Paleontology paleoecology and depositional environments within the Upper Triassic (Norian) carbonate strata of the Antimonio Formation northwest Sonora Mexico

David H. Goodwin
The University of Montana

Follow this and additional works at: https://scholarworks.umt.edu/etd
Let us know how access to this document benefits you.

Recommended Citation
https://scholarworks.umt.edu/etd/7501

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
Permission is granted by the author to reproduce this material in its entirety, provided that this material is used for scholarly purposes and is properly cited in published works and reports.

**Please check "Yes" or "No" and provide signature**

Yes, I grant permission  

No, I do not grant permission

Author's Signature:  

Date: May 18, 1998

Any copying for commercial purposes or financial gain may be undertaken only with the author's explicit consent.
PALEONTOLOGY, PALEOECOLOGY, AND DEPOSITIONAL ENVIRONMENTS WITHIN THE UPPER TRIASSIC (NORIAN) CARBONATE STRATA OF THE ANTIMONIO FORMATION, NORTHWEST SONORA, MEXICO

By

David H. Goodwin
B.S. Lyndon State College, 1994

Presented in partial fulfillment of the requirements for the degree of Master of Science University of Montana 1999

Approved by

Chairman, Board of Examiners

Dean, Graduate School

4-8-99 Date
Paleontology, paleoecology, and depositional environments within the Upper Triassic (Norian) carbonate strata of the Antimonio Formation, northwest Sonora, Mexico (209 pp.)

Director: George D. Stanley Jr.

Paleontological and sedimentological study of the Upper Triassic carbonate of the Antimonio Formation, northwestern Sonora, has documented the details of a diverse shallow water marine biota. Norian exposures of the Antimonio Formation are dominated by lenticular carbonate strata with interbedded argillite, mudstone, and limy sandstone. Constructional elements within these reefoid and biostromal buildups include corals and chambered thalamid sponges. Spongiomorphs and calcareous red algae were active sediment stabilizers. The dweller guild consisted of hydrozoans, brachiopods, bivalves, gastropods, foraminifers and green algae. The baffler guild was filled by both high growing corals and stalked echinoderms. Bivalves acted as bioeroders.

Tabular bodies of immature lime-cemented sandstone implies that a siliciclastic source lay close by, probably to the east. Different exposures of the Antimonio Formation contain varying amounts of clastic sediments. Those with less sand/silt/clay are interpreted to have been deposited in response to high-order changes in sea-level. Cyclic siliciclastic-carbonate strata exhibit distinctive small-scale successional patterns; soft substrates were colonized by bivalves and sponges which are in turn were colonized by corals. The coincidence of lithofacies and biofacies indicates that biological development of biostromes was controlled by physical processes. Together, paleontological and sedimentological signatures suggest that these units were deposited in normal to restricted marine lagoonal environments at an interface between basinward carbonates and shoreward siliciclastic environments.

The tropical, shallow water fauna of the Antimonio Formation shares affinities with both the western Tethys and inboard terranes of Western North America. Evaluation of sedimentary and paleontological similarities between the Luning Formation, in west-central Nevada, and the Antimonio Formation are consistent with the hypothesis that the Antimonio terrane experienced significant post-depositional tectonic dislocation during middle Jurassic time. Further study is needed to confirm this hypothesis.
ABSTRACT ........................................................................................................ ii

TABLE OF CONTENTS .................................................................................. iii

LIST OF FIGURES ....................................................................................... v

LIST OF TABLES ........................................................................................... vi

ACKNOWLEDGMENTS .................................................................................. vii

CHAPTER I: INTRODUCTION .................................................................... 1
TECTONOSTRATIGRAPHY OF THE ANTIMONIO TERRANE .................. 2
GEOLOGIC SETTING .................................................................................. 9
   Early Mesozoic World .............................................................................. 9
   Late Paleozoic and early Mesozoic Regional Geology of Sonora ....... 12
PREVIOUS INVESTIGATIONS .................................................................. 13
STATEMENT OF PURPOSE ...................................................................... 16
   Hypothesis 1 ......................................................................................... 18
   Hypothesis 2 ......................................................................................... 18
   Hypothesis 3 ......................................................................................... 19

CHAPTER II: GEOLOGY AND STRATIGRAPHY OF THE NORIAN CARBONATES, ANTIMONIO FORMATION ......................... 20
GEOLOGY OF SIERRA DEL ALAMO ...................................................... 20
GEOLOGY OF BARRA LOS TANQUES .................................................. 23
GEOLOGY OF SIERRA SANTA TERESA ................................................ 26

CHAPTER III: FACIES OF THE NORIAN CARBONATE INTERVAL ................................................................. 29
REEFS: BASIC DEFINITIONS .................................................................. 29
FACIES OF THE NORIAN CARBONATE INTERVAL ............................ 32
   Lithofacies, microfacies, and biofacies from Sierra del Alamo ......... 32
   Argillites And Mudstones .................................................................. 36
   Limy Sandstone .................................................................................. 36
   Sandy Limestone ................................................................................ 40
   Bedded Pure Limestone ...................................................................... 48
   Lithofacies, microfacies, and biofacies from Barra los Tanques ....... 60
   Massive Framestone Lithofacies ....................................................... 60
   Bivalve-Echinoid Packstone ............................................................... 62
   Mollusk-Bivalve Debris ..................................................................... 62
   Blue-Grey Peloidal Limestone ............................................................ 63

CHAPTER IV: PALEONTOLOGY, PALEOECOLOGY AND DEPOSITIONAL SYSTEMS OF THE NORIAN CARBONATE INTERVAL ................................................................. 63
SIERRA DEL ALAMO .............................................................................. 64
Taxonomic Composition ........................................................................ 64
Paleoautecology ........................................ 64
Algae ...................................................... 69
Foraminifers .............................................. 71
Sponges ...................................................... 73
Corals ......................................................... 74
Brachiopods ................................................. 83
Gastropods .................................................... 84
Bivalves ....................................................... 85
Cephalopods ................................................. 88
Echinoderms .................................................... 89
Paleosyneclology .......................................... 89
Sequence Stratigraphy and Paleoecology ............. 92
Successional Patterns ..................................... 95
Depositional environment .................................. 103
BARRA LOS TANQUES ....................................... 103
Taxonomic Composition .................................... 105
Paleosyneclology ........................................... 105
Reef Structure at Barra los Tanques ................. 108
Depositional environment .................................. 113

CHAPTER V: PALEOBIOGEOGRAPHY .......................... 114
TETHYAN SIMILARITIES .................................. 114
SIMILARITIES WITH OTHER NORTH AMERICAN
CORDILLERAN TERRANES ................................... 115
SIMILARITY COEFFICIENTS ................................ 116

CHAPTER VI: COMPARISON OF THE ANTIMONIO AND
LUNING FORMATIONS ..................................... 120
STRATIGRAPHIC AND BIOSTRATIGRAPHIC SIMILARITIES ... 122
FAUNAL SIMILARITIES ....................................... 124
PALEOECOLOGICAL PATTERNS ............................. 124
SIGNIFICANCE OF THE MOJAVE-SONORA MEGASHEAR .... 126

CHAPTER VII: FINDINGS AND CONCLUSIONS ............... 128
APPLICATION OF FINDINGS ................................ 129
Hypothesis 1 ................................................. 129
Hypothesis 2 ............................................... 130
Hypothesis 3 ............................................... 132
CONCLUSIONS ............................................... 136
FUTURE RESEARCH DIRECTIONS ......................... 139

REFERENCES CITED ......................................... 142

PLATES ....................................................... 171
APPENDIX A-Measured sections from Sierra del Alamo ... 181
APPENDIX B-Measured section from Barra los Tanques ... 184
APPENDIX C-Thalamis sponge similarity table ............ 186
APPENDIX D-Coral similarity table ........................ 188
APPENDIX E-Systematic Paleontology .................... 190
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Locality Map of the Antimonio terrane</td>
<td>4</td>
</tr>
<tr>
<td>1.2 Stratigraphic section of the Antimonio Formation</td>
<td>6</td>
</tr>
<tr>
<td>1.3 Upper Triassic and Lower Jurassic strata of the Antimonio Formation</td>
<td>8</td>
</tr>
<tr>
<td>1.3 Early Mesozoic World and location of Upper Triassic Carbonates</td>
<td>10</td>
</tr>
<tr>
<td>2.1 Geologic Map of Sierra del Alamo</td>
<td>21</td>
</tr>
<tr>
<td>2.2 Geologic Map of Barra los Tangues</td>
<td>24</td>
</tr>
<tr>
<td>2.3 Geologic Map of Sierra Santa Teresa</td>
<td>28</td>
</tr>
<tr>
<td>3.1 Lithofacies from Sierra del Almo</td>
<td>33</td>
</tr>
<tr>
<td>3.2 Limy Sandstone Lithofacies</td>
<td>37</td>
</tr>
<tr>
<td>3.3 SDA-1; Limy Sandstone Microfacies</td>
<td>38</td>
</tr>
<tr>
<td>3.4 SDA-2; Molluskan Limy Sandstone Microfacies</td>
<td>39</td>
</tr>
<tr>
<td>3.5 Sandy Limestone Lithofacies</td>
<td>41</td>
</tr>
<tr>
<td>3.6 SDA-3; Quartz Bioclastic Packstone Microfacies</td>
<td>43</td>
</tr>
<tr>
<td>3.7 SDA-4; Quartz Bioclastic Grainstone Microfacies</td>
<td>44</td>
</tr>
<tr>
<td>3.8 SDA-5; Coated Grain Microfacies</td>
<td>46</td>
</tr>
<tr>
<td>3.9 Pure Bedded Limestone</td>
<td>49</td>
</tr>
<tr>
<td>3.10 SDA-6; Peloidal Packstone Microfacies</td>
<td>50</td>
</tr>
<tr>
<td>3.11 SDA-7; Bioclastic Packstone Microfacies</td>
<td>51</td>
</tr>
<tr>
<td>3.12 SDA-8; Bioclastic Wackestone Microfacies</td>
<td>53</td>
</tr>
<tr>
<td>3.13 SDA-9; Carbonate Mudstone Microfacies</td>
<td>54</td>
</tr>
<tr>
<td>3.14 SDA-10; Coral/Spongiomorph Bindstone Microfacies</td>
<td>55</td>
</tr>
<tr>
<td>3.15 SDA-11; Coral Framestone/Bafflestone Microfacies</td>
<td>58</td>
</tr>
<tr>
<td>3.16 Lithofacies relationships from Barra los Tangues</td>
<td>61</td>
</tr>
<tr>
<td>4.1 Diagram of sponge/Stromatoporoid interactions</td>
<td>75</td>
</tr>
<tr>
<td>4.2 Key to symbols used in line drawings</td>
<td>76</td>
</tr>
<tr>
<td>4.3 Thalamid sponge community line drawing</td>
<td>77</td>
</tr>
<tr>
<td>4.4 Coral bindstone line drawing</td>
<td>81</td>
</tr>
<tr>
<td>4.5 Stromatoporoid bindstone line drawing</td>
<td>82</td>
</tr>
<tr>
<td>4.6 Trophic group vs. Lithofacies</td>
<td>90</td>
</tr>
<tr>
<td>4.7 Substrate relationship vs. Lithofacies</td>
<td>91</td>
</tr>
<tr>
<td>4.8 Parasequences from Sierra del Alamo</td>
<td>94</td>
</tr>
<tr>
<td>4.9 Biostrome successional patterns</td>
<td>99</td>
</tr>
<tr>
<td>4.10 Lateral thickness variation within a biostrome</td>
<td>102</td>
</tr>
<tr>
<td>4.11 Hypothetical depositional environment of Sierra del Alamo</td>
<td>104</td>
</tr>
<tr>
<td>4.12 Patch reef from Barra los Tangues</td>
<td>109</td>
</tr>
<tr>
<td>5.13 Reef structure from Barra los Tangues</td>
<td>111</td>
</tr>
<tr>
<td>5.1 Thalamid sponge similarity cluster analysis</td>
<td>118</td>
</tr>
<tr>
<td>5.2 Coral similarity cluster analysis</td>
<td>119</td>
</tr>
<tr>
<td>6.1 Map showing Luning and Antimonio Formations</td>
<td>121</td>
</tr>
<tr>
<td>6.2 Comparison of Luning and Antimonio Formation biostromes</td>
<td>123</td>
</tr>
<tr>
<td>7.1 Depositional environment of Norian carbonate interval of the Antimonio Formation</td>
<td>138</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

Table

1.1 Selected references on the Antimonio Formation..... 14  
3.1 Microfacies from the Norian carbonate interval..... 35  
4.1 Faunal list from the Norian carbonates at Sierra del Alamo........................................ 65  
4.2 Faunal list from the Norian carbonates at Barra los Tanques........................................ 106  
5.1 Thalamid sponge similarity coefficients............. 117  
5.2 Coral similarity coefficients.............................. 117
ACKNOWLEDGEMENTS

I would like to thank Dr. George D. Stanley, my thesis committee chair, for his supervision, continual advice and support, and ceaseless patience throughout the course of my thesis. I also give thanks to my other committee members, Dr. Marc Hendrix, Dr. Don Winston and Dr. Richard Sheridan for their insightful comments and constructive criticism.

Special thanks are extended to Dr. Carlos González-León, of the Estación Regional del Noroeste, Instituto de Geología, Universidad Nacional Autónoma de México, in Hermosillo, Sonora, Mexico. Carlos’ generosity with logistical support in the field, insightful observations, and friendship have made my research experience enjoyable and stimulating.

This thesis was funded by an international, U.S./Mexico, cooperative workshop funded by the National Science Foundation, and a field research grant from the National Geographic Society.

Sincere thanks are also extended to Dr. Mike Orchard, Canadian Geological Survey, for conodont identifications; Dr. Christopher McRoberts, Frankie Jackson, Jeanie Yarnell for their help in the field; Sherri Lierman for her help with photography; Dave Gaueuman for computer help; Tara Prestholdt for copies and helping keep me sane in the field; the faculty and staff of the University of Montana, Department of Geology for their help and willingness to drop everything and "talk
geology." In addition, I thank C. Healy for providing me with motivation to pursue a graduate degree.

I also thank my father for his willingness to follow his son into the wilds of the Sonoran Dessert to find a reef. I cherish the time we spent together and hope that we will have the opportunity to do it again.

I would be negligent if I did not thank my friends and fellow graduate students at UM, Eric Roberts, Tip Meckel and Mary Beck, without whose help I could have finished this thesis a year ago. In all seriousness, I have learned as much from you and our discussions as I have from any class. Good luck and success to you all!

My unbounded thanks are extended to my daughter and wife for their patience, support and love. Christina, if not, for your knowledge, of the use, of commas I never, would have been taken, seriously.

Finally, I wish to thank my parents, Marcia and Skip, Dick and JoAnn. You have made me the man I am and I will never be able to thank you enough. This thesis is dedicated to all of you.
CHAPTER I
INTRODUCTION

One of the principle interests of paleontologists is to reconstruct the physical settings and depositional environments in which plants and animals, that are now fossils, once lived. Much of this information is preserved in the geologic record. Few rock types indicate environmental conditions better than reef carbonates, principally because they were produced by the animals themselves. Because reefs are built primarily by in situ organisms, which are restricted to warm, shallow, normal marine waters, they become excellent paleoenvironmental indicators. Thus, biogenic limestones are important in paleogeographic reconstructions, especially in reconstructing the geologic evolution of highly mobile tectonic entities—tectonostratigraphic terranes (Beck et al., 1980). They are especially useful in reconstructing the early Mesozoic evolution of the North American Cordillera.

Triassic marine rocks in the North American Cordillera have been known for nearly 75 years (Smith, 1927). In the last 20 years these rocks have been investigated intensively, and many contain biogenic limestones (Stanley, 1979). Aside from their obvious importance as the first “modern” reefs to develop following the terminal Permian extinction (Erwin, 1993), these successions are important in understanding the
evolution of early Mesozoic continental margin sequences (Stanley, 1988).

The character of Late Triassic reefs has recently expanded greatly, due in part, to the study of European alpine reefs. Work carried out by the "Erlangen Reef Research Group" (see Flügel, 1981) has led to detailed understanding of European Triassic reef biotas and their paleoecology (Flügel and Flügel-Kahler, 1992). Although Triassic reefs occur in many parts of the world, they all share similar depositional environments, fauna, and paleoecology. These similarities allow the researcher to extrapolate findings from Tethyan reefs to carbonate sequences of the Circum-Pacific terrane collage. One such marine Triassic sequence is the Antimonio terrane, recognized in northwestern Sonora, Mexico.

TECTONOSTRATIGRAPHY OF THE ANTIMONIO TERRANE

Coney et al. (1980) was one of the first to discuss the significance of terranes in the North American Cordillera. In this landmark paper the authors discuss the geologic importance of Cordilleran terranes, many of which are considered allochthonous to the craton. Howell et al. (1985, p. 4) define a tectonostratigraphic terrane as "...a fault bounded package of rocks of regional extent characterized by a geologic history which differs from that of neighboring
terranes." This concept has proved to be one of the most useful tools in understanding the geologic history of the North American Cordillera, a region characterized by the amalgamation of highly mobile tectonostratigraphic terranes.

One of the southern most examples of a Cordilleran terrane containing Triassic strata is the Antimonio terrane (González-León, 1989), recognized in a region of northwestern Sonora, Mexico (Figure 1.1). This terrane is composed of two formations: the Upper Permian Monos Formation and the extremely thick Uppermost Permian to Middle Jurassic Antimonio Formation (González-León, 1997).

The Monos is approximately 500 m thick (González-León, 1980). This formation consist of thin to thick beds of bioclastic limestone and thin layers of detrital limestone which indicate a moderate to deep water origin (Stewart et al., 1990). The Monos contains brachiopods, bivalves, rare solitary corals, large fusulinids, and ammonoids, indicating an early Late Permian (Guadalupian) age (Cooper, 1953). Based on the similarity of the giant fusulinids, Parafusulina? antimonioensis, from the Monos, to other fusulinids in western Nevada, Quesnellia, the Eastern Klamath Mountains and northeastern Washington, the Monos may be correlative with inboard terranes of the North American Cordillera (Stevens, 1995). In addition, Stevens (1995) correlates the Monos with strata of west Texas based on the presence of Parafusulina? antimonioensis in both areas. Thus
Figure 1.1. Map showing the localities of the Antimonio Formation and other major geological features in Sonora.
the Permian Monos Formation may have occupied a geographic position intermediate between the North American craton and the Cordilleran terranes to the west.

The Antimonio Formation disconformably overlies a karstic surface developed on the uppermost beds of the Monos (Figure 1.2). The Antimonio Formation is unusually thick, reaching nearly 4.1 km (González-León, 1997), and has been divided into two informal members (González-León, 1980). The contact between the lower and upper members is placed at the top of biostromal carbonates, approximately 1.3 km from the base of the formation, based on the slight angular unconformity recognized by White and Guiza (1950).

The lower member is 1350 m thick and is composed of sediments deposited in Late Permian to Late Triassic time. The lowest beds of the Antimonio Formation contain Permian brachiopods and González-León (1997) assigns these beds a Permian age. The lower and middle portion of the lower member is composed of shallow to deep water marine limestone, mudstone, siltstone, and fine-grained sandstone. Abundant ammonoids in these beds indicate an Early Triassic age (Lucas et al., 1997). The upper portion of the lower member contains an interval of distinctively deep water mudstone and limestone. A fauna of ammonoids, coleoids, brachiopods, bivalves (Stanley et al., 1994) and ichthyosaur bones (Callaway and Massare, 1989) occur in this interval. Ammonoids from these beds have been placed in the Upper
Figure 1.2. Stratigraphic section of the Antimonio Formation with an interpreted sea-level curve (González-León, 1997).
Triassic Carnian, Dilleri zone (Stanley et al., 1994, p. 5). Above the Carnian beds is a distinctive interval of biogenic limestones, sandy limestones, and limy sandstones. The fauna of corals, sponges, brachiopods, bivalves, and gastropods (Stanley et al., 1994) are assigned to the middle to upper Norian stage based on characteristic ammonoid taxa and the planktonic hydrozoan Heterastridium (González-León et al., 1996). *Pinacoceras cf. P. metternichi*, *Catenohalorites*, *Sagenites cf. S. schaubachii*, and *Heterastridium conglobatum* collectively indicate the presence of the middle to upper Norian, Columbianus or Cordilleranus Zones (Stanley et al., 1994). Approximately 40 m of uppermost Triassic (Rhaetian) strata is recognized from the uppermost part of the lower member through the lowermost part of the upper member based on the occurrence of the characteristic ammonoid *Choristoceras* (González-León, 1997).

