sand. If fine, non-
peloidal carbonate mud was transported with the peloids, then it may have bypassed the environment of peloid deposition and settled out further to the east.

Once deposited, the peloidal sands were rapidly cemented since the peloids are uncompacted and they form beds of peloidal intraclasts that directly overlie scoured pelsparite. The radial fibrous cement infilling burrows suggests that the cement was precipitated subaqueously. Submarine cementation is not unusual in modern carbonate environments. Shinn (1969) described large areas of carbonate sand in the Persian Gulf that are currently being cemented by aragonite and high-magnesium calcite. In the Persian Gulf, cementation takes place at or near the sediment-water interface in water 1 to 60 m in depth. The cemented layers are 5 to 10 cm thick and are commonly exhumed and eroded during storms and deposited as intraclasts. Conditions necessary for submarine cementation include supersaturation of the sea water for both high-magnesium calcite and aragonite, slow rates of sedimentation, high primary porosities and freedom from bottom traction (DeGroot, 1969; Taylor and Illing, 1969 and Bathurst, 1975). The petrography of the peloidal rock type suggests that favorable conditions for submarine cementation existed when the peloids were deposited. The abundance of
carbonate sediment clearly shows that seawater was supersaturated with respect to calcium carbonate. The loosely packed peloidal sands provided a moderate amount of primary porosity and the absence of bed forms may indicate that slow rates of sedimentation between intervals of suspended load deposition allowed the sediments to remain within the overlying supply of supersaturated sea water long enough for lithification. Examples of Cambrian submarine cemented sediments have been reported from the Nolichucky Formation in southwestern Virginia (Markello and Read, 1981) and the Snowy Range Formation in Montana and Wyoming (Brett et al., 1983).

Dissolution of the carbonate along diffuse styolites concentrated the insoluble residues such as quartz and glauconite and may have initiated the formation of the thin dolomitic partings (Wanless, 1979). Lowered pH due to decaying organic matter below the sediment-water interface may have resulted in early dissolution of the carbonate and the formation of dolomite. The dissolution probably took place before the sediments were totally lithified because the unaltered pelsparite beds commonly collapsed and rotated in response to dissolution below the beds (Pratt, 1982). Alternatively, the dolomite may have formed as a dolomitic crust during subaerial exposure (Shinn, 1983). In recent
environments these crusts are lithified and transported as intraclasts (Shinn, 1983), but the dolomitic partings of the peloidal rock type never occur as intraclasts suggesting that either they were not cemented or they formed long enough after burial that they were not affected by storms.

**INTRACLASTIC ROCK TYPE**

*Description:*

**Primary Fabrics.** The intraclastic rock type (Plate 8) consists of poorly sorted intraclasts of pelsparite, supported in a matrix of bioclastic oosparite and pelsparite. Individual beds are tabular and range from 10 cm to 1.0 m thick.

In cross-section, intraclasts are tabular to elliptical to commonly irregular in shape and range from 1.0 mm to 5.0 cm long and 0.5 to 3.0 mm thick. In planar section, intraclasts are elliptical to irregular in shape. The edges of most intraclasts are distinctly rounded and have sharp boundaries that clearly cut skeletal grains and cement. Because the peloids are so small, it is difficult to determine if the intraclast boundaries cut across peloids.

Most intraclasts are composed of flat-laminated pelsparite identical in composition to the peloidal rock type. Other intraclasts are composed of biopelsparite and
Figure 1. Field photograph of the intraclastic rock type.
some are even composed of intrasparite exhumed from a previous storm deposit. Most of the intraclasts are oriented parallel to the bedding surface, although randomly oriented intraclasts are common.

Two types of matrix support the intraclasts. Type 1 matrix (Plate 9, Fig. 1) is oobiosparite and consists of ooids and fragments of trilobites and eocrinoids cemented by spar. Silt-sized detrital quartz and peloids constitute less than 2% of the matrix. This matrix type is most common in intraclastic intervals near the base of each measured section.

Type 2 matrix (Plate 9, Fig. 2) is pelintrasparite and consists of silt-sized peloids and sand-sized micritic intraclasts with varying amounts of trilobite and eocrinoid debris. Silt-sized detrital quartz constitutes up to 5% of the matrix. This matrix type is most common in intraclastic intervals near the top of each measured section.

Diagenesis. Intracalasts generally display fewer alteration fabrics than the enclosing matrix. Most altered intraclasts consist of microsparite and less frequently, limonitic dolomite.

Matrix alteration fabrics include progressive alteration from microcrystalline to coarse sparry calcite, replacement by limonite-coated dolomite and replacement by
Figure 1. Photomicrograph of the intraclastic rock type.

Figure 2. Photomicrograph of the intraclastic rock type.
microcrystalline quartz. Radial fibrous cement fills voids on the undersides of many large intraclasts. Near the top of the section at Nixon Gulch, primary voids in one interval of intrasparite were secondarily filled with vadose silt (Plate 10, Fig. 1) similar to that described by Dunham (1969). Many of the calcite crystals that fill voids have curved twins typical of radiaxial fibrous calcite described by Bathurst (1959) and Sailer (1986), (Plate 10, Fig. 2).

**Stratigraphic Setting.** Intraclastic beds most commonly overlie beds of pelsparite. The lower contacts with pelsparite are erosional, but the upper contacts, with either pelsparite or oosparite are sharp, but not erosional. The intraclastic beds that overlie oosparite have sharp, but not erosional basal and upper contacts. Many beds of intrasparite can be correlated from one section to another, but others pinch-out laterally into pelsparite. No intrasparite beds appear to pinch out to the west into oosparite.

**Interpretation:**

The intraclastic rock type is interpreted to represent storm scour, transport and deposition on a semi-restricted, shallow, subtidal platform on the leeward side of the oolitic sand shoals. Subtidally deposited and submarine cemented pelsparite was ripped up by strong, storm-generated
Figure 1. Photomicrograph of vadose silt.

Figure 2. Photomicrograph of radiaxial fibrous calcite.
currents and deposited as tabular intraclasts with rounded edges. Peloidal intraclasts were deposited in an oolitic and bioclastic matrix near the base, and in a peloidal matrix near the top of each section. The vertical change in matrix composition upsection reflects decreasing storm input of ooids and bioclastic debris from the shoal during a shallowing-upward sequence. Intraclasts with both rounded margins and sharply broken edges indicate that the pelsparite was moderately indurated when transported. After deposition, intrasparite beds were rapidly cemented, and often ripped-up by subsequent storms and redeposited with pelsparite intraclasts during a later storm event. Radial fibrous cement in voids suggests that the intrasparite was cemented in the submarine environment (Bricker, 1971; Sandberg, 1985). In addition, radiaxial fibrous calcite in large voids may also indicate that cementation occurred subaqueously (Saller, 1986). Vadose silt in the intraclastic interval near the top of the section at Nixon Gulch suggests that, at least some intrasparite beds were exposed to the vadose zone (Dunham, 1969), probably during shallowing conditions near the top of the Pilgrim Formation.

Intraformational conglomerate beds of the intraclastic rock type have few modern analogues. Most modern intrasparite forms by reworking desiccated mud polygons
(Hardie et al., 1977; Shinn, 1983), but radial fibrous cement in void spaces of the Pilgrim intrasparite suggests that it was subaqueously cemented. Sepkoski (1977, 1979, 1982) proposed that Cambrian intraformational conglomerates formed subtidally through rapid submarine cementation of thin-bedded grainstone. He argued that the absence of deep-burrowing animals in the Cambrian restricted sediment mixing and allowed submarine cementation of sediments that might otherwise be thoroughly mixed. Mixed sediments would be suspended during storms while un-mixed, cemented sediments would form intraclasts. In the peloidal rock type, the small number of burrows suggest that the peloidal sand was not mixed, and may have aided in early, submarine cementation and the formation of intraclasts of the intraclastic rock type.

ALGAL ROCK TYPE
Description:

**Primary Fabrics.** The algal rock type (Plate 11) consists of poorly preserved, vertical stromatolitic columns separated by patches of bioturbated biomicrite. Stromatolitic columns are vertical to slightly inclined, exhibiting irregular branching patterns in cross-section. Individual columns are small (1.0 to 3.0 cm wide and 3.0 to
Figure 1. Field photo of the algal rock type.

Figure 2. Photomicrograph of the algal rock type.
20 cm high) and closely packed, usually separated by the width of a column. Columns are composed of limonite-coated, euhedral dolomite and microcrystalline sparry calcite. Rarely preserved laminae do not extend into the interstromatolitic fill resulting in sharp boundaries between columns and biomicrite.

Interstitial fill is composed of bioturbated biopelmicrite and biomicrite with scattered, small (.05 to 8.0 mm) intraclasts. Bioclasts consist of randomly oriented trilobite and eocrinoid fragments that appear "churned" in cross-section. Intraclasts are irregular in shape, with distinct boundaries and rounded margins. The intraclasts are composed of microsparite similar in composition to the stromatolitic columns and are commonly replaced by limonitic dolomite. Detrital quartz constitutes less than 1% of this rock type.

Horizontal burrows disrupt bedding within most of the interstromatolitic fill. Bedding is preserved only in small (1.0 to 5.0 cm) intervals of biointrasparite that overlie the tops of the stromatolitic fingers.

Diagenesis. Stromatolitic columns are primarily altered to dolomitic, neomorphic calcite spar. The interstromatolitic fill is randomly altered to microspar, leaving patches of un-neomorphosed biomicrite. Patches of
limonitic, euhedral dolomite have also replaced the interstromatolitic biomicrite and small microspar intraclasts within the biomicrite. Radial fibrous cement, composed of elongate calcite crystals, radiates out from the surfaces of intraclasts and low amplitude styolites concentrate limonitic dolomite and cut all the other alteration fabrics.

**Stratigraphic Setting.** Stromatolites occupy the upper 3.0 to 8.0 m of the Pilgrim Formation at each locality. The lower contact with pelsparite and the upper contact with the Dry Creek Shale are sharp. The algal rock type contains no interbeds of the other rock types at Logan or Nixon Gulch, but is interbedded with a 1.4 m interval of interbedded pelsparite and intrasparite at Sacajawea Peak.

**Interpretation:**

The algal rock type represents shallow subtidal to lower intertidal buildups of digitate stromatolites similar to those described by Howe (1966) from the Cambrian and Ordovician of Missouri.

Howe (1966) described digitate stromatolites as colonial structures characterized by slender, vertically to obliquely oriented columns. The columns are "meandrine" to subcircular in cross-section and display irregular branching patterns. The interstromatolitic fill typically consists of
coarse carbonate debris, including fragments of the stromatolitic columns. Aitken (1967) described similar stromatolites from the Cambrian and Ordovician of southwestern Alberta, and both workers concluded that digitate stromatolites developed in the outer regions of the littoral (intertidal) zone.

Howe (1966) cited the consistent association of digitate stromatolites with oolitic dolarenite as evidence for restriction of digitate stromatolites to areas dominated by a high degree of wave and current energy. He described the stromatolites as forming relatively large "reef-like" buildups parallel to the shoreline and separated from it by shallow lagoonal regions.

Stromatolites from the upper oolitic member exhibit most of the diagnostic features of digitate stromatolites from Missouri and probably occupied similar depositional environments. Small biomicrosparine intraclasts within the interstromatolitic fill and intervals of intrasparite terminating algal growth, indicate that the stromatolites were commonly subjected to moderately strong waves and currents. However, numerous small horizontal burrows in the interstromatolitic fill suggests that the stromatolites were commonly submerged, because analogous recent, small polychaete burrows are more common in submerged
stromatolites than in intertidal stromatolites (Ginsburg et al., 1970). In addition, mudcrack polygons and other desiccation features were not observed.

The Radial fibrous cement radiating from the surfaces of intraclasts indicates cementation took place subaqueously (Bathurst, 1975). Alteration fabrics also suggest that the stromatolites were commonly submerged since the irregular distribution of microspar within interstromatolitic micrite is a result of neomorphism rather than vadose dissolution and precipitation (Folk, 1965).

The abrupt appearance of digitate stromatolites at the top of the Pilgrim Formation at each locality indicates continued shallowing upsection to shallow subtidal or possibly lower intertidal environments. Sepkoski (1977) proposed that the appearance of digitate stromatolites at the top of the Pilgrim Formation resulted from uplift and shallowing associated with the "Skull Canyon Uplift". The shallowing, however, may be an early response to regional regression near the end of the Dresbachian Stage (Lochman-Balk, 1970).
CHAPTER III

STRATIGRAPHIC CORRELATIONS

The Logan and Nixon Gulch sections in the Horseshoe Hills and the Sacajawea Peak section in the Bridger Range provide the data for lithostratigraphic and biostratigraphic correlations. Most of the lithostratigraphic correlations are based on lithic continuity from one section to another, although minor variations exist in each section. I terminated each measured section at the boundary between the Pilgrim Formation and the overlying Dry Creek Shale.

Lithostratigraphic Correlations:

The four rock types form 7 units that can be correlated between the Logan and Nixon Gulch sections. Only 3 units can be correlated to the stratigraphically shorter Sacajawea Peak section (Fig. 11 and Fig. 12). Unit 1 consists of the oolitic rock type and can be correlated from Logan to Nixon Gulch. A 20 cm interval of the intraclastic rock type within this unit at Logan has a peloidal matrix and marks the transition from intrasparite with a bioclastic-oolitic matrix to intrasparite with a peloidal matrix. The upward change in matrix type indicates the beginning of a shallowing-upward sequence. Units 2 and 4 are thick intervals of the peloidal rock type that are separated by a
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Figure 11. Legend for stratigraphic columns.
thin interval of the intraclastic rock type (unit 3). All three units can be correlated from Logan to Nixon Gulch, and the biomere boundary occurs 30 cm below unit 3 at both localities. Units 4 and 6 are thick intervals of the peloidal rock type that are separated by interbeds of the oolitic rock type (unit 5). The increase in the peloidal rock type with a decrease in the oolitic rock type upsection indicates continued shallowing. With further shallowing, the algal rock type (unit 7) appears and continues uninterrupted to the top of each section. A thin interval of the peloidal rock type within the algal rock type at Sacajawea Peak demonstrates that deposition of the peloidal rock type continued in areas adjacent to the stromatolitic buildups.

Biostratigraphic Correlations:

Figures 14, 15 and 16 illustrate the stratigraphic ranges for trilobites at each section. Both the Crepicephalus and the Aphelaspis Zones were collected at Logan and Nixon Gulch, but only the Aphelaspis Zone was collected at Sacajawea Peak. The biomere boundary at Logan (Horizon 1.2), is confined to collections 5 cm apart and can be traced to the same position in unit 2 at Nixon Gulch (Horizon 7.6). Unit 3 overlies the biomere boundary by 30 cm at both Logan and Nixon Gulch (Fig. 13), and since this
Figure 13.

Marjumiid Biomere

Pteroccephaliid Biomere
unit represents a single depositional event it demonstrates that the extinction, at least in the study area, was a synchronous event.

At Logan (fig. 14), *Tricrepicephalus*, *Pemphigaspis* and *Coosella* of the *Crepicephalus* Zone (Marjumiid Biomere) are abruptly overlain within 5 cm of uniform pelsparite by *Glaphyraspis* of the *Aphelaspis* Zone (Pterocephaliid Biomere). A field and polished slab photo of the 5 cm interval shows that no discontinuity surfaces or changes in lithology are associated with the extinction (Plates 12 and 13). *Cheilocephalus* and *Aphelaspis* first appear 40 cm above the first appearance of *Glaphyraspis* and all three genera proliferate and diversify upsection. *Blountia nixonensis*, an opportunistic species descended from genera of the *Crepicephalus* Zone (Palmer, 1984), appears 5.8 m above the extinction boundary and is restricted to the algal rock type.

At Nixon Gulch (fig. 15), the faunal turnover is strikingly similar to the Logan section and occurs within the same pelsparite unit. At the boundary, *Crepicephalus*, *Tricrepicephalus*, *Coosella* and *Coosina* are abruptly overlain within 5 cm of uniform pelsparite by *Glaphyraspis*. A field and a polished slab photo of the 5 cm interval again shows that no physical discontinuities or changes in lithology
Figure 1. Field photo of the biomere boundary at Logan.
Figure 1. Polished slab photo of the biomere boundary at Logan.
occur within the interval containing the biomere boundary (Plates 14 and 15). *Coosella perplexa*, another opportunistic species descended from genera of the *Crepicephalus* Zone, appears together with *Glaphyraspis* for 30 cm above the boundary, but was extinct by the time the unrelated trilobites, *Cheilocephalus* and *Aphelaspis*, appear in the section. *Cheilocephalus* appears 40 cm above the boundary and *Aphelaspis* appears 50 cm above the boundary suggesting a short "lag" time before their appearance on the shallow platform. This supports Palmer's (1965) interpretation that these genera are immigrants and did not originate on the shelf. *Blountia nixonensis* appears 6.2 m above the boundary and is restricted to the algal rock type.

At Sacajawea Peak (fig. 16), the boundary interval was not collected, but the faunal patterns above the boundary are the same as the Logan and Nixon Gulch sections. *Aphelaspis*, *Glaphyraspis* and *Cheilocephalus* are common above the boundary, and *Blountia nixonensis* occurs well above the boundary, again restricted to the algal rock type. The survival of *Blountia* well above the boundary inbetween the stromatolitic heads of the algal rock type indicates that it must have been well adapted to the changing environmental conditions that exterminated the remainder of the *Crepicephalus* Zone fauna.
Figure 1. Field photo of the biomere boundary at Nixon Gulch.
Figure 1. Polished slab of the biomere boundary at Nixon Gulch.
Figure 16: Pteroccephaliid Biomere

- Cheilocephalus
- Glaphyraspis
- Aphelaspis
- Blountia
- Dytemacephalus
The persistence of *Blountia* well after the extinction supports the boundary revisions proposed by Palmer (1979). As mentioned in the introduction, Palmer (1979) lowered the biomere boundaries to the base of stage 4 to include a 20 cm interval where opportunists from the pre-existing faunas are mixed with the new, immigrant faunas during a time of environmental crisis. This boundary change left some question as to whether "extinction" should be the last appearance of all the *Crepicephalus* Zone fauna or the last appearance of most of the *Crepicephalus* Zone fauna. In Montana, the opportunist, *Coosella perplexa*, is similarly mixed with the new fauna for approximately 30 cm, but the appearance of *Blountia* well above this interval extends the mixed zone nearly 9.0 m above the extinction of the remainder of the *Crepicephalus* Zone trilobites. *Blountia* apparently was well adapted to the changing environmental conditions and coexisted with the new fauna while they adapted and diversified on the shallow shelf platform.

Although the mixed interval in Montana differs from the mixed interval in Texas and the Great Basin (Palmer, 1954, 1979), it clearly shows that the extinction boundary should be placed at the base of stage 4 of Stitt (1977). Without the revisions, the biomere boundary would be placed nearly 9.0 m above the extinction of most of the *Crepicephalus* Zone.
trilobites and a long period of adaptation and
diversification of the new fauna would wrongly be included
in Stitt's (1975) terminal declining stage 4.
CHAPTER IV
ENVIRONMENTAL SYNTHESIS

The environmental synthesis is based on lithostratigraphic correlations and interpretations of the (1) oolitic rock type, (2) the peloidal rock type, (3) the intraclastic rock type and (4) the algal rock type. These carbonate sediments record shallow water shoal, restricted platform and shallow subtidal to possibly lower intertidal deposition during a shallowing-upward sequence (Fig. 17). Oosparite is the dominant lithology at the base of each section and represents platform-edge sand belts similar to those along the western margin of the Great Bahama Bank (Halley, Harris and Hine, 1983).

Oosparite decrease in abundance upsection as pelsparite increases, reflecting a westward migration of pelsparite with shallowing conditions. Pelsparite was deposited in shallow, semi-restricted areas landward (east) of the oolitic shoals and thin interbeds of oosparite in dominantly pelsparite intervals reflect lateral shifting and migration of the sand belts by lobate spillover sheets. A high percentage of broken ooids in oosparite intervals near the top of each section may indicate a change in normal marine salinity resulting from increased restriction with shallowing conditions.
Figure 17

ROCK TYPE

- OOLITIC
- INTRAQLASTIC
- PELOIDAL
- ALGAL

0 km

Sea Level
Cement fabrics show that both oosparite and pelsparite were cemented shortly after deposition, probably in the submarine environment. The early-cemented pelsparite was ripped-up and transported as intraclasts by large storms and accumulated as debris piles and sheets on the floor of the restricted platform. The piles of intraclasts were also cemented shortly after deposition since the lithified intrasparites were ripped-up during later storms and incorporated as intraclasts in subsequent intrasparite beds. The composition of the matrix supporting the intraclasts changes upsection from bioclastic-oolitic to peloidal reflecting shallowing conditions and decreasing landward input of ooids and bioclasts during storm events that formed the intrasparite beds.

With further shallowing, digitate stromatolites migrated to the west over pelsparite at the top of each section. These stromatolites are similar to those described from the Upper Cambrian of Missouri (Howe, 1966) which are interpreted to have occupied the lower intertidal zone. Cementation fabrics and abundant burrows in the interstromatolitic fill between the stromatolitic fingers in the Pilgrim Formation however, suggest that the algal buildups were rarely exposed and may have occupied shallow subtidal to lowermost intertidal environments.
Shallowing conditions in the upper part of the Pilgrim Formation can be explained by at least three possible mechanisms: (1) Dresbachian uplift associated with the "Skull Canyon Uplift", (2) carbonate accumulation rates exceeding subsidence rates and (3) eustatic sea level drop.

Dresbachian Uplift. Dresbachian uplift along the Montana-Idaho border west of Yellowstone Park was termed the "Skull Canyon disturbance" by Scholten (1957). According to Sepkoski (1977), block-faulting along the hingeline of the craton during the Dresbachian resulted in the deposition of quartz sands and the appearance of digitate stromatolites at the top of the Pilgrim Formation in southwestern Montana. Sepkoski (1977) proposed that digitate stromatolites developed in belts near the margins of this uplifted area, but pointed out that the proposal could not be tested since the margins were eroded.

Carbonate Accumulation Rates. Carbonate sediments characteristically accumulate at rates exceeding subsidence and repeatedly build up to, and above, sea level (James, 1984). As a result, characteristic sequences of deposits are produced in which each unit is deposited in progressively shallower water. This shallowing-upward sequence is commonly repeated, resulting in stratigraphic intervals consisting of many shallowing-upward cycles.
Similarly, shallowing conditions at the top of the Pilgrim Formation may have been produced by a greater rate of carbonate accumulation than subsidence, although the Pilgrim Formation characteristically does not consist of repeated shallowing-upward cycles.