The Triassic/Jurassic boundary is located in the lower reaches of the upper member and based on the occurrence of beds containing the Triassic ammonoid *Choristoceras* in contact with overlying strata containing the Jurassic ammonoids *Badouxia* and *Sunrisites* (González-León, 1997).

The Triassic/Jurassic sedimentary strata from the upper lower member and the lower upper member have been subdivided into five informal lithostratigraphic sedimentary divisions (Figure 1.3), referred to as packages (González-León et al. 1996). These packages range in age from the middle Norian
Figure 1.3. Lithostratigraphic column showing the upper part of the lower member and lower part of the upper member. Modified from González-León et al. (1996).
Columbianus zone to the upper Hettangian/lower Sinemurian Canadensis zone (González-León et al. 1996). The contact between the upper and lower member is placed at the boundary of package one and two (González-León et al. 1996).

The upper member, more than 2000 m thick, contains Upper Triassic and Lower Jurassic rocks. The lower portion of the upper member is dominated by siltstone, mudstone and limestone. This member grades upward into sandstone, siltstone and conglomerate. Lower Jurassic (uppermost Hettangian or lower Sinemurian?) ammonoids have been located in the lower portion of the upper member above the Rhaetian ammonoids (González-León, 1997). The upper half of the upper member is composed almost entirely of sandstone and conglomerates. This thesis focuses on the Upper Triassic (Norian) carbonates of package 1 of the Antimonio Formation.

GEOLOGIC SETTING

Early Mesozoic World

The early Mesozoic world was dominated by the a single continent, Pangea (Figure 1.4). The north to south arrangement of most of the worlds land masses stretched nearly from pole to pole. The eastern portion of the Pangean supercontinent was home to the Tethys Ocean. This east facing gulf contained Middle to Late Triassic carbonates of
Figure 1.4. A) Paleogeographic map of Pangea in the Late Triassic (Golonka et al., 1993). B) Worldwide distribution of Upper Triassic (Norian) coral reef carbonates, modified after Bernecker (1996).
the shallow Tethys Ocean including thick, well-developed reef complexes (Flügel, 1994). Perhaps the most famous and well-studied example is the Dachstein Limestone. This formation records widespread reef development across much of the Tethys during Late Triassic (Norian-Rhaetian) time and contains some carbonate facies similar to those of modern ecological reefs.

The Tethys Ocean opened eastward into the Panthalassa Ocean. This enormous body of water covered nearly 75 percent of the globe.

During the latest Paleozoic and early Mesozoic the Pangean Supercontinent began to break apart. This rifting caused North America to move away from Europe and north Africa, forming the Atlantic Ocean. This fledgling extensional regime altered plate configurations resulting in a compressional setting on the western margin of North America. Volcanic island arc sequences produced by compressional tectonism, formed in oceanic basins somewhere off the margin of North America. These arc volcanics form the basement of many allochthonous terranes of Western North America. Associated Paleozoic and Mesozoic carbonates show rapid facies changes, with reef facies, well developed lagoons, and high degrees of faunal endemism (Soja, 1996). Stanley (1994) reviewed the mechanisms which can account for the presence of Triassic island-arc sequences and their distinctive faunas in the North American Cordillera.
Late Paleozoic and early Mesozoic regional geology of Sonora

During much of the Paleozoic, the depositional setting of the west coast of Pangea, in what was to become the United States and Mexico, was dominated by passive continental margin sedimentation. Miogeoclinal strata and correlative deep water facies occur throughout western Sonora (Gastil et al., 1991). In Early Permian time, the depositional setting of Sonora changed from shallow shelf to deep water facies (Stewart, 1997). This change in sedimentation coincides with the truncation of southwest North America in Late Paleozoic time (Sedlock et al., 1993). Based partly on the presence of Triassic melange sequences in Baja California, Mexico (Sedlock, 1988), Stanley and González-León (1995) proposed that a compressional arc system existed on the western margin of Sonora during Triassic and Early Jurassic time. However, the location of the subduction zone remains enigmatic.

The relationship of the Antimonio terrane with other tectonic blocks in Triassic time remains unclear. Stanley and González-León (1995) contended that the Antimonio terrane was thrust onto a fragmented portion of the North American craton (Caborca terrane of Campa and Coney, 1983) in Middle Jurassic time. An alternative hypothesis, presented by Stewart et al. (1997), proposes that the Antimonio Formation is autochthonous to the craton and that it was deposited as an onlap assemblage on Paleozoic miogeoclinal rocks. This
view also implies that the Upper Triassic Barranca Group, a predominantly fluvial to marine deltaic "rift sequence" (Stewart and Roldán-Quintana, 1991), is a facies laterally equivalent to the Antimonio Formation. Stewart (1997) also suggests that the Upper Triassic strata at Sierra Santa Teresa (Figure 1.1) may represent a facies transitional between the Barranca Group and the Antimonio Formation.

Perhaps the most contentious aspect of Sonoran geology is the proposed Mojave-Sonora Megashear (Silver and Anderson, 1974; Anderson and Silver, 1979; and Figure 1.1). This regional left-lateral strike-slip fault is based of the juxtaposition of Precambrian basement provinces with Paleozoic rocks in Sonora. The youngest rocks disturbed by the displacement of the megashear are Jurassic (Anderson and Silver, 1979). The Antimonio terrane lies southwest of the inferred trace of the megashear and may have been moved southeastward along this fault.

PREVIOUS INVESTIGATIONS

Previous study of the Antimonio Formation focused on the general geology, tectonic evolution, stratigraphy and paleontology (Table 1.1). The presence of carbonate strata in the Antimonio Formation has been recognized for more than sixty years. The Upper Triassic sequence was first described by Burckhardt (1930). He published the first stratigraphic
<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>DATE</th>
<th>SUBJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keller, W. T.</td>
<td>1928</td>
<td>Stratigraphic observations in Sonora</td>
</tr>
<tr>
<td>Burckhardt, C.</td>
<td>1930</td>
<td>Synthesis of the Mexican Mesozoic</td>
</tr>
<tr>
<td>King, R. E.</td>
<td>1939</td>
<td>Geological reconnaissance in northern Sierra Madre Occidental of Mexico</td>
</tr>
<tr>
<td>Cooper, G. A. and A. R. V. Arellano</td>
<td>1946</td>
<td>Stratigraphy near Caborca</td>
</tr>
<tr>
<td>White, D. E. and R. Guiza</td>
<td>1950</td>
<td>Antimony deposits of El Antimonio district</td>
</tr>
<tr>
<td>Miller, H. W.</td>
<td>1961</td>
<td>Belomnites [Coleoids] from the Upper Triassic in Eastern Sonora</td>
</tr>
<tr>
<td>Silver, L. T. and T. H. Anderson</td>
<td>1974</td>
<td>Possible left-lateral early to middle Mesozoic disruption of the southwestern North American craton margin (The first reference to the Mojave-Sonora Megashear)</td>
</tr>
<tr>
<td>Anderson, T. H. and L. T. Silver</td>
<td>1979</td>
<td>The role of the Mojave-Sonora Megashear in the evolution of northern Sonora</td>
</tr>
<tr>
<td>González-León, C. M.</td>
<td>1980</td>
<td>The first modern examination of the Antimonio Formation</td>
</tr>
<tr>
<td>Cohen, K. K., T. H. Anderson and V. A. Schmidt</td>
<td>1986</td>
<td>A paleomagnetic test of the proposed Mojave-Sonora Megashear in northwestern Mexico</td>
</tr>
<tr>
<td>González-León, C. M.</td>
<td>1989</td>
<td>Evolution of Mesozoic terranes in northeast Mexico</td>
</tr>
<tr>
<td>Callaway, J. M. and J. A. Massare</td>
<td>1989</td>
<td>Shastasaurus altispinus (Ichthyosauria, Shastasauridae) from the Upper Triassic from the Antimonio Formation</td>
</tr>
<tr>
<td>Stewart et al.</td>
<td>1990</td>
<td>Tectonics and stratigraphy of the Paleozoic and Triassic southern margin of North America, Sonora, Mexico</td>
</tr>
<tr>
<td>Stanley et al.</td>
<td>1991</td>
<td>Upper Triassic fossils from the Antimonio Formation, northern Sonora, support for the Mojave-Sonora Megashear</td>
</tr>
<tr>
<td>Lucas, S. G.</td>
<td>1993</td>
<td>The Triassic-Jurassic boundary in the Sierra del Alamo</td>
</tr>
<tr>
<td>Stwart, J. H. and R. Amaya-Martínez</td>
<td>1993</td>
<td>Stratigraphy and structure of the Sierra Santa Teresa near Hermosillo, Sonora, Mexico: A preliminary appraisal</td>
</tr>
<tr>
<td>González-León, C. M. and G. D. Stanley Jr.</td>
<td>1993</td>
<td>The paleogeographical significance of the Antimonio terrane</td>
</tr>
<tr>
<td>Stanley et al.</td>
<td>1994</td>
<td>Upper Triassic invertebrates from the Antimonio Formation</td>
</tr>
<tr>
<td>Lucas, S. G. and C. M. González-León</td>
<td>1994</td>
<td>Upper Triassic ammonites from Cerro La Flojera</td>
</tr>
<tr>
<td>Stanley Jr., G. D. and C. M. González-León</td>
<td>1995</td>
<td>Paleogeographic and tectonic implications of Triassic fossils and strata from the Antimonio Formation</td>
</tr>
<tr>
<td>Molina Garza, R. S. and J. W. Geissman</td>
<td>1996</td>
<td>Timing and deformation and accretion of the Antimonio terrane from paleomagnetic data</td>
</tr>
<tr>
<td>González-León et al</td>
<td>1996</td>
<td>The Triassic-Jurassic boundary from the Antimonio Formation</td>
</tr>
<tr>
<td>González-León, C. M. and G. D. Stanley Jr., Eds.</td>
<td>1997</td>
<td>A special issue of Revista Mexicana de Ciencias Geológicas concerning the geology of Sonora</td>
</tr>
</tbody>
</table>

Table 1.1. A table of selected references concerned with the strata and fossils of the Antimonio Formation.
column, which placed the Antimonio unconformably on the Upper Permian Monos Formation. The fauna of the Antimonio was listed by King (1939) and Keller (1928). Later White and Guiza (1950) recognized the presence of a Jurassic sequence in depositional contact with the Late Triassic Antimonio strata.

González-León (1980) initiated the most recent investigations. He formally named this strata the Antimonio Formation and divided the Antimonio into a 1350 m thick lower member and a 2000+ m upper member. Together the Monos and the Antimonio Formations were included in the Antimonio terrane (González-León, 1989). Stanley et al. (1994) recently investigated the paleontology of Upper Triassic strata of the Antimonio Formation. They identified a diverse shallow water fauna of Late Triassic (Carnian to Norian) age. Stanley and González-León (1995) explained the paleogeographic and tectonic implications of the Triassic fossils in the Antimonio Formation. They asserted that the Antimonio Formation is intimately related to the Luning Formation of the Marine Mesozoic Province in Western Nevada. They inferred that the Mojave-Sonora Megashear offset the Antimonio terrane to the southeast. González-León et al. (1996) focussed on the Triassic/Jurassic boundary at the meter scale and suggested that the Antimonio Formation is a nearly continuous succession which contains the Triassic/Jurassic boundary.
The latest findings regarding the Antimonio Formation have come out of the International Workshop on the Geology of Sonora, cosponsored by the National Science Foundation and CONACYT, in Hermosillo, Mexico, on January 6-10, 1997. This meeting was convened to bring together U.S. and Mexican geologists studying the Late Paleozoic and Early Mesozoic evolution of Sonora (González-León and Stanley, 1997). This meeting was devoted to discussing location, stratigraphy, and interpretations of the depositional setting of the Antimonio Formation. From these discussions three large questions arose which remain to be answered:

1) What is the relationship (structural, depositional, or other) of the Antimonio terrane to other terranes in Sonora;

2) How do the Barranca Group and the Antimonio terrane relate to each other;

3) What is the relationship of the Antimonio terrane to Paleozoic and Mesozoic sequences farther north, in the Cordillera?

STATEMENT OF PURPOSE

From the above discussion, the Antimonio Formation seems pivotal in answering key paleontological and stratigraphic questions. Because the Norian carbonates are so
fossiliferous biota offers to shed light on geologic problems of a much broader scope. Using these rocks and fossils, this thesis concentrates on two questions. First, what are the facies relationships within the Norian carbonates and can these relationships be used to erect a depositional model for the (Norian) Antimonio Formation. The second problem concerns the stratigraphic and tectonic correlation of the Norian carbonate strata of the Antimonio Formation to other Norian carbonates in allochthonous terranes of western North America. That is, was the Antimonio Formation deposited in situ or has it experienced significant post-depositional tectonic displacement.

To address these issues, I plan to answer three questions: 1) what depositional process or processes are responsible for the cyclic strata exposed in the Norian interval; 2) do the fossils in the Norian carbonates represent a controlled and predictable successional faunal pattern, that is, do they represent a biologically accommodated environment or one governed by physical processes; and 3) has the Antimonio Formation experienced significant tectonic dislocation.

To answer these questions I have constructed three hypotheses, which can be tested using the fossils and strata of the Norian carbonate interval of the Antimonio Formation.
Hypothesis 1

Cyclic carbonate strata have been widely recognized Triassic strata (Wilson, 1975). In addition, Haq et al. (1987) has applied sequence stratigraphy to Triassic resulting in the construction of a global sea level curve. Further evidence for eustatic control of Triassic cyclic strata was presented by Embry (1988), who interpreted strata from the Svedrup Basin in the Canadian Arctic using a eustatic paradigm. Recent studies, however, have questioned the validity of static sea-level models (Satterley, 1996). The relatively complete strata of the Antimonio Formation offer me the ability to evaluate eustatically controlled sedimentation in the Norian carbonate interval.

Hypothesis 2

The question of reef succession has been one of the most controversial issues in paleoecological reef studies (Copper, 1988). Since the early recognition of environmentally dependant biotic assemblages (Lowenstam, 1957), the existence reef succession has been questioned. For example, do vertical changes in growth form within a reef reflect biological accommodation or are they merely the result of physical changes in the environment? The remarkable vertical changes of fauna and growth forms in the biostromes of the Norian
interval offer the ability to evaluate these reef succession concepts.

Hypothesis 3

Stanley and González-León (1995) suggested that biostromes in the Norian carbonate interval of the Antimonio Formation and the Luning Formation, in the parautochthonous Luning assemblage of Western Nevada (Oldow et al., 1983), have similar faunal compositions and may provide a pinning point to reconstruct paleogeography prior to movement of the Mojave-Sonora Megashear or some other unidentified tectonic entity. Tectonic dislocation of the Antimonio Formation from somewhere in the southwestern United States continues to be a central theme in the relative literature. González-León (1997) points out that no correlative rocks of the Antimonio terrane occur north of the proposed Mojave-Sonora Megashear, suggesting that the Antimonio terrane is not in its original position. To evaluate the validity of the tectonic dislocation hypothesis, I propose assess the similarity of the Luning and Antimonio Formation by comparing and contrasting three independent lines of evidence within the respective Norian carbonate intervals: 1) sedimentary history and depositional patterns, 2) faunal similarities, and 3) reef successional patterns. Similar patterns in sedimentary character, faunal composition, and paleoecological patterns
would support the hypothesis that these sections were deposited close together and subsequently separated by significant post-accretional strike-slip faulting on the proposed Mojave-Sonora megashear (Anderson and Silver, 1979).

CHAPTER II

GEOLOGY OF NORIAN CARBONATES, ANTIMONIO FORMATION

The Antimonio terrane is known from eight localities in northwestern Sonora (Figure 1.1). These localities contain strata from various stratigraphic levels of the Antimonio terrane. Only three, Sierra del Alamo, Barra los Tanques, and Sierra Santa Teresa, are known to contain Norian carbonates.

GEOLOGY OF SIERRA DEL ALAMO

Most of the rocks exposed in the Sierra del Alamo (Figure 2.1) belong to the Antimonio terrane (González-león, 1989). Sections in the foothills of the Sierra del Alamo were designated as the stratotype of both the Monos and the Antimonio Formations by González-León (1980). Unconformably overlying the Antimonio terrane are volcanic flows, pyroclastic and volcanosedimentary rock of probable
Figure 2.1. Geologic map of the stratotype of the Antimonio Formation in the foothills of the Sierra del Alamo (modified from González-León, 1997).
Cretaceous age (González-León, 1980). The entire sedimentary
and volcanic sequence is cut by felsic to intermediate
intrusives of Cretaceous-Tertiary age.

The strata of the Monos and Antimonio Formations at
Sierra del Alamo represent a nearly complete succession of
marine sedimentary rock that ranges from Late Permian to
Early Jurassic age. These strata generally strike NNW and
dip to the southwest. In the northern part of the range
these rocks are folded into a broad anticline/syncline pair
that gently dips to the southwest.

The two members of the Antimonio Formation defined by
González-León (1980), are well exposed at the Sierra del
Alamo site. The lower member is 1,350-m thick. The lower
and middle portion of the lower member is composed of shallow
to deep water marine limestones and mudstone, siltstone and
fine-grained sandstone. The upper portion of the lower
member contains an interval of distinctively deep water
mudstone and limestone. High in the lower member are
lenticular carbonate biostromes which are the focus of this
thesis. This cyclic siliciclastic/carbonate sequence
(Package 1, Figure 1.3) is the only biostromal strata exposed
in the entire 4.1 km thickness of the Antimonio Formation.
Originally the lower member was thought to be Late Triassic
in age. However, new fossil discoveries in the section show
that Lower Member is much more complete than previously
realized (González-León, 1997) ranging from Permian, to
lower, middle, and upper Triassic strata.

The upper member, more than 2,700 m thick, contains Upper Triassic and Lower Jurassic rocks. Approximately 40 m of uppermost Triassic (Rhaetian) strata is recognized from the lowermost part of the upper member based on the occurrence of Rhaetian ammonoids. The lower portion of the upper member is dominated by siltstone, mudstone and limestone. The upper member grades upward into sandstone, siltstone and conglomerate. Lower Jurassic (uppermost Hettangian? or lower Sinemurian) ammonoids of the Canadensis Zone (Stanley et al., 1994) occur in the lower portion of the upper member above the Rhaetian ammonoids. The upper half of the upper member is composed almost entirely of sandstone and conglomerates and may range into Middle Jurassic strata (González-León, 1980).

GEOLOGY OF BARRA LOS TANQUES

Barra los Tanques, the second area studied, is located approximately 35-km southwest of Sierra del Alamo (Figure 1.1). The information presented here represents the first detailed stratigraphic investigation of this locality. Exposures occur on small isolated hills (Figure 2.2) which contain bedded Triassic (Norian) limestone, minor dolomitic limestone, sandstone, and small lenticular reefs. The lower and middle portion of the section contains bioclastic and
Figure 2.2. Geologic map of the Barra los Tanques locality of the Antimonio terrane. The section is discussed in Appendix B.
peloidal wackestones and packstones as well as fine grained carbonate mudstone. The reefoid deposits at the top of the section are composed of numerous patch reefs surrounded by biogenic debris.

The lithologic similarity of these rocks to strata exposed at Sierra del Alamo led Stanley and González-León (1995) to correlate them lithostratigraphically to the uppermost part of the lower member of the Antimonio Formation. Pebble- to cobble-sized conglomerates stratigraphically above the carbonate interval are correlated with the lower portion of the upper member of the Antimonio Formation. These isolated carbonate and conglomeratic exposures are separated by Quaternary sands. Based on the assumption that the carbonates at Barra los Tanques correlate with the Norian carbonates at Sierra del Alamo, I carried out the first detailed field investigation of these strata.

The Triassic and Jurassic strata at Barra los Tanques are interpreted to be tectonically dislocated (Stanley and González-León, 1995). In addition, these authors speculate that these rocks are thrust over Paleozoic carbonates. While extensive brecciation and recrystallization supports thrusting in the area, no biostratigraphic control on the "Paleozoic carbonate interval" is as yet available. To rectify this gap in understanding I collected samples in the hope of finding conodonts. Unfortunately, these samples are yielded no biostratigraphic fossils.
As part of my field investigation I measured a stratigraphic section at a decimeter scale through the most complete part of the section (see Figure 2.2). The 44.8 m thick section is dominated by bedded limestone with minor dolomite, reefoid carbonate buildups and minor limy sandstone beds (Appendix B). These strata are strikingly similar to those in the Norian carbonates from Sierra del Alamo, with the noteworthy exception that much less limy sandstone is exposed at Barra los Tanques. In addition, the reefoid limestones contain a coral fauna similar to the Norian carbonate interval at Sierra del Alamo. The conodont *Epigondolella* sp. cf. *E. quadrata* Orchard (M. Orchard, Geological Survey of Canada, written communication, Report No. MJO-1998-11, GSC Loc. No: C-303720) indicates a Late Triassic, early? Norian age.

The upper strata of the Barra los Tanques section (not included in my measured section) consist of pebble to cobble conglomerates with clasts of similar composition to those in the Jurassic section at Sierra del Alamo (González-León, personal communication, January, 1998).

**GEOLOGY OF SIERRA SANTA TERESA**

The third locality, Sierra Santa Teresa has been investigated thoroughly by J. H. Stewart. Stewart et al. (1997) recently reviewed the stratigraphy of Sierra Santa
Teresa, and they divided these strata based on structural relationships. He recognized two stratigraphic elements separated by a regional thrust which cuts the range. The main part (upper plate) of Sierra Santa Teresa is composed of middle to upper Paleozoic strata (Figure 2.3). The upper plate lies on a tectonic contact above an overturned Lower to middle Mesozoic section (lower plate).

The upper plate is best exposed in a large cliff in the northern part of the range. Here 2,300 m of Upper Mississippian through Lower Permian shallow water deposits are overlain depositionally by deep-water silty limestones which yield Early Permian (Leonardian) fusulinids (Stewart, 1997).

Two units occur in the lower steeply east-dipping overturned plate. The lower of these two units is approximately 500 m thick and contains several coral and sponge biostromes identical to those at Sierra del Alamo (Stanley et al., 1994). Based on their faunal and sedimentological similarities these rocks are biostratigraphically and lithostratigraphically correlated with the Norian carbonate interval in the upper part of the lower member of the Antimonio Formation exposed at the stratotype in Sierra del Alamo (Stanley and González-León, 1996). The conodont *Epigondolella* sp. cf. *E. spiculata* Orchard (M. Orchard, Geological Survey of Canada, written communication, Report No. MJO-1997-25, GSC Loc. No: C-303412)
Figure 2.3. Geologic map of part of the Sierra Santa Teressa locality of the Antimonio terrane (modified after Stewart et al., 1998)
indicates a Late Triassic probably middle Norian age and supports this correlation. Overlying the lower to middle Mesozoic sedimentary section is a thick, undated andesite (Figure 2.3), composed of massive and brecciated beds. The andesitic rocks are similar to other Mesozoic strata in Sonora (Stewart et al., 1997).

CHAPTER III
FACIES OF THE NORIAN CARBONATE INTERVAL

REEFS: BASIC DEFINITIONS

Two main definitions of reefs have emerged from the study of carbonate accumulations: stratigraphic reefs and ecologic reefs. Stratigraphic reefs are defined simply as laterally restricted thickenings of carbonate rock (Dunham, 1970). Ecologic reefs, on the other hand, are characterized by diverse biotas which demonstrate sediment binding potential and framework producing wave resistant structures within a laterally restricted thickened carbonate body (Dunham, 1970). For the most part ecologic reefs are formed by intense biologic skeletal precipitation.

While these definitions may seem straight forward and concise, their application to sequences in the rock record is difficult. Stratigraphic reefs are easy to recognize because
all that is required to identify them is a mass of thickened carbonate. However, ecologic reefs are more difficult to identify, because the geologist must not only describe the entombed fauna, but also demonstrate their paleoecologic relationships.

The reef concept is further complicated by the recognition of laterally continuous bodies of carbonate with both diverse faunas and paleoecological interactions but which do not demonstrate topographic relief. These lenticular bedded deposits, or biostromes (Cummings, 1932), are common in the geologic record.

The following definitions will be used throughout this thesis:

**Reef**: "...is the product of the actively building and sediment-binding biotic constituents, which, because of their potential wave resistance, have the ability to erect rigid, wave-resistant topographic structures."

(Lowenstam, 1950; p. 433)

**Biostrome**: is a "...purely bedded structure,..., consisting of and built mainly by sedentary organisms, and not swelling into moundlike or lenslike forms,..."

(Cummings, 1932; p. 334)

It is noteworthy to point out that a new descriptive
classification of fossil scleractinian reefs has been erected by Insalaco (1998). This scheme is significant because it establishes 'growth fabric' as new descriptive term to be applied to fossil reefs. He defines two growth fabric types: Superstratal and Constratal. Superstratal growth fabrics consist of organisms which "collectively projected decimeters to meters above the substratum creating positive topographic relief" (Insalaco, 1998). Constratal growth fabrics, on the other hand, are characteristic of environments "where vertical organic accretion occurred at a similar rate to sediment accumulation" (Insalaco, 1998). Both superstratal and constratal growth fabrics are present in the Norian interval. Branching Retiophyllia colonies are examples of superstratal growth fabrics while platy Astraeomorpha colonies typify constratal fabrics. Growth fabric interpretation is important because each end member will influence sedimentary patterns and paleoecological development. Superstratal growth fabrics, for example, will tend slow bottom currents thus causing sedimentation. Constratal colonies, on the other hand, may have a greater amount of sediment between their colonies and be subjected to high levels of bioerosion (Insalaco, 1998). This condition is observed in the Norian interval where bored Astraeomorpha colonies are isolated from each other by medium- to coarse-grained sediment. While this classification scheme is not used in depth in this thesis, the concepts behind Insalaco's
scheme played a significant role during my interpretation of the rocks and fossils of the Norian interval.

FACIES OF THE NORIAN CARBONATE INTERVAL

Exposures of Norian carbonates in the Antimonio Formation contain distinctive and separate rock types, or lithofacies. These lithofacies are generally stacked stratigraphically, although lateral changes in rock types are common. Generally, the boundaries between lithofacies are gradational. My lithofacies definitions are generalized composites of the entire Norian interval.

Lithofacies, microfacies, and biofacies from Sierra del Alamo

Four sedimentary lithofacies are recognized within the Norian carbonate interval of Sierra del Alamo (Figure 3.1). These are dominated by carbonates but are interbedded with argillites, mudstones, and sandstones. The Norian outcrops in the northern foothills of the Sierra del Alamo extend for approximately 6 km in an east-west direction. However, in many locations the Norian interval is covered, faulted, recrystallized, and intruded by small dikes and sills. The effects of recrystallization are most pronounced in the west, where Cretaceous intrusives cut the Norian carbonates (Figure 2.1). The best preserved Late Triassic biostromes are at the
Figure 3.1. A generalized stratigraphic section illustrating the lithofacies relationships from the Norian carbonate interval at Sierra del Alamo.
east end of the exposure. Each lithofacies of the Norian carbonate interval contains a distinct fauna that reflects a different depositional environment. These changes likely reflect increases or decreases in siliciclastic input. Thus, biofacies and their associated faunas approximately coincide with the following lithofacies.

The four lithofacies were first described by Goodwin and Stanley (1997). They are: 1) Argillite and Mudstone, 2) Limy Sandstone, 3) Sandy Limestone, and 4) Bedded Pure Limestone which combined with the Sandy Limestone form the most conspicuous units in the biostromes. Each of these lithofacies, except for of the Argillite and Mudstone, contain a distinctive faunal assemblage, or biofacies. These biofacies and lithofacies reoccur vertically with remarkable fidelity, suggesting that the fauna responded directly to changes in the depositional environment (Goodwin and Stanley, 1997).

I made over 90 thin section which lithologically and paleontologically characterize the Norian carbonate interval. Three sizes of thin sections were used: 1) 2.5 cm x 4.5 cm, 2) 5 cm x 7.5 cm, and 3) 10 cm x 15 cm. This study uses the classification schemes developed by Folk (1962), Dunham (1962) and modifications made by Embry and Klovan (1971). Eleven microfacies are identified in the Norian carbonate interval at Sierra del Alamo (Table 3.1). Each microfacies is first described in hand specimen and then in
<table>
<thead>
<tr>
<th>MICROFACIES</th>
<th>LITHOFACIES</th>
<th>INTERPRETATION (DEPOSITIONAL ENVIRONMENT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDA-1: Limy Sandstone</td>
<td>LS</td>
<td>Proximal to offshore-onshore transitional setting</td>
</tr>
<tr>
<td>SDA-2: Molluskan Limy Sandstone</td>
<td>LS</td>
<td>Proximal to offshore-onshore transitional setting</td>
</tr>
<tr>
<td>SDA-3: Quartz Bioclastic Packstone</td>
<td>SL</td>
<td>Near normal wave-base close to a siliciclastic source</td>
</tr>
<tr>
<td>SDA-4: Quartz Bioclastic Grainstone</td>
<td>SL</td>
<td>Above normal wave-base close to a siliciclastic source</td>
</tr>
<tr>
<td>SDA-5: Coated Grain Microfacies</td>
<td>SL</td>
<td>Intermittently agitated lagoon dominated by microbial/algal boring organisms</td>
</tr>
<tr>
<td>SDA-6: Peloidal Packstone</td>
<td>BPL</td>
<td>Lagoonal environment near normal wave-base with restricted circulation</td>
</tr>
<tr>
<td>SDA-7: Bioclastic Packstone</td>
<td>BPL</td>
<td>Lagoonal environment near normal wave-base</td>
</tr>
<tr>
<td>SDA-8: Bioclastic Wackestone</td>
<td>BPL</td>
<td>Lagoonal environment below normal wave-base</td>
</tr>
<tr>
<td>SDA-9: Carbonate Mudstone</td>
<td>BPL</td>
<td>Low energy lagoon environment</td>
</tr>
<tr>
<td>SDA-10: Coral/Spongiomorph Bindstone</td>
<td>BPL</td>
<td>Moderately energetic shallow biostrome</td>
</tr>
<tr>
<td>SDA-11: Coral Bafflestone</td>
<td>BPL</td>
<td>Low energy, deeper, biostrome</td>
</tr>
</tbody>
</table>

Table 3.1. Microfacies from the Norian carbonate interval at Sierra del Alamo. LS = Limy Sandstone, SL = Sandy Limestone, BPL = Bedded Pure Limestone.
thin section, and finally an interpreted depositional environment is presented.

**Argillites And Mudstones**

This lithology is typically covered by float from other lithofacies, though it is exposed in places. Exposures are commonly unfossiliferous and display one cleavage direction at a low angle to the bedding plane. The paucity of suitable material to sample reflects the cleavage in this rock and its tendency to crumble. This lithology appears to grade conformably into the limy sandstone, although the boundary is everywhere covered.

**Limy Sandstone**

This unit of fine- to medium-grained sand thickens and thins laterally from 0.40 to 1 m (Figure 3.2). In thin sections this lithofacies is composed of poorly sorted, fine- to coarse-grained angular quartz grains in a calcite matrix. No sedimentary structures were evident in this lithology. Bedding may have been obliterated by burrowing bivalves or unpreserved soft-bodied organisms. Disarticulated bivalve shells are common in the upper portions of limy sandstone beds.

Two microfacies occur in the Limy Sandstone lithofacies:
Figure 3.2. Limy Sandstone lithofacies with the Mollusk Biofacies showing disarticulated bivalve shells oriented both concave up and down.
SDA-1; Limy Sandstone; Figure 3.3.

Hand Specimen - Dark brown to maroon, fine- to medium-grained lime-cemented sandstone.

Figure 3.3. SDA-1 Limy Sandstone x 7.

Thin Section - This microfacies is composed of medium- to fine-grained, subrounded and well sorted quartz sand. Accessory minerals include plagioclase, microcline, biotite, hematite, and ilmanite. Quartz with undulose extinction is the dominant quartz species, although compound and sutured grains have been observed. Many of the feldspar grains show evidence of partial to complete replacement by calcite.

Fossil Content - The microfacies is unfossiliferous.
Interpretation - The microfacies was deposited in an environment dominated by siliciclastic sediments. A depositional environment close to the offshore-shoreface is interpreted for this microfacies.

SDA-2; Molluskan Limy Sandstone; Figure 3.4.

Figure 3.4. SDA-2 Molluskan Limy Sandstone x 5.

Hand Specimen - Dark brown to maroon, fine- to medium-grained lime-cemented sandstone with abundant bivalve fragments.

Thin Section - This microfacies is very similar to the lime cemented sandstone. The most abundant component of this microfacies is very fine to fine grained angular to subrounded moderately well sorted quartz sand. The quartz, along with accessory minerals, mentioned above, plagioclase, microcline, biotite, hematite, and ilmenite is cemented by
calcium carbonate. Faunal elements include bivalve fragments and rare gastropods.

Fossil Content - Molluska: indeterminant bivalve shell fragments, indeterminant gastropod fragments; Echinodermata: indeterminant skeletal fragments

Interpretation - This microfacies was deposited in an environment very similar to the Lime Cemented Microfacies. However, this microfacies was colonized by abundant bivalves and gastropods.

The first faunal association in the Norian interval, the Mollusk Biofacies, composed of bivalves and gastropods occurs in the Limy Sandstone (Goodwin and Stanley, 1997). Mollusks are most common in the finer grained intervals and consist of diverse, unidentified gastropods and the bivalves *Myophorogonia jaworskii, Gervillaria sp., Gryphaea sp., Septocardia sp.*, and *Palaecocardita peruviana*. The bivalves are interpreted to have lived in and on the sand prior to being reworked and disarticulated. Based on rock and faunal associations, a shallow distal siliciclastic near-shore environment is inferred.

**Sandy Limestone**

The Sandy Limestone (Figure 3.5) lithofacies lies above
Figure 3.5. Sandy Limestone lithofacies with the Sponge-Gastropod Biofacies. Note the presence of *Fanthalamia polystoma* (center and center-left) and the oyster *Lopha* (center-right).
the lime-cemented sandstone and below and above the bedded pure limestone. This unit varies little in thickness; averaging 1 m. It consists of limestone with abundant sand to silt-sized quartz grains. Profuse subparallel dissolution residues, stylolites, and geopetal structures are characteristic. Thalamid sponges are the most abundant biotic constituents.

Three microfacies occur in the Sandy Limestone Lithofacies:

SDA-3; Quartz Bioclastic Packstone; Figure 3.6.

Hand Specimen - Quartz rich, light red to grey, sponge and mollusk bioclastic limestone.

Thin Section - Bioclasts form up to 30-40% of the rock by visual estimates, and coarse silt to very fine quartz sand grains make up 5-15%. The matrix is predominantly micrite. In places authigenic oxide minerals (hematite and illmanite) stains the matrix a distinctive red-brown color, similar to that of the Quartz Bioclastic Grainstone. Mollusk shell fragments form the bulk of the biological components. Auxiliary bioclasts include, echinoderms, brachiopods, and serpulid worm tubes. Many bioclasts have micritic rims.
Figure 3.6. SDA-3 Quartz Bioclastic Packstone x 8.

Fossil Content - Foraminifera: indeterminant forms; Porifera: Cinnabaria expansa; indeterminant brachiopod shell fragments
Molluska: indeterminant bivalve shell fragments, indeterminant gastropod fragments; Annelida: Serpulid tubes;
Echinodermata: indeterminant cidarid spines

Interpretation - The large proportion of allochems and quartz grains in grain-to-grain contact indicate an environment of intermittent moderate currents and waves which winnowed and redistributed sediment. The large percentage of quartz suggest depositional site relatively close to a siliciclastic shore or sand shoal. The evidence suggests that this microfacies was formed in shallow water at or near fairweather wave base, proximal to a siliciclastic source,
possibly near shore.

SDA-4; Quartz Bioclastic Grainstone; Figure 3.7.

Figure 3.7. SDA-4 Quartz Bioclastic Grainstone, note large bivalve shell fragments, x 6.

Hand Specimen - Pink to grey, quartz rich, mollusk-fragment bioclastic limestone.

Thin Section - 30% of this microfacies is composed of allochems, 20% is very fine to fine grained quartz sand in a matrix of fine sparry cement. Allochems are mostly echinoderm and molluskan fragments with subordinate Dasycladacian algae, gastropods, and foraminifers. Many bioclasts are coated with thin micritic rinds. These rinds together with minor aggregate grains, suggest that cement formation and diagenetic processes occurred early in this
rock's history. Most of the echinoderm skeletal fragments are in varying stages of grain diminution. Elongated skeletal grains (mollusk; bivalve fragments) are oriented parallel to bedding. Compaction or "umbrella" porosity structures filled with sparry calcite are also present. This microfacies also contains abundant iron oxide, which often takes the form of euhedral hematite and subhedral ilmenite crystals. These oxides give this microfacies a distinctive red-brown color.


Interpretation - The large proportion of bioclasts and quartz in grain-to-grain contact and the lack of lime mud suggest that this microfacies was deposited in strongly energetic water. The presence of quartz grains suggests that a siliclastic source was proximal. A depositional site above fair-weather wave base in a open lagoon is inferred.

SDA-5; Coated Grain Microfacies; Figure 3.8.
Hand Specimen - Grey to yellow to red bioclastic limestone. Outcrops of this microfacies display numerous stylolites and abundant dissolution residue. The dominant bioclast are mollusk fragments.

Thin Section - Moderately rounded allochems composed chiefly of gastropods and bivalves shell fragments constitute 30% of the whole rock. Aggregate grains composed of neomorphosed carbonate are present. The most distinctive character of this microfacies is the presence of abundant micritic endolithic algal rims on bioclasts. Approximately 5-10% of the rock is composed of subangular to subrounded medium to fine grained quartz sand grains with undulose extinction. The matrix of the microfacies is micrite. Geopetal
structures are common in this microfacies. Many shells show evidence of diagenetic neomorphism where original shell material has been replaced by sparry calcite.

Fossil Content - Molluska: indeterminant bivalve shell fragments, indeterminant gastropod fragments; Echinodermata: indeterminant skeletal fragments; Arthropoda: indeterminant ostracodes

Interpretation - The predominance of rounded, coated and, aggregate grains indicate that allochems were heavily reworked prior to deposition. The approximately equal proportions of allochems and micrite matrix suggest that this rock was deposited in intermittently agitated water. A quiet to intermittently agitated, restricted lagoon was probably the site of deposition.

The second fossil assemblage, the Sponge Gastropod Biofacies, occurs in the sandy limestone lithofacies (Goodwin and Stanley, 1997). It is composed of inozoan and sphinctozoan sponges, gastropods, bivalves, the oyster Lopha and minor coral fragments. These larger fossils occur in a wackestone or packstone matrix. The dominant taxa in this biofacies are thalamid sponges including Nevadathalamia, Panthalamia, and Cinnabaria. This Sponge Gastropod Biofacies is less tolerant of coarse-grained siliciclastics than that
of the Mollusk Biofacies. Its presence represents a major shift in the local depositional environment from one dominated by sand and siliciclastic input to a setting with significant carbonate deposition.

**Bedded Pure Limestone**

This thick-bedded pure to impure limestone lithofacies lies above and below the sandy limestone. This unit is by far the most fossiliferous in the Norian carbonates (Figure 3.9). The biota consists of upright-growing, encrusting, and binding corals and large upright and encrusting, chambered thalamid sponges, massive, encrusting red algae, spongiomorphs and disjectoporoid sponges. The texture ranges from carbonate mudstone to bioclastic wackestone and packstone. Dissolution cavities and karstic features in the limestone indicate episodes vadose digenesis. The upper portion of the Norian biostratal interval contains distinctive red mottling. This infilling is attributed to post-depositional vadose diagenesis and/or karstification with resultant redeposition of insoluble residues derived from carbonate dissolution. This lithofacies represents the purer carbonate end member in the Norian biostratal interval, indicating that siliciclastic input was minimal.

Six microfacies occur in the Pure Bedded Limestone lithofacies.
Figure 3.4. A) Phaceloid coral, *Retiophyllia opelli*, from the lower portion of the Bedded Pure Limestone, B) encrusting coral, *Astraeomorpha sonorensis*, from the upper portion of the Bedded Pure Limestone.
Figure 3.10. SDA-6 Peloidal Packstone microfacies x 12.

Hand Specimen - Dark grey, finely crystalline, limestone with small (<2 cm thick) dissolution residues and some stylolites. Rock weathers light to dark grey color.

Thin Section - The Peloidal Packstone is characterized by very fine-grained (4.0-3.0 Ø) peloids in a carbonate mud matrix. In addition to peloids, allochems, consist of foraminifers, ostracodes, and gastropods. Fine quartz sand grains are uncommon. Following deposition and cementation the rock was heavily stylolitized. Stylolites exhibit an anastomosing or “horsetail” morphology which grade laterally into a stylomottled morphology (Flügel, 1982). Stylolitization and formation of dissolution residues was followed by fracturing and deposition of sparry calcite.
Fossil Content - Foraminifera: uniserial form cf. *Nodosaria*; indeterminant brachiopods; Molluska: indeterminant bivalves; indeterminant gastropods; indeterminant ostracodes

Interpretation - The large proportion of lime mud indicates that this microfacies is the product of a low energy environment, where current and wave action was intermittent at best. The restricted biota suggests deposition in a restricted lagoon environment below normal wave base.