Eustatic Sea Level Drop. The Dry Creek Shale Member of the Snowy Range Formation conformably overlies the Pilgrim Formation at all three localities. This shale is interpreted by most workers to represent a major sea level drop that brought inner detrital belt facies over middle carbonate facies (Lochman-Balk and Wilson, 1958; Palmer, 1960 and Lochman-Balk, 1970). The shallowing-upward sequence near the top of the Pilgrim Formation in southwestern Montana may be an early and fairly subtle lithologic response to the sea level drop that eventually brought the inner detrital belt Dry Creek shale westward over the middle carbonate belt Pilgrim limestone. This mechanism is consistent with stratigraphically similar shallowing-upward sequences in Wyoming (Chronic, 1987), Texas (Palmer, 1954) and Illinois (Buschbach, 1964) and serves as the basis for the following discussion on the Marjumiid-Pterocephaliid biomere boundary in southwestern Montana.
CHAPTER V
MARJUMIID-PTEROCEPHALIID BIOMERE BOUNDARY

In southwestern Montana, the Marjumiid-Pterocephaliid biomere boundary is abrupt and does not coincide with any physical discontinuity or subtle change in carbonate deposition at the boundary. The boundary does, however, occur within a shallowing-upward sequence within the upper part of the Pilgrim Formation that precedes a regionally recognized regression at the base of the overlying Dry Creek Shale (Lochman-Balk, 1970). This shale unit records the westward migration of the clastic-dominated inner detrital belt over the carbonate-dominated middle carbonate belt during eustatic sea level drop and represents the most extensive westward migration of the shoreline documented in the Late Cambrian (Lochman-Balk, 1970).

In the nearest shore sections, the faunal change at the Marjumiid-Pterocephaliid biomere boundary coincides with a shallowing-upward sequence within the inner detrital belt (Palmer, 1954; Buschbach, 1964 and Emrich, 1966), but in the middle carbonate belt sections a shallowing-upward sequence has previously not been recognized. This study (Thomas, 1987) and a similar study in Wyoming (Chronic, 1987) however, have shown that the Marjumiid-Pterocephaliid biomere boundary does coincide with a shallowing-upward
sequence in the offshore carbonates and indicates that regional regression began prior to the trilobite extinctions.

Based on this more regional association of the Marjumiid-Pterocephaliid biomere boundary with a shallowing upward sequence, I propose that the extinction of the Crepicephalus Zone trilobites and subsequent invasion of the Aphelaspis Zone trilobites was caused by environmental changes resulting from regression. A progressive drop in sea level of the Cambrian shallow epicontinental sea may have affected ocean temperature, oxygen levels or salinity in a manner that exceeded some critical tolerance level and was therefore lethal to the highly specialized shelf and miogeoclinal trilobites. In this way, the extinction would be abrupt, but would not coincide with a discontinuity surface or subtle change in carbonate deposition at the boundary.

The coincidence of mass extinction with marine regression is not uncommon, in fact, all the major Phanerozoic extinctions coincide with marine regressions (Raup and Sepkoski, 1982 and Sepkoski, 1982b). Proposed environmental changes caused by regression include: reduction in habitable area (Schopf, 1974 and Hallam, 1981); reduction in the number of shallow-water provinces.
(Jablonski, 1985); the development of brackish oceans
(Stevens, 1977); the development of hypersaline oceans
(Bowen, 1970) and a drop in mean ocean temperature due to
the introduction of cold, dense polar water (Lochman-Balk,
1970).

Palmer (1984) argued against regression because on the
western margin of the North American Cambrian shelf, the
extinction is followed by a slight deepening. Lochman
(1970) however, believed that the change in lithofacies
signifies a progressive shallowing and is consistent with
shallowing conditions in the nearshore sites. Palmer (1984)
also cited the continued diversification of the Aphelaspis
Zone trilobites through maximum regression at the end of the
Dresbachian stage as evidence that regression has no obvious
faunal effect. While it is true that maximum regression at
the end of the Dresbachian had no effect on the new,
imigrant populations, extinction of these trilobites would
not be expected since they were already adapted to the
changes that wiped-out the pre-existing fauna.

Previous workers (Lochman-Balk, 1970 and Stitt, 1975)
have concentrated on the paleoecological tolerances of the
invading trilobites to support their interpretations that
the extinction was caused by a rapid cooling event, but have
not given enough consideration to the paleoecological
tolerances of the trilobites that survived the extinction. The trilobites that did survive long after the extinction, *Blountia* and *Glaphyraspis*, were probably adapted to high stress environments. Both *Blountia* and *Glaphyraspis* survived the extinction in shallow, rigorous environments of the stromatolite "reef" facies (Lochman-Balk, 1970) where ocean temperature and salinity probably fluctuated. Since these trilobites survived the environmental changes that exterminated the remainder of the *Crepicephalus* Zone fauna, I believe they may more accurately reflect the cause(s) of the extinction than the invading faunas. Unfortunately, few studies have focused on the paleoecology of these trilobites, and their paleoecology was not directly considered in this study.

The only physical evidence for changing environmental conditions in the Pilgrim Formation is the upward increase in broken ooids. An increase in broken ooids may suggest that normal marine salinity was changing with regression, but whether this change or another change resulting from regression caused the extinction is difficult to determine.
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APPENDIX A
MEASURED SECTIONS

Strata in the Horseshoe Hills are moderately folded, and faulted by many small normal faults and a few thrust faults. The Cambrian section is well exposed and dips gently at 35 degrees to the northwest. Geology of the Horseshoe Hills has been mapped in detail by Verrall (1954).

Strata in the Bridger Range dip steeply to the east as part of a large north trending fold and are dissected by several small east-west trending normal faults. Geology of the Bridger Range has been mapped in detail by McMannis (1955). Crustal shortening by eastward directed thrusting probably displaced the sections a minimum of 15 km to the east (Schmidt and O'Neill, 1982).

I terminated each stratigraphic section at the boundary between the Dry Creek Shale Member of the Snowy Range Formation and the Pilgrim Formation. The scale for each measured section is in meters. Prepared thin sections and collected trilobites are listed for each horizon and trilobites are listed in order of decreasing abundance. All collections, including field notes, are housed at the Museum of Paleontology, University of Montana.
### Figure 18. Legend for measured sections.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oolitic rock type</td>
<td><img src="image" alt="Oolitic rock type" /></td>
</tr>
<tr>
<td>Peloidal rock type</td>
<td><img src="image" alt="Peloidal rock type" /></td>
</tr>
<tr>
<td>Intraclastic rock type</td>
<td><img src="image" alt="Intraclastic rock type" /></td>
</tr>
<tr>
<td>Algal rock type</td>
<td><img src="image" alt="Algal rock type" /></td>
</tr>
</tbody>
</table>
Section measured on the southeast flank of the Pilgrim ridge, directly north of the Gallatin River. The section is accessible by driving northeast on Cottonwood Gulch road for approximately 3.0 km to a fork in the road. Park at the fork and walk directly east for 1.5 km, following the power lines to the cliff-forming Pilgrim limestone. Walk south along the ridge to its southern end where the Pilgrim is truncated by the Gallatin River. The section is well exposed along the east-facing slope and the strata dip at approximately 49 degrees to the west. Located in SE1/4 sec. 25, T.1N., R.2E., Gallatin County, Montana: Manhattan 15' Quadrangle.
Algal rock type - Deeply weathered, very dolomitic and unfossiliferous to the base of the Dry Creek Shale. N46E49W

Algal rock type - Very dolomitic, unfossiliferous. N46E49W

Algal rock type - Weathered, dolomitic and unfossiliferous. N46E49W

Algal rock type - Vertical dolomitic columns separated by brown-colored limestone. N46E49W
Algal rock type - Weathered, dolomitic columns separated by brown-colored limestone. A few intraclastic beds cut across the dolomitic columns. N46E49W

Algal rock type - Vertical dolomitic columns with faint laminations. L9.0; N46E49W

Algal rock type - Vertical dolomitic columns with faint laminations. Intraclastic beds cut across the dolomitic columns. Glaphyraspis, Cheilocephalus and Aphelaspis. L8.7, L8.5, L8.2; N46E49W

Algal rock type - Dolomitic columns with well preserved laminations. Cheilocephalus, Glaphyraspis and Blountia. L7.2, L7.0; N45E49W
Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Oriented parallel to bedding. N46E49W

Peloidal rock type - Flat-laminated limestone separated by thin, dolomitic partings that are parallel to the flat laminations. Limestone beds moderately disrupted. L6.7, L6.4, L6.2; N46E49W

Oolitic rock type - Massive, mottled oolite. Ooids are black in color and are well sorted. Very fossiliferous, dominated by librigenae. Aphelaspis and Cheilocephalus. L5.3, L5.2, L5.0; N46E49W

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. L4.3; N46E49W

Peloidal rock type - Flat-laminated limestone separated by dolomitic partings. Upper contact erosional, lower contact sharp, but not erosional. N46E49W

Oolitic rock type - Mottled oolite with faint low angle crossbeds. L3.5, L3.4; N46E49W
Peloidal rock type - Flat-laminated limestone separated by dolomitic partings. Laminations can be traced from limestone into the dolomitic partings. L2.5, L2.3, L2.2; N46E49W

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Upper contact sharp, lower contact erosional. N46E49W

Peloidal rock type - Flat-laminated with irregular dolomitic partings. Aphelaspis, Cheilocephalus, Glaphyraspis, Coosella, Tricrepicephalus and Pemphigaspis. L1.6, L1.5, L1.2, L1.1, L1.0; N46E49W


Peloidal rock type - Flat-laminated with irregular dolomitic partings. L.1; N46E49W
Section measured on the south-facing slope of the Pilgrim ridge, north of where it is cut by Nixon Gulch. The section is accessible from the Manhattan exit off Interstate 90. Follow the road north into Manhattan across U.S. Rt. 10 and the Northern Pacific Railroad. Turn northwest onto the gravel road running parallel to the railroad tracks (fishing access) and follow it to the bridge that crosses the Gallatin River. Cross the bridge and follow the lower road into Nixon Gulch. The section is located on the north side of the road approximately 4 km from the river. Strata are well exposed and dip at approximately 47 degrees to the east. Located in SE1/4 sec. 14, T.2N., R.3E., Gallatin County, Montana: Manhattan 15' Quadrangle.
Algal rock type - Weathered, dolomitic columns separated by brown-colored carbonate. Laminations difficult to see in the dolomitic columns. *Blountia, Glaphyraspis, Aphelaspis, Dytremacephalus* and *Dictyonina perforata*. NG16.8, NG16.6, NG16.5, NG16.3, NG16.0; N85W47E

Algal rock type - Weathered, a few intraclastic beds cut across the vertical dolomitic columns. *Blountia* and *Glaphyraspis*. NG15.8, NG15.6, NG15.5, NG15.4, NG15.0; N85W47E


Algal rock type - Faint laminations in the dolomitic columns. Very fossiliferous. *Glaphyraspis* and *Blountia*. NG13.8, NG13.6; N85W47E

Intraclastic rock type - Tabular to irregular intraclasts in a peloidal matrix. *Glaphyraspis*. NG13.5, NG13.4; N85W47E

Peloidal rock type - Flat-laminated limestone separated by thin dolomitic partings. *Glaphyraspis, Aphelaspis, Cheilocephalus* and *Proplina loganensis*. NG13.3, NG12.9; N85W47E
Intraclastic rock type - Tabular to irregular intraclasts in a peloidal matrix. N85W47E

Peloidal rock type - Flat-laminated limestone separated by thin dolomitic partings. Partings are parallel to bedding. Cheilocephalus. NG12.4, NG12.3; N85W47E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Upper contact is sharp, lower contact is erosional. Intraclasts oriented parallel to bedding. NG11.6; N85W47E

Peloidal rock type - Flat-laminated, dolomitic partings faint. NG11.0; N85W47E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Lower contact erosional. Several intraclasts with spherical holes. N85W47E


Peloidal rock type - Flat-laminated. NG10.2; N85W47E


Peloidal rock type - Flat-laminated limestone separated by dolomitic partings. Upper contact is sharp. Cheilocephalus. NG9.4, NG9.3, NG9.2, NG8.9, NG8.8, NG8.7; N85W47E
Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Intraclasts oriented at a high angle to bedding. *Aphelaspis* and *Cheilocephalus*. NG8.2, NG8.1; N85W47E

Peloidal rock type - Flat-laminated. *Aphelaspis*, *Cheilocephalus*, *Glapthyraspis*, *Coosella*, *Coosina* and *Crepicephalus*. NG7.7; N85W47E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. N85W47E

Peloidal rock type - Flat-laminated. *Tricrepicephalus*, *Crepicephalus* and *Coosina*. NG7.2; N85W47E

Oolitic rock type - Massive, mottled oolite. NG7.0; N85W47E

Peloidal rock type - Flat-laminated, dolomitic partings faint. NG6.7, NG6.6, NG6.5; N85W47E

Intraclastic rock type - Tabular intraclasts in a bioclast-oolitic matrix. *Pseudagnostus*. NG6.4; N85W47E

Hummocky crossbedded quartz siltstone with a minor amount of limestone intraclasts. NG6.0; N85W47E

Peloidal rock type - Flat-laminated limestone with faint dolomitic partings. NG5.9, NG5.7, NG5.5, NG5.4; N85W47E

Oolitic rock type - Massive, mottled oolite. Ooids black in color and well sorted. NG4.6; N85W47E
Intraclastic rock type - Tabular intraclasts in a bioclastic-oolitic matrix. Intraclasts are oriented at a high angle to bedding. NG4.5, NG4.1; N85W47E

Peloidal rock type - Flat-laminated limestone separated by thin dolomitic partings. Dolomitic partings faint. NG3.8; N85W47E

Oolitic rock type - Massive oolite. Pemphigaspis, Coosella and Crepicephalus. NG3.6, NG3.5; N85W47E

Intraclastic rock type - Tabular intraclasts in a bioclastic matrix. NG3.4, NG3.2, NG3.1; N85W47E

Peloidal rock type - Flat-laminated with scattered intraclasts. Tricrepicephalus. NG2.8; N85W47E

Oolitic rock type - Massive oolite with scattered peloidal intraclasts.

Intraclastic rock type - Tabular intraclasts in a bioclastic-oolitic matrix. NG2.5; N85W47E

Oolitic rock type - Massive, mottled oolite. Very fossiliferous. Scattered peloidal intraclasts. Crepicephalus. NG2.4, NG2.2, NG2.0, NG1.7, NG1.6, NG1.5, NG1.4; N85W47E

Peloidal rock type - Flat-laminated. Upper contact sharp. NG1.3, NG1.2, NG1.1; N85W47E

Intraclastic rock type - NG1.0, NG.9; N85W47E
Peloidal rock type - Flat-laminated, very faint dolomitic partings.
NG.8, NG.7; N85W47E

Intraclastic rock type - Tabular intraclasts, many with holes.
NG.6, NG.5; N85W47E

Oolitic rock type - Massive oolite.
NG.4, NG.2, NG.1, NG0; N85W47E
Section measured on the southwest flank of Sacajawea Peak in the central Bridger Range. The section is accessible from Fairy Lake Campground by taking the trail west up the cirque wall to Bridger Divide. Walk south from the divide to the first saddle below the west flank of Sacajawea Peak. The section is well exposed on the west-facing slope and the strata dip approximately 49 degrees to the east. Located in SW1/4 sec. 27, T.2N., R.6E., Gallatin County, Montana: Sedan 15' Quadrangle.
Algal rock type - Thin, dolomitic columns separated by brown-colored limestone. Laminations very faint in the dolomitic columns. SP8.1, SP8.0, SP7.9, SP7.4, SP7.2, SP7.1, SP7.0; N16W49E

Intraclastic rock type - Tabular to irregular intraclasts in a peloidal matrix. SP5.9; N16W49E
Peloidal rock type - Flat-laminated with dolomitic partings. SP5.7; N16W49E
Intraclastic rock type - Irregular intraclasts in a peloidal matrix. SP5.6; N16W49E
Peloidal rock type - Flat-laminated. SP5.5; N16W49E
Intraclastic rock type - Irregular intraclasts in a peloidal matrix. SP5.3; N16W49E

Algal rock type - Dolomitic columns with faint laminations. A few intraclastic beds cut across the dolomitic columns. Dytremacephalus, Aphelaspis, Gephyraaspis and Blountia. SP6.9, SP6.8, SP6.7, SP6.6, SP6.5, SP6.4, SP6.1; N16W49E

Peloidal rock type - Flat-laminated limestone with dolomitic partings parallel to the laminations. SP5.0, SP4.8, SP4.6; N16W49E
Algal rock type - Dolomitic columns with faint laminations separated by brown-colored limestone. Limestone is very fossiliferous, containing well preserved cranidia and pygidia. *Blountia* and *Glaphyraspis*. SP4.5, SP4.2, SP4.1; N16W49E

Algal rock type - Dolomitic columns separated by fossiliferous brown-colored limestone. *Blountia* and *Glaphyraspis*. SP3.8, SP3.6, SP3.5, SP3.3, SP3.2, SP3.1; N16W49E

Peloidal rock type - Flat-laminated limestone separated by thin, dolomitic partings. Partings parallel to bedding. Very un-fossiliferous. SP2.8, SP2.6, SP2.5, SP2.4, SP2.2, SP2.0; N16W49E

Peloidal rock type - Flat-laminated with dolomitic partings. SP1.9, SP1.8; N16W49E

Intraclastic rock type - Tabular intraclasts in peloidal matrix. SP1.7; N16W49E

Oolitic rock type - Massive oolite. *Aphelaspis* and *Glaphyraspis*. SP1.6, SP1.5; N16W49E

Intraclastic rock type - Tabular intraclasts in peloidal matrix. SP1.3; N16W49E

Oolitic rock type - Massive, mottled oolite. SP1.2, SP1.1; N16W49E
Oolitic rock type - SP.9, SP.7; N16W49E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. SP.5; N16W49E

Oolitic rock type - Massive, mottled oolite. Cheilocephalus. SP.3, SP.2, SP0; N16W49E
APPENDIX B
SYSTEMATIC PALEONTOLOGY

Phyla represented in the upper oolitic member of the Pilgrim Formation are arranged in alphabetical order. Arrangement of lower taxa within each phylum is also alphabetical. The phylum Arthropoda is represented by 8 families, 11 genera and 17 species of trilobites. The phylum Brachiopoda is represented by one inarticulate brachiopod species and the phylum Mollusca is represented by one gastropod species. All fossil material was identified from published descriptions to species level when possible. Definitions of the morphological terms used for trilobite descriptions are discussed and illustrated in the Treatise on Invertebrate Paleontology (Harrington and others, 1959; p. 042-047; glossary, p. 0117-0126).

For each species, the biostratigraphic stage and faunal zone are listed. Collecting localities and stratigraphic position in meters above the base of the section at each locality are also listed. The localities are ordered: (1) Logan, (2) Nixon Gulch and (3) Sacajawea Peak. All fossil material is housed at the Museum of Paleontology, University of Montana.
<table>
<thead>
<tr>
<th>GENUS</th>
<th>LOGAN</th>
<th>NIXON GULCH</th>
<th>SACAJAWEA PEAK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudagnostus</td>
<td>----</td>
<td>6.4</td>
<td>----</td>
</tr>
<tr>
<td>Blountia</td>
<td>7.9</td>
<td>13.8-16.6</td>
<td>3.0-6.8</td>
</tr>
<tr>
<td>Pemphigaspis</td>
<td>.5-1.1</td>
<td>3.6-5.2</td>
<td>----</td>
</tr>
<tr>
<td>Cheilocephalus</td>
<td>1.6-8.6</td>
<td>8.0-12.9</td>
<td>.1-1.6</td>
</tr>
<tr>
<td>Coosella</td>
<td>.5-1.1</td>
<td>3.6-7.9</td>
<td>----</td>
</tr>
<tr>
<td>Coosina</td>
<td>----</td>
<td>7.1-7.5</td>
<td>----</td>
</tr>
<tr>
<td>Crepicephalus</td>
<td>----</td>
<td>2.0-7.5</td>
<td>----</td>
</tr>
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<td>7.6-16.8</td>
<td>1.6-6.8</td>
</tr>
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<td>1.6-8.2</td>
<td>8.1-15.4</td>
<td>1.6-6.8</td>
</tr>
<tr>
<td>Dytremacephalus</td>
<td>----</td>
<td>15.4-16.8</td>
<td>6.6-6.8</td>
</tr>
<tr>
<td>Tricrepicephalus</td>
<td>.5-1.1</td>
<td>2.8-7.1</td>
<td>----</td>
</tr>
<tr>
<td>Dictyonina</td>
<td>----</td>
<td>16.0-16.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Proplina</td>
<td>----</td>
<td>12.9</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Figure 19. Stratigraphic ranges for trilobite, brachiopod and gastropod genera at the Logan, Nixon Gulch and Sacajawea Peak sections.
Phylum ARTHROPODA Siebold and Stannius, 1845
Class TRILOBITA Walch, 1771
Order AGNOSTITIDA Kobayashi, 1935
Family PSEUDAGNOSTIDAE Whitehouse, 1936
Genus Pseudagnostus Jaekel, 1909
Pseudagnostus sp. (undet.)
(Plate 20, Figure 3)

Pseudagnostus Jaekel, 1909, p.400; Kobayashi, 1935, p.107;
1937, p.451; 1939, p.157; Shimer and Shrock, 1944,
p.601; Shaw, 1951, p.112; Palmer, 1954, p.719; 1955,
p.93; 1960, p.61.

Plethagnostus Clark, 1923, p.124.

Rhaptagnostus Whitehouse, 1936, p.97.

Description: Pygidium with anterior portion of axial
lobe defined by parallel axial furrows. Posterior lobe
expanded and moderately well defined by extension of axial
furrows. Axial furrows reach the border and no marginal
spines are present.

Discussion: The upper Crepicephalus zone and lower
Aphelaspis zone in Montana are noted for the absence of
Agnostid trilobites (Lochman and Duncan, 1944). One
pygidium was collected at Nixon Gulch, but none were found
at the Sacajawea Peak or Logan sections.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim
Formation (Crepicephalus Zone). Nixon Gulch (Horizon 6.4).
Description: Cranidium moderately convex, broadly conical with large, strongly convex glabella. The glabella is furrowless with a shallow occipital furrow and narrow occipital ring. The anterior margin is evenly rounded and the anterior border is distinct. The anterior border is separated from the preglabellar field by a slight change in slope but the overall transverse convexity of the glabella is maintained. The posterior limbs are short and broad with sharply pointed ends.