SDA-7; Bioclastic Packstone; Figure 3.11.

![Figure 3.11. SDA-7 Bioclastic Packstone microfacies x 9.](image)

Hand Specimen - Dark grey, fine- to coarse-grained limestone with some bioclasts approaching 2 mm in diameter. Weathers light to dark grey.
Thin Section - composed of 30-40% allochems, which include, red and green alga, foraminifers, gastropods, echinoderms, and brachiopods. The grains are in contact and surrounded by grey micrite matrix. In some places the matrix becomes coarse-grained and it appears to be microspar. Early cementation consisted of sparry calcite filling primary voids and preserving geopetal structures. This cementation was followed by dissolution of many bioclasts. The resulting secondary porosity was filled with sparry cement. Other grains, most notably echinoderm skeletal elements, have been partially replaced by neomorphic spar.


Interpretation - The rounded bioclasts and grain to grain contact suggests a higher energy setting than SDA-1. This microfacies represents deposition in a shallow location with moderate to intense current energy.

SDA-8; Bioclastic Wackestone; Figure 3.12.
Hand Specimen - Hand specimens are fine-grained, red to pink to brown limestone. Bioclasts are molluskan and generally greater than 1 mm across.

Figure 3.12. SDA-8 Bioclastic Wackestone microfacies x 6.

Thin Section - The bioclastic wackestone is characterized by bioclasts embedded in a silt-sized peloidal micrite matrix. Bioclasts include, gastropods, bivalves, and brachiopods. Fine to very fine quartz sand grains form <1% of the rock. In places iron oxidation produces a red-brown color.

Fossil Content - indeterminant brachiopod shell fragments; Molluska: indeterminant bivalve shell fragments; indeterminant gastropods shell fragments

Interpretation - The abundance of silt-sized peloids and
micrite suggests a very low-energy depositional environment. The low-diversity biota, dominated by herbivorous gastropods, points to a setting with little open marine circulation. A restricted lagoon below normal wave base is inferred.

SDA-9; Carbonate Mudstone; Figure 3.13.

Hand Specimen - The rock is a finely crystalline, light grey limestone. Specimens are heavily mottled and in places red oxidized patches and dissolution residues dominate.

Thin Section - This microfacies is dominated by grey micrite, which forms approximately 95% of the rock. Biogenic grains form less than 5% of the rock and include gastropods, bivalve fragments, and rare peloids. Quartz grains are exceedingly rare. This microfacies has been heavily stylolitized and
oxidized dissolution residues are abundant.

Fossil Content - indeterminant brachiopods shell fragments; Molluska: indeterminant bivalve shell fragments; indeterminant gastropods shell fragments

Interpretation - The dominance of lime mud points to a very low energy depositional environment where wave energy did not winnow away the fines. Because lime mud accumulates in a variety of settings a depositional interpretation is problematic. However, the intercalation of the Carbonate Mudstone with SDA-2 and SDA-3 suggests that this microfacies was deposited below normal wave-base in a lagoon.

SDA-10; Coral/Spongiomorph Bindstone; Figure 3.14.

![Figure 3.14. SDA-10 Coral/Spongiomorph bindstone formed by Stromaporidium lamellatum, x 3.](image)
Hand Specimen - Light to dark grey bioclastic limestone with alternate layers of lamellar corals and/or spongiomorphs and medium- to fine-grained bioclastic limestone.

Thin Section - This microfacies is characterized by tabular corals and spongiomorphs in growth position. Generally either corals or spongiomorphs dominate the binding component of a given specimen. *Astraeomorpha sonorensis* (Stanley et al., 1994) is the most common coral in this microfacies and forms beds up to 0.5 m thick, composed of debris bound by laminar growth forms up to 10 cm thick. The bindstone microfacies is also formed by the stromatoporoid, *Stromaporidium lamellatum* (Stanley et al., 1994). Generally the lamellar growth of *S. lamellatum* is very thin, rarely exceeding more than 20 mm. The texture and field appearance of both binding organisms is quite similar. The encrusted bioclastic wackestone to packstone forms the supporting framework of the rock. It consists of varying combinations of the following bioclasts: gastropods, bivalves, echinoderm fragments, sponges, brachiopods, and foraminifers. The matrix is embedded in micrite, however, in places individual crystals become large enough to suggest microspar. Fine quartz sand grains constitute <1% of the rock.

Fossil Content - Red Algae: nodular form cf. *Solenopora*;
Foraminifera: *Alpinophragmum sp.*, encrusting form cf. *Tolypammina*, Porifera: *Stromatoporidium lamellatum* (Stanley et al., 1994); Cnidaria: *Astraeomorpha sonorensis* (Stanley et al., 1994); articulated brachiopods in thin section cf. *Pseudorhaetina antimonienensis* (Stanley et al., 1994) and indeterminant shell fragments; Mollusca: indeterminant bivalve shell fragments; indeterminant gastropod shell fragments; Echinodermata: indeterminant cidarid spines

Interpretation - The alternating layers of sediment and fossil binding agents suggests a varying depositional pattern. These cycles are the result of episodes of sediment flux. During this interval skeletal grains and lime mud were deposited. This pattern alternated with periods of coral and/or spongiomorph growth. The laminar to tabular growth of *Astraeomorpha sonorensis* and *Stromaporidium lamellatum* helped trap and bind sediment.

SDA-11; Coral Framestone/Bafflestone; Figure 3.15.

Hand Specimen - Red to grey fine-grained carbonate matrix with large (~2-3 m x ~1 m) phaceloid coral colonies.

Thin Section - The Coral Framestone/Bafflestone microfacies is dominated by two species of in the genus *Retiophyllia*, *R. norica* and *R. opelli*. These phaceloid corals constitute the
Figure 3.15. SDA-11 Coral Framestone/Bafflestone; 
*Retiophyllia opelli*, enclosed in micrite, x 3.

"in situ stalk-shaped fossils" required as the first 
ingredient of a bafflestone (Embry and Klovan, 1971). The 
corallites are surrounded by a sparse bioclastic wackestone 
and some posses biogenic crusts. The dominant bioclasts are 
whole and broken brachiopod shells. Auxiliary bioclasts 
include: echinoderm skeletal fragments, bivalves, gastropods 
and foraminifers. These bioclasts are embedded in a red 
micrite matrix.

Fossil Content - Foraminifera: *Discorbidae* cf. *Diplotremina*,
encrusting form cf. *Alpinophragmum*; Cnidaria: *Retiophyllia 
opelli* and *R. norica*; indeterminant punctate brachiopod shell 
fragments; Molluska: indeterminant bivalve shell fragments;
Echinodermata: indeterminant skeletal fragments

Interpretation - This microfacies represents growing *Retiophyllia* which were infilled by suspended lime mud. These high-growing phaceloid corals reduced the rate of water flow, causing deposition of micrite within the coral framework. The microfacies was probably formed in an environment with quiet to intermittently agitated water.

The third biofacies, the Coral Biofacies, is volumetrically dominated by corals. Phaceloid colonies of the coral *Retiophyllia* forms patches up to 3 m across and over half a meter thick (Figure 3.9A). Lateral facies contain overturned colonies of *Retiophyllia*. The encrusting coral *Astreaomorpha* (Figure 3.9B) is also abundant in this lithofacies generally occurring above *Retiophyllia* patches. *Astreaomorpha* overgrows bioclastic debris consisting of bivalves, gastropods, brachiopods, and coral debris. Also present are, unusual giant alatoform bivalves with wing-like extensions. These are endemic forms related to Triassic megalodontids (Stanley et al., 1994; Yancey and Stanley, 1999). In addition to sphinctozoan sponges, inozoan sponges occur in this lithology, but they are not volumetrically important. The Coral Biofacies is interpreted to have lived as shallow-water biostromes in an offshore lagoonal environment.
Lithofacies, microfacies, and biofacies from Barra los Tanques

The Norian strata exposed at the Barra los Tanques locality are dominated by bedded and massive carbonates. Ten beds 44.8 m thick (Appendix B) are characterized by grey to tan limestone, with minor sandy limestone and a limy sandstone unit of predominantly recrystallized, very fine-grained carbonate lithology with little biogenic debris. Immediately above the strata of my measured section is a nonbedded reef unit.

This unit is characterized by four discontinuous and interfingered lithofacies within a large mass of limestone interpreted to be a reef (Figure 3.16). They are: 1) Massive Framestone lithofacies, 2) Bivalve-Echinoid packstone lithofacies, 3) Blue-Grey Peloidal Limestone, and 4) Bivalve Debris lithofacies.

Massive Framestone Lithofacies

This lithofacies of small in situ patch reefs is composed of platy and erect growing corals and spongiomorphs. These dominate upward reefs with flat bases range from about 1.0 to 3.0 m in diameter and 1.5 to 2.0 m thick. The internal structure of individual patches varies. Phaceloid
Figure 3.16. A cartoon illustrating the relationships of the lithofacies from the reefal interval at Barra los Tanques.
and cerioid encrusting corals are the most common constructional elements. Pervasive recrystallization precludes a detailed investigation of these coral taxa, however, specimens which closely resemble Retiophyllia and Chondrocoenia cf. C. waltheri have been observed.

**Bivalve-Echinoid Packstone**

The bivalve-echinoid packstone consists mostly of broken and disarticulated bivalves, and cidarid echinoid spines. This lithofacies forms lenticular beds 1.5-2.0 m thick which tend to onlap the other lithofacies. This lithofacies dominates the reefal unit; in places it was the only lithofacies in the reefal interval. The Massive Framestone Lithofacies occurs in close association with the Bivalve-Echinoid Packstone, in places being completely encased in echinoid skeletal debris.

**Mollusk-Bivalve Debris**

The bivalve lithofacies is approximately 1.0-1.5 m thick and is dominated by disarticulated, concave up and down, bivalve shells which are concentrated in small fossiliferous beds 10-20 cm thick. This lithofacies is restricted to the base of the reefal interval and is laterally equivalent to the blue-grey limestone lithofacies.
Blue-Grey Peloidal Limestone

This lithofacies, occurs at the base of the reefal interval between patch reefs, consists of peloidal to bioclastic peloidal wackestone. The only fossils encountered in hand specimen are small, thin bivalve fragments. The Blue-Grey Limestone is laterally equivalent to the Bivalve-Echinoid Packstone Lithofacies.

CHAPTER IV
PALEONTOLOGY, PALEOECOLOGY AND DEPOSITIONAL SYSTEMS OF THE NORIAN CARBONATE INTERVAL

This chapter focuses on documentation, analysis and characterization of the fauna and depositional environments in the Norian carbonate interval. This project is an extension of the work described by Stanley et al. (1994), in which, the authors presented the first detailed description of the fauna from the Upper Triassic strata of the Antimonio Formation. However, paleoecological relationships of fauna and their adaptations to changes in the physical environment were not addressed. This thesis represents new information regarding the paleoautecology, paleosyneceology and the depositional controls which operated during deposition the
Norian carbonate interval.

SIERRA DEL ALAMO

Taxonomic Composition

Table 4.1 is a faunal list of all of the taxa that have been identified from the Norian carbonate interval, compiled from: Stanley et al. (1994), McRoberts (1997), Damborenea and González-León (1997), Stanley and González-León (1997), as well as study of my own collected fossils.

The fauna of the Norian carbonate interval in the Antimonio Formation has been the subject of several taxonomic studies within the six years. My study demonstrates that the taxonomic diversity was high, especially in the reefal and biostromal carbonates. It also documents the presence of heretofore unknown forms (see Systematic Paleontology section).

Paleoautecology

To understand the depositional setting of shallow marine sequences in the rock record one must not only study the physical characters of the rock unit but also the clues provided by the biogenic components. My study assesses the ancient depositional environment using separate physical and
Table 4.1. Faunal list from the Norian carbonate interval of the Antimonio Formation at Sierra del Alamo with paleoecological information. BPL = Bedded Pure Limestone, SL = Sandy Limestone, LS = Limy Sandstone
<table>
<thead>
<tr>
<th>NAME</th>
<th>GROWTH FORM</th>
<th>TROPHIC HABIT</th>
<th>RELATIONSHIP TO SUBSTRATE</th>
<th>LITHOFACIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Red Algae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cayeuxia sp.</td>
<td>Nodular</td>
<td>Photoautotroph</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td>Parachaetetes sp.</td>
<td>Nodular</td>
<td>Photoautotroph</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td>Solenopora sp.</td>
<td>Nodular</td>
<td>Photoautotroph</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td><strong>Green Algae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Griphoporella</td>
<td>Erect</td>
<td>Photoautotroph</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td><strong>Foraminifers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diplotremina</td>
<td>Evolute</td>
<td>Heterotroph</td>
<td>Free Living</td>
<td>BPL</td>
</tr>
<tr>
<td>Tolypammina</td>
<td>Nodular</td>
<td>Heterotroph</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td>Glomospirella</td>
<td>Evolute</td>
<td>Heterotroph</td>
<td>Free Living</td>
<td>BPL</td>
</tr>
<tr>
<td>Nodosaria sp. 1</td>
<td>Uniserial</td>
<td>Heterotroph</td>
<td>Free Living</td>
<td>BPL</td>
</tr>
<tr>
<td>Nodosaria sp. 2</td>
<td>Uniserial</td>
<td>Heterotroph</td>
<td>Free Living</td>
<td>BPL</td>
</tr>
<tr>
<td>Nodosaria sp. 3</td>
<td>Uniserial</td>
<td>Heterotroph</td>
<td>Free Living</td>
<td>BPL</td>
</tr>
<tr>
<td>Indet. form</td>
<td>Irregular</td>
<td>Heterotroph</td>
<td>Free Living?</td>
<td>BPL</td>
</tr>
<tr>
<td><strong>Sponge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cinnabaria expansa</td>
<td>Sheets</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>SL/BPL</td>
</tr>
<tr>
<td>Fanthalamia astoma</td>
<td>Nodular</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>SL/BPL</td>
</tr>
<tr>
<td>Fanthalamia polystoma</td>
<td>Nodular/Branching</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>SL/BPL</td>
</tr>
<tr>
<td>Nevadathamla cylindrica cylindrica</td>
<td>Cylindrical</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>SL/BPL</td>
</tr>
<tr>
<td>Nevadathamla cylindrica dialatata</td>
<td>Cylindrical/conical</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>SL/BPL</td>
</tr>
<tr>
<td>Sponge gen. and sp. indet.</td>
<td>Nodular</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>SL/BPL</td>
</tr>
<tr>
<td>Pamiropora sonorensis</td>
<td>Massive</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td>Stromaporidium lamellatum</td>
<td>Tabular/Domate</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td><strong>Hydrozoan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heterastrandium conglobatum</td>
<td>Spherical</td>
<td>Micropredator</td>
<td>Planktonic</td>
<td>NA (Float)</td>
</tr>
<tr>
<td>Spongiomorpha ramosa</td>
<td>Nodular/Branching</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td>BPL</td>
</tr>
<tr>
<td>Coral</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><em>Acanthostylis acanthophora</em></td>
<td>Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Acanthostylis</em> sp.</td>
<td>Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Alpinophyllia flexuosa</em></td>
<td>Massive</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Astraeomorpha sonorensis</em></td>
<td>Nodular/Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Chondrocoenia</em> sp. B</td>
<td>Massive</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Chondrocoenia waltheri</em></td>
<td>Massive/Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Cuifastraea granulata</em></td>
<td>Massive/Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Distichomeandra austriaca</em></td>
<td>Massive/Irregular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Gablonzeria profunda</em></td>
<td>Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Maendrostylis ? antimonioensis</em></td>
<td>Massive/Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Meandrostylis frechi</em></td>
<td>Massive/Tabular</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Retiophyllia norica</em></td>
<td>Branching</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Stylophyllopsis lindstroemi</em></td>
<td>Branching</td>
<td>Micropredator</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td>Brachiopod</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pseudorhaetina antimonioensis</em></td>
<td>Bivalve</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td><em>Spondylorhaphia lewisensis</em></td>
<td>Bivalve</td>
<td>Suspension</td>
<td>Epifaunal-Sessile</td>
<td></td>
</tr>
<tr>
<td>Gastropod</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucycloscala subbisertus</em></td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Glabrocingulum</em> sp.</td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Guidonia</em> cf. <em>G. intermedia</em></td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Guidonia</em> cf. <em>G. parvula</em></td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Omphalopychi a sp.</em></td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Promathilda</em></td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Tyrosoecus</em> sp.</td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><em>Worthenia ? sp.</em></td>
<td>Conispiral</td>
<td>Grazers</td>
<td>Epifaunal-Vagile</td>
<td></td>
</tr>
<tr>
<td><strong>Bivalve</strong></td>
<td><strong>Cephalopod</strong></td>
<td><strong>Crustacean</strong></td>
<td><strong>Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------------------------------------------</td>
<td>------------------------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td><strong>Wallowaconcha</strong> sp.</td>
<td><strong>Arcestes</strong> sp.</td>
<td><strong>Anomuran shrimp</strong></td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid (Pentacrinus)</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (free living)</td>
<td>Planispiral Predator Pelagic</td>
<td>Predator Infaunal-Vagile</td>
<td>Spherical/Pentameral Grazers Epifaunal-Vagile</td>
<td>Erect/Branching Suspension Epifaunal-Sessile</td>
</tr>
<tr>
<td><strong>Gervillaria</strong> sp.</td>
<td></td>
<td><strong>Ostracods</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (byssate)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gryphaea</strong> sp.</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (free living)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indet. boring bivalve</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Sessile (boring)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>?Lopha cordillerana</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (cementing)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Megalodontidea</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (byssate)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Monotis</strong> sp. cf. M. subcircularis</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (byssate)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Myophorigonia jaworskii</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Vagile</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Myodiptera mexicana</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Vagile</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Palaeocardita peruviana</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Vagile</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Propeamussium cf. P. schafhaeutli</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (byssate)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Septocardia</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Vagile</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Myophorigonia jaworskii</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Vagile</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Propeamussium cf. P. schafhaeutli</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Epifaunal-Sessile (byssate)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Septocardia</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Bivalve Suspension Infaunal-Vagile</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cephalopod</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Arcestes</strong> sp.</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planispiral Predator Pelagic</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Catenohalorites</strong></td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planispiral Predator Pelagic</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Pinacoceras cf. P. matternichi</strong></td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planispiral Predator Pelagic</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Sagenites cf. S schaubachi</strong></td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planispiral Predator Pelagic</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Worm</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td>Serpulids Tubular Suspension Epifaunal-Sessile (cementing)</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Crustacean</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Anomuran shrimp</strong></td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predator Infaunal-Vagile</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Ostracods</strong> Bivalved</td>
<td></td>
<td>Epifaunal-vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predator Infaunal-Vagile</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Echinoid</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Cidarid Echinoid</strong></td>
<td></td>
<td>Epifaunal-Vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spherical/Pentameral Grazers Epifaunal-Vagile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Crinoid</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Vertebrate</strong></td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>Ichthyosaur</strong></td>
<td></td>
<td>Epifaunal-Vagile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predator Pelagic</td>
<td></td>
<td><strong>Echinoid</strong> Bivalved</td>
<td><strong>Cidarid Echinoid</strong></td>
<td><strong>Crinoid</strong></td>
</tr>
<tr>
<td><strong>BPL</strong></td>
<td></td>
<td></td>
<td><strong>BPL</strong></td>
<td><strong>BPL</strong></td>
</tr>
</tbody>
</table>
biological approaches. In theory, both should reinforce each other, indicating the same depositional environment. If they do, they increase the confidence in the environmental interpretation. If not, a reassessment is required. The analysis presented in Chapters III and IV was undertaken to analyze the depositional environment of the Norian carbonate interval. The information presented below reflects study of the biogenic elements from the Norian carbonate interval.

Algae

The recognition of marine calcareous algae in the Antimonio is significant because, with the notable exception of the red alga, they are a relatively poorly known from the North American Cordillera. Calcareous algae have been identified from western North America by Reid (1985) and Flügel et al. (1989).

In Middle and Upper Triassic Tethyan strata, they are well known as sediment producers and are reliable indicators of paleoenvironments. Flügel (1982, p. 332) presents the ecological distribution and zonation of modern calcareous algae in shallow marine carbonate environments. These data were used as a proxy for those from the Norian strata of the Antimonio Formation, however, Flügel cautions that environmental preferences may have changed over geologic time. Modern calcareous algae have a wide ecological
distribution, ranging from the terrestrial and fresh water realms to normal-marine and hypersaline environments. According to Flügel (1982, p. 331) the distribution of calcareous algae is controlled by three primary factors:

1) **physical factors** such as light intensity, water temperature, water energy, and condition of the substrate,
2) **chemical factors** such as water chemistry: pH, salinity, etc., and
3) **biological factors** such as competition and presence and abundance of herbivorous organisms.

I have recognized four distinct taxa representing three classes of calcareous algae. Taken together, the modern environmental ranges of these three classes (Cyanophyceae, Rhodophyceae, Chlorophyceae) is marginal- to normal-marine (Flügel, 1982). I have identified the Chlorophyte, *Griphoporella* sp., the Rhodophytes, *Solenopora* and *Parachaetetes* and a Cyanophyte, *Cayeuxia*. The coincidence of these taxa indicates deposition near coral/sponge and oncolitic facies (Senowbari-Daryan and Schäfer, 1979). I interpret the presence of this flora to indicate deposition on and around small coral/sponge biostromes in relatively normal-marine conditions.
Foraminifera

Documentation of any foraminifers is especially significant when one considers the paucity of known examples from Mesozoic terranes of western North America. Previously Triassic foraminiferal assemblages in North America have been documented by: Gazdzicki and Reid (1983), Gazdzicki and Stanley (1983) and Kristan-Tollmann and Tollmann (1983). This newly discovered fauna from the Antimonio Formation represents the southern most Upper Triassic foraminiferal assemblage in the Cordillera.

In addition to the biostratigraphic control that foraminifers can provide, they are extremely useful in facies reconstructions. As a group, modern Foraminifera occupy a variety of habitats, ranging form the open ocean to marginal marine marshes to the deep abyss, yet the benthic, shallow marine forms are most useful in facies reconstructions. The same is true in the Triassic. The utility of foraminifers in facies reconstructions has been documented by many authors (see Flügel, 1982, p. 280 and references within). Of particular interest to this study is the work of Gazdzicki (1983). He identifies six lithofacies from the uppermost Triassic Fatra Formation of Slovakia and Poland, ranging from near shore dolomites, through lagoonal-biostromal limestones, to marginal shelf-slope deposits. While this formation is dated as Rhaetian, all foraminifers identified from the
Antimonio Formation are also present in the Fatra Formation (at the generic level). Gazdzicki lists the accompanying macrofauna from the Fatra Formation which includes: the corals, *Retiophyllia* and *Astraeomorpha*, the brachiopods *Rhaetina* and *Zugmayerella*, both found in Triassic Cordillera, and the bivalves *Lopha* and *Chlamys*. All of these taxa with the exception of the brachiopods have been identified from the Norian carbonate interval in the Antimonio Formation. In addition, the Fatra and Antimonio Formations share similar lithologic character; both units contain coral/sponge biostromes and bioclastic limestones with varying admixtures of detrital quartz. Based on these similarities I used Gazdzicki's study to interpret the foraminiferal paleoecological reconstruction of the Norian carbonate interval.

All of the foraminifers I identified occur in the Bedded Pure Limestones (Table 4.1). With the exception of the encrusting form *Tolypammina* and *Diplotremina*, all occur in bioclastic packstones. According to Gazdzicki's reconstruction *Glomospirella* and *Nodosaria* occur predominantly in lagoonal settings. Interestingly, *Diplotremina* is limited to marginal slope deposits in the Fatra. However, Flügel (1982) assigns *Diplotremina* to the back reef facies. Undoubtedly, postmortem transportation by currents and wave action obscured the facies distribution of free-living forms, yet, the coincidence of these facies
distribution suggests that these taxa were deposited in a back-reef lagoon. The foraminifer *Tolypammina* encrusts stromatoporoids in the Antimonio Formation. Based on this observation and Gazdzicki's statement that *Tolypammina* often occur encrusting corals in biostromal elevations, I interpret the presence of *Tolypammina* to indicate deposition on and around a slightly elevated, higher energy environments of the biostromes.

**Sponges**

Triassic calcareous thalamid sponges were first described from North America by Seilacher (1962). They were one of the important constructional reef builders in the Tethyan Triassic, often preferring protected, muddy soft bottom, back reef areas (Flügel, 1981). This environmental preference was also documented in the Luning Formation in Nevada. Stanley (1979) noted that thalamid sponges occur in impure limestones directly above a shale interval and provided a hard substrate for the subsequent growth of corals.

The thalamid sponges occur in environments interpreted to have had high nutrient levels and generally turbid water conditions. Since sponges are filter feeders and excellent fine-grained sediment rejecters, they were highly successful in this type of environment. Upper Triassic thalamid sponges
probably derived some of their nourishment from this clastic material and its associated nutrient load. Because the thalamid sponges from the Norian interval are generally restricted to the Sandy Limestone lithofacies, and these environments occupied an intermediate position between basinward carbonates and shoreward siliciclastics, the sponges were in part nourished by this clastic input.

Thalamid sponges from Sierra del Alamo represent a pioneer community. They appear to have occupied environments characterized by a relatively high siliciclastic input which worked to exclude corals. Sponges stabilized the mixed carbonate/siliciclastic sediments and provided hard substrates allowing for later growth of corals, hydrozoans and disjectoporoids (Figure 4.1). Six sponge taxa have been identified from Sierra del Alamo, include the erect forms: *Nevadathalamia cylindrica cylindrica*, *Nevadathalamia cylindrica dialatata*, and the low-growing and encrusting forms: *Cinnabaria expansa*, *Fanthalamia polystoma*, *F. astoma* and an indeterminate form (Table 4.1). These taxa dominate the sandy lithofacies but are associated with inozoan sponges, corals, gastropods and bivalves (Figure 4.3).

**Corals**

Coral diversity from the Norian interval has doubled in the last four years; to date fifteen taxa representing 11
Figure 4.1. Line drawing (right) based on a polished slab (left), ERNO 2786, x1. Note that stromatoporoid growth is facilitated by the presence of thalamid sponges. Key to the symbols is shown in Figure 4.2.
Figure 4.2. Key to fossil line drawings; Figures 4.1, 4.3, 4.4, 4.5. In all of these figures the rock is oriented up.
Figure 4.3. An example of the diverse biological associations in which sponges dominate. Note the numerous biotic interactions in this rock, indicated by the proximity and overgrowths of different taxa. Drawing based on polished slab ERNO 2787.
genera have been identified (see Table 4.1). This increase reflects the work of Stanley and González-León (1997) and efforts of this study.

The coral fauna from the Norian carbonates are one of the best paleoenvironmental indicators of all the sessile benthic organisms. Stanley and Swart (1995) analyzed \( \delta^{18}O \) and \( \delta^{13}C \) from 13 Triassic scleractinian corals from Italy and Turkey. Based on the covariance of carbon and oxygen isotopes they determined that they all hosted symbiotic algae and thus were zooxanthellate. Of the 13 Tethyan genera, 8 are known from the Cordillera of North and South America, and 3 are known from the Antimonio Formation. These data support the conclusion that Upper Triassic corals from the Antimonio Formation also were zooxanthellate and probably capable of rapid growth as in modern reef-building taxa. The presence of hermatypic (zooxanthellate) corals, today living exclusively in shallow, stenohaline, warm and well lighted environments, suggests that these conditions existed in Norian time in the Antimonio Formation.

Besides indicating gross environmental conditions, the development, morphology, physical and chemical alterations of Antimonio corals can be used to deduce a wealth of information about the depositional environment. The phaceloid corals *Retiophyllia norica* and *R. opelli* are generally limited in their occurrences to the base of the
Bedded Pure Limestones. *Retiophyllia* thickets are one of the most conspicuous biological components in the biostromes (Figure 3.4a), often more than 3.0 m across and 1.0 m high. These coral colonies form the framework of the lower portions of patch reefs. In addition, they undoubtedly facilitated sedimentation on patch reefs by acting as baffles: slowing currents, ergo promoting sedimentation. Embry and Klován (1971) have termed the former framestone, and the latter bafflestone. I have debated which term to apply to these fossils and come to the conclusion that both apply. Hence, what ever label is applied is inconsequential, what is important is to realize that the corals *Retiophyllia norica* and *R. opelli* acted as both framebuilders and bafflers.

The remainder of the corals from the Norian carbonates at Sierra del Alamo (Table 4.1) are massive or tabular, with the exception of two solitary forms. The tabular forms are represented by the genera: *Acanthostylis, Alpinophyllia, Astraeomorpha, Chondrocoenia, Cuifastraea, Distichomeandra, Gablonzeria, Meandrostyle*. With the exception of *Astraeomorpha*, the taxa are represented by relatively small sized specimens. While these small tabular forms account for most of the coral diversity, they were probably not dominant in terms of biomass (inferred from skeletal mass). This distinction belongs to *Astraeomorpha sonorensis*. The upper reaches of some biostromes are dominated by *Astraeomorpha sonorensis* (Figure 3.4b), which form colonies reaching nearly
1.0 m in length and 10 cm in thickness. This coral acted as a binder. Embry and Klovan (1971) define binders as, "tabular or lamellar fossils which encrusted and bound sediment during deposition." They modify this definition by adding the rider, "...the matrix, not the in situ fossils, forms the supporting framework of the rock,..." The syndepositional binding by corals from the Norian carbonate interval is evident by the morphologies which reflect vertical growth phases followed by lateral growth (Figure 4.4). These morphologies can only be formed if sediment is the supporting framework.

The corals from the Norian carbonate interval occur with hydrozoans, stromatoporoids, and a recently discovered spongiomorph. The taxonomic relationships of these groups to scleractinians is at best problematic. Stanley et al. (1994) identified the Hydrozoan, *Heterastridium conglobatum*, and the Stromatoporoids, *Pamiropora sonorensis* and *Stromaporidium lamellatum*. In addition, I have identified the Spongiomorph, *Spongiomorpha ramosa*. These taxa, with the exception of *H. conglobatum*, a planktonic form, acted as encrusters, sediment stabilizers and bafflers. Figures 4.1 and 4.4 illustrate the encrusting life habit of *S. lamellatum*. Figure 4.5 is an example of the sediment stabilizing, or binding, behavior of *S. lamellatum*. Note in all examples that stromatoporoids, corals and sponges occur and constitute a large proportion of the whole rock and essentially form the framework.
Figure 4.4. Coral bindstone from the Norian carbonate interval, x1. Note the vertical growth phases followed by horizontal growth of the coral. The matrix forms the framework of the rock. Also note that sponges form the foundation upon which corals and other encrusting organisms grew. Polished slab ERNO 2788.
Figure 4.5. Line drawing of a stromatoporoid bindstone enclosing a small coral. From polished slab ERNO 2789.
The coral, stromatoporoids, spongiomorphs, and to a lesser degree, thalamid sponges are all heavily bored by lithophagous bivalves. Borings are generally 2-3 mm in diameter. In some thin sections I have observed thin articulated bivalve shells in these borings. Based on the uniform diameter of borings and the occurrence of bivalve shell, I attribute most of the internal bioerosion to bivalves.

Brachiopods

The brachiopods from the Norian carbonates in the Antimonio Formation were identified and documented by Mike Sandy in (Stanley et al., 1994). Two taxa were identified, *Spondylospira lewesensis* a spiriferid, and a terabratulid, *Pseudorhaetina antimoniiensis*. Sandy (1998) discussed the ontogeny an taxonomic significance of *P. antimoniiensis*. Sandy notes that the brachiopods were collected from a Carnian interval at Sierra del Alamo, however, I have collected *P. antimoniiensis* in the Norian carbonates. In addition, I have observed both ribbed and smooth shelled punctate brachiopods in thin section. Sandy (personal communication, 10/10/97) suggests that the smooth shelled specimens are terabratulid and the ribbed specimens are spiriferid. I have not identified any other brachiopods from the Norian carbonate interval.
The Triassic saw a major radiation of terabratulids as they exploited niches left unoccupied following the end-Permian extinction (Sandy, 1998). The spiriferids were also a diverse group in Triassic time, although they did not survive beyond the Early Jurassic (Sandy, 1998).

The brachiopods from the Norian carbonates are most often associated with small patch reefs in the pure bedded limestones. This relationship has been documented from other localities in the Cordillera. Stanley (1979) noted that brachiopods from the Luning Formation occur in great abundance in cavities between corals and sponges. Sandy and Stanley (1993) further noted that brachiopods from the lower member of the Luning Formation flourished in clear water and occurring with invertebrates from lagoonal biostromes. While I have not observed great aggregations of brachiopods in the biostromes, I did find them in presumed life-associations in interstices and cavities between corals and sponges in a manner like those of the Luning Formation.

**Gastropods**

The gastropods from the Norian carbonate interval were studied by Erwin (in Stanley et al., 1994). Generally their preservation is poor, most are heavily abraded and recrystallized but included seven genera: Glabrocingulum, Worthenia, Eucycloscala, Omphalaptychia, Promathilda,
Guidonia and Tyroseus. The gastropod fauna is essentially tropical and contains some Permian holdover genera. They are similar to both Tethyan and Peruvian faunas (Stanley et al., 1994). Most gastropods occur in argillites, Limy Sandstone, and Sandy Limestone. Specimens encountered in thin section commonly possessed micritic rims interpreted to represent bacterial and algal crusts. With the exception of Omphalaptychia (a filter feeder or detritivore), the fauna consists exclusively of browsers and grazers (R. Batton, personal communication, 3/30/98). The predominance of grazers as well as their food—a well developed algal flora—reinforces the tropical nature of the carbonate environment.

Bivalves

Perhaps more than any other group from the Norian carbonate interval, the bivalves have been at the center of recent paleontological investigation. My newly discovered faunal elements have important environmental, biostratigraphic, and paleobiogeographic implications. While bivalves from the Upper Triassic strata of the Antimonio Formation and correlative units in Mexico were discussed by Alencaster (1961) and Kristan-Tollmann (1987), those from the Norian interval were first described in Stanley et al. (1994). Three taxa were identified: Paleocardita peruviana, Myophorigonia jaworskii, and M. salasi. McRoberts (1997)
recently reevaluated the bivalves from the Norian interval. He reassigned one of Tamura's taxa in addition to significantly increasing the bivalve diversity. McRoberts (1997) identified the following taxa from the Norian strata at Sierra del Alamo: Gervillaria sp., ?Lopha mexicana, Propeamussium cf. schafhaeutli, Myophorigonia jaworskii, Paleocardita peruviana, Monotis sp., a new alatomorph, and Septocardia. Damborenea and González-León (1997) have identified Mysidioptera mexicana from strata presumed to be Norian based on the presence of Heterastridium conglobatum. In the course of my own investigations I have identified: Gryphaea sp., Monotis sp. cf. M. subcircularis, megalodonts, and indet. lithophagous bivalves.

McRoberts (1997) stated that the shallow water setting of the Norian interval and the relatively high degree of bivalve skeletal breakage suggests that the bivalve assemblage represents a time-averaged sample. However, the bivalve fauna from the Norian interval contains approximately equal proportions of epifaunal and infaunal taxa. So regardless of the taphonomy, a sound paleoecological interpretation can be inferred.

The recognition of Gryphaea (Plate 5, Figure 4), an epifaunal bivalve well known from the Jurassic period occurs with other bivalves in the lower portion of the Norian interval. It is unique for two reasons. First, McRoberts (1992) suggests, based on material from three Cordilleran and
one high-latitude cratonic locality, that Gryphaea was likely restricted to cooler and/or deeper parts of Triassic seas. The occurrence of Gryphaea in the Norian interval at Sierra del Alamo, interpreted to represent warm, shallow environments, casts some doubt on McRoberts' claim. Second, in addition to its Jurassic occurrences, Gryphaea is also known from lower Carnian to upper Norian strata of the Cordillera and from circum-Pacific Jurassic strata. However, it has not been reported from uppermost Norian strata, so the Antimonio Formation discovery helps fill a geologic gap. McRoberts (1992) suggests that Gryphaea existed on refugia during latest Norian time. The occurrence of Gryphaea in the uppermost Triassic strata of the Antimonio Formation may further represent one of many refugia in North American inboard terranes (Stanley and McRoberts, 1993).

The recognition of Monotis cf. M. subcircularis (Plate 5, Figure 3) from the Norian strata of the Antimonio Formation further reconfirms the biostratigraphic range of the biostromes. Unfortunately, this specimen was collected from float so its exact stratigraphic position is unknown. Monotis subcircularis has been reported previously from the Antimonio Formation by Burckhardt (1930) and King (1939). McRoberts (1997) has also identified Monotis sp. from the Norian carbonates, but unfortunately it was never figured.

In addition to these newly discovered taxa I located the two beds dominated by megalodonts, a diverse group which
occupied tropical, lagoon environments in the Triassic Tethys. The lower bed (M1 in Appendix A) located at the base of the Norian interval contains abundant megalodonts. Although poor preservation precludes detailed taxonomic analysis, the specimens display the characteristic "cow hoof" morphology of the Megalodontidae (Plate 5, Figure 2). A higher bed, composed of Bedded Pure Limestone located in the middle of the Norian interval (M2 in Appendix A), contains distinctive alatoform bivalves, Wallowaconcha sp. placed in the Superfamily Megalodontoidea (Stanley et al., 1994). These gregarious, tropical bivalves lagoon-adapted bivalves most likely lived with the comisure vertical, partially buried in the sediment. They possess peculiar wing-like chambered extensions which may have hosted zooxanthallate algae. These alatoform bivalves also occur in the Wallowa and Stikine terranes (Yancey and Stanley, 1999). As yet unreported examples recently discovered in the Chulitna terrane in southeastern Alaska bear general similarity with those from the Antimonio Formation (G. Stanley, personal communication, July 1998).

Cephalopods

Both nautiloids and ammonoids occur in the Norian carbonate interval. Ammonoids were nektonic swimmers interpreted to have lived in deeper water. Their occurrence
in the Norian carbonates may represent their post-mortem transport into the shallow water environment. However, modern nautiloid are carnivorous and hunt on reefs at night (Ward, 1987), it is presumed that their ancestors, the ammonoids, did as well. Thus, the ammonoids from the Norian strata in the Antimonio Formation, may represent part of the predator guild in this ecosystem.

**Echinoderms**

Echinoderm plates and spines are ubiquitous within the Norian carbonates. Thin section examination of the Bedded Pure Limestones confirms this observation. Identification of these skeletal elements is difficult. However, the presence of club shaped spines, probably belonging to cidaroids, and crinoid columnals resembling "Pentacrinus", suggests that stalked crinoids and regular echinoids were important biotic elements of the biostromes.

**Paleosynecology**

The fauna from the Norian interval contains a diverse group of organisms (Table 4.1). Figure 4.6 is a plot of the trophic group versus lithofacies taken from Table 4.1. This plot is based on number of taxa, not number of individuals, encountered in each lithofacies. From one glance at this
Figure 4.6. Graph of taxonomic diversity and comparing trophic group vs. lithofacies. Note that the most complex community is in the bedded pure limestone.
Figure 4.7. Graph illustrating taxonomic diversity and comparing substrate relationship vs. lithofacies.
graph it is clear that the Bedded Pure Limestone lithofacies hosted the most diverse community. The Limy Sandstone and the Sandy Limestone lithofacies contained predominantly suspension feeders and grazers. For the most part these trophic groups are represented by bivalves, gastropods and thalamid sponges. The Bedded Pure Limestone consists of taxa which exploited the widest variety of feeding strategies. These taxa include algae, foraminifers, gastropods and bivalves, thalamid sponges, stromatoporoids and spongiomorphs, corals, echinoderms, ammonoids, and vertebrates.

Figure 4.7 is a graph of the substrate relationship of the fauna from Norian carbonate interval versus substrate. As in Figure 4.6, the Bedded Pure Limestone has the most diverse community (measured as number of taxa in each lithofacies). The Limy Sandstone and the Sandy Limestone lithofacies contain predominantly epifaunal vagile and sessile organisms. In contrast, the Bedded Pure Limestone, contains a fauna that exploited six different substrate relationships ranging from infaunal sessile habits to pelagic and free living strategies.

Sequence Stratigraphy and Paleoecology

The Antimonio Formation can be placed in a sequence stratigraphic framework (Gonzáalaz-León, 1997). Fourteen
fining-upward unconformity bounded units were recognized and interpreted to represent third-order eustatic cycles (Figure 1.2). Excellent biostratigraphic control indicates that these unconformity bound sequences correlate closely with unconformities recognized by Haq et al. (1987).