The pygidium is subtriangular with a long, narrow axis composed of eight or nine segments. The pleural lobes are slightly convex and approximately the same width as the axis. The border is separated from the pleural lobes by a distinct border furrow.

Discussion: This species has been fully described by Lochman and Duncan (1944) and the holotype cranidium is from Nixon Gulch, Montana. Blountia nixonensis is an opportunist and, although related to genera of the Crepicephalus Zone, occurs only in the lower part of the Aphelaspis Zone at each
locality in this study. Lochman and Duncan (1944) point out that *Blountia nixonensis* is much more like early *Blountia* species of the Cedaria Zone than the more diverse species of the Crepicephalus Zone.

**Occurrence:** Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 7.9); Nixon Gulch (Horizon 16.6, 16.0, 15.0, 14.8, 14.6, 14.3, 13.8); Sacajawea Peak (Horizon 6.8, 4.4, 4.3, 4.2, 4.1, 4.0, 3.9, 3.8, 3.6, 3.4, 3.1, 3.0).

**Family CATILLICEPHALIDAE** Raymond, 1938

**Genus Pemphigaspis Hall, 1863**

*Pemphigaspis sp.* (undet.)

(Plate 20, Figure 4)

Pemphigaspis Hall, 1863, p.221; Palmer, 1951, p.763; Tasch, 1951, p.302; Rasetti, 1945, p.603.


**Description:** A few cranidia have the anteriorly expanded glabella and Y-shaped posterior glabellar furrows characteristic of this genus. Librigena and pygidium are unknown.

**Discussion:** A few fragmented cranidia were found at the same horizon as *Tricrepicephalus* sp. in the upper part of the Crepicephalus Zone at the Logan and Nixon Gulch sections. Lochman and Duncan (1944) also collected species
of *Pemphigaspis* from the *Crepicephalus* Zone at the Half Moon Pass and Dry Wolf Creek sections in Montana.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (*Crepicephalus* Zone). Logan (Horizon 1.1, .5); Nixon Gulch (Horizon 5.2, 3.6).

Family **CHEILOCEPHALIDAE** Shaw, 1956
Genus *Cheilocephalus* Berkey, 1898
*Cheilocephalus granulosus* Palmer, 1965
(Plate 18, Fig. 4; Plate 19, Fig. 1)

*Cheilocephalus* sp. Palmer, 1962, p.27, pl.3, figs.30,31.


Description: Cranidium broadly conical with a low, moderately convex glabella. The glabella is subrectangular and contains up to three pairs of faint lateral furrows. Occipital furrow is deep and curved anteriorly at the midline of the glabella. The frontal area is slightly concave and is not divided into preglabellar field and border. The posterior limbs are broad with shallow border furrows that curve forward distally. The limbs also contain the distinct "elbows" characteristic of this genus.

The pygidium is semicircular with a long, tapered axis composed of seven segments. The articulating facet is well developed on the pleural lobe and the interpleural furrow is
deep, extending across the border. The border is broad and slightly concave on most specimens. The interpleural furrows continue from the pleural field as broad, shallow depressions across the border.

The outer surface of the cranidium and pygidium is covered with small, closely spaced granules.

Discussion: This species has been fully described by Palmer (1965) and Lochman and Hu (1962). It occurs at the base of the Aphelaspis Zone at each locality and represents one of the new trilobites unrelated to families of the underlying Crepicephalus Zone. This species is distinguished from Cheilocephalus brevilobus by the presence of small granules on the external surfaces of most parts of the exoskeleton.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.6, 8.3, 8.2, 8.1, 8.0, 7.9, 7.8, 7.7, 7.3, 7.1, 7.0, 5.2, 1.8, 1.7, 1.6); Nixon Gulch (Horizon 12.9, 12.0, 10.3, 9.8, 8.6, 8.2, 8.0); Sacajawea Peak (Horizon 1.6, .1).

Cheilocephalus omega (Lochman and Hu) (Plate 17, Figures 2, 3)

Cheilocephalus delandi Shaw, 1956, p.49, pl.10, figs.1-7, pl.11, figs.1-6, pl.12, figs.1, 6.
**Maryvillia omega** Lochman and Hu, 1962, p.435, pl.70, figs.1-21.


Description: Cranidium convex with a strongly convex, broadly conical glabella. The axial furrows are shallow and lateral furrows are absent from the glabella. The frontal area is concave and is not divided into preglabellar field and border. Palpebral lobes are small, flat and contain no palpebral furrow. Eye ridges are faint, intersecting the axial furrows at a slight angle. The occipital furrow is shallow and the occipital ring is narrow. The posterior limbs are short with broad, shallow border furrows. The limbs also have the distinct "elbows" that are characteristic of the genus.

The pygidium is subtriangular in outline with a long, posteriorly tapering axis composed of seven segments. The pleural fields are slightly convex, approximately the same width as the axis anteriorly, but narrowing posteriorly. The border is narrow and steep anteriorly but widens posteriorly with a more gentle slope. The border contains a narrow border furrow that terminates the pleural furrows but not the interpleural grooves.

Discussion: There has been much confusion in the past concerning this species. Shaw (1956) described *C. delandi*...
from Wyoming, recognizing a strongly convex, furrowless glabella in juveniles and a low glabella with three pairs of lateral furrows in adults. Lochman and Hu (1962), working on the Pilgrim Formation in Montana, described several cranidia and pygidia identical to the juveniles in Shaw's collections and renamed them Maryvillia omega. A.R. Palmer (1965) recognized that Lochman and Hu's assignment of C. delandi to Maryvillia was not "justified" and reassigned it to Cheilocephalus omega, acknowledging the species as different from C. delandi. According to Palmer (1965), the congeneric association of C. omega and C. granulosus in Montana is uncommon for the genus.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.6, 8.2, 8.1, 7.9, 7.8, 7.7, 7.3, 7.2, 7.1, 7.0); Nixon Gulch (Horizon 12.9).

Family CREPICEPHALIDAE Kobayashi, 1935
Genus Coosella Lochman, 1936
Coosella perplexa? (Palmer)
(Plate 19, Figure 4)

Crepicephalus? perplexus Palmer, 1954, p.733, pl.77, figs. 1, 2, 4.
**Description:** Pygidium semicircular in outline with a narrow, posteriorly tapering axis composed of three segments and a terminal portion that ends on the border in a pointed ridge. The pleural field is subtriangular with three pairs of distinct pleural furrows and faint interpleural grooves. The border is broad and gently downsloping with a slight median inbend along the posterior margin. The border is narrowest at the anterolateral corners and widens posteriorly. Cranidium and librigena unknown.

**Discussion:** Several poorly preserved pygidia exhibit the characteristics of the species. The specimens closely resemble *C. perplexa* and occur in the basal Aphelaspis Zone beds. This species also occurs in the lowest beds of the Aphelaspis Zone in Texas (Palmer, 1954) and Tennessee (Rasetti, 1965).

**Occurrence:** Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Nixon Gulch (Horizon 7.9).

---

**coosella sp. (undet.)** *(Plate 21, Figure 2)*

*Coosella* Lochman, 1936, p.39; Shimer and Shrock, 1944, p.621.

**Description:** Pygidia similar to *Coosella perplexa*?, except for the absence of a median inbend along the
posterior margin. The border is narrowest at the anterolateral corners and widens posteriorly. The axis is narrow, slightly tapering and terminates in a slender, pointed ridge. Associated cranidium and librigena unknown.

Discussion: Three pygidia without the posterior median inbend were found below the stratigraphic horizon with specimens that do contain the median inbend. Both types of pygidia have smooth surfaces. The absence of a median inbend may result from individual variation or possibly poor preservation.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.5, 3.6).

Genus Coosina Rasetti, 1956
Coosina ariston (Walcott)
(Plate 20, Figure 2)

Maryvillia ariston Walcott, 1916, p.401, pl.64, figs.5, 5'.

Coosina ariston (Walcott) Rasetti, 1956, p.1267 (complete synonymy); 1961, p.111, pl.21, figs.12, 13.

Description: Cranidium moderately low with a tapering, furrowless glabella. Frontal area separated into preglabellar field and border by a broad, shallow anterior border furrow. Palpebral lobes placed slightly anterior to
the center of the glabella and contain a shallow palpebral furrow. The occipital furrow is broad and shallow with a slight median inbend. The occipital ring is narrow. The posterior limbs are short and blunt with very broad posterior border furrows.

The pygidium is semicircular in outline with a wide axis composed of five segments. Pleural fields are convex and contain four pleurae. The border is sharply downsloping and the border furrow is obsolete. Librigenae are unknown.

Discussion: Several large cranidia and pygidia represent this species in the collections. A "coquina" of *C. ariston* occurs just below the base of the *Aphelaspis* Zone at Nixon Gulch and occurs at the same stratigraphic horizon as species of *Coosella* and *Crepicephalus*.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.5, 7.1).

Genus *Crepicephalus* Owen, 1852

*Crepicephalus iowensis* (Owen)

(Plate 20, Figure 1)

*Dikelocephalus iowensis* Owen, 1852, p.575, pl.1, fig.4, pl. 1a, fig.13.

*Crepicephalus iowensis* (Owen) Walcott, 1916, p.207, pl.29, figs.1, 2, 2a-f; Shimer and Shrock, 1944, pl.262, figs.
7, 8.


Description: Cranidium elongate with gently rounded margin. Glabella bluntly rounded with no glabellar furrows visible. Frontal area contains a distinct border furrow and a strongly upturned border. Palpebral lobes are long and slender with a moderately shallow and broad posterior border furrow. The surface of the cranidium is strongly granulated. Pygidia and librigenae unknown.

Discussion: Several cranidia belonging to this species occur in the upper part of the Crepicephalus Zone. This species also occurs in the upper Crepicephalus Zone in Texas (Palmer, 1954) and Montana (Lochman and Duncan, 1944).

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.5).

Crepicephalus sp. (undet. 1) (Plate 21, Figure 4)


Description: Pygidium nearly twice as wide as it is long. Axial lobe is narrow and reaches to the posterior margin. Four pleurae with deep interpleural furrows and
border furrow very prominent. Marginal spines directed straight posteriorly, curving medially near the posterior end of the spines. Length of spines about two-thirds that of the axial lobe. Cranidia and librigenae unknown.

Discussion: This species is most similar to *C. australis*, but is too poorly preserved for specific identification. Several pygidia occur near the top of the Crepicephalus Zone at Nixon Gulch.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.1, 3.6, 2.0).

_Crepicephalus sp. (undet. 2)_  
_(Plate 21, Figure 1)_


Description: The pygidium is broad with a long narrow axis that is two-thirds the length of the pygidium and extends into a border furrow near the posterior margin. The pleural field is relatively small, composed of three distinct furrows but no interpleural grooves. Posterolateral spines are short and curve inward producing a strong curvature to the margin between the spines. Associated cranidium and librigena unknown.
Discussion: Pygidia differ from Crepicephalus sp. (undet. 1) in the stronger curvature of the posterior margin, the presence of three pleural furrows and absence of interpleural grooves and the less distinct border furrow.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.1, 3.6).

Family LONCHOCEPHALIDAE Hupe, 1953
Genus Glaphyraspis Resser, 1937
Glaphyraspis parva (Walcott)
(Plate 19, Figures 2, 3)

Liostracus parvus Walcott, 1899, p.463, pl.65, fig.6.
Raaschella occidentalis Lochman and Duncan, 1944, p.43-44, pl.4, figs.1-5; Shaw, 1956, p.51, pl.12, figs.4, 5.

Description: Cranidium is small with a strongly convex glabella that contains two pairs of deep glabellar furrows. The anterior pair are short and straight and the posterior pair are arcuate posteriorly. The anterior border is short and is separated from the preglabellar field by a distinct anterior border furrow. Faint eye ridges reach the axial furrow well behind the front of the glabella. The occipital furrow is deep and curved along the sides, the occipital ring is broad and flat. The posterior limbs are short with
deep posterior border furrows. Librigenae are short and broad with a distinct lateral border furrow.

Pygidium is short with a moderately wide axis composed of four to five segments and a terminal axial piece. The pleural field is flat and turns down abruptly at the border.

The outer surfaces of the cranidium, pygidium and librigena are covered with irregularly dispersed granules.

Discussion: This species has been fully described by Lochman et al. (1944 and 1962). It is represented in the collections by numerous cranidia, several pygidia and a few librigenae. The species is abundant in the lower Aphelaspis Zone but has also been reported from the upper Crepicephalus Zone in Virginia and Tennessee (Rasetti, 1961, 1965).

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.6, 8.4, 8.3, 8.2, 8.1, 7.8, 7.7, 7.1, 1.4, 1.2); Nixon Gulch (Horizon 16.8, 16.6, 16.0, 14.8, 14.6, 14.1, 13.8, 13.6, 13.5, 13.4, 12.9, 12.0, 7.7, 7.6); Sacajawea Peak (Horizon 6.8, 3.8, 3.2, 3.0, 1.6).

Family PTEROCEPHALIIDAE Kobayashi, 1935
Subfamily APHELASPIDINAE Palmer, 1954
Genus Aphelaspis Resser, 1935
Aphelaspis walcotti Resser, 1938
(Plate 18, Figure 3)
Not *Conocephalites depressus* Shumard, 1861, p.219.

*Aphelaspis depressa* (Shumard) Bridge, in Bridge and Girty, 1937, p.255, pl.69, figs.23-26; Shimer and Shrock, 1944, pl.263, figs.35, 36; Nelson, 1951, p.774, pl.106, fig.14.

*Aphelaspis walcotti* Resser, 1938, p.59, pl.13, fig.14; Shimer and Shrock, 1944, pl.263, figs. 19, 20.

*Aphelaspis hamblenensis* Resser, 1938, p.60, pl.13, fig.28; Shimer and Shrock, 1944, pl.263, fig.37.

**Description:** Cranidium is subrectangular with a straight-sided glabella that is truncate anteriorly. The glabella is commonly featureless although three pairs of faint, slightly arcuate lateral furrows are present on exfoliated specimens. The frontal area is divided into preglabellar field and border that are separated by a sharp break in slope although no border furrow is present. The palpebral lobes are distinct, semicircular in outline and contain shallow palpebral furrows. Faint eye ridges extend to the axial furrow and intersect the furrow at less than a right angle. The occipital furrow is shallow and the occipital ring is broad and flat. The posterior limbs are narrow and contain a distinct posterior border furrow.

The librigena has a distinct lateral border furrow that merges with the posterior border furrow and extends a short distance along the genal spine. The genal spine is of moderate length, distinguishing this species from *A. buttsi*.

**Discussion:** This is the most widespread species of
Aphelaspis in North America and is moderately abundant at the base of the Aphelaspis Zone at each locality. A. walcotti occurs with Cheilocephalus granulosus several centimeters above the last appearance of the Crepicephalus Zone fauna and occurs stratigraphically with the opportunist, Blountia nixonensis approximately six meters above its initial appearance.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 5.2); Nixon Gulch (Horizon 15.4, 10.5, 10.3, 8.1); Sacajawea Peak (Horizon 1.6).

Aphelaspis buttsi (Kobayashi)
(Plate 18, Figures 1, 2)

Olenus cf. O. truncatus Butts, 1926, p.77, pl.9, figs.6, 7.

Proaulacopleura buttsi Kobayashi, 1936, p.93, pl.15, fig.6; Resser 1938, p.95, pl.16, fig.18.

Aphelaspis buttsi (Kobayashi) Palmer, 1962, p.35, pl.4, figs.23, 26, 31, 32.

Description: Cranidium with slightly tapering, subrectangular glabella. Posterior pair of lateral glabellar furrows are moderately impressed, straight and inclined posteriorly. The frontal area is divided into preglabellar field and border that are separated by a
distinct border furrow. The anterior border is moderately convex and tappers laterally from the axial line. The eye ridges are prominent and directed laterally at right angles to the axial furrow. The occipital furrow is shallow and the occipital ring is broad and flat containing a low median node. The posterior limbs are narrow with a shallow border furrow. The librigenae are similar to those of A. walcotti, but have much longer genal spines.

Discussion: This species is distinguished from other species of Aphelaspis by the presence of glabellar furrows, a convex anterior border with a prominent border furrow and eye ridges that intersect the axial furrow at right angles. This is also a common and widespread species of Aphelaspis in North America and is very abundant at the base of the Aphelaspis Zone at each locality.

This species has been reported from the lower Aphelaspis Zone in Tennessee (Rasetti, 1965), the Great Basin (Palmer, 1965) and Alabama (Butts, 1926). A. buttsi is represented in the collections by several cranidia and librigenae but no pygidia were found.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.2, 5.2, 1.6); Nixon Gulch (Horizon 10.6, 10.5, 10.3, 9.8, 8.1); Sacajawea Peak (Horizon 1.6).
Aphelaspis sp. (undet.)
(Plate 17, Figure 4)


Clevelandella Resser, 1938, p.68.


Description: Cranidia showing characteristics of the genus but too poorly preserved for specific identification. Glabella tapering, subrectangular in shape containing faint impressions of two lateral furrows. Frontal area divided into preglabellar field and border that are separated by a distinct border furrow. Anterior border convex and broadest at the axial line. Ocular ridges are prominent and intersect the axial furrow at substantially less than a 90 degree angle. The occipital furrow is broad and shallow and the occipital ring is narrow and flat.

Discussion: Thirteen specimens agree with the concept of the genus Aphelaspis, but are too poorly preserved for specific identification. They differ from A. buttsi in the position of the ocular ridge at an angle to the axial furrow and from A. walcotti in the presence of a distinct anterior
border furrow. They are most similar to *A. conveximarginatus* but lack a posterior median inbend of the marginal furrow.

**Occurrence:** Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Nixon Gulch (Horizon 12.9); Sacajawea Peak (Horizon 1.6).

**Genus Dytremacephalus Palmer, 1954**

*Dytremacephalus granulosus* Palmer, 1954  
(Plate 16, Figure 1)

*Dytremacephalus granulosus* Palmer, 1954, p.750, pl.85, figs.5, 6.

**Description:** Cranidium with slightly tapering, subrectangular glabella. Glabella prominent, elevated above free cheeks with three moderately deep glabellar furrows. The anterior two pair of glabellar furrows are straight and the posterior pair are slightly arcuate posteriorly. The frontal area is divided into preglabellar field and border, separated by a distinct border furrow. Dorsal furrow is deep along the sides of the glabella, but is shallow anteriorly with distinct pits at the anterolateral corners of the glabella. Fixed cheeks moderately arched and gently upsloping. Eye ridges prominent, directed laterally at a slight angle to the axial furrow. Occipital furrow shallow
and occipital ring moderately arched with a low median node. Entire surface of cranidium covered with small, evenly spaced granules. Pygidia and librigenae unknown.

Discussion: Several cranidia were found near the top of the Pilgrim Formation at Nixon Gulch and Sacajawea Peak. Distinguished from other species of Dytremacephalus by the presence of small granules. This species is common in the post-Aphelaspis Zone in Texas and the basal Dunderbergia Zone in the Great Basin. D. granulosus occurs together with B. nixonensis in Montana indicating that B. nixonensis survived long after the extinction of the Crepicephalus Zone fauna. Dytremacephalus also occurs in the overlying Dry Creek Shale (Grant, 1965) indicating the faunal sequence is complete across the Pilgrim-Dry Creek Shale boundary.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis or Dunderbergia? Zone). Nixon Gulch (Horizon 16.8, 16.6, 16.0, 15.4); Sacajawea Peak (Horizon 6.8, 6.6).

Family TRICREPICEPHALIDAE Palmer, 1954
Genus Tricrepicephalus Kobayashi, 1935
Tricrepicephalus sp. (undet.)
(Plate 21, Figure 3)
Tricrepicephalus Kobayashi, 1935, p.278; Shimer and Shrock, 1944, p.635.

Paracrepicephalus Lochman, 1936, p.36.

Description: Pygidium with long spines developed from the surface of the pleural lobes. The width of the axial lobe is greater than one-third of the total pygidial width. The axis is composed of three segments and tappers posteriorly.

The librigenae has a broad, flat border and a well defined border furrow. The genal spine tappers and is sharply pointed posteriorly. The outer surface of the carapace is covered with moderately large, evenly spaced granules.

Discussion: This genus is represented in the collections by two pygidia and five librigenae that are too poorly preserved for specific identification. The pygidia agree with the concept of the genus in that the paired pygidial spines are developed from the surface of the pleural lobes.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Logan (Horizon 1.1, .5); Nixon Gulch (Horizon 7.1, 2.8).

Phylum BRACHIOPODA Cuvier, 1805
Class INARTICULATA Huxley, 1869
Iphidella Walcott, 1912, p.359.

Dictyonina Cooper, 1942, p.228; Shimer and Shrock, 1944, p.287; Cooper, in Cooper et. al., 1952, p.40.

Description: The surface of the shell is composed of a meshwork of hexagonal perforations that resemble a screen. The perforations are separated by ridges of solid shell material composed of closely spaced perforations. The beak and margin are also composed of solid shell material similar to the ridges.

Discussion: This species is characterized by the distinct perforations of the shell and is moderately abundant near the base of the Aphelaspis Zone. Palmer (1954) suggests that the perforations result from slight solution by acetic acid during extraction, but several specimens collected in the field from Nixon Gulch show that the perforations are a distinct feature of the original morphology. This species usually appears at the very base of the Aphelaspis Zone (Palmer, personal communication) but occurs up to nine meters above the lowest appearance of Aphelaspis at Nixon Gulch. The species is represented in the collections by numerous fragments and several intact pedicle valves that are remarkably well-preserved.
Phylum MOLLUSCA
Class GASTROPODA Cuvier, 1797
Order MONOPLACOPHORA Wenz in Knight, 1952
Family TRYBLIDIIDAE Pilsbry in Zittel-Eastman, 1899
Genus Proplina Kobayashi, 1933
Proplina loganensis Lochman and Hu, 1962
(Plate 17, Figure 1)


Description: Internal mold of shell with pointed apex broken. Aperture smoothly curved along anterior margin and straight along lateral margins. Surface shows closely spaced growth ridges that parallel the aperture. The fine lirae radiating from the apex in Lochman's specimens are not visible.

Discussion: One internal mold found at Nixon Gulch and one found at Sacajawea Peak are nearly identical to the specimens collected by Lochman at Logan, Montana.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Nixon Gulch (Horizon 12.9); Sacajawea Peak (Horizon 6.8).
At least one of the best preserved specimens of each described species is illustrated. Each fossil was coated with magnesium oxide by holding the specimens over a burning magnesium ribbon. The magnesium ribbon was held under an inverted funnel on a stand in order to concentrate the smoke and allow for a more uniform application to the specimens. Plates and specimens are listed in biostratigraphic order from oldest to youngest. All of the collection is housed at the Museum of Paleontology, University of Montana.
### Plate 16. Aphelespis Zone Fossils

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dytremacephalus Palmer</td>
<td>137</td>
</tr>
<tr>
<td>Partly exfoliated cranidium.</td>
<td></td>
</tr>
<tr>
<td>2. Dictyonina perforata Palmer</td>
<td>137</td>
</tr>
<tr>
<td>Exterior of brachial valve.</td>
<td></td>
</tr>
<tr>
<td>3. Blountia nixonensis Lochman and Duncan</td>
<td>137</td>
</tr>
<tr>
<td>Cranidium.</td>
<td></td>
</tr>
<tr>
<td>4. Blountia nixonensis Lochman and Duncan</td>
<td>137</td>
</tr>
<tr>
<td>Pygidium.</td>
<td></td>
</tr>
</tbody>
</table>
# Plate 17. Aphelaspis Zone Fossils

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Proplina loganensis Lochman and Hu ..........</td>
<td>139</td>
</tr>
<tr>
<td>Internal mold of shell.</td>
<td></td>
</tr>
<tr>
<td>2. Cheilocephalus omega (Lochman and Hu) ........</td>
<td>139</td>
</tr>
<tr>
<td>Exfoliated cranidium.</td>
<td></td>
</tr>
<tr>
<td>3. Cheilocephalus omega (Lochman and Hu) ........</td>
<td>139</td>
</tr>
<tr>
<td>Exfoliated pygidium.</td>
<td></td>
</tr>
<tr>
<td>4. Aphelaspis sp. (undet.) .......................</td>
<td>139</td>
</tr>
<tr>
<td>Partly exfoliated cranidium.</td>
<td></td>
</tr>
</tbody>
</table>
PLATE 18. APHELASPIS ZONE FOSSILS

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aphelaspis buttsi (Kobayashi) ................. 141</td>
<td>Exfoliated cranidium.</td>
</tr>
<tr>
<td>2. Aphelaspis buttsi (Kobayashi) ................. 141</td>
<td>Partly exfoliated librigena.</td>
</tr>
<tr>
<td>3. Aphelaspis walcotti Resser .................... 141</td>
<td>Fragment of an exfoliated cranidium.</td>
</tr>
</tbody>
</table>
PLATE 19. APHELASPIS AND CREPICEPHALUS ZONE FOSSILS

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cheilocephalus granulosus Palmer</td>
<td>143</td>
</tr>
<tr>
<td>Exfoliated pygidium.</td>
<td></td>
</tr>
<tr>
<td>2. Glaphyraspis parva (Walcott)</td>
<td>143</td>
</tr>
<tr>
<td>Cranidium.</td>
<td></td>
</tr>
<tr>
<td>3. Glaphyraspis parva (Walcott)</td>
<td>143</td>
</tr>
<tr>
<td>Pygidium.</td>
<td></td>
</tr>
<tr>
<td>4. Coosella perplexa?</td>
<td>143</td>
</tr>
<tr>
<td>Exfoliated pygidium.</td>
<td></td>
</tr>
</tbody>
</table>
PLATE 20. CREPICEPHALUS ZONE FOSSILS

Figures Page

1. Crepicephalus iowensis (Owen) .................. 145 Cranidium.
2. Coosina ariston (Walcott) ....................... 145 Exfoliated cranidium.
4. Pemphigaspis sp. (undet.) ....................... 145 Rubber cast of a cranidium.
PLATE 21. CREPICEPHALUS ZONE FOSSILS

Figures Page

1. Crepicephalus sp. (undet. 2) ..................... 147
   Partly exfoliated pygidium.

2. Coosella sp. (undet.) .......................... 147
   Partly exfoliated pygidium.

3. Tricrepicephalus sp. (undet.) .................. 147
   Exfoliated pygidium.

4. Crepicephalus sp. (undet. 1) .................... 147
   Exfoliated pygidium.
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PALEONTOLOGY AND CARBONATE PETROLOGY
ACROSS THE
MARJUMIID-PTEROCEPHALIID BIOMERE BOUNDARY
SOUTHWESTERN MONTANA

by

Robert C. Thomas

B.A. Humboldt State University, 1985
Presented in partial fulfillment of the requirements
for the degree
Master of Science
University of Montana
1987

Approved by:

[Signatures]
Chairman, Board of Examiners
Dean, Graduate School

Date
THOMAS, Robert C., M.S., June 1987

Geology

Paleontology and Carbonate Petrology Across The Marjumiid-Pterocephaliid Biomere Boundary, Southwestern Montana (147 pp.)

Director: Don Winston

The Upper Cambrian (Dresbachian) Marjumiid-Pterocephaliid trilobite biomere boundary occurs within the upper oolitic member of the Pilgrim Formation in the Bridger Range and Horseshoe Hills, southwestern Montana. Three stratigraphic sections collected at 10 cm intervals across the boundary show that Coosina, Coosella, Pemphigaspis, Tricrepicephalus, and Crepicephalus of the Crepicephalus Zone (Marjumiid biomere) are abruptly succeeded within 5 cm of uniform pelsparite by Glaphyraspis of the Aphelaspis Zone (Pterocephaliid biomere). Cheilocephalus and Aphelaspis, unrelated trilobites of the Aphelaspis Zone appear 40 cm above the boundary indicating that these genera are immigrants and did not originate on the shelf. Blountia nixonensis, an opportunistic species related to genera of the Crepicephalus Zone, appears in the section well above the extinction boundary and was apparently well adapted to the environmental changes that exterminated the remainder of the Crepicephalus Zone fauna.

The upper oolitic member of the Pilgrim Formation consists primarily of interbedded oolite and pelsparite. Digitate stromatolites occur at the top of the member at each locality. These lithologies record shallow water shoal, restricted platform and shallow subtidal to possibly lower intertidal deposition during a shallowing-upward sequence. The biomere boundary occurs within uniform pelsparite and does not coincide with any physical break in carbonate deposition at the boundary. The boundary does, however, occur within a shallowing-upward sequence that precedes a regionally recognized regression at the base of the overlying Dry Creek Shale. Changing environmental conditions during regression may have exterminated the Crepicephalus Zone fauna without leaving any record of the change in the sediments at the boundary.
ACKNOWLEDGMENTS

Field and laboratory expenses for this project were funded in part by a grant-in-aid of research from Sigma Xi Research Society. Travel funds for field reconnaissance and a trip to Boulder, Colorado to consult with Dr. Allison R. Palmer were provided by Dr. Don Winston. John Cuplin and DeWayne Williams helped prepare the photographic plates. I thank my advisors, Dr. Fred Allendorf, Dr. Ray Murray and Dr. Don Winston for taking a genuine interest in this project. Special thanks to Don Winston who gave unsparingly of his time and critically reviewed this manuscript with a generous supply of green ink. Thanks also to Dr. Allison R. Palmer of the Geologic Society of America and Lucy Chronic of the University of Wyoming for many informative "biomere" conversations.

Thanks to ranchers Jim Walma and Mark Cosier for access to collecting localities and to Don and Marlene Bastian for their hospitality throughout the summer field season. Field assistance provided by Dan Garcia and Anneliese Ripley added much to the effectiveness and accuracy of the field work. Their energy and interest helped me through the times of fatigue and frustration.

I most sincerely thank my parents for financial support during hard times and for persistent encouragement.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Biomeres</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Purpose and Scope</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Methods</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Depositional Model and Interpretations</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Regional Cambrian Stratigraphy</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Dresbachian Biostratigraphy of Montana</td>
<td>23</td>
</tr>
<tr>
<td>II.</td>
<td>DESCRIPTION AND INTERPRETATION OF ROCK TYPES</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Oolitic Rock Type</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Peloidal Rock Type</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Intraclastic Rock type</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Algal Rock Type</td>
<td>51</td>
</tr>
<tr>
<td>III.</td>
<td>STRATIGRAPHIC CORRELATIONS</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Lithostratigraphic Correlations</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Biostratigraphic Correlations</td>
<td>60</td>
</tr>
<tr>
<td>IV.</td>
<td>ENVIRONMENTAL SYNTHESIS</td>
<td>73</td>
</tr>
<tr>
<td>V.</td>
<td>MARJUMIID-PTEROCEPHALIID BIOMERE BOUNDARY</td>
<td>78</td>
</tr>
<tr>
<td>REFERENCES CITED</td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Measured Sections</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Systematic Paleontology</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Fossil Illustrations (Plates)</td>
<td>135</td>
<td></td>
</tr>
</tbody>
</table>
LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stitt's four stages of a biomere</td>
<td>2</td>
</tr>
<tr>
<td>2. Palmer's original conceptualization of a biomere</td>
<td>4</td>
</tr>
<tr>
<td>3. Documented biomeres</td>
<td>6</td>
</tr>
<tr>
<td>4. Well documented biomere localities</td>
<td>7</td>
</tr>
<tr>
<td>5. Biomere boundary revisions</td>
<td>9</td>
</tr>
<tr>
<td>6. Location map of study area and measured sections</td>
<td>12</td>
</tr>
<tr>
<td>7. Cambrian stratigraphy in Montana</td>
<td>20</td>
</tr>
<tr>
<td>8. Relationship of the three Upper Cambrian biomeres to Cambrian strata in Montana</td>
<td>22</td>
</tr>
<tr>
<td>9. Proposed strato-type stages based on biomeres</td>
<td>25</td>
</tr>
<tr>
<td>10. Stratigraphic ranges for Dresbachian trilobites in Montana</td>
<td>27</td>
</tr>
<tr>
<td>11. Legend for stratigraphic columns</td>
<td>58</td>
</tr>
<tr>
<td>12. Lithostratigraphic correlations</td>
<td>59</td>
</tr>
<tr>
<td>13. Correlation of the biomere boundary between Logan and Nixon Gulch</td>
<td>61</td>
</tr>
<tr>
<td>14. Stratigraphic ranges for trilobites at Logan</td>
<td>63</td>
</tr>
<tr>
<td>15. Stratigraphic ranges for trilobites at Nixon Gulch</td>
<td>66</td>
</tr>
<tr>
<td>16. Stratigraphic ranges for trilobites at Sacajawea Peak</td>
<td>70</td>
</tr>
</tbody>
</table>
17. Block diagram of the environments of deposition ........................................ 74
18. Legend for measured sections .................. 94
19. Stratigraphic ranges for trilobites, brachiopods and gastropods at each section .......................... 111

PLATE

1. Figure 1 - field photo of the Logan section ........................................ 13
2. Figure 1 - field photo of the Nixon Gulch section ........................... 14
3. Figure 1 - field photo of the Sacajawea Peak section .................... 15
4. Figure 1 - field photo of the oolitic rock type .................................. 29
4. Figure 2 - photomicrograph of the oolitic rock type .......................... 29
5. Figure 1 - radial pattern in a ooid .............. 32
6. Figure 1 - field photo of the peloidal rock type ................................. 36
6. Figure 2 - photomicrograph of the peloidal rock type .......................... 36
7. Figure 1 - photomicrograph of the dolomitic partings ...................... 37
8. Figure 1 - field photo of the intraclastic rock type ............................. 45
9. Figure 1 - photomicrograph of the intraclastic rock type .................. 47
9. Figure 2 - photomicrograph of the intraclastic rock type .................. 47
10. Figure 1 - photomicrograph of vadose silt ................................. 49
10. Figure 2 - photomicrograph of radiaxial fibrous calcite ...................... 49
11. Figure 1 - field photo of the algal rock type .................................. 52
11. Figure 2 - photomicrograph of the algal rock type ............................ 52
12. Figure 1 - field photo of biomere boundary at Logan .......................... 64
13. Figure 1 - polished slab photo of the biomere boundary at Logan .......... 65
14. Figure 1 - field photo of biomere boundary at Nixon Gulch .................. 68
15. Figure 1 - polished slab photo of the biomere boundary at Nixon Gulch .... 69
16. Aphelaspis Zone trilobites .................................................. 137
17. Aphelaspis Zone trilobites .................................................. 139
18. Aphelaspis Zone trilobites .................................................. 141
19. Aphelaspis Zone and Crepicephalus Zone trilobites ............................ 143
20. Crepicephalus Zone trilobites ............................................. 145
21. Crepicephalus Zone trilobites ............................................. 147
CHAPTER I
INTRODUCTION

BIOMERES

The Late Cambrian trilobite sequence in North America is punctuated by three mass extinction events that define three extinction-bounded biostratigraphic units called biomeres (Palmer, 1965). Allison R. Palmer (1965) first described biomeres from the non-agnostid trilobite sequences in Cambrian shallow water shelf limestones of the Great Basin. A biomere is a sharply bounded biostratigraphic unit representing immigration of trilobite stocks, progressive evolutionary development and diversification of those stocks ending with abrupt extinction (Palmer, 1965). At many localities, these extinctions are not accompanied by apparent physical discontinuities in the sedimentary record, and they may be diachronous (Palmer, 1984).

James Stitt (1971, 1975 and 1977) recognized a repeating pattern of evolution of the non-agnostid trilobite populations of the Pterocephaliid and Ptychaspid biomeres, and established a four-stage evolutionary sequence for each biomere (Fig. 1). Stage 1 trilobites are immigrants characterized by low faunal diversity, wide intraspecific variation and short stratigraphic ranges. Low faunal diversity persists into stage 2, but intraspecific variation
Figure 1. (Modified from Stitt, 1977)

Stage 1: Immigrants (generalists) with low faunal diversity and wide intraspecific variation.

Stage 2: Low faunal diversity continues but intraspecific variation is reduced.

Stage 3: High faunal diversity, low intraspecific variation. Stratigraphic ranges of species are long.

Stage 4: Low faunal diversity, short stratigraphic ranges and coquinoid abundances of one or two species. Stage 4 ends with total extinction of the pre-existing fauna.
is reduced and stratigraphic ranges of individual species are longer than the previous stage. Stage 3 is characterized by high species diversity and low intraspecific variation. The stratigraphic ranges of individual species are long, and new species evolved only as minor adjustments to well adapted trilobite stocks. Stage 4 is characterized by low species diversity, short stratigraphic ranges and coquinoid abundances of one or two species that are members of the established families of the biomere. The end of stage 4 is marked by the total extinction of the pre-existing fauna. This evolutionary sequence is repeated in each biomere and records an iterative pattern of invasion, evolution and extinction. The morphological similarity of successive invaders in stage 1 of each biomere suggests that the immigrants came from similar, slowly evolving lineages, but no record of where the invading trilobites of these lineages came from has been preserved.

Palmer (1965) proposed that the immigrants came from a slowly evolving stock of oceanic trilobites that appeared on the shallow shelf only after the extinction of the established shelf fauna (Fig. 2). Stitt (1975) elaborated on this idea, suggesting that a rapid rise in the thermocline and subsequent temperature drop of the Late
Figure 2. Palmer's (1965) original conceptualization of a biomere. (Modified from Palmer, 1984)
Cambrian epicontinental seas might have killed the highly specialized shelf faunas and instigated a migration of oceanic trilobites adapted to cooler waters. He (1975) argued that in this fashion, the extinction would be slightly diachronous and would leave no recognizable imprint within the sedimentary record. Ludvigsen (1982), on the other hand, argued that biomere extinctions are a response to environmental shifts that brought outer shelf environments over inner shelf environments and therefore coincide with lithological changes in the sedimentary record. In addition, Lochman-Balk (1974) proposed that the extinctions were caused by widespread cooling events that coincide with global regressions at each biomere boundary. Palmer (1982) has even suggested that extraterrestrial impacts may have caused the extinctions.

Since the introduction of the biomere concept, three Late Cambrian biomeres have been recognized and well documented: (1) the Marjumiid biomere, (2) the Pterocephaliid biomere and (3) the Ptychaspid biomere (Fig. 3). At well documented biomere boundaries (Fig. 4), relatively rich assemblages of trilobites, including genera and species of several families, are abruptly overlain by assemblages of new trilobites belonging to different families. These faunal changes rarely coincide with
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<th>ZONE</th>
<th>BIOMERE</th>
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<td>Saukia</td>
<td>Ptychaspid Biomere</td>
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<td>Franconian</td>
<td>Saratogia</td>
<td>Taenicephalus</td>
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<td>Elvinia</td>
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<td>Dunderbergia</td>
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<td>Aphelaspis</td>
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<td>Crepicephalus</td>
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<td>Middle Camb.</td>
<td>Bolaspidella</td>
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<td>Bathyuris.-Elrath.</td>
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Figure 3. Well documented biomeres and their relationship to Cambrian stages and faunal zones. (Compiled from Sepkoski, 1977 and Palmer, 1984)
Figure 4.

physical discontinuities in the sedimentary record.

Palmer (1979), in an attempt to document the sharpness of a biomere boundary, recollected across the Marjumiid-Pterocephaliid biomere boundary at several localities across the Great Basin. The added detail narrowed the boundary interval to a few centimeters at several localities and brought about a revision in the biostratigraphic placement of the boundary (Fig. 5). According to Palmer (1979), a 10-20 centimeter interval exists where opportunists from the pre-existing fauna occur together with generalists of the new fauna. Palmer interprets this "zone of mixing" as a time of crisis when opportunists from the earlier fauna attempt to adjust to new environmental conditions, while competing with the incoming, more generalized trilobites. He (1979) concluded that the emphasis should be placed on the crisis aspect of biomere boundaries and shifted the base of each biomere downward to include the opportunists Corbinia apopsis, Irvingella major and Coosella perplexa (Fig. 5). The revision redefines Stitt's terminal declining stage (stage 4) as the initial developmental stage of a biomere (stage 1) and makes the trilobite extinctions consistent with major changes in the inarticulate brachiopod and conodont faunas (Rowell and Brady, 1976; Miller, 1978).

The mixed zone is now recognized at many localities in
### PROPOSED BOUNDARY REVISIONS

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<td>stage 1</td>
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<td>stage 4</td>
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<td>stage 3</td>
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<tr>
<td>Saratogia Zone</td>
<td>stage 1</td>
<td>stage 2</td>
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<td>Taenicephalus Zone</td>
<td>stage 4</td>
<td>stage 1</td>
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<td>Irvingella major</td>
<td>stage 3</td>
<td>stage 4</td>
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<td>Elvinia Zone</td>
<td>stage 1</td>
<td>stage 2</td>
</tr>
<tr>
<td>Dunderbergia Zone</td>
<td>stage 3</td>
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<td>Prehousia Zone</td>
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<td>Dicanthopyge Zone</td>
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<td>stage 2</td>
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<td>Aphelaspis Zone</td>
<td>stage 1</td>
<td>stage 2</td>
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<tr>
<td>Coosella perplexa</td>
<td>stage 1</td>
<td>stage 1</td>
</tr>
<tr>
<td>Crepicephalus Zone</td>
<td>Marjumiid Biomere</td>
<td>Marjumiid Biomere</td>
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Figure 5. Palmer's (1979) proposed boundary revisions.
North America, including sections across the Marjumiid-Pterocephaliid biomere boundary within the Pilgrim Formation in southwestern Montana (Bonem, 1972). However, previous collections across the boundary in Montana have been very widely spaced and the details, on a centimeter scale, are still unknown.

PURPOSE AND SCOPE

The objectives of this study are to: (1) describe the Marjumiid-Pterocephaliid biomere boundary in southwestern Montana from detailed collections of trilobites, (2) determine if the faunal change coincides with any physical discontinuities or subtle changes in carbonate deposition and (3) evaluate Palmer's (1979) boundary revisions.

Petrography of the carbonate sedimentation and subsequent diagenesis across the boundary, especially with tight biostratigraphic control, was analyzed to determine if the faunal change occurs at a physical discontinuity or subtle change in carbonate sedimentation. The validity of Palmer's boundary revisions was evaluated by determining the extent of the mixed interval at the base of the Aphelaspis Zone in southwestern Montana.
METHODS

Three stratigraphic sections across the Marjumiid-Pterocephaliid biomere boundary were measured in the Bridger Range and Horseshoe Hills in southwestern Montana. The sections are named: (1) Logan, (2) Nixon Gulch and (3) Sacajawea Peak (Fig. 6). Field photographs of each section are illustrated in Plates 1, 2 and 3. Each section was measured and described at 10 cm intervals across the boundary, ending each section at the overlying Dry Creek Shale. Trilobites and hand samples for petrographic analysis were collected both vertically and laterally from each 10 cm interval, but trilobite collections tend to be more widely spaced because of unfossiliferous intervals. Lithostratigraphic and biostratigraphic intervals were correlated between each measured section, noting any lateral and/or vertical change in petrography across the boundary.

Large (2" X 3" and 3" X 4") thin sections of the carbonate rocks were prepared, and the primary and diagenetic fabrics were described and interpreted. Trilobites were identified from published descriptions to species level when possible, and many identifications were reviewed and confirmed by Dr. A. R. Palmer. Many trilobites were exhumed by heating and quenching of fossiliferous samples as suggested by Palmer (Palmer, personal
Figure 6. Location map of study area and measured sections.
1 - Logan
2 - Nixon Gulch
3 - Sacajawea Peak
Figure 1. Field photo of the Logan section.
Figure 1. Field photo of the Nixon Gulch section.
Figure 1. Field photo of the Sacajawea Peak section.
communication, 1986), and several samples were treated with formic acid for brachiopods, although very few brachiopods or other fossils were found.

DEPOSITIONAL MODEL AND INTERPRETATIONS

The upper oolitic member of the Pilgrim Formation represents shallow water shoal, restricted platform and shallow subtidal to possibly lower intertidal deposition along the eastward margin of a stable shelf environment.

Interbedded oolite and pelsparite at the base of each section grades upsection to predominantly pelsparite. A thick sequence of digitate stromatolites occurs at the top of each section and is abruptly overlain by the Dry Creek Shale Member of the Snowy Range Formation.

Oolites probably represent platform-edge shoals similar to those along the western edge of the Great Bahama Bank (Newell et al., 1960; Ball, 1967). Overlying pelsparite intervals were deposited on a moderately restricted platform cratonward of the distal margins of the ooid shoals and thin oolitic interbeds within pelsparites probably represent lobate ooid spillover sheets deposited by migrating shoals. The increase in pelsparite upsection and the abrupt appearance of digitate stromatolites at the top of each section is interpreted to record continued shallowing
upsection to the base of the overlying Dry Creek Shale.