The Norian carbonate interval can also be interpreted within the sequence stratigraphic paradigm. Goodwin (1998) recognized that tabular bodies of immature limy sandstone intercalated with carbonates represent parasequences. Five complete parasequences have been identified from the Norian carbonate interval at Sierra del Alamo (Goodwin, 1998) as shown in Figure 4.8. Each parasequence represents a shallowing upward event and probably corresponds with a fourth-order transgressive-regressive event based on González-León’s (1997) recognition of third-order eustatic cycles bracketing the Norian interval. This interpretation assumes that the four lithofacies from Sierra del Alamo (Chapter III) were deposited at an interface between basinward carbonates and shoreward siliciclastic environments. In this context the presence of distinct, repeating lithologies can be used to indicate repeated changes in sediment source and relative sea-level. The presence of Limy Sandstone indicates a depositional setting close to a siliciclastic source probably to the east. Conversely, the presence of Bedded Pure Limestone indicates that the depositional environment was not influenced by
Figure 4.8. View of the Norian carbonate interval in the foothills of Sierra del Alamo looking south, down strike. Note the five well developed parasequences. The resistant bed are composed of Sandy Limestone and Bedded Pure Limestone. Note small fault in the lower right of the photo which offsets bedding.
siliciclastic sedimentation. It most likely was located farther from shore, in deeper water, during specific transgressive events. The Sandy Limestone lithofacies, located gradationally above and below the Bedded Pure Limestone, is a transitional deposit and represents an environment influenced by both siliciclastic and carbonate sedimentation. Generally, the Sandy Limestone beds, which bracket the Bedded Pure Limestones, are much thicker below the Bedded Pure Limestones, often up to 1.5 m thick; while those above the pure limestones are thin rarely exceeding 0.5 m thickness.

Successional Patterns

Perhaps the most striking feature of the Norian carbonate interval is the remarkable vertical faunal changes that occur within each parasequence. Such vertical changes in growth form and taxonomic composition in carbonate reef sequences have been recognized by many authors (see Copper, 1988). One of the earliest studies of succession in reef communities was by Lowenstam (1957). He recognized the presence of environmentally dependant biotic assemblages. Although he did not cite specific names for developmental stages, he did recognize an orderly vertical progression of reef development. Another pioneering study of reef succession was reported in a series of papers by Walker and
Alberstadt (Alberstadt et al, 1974; Walker and Alberstadt, 1975; Alberstadt and Walker, 1976). Based on the study of Ordovician reefs, the authors discuss succession on three temporal scales: 1) long term successions (macro-scale) recorded in thick stratigraphic sequences, 2) fossil reef successions (meso-scale) recorded in a laterally extensive reef sequences, and 3) short-term successions (micro-scale) where environmental degradation destroys an established community which reinitiates ecologic succession. Study of the Norian carbonate interval in the Antimonio Formation led to the recognition of vertical succession on the meso- and micro-scales.

As discussed above, the five complete shallowing upward sequences are the result of bimodal sedimentary cycles: Bedded Pure Carbonates representing transgressive clear water sedimentation, alternating with regressive shallow water Limy Sandstones representing episodes of siliciclastic deposition. The fauna and flora from the Norian interval reflect this sedimentary variability with remarkable fidelity resulting in distinctive successional patterns.

The coincidence of both lithofacies and biofacies indicates that these deposits were largely controlled by physical processes producing an allogenic successional pattern. Allogenic succession has been retermed “Community Replacement,” by Copper (1988) and defined as, “[occurring] where changing external factors have forced the migration of
organisms into an area thereby replacing existing species and communities." However, predictable faunal changes are observed within the Bedded Pure Limestones. These deposits were not governed by physical factors. Faunal changes in the absence inhibiting physical controls results is autogenic succession. Autogenic succession, or ecologic succession, is defined by Odum (1969, p. 262) as, "(i)...an orderly community development that is reasonably directional...(ii) It results from modification of the physical environment by the community; that is, succession is community-controlled even though the physical environment determines the pattern,...(iii) It culminates in a stabilized ecosystem..."

Both community replacement and ecologic succession are evident in the Norian carbonate interval.

Goodwin and Stanley (1997) identified the lithofacies and paleoecological associations of the Norian carbonate interval. They report the faunal composition of three distinct biofacies: 1) Mollusk Biofacies in the Limy Sandstone, 2) Sponge-Gastropod Biofacies in the Sandy Limestone, and 3) a Coral/Spongiomorph Biofacies from the Bedded Pure Limestone. The presence of these biofacies is taken to reflect the ability of organisms to adapt to environmental conditions - namely siliciclastic input. Bivalves from the Mollusk Biofacies are interpreted to have lived in and on the sand prior to lithification. The Sponge/Gastropod assemblage, a predominantly epifaunal
community, represents a fauna less tolerant of siliciclastic input than the Mollusk Biofacies. The corals and spongiomorphs in the Bedded Pure Limestone are the most sensitive to siliciclastic input and are limited almost exclusively to this lithofacies. The correlation of biofacies to an external factor (siliciclastic input) indicates that inter-biofacies development was probably physically controlled. Thus, according to Odum's definition, the physical-environment controlled the pattern of succession resulting in an orderly community development from siliciclastic tolerant species to taxa adapted to clear water environments.

External physical control also influenced intra-biofacies patterns. The Coral/Spongiomorph Biofacies displays a vertical faunal zonation within the Bedded Pure Limestone. The lower portion of the Bedded Pure Limestone are dominated by phaceloid (branching) corals while the upper reaches are characterized by corals and spongiomorphs with tabular morphologies (Figure 4.9). Embry and Klovan (1972) attributed such changes to water energy. This interpretation is supported by the sequence stratigraphic model. The lower portion of the Bedded Pure Limestone would have been deposited during a transgressive episode and coral would have experienced diminishing energy conditions. The upper reaches of this unit, host to massive and platy growth forms, would have experienced increasingly energetic conditions as a
Figure 4.9. Illustration of the successional patterns within a biostrome. In the bottom third of the photo is sandy limestone and chambered sponges, above this is a branching coral interval. The top third of the photo shows a laminar, encrusting coral interval.
marine regression progressed.

While external physical factors were controlling biofacies development (both between and within lithofacies) there were more subtle ecological interactions within the Bedded Pure Limestone. Thus the biofacies development was controlled by external physical factors – most likely siliciclastic input, and associated turbidity, fresh water incursions, etc. However, when siliciclastics were not being deposited, biofacies diversity increased (Figures 4.6 and 4.7), and all ecological reef guilds (see Fagerstrom, 1987) were filled. With this increased biofacies diversity, came more complex interspecific interactions. According to Copper (1988) an increase in biotic diversity and niche utilization are major trends in an ecological succession.

According the Alberstadt et al. (1974) reef successions follow a transitional pattern, from stabilization and colonization to diversification and dominance. During stabilization and colonization soft substrates are colonized by organisms which provide hard substrates for future reef growth. In the Norian carbonate interval these stages are represented by the Mollusk and Sponge-Gastropod Biofacies. Together the mollusks and sponges stabilized the Limy Sandstone lithofacies and produced a hard calcified substrate. The next successional stage, diversification, represents the interval in which the reef is populated by the greatest diversity. This stage is represented by the
Coral/Spongiomorph biofacies in the Bedded Pure Limestone. Here the biostromes contain the greatest number of taxa (Table 4.1; Figures 4.6 and 4.7). This biofacies developed on the hard substrate provided by the Mollusk and Sponge/Gastropod biofacies (Figure 4.9). The final reef successional phase, the domination stage, one in which a small number taxa dominate the ecosystem, is not recognized in the Norian carbonate interval. However, in places the upper reaches of the biostromes are dominated by the platy and encrusting coral *Astraeomorpha antimoniiensis*.

These patch reef successional patterns operated on the meso-scale (sensu stricto, Walker and Alberstadt, 1975). That is on the outcrop scale within a parasequence. Interestingly, these successional patterns also occur on the micro-scale. For instance, in Figure 4.1, the thalamid sponge *Fanthalamia polystoma* provided the hard substrate upon which the stromatoporoid *Stromaporidium lamellatum* grew. This micro-scale succession is also present in Figures 4.3 and 4.4. In each of these figures sponges and bivalves were encrusted and overgrown by taxa which required calcified substrates.

In addition to the recognition to these reef successional stages, biological modification of the environment also is present. Figure 4.10 illustrates how biostromes were vertically thickened by the constructional growth of corals. Thus, while the ecological succession of
Figure 4.10. Vertical sections measured across the lowest biostrome in the Norian carbonate interval at Sierra del Alamo to illustrate its lateral thickness variability. Dots indicate the presence of corals at the top of the section. Note that corals are associated with thickest parts of the biostrome. 3 m separates each section.
the Norian interval was controlled by physical factors, animals were, in a limited fashion, able to modify their own environment. The thickening of the biostromes raised the upper surface of small coral patches a few meters above the substrate, placing them in more favorable currents with lower detrital sedimentation rates.

Depositional Environment

The Norian strata from the Antimonio Formation at Sierra del Alamo were deposited during fluctuating sea-level changes, in shallow water close to a siliciclastic source (Figure 4.11). Microfacies analysis and paleontological criteria suggest that the environment was normal marine within a warm, well lighted, euhaline lagoon. Periodically, the lagoon experienced incursions of siliciclastic sediments associated with high-order regressive events.

BARRA LOS TANQUES

The Barra los Tanques locality of the Antimonio terrane, located on the eastern shore of the northern Gulf of California, contains carbonate strata previously correlated with the Antimonio Formation stratotype (Stanley and González-León, 1995). Strata at this locality have been dated by a single conodont as Norian (M. Orchard, personal
Figure 4.11. A cartoon illustrating the hypothetical depositional environment of the Norian carbonate interval at Sierra del Alamo.
communication, 6/12/98). The similarity of the litho- and microfacies to the Norian carbonate interval at Sierra del Alamo has helped establish correlation between the two localities.

Taxonomic Composition

Table 4.2 is a list of the taxa I have identified from the Norian strata at Barra los Tangues. It should be noted, that while this locality has received little attention in the past, the low faunal diversity from this locality, compared to Sierra del Alamo (see Table 4.1), most likely arises from the recrystallization and metamorphism so pervasive at Barra los Tangues. Thus, it is likely that the true taxonomic diversity from Barra los Tangues is probably much higher than is reflected in Table 4.2.

Paleosynecology

The depositional style of the Norian interval at Barra los Tangues was quite similar to that at Sierra del Alamo, with one notable exception. There is very little Limy Sandstone or Sandy Limestone at Barra los Tangues. The lack of coarse, terrigenous sediment, relative to Sierra del Alamo, is taken to indicate a depositional setting farther from a siliciclastic source. Both localities were influenced
<table>
<thead>
<tr>
<th>Category</th>
<th>Specimen Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae</td>
<td>indet. red algae</td>
</tr>
<tr>
<td>Sponge</td>
<td><strong>Fanthalamia polystoma</strong></td>
</tr>
<tr>
<td></td>
<td>Sponge gen. and sp. indet. (New Species)</td>
</tr>
<tr>
<td>Hydrozoan</td>
<td><strong>Spongiomorpha ramosa</strong></td>
</tr>
<tr>
<td>Coral</td>
<td><strong>Chondrocoenia waltheri</strong></td>
</tr>
<tr>
<td></td>
<td>7Retiophyllia opelli</td>
</tr>
<tr>
<td>Gastropod</td>
<td>indet. gastropods</td>
</tr>
<tr>
<td>Bivalve</td>
<td>indet. bivalves</td>
</tr>
<tr>
<td>Cephalopod</td>
<td>indet nautiloids</td>
</tr>
<tr>
<td>Echinoid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cidarid echinoid spines</td>
</tr>
</tbody>
</table>

Table 5.2. Fauna from the Barra los Tanques locality of the Antimonio Formation.
by high, probably fourth-order, sea-level fluctuations. Evidence of a sequence stratigraphic control of sedimentation at Barra los Tanques is shown by the presence of three or four carbonate mudstone to wackestone-packstone cycles in the Norian interval. Each cycle represents a shallowing upward event, in which system energy increased and caused the progressive winnowing of silt and clay sized particles. In this context, carbonate mudstone beds represent transgressive events and packstones formed during regressive intervals. Only one sandstone bed occurs at Barra los Tanques (Appendix B). This bed may be the result of a migrating, offshore sand body or the result of a large scale regressive event. Like Sierra del Alamo, biostratigraphic control of individual shallowing upward sequences is not available, nor can individual parasequences be correlated from Sierra del Alamo to Barra los Tanques. However, the similar number of shallowing upward sequences (five at Sierra del Alamo; three, perhaps four, at Barra los Tanques) reinforces the idea that these localities are correlative.

The faunal composition of Barra los Tanques and Sierra del Alamo are presumed to be similar. However, these faunas were not deposited under the same environmental constraints. The siliciclastic input, important in controlling biotas at Sierra del Alamo, was attenuated at Barra los Tanques. Thus the fauna was not forced to react to this external influence.
Reef Structure at Barra los Tanques

The Barra los Tanques locality of the Antimonio terrane contains a distinctive interval of nonbedded pure carbonates. This interval is composed of numerous small patches of framework surrounded by bioclastic debris. This deposit meets the criteria necessary to be recognized as a reef (see Chapter III). The strata at Barra los Tanques become especially significant because they represent the only reef deposits in the Antimonio terrane - the strata at Sierra del Alamo are biostromes.

As discussed in Chapter III, the reefs exposed at Barra los Tanques, are actually a group of small patch reefs surrounded, and buried by, their own bioclastic debris. The development of the overall reef structure at Barra los Tanques can be divided into two phases. In the first phase, the base of these reefs were formed by the accumulation of Blue-Grey Limestone and Bivalve Lithofacies (Figure 3.5). These lithofacies are composed of varying amounts of bioclasts, peloids and bivalves. These deposits represent the initiation of reef development by providing the substrate upon which the second phase developed.

The second phase of reef development was the result of sedimentation on and around the small patch reefs (Figure 4.12). As discussed previously these patch reefs have varying biological compositions. The most common
Figure 4.12. Details one of many patch reefs structures at Barra los Tanques. The flat base of the patch is just below the person's hand, the top is at about the same level as her head. Note other smaller framework growth of corals and spongiomorphs (bottom-center).
constructional elements are phaceloid and cerioid corals, however, some patch reefs are composed of digitate organisms resembling spongiomorphs and/or algae. These patch reefs rarely attained a size greater than 3 m across. They are commonly covered by skeletal debris and the Bivalve-Echinoid lithofacies. Individual patch reefs were buried by debris from surrounding reefs as well as migrating skeletal debris shoals. The lenticular carbonate at Barra los Tanques is, therefore, the result of numerous small patch reefs which are covered and buried by the debris of neighboring patch reefs (Figure 3.5). The result of this type of sedimentation is a single carbonate deposit with topographic relief. In this way the growth of many small structures results in the formation of a larger reef like deposit (Figure 4.13).

Such sedimentary structures are not without precedent in Upper Triassic strata. The Hohe Göll carbonate complex, of southern Austrian and northern Italy, was deposited in the western Tethys during Late Triassic time (Wilson, 1975). The Hohe Göll was intensively investigated by Zankl (1967, 1969 and 1971; not see by author; however, his conclusions were reviewed by Wilson, 1975). Like the Norian strata of the Antimonio Formation, the Hohe Göll is interpreted to represent a series of small patch reefs.

The Hohe Göll patch reefs and those from Barra los Tanques were deposited in a very similar manner. In each locality the patch reefs were dominated by one or two
Figure 4.13. Looking south along strike at the patch reef limestone from the Barra los Tanques locality of the Antimonio terrane. Note that the bed thickens toward the field assistant.
framebuilding species with minor contributions from other taxa. Phaceloid corals like *Retiophyllia* and encrusting corals were important constructional elements in both deposits. Additionally, in both the Hohe Göll and Barra los Tanques, the sediments which surround patch reefs are composed of bioclastic debris which volumetrically dominates the reefs.

Sedimentary analogues also occur in the eastern Tethys. Off of the northwestern coast of Australia lies the Exmouth Plateau. Upper Triassic strata were discovered in more than 2,000 m of water during Ocean Drilling Program Leg 122. As part of this drilling and dredging project Norian carbonates with remarkable faunal and facies similarities to both the western Tethys and the Antimonio terrane were investigated. Microfacies analysis of dredged and cored Norian specimens suggests deposition between basinward carbonates and shoreward fluviodeltaic sediments. Röhl et al. (1991) and Röhl et al. (1992) describe lagoonal facies analogous to the Sierra del Alamo strata. These deposits contain detrital bioclastic beds intercalated with fine-grained siliciclastic sediment. These authors also suggest that much of this bioclastic debris was provided by patch reefs. These patch reefs were located in protected environments which prevented siliciclastic dilution. This environment is similar to the depositional setting interpreted for Barra los Tanques.

Additionally, Röhl et al. (1992) identified the end
Norian regression of Haq et al. (1987) which also is recognized at Sierra del Alamo. They also interpret the Norian sediments from the Exmouth Plateau as being deposited during a series of high-order shallowing-upward events. Again much like the interpreted depositional environment of the Antimonio Formation.

Depositional Environment

The depositional setting of Barra los Tanques was dominated by pure carbonate deposition. The lack of nearshore sands at Barra los Tanques suggests it was located farther from shore compared to Sierra del Alamo. The finer grained carbonate sediment in the lower portion of the Barra los Tanques section at Barra los Tanques suggests that it experienced less energetic conditions. This diminished energy and its outboard setting suggest that Barra los Tanques was deposited in deeper water than Sierra del Alamo, but the presence of hermatypic corals on small patch reefs points to warm, shallow, well lighted water with normal salinity.
Coney et al. (1980, p. 329) stated that much of western North America is allochthonous to the craton, "...and seem[s] to have been swept from far reaches of the Pacific Ocean before collision and accretion into the Cordilleran margin mostly in Mesozoic to early Cenozoic time." Fossils in these rocks help reconstruct terrane paleogeography.

TETHYAN SIMILARITIES

The late Paleozoic and early Mesozoic faunas from the allochthonous terranes contain "Tethyan" elements (Newton, 1988), referred to as such because of their occurrence in the distant Tethys ocean (Figure 1.4). The presence of Tethyan faunas in the American Cordillera has prompted some authors to suggest that the allochthonous terranes of North America developed in or near the Tethys Ocean (e.g. Tozer, 1982), whereas other authors view them as having formed close to the North American Craton (Miller, 1987).

The fauna of the Antimonio Formation contains many taxa with Tethyan counterparts. Stanley et al. (1994) pointed out that a large proportion of the taxa also are known from the western Tethys. The coincidence of these faunas led Stanley and González-León (1995) to speculate on the dispersal
mechanisms responsible for this pattern. Many models have been developed to explain Tethyan faunas in the North American Cordillera (Tozer, 1982; Newton, 1988; Smith et al., 1990, Stanley; 1994). These hypotheses attempt to explain for how faunas from so distant a region can bridge the vast Panthalassa Ocean.

SIMILARITIES WITH OTHER NORTH AMERICAN CORDILLERAN TERRANES

The Antimonio Formation shares many similarities with other Upper Triassic stratigraphic sequences in the Cordillera. Chief among these are: 1) an underlying volcanic or volcanogenic basement, 2) initiation of biogenic carbonate deposition in Carnian-Norian time, 3) similar biotas within these biogenic carbonates, and 4) the replacement of carbonate deposition by siliciclastic deposition in latest Triassic to early Jurassic time.

The similarity of the Upper Triassic to Lower Jurassic strata of the Antimonio Formation to specific localities within four different terranes will be assessed in the following section. They include: 1) Eaglenest Reef, Quesnel terrane (Stanley and Nelson, 1996; Stanley and Senowbari-Daryan, in press); 2) Lime Peak, Stikine terrane (Reid, 1985; Reid and Ginsberg, 1986; Reid and Tempelman-Kluit, 1987; Reid, 1988); 3) Martin Bridge Formation, Wallowa terrane (Stanley, 1979; Whalen 1988; Stanley and Whalen, 1989); 4)

SIMILARITY COEFFICIENTS

In addition to recognizing similarities of depositional styles, tectonic histories, and age of strata, the faunas can be compared using the coefficient of similarity technique. I calculated the Dice (D) and Jaccard (J) (Cheetham and Hazel, 1969) coefficients for sponge and coral taxa within these five localities. The faunal lists used to generate these tables are located in Appendices C and D. These particular coefficients were useful because they provide meaningful results when comparing small sample sizes (Shi, 1993). They are defined as follows:

\[ D = \frac{2C}{N_1 + N_2} \]

\[ J = \frac{C}{N_1 + N_2 - C} \]

where \( N_1 \) is the number of taxa in sample 1, \( N_2 \) is the number of taxa in sample 2, and \( C \) is the number of taxa common to both localities. The results of these analyses are presented in Table 5.1 and 5.2. (Because the results of both Dice and Jaccard coefficients behave in a similar manner, only the results from the Dice analysis will be presented.)
Table 5.1. Calculated sponge similarity coefficients for selected Norian localities in the Cordillera. Values were calculated using the Dice Similarity Coefficient which ranges from 0 to 1.00. 1.00 indicates total similarity.