The Marjumiid-Pterocephaliid biomere boundary occurs within uniform pelsparite and does not coincide with any physical discontinuity or subtle change in carbonate deposition. At the boundary, trilobites of the Crepicephalus Zone (Coosina, Coosella, Pemphigaspis, Tricrepicephalus and Crepicephalus) are abruptly overlain by trilobites of the Aphelaspis Zone (Glaphyraspis, Aphelaspis and Cheilocephalus). Coosella perplexa, an opportunistic species related to genera of the Crepicephalus Zone, is mixed with Glaphyraspis of the Aphelaspis Zone for approximately 30 cm above the boundary. Another opportunist, Blountia nixonensis, appears several meters above the boundary and is confined to the algal rock type at each locality. Blountia's persistence into the Aphelaspis Zone well after the extinction indicates that it was well adapted to the environmental changes that exterminated the remainder of the Crepicephalus Zone fauna. The extension of Blountia well into the Aphelaspis Zone, and therefore the extension of the "mixed" or "crisis" interval well into the Aphelaspis Zone, suggests that Palmer's (1979) boundary revisions are valid. Without the revisions, the biomere boundary would be placed nearly 9.0 m above the extinction of most of the Crepicephalus Zone fauna and a long period of
adaptation and diversification of the new fauna would wrongly be included in Stitt's (1975) terminal declining stage 4.

Although the extinction of the *Crepicephalus* Zone fauna does not precisely coincide with a discontinuity surface, the extinction does occur within a shallowing upward sequence within the upper part of the Pilgrim Formation that precedes the regionally recognized Dresbachian-Franconian regression at the base of the overlying Dry Creek Shale (Lochman-Balk, 1970). Changing environmental conditions during regression may have exterminated the *Crepicephalus* Zone fauna without leaving any record of the change in the sediments at the boundary.

**REGIONAL CAMBRIAN STRATIGRAPHY**

A westward thickening sequence of Middle Cambrian through Upper Cambrian platform carbonates and shales record eastward transgression of the Cambrian epicontinental sea on the subsiding, early Paleozoic, trailing continental margin. Cyclic sedimentary patterns similar to those described by Aitken (1966, 1978, 1981) characterize the Cambrian sequence. Each cycle consists of a lower, shaly half-cycle gradationally overlain by a thick carbonate half-cycle. These cycles are produced by lateral shifts of the inner
detrital, middle carbonate and outer detrital belts (Palmer, 1960) during eustatic sea level fluctuations or changes in the rate of carbonate production (Aitken, 1966).

In western Montana near Philipsburg, the Cambrian reaches a maximum thickness of 2200 ft. (Hanson, 1952) and thins to approximately 900 ft. to the east in the Little Rocky Mountains. Cambrian positive cratonic features include "Montania" in northwestern Montana and "The Skull Canyon Uplift" along the Idaho-Montana border west of Yellowstone Park. Sepkoski (1977) suggests that "The Skull Canyon Uplift" may have influenced deposition of the upper oolitic member of the Pilgrim Formation through Dresbachian uplift, erosion and deposition of thick quartz sands near the top of the Pilgrim Formation in southwestern Montana. He (1977) also attributes the appearance of stromatolites at the top of the Pilgrim Formation in southwestern Montana to Dresbachian uplift and the establishment of intertidal flats.

Middle and Upper Cambrian platform carbonates and shales conformably overlie the lower Middle Cambrian Flathead Sandstone in southwestern Montana (Fig. 7). Cambrian strata above the Flathead Sandstone consists of alternating shales (Wolsey Shale, Park Shale and Dry Creek Shale Member of the Snowy Range Formation) and limestones
CAMBRIAN STRATIGRAPHY IN MONTANA

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<th>PHILLIPSBURG</th>
<th>BIG SNOWY RANGE</th>
<th>BRIDGER RANGE</th>
<th>S.E. MONTANA</th>
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<td>Steam-boat 1s</td>
<td>Park sh</td>
<td>Meagher sh</td>
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Figure 7. Cambrian stratigraphy in Montana. (Modified from Hanson, 1952)
(Meagher Formation, Pilgrim Formation and Snowy Range Formation). The Marjumiid-Pterocephaliid biomere boundary occurs within the Pilgrim Formation in southwestern Montana. The relationship of the three Upper Cambrian biomeres to Cambrian strata in southwestern Montana is illustrated in Figure 8.

The Pilgrim Formation and its stratigraphic equivalents (Hasmark Formation to the west and Dunoir Formation in western Wyoming) vary in both thickness and lithology. Variations in thickness reflect a possible intra-Cambrian unconformity produced by "The Skull Canyon Uplift" and post-Cambrian-pre-Upper Devonian erosion produced by the Central Montana Uplift (Lochman and Duncan, 1944; Sepkoski, 1977).

The Pilgrim Formation consists primarily of oolitic limestone, laminated pelsparite, shale, various stromatolitic carbonates and intra-formational conglomerate beds. These dominantly carbonate lithologies pass laterally to massive dolomite to the north (Devils Glen Dolomite) and west (Hasmark Formation) and flat-laminated quartz siltstone and peloidal limestone to the southeast (Gros Ventre Formation) in Wyoming (Sepkoski, 1977).

Within the study area, the Pilgrim Formation consists of three well-defined informal members: (1) the lower oolitic member, (2) the middle member and (3) the upper
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<td>+ APHELASPIS</td>
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Figure 8. Relationship of the three Upper Cambrian biomeres to Cambrian strata in southwestern Montana. (Compiled from Grant, 1965 and Sepkoski, 1977)
oolitic member (Sepkoski, 1977). The lower oolitic member is a thick-bedded limestone (3 to 15 m thick) composed primarily of oosparite with a few non-oolitic interbeds. The middle member is a less resistant unit, 30 to 60 m thick, composed of laminated limestone or dolomite interbedded with quartz siltstone in the west and intercalated shale, limestone and flat-pebble conglomerate in the east. The upper oolitic member is a thick-bedded to massive limestone (0 to 75 m thick), composed primarily of oolite that is interbedded with pelsparite and intrasparite near the top of the member. The member is capped by a thick (2 to 8 m) sequence of digitate stromatolites at several localities in southwestern Montana, and the Marjumiid-Pterocephaliid biomere boundary occurs within the upper part of this member.

DRESBACHIAN BIOSTRATIGRAPHY OF MONTANA

Upper Cambrian strata of North America is currently divided into three stages and eight biostratigraphic zones (refer to Fig. 3). The boundaries of the three Upper Cambrian stages coincide with established zonal boundaries, but do not coincide with major faunal extinctions (biomeres) recognized throughout North America. This inconsistency has
recently prompted Ludvigsen and Westrop (1985, 1987) to propose a succession of new strato-type defined stages based on biomerces (Fig. 9). Opposition to the proposed stages has been strong (Geology Forum, 1985) and the problem is currently unresolved. In this study, the traditional Upper Cambrian stages are used and biomerces are treated as unique biostratigraphic units that are not synonymous with stages.

The Dresbachian stage consists of three faunal zones in southwestern Montana: (1) Cedaria, (2) Crepicephalus and (3) Aphelaspis Zones (refer to Fig. 3). The Dunderbergia Zone has been recognized only in the outer middle carbonate belt of the Great Basin (Palmer, 1960) and is apparently absent in southwestern Montana and elsewhere (Grant, 1965; Bonem, 1972; Lochman-Balk, 1974). Traditionally, the absence of the Dunderbergia Zone has been explained by nondeposition or erosion during a Late Dresbachian regression (Lochman-Balk and Wilson, 1958). Sepkoski (1977), however, proposed that the Dunderbergia Zone may be a biofacies restricted to the margins of the craton rather than a regional faunal assemblage. He based the proposal on the discovery of Aphelaspis Zone trilobites in the lower Dry Creek Shale in southwestern Montana (Shaw, 1956; Grant, 1965) and noted that an unconformity does not exist at or near the last appearance of trilobites of the Aphelaspis
### Table: Proposed Stages and Biomeres

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<tr>
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<td>Middle Cambrian</td>
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<td>Marjumiid Biomere</td>
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**Figure 9.** Strato-type stages proposed by Ludvigsen and Westrop (1985). (Modified from Ludvigsen and Westrop, 1985)
Zone.

The **Cedaria**, **Crepicephalus** and **Aphelaspis** Zones occur in the Pilgrim Formation in southwestern Montana (Lochman and Duncan, 1944; Bonem, 1972). The stratigraphic ranges for Dresbachian trilobites in the Pilgrim Formation in southwestern Montana (Fig. 10) shows that the transition between the **Cedaria** and **Crepicephalus** Zones is gradational while the **Crepicephalus-Aphelaspis** boundary is sharp. The abrupt change in fauna at the **Crepicephalus-Aphelaspis** boundary reflects the extinction of most of the **Crepicephalus** Zone fauna at the Marjumiid-Pterocephaliid biomere boundary. Mixed faunas consisting of **Aphelaspis** and species related to genera of the **Crepicephalus** Zone occur near the base of the **Aphelaspis** Zone in southwestern Montana (Bonem, 1972). These mixed faunas are similar to those described by Palmer (1954) from Texas and by Rasetti (1965) from Tennessee.
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Figure 10. Stratigraphic ranges for Dresbachian trilobites in the Pilgrim Formation in Montana. (Compiled from Lochman and Duncan, 1944; Lochman and Hu, 1962; Lochman, 1950, and Sepkoski, 1977)
CHAPTER II
DESCRIPTION AND INTERPRETATION OF ROCK TYPES

The primary rock types in the upper oolitic member of the Pilgrim Formation are: (1) the oolitic rock type, (2) the peloidal rock type, (3) the intraclastic rock type and (4) the algal rock type.

Rock type descriptions are based on field observations and petrographic analysis of 151 thin sections. The descriptions include composition, morphology, and distribution of grains, cements and diagenetic fabrics. Folk's (1959) classification for carbonate rocks is used in preference to Dunham's (1962) classification because I feel Folk's classification focuses more on grain composition. Rock types are based on descriptions of primary fabrics and diagenesis while interpretations are based on stratigraphic relationships, analogies with modern carbonate environments and comparisons to similar paleoenvironments.

OOLITIC ROCK TYPE
Description:

Primary Fabrics. The oolitic rock type (Plate 4) consists of well-sorted, grain supported, mottled oosparite in tabular beds .50 to 1.0 m thick. Ooids are spherical and
Figure 1. Field photo of the oolitic rock type.

Figure 2. Photomicrograph of the oolitic rock type.
range from .30 to .50 mm in diameter. The nuclei of well preserved ooids are composed of fine-grained micritic peloids, trilobite and eocrinoid bioclasts and broken ooids. Ooids with bioclastic cores are commonly kidney-shaped. Quartz grains, which constitute less than 3% of this rock type, never act as nuclei.

Other common carbonate grains include compound ooids, oolitic grapestone aggregates and intraclasts of cemented oosparite. The oosparite intraclasts range from .20 to 4.0 cm in length and are generally ellipsoidal with well rounded margins. Oosparite intraclasts are restricted to the oolitic rock type. Asymmetric and broken ooids are abundant near the top of the Pilgrim Formation at each locality.

Trilobites and eocrinoids are the dominant skeletal grains in oosparite, but rarely constitute more than 20% of the allochems. Most of the bioclasts are broken and randomly dispersed.

Rare burrows, .30 to .70 mm in diameter, occur in small patches of micrite within the oosparite. The burrows have compaction rims of micrite, and carbonate grains at the bases of the burrows are loosely packed and overlain by sparry calcite, producing geopetal structures.

**Diagenesis.** Ooids display a variety of alteration fabrics ranging from ooids with well preserved lamellae to
oooids with no preserved internal structure. This alteration imparts a distinctive mottling to the oolite beds, typical of the upper oolitic member in the region (Peale, 1893; Brown, 1959 and Sepkoski, 1977).

Well preserved ooids have distinct internal lamellae with superimposed patterns of radial fibrous calcite crystals (Plate 5). The radial fibrous pattern is probably acquired early, since radial fibrous cement surrounding the ooids is optically continuous with the pattern (Wilkinson and Landing, 1978). The nuclei are usually preserved, although scattered nuclei are neomorphosed to single calcite crystals or clusters of micron-sized calcite spar. Radial fibrous cement, composed of stubby calcite crystals, radiates perpendicular from the surfaces of ooids. The cement surrounds ooids in all stages of alteration and is commonly neomorphosed to granular calcite spar.

Aggrading neomorphism produced ooids composed of nonequigranular mosaics of calcite spar and ooids composed entirely of one or two crystals of coarse calcite spar. The outlines of the ooids remain as amber-colored rims of microspar.

Other types of alteration include replacement of ooids by circular clusters of idiotopic dolomite rhombs and less frequently, microcrystalline quartz and pyrite. Styolites
Figure 1. Radial pattern in a ooid.
are also common, exhibiting amplitudes of up to 3 mm. Styolitization appears to post-date all other diagenetic features since styolites cut all alteration fabrics.

**Stratigraphic Setting.** Much of the upper oolitic member in the study area consists of thin (less than one meter) intervals of oosparite interbedded with thick (greater than one meter) intervals of pelsparite. Some intervals of oosparite pinch-out laterally to the east into intervals of pelsparite. Internal sedimentary structures are difficult to see in the field because of neomorphic alteration of the oolite.

**Interpretation:**

The oolitic rock type is interpreted to represent subtidal, platform-edge sand belts analogous to ooid sand bars along the western edge of the Great Bahama Bank (Newell et al., 1960; Ball, 1967, Halley, Harris and Hine, 1983). Open ocean circulation and tidal flow from the west controlled formation of ooids, and storms transported the ooids bankward (east) in the form of lobate spillover sheets.

The thin oosparite intervals that pinch-out to the east probably represent spillover sheets that were driven landward by storms over a platform of peloidal carbonates (pelsparite). In a similar fashion, modern ooids are
transported bankward from the leeward side of the ooid shoals of the Great Bahama Bank (Ball, 1967; Halley, Harris, Hine, 1983). On the leeward side of the Bahamian shoals where turbulence is reduced, asymmetric ooids and oolitic grapestone aggregates are common in the grapestone lithofacies (Illing, 1954; Freeman, 1962; Purdy, 1963; Bathurst, 1975). Similarly, the oolitic grapestone aggregates and asymmetric ooids in some intervals of oosparite in the Pilgrim Formation may also indicate deposition on the leeward margin of the shoal where turbulence was reduced. Abundant broken ooids with early radial fabrics in oolite near the top of the section at Nixon Gulch, may even indicate that water behind the shoal was slightly hypersaline. Robert B. Halley (1974, 1977) showed that syndepositionally developed radial calcite crystals in ooids formed in hypersaline conditions are weaker than tangential aragonite needles formed in normal marine waters, resulting in a high percentage of broken ooids. Similarly, a change in normal marine salinity near the top of the Pilgrim Formation may have resulted in an unusually high percentage of broken ooids.

The radial fibrous calcite cement surrounding individual ooids indicates they were cemented early in a submarine environment (Bathurst, 1975; Sandberg, 1985). The
radial fibrous calcite may be the inversion product of original aragonite cement (Cotter, 1966; Mathews, 1967), although primary radial fibrous calcite cement has been reported (Friedman, 1964; Wilkinson et al. 1982). Early radial fibrous aragonite cement around ooids in stabilized portions of the Great Bahama Bank is strong enough to form oolitic intraclasts (Ball, 1967). Similar intraclasts in the oolitic rock type of the Pilgrim Formation supports the interpretation that oolites were cemented early, probably in the submarine environment.

Alteration fabrics also support restriction of oolites to subaqueous environments since the fabrics produced resulted from neomorphism rather than vadose dissolution (Bathurst, 1975).

PELOIDAL ROCK TYPE

Description:

Primary Fabrics. The peloidal rock type (Plate 6) consists of very well sorted, grain supported, flat-laminated pelsparite in slightly irregular beds 2.0 to 8.0 cm thick. These beds are separated by .50 to 1.0 cm thick quartz and glauconite-rich, dolomitic partings (Plate 7). Peloids are well rounded, spherical to elliptical in shape and range from .05 to .10 mm in diameter. Well preserved
Figure 1. Field photo of the peloidal rock type.

Figure 2. Photomicrograph of the peloidal rock type.
Figure 1. Photomicrograph of the dolomitic partings.
peloids are composed of micrite and constitute up to 98% of the allochems in this rock type.

Scattered intraclasts of flat-laminated pelsparite are the most common non-peloidal allochems. These intraclasts range from 0.50 to 2.0 cm in length and are ellipsoidal with rounded margins. They are identical in grain and cement composition to the enclosing peloidal groundmass. Other allochems include ooids and peloids with radial fibrous oolitic coatings.

Skeletal fragments are rare in most pelsparite and are absent from the dolomitic partings. The dominant bioclasts include calcareous sponge spicules, silt-sized, macerated trilobite fragments and eocrinoid fragments that are all oriented parallel to the flat laminations. Glauconite and quartz silt grains form from 5 to 8% of this rock type.

Rare small (0.50 to 1.0 mm) burrows have thin (0.10 to 0.50 mm) compaction rims of compressed and homogenized peloids. Most burrows are filled with radial fibrous calcite, while others are partially filled with peloids producing geopetal structures.

Pelsparite is mostly flat-laminated and less commonly, cross-laminated. The cross-laminations consist of low angle cross-beds approximately 1 to 2 cm wide. Differences in peloid packing densities produce the internal flat-
laminations which range from .50 to 2.0 mm in thickness.

**Diagenesis.** In the first stage of neomorphism, micritic peloids are neomorphosed to coarse (10 to 15 microns) microspar. Neomorphism also obliterates the original cement fabric, leaving the cement a slightly coarser microspar than the neomorphosed peloids. Continued neomorphism produces amber-colored peloid ghosts that appear to float in a matrix of coarse calcite spar.

The dolomitic partings consist of limonite-coated, euhedral to subhedral dolomite rhombs averaging 20 to 100 microns wide. The partings are normally flat to wavy, but are extremely disrupted at the Logan section. Moderate amounts of clay, glauconite and quartz concentrated within the partings suggests that dissolution of the carbonate grains results in concentration of insoluble residues.

Diffuse styolites occur along the boundaries between the pelsparite and the dolomitic partings, and well defined styolites, with amplitudes less than 3 mm, occur within the pelsparite and cut all other alteration fabrics.

**Stratigraphic Setting.** On a regional scale, the thickness and frequency of pelsparite intervals greatly increase from west to east as the proportion of oolite declines (Sepkoski, 1977). Further east and southeast, pelsparite intervals gradually decrease, passing laterally
to the shale, siltstone and conglomerate facies of the Gros Ventre Formation. Sepkoski (1977) interprets the shale, siltstone and conglomerate facies of the Gros Ventre Formation to represent a subtidal lagoon located between the peloidal sands to the west and the nearshore clastics of the Deadwood Formation to the east.

**Interpretation:**

The peloidal rock type is interpreted to represent deposition on a shallow subtidal, semi-restricted platform on the leeward side (east) of the ooid sand belts. Extremely low faunal diversity within the pelsparite indicates deposition in a restricted environment. The well sorted, silt-sized fragments of trilobites and eocrinoids indicate that the bioclasts were transported into the depositional environment, probably from the seaward side of the ooid sand shoals.

The similar shape and fine size of both the peloids and the bioclasts indicates that the peloids are also allochthonous and were transported into the depositional environment with the bioclastic debris. The well sorted peloids may be fecal pellets and/or small micrite intraclasts that originated on the seaward side of the ooid shoals and were transported through channels in the shoals by flood tides and storms. The lack of burrows in the
pelsparite supports the interpretation that the fecal pellets are allochthonous, since few fecal pellet producing animals lived in the environment of deposition. The small size and loose packing of the peloids indicates that they were transported by suspended load rather than traction load, settling out landward of the shoals on the platform where turbulence was reduced. In modern carbonate environments, peloidal sand is common on the leeward margins of ooid shoals, but is mixed with abundant carbonate mud that is interpreted to have formed insitu through the breakdown of calcareous algae (Shinn et al., 1969; Taylor and Illing, 1969 and Bathurst, 1975). For example, Stockman et al., (1967), demonstrated the codiacean alga *Penicillus* was totally responsible for the accumulation of mud in Florida bay. Neumann and Land (1969) also demonstrated the importance of algae-produced mud off Great Abaco in the Bahamas. The absence of carbonate mud producers like *Penicillus* in the Cambrian, may be responsible for the lack of insitu carbonate mud matrix in the pelsparite of the peloidal rock type. Carbonate mud produced by abrasion of shell fragments and/or direct precipitation on the deeper marine shelf west of the study area, would be transported as peloidal clasts and pellets through the ooid shoals and deposited as loosely packed peloidal sand. If fine, non-
peloidal carbonate mud was transported with the peloids, then it may have bypassed the environment of peloid deposition and settled out further to the east.

Once deposited, the peloidal sands were rapidly cemented since the peloids are uncompacted and they form beds of peloidal intraclasts that directly overlie scoured pelsparite. The radial fibrous cement infilling burrows suggests that the cement was precipitated subaqueously. Submarine cementation is not unusual in modern carbonate environments. Shinn (1969) described large areas of carbonate sand in the Persian Gulf that are currently being cemented by aragonite and high-magnesium calcite. In the Persian Gulf, cementation takes place at or near the sediment-water interface in water 1 to 60 m in depth. The cemented layers are 5 to 10 cm thick and are commonly exhumed and eroded during storms and deposited as intraclasts. Conditions necessary for submarine cementation include supersaturation of the sea water for both high-magnesium calcite and aragonite, slow rates of sedimentation, high primary porosities and freedom from bottom traction (DeGroot, 1969; Taylor and Illing, 1969 and Bathurst, 1975). The petrography of the peloidal rock type suggests that favorable conditions for submarine cementation existed when the peloids were deposited. The abundance of
carbonate sediment clearly shows that seawater was supersaturated with respect to calcium carbonate. The loosely packed peloidal sands provided a moderate amount of primary porosity and the absence of bed forms may indicate that slow rates of sedimentation between intervals of suspended load deposition allowed the sediments to remain within the overlying supply of supersaturated sea water long enough for lithification. Examples of Cambrian submarine cemented sediments have been reported from the Nolichucky Formation in southwestern Virginia (Markello and Read, 1981) and the Snowy Range Formation in Montana and Wyoming (Brett et al., 1983).

Dissolution of the carbonate along diffuse styolites concentrated the insoluble residues such as quartz and glauconite and may have initiated the formation of the thin dolomitic partings (Wanless, 1979). Lowered pH due to decaying organic matter below the sediment-water interface may have resulted in early dissolution of the carbonate and the formation of dolomite. The dissolution probably took place before the sediments were totally lithified because the unaltered pelsparite beds commonly collapsed and rotated in response to dissolution below the beds (Pratt, 1982). Alternatively, the dolomite may have formed as a dolomitic crust during subaerial exposure (Shinn, 1983). In recent
environments these crusts are lithified and transported as intraclasts (Shinn, 1983), but the dolomitic partings of the peloidal rock type never occur as intraclasts suggesting that either they were not cemented or they formed long enough after burial that they were not affected by storms.

INTRACLASTIC ROCK TYPE

Description:

Primary Fabrics. The intraclastic rock type (Plate 8) consists of poorly sorted intraclasts of pelsparite, supported in a matrix of bioclastic oosparite and pelsparite. Individual beds are tabular and range from 10 cm to 1.0 m thick.

In cross-section, intraclasts are tabular to elliptical to commonly irregular in shape and range from 1.0 mm to 5.0 cm long and 0.5 to 3.0 mm thick. In planar section, intraclasts are elliptical to irregular in shape. The edges of most intraclasts are distinctly rounded and have sharp boundaries that clearly cut skeletal grains and cement. Because the peloids are so small, it is difficult to determine if the intraclast boundaries cut across peloids.

Most intraclasts are composed of flat-laminated pelsparite identical in composition to the peloidal rock type. Other intraclasts are composed of biopelsparite and
Figure 1. Field photograph of the intraclastic rock type.
some are even composed of intrasparite exhumed from a previous storm deposit. Most of the intraclasts are oriented parallel to the bedding surface, although randomly oriented intraclasts are common.

Two types of matrix support the intraclasts. Type 1 matrix (Plate 9, Fig. 1) is oobiosparite and consists of ooids and fragments of trilobites and eocrinoids cemented by spar. Silt-sized detrital quartz and peloids constitute less than 2% of the matrix. This matrix type is most common in intraclastic intervals near the base of each measured section.

Type 2 matrix (Plate 9, Fig. 2) is pelintrasparite and consists of silt-sized peloids and sand-sized micritic intraclasts with varying amounts of trilobite and eocrinoid debris. Silt-sized detrital quartz constitutes up to 5% of the matrix. This matrix type is most common in intraclastic intervals near the top of each measured section.

**Diagenesis.** Intralasts generally display fewer alteration fabrics than the enclosing matrix. Most altered intraclasts consist of microsparite and less frequently, limonitic dolomite.

Matrix alteration fabrics include progressive alteration from microcrystalline to coarse sparry calcite, replacement by limonite-coated dolomite and replacement by
Figure 1. Photomicrograph of the intraclastic rock type.

Figure 2. Photomicrograph of the intraclastic rock type.
microcrystalline quartz. Radial fibrous cement fills voids on the undersides of many large intraclasts. Near the top of the section at Nixon Gulch, primary voids in one interval of intrasparite were secondarily filled with vadose silt (Plate 10, Fig. 1) similar to that described by Dunham (1969). Many of the calcite crystals that fill voids have curved twins typical of radiaxial fibrous calcite described by Bathurst (1959) and Sailer (1986), (Plate 10, Fig. 2).

**Stratigraphic Setting.** Intraclastic beds most commonly overlie beds of pelsparite. The lower contacts with pelsparite are erosional, but the upper contacts, with either pelsparite or oosparite are sharp, but not erosional. The intraclastic beds that overlie oosparite have sharp, but not erosional basal and upper contacts. Many beds of intrasparite can be correlated from one section to another, but others pinch-out laterally into pelsparite. No intrasparite beds appear to pinch out to the west into oosparite.

**Interpretation:**

The intraclastic rock type is interpreted to represent storm scour, transport and deposition on a semi-restricted, shallow, subtidal platform on the leeward side of the oolitic sand shoals. Subtidally deposited and submarine cemented pelsparite was ripped up by strong, storm-generated
Figure 1. Photomicrograph of vadose silt.

Figure 2. Photomicrograph of radiaxial fibrous calcite.
currents and deposited as tabular intraclasts with rounded edges. Peloidal intraclasts were deposited in an oolitic and bioclastic matrix near the base, and in a peloidal matrix near the top of each section. The vertical change in matrix composition upsection reflects decreasing storm input of ooids and bioclastic debris from the shoal during a shallowing-upward sequence. Intraclasts with both rounded margins and sharply broken edges indicate that the pelsparite was moderately indurated when transported. After deposition, intrasparite beds were rapidly cemented, and often ripped-up by subsequent storms and redeposited with pelsparite intraclasts during a later storm event. Radial fibrous cement in voids suggests that the intrasparite was cemented in the submarine environment (Bricker, 1971; Sandberg, 1985). In addition, radiaxial fibrous calcite in large voids may also indicate that cementation occurred subaqueously (Sailer, 1986). Vadose silt in the intraclastic interval near the top of the section at Nixon Gulch suggests that, at least some intrasparite beds were exposed to the vadose zone (Dunham, 1969), probably during shallowing conditions near the top of the Pilgrim Formation.

Intraformational conglomerate beds of the intraclastic rock type have few modern analogues. Most modern intrasparite forms by reworking desiccated mud polygons
(Hardie et al., 1977; Shinn, 1983), but radial fibrous cement in void spaces of the Pilgrim intrasparite suggests that it was subaqueously cemented. Sepkoski (1977, 1979, 1982) proposed that Cambrian intraformational conglomerates formed subtidally through rapid submarine cementation of thin-bedded grainstone. He argued that the absence of deep-burrowing animals in the Cambrian restricted sediment mixing and allowed submarine cementation of sediments that might otherwise be thoroughly mixed. Mixed sediments would be suspended during storms while un-mixed, cemented sediments would form intraclasts. In the peloidal rock type, the small number of burrows suggest that the peloidal sand was not mixed, and may have aided in early, submarine cementation and the formation of intraclasts of the intraclastic rock type.

ALGAL ROCK TYPE

Description:

**Primary Fabrics.** The algal rock type (Plate 11) consists of poorly preserved, vertical stromatolitic columns separated by patches of bioturbated biomicrite. Stromatolitic columns are vertical to slightly inclined, exhibiting irregular branching patterns in cross-section. Individual columns are small (1.0 to 3.0 cm wide and 3.0 to
Figure 1. Field photo of the algal rock type.

Figure 2. Photomicrograph of the algal rock type.
20 cm high) and closely packed, usually separated by the width of a column. Columns are composed of limonite-coated, euhedral dolomite and microcrystalline sparry calcite. Rarely preserved laminae do not extend into the interstromatolitic fill resulting in sharp boundaries between columns and biomicrite.

Interstromatolitic fill is composed of bioturbated biopelmicrite and biomicrosparite with scattered, small (.05 to 8.0 mm) intraclasts. Bioclasts consist of randomly oriented trilobite and eocrinoid fragments that appear "churned" in cross-section. Intraclasts are irregular in shape, with distinct boundaries and rounded margins. The intraclasts are composed of microsparite similar in composition to the stromatolitic columns and are commonly replaced by limonic dolomite. Detrital quartz constitutes less than 1% of this rock type.

Horizontal burrows disrupt bedding within most of the interstromatolitic fill. Bedding is preserved only in small (1.0 to 5.0 cm) intervals of biointrasparite that overlie the tops of the stromatolitic fingers.

Diagenesis. Stromatolitic columns are primarily altered to dolomitic, neomorphic calcite spar. The interstromatolitic fill is randomly altered to microspar, leaving patches of un-neomorphosed biomicrite. Patches of
limonitic, euhedral dolomite have also replaced the
interstromatolitic biomicrite and small microspar
intraclasts within the biomicrite. Radial fibrous cement,
composed of elongate calcite crystals, radiates out from the
surfaces of intraclasts and low amplitude styolites
concentrate limonitic dolomite and cut all the other
alteration fabrics.

Stratigraphic Setting. Stromatolites occupy the upper
3.0 to 8.0 m of the Pilgrim Formation at each locality. The
lower contact with pelsparite and the upper contact with the
Dry Creek Shale are sharp. The algal rock type contains no
interbeds of the other rock types at Logan or Nixon Gulch,
but is interbedded with a 1.4 m interval of interbedded
pelsparite and intrasparite at Sacajawea Peak.
Interpretation:
The algal rock type represents shallow subtidal to
lower intertidal buildups of digitate stromatolites similar
to those described by Howe (1966) from the Cambrian and
Ordovician of Missouri.

Howe (1966) described digitate stromatolites as
colonial structures characterized by slender, vertically to
obliquely oriented columns. The columns are "meandrine" to
subcircular in cross-section and display irregular branching
patterns. The interstromatolitic fill typically consists of
coarse carbonate debris, including fragments of the stromatolitic columns. Aitken (1967) described similar stromatolites from the Cambrian and Ordovician of southwestern Alberta, and both workers concluded that digitate stromatolites developed in the outer regions of the littoral (intertidal) zone.

Howe (1966) cited the consistent association of digitate stromatolites with oolitic dolarenite as evidence for restriction of digitate stromatolites to areas dominated by a high degree of wave and current energy. He described the stromatolites as forming relatively large "reef-like" buildups parallel to the shoreline and separated from it by shallow lagoonal regions.

Stromatolites from the upper oolitic member exhibit most of the diagnostic features of digitate stromatolites from Missouri and probably occupied similar depositional environments. Small biomicrosparite intraclasts within the interstromatolitic fill and intervals of intrasparite terminating algal growth, indicate that the stromatolites were commonly subjected to moderately strong waves and currents. However, numerous small horizontal burrows in the interstromatolitic fill suggest that the stromatolites were commonly submerged, because analogous recent, small polychaete burrows are more common in submerged
stromatolites than in intertidal stromatolites (Ginsburg et al., 1970). In addition, mudcrack polygons and other desiccation features were not observed.

The Radial fibrous cement radiating from the surfaces of intraclasts indicates cementation took place subaqueously (Bathurst, 1975). Alteration fabrics also suggest that the stromatolites were commonly submerged since the irregular distribution of microspar within interstromatolitic micrite is a result of neomorphism rather than vadose dissolution and precipitation (Folk, 1965).

The abrupt appearance of digitate stromatolites at the top of the Pilgrim Formation at each locality indicates continued shallowing upsection to shallow subtidal or possibly lower intertidal environments. Sepkoski (1977) proposed that the appearance of digitate stromatolites at the top of the Pilgrim Formation resulted from uplift and shallowing associated with the "Skull Canyon Uplift". The shallowing, however, may be an early response to regional regression near the end of the Dresbachian Stage (Lochman-Balk, 1970).
CHAPTER III
STRATIGRAPHIC CORRELATIONS

The Logan and Nixon Gulch sections in the Horseshoe Hills and the Sacajawea Peak section in the Bridger Range provide the data for lithostratigraphic and biostratigraphic correlations. Most of the lithostratigraphic correlations are based on lithic continuity from one section to another, although minor variations exist in each section. I terminated each measured section at the boundary between the Pilgrim Formation and the overlying Dry Creek Shale.

Lithostratigraphic Correlations:

The four rock types form 7 units that can be correlated between the Logan and Nixon Gulch sections. Only 3 units can be correlated to the stratigraphically shorter Sacajawea Peak section (Fig. 11 and Fig. 12). Unit 1 consists of the oolitic rock type and can be correlated from Logan to Nixon Gulch. A 20 cm interval of the intraclastic rock type within this unit at Logan has a peloidal matrix and marks the transition from intrasparite with a bioclastic-oolitic matrix to intrasparite with a peloidal matrix. The upward change in matrix type indicates the beginning of a shallowing-upward sequence. Units 2 and 4 are thick intervals of the peloidal rock type that are separated by a
**Figure 11.** Legend for stratigraphic columns.
Figure 12.
thin interval of the intraclastic rock type (unit 3). All three units can be correlated from Logan to Nixon Gulch, and the biomere boundary occurs 30 cm below unit 3 at both localities. Units 4 and 6 are thick intervals of the peloidal rock type that are separated by interbeds of the oolitic rock type (unit 5). The increase in the peloidal rock type with a decrease in the oolitic rock type upsection indicates continued shallowing. With further shallowing, the algal rock type (unit 7) appears and continues uninterrupted to the top of each section. A thin interval of the peloidal rock type within the algal rock type at Sacajawea Peak demonstrates that deposition of the peloidal rock type continued in areas adjacent to the stromatolitic buildups.

Biostratigraphic Correlations:

Figures 14, 15 and 16 illustrate the stratigraphic ranges for trilobites at each section. Both the Crepicephalus and the Aphelaspis Zones were collected at Logan and Nixon Gulch, but only the Aphelaspis Zone was collected at Sacajawea Peak. The biomere boundary at Logan (Horizon 1.2), is confined to collections 5 cm apart and can be traced to the same position in unit 2 at Nixon Gulch (Horizon 7.6). Unit 3 overlies the biomere boundary by 30 cm at both Logan and Nixon Gulch (Fig. 13), and since this
Figure 13.

MarjumIID Biomere

Pteroschaliid Biomere
unit represents a single depositional event it demonstrates that the extinction, at least in the study area, was a synchronous event.

At Logan (fig. 14), Tricrepicephalus, Pemphigaspis and Coosella of the Crepicephalus Zone (Marjumiid Biomere) are abruptly overlain within 5 cm of uniform pelsparite by Glaphyraspis of the Aphelaspis Zone (Pterocephaliid Biomere). A field and polished slab photo of the 5 cm interval shows that no discontinuity surfaces or changes in lithology are associated with the extinction (Plates 12 and 13). Cheilocephalus and Aphelaspis first appear 40 cm above the first appearance of Glaphyraspis and all three genera proliferate and diversify upsection. Blountia nixonensis, an opportunistic species descended from genera of the Crepicephalus Zone (Palmer, 1984), appears 5.8 m above the extinction boundary and is restricted to the algal rock type.

At Nixon Gulch (fig. 15), the faunal turnover is strikingly similar to the Logan section and occurs within the same pelsparite unit. At the boundary, Crepicephalus, Tricrepicephalus, Coosella and Coosina are abruptly overlain within 5 cm of uniform pelsparite by Glaphyraspis. A field and a polished slab photo of the 5 cm interval again shows that no physical discontinuities or changes in lithology
Figure 1. Field photo of the biomere boundary at Logan.
Figure 1. Polished slab photo of the biomere boundary at Logan.
occur within the interval containing the biomere boundary (Plates 14 and 15). *Coosella perplexa*, another opportunistic species descended from genera of the Crepicephalus Zone, appears together with *Glaphyraspis* for 30 cm above the boundary, but was extinct by the time the unrelated trilobites, *Cheilocephalus* and *Aphelaspis*, appear in the section. *Cheilocephalus* appears 40 cm above the boundary and *Aphelaspis* appears 50 cm above the boundary suggesting a short "lag" time before their appearance on the shallow platform. This supports Palmer's (1965) interpretation that these genera are immigrants and did not originate on the shelf. *Blountia nixonensis* appears 6.2 m above the boundary and is restricted to the algal rock type.

At Sacajawea Peak (fig. 16), the boundary interval was not collected, but the faunal patterns above the boundary are the same as the Logan and Nixon Gulch sections. *Aphelaspis*, *Glaphyraspis* and *Cheilocephalus* are common above the boundary, and *Blountia nixonensis* occurs well above the boundary, again restricted to the algal rock type. The survival of *Blountia* well above the boundary inbetween the stromatolitic heads of the algal rock type indicates that it must have been well adapted to the changing environmental conditions that exterminated the remainder of the Crepicephalus Zone fauna.
Figure 1. Field photo of the biomere boundary at Nixon Gulch.
Figure 1. Polished slab of the biomere boundary at Nixon Gulch.
Pteroccephaliid Biomere

Cheilocephalus

Glaphyraspis

Aphelaspis

Blountia

Dytremacephalus
The persistence of **Blountia** well after the extinction supports the boundary revisions proposed by Palmer (1979). As mentioned in the introduction, Palmer (1979) lowered the biomere boundaries to the base of stage 4 to include a 20 cm interval where opportunists from the pre-existing faunas are mixed with the new, immigrant faunas during a time of environmental crisis. This boundary change left some question as to whether "extinction" should be the last appearance of all the *Crepicephalus* Zone fauna or the last appearance of most of the *Crepicephalus* Zone fauna. In Montana, the opportunist, *Coosella perplexa*, is similarly mixed with the new fauna for approximately 30 cm, but the appearance of **Blountia** well above this interval extends the mixed zone nearly 9.0 m above the extinction of the remainder of the *Crepicephalus* Zone trilobites. **Blountia** apparently was well adapted to the changing environmental conditions and coexisted with the new fauna while they adapted and diversified on the shallow shelf platform.

Although the mixed interval in Montana differs from the mixed interval in Texas and the Great Basin (Palmer, 1954, 1979), it clearly shows that the extinction boundary should be placed at the base of stage 4 of Stitt (1977). Without the revisions, the biomere boundary would be placed nearly 9.0 m above the extinction of most of the *Crepicephalus* Zone.
trilobites and a long period of adaptation and
diversification of the new fauna would wrongly be included
in Stitt's (1975) terminal declining stage 4.
CHAPTER IV
ENVIRONMENTAL SYNTHESIS

The environmental synthesis is based on lithostratigraphic correlations and interpretations of the (1) oolitic rock type, (2) the peloidal rock type, (3) the intraclastic rock type and (4) the algal rock type. These carbonate sediments record shallow water shoal, restricted platform and shallow subtidal to possibly lower intertidal deposition during a shallowing-upward sequence (Fig. 17). Oosparite is the dominant lithology at the base of each section and represents platform-edge sand belts similar to those along the western margin of the Great Bahama Bank (Halley, Harris and Hine, 1983).

Oosparite decrease in abundance upsection as pelsparite increases, reflecting a westward migration of pelsparite with shallowing conditions. Pelsparite was deposited in shallow, semi-restricted areas landward (east) of the oolitic shoals and thin interbeds of oosparite in dominantly pelsparite intervals reflect lateral shifting and migration of the sand belts by lobate spillover sheets. A high percentage of broken ooids in oosparite intervals near the top of each section may indicate a change in normal marine salinity resulting from increased restriction with shallowing conditions.
Cement fabrics show that both oosparite and pelsparite were cemented shortly after deposition, probably in the submarine environment. The early-cemented pelsparite was ripped-up and transported as intraclasts by large storms and accumulated as debris piles and sheets on the floor of the restricted platform. The piles of intraclasts were also cemented shortly after deposition since the lithified intrasparites were ripped-up during later storms and incorporated as intraclasts in subsequent intrasparite beds. The composition of the matrix supporting the intraclasts changes upsection from bioclastic-oolitic to peloidal reflecting shallowing conditions and decreasing landward input of ooids and bioclasts during storm events that formed the intrasparite beds.

With further shallowing, digitate stromatolites migrated to the west over pelsparite at the top of each section. These stromatolites are similar to those described from the Upper Cambrian of Missouri (Howe, 1966) which are interpreted to have occupied the lower intertidal zone. Cementation fabrics and abundant burrows in the interstromatolitic fill between the stromatolitic fingers in the Pilgrim Formation however, suggest that the algal buildups were rarely exposed and may have occupied shallow subtidal to lowermost intertidal environments.
Shallowing conditions in the upper part of the Pilgrim Formation can be explained by at least three possible mechanisms: (1) Dresbachian uplift associated with the "Skull Canyon Uplift", (2) carbonate accumulation rates exceeding subsidence rates and (3) eustatic sea level drop.

Dresbachian Uplift. Dresbachian uplift along the Montana-Idaho border west of Yellowstone Park was termed the "Skull Canyon disturbance" by Scholten (1957). According to Sepkoski (1977), block-faulting along the hingeline of the craton during the Dresbachian resulted in the deposition of quartz sands and the appearance of digitate stromatolites at the top of the Pilgrim Formation in southwestern Montana. Sepkoski (1977) proposed that digitate stromatolites developed in belts near the margins of this uplifted area, but pointed out that the proposal could not be tested since the margins were eroded.

Carbonate Accumulation Rates. Carbonate sediments characteristically accumulate at rates exceeding subsidence and repeatedly build up to, and above, sea level (James, 1984). As a result, characteristic sequences of deposits are produced in which each unit is deposited in progressively shallower water. This shallowing-upward sequence is commonly repeated, resulting in stratigraphic intervals consisting of many shallowing-upward cycles.
Similarly, shallowing conditions at the top of the Pilgrim Formation may have been produced by a greater rate of carbonate accumulation than subsidence, although the Pilgrim Formation characteristically does not consist of repeated shallowing-upward cycles.

Eustatic Sea Level Drop. The Dry Creek Shale Member of the Snowy Range Formation conformably overlies the Pilgrim Formation at all three localities. This shale is interpreted by most workers to represent a major sea level drop that brought inner detrital belt facies over middle carbonate facies (Lochman-Balk and Wilson, 1958; Palmer, 1960 and Lochman-Balk, 1970). The shallowing-upward sequence near the top of the Pilgrim Formation in southwestern Montana may be an early and fairly subtle lithologic response to the sea level drop that eventually brought the inner detrital belt Dry Creek shale westward over the middle carbonate belt Pilgrim limestone. This mechanism is consistent with stratigraphically similar shallowing-upward sequences in Wyoming (Chronic, 1987), Texas (Palmer, 1954) and Illinois (Buschbach, 1964) and serves as the basis for the following discussion on the Marjumiid-Pterocephaliid biomere boundary in southwestern Montana.
In southwestern Montana, the Marjumiid-Pterocephaliid biomere boundary is abrupt and does not coincide with any physical discontinuity or subtle change in carbonate deposition at the boundary. The boundary does, however, occur within a shallowing-upward sequence within the upper part of the Pilgrim Formation that precedes a regionally recognized regression at the base of the overlying Dry Creek Shale (Lochman-Balk, 1970). This shale unit records the westward migration of the clastic-dominated inner detrital belt over the carbonate-dominated middle carbonate belt during eustatic sea level drop and represents the most extensive westward migration of the shoreline documented in the Late Cambrian (Lochman-Balk, 1970).

In the nearest shore sections, the faunal change at the Marjumiid-Pterocephaliid biomere boundary coincides with a shallowing-upward sequence within the inner detrital belt (Palmer, 1954; Buschbach, 1964 and Emrich, 1966), but in the middle carbonate belt sections a shallowing-upward sequence has previously not been recognized. This study (Thomas, 1987) and a similar study in Wyoming (Chronic, 1987) however, have shown that the Marjumiid-Pterocephaliid biomere boundary does coincide with a shallowing-upward
sequence in the offshore carbonates and indicates that regional regression began prior to the trilobite extinctions.

Based on this more regional association of the Marjumiid-Pterocephaliid biomere boundary with a shallowing upward sequence, I propose that the extinction of the Crepicephalus Zone trilobites and subsequent invasion of the Aphelaspis Zone trilobites was caused by environmental changes resulting from regression. A progressive drop in sea level of the Cambrian shallow epicontinental sea may have affected ocean temperature, oxygen levels or salinity in a manner that exceeded some critical tolerance level and was therefore lethal to the highly specialized shelf and miogeoclinal trilobites. In this way, the extinction would be abrupt, but would not coincide with a discontinuity surface or subtle change in carbonate deposition at the boundary.