<table>
<thead>
<tr>
<th></th>
<th>Antimonio Formation</th>
<th>Luning Formation</th>
<th>Eaglenest Reef</th>
<th>Martin Bridge</th>
<th>Lime Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimonio</td>
<td>1</td>
<td>0.71</td>
<td>0.36</td>
<td>0</td>
<td>0.19</td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luning</td>
<td>1</td>
<td>0.36</td>
<td>0</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eaglenest Reef</td>
<td>1</td>
<td>0.07</td>
<td>0</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Martin Bridge</td>
<td></td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lime Peak</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2. Calculated coral similarity coefficients for selected Norian localities in the Cordillera. Values were calculated using the Dice Similarity Coefficient which ranges from 0 to 1.00. 1.00 indicates total similarity.

<table>
<thead>
<tr>
<th></th>
<th>Antimonio Formation</th>
<th>Luning Formation</th>
<th>Eaglenest Reef</th>
<th>Martin Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimonio</td>
<td>1</td>
<td>0.4</td>
<td>0.3</td>
<td>0.34</td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luning</td>
<td>1</td>
<td>0.3</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eaglenest Reef</td>
<td>1</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Martin Bridge</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Cluster analysis dendrograms were then constructed using the Windows based statistical package Splus (Figures 5.1 and 5.2). The clusters are based on unweighted average similarity values. The data from the similarity coefficients show that the Antimonio Formation is most similar to the
Figure 5.1. Dendrogram cluster analysis of the thalamid sponge similarity data in Table 6.1.
Figure 5.2. Dendrogram cluster analysis of the coral similarity data in Table 6.2.
Luning Formation. (Note: coral taxonomic data from the Lime Peak was deemed unreliable and was not used in the analysis. This material is currently under study at the University of Montana.)

CHAPTER VI

COMPARISON OF THE ANTIMONIO AND LUNING FORMATIONS

The Upper Triassic strata of the Luning and Antimonio Formations have strikingly similar stratigraphic and paleontological characters which led Stanley and González-León (1995) to suggest that these similarities supported the Mojave-Sonora Megashear (Anderson and Silver, 1979). The Mojave-Sonora Megashear is often cited as a tectonic element which dislocated the Antimonio Formation from its original position farther north in the Cordillera (Figure 6.1).

In addition to evaluating the faunas and paleoecological patterns of the Antimonio Formation’s Norian carbonate interval, an important component of my thesis addresses the similarity of the Luning and Antimonio Formations. In the Summer of 1997, I visited Shoshone Mountains, Pilot Mountains, Garfield Hills, and the Gabbs Valley Range in Nevada to evaluate their similarity to the Sonora section. The carbonate biostromes most similar to the Antimonio
Figure 6.1. Stratigraphic-tectonic features of northwestern Mexico and southwestern North America during Middle Jurassic time. Outcrops of the Antimonio Formation are numbered. (see Figure 1.1 for individual localities). Locations of Mesozoic strata in Nevada (A,B,C)and rift deposits of of the Barranca Group in central Sonora are indicated. Figure from Stanley and González-León (1995).
Formation are those in the Pilot Mountains, and were used in the comparison of these two sections.

The carbonates in the Luning Formation are represented by thin biostromes which contain a diverse fauna of corals, sponges, spongiomorphs, mollusks, brachiopods, and a small number of microfossils (Stanley, 1979; Cornwall, 1979).

**STRATIGRAPHIC AND BIOSTRATIGRAPHIC SIMILARITIES**

The Antimonio Formation and Luning Assemblages are the same age and contain similar lithofacies. The lower portions of both the Antimonio and Luning Formations contain fine-grained sandstone, siltstone, and mudstone, and thin limestone. Ascending stratigraphically, shallow marine carbonates dominate. Deep water transgressive shales and mudstone, followed by terrigenous conglomerates, form the upper reaches of both stratigraphic sections.

In addition to the similarities mentioned above, the Norian biostromes from the Luning and Antimonio Formations are strikingly similar. Figure 6.2 is a chart summarizing the similarities and differences of the Norian biostromes from both localities.

Both the Luning Assemblage and the Antimonio Formation contain strata deposited in early to middle Mesozoic time. These formations also share similar depositional histories during Late Triassic to Lower Jurassic time. In each
<table>
<thead>
<tr>
<th></th>
<th>Antimonio Biostromes</th>
<th>Luning Biostromes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>Upper Norian</td>
<td>Lower Norian</td>
</tr>
<tr>
<td><strong>Rock Types</strong></td>
<td>Limestone/</td>
<td>Limestone/</td>
</tr>
<tr>
<td></td>
<td>Sandy Limestone/</td>
<td>Shale/</td>
</tr>
<tr>
<td></td>
<td>Limy Sandstone/</td>
<td>Argillite</td>
</tr>
<tr>
<td></td>
<td>Shale/</td>
<td></td>
</tr>
<tr>
<td><strong>Biostrome Foundation</strong></td>
<td>Sandstone</td>
<td>Shale</td>
</tr>
<tr>
<td><strong>Sediment Stabilizing Organism</strong></td>
<td>Bivalves and Sponges</td>
<td>Bivalves and Sponges</td>
</tr>
<tr>
<td><strong>Dominant Taxon</strong></td>
<td>Coral</td>
<td>Coral</td>
</tr>
<tr>
<td><strong>Secondary Taxon</strong></td>
<td>Sponge</td>
<td>Spongiomorphs</td>
</tr>
<tr>
<td><strong>Evidence of Biologic Zonation</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Shape of Buildup</strong></td>
<td>Thin, lenticular</td>
<td>Thin, lenticular</td>
</tr>
<tr>
<td><strong>Depositional Environment</strong></td>
<td>Nearshore lagoon/ Offshore ramp</td>
<td>Nearshore delta/ Offshore carbonates</td>
</tr>
</tbody>
</table>

**Figure 6.2.** Summary of the similarities and differences between the Norian biostromes in the Antimonio and Luning Formations.
locality, Upper Triassic rocks are generally represented by biogenic carbonates intercalated with fine-grained terrigenous, followed by siliciclastic sedimentation in latest Triassic to Early Jurassic time.

FAUNAL SIMILARITIES

The gross lithologic similarity and temporal correlation provide strong evidence that the Luning and Antimonio Formation are correlative but they do not prove that the Antimonio and Luning Formations were deposited in close proximity to each other. However, these similarities combined with like faunas and paleoecological patterns, would bolster this interpretation.

The fauna and paleoecology from the biostromal interval in the Luning was investigated by Stanley (1979), Cornwall (1979), Kristan-Tollman and Tollman (1983), and Sandy and Stanley (1993). Their findings will be compared with findings from the study of the Norian carbonate interval in the Antimonio Formation, as outlined by Stanley et al. (1994), as well as my own paleontological observations.

PALEOECOLOGICAL PATTERNS

In addition to faunal similarity (Chapter VI), the Norian carbonate intervals of the Antimonio and Luning
Formations contain distinctive and similar paleoecological patterns. In both localities the same pattern of sediment stabilization, colonization leading to ecologically diverse communities, and eventual community termination due to siliciclastic input, is present. The recognition of these patterns spurred speculation that these formations might represent piercing points and therefore can be used to help reconstruct the early Mesozoic paleogeography of North America (Stanley and González-León, 1995).

In the Luning, Stanley (1979) recognized a distinct biostromal successional pattern. The first stage consists of mud colonized by sponges and brachiopods. The growth of these organisms formed a hard substrate upon which massive and platy corals and spongiomorphs developed. This stage was followed by the growth of the branching coral *Retiophyllia* upon the platy forms (Stanley, 1979; figure 7). Biostromes were terminated by the reintroduction of terrigenous sediment. The introduction and removal of this fine-grained material controlled the biological development of the biostromes in the Luning (Stanley, 1982). Reilly et al. (1980) attributes the introduction of clastic material into the Luning Formation to influx from a deltaic complex. This pattern of development and subsequent destruction of biostromes occurred at least six times (Stanley, 1979).

A similar successional pattern is present in the Antimonio Formation’s Norian carbonate interval. Here, fine-
grained muddy substrates were colonized by bivalves. As the fine-grained sediment input began to wain, sponges and mollusks became abundant. Next, branching coral colonies developed on the hard substrate of mollusks and sponges. Finally, platy corals and spongiomorphs grew on the branching coral interval. Biostromal growth was terminated by reintroduction of siliciclastic sediment. This pattern occurred five times in the Norian carbonates of the Antimonio Formation.

SIGNIFICANCE OF THE MOJAVE-SONORA MEGASHEAR

The similarities of the Luning and Antimonio Formation may help resolve proposed movement on the controversial Mojave-Sonora Megashear (Figure 1.1). The exact position of the megashear, and even its existence is debated (see Marzolf, 1997; Stanley and González-León, 1995). Yet, it may explain many perplexing issues in the evolution of southwestern North America. Based on the abrupt truncation of Precambrian trends in the southwest United States and their reappearance in Sonora, Silver and Anderson (1974) proposed approximately 800 km of left-lateral displacement along the Megashear during Late Jurassic time. Silver and Anderson (1974) hypothesized that the megashear moved the Precambrian Caborca Block, as well as associated Paleozoic and early Mesozoic sedimentary cover southward from western
Nevada and east central California into Sonora. The recognition of the similarity of the Luning and the Antimonio Formations may provide a sedimentary and paleontological piercing point.

The northwestern extension of the Mojave-Sonora Megashear in the southwestern United States is still problematic. T. H. Anderson (personal communication, May, 1998) speculated that in Triassic time the Antimonio Formation occupied a position close to what is now Mono Lake, California. According to this hypothesis the Megashear would have existed in a position now occupied by the Sierra-Nevada Batholith. Alternatively, Oldow (1993) and Stanley and González-León (1995) speculated that the Pine Nut Fault, in west-central Nevada, could represent the northern extension of the Megashear.

Despite the problems identifying the tectonic elements responsible for the dislocation of the Antimonio terrane, several conclusions can be drawn based on the remarkable sedimentological, paleontologic and paleoecological similarities of the Luning and Antimonio Formations. First, the coincidence of the taxonomic composition of the biostromes from the Luning and Antimonio suggest that they were deposited close to each other. In addition, dissimilarity with outboard terranes suggests that during Late Triassic time the Antimonio terrane lay closer to the North American craton than to other Pacific terranes.
Second, the similarity of the paleoecological patterns in these biostromes suggests that these deposits were governed by similar sedimentary controls. Similar sedimentological and paleoecological patterns in the Luning and Antimonio Formation supports the hypothesis that they were deposited close together and subsequently moved to their present positions.

CHAPTER VII

FINDINGS AND CONCLUSIONS

Important findings from the investigation of the Norian carbonate interval include new paleontological, paleoecological and sedimentological insights into the deposition of the Antimonio Formation. A summary of the findings of this study are listed below:

- Recognition of distinct lithofacies and biofacies from the Norian carbonate interval at Sierra del Alamo;
- Identification of eleven microfacies from Sierra del Alamo and placement of these microfacies in a depositional model;
- Recognition of heretofore unrecognized Norian fauna and flora;
Identification of high-order parasequences in the Norian carbonate interval;

Identification of the Barra los Tanques section as an offshore correlative of the Sierra del Alamo.

APPLICATION OF FINDINGS

These findings are both new and interesting, and they can be used to test the hypotheses outlined in Chapter I. They are: 1) were the cyclic strata of the Norian carbonate interval deposited in response to changes in relative sea-level, or some other forcing mechanism such as climate change; 2) do the vertical successional patterns in the Norian interval reflect physical control or biological accommodation; and 3) has the Antimonio terrane been moved from its depositional site in Nevada or California, southward into Mexico?

Hypothesis 1

Tectono-eustatic forcing of sedimentation is the most parsimonious explanation of the cyclic strata in the Norian interval. González-León (1997) recently identified 14 upward-fining unconformity bound sequences, attributed to third-order eustatic cycles, in the Antimonio Formation. Many of these unconformities can be correlated to worldwide regressions identified by Haq et al. (1987) and Embry (1988),
including both the end-Norian and end-Rhaetian events. Additionally, gradual lithologic transitions in the Norian interval are consistent with expected pattern of migrating facies forced by changes in relative sea-level. Based on the eustatic control of deposition of the Antimonio Formation and the lack of evidence of climate change, I interpret the parasequences in the Norian interval to be the result of high-order changes in relative sea-level.

Facies changes in the Norian interval could reflect changing climatic regimes. Soreghan (1997) evoked glacio-climatic facies changes in carbonate-siliciclastic strata. Such models suppose that climate change causes depositional environments to fundamentally change rather than migrate according to Walther's Law. However, a climatically forced sedimentation pattern can be ruled out for several reasons. First, in Soreghan's (1997) examples the model produced sediments characterized by sharp facies boundaries. This pattern has not been identified in the Norian interval. In addition, climatic changes were linked to the presence of polar ice-caps, which did not exist during Triassic time.

Hypothesis 2

The fossil preservation in the Norian carbonate interval makes this strata exceptionally well suited for evaluation of
reef succession. There are two schools of thought on this issue. The first states that so-called successional pattern merely reflect physical changes in the environment resulting in "community replacement" (sensu Copper, 1988). The second school teaches, that successional patterns are orderly, predictable, and most importantly, biologically mediated (Odum, 1969). If physical control governed biofacies development, a change in the physical environment would be accompanied by a biological response. As discussed in Chapter III, each lithofacies is associated with a discrete biofacies, and their coincidence indicates that faunal changes were caused by changes in the environment, most notably flux of siliciclastic input. The dominance of siliciclastic tolerant taxa (bivalves and gastropods) in Limy Sandstones, and their low relative abundance in Bedded Pure Limestones supports this conclusion. On the other hand, if the successional patterns in the Norian carbonates were biologically mediated, the environment would have been actively modified by biological activity, resulting in further faunal turnover. Elevated patch reefs associated with colonial branching corals, upon which further successional patterns are superimposed, suggest that, in the absence of siliciclastic input, biological accommodation is common. In addition, when the external control (siliciclastic input) was removed, biofacies diversity increased, and all of the modern ecological reef guilds were
filled. With this increased biofacies diversity, came more
complex interspecific interactions. This increase in
paleoecological complexity, in the absence of the above
mentioned physical control, reflects a biologically
accommodated environment. Thus, the Norian carbonates are
both physically controlled and biologically accommodated.
This conclusion reflects the multifaceted nature of the
development of the Norian carbonate interval.

Hypothesis 3

The principle thrust of this project was to test the
hypothesis presented by Stanley and González-León (1995), who
proposed that the Antimonio terrane is not autochthonous.
That is, strata of the Antimonio terrane (Monos and Antimonio
Formations) were deposited to the north and subsequently
dislocated to their present position along a major fault
system. Perhaps the most compelling evidence in favor of
this hypothesis was presented by González-León (1997), who
stated, that no correlative rocks of the Antimonio terrane
occur north of the Mojave-Sonora megashear. In order to test
the ideas of Stanley and González-León (1995), I set out to
compare contemporaneous strata from the Antimonio Formation
with the Luning Formation in westcentral Nevada. The Luning
Formation was chosen for two reasons. First, it has Upper
Triassic carbonate biostromes similar to the Antimonio
Formation's Norian interval. Second, if the Antimonio terrane was restored to its pre-dislocation position, it would be very close the Luning Formation (T. Anderson, personal communication, 1/97).

Initial literature review confirmed that these formation have many similarities, attesting to the validity of the comparison. Below I present a summary illustrating some the similarities and differences of the Antimonio Formation and the Luning Assemblage, many of which are discussed in detail in Gomez-Luna and Martinez-Cortes (1997).

Similarities

- Age of the entire stratigraphic succession
  Luning Assemblage: Middle Triassic - Early Jurassic
  Antimonio: Latest Permian - ?Middle Jurassic

- Stratigraphic thickness
  Luning Assemblage: up to 4.2 km thick
  Antimonio: 4.1 km thick

- Similar sequence stratigraphic patterns both through out the formations and in the Norian intervals

- Both stratigraphic successions contain distinctive carbonate intervals deposited during Norian time

- Faunas are generally similar between Nevada and Sonora within the Norian biostromes

- Initiation of continental siliciclastic sedimentation in Early Jurassic time
Age of initiation of Emplacement:

- Luning Assemblage: post-Early Jurassic (Oldow, 1981)
- Antimonio terrane: Middle Jurassic (Stanley and González-León, 1995)

Differences

- Basement
  - Luning Assemblage: unknown due to Luning fault
  - Antimonio Formation: Permian Monos Formation
- Tectonosedimentary Setting
  - Luning Assemblage: back-arc deposit
  - Antimonio Formation: fore-arc deposit
- Age of the Norian biostromes
  - Luning Assemblage: early Norian
  - Antimonio Formation: late Norian

I used three independent lines of evidence to test the hypothesis that the Luning and Antimonio Formations were deposited close together (Stanley and González-León, 1995). First, I examined the sedimentary patterns from the Antimonio Formation, keeping in mind that if these units were deposited in close proximity they would exhibit similar sedimentary patterns. The coincidence of sedimentary cycles in both units, consisting of fine-grained siliciclastics followed by increasingly carbonate-rich sediments leading to biostromal
buildups, is consistent with the hypothesis, therefore supporting Stanley and González-León (1995). Next, I looked at faunal similarity indices from several inboard terranes. The results of this analysis indicated that the Luning and Antimonio Formations form a cluster with the highest degree of both sponge and coral taxonomic similarity. Again, this would be the expected pattern if the two formations were deposited close together, and this conclusion is consistent with the hypothesis. Finally, I characterized the successional patterns in the biostromes from the Antimonio Formation to compare them with those from the Luning. Similar biotic successions would be expected if these deposits were geographically related during their genesis. The pattern from the Norian interval of the Antimonio Formation, shows a biotic response to decreasing siliciclastic input during deposition of parasequences. That is, siliciclastic sands and shales were colonized by bivalves, and to a lesser degree sponges, and as siliciclastic input waned sponges became more abundant. The zenith of biostromal development was reached when corals as well as other reef-type taxa, became dominant. This period of relatively pure carbonate deposition ended when siliciclastic sediment was reintroduced during small-scale regressive events. My examination of the Norian biostromes in the Luning Formation revealed a similar pattern. During the transitional phase from siliciclastic to carbonate
sedimentation, the same pattern of bivalve communities followed by sponges and finally coral communities, found in the Antimonio Formation, is present in the Luning. Again the similarity of these patterns supports the hypothesis.

These formations were deposited close enough to each other to allow a large degree of faunal communication. Based on degree of faunal similarity indices (Dice and Jaccard coefficients; see Chapters VI and VII), the Antimonio and Luning Formations were deposited closer to each other than to other inboard terranes of the North American Cordillera. This observation combined with the similarity of the sedimentological and paleoecological patterns attests to their proximity. This similarity, combined with the mounting support for the Mojave-Sonora Megashear, further supports ideas, such as Stanley and González-León (1995) and González-León (1997), which suggest that the Antimonio Formation was deposited far to the north and subsequently moved southward.

CONCLUSIONS

The strata of the Norian carbonate interval are divided into three main categories: 1) Limy Sandstones, 2) Sandy Limestones, and 3) Bedded Pure Limestones. The presence of tabular bodies of immature Limy Sandstone intercalated with carbonates suggests that these units were deposited at an interface between basinward carbonates and shoreward
siliciclastic environments (Figure 8.1). In this context, the presence of the three above mentioned lithofacies can be used to infer changes in the depositional environment. Limy Sandstone indicates a depositional environment close to a siliciclastic source - the shore to the east. Conversely, Bedded Pure Limestone indicates that the depositional environment was not significantly influenced by siliciclastic input, and thus, is interpreted to have been deposited farther from the siliciclastic source - probably offshore. The Sandy Limestone represents a transitional environment between shoreward quartz sands and basinward carbonates.

Thin section examination revealed eleven microfacies. The microfacies analysis suggests that deposition of the strata of the Norian carbonate interval occurred at an interface between carbonate and siliciclastic environments, on and around biostromes and small patch reefs, in a restricted to open-marine lagoon with variable water energy.