The coincidence of mass extinction with marine regression is not uncommon, in fact, all the major Phanerozoic extinctions coincide with marine regressions (Raup and Sepkoski, 1982 and Sepkoski, 1982b). Proposed environmental changes caused by regression include: reduction in habitable area (Schopf, 1974 and Hallam, 1981); reduction in the number of shallow-water provinces
(Jablonski, 1985); the development of brackish oceans (Stevens, 1977); the development of hypersaline oceans (Bowen, 1970) and a drop in mean ocean temperature due to the introduction of cold, dense polar water (Lochman-Balk, 1970).

Palmer (1984) argued against regression because on the western margin of the North American Cambrian shelf, the extinction is followed by a slight deepening. Lochman (1970) however, believed that the change in lithofacies signifies a progressive shallowing and is consistent with shallowing conditions in the nearshore sites. Palmer (1984) also cited the continued diversification of the Aphelaspis Zone trilobites through maximum regression at the end of the Dresbachian stage as evidence that regression has no obvious faunal effect. While it is true that maximum regression at the end of the Dresbachian had no effect on the new, immigrant populations, extinction of these trilobites would not be expected since they were already adapted to the changes that wiped-out the pre-existing fauna.

Previous workers (Lochman-Balk, 1970 and Stitt, 1975) have concentrated on the paleoecological tolerances of the invading trilobites to support their interpretations that the extinction was caused by a rapid cooling event, but have not given enough consideration to the paleoecological
tolerances of the trilobites that survived the extinction. The trilobites that did survive long after the extinction, *Blountia* and *Glaphyraspis*, were probably adapted to high stress environments. Both *Blountia* and *Glaphyraspis* survived the extinction in shallow, rigorous environments of the stromatolite "reef" facies (Lochman-Balk, 1970) where ocean temperature and salinity probably fluctuated. Since these trilobites survived the environmental changes that exterminated the remainder of the *Crepicephalus* Zone fauna, I believe they may more accurately reflect the cause(s) of the extinction than the invading faunas. Unfortunately, few studies have focused on the paleoecology of these trilobites, and their paleoecology was not directly considered in this study.

The only physical evidence for changing environmental conditions in the Pilgrim Formation is the upward increase in broken ooids. An increase in broken ooids may suggest that normal marine salinity was changing with regression, but whether this change or another change resulting from regression caused the extinction is difficult to determine.
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APPENDIX A
MEASURED SECTIONS

Strata in the Horseshoe Hills are moderately folded, and faulted by many small normal faults and a few thrust faults. The Cambrian section is well exposed and dips gently at 35 degrees to the northwest. Geology of the Horseshoe Hills has been mapped in detail by Verrall (1954).

Strata in the Bridger Range dip steeply to the east as part of a large north trending fold and are dissected by several small east-west trending normal faults. Geology of the Bridger Range has been mapped in detail by McMannis (1955). Crustal shortening by eastward directed thrusting probably displaced the sections a minimum of 15 km to the east (Schmidt and O'Neill, 1982).

I terminated each stratigraphic section at the boundary between the Dry Creek Shale Member of the Snowy Range Formation and the Pilgrim Formation. The scale for each measured section is in meters. Prepared thin sections and collected trilobites are listed for each horizon and trilobites are listed in order of decreasing abundance. All collections, including field notes, are housed at the Museum of Paleontology, University of Montana.
Figure 18. Legend for measured sections.
Section measured on the southeast flank of the Pilgrim ridge, directly north of the Gallatin River. The section is accessible by driving northeast on Cottonwood Gulch road for approximately 3.0 km to a fork in the road. Park at the fork and walk directly east for 1.5 km, following the power lines to the cliff-forming Pilgrim limestone. Walk south along the ridge to its southern end where the Pilgrim is truncated by the Gallatin River. The section is well exposed along the east-facing slope and the strata dip at approximately 49 degrees to the west. Located in SE1/4 sec. 25, T.1N., R.2E., Gallatin County, Montana: Manhattan 15' Quadrangle.
Algal rock type - Deeply weathered, very dolomitic and unfossiliferous to the base of the Dry Creek Shale. N46E49W

Algal rock type - Very dolomitic, unfossiliferous. N46E49W

Algal rock type - Weathered, dolomitic and unfossiliferous. N46E49W

Algal rock type - Vertical dolomitic columns separated by brown-colored limestone. N46E49W
Algal rock type - Weathered, dolomitic columns separated by brown-colored limestone. A few intraclastic beds cut across the dolomitic columns. N46E49W

Algal rock type - Vertical dolomitic columns with faint laminations. L9.0; N46E49W

Algal rock type - Vertical dolomitic columns with faint laminations. Intraclastic beds cut across the dolomitic columns. Glaphyraspis, Cheilocephalus and Aphelaspis. L8.7, L8.5, L8.2; N46E49W

Algal rock type - Dolomitic columns with well preserved laminations. Cheilocephalus, Glaphyraspis and Blountia. L7.2, L7.0; N45E49W
Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Oriented parallel to bedding. N46E49W

Peloidal rock type - Flat-laminated limestone separated by thin, dolomitic partings that are parallel to the flat laminations. Limestone beds moderately disrupted. L6.7, L6.4, L6.2; N46E49W

Oolitic rock type - Massive, mottled oolite. Ooids are black in color and are well sorted. Very fossiliferous, dominated by librigenae. Aphelaspis and Cheilocephalus. L5.3, L5.2, L5.0; N46E49W

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. L4.3; N46E49W

Peloidal rock type - Flat-laminated limestone separated by dolomitic partings. Upper contact erosional, lower contact sharp, but not erosional. N46E49W

Oolitic rock type - Mottled oolite with faint low angle crossbeds. L3.5, L3.4; N46E49W
Peloidal rock type - Flat-laminated limestone separated by dolomitic partings. Laminations can be traced from limestone into the dolomitic partings. L2.5, L2.3, L2.2; N46E49W

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Upper contact sharp, lower contact erosional. N46E49W

Peloidal rock type - Flat-laminated with irregular dolomitic partings. Aphelaspis, Cheilocephalus, Glaphyraspis, Coosella, Tricrepicephalus and Pemphigaspis. L1.6, L1.5, L1.2, L1.1, L1.0; N46E49W


Peloidal rock type - Flat-laminated with irregular dolomitic partings. L.1; N46E49W
Section measured on the south-facing slope of the Pilgrim ridge, north of where it is cut by Nixon Gulch. The section is accessible from the Manhattan exit off Interstate 90. Follow the road north into Manhattan across U.S. Rt. 10 and the Northern Pacific Railroad. Turn northwest onto the gravel road running parallel to the railroad tracks (fishing access) and follow it to the bridge that crosses the Gallatin River. Cross the bridge and follow the lower road into Nixon Gulch. The section is located on the north side of the road approximately 4 km from the river. Strata are well exposed and dip at approximately 47 degrees to the east. Located in SE1/4 sec. 14, T.2N., R.3E., Gallatin County, Montana: Manhattan 15' Quadrangle.
Algal rock type - Weathered, dolomitic columns separated by brown-colored carbonate. Laminations difficult to see in the dolomitic columns. Blountia, Glaphyraspis, Aphelaspis, Dytrema cephalus and Dictyonina perforata. NG16.8, NG16.6, NG16.5, NG16.3, NG16.0; N85W47E

Algal rock type - Weathered, a few intraclastic beds cut across the vertical dolomitic columns. Blountia and Glaphyraspis. NG15.8, NG15.6, NG15.5, NG15.4, NG15.0; N85W47E


Algal rock type - Faint laminations in the dolomitic columns. Very fossiliferous. Glaphyraspis and Blountia. NG13.8, NG13.6; N85W47E

Intraclastic rock type - Tabular to irregular intraclasts in a peloidal matrix. Glaphyraspis. NG13.5, NG13.4; N85W47E

Peloidal rock type - Flat-laminated limestone separated by thin dolomitic partings. Glaphyraspis, Aphelaspis, Cheilocephalus and Proplina Loganensis. NG13.3, NG12.9; N85W47E
Intraclastic rock type - Tabular to irregular intraclasts in a peloidal matrix. N85W47E

Peloidal rock type - Flat-laminated limestone separated by thin dolomitic partings. Partings are parallel to bedding. Cheilocephalus. NG12.4, NG12.3; N85W47E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Upper contact is sharp, lower contact is erosional. Intraclasts oriented parallel to bedding. NG11.6; N85W47E

Peloidal rock type - Flat-laminated, dolomitic partings faint. NG11.0; N85W47E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. Lower contact erosional. Several intraclasts with spherical holes. N85W47E


Peloidal rock type - Flat-laminated. NG10.2; N85W47E


Peloidal rock type - Flat-laminated limestone separated by dolomitic partings. Upper contact is sharp. Cheilocephalus. NG9.4, NG9.3, NG9.2, NG8.9, NG8.8, NG8.7; N85W47E
Intraclastic rock type - Tabular intraclasts in a peloidal matrix. 
Intraclasts oriented at a high angle to bedding. *Aphelaspis* and *Cheilocephalus*. NG8.2, NG8.1; N85W47E

Peloidal rock type - Flat-laminated. 
*Aphelaspis*, *Cheilocephalus*, *Glaphyraspis*, *Coosella*, *Coosina* and *Crepicephalus*. NG7.7; N85W47E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. N85W47E

Peloidal rock type - Flat-laminated. 
*Tricrepicephalus*, *Crepicephalus* and *Coosina*. NG7.2; N85W47E

Oolitic rock type - Massive, mottled oolite. NG7.0; N85W47E

Peloidal rock type - Flat-laminated, dolomitic partings faint. NG6.7, NG6.6, NG6.5; N85W47E

Intraclastic rock type - Tabular intraclasts in a bioclastic-oolitic matrix. *Pseudagnostus*. NG6.4; N85W47E

Hummocky crossbedded quartz siltstone with a minor amount of limestone intraclasts. NG6.0; N85W47E

Peloidal rock type - Flat-laminated limestone with faint dolomitic partings. NG5.9, NG5.7, NG5.5, NG5.4; N85W47E

Oolitic rock type - Massive, mottled oolite. Ooids black in color and well sorted. NG4.6; N85W47E
Intraclastic rock type - Tabular intraclasts in a bioclastic-oolitic matrix. Intraclasts are oriented at a high angle to bedding. NG4.5, NG4.1; N85W47E

Peloidal rock type - Flat-laminated limestone separated by thin dolomitic partings. Dolomitic partings faint. NG3.8; N85W47E

Oolitic rock type - Massive oolite. Pemphigaspis, Coosella and Crepicephalus. NG3.6, NG3.5; N85W47E

Intraclastic rock type - Tabular intraclasts in a bioclastic matrix. NG3.4, NG3.2, NG3.1; N85W47E

Peloidal rock type - Flat-laminated with scattered intraclasts. Tricrepicephalus. NG2.8; N85W47E

Oolitic rock type - Massive oolite with scattered peloidal intraclasts.

Intraclastic rock type - Tabular intraclasts in a bioclastic-oolitic matrix. NG2.5; N85W47E

Oolitic rock type - Massive, mottled oolite. Very fossiliferous. Scattered peloidal intraclasts. Crepicephalus. NG2.4, NG2.2, NG2.0, NG1.7, NG1.6, NG1.5, NG1.4; N85W47E

Peloidal rock type - Flat-laminated. Upper contact sharp. NG1.3, NG1.2, NG1.1; N85W47E

Intraclastic rock type - NG1.0, NG.9; N85W47E
Peloidal rock type - Flat-laminated, very faint dolomitic partings.
NG.8, NG.7; N85W47E

Intraclastic rock type - Tabular intraclasts, many with holes.
NG.6, NG.5; N85W47E

Oolitic rock type - Massive oolite.
NG.4, NG.2, NG.1, NG0; N85W47E
Section measured on the southwest flank of Sacajawea Peak in the central Bridger Range. The section is accessible from Fairy Lake Campground by taking the trail west up the cirque wall to Bridger Divide. Walk south from the divide to the first saddle below the west flank of Sacajawea Peak. The section is well exposed on the west-facing slope and the strata dip approximately 49 degrees to the east. Located in SW1/4 sec. 27, T.2N., R.6E., Gallatin County, Montana: Sedan 15' Quadrangle.
Algal rock type - Thin, dolomitic columns separated by brown-colored limestone. Laminations very faint in the dolomitic columns. SP8.1, SP8.0, SP7.9, SP7.4, SP7.2, SP7.1, SP7.0; N16W49E

Algal rock type - Dolomitic columns with faint laminations. A few intraclastic beds cut across the dolomitic columns. *Dytremacephalus*, *Aphelaspis*, *Glaphyraspis* and *Blountia*. SP6.9, SP6.8, SP6.7, SP6.6, SP6.5, SP6.4, SP6.1; N16W49E

Intraclastic rock type - Tabular to irregular intraclasts in a peloidal matrix. SP5.9; N16W49E

Peloidal rock type - Flat-laminated with dolomitic partings. SP5.7; N16W49E

Intraclastic rock type - Irregular intraclasts in a peloidal matrix. SP5.6; N16W49E

Peloidal rock type - Flat-laminated. SP5.5; N16W49E

Intraclastic rock type - Irregular intraclasts in a peloidal matrix. SP5.3; N16W49E

Peloidal rock type - Flat-laminated limestone with dolomitic partings parallel to the laminations. SP5.0, SP4.8, SP4.6; N16W49E
Algal rock type - Dolomitic columns with faint laminations separated by brown-colored limestone. Limestone is very fossiliferous, containing well preserved cranidia and pygidia. Blountia and Glaphyraspis. SP4.5, SP4.2, SP4.1; N16W49E

Algal rock type - Dolomitic columns separated by fossiliferous brown-colored limestone. Blountia and Glaphyraspis. SP3.8, SP3.6, SP3.5, SP3.3, SP3.2, SP3.1; N16W49E

Peloidal rock type - Flat-laminated limestone separated by thin, dolomitic partings. Partings parallel to bedding. Very un-fossiliferous. SP2.8, SP2.6, SP 2.5, SP2.4, SP2.2, SP2.0; N16W49E

Peloidal rock type - Flat-laminated with dolomitic partings. SP1.9, SP1.8; N16W49E

Intraclastic rock type - Tabular intraclasts in peloidal matrix. SP1.7; N16W49E
Oolitic rock type - Massive oolite. Aphelaspis and Glaphyraspis. SP 1.6, SP1.5; N16W49E
Intraclastic rock type - Tabular intraclasts in peloidal matrix. SP1.3; N16W49E
Oolitic rock type - Massive, mottled oolite. SP1.2, SP1.1; N16W49E
Oolitic rock type - SP.9, SP.7; N16W49E

Intraclastic rock type - Tabular intraclasts in a peloidal matrix. SP.5; N16W49E

Oolitic rock type - Massive, mottled oolite. Cheilocephalus. SP.3, SP.2, SP0; N16W49E
Phyla represented in the upper oolitic member of the Pilgrim Formation are arranged in alphabetical order. Arrangement of lower taxa within each phylum is also alphabetical. The phylum Arthropoda is represented by 8 families, 11 genera and 17 species of trilobites. The phylum Brachiopoda is represented by one inarticulate brachiopod species and the phylum Mollusca is represented by one gastropod species. All fossil material was identified from published descriptions to species level when possible. Definitions of the morphological terms used for trilobite descriptions are discussed and illustrated in the Treatise on Invertebrate Paleontology (Harrington and others, 1959; p. 042-047; glossary, p. 0117-0126).

For each species, the biostratigraphic stage and faunal zone are listed. Collecting localities and stratigraphic position in meters above the base of the section at each locality are also listed. The localities are ordered: (1) Logan, (2) Nixon Gulch and (3) Sacajawea Peak. All fossil material is housed at the Museum of Paleontology, University of Montana.
<table>
<thead>
<tr>
<th>GENUS</th>
<th>LOGAN</th>
<th>NIXON GULCH</th>
<th>SACAJAWEA PEAK</th>
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<tr>
<td>Pseudagnostus</td>
<td>----</td>
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<td>----</td>
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<tr>
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<td>13.8-16.6</td>
<td>3.0-6.8</td>
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<td>3.6-5.2</td>
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<td>8.0-12.9</td>
<td>.1-1.6</td>
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<td>----</td>
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<td>Dictyonina</td>
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<td>6.8</td>
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<tr>
<td>Proplina</td>
<td>----</td>
<td>12.9</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Figure 19. Stratigraphic ranges for trilobite, brachiopod and gastropod genera at the Logan, Nixon Gulch and Sacajawea Peak sections.
Phylum ARTHROPODA Siebold and Stannius, 1845  
Class TRILOBITA Walch, 1771  
Order AGNOSTIDA Kobayashi, 1935  
Family PSEUDAGNOSTIDAE Whitehouse, 1936  
Genus Pseudagnostus Jaekel, 1909  
Pseudagnostus sp. (undet.)  
(Plate 20, Figure 3)

Pseudagnostus Jaekel, 1909, p.400; Kobayashi, 1935, p.107;  
1937, p.451; 1939, p.157; Shimer and Shrock, 1944,  
p.601; Shaw, 1951, p.112; Palmer, 1954, p.719; 1955,  
p.93; 1960, p.61.

Plethagnostus Clark, 1923, p.124.

Rhaptagnostus Whitehouse, 1936, p.97.

Description: Pygidium with anterior portion of axial  
lobe defined by parallel axial furrows. Posterior lobe  
expanded and moderately well defined by extension of axial  
furrows. Axial furrows reach the border and no marginal  
spines are present.

Discussion: The upper Crepicephalus zone and lower  
Aphelaspis zone in Montana are noted for the absence of  
Agnostid trilobites (Lochman and Duncan, 1944). One  
pygidium was collected at Nixon Gulch, but none were found  
at the Sacajawea Peak or Logan sections.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim  
Formation (Crepicephalus Zone). Nixon Gulch (Horizon 6.4).

Order PTYCHOPARIIDA Swinnerton, 1915  
Family ASAPHISCIDAE Raymond, 1924
Subfamily BLOUNTIINAE Lochman, 1944
Genus Blountia Walcott, 1916
Blountia nixonensis Lochman and Duncan, 1944
(Plate 16, Figures 3, 4)

Blountia nixonensis Lochman and Duncan, 1944, p.43, pl.4, figs.7-12; Palmer, 1954, p.722, pl. 79, fig. 4.

Description: Cranidium moderately convex, broadly conical with large, strongly convex glabella. The glabella is furrowless with a shallow occipital furrow and narrow occipital ring. The anterior margin is evenly rounded and the anterior border is distinct. The anterior border is separated from the preglabellar field by a slight change in slope but the overall transverse convexity of the glabella is maintained. The posterior limbs are short and broad with sharply pointed ends.

The pygidium is subtriangular with a long, narrow axis composed of eight or nine segments. The pleural lobes are slightly convex and approximately the same width as the axis. The border is separated from the pleural lobes by a distinct border furrow.

Discussion: This species has been fully described by Lochman and Duncan (1944) and the holotype cranidium is from Nixon Gulch, Montana. Blountia nixonensis is an opportunist and, although related to genera of the Crepicephalus Zone, occurs only in the lower part of the Aphelaspis Zone at each
locality in this study. Lochman and Duncan (1944) point out that *Blountia nixonensis* is much more like early *Blountia* species of the Cedaria Zone than the more diverse species of the Crepicephalus Zone.

**Occurrence:** Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 7.9); Nixon Gulch (Horizon 16.6, 16.0, 15.0, 14.8, 14.6, 14.3, 13.8); Sacajawea Peak (Horizon 6.8, 4.4, 4.3, 4.2, 4.1, 4.0, 3.9, 3.8, 3.6, 3.4, 3.1, 3.0).

**Family CATILLICEPHALIDAE** Raymond, 1938
**Genus Pemphigaspis Hall, 1863**

*Pemphigaspis* sp. (undet.)

(Plate 20, Figure 4)


**Description:** A few cranidia have the anteriorly expanded glabella and Y-shaped posterior glabellar furrows characteristic of this genus. Librigena and pygidium are unknown.

**Discussion:** A few fragmented cranidia were found at the same horizon as _Tricrepicephalus_ sp. in the upper part of the Crepicephalus Zone at the Logan and Nixon Gulch sections. Lochman and Duncan (1944) also collected species
of *Pemphigaspis* from the *Crepicephalus* Zone at the Half Moon Pass and Dry Wolf Creek sections in Montana.

**Occurrence:** Upper Cambrian (Dresbachian) Pilgrim Formation (*Crepicephalus* Zone). Logan (Horizon 1.1, .5); Nixon Gulch (Horizon 5.2, 3.6).

**Family CHEILOCEPHALIDAE** Shaw, 1956  
**Genus Cheilocephalus** Berkey, 1898  
*Cheilocephalus granulosus* Palmer, 1965  
(Plate 18, Fig. 4; Plate 19, Fig. 1)

*Cheilocephalus* sp. Palmer, 1962, p.27, pl.3, figs.30,31.  

**Description:** Cranidium broadly conical with a low, moderately convex glabella. The glabella is subrectangular and contains up to three pairs of faint lateral furrows. Occipital furrow is deep and curved anteriorly at the midline of the glabella. The frontal area is slightly concave and is not divided into preglabellar field and border. The posterior limbs are broad with shallow border furrows that curve forward distally. The limbs also contain the distinct "elbows" characteristic of this genus.

The pygidium is semicircular with a long, tapered axis composed of seven segments. The articulating facet is well developed on the pleural lobe and the interpleural furrow is
deep, extending across the border. The border is broad and slightly concave on most specimens. The interpleural furrows continue from the pleural field as broad, shallow depressions across the border.

The outer surface of the cranidium and pygidium is covered with small, closely spaced granules.

Discussion: This species has been fully described by Palmer (1965) and Lochman and Hu (1962). It occurs at the base of the Aphelaspis Zone at each locality and represents one of the new trilobites unrelated to families of the underlying Crepicephalus Zone. This species is distinguished from Cheilocephalus brevilobus by the presence of small granules on the external surfaces of most parts of the exoskeleton.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.6, 8.3, 8.2, 8.1, 8.0, 7.9, 7.8, 7.7, 7.3, 7.1, 7.0, 5.2, 1.8, 1.7, 1.6); Nixon Gulch (Horizon 12.9, 12.0, 10.3, 9.8, 8.6, 8.2, 8.0); Sacajawea Peak (Horizon 1.6, .1).

Cheilocephalus omega (Lochman and Hu) (Plate 17, Figures 2, 3)

Cheilocephalus delandi Shaw, 1956, p.49, pl.10, figs.1-7, pl.11, figs.1-6, pl.12, figs.1, 6.

Description: Cranidium convex with a strongly convex, broadly conical glabella. The axial furrows are shallow and lateral furrows are absent from the glabella. The frontal area is concave and is not divided into preglabellar field and border. Palpebral lobes are small, flat and contain no palpebral furrow. Eye ridges are faint, intersecting the axial furrows at a slight angle. The occipital furrow is shallow and the occipital ring is narrow. The posterior limbs are short with broad, shallow border furrows. The limbs also have the distinct "elbows" that are characteristic of the genus.

The pygidium is subtriangular in outline with a long, posteriorly tapering axis composed of seven segments. The pleural fields are slightly convex, approximately the same width as the axis anteriorly, but narrowing posteriorly. The border is narrow and steep anteriorly but widens posteriorly with a more gentle slope. The border contains a narrow border furrow that terminates the pleural furrows but not the interpleural grooves.

Discussion: There has been much confusion in the past concerning this species. Shaw (1956) described C. delandi
from Wyoming, recognizing a strongly convex, furrowless glabella in juveniles and a low glabella with three pairs of lateral furrows in adults. Lochman and Hu (1962), working on the Pilgrim Formation in Montana, described several cranidia and pygidia identical to the juveniles in Shaw's collections and renamed them Maryvillia omega. A.R. Palmer (1965) recognized that Lochman and Hu's assignment of C. delandi to Maryvillia was not "justified" and reassigned it to Cheilocephalus omega, acknowledging the species as different from C. delandi. According to Palmer (1965), the congeneric association of C. omega and C. granulosus in Montana is uncommon for the genus.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.6, 8.2, 8.1, 7.9, 7.8, 7.7, 7.3, 7.2, 7.1, 7.0); Nixon Gulch (Horizon 12.9).

Family CREPICEPHALIDAE Kobayashi, 1935
Genus Coosella Lochman, 1936
Coosella perplexa? (Palmer)
(Plate 19, Figure 4)

Crepicephalus? perplexus Palmer, 1954, p.733, pl.77, figs. 1, 2, 4.

Description: Pygidium semicircular in outline with a narrow, posteriorly tapering axis composed of three segments and a terminal portion that ends on the border in a pointed ridge. The pleural field is subtriangular with three pairs of distinct pleural furrows and faint interpleural grooves. The border is broad and gently downsloping with a slight median inbend along the posterior margin. The border is narrowest at the anterolateral corners and widens posteriorly. Cranidium and librigena unknown.

Discussion: Several poorly preserved pygidia exhibit the characteristics of the species. The specimens closely resemble C. perplexa and occur in the basal Aphelaspis Zone beds. This species also occurs in the lowest beds of the Aphelaspis Zone in Texas (Palmer, 1954) and Tennessee (Rasetti, 1965).


Coosella sp. (undet.)
(Plate 21, Figure 2)

Coosella Lochman, 1936, p.39; Shimer and Shrock, 1944, p.621.

Description: Pygidia similar to Coosella perplexa?, except for the absence of a median inbend along the
posterior margin. The border is narrowest at the anterolateral corners and widens posteriorly. The axis is narrow, slightly tapering and terminates in a slender, pointed ridge. Associated cranidium and librigena unknown.

Discussion: Three pygidia without the posterior median inbend were found below the stratigraphic horizon with specimens that do contain the median inbend. Both types of pygidia have smooth surfaces. The absence of a median inbend may result from individual variation or possibly poor preservation.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.5, 3.6).

Genus Coosina Rasetti, 1956
Coosina ariston (Walcott) (Plate 20, Figure 2)

Maryvillia ariston Walcott, 1916, p.401, pl.64, figs.5, 5'.

Coosina ariston (Walcott) Rasetti, 1956, p.1267 (complete synonymy); 1961, p.111, pl.21, figs.12, 13.

Description: Cranidium moderately low with a tapering, furrowless glabella. Frontal area separated into preglabellar field and border by a broad, shallow anterior border furrow. Palpebral lobes placed slightly anterior to
the center of the glabella and contain a shallow palpebral furrow. The occipital furrow is broad and shallow with a slight median inbend. The occipital ring is narrow. The posterior limbs are short and blunt with very broad posterior border furrows.

The pygidium is semicircular in outline with a wide axis composed of five segments. Pleural fields are convex and contain four pleurae. The border is sharply downsloping and the border furrow is obsolete. Librigenae are unknown.

Discussion: Several large cranidia and pygidia represent this species in the collections. A "coquina" of C. ariston occurs just below the base of the Aphelaspis Zone at Nixon Gulch and occurs at the same stratigraphic horizon as species of Coosella and Crepicephalus.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.5, 7.1).

Genus Crepicephalus Owen, 1852
Crepicephalus iowensis (Owen) (Plate 20, Figure 1)

Dikelocephalus iowensis Owen, 1852, p.575, pl.1, fig.4, pl. 1a, fig.13.

Crepicephalus iowensis (Owen) Walcott, 1916, p.207, pl.29, figs.1, 2, 2a-f; Shimer and Shrock, 1944, pl.262, figs.

Description: Cranidium elongate with gently rounded margin. Glabella bluntly rounded with no glabellar furrows visible. Frontal area contains a distinct border furrow and a strongly upturned border. Palpebral lobes are long and slender with a moderately shallow and broad posterior border furrow. The surface of the cranidium is strongly granulated. Pygidia and librigenae unknown.

Discussion: Several cranidia belonging to this species occur in the upper part of the Crepicephalus Zone. This species also occurs in the upper Crepicephalus Zone in Texas (Palmer, 1954) and Montana (Lochman and Duncan, 1944).

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.5).

Crepicephalus sp. (undet. 1) (Plate 21, Figure 4)


Description: Pygidium nearly twice as wide as it is long. Axial lobe is narrow and reaches to the posterior margin. Four pleurae with deep interpleural furrows and
border furrow very prominent. Marginal spines directed straight posteriorly, curving medially near the posterior end of the spines. Length of spines about two-thirds that of the axial lobe. Cranidia and librigenae unknown.

Discussion: This species is most similar to *C. australis*, but is too poorly preserved for specific identification. Several pygidia occur near the top of the Crepicephalus Zone at Nixon Gulch.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.1, 3.6, 2.0).

*Crepicephalus* (undet. 2) (Plate 21, Figure 1)


Description: The pygidium is broad with a long narrow axis that is two-thirds the length of the pygidium and extends into a border furrow near the posterior margin. The pleural field is relatively small, composed of three distinct furrows but no interpleural grooves. Posterolateral spines are short and curve inward producing a strong curvature to the margin between the spines. Associated cranidium and librigena unknown.
Discussion: Pygidia differ from Crepicephalus sp. (undet. 1) in the stronger curvature of the posterior margin, the presence of three pleural furrows and absence of interpleural grooves and the less distinct border furrow.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Nixon Gulch (Horizon 7.1, 3.6).

Family LONCHOCEPHALIDAE Hupe, 1953
Genus Glaphyraspis Resser, 1937
Glaphyraspis parva (Walcott)
(Plate 19, Figures 2, 3)

Liostracus parvus Walcott, 1899, p.463, pl.65, fig.6.
Raaschella occidentalis Lochman and Duncan, 1944, p.43-44, pl.4, figs.1-5; Shaw, 1956, p.51, pl.12, figs.4, 5.

Description: Cranidium is small with a strongly convex glabella that contains two pairs of deep glabellar furrows. The anterior pair are short and straight and the posterior pair are arcuate posteriorly. The anterior border is short and is separated from the preglabellar field by a distinct anterior border furrow. Faint eye ridges reach the axial furrow well behind the front of the glabella. The occipital furrow is deep and curved along the sides, the occipital ring is broad and flat. The posterior limbs are short with
deep posterior border furrows. Librigenae are short and broad with a distinct lateral border furrow.

Pygidium is short with a moderately wide axis composed of four to five segments and a terminal axial piece. The pleural field is flat and turns down abruptly at the border.

The outer surfaces of the cranidium, pygidium and librigena are covered with irregularly dispersed granules.

Discussion: This species has been fully described by Lochman et al. (1944 and 1962). It is represented in the collections by numerous cranidia, several pygidia and a few librigenae. The species is abundant in the lower Aphelaspis Zone but has also been reported from the upper Crepicephalus Zone in Virginia and Tennessee (Rasetti, 1961, 1965).

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.6, 8.4, 8.3, 8.2, 8.1, 7.8, 7.7, 7.1, 1.4, 1.2); Nixon Gulch (Horizon 16.8, 16.6, 16.0, 14.8, 14.6, 14.1, 13.8, 13.6, 13.5, 13.4, 12.9, 12.0, 7.7, 7.6); Sacajawea Peak (Horizon 6.8, 3.8, 3.2, 3.0, 1.6).

Family PTEROCEPHALIIDAE Kobayashi, 1935
Subfamily APHELASPIDINAE Palmer, 1954
Genus Aphelaspis Resser, 1935
Aphelaspis walcotti Resser, 1938
(Plate 18, Figure 3)
Not *Conocephalites depressus* Shumard, 1861, p.219.

*Aphelaspis depressa* (Shumard) Bridge, in Bridge and Girty, 1937, p.255, pl.69, figs.23-26; Shimer and Shrock, 1944, pl.263, figs.35, 36; Nelson, 1951, p.774, pl.106, fig.14.

*Aphelaspis walcotti* Resser, 1938, p.59, pl.13, fig.14; Shimer and Shrock, 1944, pl.263, figs. 19, 20.

*Aphelaspis hamblenensis* Resser, 1938, p.60, pl.13, fig.28; Shimer and Shrock, 1944, pl.263, fig.37.

Description: Cranidium is subrectangular with a straight-sided glabella that is truncate anteriorly. The glabella is commonly featureless although three pairs of faint, slightly arcuate lateral furrows are present on exfoliated specimens. The frontal area is divided into preglabellar field and border that are separated by a sharp break in slope although no border furrow is present. The palpebral lobes are distinct, semicircular in outline and contain shallow palpebral furrows. Faint eye ridges extend to the axial furrow and intersect the furrow at less than a right angle. The occipital furrow is shallow and the occipital ring is broad and flat. The posterior limbs are narrow and contain a distinct posterior border furrow.

The librigena has a distinct lateral border furrow that merges with the posterior border furrow and extends a short distance along the genal spine. The genal spine is of moderate length, distinguishing this species from *A. buttsi*.

Discussion: This is the most widespread species of
Aphelaspis in North America and is moderately abundant at
the base of the Aphelaspis Zone at each locality. A.
walcotti occurs with Cheilocephalus granulosus several
centimeters above the last appearance of the Crepicephalus
Zone fauna and occurs stratigraphically with the
opportunist, Blountia nixonensis approximately six meters
above its initial appearance.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim
Formation (Aphelaspis Zone). Logan (Horizon 5.2); Nixon
Gulch (Horizon 15.4, 10.5, 10.3, 8.1); Sacajawea Peak
(Horizon 1.6).

Aphelaspis buttsi (Kobayashi)
(Plate 18, Figures 1, 2)

Olenus cf. O. truncatus Butts, 1926, p.77, pl.9, figs.6, 7.
Proaulacopleura buttsi Kobayashi, 1936, p.93, pl.15, fig.6;
Resser 1938, p.95, pl.16, fig.18.

Aphelaspis buttsi (Kobayashi) Palmer, 1962, p.35, pl.4,
figs.23, 26, 31, 32.

Description: Cranidium with slightly tapering,
subrectangular glabella. Posterior pair of lateral
glabellar furrows are moderately impressed, straight and
inclined posteriorly. The frontal area is divided into
preglabellar field and border that are separated by a
distinct border furrow. The anterior border is moderately convex and tappers laterally from the axial line. The eye ridges are prominent and directed laterally at right angles to the axial furrow. The occipital furrow is shallow and the occipital ring is broad and flat containing a low median node. The posterior limbs are narrow with a shallow border furrow. The librigenae are similar to those of A. walcottii, but have much longer genal spines.

Discussion: This species is distinguished from other species of Aphelaspis by the presence of glabellar furrows, a convex anterior border with a prominent border furrow and eye ridges that intersect the axial furrow at right angles. This is also a common and widespread species of Aphelaspis in North America and is very abundant at the base of the Aphelaspis Zone at each locality. This species has been reported from the lower Aphelaspis Zone in Tennessee (Rasetti, 1965), the Great Basin (Palmer, 1965) and Alabama (Butts, 1926). A. buttsi is represented in the collections by several cranidia and librigenae but no pygidia were found.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Logan (Horizon 8.2, 5.2, 1.6); Nixon Gulch (Horizon 10.6, 10.5, 10.3, 9.8, 8.1); Sacajawea Peak (Horizon 1.6).
Aphelaspis sp. (undet.)  
(Plate 17, Figure 4)


Clevelandella Resser, 1938, p.68.


Description: Cranidia showing characteristics of the genus but too poorly preserved for specific identification. Glabella tapering, subrectangular in shape containing faint impressions of two lateral furrows. Frontal area divided into preglabellar field and border that are separated by a distinct border furrow. Anterior border convex and broadest at the axial line. Ocular ridges are prominent and intersect the axial furrow at substantially less than a 90 degree angle. The occipital furrow is broad and shallow and the occipital ring is narrow and flat.

Discussion: Thirteen specimens agree with the concept of the genus Aphelaspis, but are too poorly preserved for specific identification. They differ from A. buttsi in the position of the ocular ridge at an angle to the axial furrow and from A. walcotti in the presence of a distinct anterior
border furrow. They are most similar to *A. conveximarginatus* but lack a posterior median inbend of the marginal furrow.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Nixon Gulch (Horizon 12.9); Sacajawea Peak (Horizon 1.6).

Genus *Dytremacephalus* Palmer, 1954

*Dytremacephalus granulosus* Palmer, 1954

(Plate 16, Figure 1)

*Dytremacephalus granulosus* Palmer, 1954, p.750, pl.85, figs.5, 6.

Description: Cranidium with slightly tapering, subrectangular glabella. Glabella prominent, elevated above free cheeks with three moderately deep glabellar furrows. The anterior two pair of glabellar furrows are straight and the posterior pair are slightly arcuate posteriorly. The frontal area is divided into preglabellar field and border, separated by a distinct border furrow. Dorsal furrow is deep along the sides of the glabella, but is shallow anteriorly with distinct pits at the anterolateral corners of the glabella. Fixed cheeks moderately arched and gently upsloping. Eye ridges prominent, directed laterally at a slight angle to the axial furrow. Occipital furrow shallow
and occipital ring moderately arched with a low median node. Entire surface of cranidium covered with small, evenly spaced granules. Pygidia and librigenae unknown.

Discussion: Several cranidia were found near the top of the Pilgrim Formation at Nixon Gulch and Sacajawea Peak. Distinguished from other species of Dytremacephalus by the presence of small granules. This species is common in the post-Aphelaspis Zone in Texas and the basal Dunderbergia Zone in the Great Basin. D. granulosus occurs together with B. nixonensis in Montana indicating that B. nixonensis survived long after the extinction of the Crepicephalus Zone fauna. Dytremacephalus also occurs in the overlying Dry Creek Shale (Grant, 1965) indicating the faunal sequence is complete across the Pilgrim-Dry Creek Shale boundary.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis or Dunderbergia? Zone). Nixon Gulch (Horizon 16.8, 16.6, 16.0, 15.4); Sacajawea Peak (Horizon 6.8, 6.6).

Family TRICREPICEPHALIDAE Palmer, 1954
Genus Tricrepicephalus Kobayashi, 1935
Tricrepicephalus sp. (undet.)
(Plate 21, Figure 3)
Tricrepicephalus Kobayashi, 1935, p.278; Shimer and Shrock, 1944, p.635.

Paracrepicephalus Lochman, 1936, p.36.

**Description:** Pygidium with long spines developed from the surface of the pleural lobes. The width of the axial lobe is greater than one-third of the total pygidial width. The axis is composed of three segments and tappers posteriorly.

The librigenae has a broad, flat border and a well defined border furrow. The genal spine tappers and is sharply pointed posteriorly. The outer surface of the carapace is covered with moderately large, evenly spaced granules.

**Discussion:** This genus is represented in the collections by two pygidia and five librigenae that are too poorly preserved for specific identification. The pygidia agree with the concept of the genus in that the paired pygidial spines are developed from the surface of the pleural lobes.

**Occurrence:** Upper Cambrian (Dresbachian) Pilgrim Formation (Crepicephalus Zone). Logan (Horizon 1.1, .5); Nixon Gulch (Horizon 7.1, 2.8).

Phylum BRACHIOPODA Cuvier, 1805
Class INARTICULATA Huxley, 1869
Iphidella Walcott, 1912, p.359.

Dictyonina Cooper, 1942, p.228; Shimer and Shrock, 1944, p.287; Cooper, in Cooper et. al., 1952, p.40.

Description: The surface of the shell is composed of a meshwork of hexagonal perforations that resemble a screen. The perforations are separated by ridges of solid shell material composed of closely spaced perforations. The beak and margin are also composed of solid shell material similar to the ridges.

Discussion: This species is characterized by the distinct perforations of the shell and is moderately abundant near the base of the Aphelaspis Zone. Palmer (1954) suggests that the perforations result from slight solution by acetic acid during extraction, but several specimens collected in the field from Nixon Gulch show that the perforations are a distinct feature of the original morphology. This species usually appears at the very base of the Aphelaspis Zone (Palmer, personal communication) but occurs up to nine meters above the lowest appearance of Aphelaspis at Nixon Gulch. The species is represented in the collections by numerous fragments and several intact pedicle valves that are remarkably well-preserved.
Phylum MOLLUSCA
Class GASTROPODA Cuvier, 1797
Order MONOPLACOPHORA Wenz in Knight, 1952
Family TRYBLIDIIDAE Pilsbry in Zittel-Eastman, 1899
Genus Proplina Kobayashi, 1933
Proplina loganensis Lochman and Hu, 1962
(Plate 17, Figure 1)


Description: Internal mold of shell with pointed apex broken. Aperture smoothly curved along anterior margin and straight along lateral margins. Surface shows closely spaced growth ridges that parallel the aperture. The fine lirae radiating from the apex in Lochman's specimens are not visible.

Discussion: One internal mold found at Nixon Gulch and one found at Sacajawea Peak are nearly identical to the specimens collected by Lochman at Logan, Montana.

Occurrence: Upper Cambrian (Dresbachian) Pilgrim Formation (Aphelaspis Zone). Nixon Gulch (Horizon 12.9); Sacajawea Peak (Horizon 6.8).
APPENDIX C

FOSSIL ILLUSTRATIONS

At least one of the best preserved specimens of each described species is illustrated. Each fossil was coated with magnesium oxide by holding the specimens over a burning magnesium ribbon. The magnesium ribbon was held under a inverted funnel on a stand in order to concentrate the smoke and allow for a more uniform application to the specimens. Plates and specimens are listed in biostratigraphic order from oldest to youngest. All of the collection is housed at the Museum of Paleontology, University of Montana.
<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dytremacephalus Palmer ................................................. 137</td>
<td></td>
</tr>
<tr>
<td>Partly exfoliated cranidium.</td>
<td></td>
</tr>
<tr>
<td>2. Dictyonina perforata Palmer ........................................... 137</td>
<td></td>
</tr>
<tr>
<td>Exterior of brachial valve.</td>
<td></td>
</tr>
<tr>
<td>3. Blountia nixonensis Lochman and Duncan .............................. 137</td>
<td></td>
</tr>
<tr>
<td>Cranidium.</td>
<td></td>
</tr>
<tr>
<td>4. Blountia nixonensis Lochman and Duncan .............................. 137</td>
<td></td>
</tr>
<tr>
<td>Pygidium.</td>
<td></td>
</tr>
</tbody>
</table>
### Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Proplina loganensis Lochman and Hu</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Internal mold of shell.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Cheilocephalus omega (Lochman and Hu)</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Exfoliated cranidium.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Cheilocephalus omega (Lochman and Hu)</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Exfoliated pygidium.</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Aphelaspis sp. (undet.)</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Partly exfoliated cranidium.</td>
<td></td>
</tr>
</tbody>
</table>
PLATE 18. APHELASPIS ZONE FOSSILS

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aphelaspis buttsi (Kobayashi)</td>
<td>141</td>
</tr>
<tr>
<td>Exfoliated cranidium.</td>
<td></td>
</tr>
<tr>
<td>2. Aphelaspis buttsi (Kobayashi)</td>
<td>141</td>
</tr>
<tr>
<td>Partly exfoliated librigena.</td>
<td></td>
</tr>
<tr>
<td>3. Aphelaspis walcotti Resser</td>
<td>141</td>
</tr>
<tr>
<td>Fragment of an exfoliated cranidium.</td>
<td></td>
</tr>
<tr>
<td>4. Cheilocephalus granulosus Palmer</td>
<td>141</td>
</tr>
<tr>
<td>Exfoliated cranidium.</td>
<td></td>
</tr>
</tbody>
</table>
PLATE 19. *APELASPIS* AND *CREPICEPHALUS* ZONE FOSSILS

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Glaphyraspis parva (Walcott) .................... 143</td>
<td>Cranidium.</td>
</tr>
<tr>
<td>3. Glaphyraspis parva (Walcott) ..................... 143</td>
<td>Pygidium.</td>
</tr>
</tbody>
</table>
PLATE 20. CREPICEPHALUS ZONE FOSSILS

Figures

1. Crepicephalus iowensis (Owen) .................. 145
   Cranidium.

2. Coosina ariston (Walcott) ....................... 145
   Exfoliated cranidium.

3. Pseudagnostus sp. (undet.) ...................... 145
   Pygidium.

4. Pemphigaspis sp. (undet.) ....................... 145
   Rubber cast of a cranidium.
<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Crepicephalus sp. (undet. 2)</td>
<td>147</td>
</tr>
<tr>
<td>Partly exfoliated pygidium.</td>
<td></td>
</tr>
<tr>
<td>2. Coosella sp. (undet.)</td>
<td>147</td>
</tr>
<tr>
<td>Partly exfoliated pygidium.</td>
<td></td>
</tr>
<tr>
<td>3. Tricrepicephalus sp. (undet.)</td>
<td>147</td>
</tr>
<tr>
<td>Exfoliated pygidium.</td>
<td></td>
</tr>
<tr>
<td>4. Crepicephalus sp. (undet. 1)</td>
<td>147</td>
</tr>
<tr>
<td>Exfoliated pygidium.</td>
<td></td>
</tr>
</tbody>
</table>