From the above discussion, it becomes clear that the depositional environment was controlled by an external physical factor which governed biofacies development. However, when this external control was removed biofacies diversity increased, and all of the ecological guilds on modern reef were established in the biostromes. With this increased biofacies diversity, came more complex interspecific interactions. This increase in paleoecological complexity, in the absence of the above mentioned physical
Figure 7.1. Interpreted depositional model for the Norian carbonate interval from the Antimonio Formation. For further explanations, see text.
control, reflects a biologically accommodated environment. Thus, while primary biofacies development is physically controlled, second order changes within the Bedded Pure Limestones reflect biological accommodation.

Comparison of the Antimonio and Luning Formations, to test the hypothesis that these formations share similar faunas and paleoecological patterns due to their Late Triassic paleogeographic proximity, was not conclusive. However, their high degree of both faunal and sedimentological similarity suggests that they were closer to each other than any other Cordilleran terrane.

FUTURE RESEARCH DIRECTIONS

In order to better understand the relationship of the Antimonio Formation to units farther in the Cordillera, I see four directions of future research. First, the relationship of the Caborca Block to other Precambrian rocks farther north in the southwestern United States must be understood. Since the recognition of the truncated Precambrian basement trends by Silver and Anderson (1974) much research has centered on the northern exposures of these rocks, yet little research has focused on the Caborca Block and its relationship to Precambrian basement trends of Arizona, New Mexico and Colorado. Establishing this connection is key because it will allow for a better understanding of the overlying rocks.
Second, the relationship of the Antimonio terrane to the Caborca Block must be understood. At present the relationship of these tectonic entities is poorly known. Stanley and González-León (1995) state that the Antimonio terrane "most likely" lies in tectonic contact with the Caborca Block. However, this contact has not been observed in the field (C. González-León, personal communication, January, 1998). This contact is critical in understanding the paleogeography of the Antimonio terrane, because, if these units are in depositional or erosional contact then may have been moved to their present positions together. On the other hand, if a fault contact is revealed they may have completely separate depositional and tectonic histories.

Third, the relationship of the Antimonio terrane with strata in southern California should be investigated. González-León (1997) suggests that the Antimonio terrane may have occupied a position in southern California during early Mesozoic time. This intriguing idea still requires that the Antimonio Formation be tectonically dislocated in middle Mesozoic time. Further more, it would place the Luning and Antimonio Formations close enough to allow faunal communication during Triassic time, while separating them sufficiently to account for stratigraphic differences. A logical way to test this hypothesis involves detrital zircon analysis to establish depositional similarity. Such analysis are currently being preformed at the University of Arizona.
Finally, the relationship of the Antimonio terrane to the Barranca Group should be addressed. Stewart et al. (1997) has suggested that the Antimonio terrane and the Barranca Group are lateral equivalent. In this model the Sierra Santa Teresa locality of the Antimonio terrane represents an intermediate facies between these two localities. This hypothesis is intriguing because the Sierra Santa Teresa locality does indeed contain conglomerates similar to conglomerates in the Barranca Group. In addition, the carbonate interval at Sierra Santa Teresa is lithologically quite similar to the Norian carbonate interval at Sierra del Alamo. If this hypothesis is correct it would require a new explanation of the basement relationship of the Antimonio terrane, as the Barranca Group was deposited in a rift basin (Stewart and Roldan-Quintana, 1991).
REFERENCES


Anderson, T., and Silver, L., 1979, The role of the
Mojave-Sonora megashear in the tectonic evolution of
northern Sonora, in Anderson, T. and Roldan-Quintana,
J., Geology of Northern Sonora: Geological Guidebook,
Geological Society of America, Field Trip 27, p. 59-68.

Anderson, T., and Silver, L., 1981, An overview of
Precambrian rocks in Sonora: Revista Mexicana de
Ciencias Geológicas, vol. 5, p. 131-139.

Beck, M., Cox, A., and Jones, D., 1980, Mesozoic and Cenozoic
microplate tectonics of western North America: Geology,
vol. 8, p. 454-456.

Belasky, P., and Runnegar, B., 1994, Permian longitudes of
Wrangellia, Stikinia, and Eastern Klamath terranes based

Bernecker, M., 1996, Upper Triassic reefs of the Oman
Mountains: Data from the South Tethyan Margin: Facies,
vol. 34, p. 41-76.

Burckhardt, C., 1930, Etude synthetiquen sur la Mesozoique
mexican: Mémoires de la Société paléontologique Suisse
(=Abhandlungen der Schweizerischen Paläontologischen


Geological Society of America.


Cornwall, D., 1979, Paleoecology of Upper Triassic Bioherms in the Pilot Mountains, Mineral County, West-Central Nevada [Masters thesis]: Reno, University of Nevada.


Dybowski, W., 1877, Die Chaetetiden der ostbaltischen Silur-Formation: Dorpat, p. 134.


Flügel, E., 1994, Pangean shelf carbonates: controls and


Frollo, M., 1938, Sur un nouveau genre de Codiiacee du


González-León, C., 1997, Stratigraphy and paleogeographic setting of the Antimonio Formation, Sonora, Mexico, in González-León, C., and Stanley, G., Jr., eds., US-Mexico cooperative research: International workshop on the geology of Sonora, memoir, Volume 1, Universidad Nacional Autónoma de México, Instituto de Geología,


Miller, K., and West, R., 1997, Growth-interruption surfaces within chaetetid skeletons: Records of physical
disturbance and depositional dynamics: Lethaia, vol. 29, p. 289-299.


Odum, E.P., 1969, The strategy of ecosystem development:


Reid, R., 1988, Lime Peak reef complex, Norian age, Yukon, in Geldsetzer, H., James, N., and Tebbutt, G., eds., Reefs,


Sedlock, R., 1988, Tectonic setting of blue-schist and island-arc terranes of west-central Baja California,


Silberling, N., Jones, D., Blake, M., Jr., and Howell, D., 1987, Lithotectonic terrane map of the western conterminous United States, Map MF, 1874-C.


Soja, C., 1996, Island-arc carbonates: characterization and recognition in the ancient geologic record: Earth
Science Reviews, vol. 41, p. 31-65.


Stanley, G., Jr., and Nelson, J., 1996, New investigations on Eaglenest Mountain, northern Quesnel terrane: an Upper Triassic reef facies in the Takla Group, central British Columbia (93N/11E), in Grant, B., and Newell,


Stanley, G., Jr., and Senowbari-Daryan, B., in press, Upper Triassic reef fauna from the Quesnel Terrane, central British Columbia, Canada: Journal of Paleontology.


Stanley, G., Jr., and González-Leon, C., 1995,
Paleogeographic and tectonic implications of Triassic fossils and strata from the Antimonio Formation, northwestern Sonora: Geological Society of America, Special Paper 301, p. 1-16.


Geología, Estación Regional del Noroeste, p. 67-68.

Stewart, J., Amaya-Martinez, R., Stamm, R., Wardlaw, B.,
Stanley, G., Jr., and Stevens, C., 1997, Stratigraphy
and regional significance of middle Paleozoic to early
Mesozoic rocks in Sierra Santa Teresa, Sonora, Mexico:
115-135.

Stewart, J., Poole, F., Ketner, K., Madrid, R., Roldán-
Quintana, J., and Amaya-Martinez, R., 1990, Techtonics
and stratigraphy of the Paleozoic and Triassic southern
margin of North America, Sonora, Mexico, in Gehrels,
G., and Spencer, J., eds., Geologic Excursions
through the Sonoran Desert region, Arizona and Sonora,

Barranca Group; Nonmarine and shallow-marine rift-basin
deposits of northwestern Mexico: Geological Society of
America, Special Paper 254, p. 19-36.

and Jurassic stratigraphy and paleogeography of west-
central Nevada and eastern California, with a
correlation diagram of Triassic and Jurassic rocks: U.S.


Vallier, T., 1967, The geology of part of the Snake River Canyon and adjacent areas in northeastern Oregon and western Idaho [Ph.D thesis], Oregon State University.


Yancey, T.E., and Stanley, G., Jr., 1996, Giant alatoform bivalves of the Late Triassic in western North America, Abstracts with Programs of the Geological Society of


Plate 1. 1) Cayeuxia sp. ERNO-2790, x66; 2) Solenopora sp. ERNO-2790, x50; 3) Parachaetetes sp. ERNO-2791, x50; 4) Griphoporella sp. ERNO-2792, x50.
Plate 2. 1) *Nevadathalamia cylindrica dilatata* ERNO-2793, x0.75; 2) *Nevadathalamia cylindrica cylindrica* ERNO-2794, x1.5; 3) *Fanthalamia astoma* ERNO-2795, x5; 4) unidentified sponge from Barra los Tanques ERNO-2796, x2.
Plate 3. 1) Gablonzeria profunda ERNO-2797; a) x5; b) same specimen, x10; 2) Retiophyllia opelli ERNO-2798; a) x4; b) x15; 3) Distichophyllia norica ERNO-2799, x3.
Plate 4. 1) *Chondrocoenia* sp. B ERNO-2800; a) x9; b) x10; 2) *Stylophyllopsis lindstroemi* ERNO-2801, x3.5; 3) *Meandrostylis frechi* ERNO-2802; a) calicular surface, x3; b) polished cross-section, x9; c) longitudinal polished section, x16.
Plate 5. 1) *Spongiomorpha ramosa* ERNO-2803; a) longitudinal view in thin section, x40; b) cross section in thin section, x40; 2) *Megalodont* ERNO-2804, x0.75; 3) *Monotis* cf. *M. subcircularis* ERNO-2805, x2; 4) *Gryphaea* sp. ERNO-2806, x1.5.
Appendix A
Generalized geologic map of part of the Antimonio Formation at Sierra del Alamowith locations of my measured sections. Packages are from González-León et al., (1995). Map courtesy of González-León.
Stratigraphic sections from the Sierra del Alamo locality of the Antimonio Formation
Appendix B
Measured section from the Barra los Tanques locality of the Antimonio Formation. Scale bar in meters.
Appendix C

Sponge taxa used to construct faunal similarities

Data culled from the following sources:

Eaglenest Reef: Stanley and Senowbani-Daryan (in press);
Lime Peak Reef: Senowbani-Daryan and Reid (1987); Martin
Bridge Formation: Stanley (1979), Whalen (1985), Stanley
and Senowbani-Daryan (1986), and Senowbani-Daryan and
Stanley (1988); Luning Formation: Seilacher (1962), Stanley
(1979), Kristan-Tollmann et al. (1983), Senowbani-Daryan
and Stanley (1992); Antimonio Formation: Stanley et al.
(1994), and this thesis.
<table>
<thead>
<tr>
<th>Taxa</th>
<th>Antimonio</th>
<th>Eaglenest</th>
<th>Martin Bridge</th>
<th>Luning</th>
<th>Lime Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amblysiphonella sp.</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amblysiphonella cf. A. steinmanni</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Cinnabarina cf. C expansa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cinnabarina expansa</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Colospongia bimuralis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Colospongia cf. mennulensis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Colospongia dubia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Colospongia sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Colospongia whaleni</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cryptocoelia sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cryptocoelia zetteli</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dictocoelia sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Fanthalamia astoma</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Fanthalamia multicanalis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Fanthalamia polystoma</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Follicatena irregularis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Henricellum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Neoguadalupia? norica</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Nevadathalamia cylindrica cylindrica</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Nevadathalamia cylindrica dialatata</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Nevadathalamia ramosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Paradeningeria alpina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peronidella sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Polycystocoelia norica</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Polycystocoelia silbertingi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Polycystocoelia sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Salzburgia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Sponge gen. and sp. indet A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Sponge gen. and sp. indet B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Uvanalla irregularis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Yukonella rigbyi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>?Zardinia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Appendix D
Coral taxa used to construct faunal similarities

Data culled from the following sources:

Eaglenest Reef: Stanley and Senowbari-Daryan (in press);
Martin Bridge Formation: Stanley (1986), and Stanley and Whalen (1989);
Luning Formation: Stanley (1979), Kristan-Tollmann et al. (1983);
Antimonio Formation: Stanley et al. (1994), Stanley and González-León (1999), This thesis
<table>
<thead>
<tr>
<th>Taxa</th>
<th>Antimonio</th>
<th>Eaglenest</th>
<th>Martin Bridge</th>
<th>Luning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthostylis acanthophora</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Acanthostylis sp.</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpinophyllia flexuosa</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astraeomorpha confusa</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Astraeomorpha crassisepta</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Astraeomorpha sonorensis</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Chondrocoenia paradoxa</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Chondrocoenia sp. B.</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Chondrocoenia waltheri</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Crassistella juvavica</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Crassistella vesiculosa</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Cuifastreae granulata</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>&quot;Cyathocoenia&quot; gerthi</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>&quot;Cyathocoenia&quot; parva</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>&quot;Cyathocoenia&quot; shastensis</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Distichomeandra austriaca</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Distichomeandra marmorea</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Distichophyllia norica</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Gablonzeria profunda</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Kuhnastraea cowichanensis</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Kuhnastraea descussata</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Kuhnastraea incrassata</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Margarastraea eucystis</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Margarastraea pulchra</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Meandrostylis antimonioensis</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meandrostylis grandiseptus</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Meandrostylus frechi</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pamiroseris rectilamellosa</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pamiroseris meriani</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pinacophyllum parallellum</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pinacophyllum parviseptum</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rectiostastraea wallowaensis</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Retiophyllia dawsoni</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Retiophyllia delicatula</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Retiophyllia norica</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Retiophyllia opelli</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Retiophyllia quesneliana</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Struoresia libratosepta</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stylophyllopsis lindstroemi</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stylophyllopsis rudis</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stylophyllopsis zitteli</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Thammasteriomorpha frechi</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Appendix E
SYSTEMATIC PALEONTOLOGY

Calcareous Algae

Calcareous algal floras are, for the most part, conspicuously absent from the North American Cordillera (Flügel et al, 1989). With this in mind, the recognition of an algal assemblage in the Antimonio Formation is especially significant.

Three classes of algae have been recognized from the Norian carbonate interval in the Antimonio Formation: Cyanophyceae, Rhodophyceae, Chlorophyceae. All of the algae from the Antimonio Formation have been identified from Sierra del Alamo.

Cyanophyta: 'Porostomata'

The Porostomate Blue-Green algae are a problematic group and there are limited morphological characters for their identification. Porostomates generally are composed of a small thalli of filaments which branch distinctively, yet there is no generally accepted classification of these fossils (Flügel, 1981).

Cayeuxia Frollo, 1938

(Plate 1, Figure 1)

Small subrounded thallus consisting of round to ovate
tubular filaments. Tubes are cut both longitudinally and transverse. Branching angle of filaments is acute with original and branched filaments subsequently growing parallel. *Cayeuxia* is known from the Bioclastic Packstone microfacies (SDA-7) at Sierra del Alamo.

This is the first report of *Cayeuxia* from Triassic strata in North America.

**Rhodophyta: Solenoporaceans**

Solenoporaceans are represented by two genera: *Solenopora* and *Parachaetetes*. Like the Cyanophytes, the classification of the Solenoporaceans is enigmatic. Differentiation of *Solenopora* and *Parachaetetes* is based on the presence (Parachaetetes) or absence (*Solenopora*) of growth lines. Other taxonomic criteria include diameter of cells and frequency of growth lines.

The Solenoporaceans from the Antimonio Formation occur exclusively from the Bioclastic Packstone microfacies (SDA-7) at Sierra del Alamo.

*Solenopora* Dybowski, 1877

(Plate 1, Figure 2)

Rounded and nodular masses composed of parallel filaments. In cross section, cells are round. The superficial morphology of *Solenopora* is similar to *Cayeuxia*, however, the diameter of cells is generally larger in
Solenopora. All of the Solenopora specimens occur in Bioclastic Packstones.

Parachaetetes Deninger, 1906

(Plate 1, Figure 3)

Nodular thalli composed of regular spaced wavy laminae or 'growth lines.' Vertical cellular partitions are weakly developed or have been erased diagenetically. Fragments of Parachaetetes were collected from the middle and upper parts of the Norian interval in Bioclastic Packstones.

Chlorophyta: Dasycladaceans

The Dasycladaceans are characterized by forms which possess a central stem from which primary branches develop. The plants grow upright and are attached to the substrate. The reproductive bodies of the Dasycladaceans, known as calcispheres, are important sediment producers (Marsalek, 1975). Detailed descriptions of morphologies and characteristics can be found in Johnson (1961) and Wray (1977).

Griphoporella Pia, 1915

(Plate 1, Figure 4)

The porous skeleton is cut obliquely resulting in an irregular ovate shape. The diameter of the central cavity is quite large compared to the thickness of the wall. The
material is quite similar to *Griphoporella curvata* Gümbel, whose identification hinges on the geometries of the pores in the wall. Due to varying degrees of recrystallization, which destroyed any pore detail, I have not attempted and identification at the specific level

**Foraminifera**

The Triassic foraminifers have worldwide distribution today. (See Bernecker (1996) for a list of publications documenting the distribution of Triassic forams). My thesis represents the first description of Triassic forams from the Norian carbonate interval in the Antimonio Formation. The recorded foraminifers are represented by the rotalids, robertinids, and textularids, as well as an unidentified form, and consist of encrusting and free-living forms. Interestingly, involutinids, which have been reported from inboard terranes of the Cordillera by Gazdzicki and Stanley (1983) and Gazdzicki and Reid (1983), have not been found in the Antimonio terrane. Most foraminifers from the Norian carbonate interval of the Antimonio Formation are poorly preserved and difficult to photograph.

**Textulariina**

Delage and Herouard, 1896

This group contains agglutinated and uniserial
foraminifers and are common in the carbonate beds limestone beds of the Norian interval.

*Tolypammina* Rhumbler, 1895

The irregular entrusting foraminifer occurs commonly attach to the stromatoporoid *S. Lamellatum*. It occurs exclusively in small biostromal elevations and patch reefs containing frame-building and binding organisms. *Tolypammina* is unknown in the Limy Sandstone or the Sandy Limestone. This genus has been identified from the Cordillera, in the Luning Formation by Kristan-Tollmann and Tollmann (1983).

*Glomospirella* Plummer, 1945

One specimen of *Glomospirella* sp. was encountered from the Norian interval at Sierra del Alamo. It occurs in the Bioclastic Packstone microfacies (SDA-7). The specimen is cut perpendicular to the plane of coiling so that many of the diagnostic features discussed by Gazdzicki (1982) are not recognizable, however, the shape of the chambers and their arrangement lead me to assign this specimen to *Glomospirella*. The genus *Glomospirella* is a stratigraphically long-ranging taxa in the Triassic. At the specific level this genus is quite useful in biostratigraphic analysis. However, the limited material and strong recrystallization precluded a specific identification. Thus, *Glomospirella* from the Norian interval is not biostratigraphically useful.
Robertinina
Loeblich and Tappan, 1984

Planispiral to trochospiral tests with hyaline perforate tests composed of aragonite.

Diplotremina Kristan-Tollmann, 1960

Trochospiral test with chambers gradually increasing in size. Microstructure and nature of the aperture is unknown in my material. This taxa is common in the biostromal limestones of the Norian interval and occurs in the Bioclastic Limestone and Coral Framestone/Bafflestone microfacies. Bernecker (1996) points out that Diplotremina, Duostomina, and Variostoma are difficult to distinguish in thin section and thus the facies reconstruction based solely on these taxa is dubious. However, the all prefer arenitic carbonates characteristic of the Bedded Pure Limestones from the Norian carbonate interval at Sierra del Alamo.

Rotaliina
Delange and Hérouard, 1896

The morphological variability of this group is significant. Examples range from enrolled to uniserial to entrusting forms. A plethora of microstructures are known.

Nodosaria Lamark, 1812
Three forms Nodosaria have been encountered in thin sections from the Norian carbonate interval. They all occur in the Bioclastic Packstone microfacies (SDA-7). All are variations on the Nodosarid body plan which is essentially a uniserial chamber arrangement with various external ornamentations and modifications. Due to the ubiquitous distribution of the nodosarids in shallow marine environments in the Triassic they are not useful in facies reconstructions.

**Sponges**

Class DEMOSPONGEA Sollas, 1875  
Subclass CERACTINOMORPHA Levi, 1973  
Order PERMOSPHINCTA Termier and Temier, 1974  
Suborder PORATA Seilacher, 1962  
Family POLYTHOLOSIIDAE Seilacher, 1962  
Subfamily FANTHALAMIINAE Senowari-Daryan and Engeser, 1996  
Genus FANTHALAMIA Senowari-Daryan and Engeser, 1996

*Type species.*—*Polytholosia astoma* Seilacher, 1962

**FANTHALAMIA ASTOMA** (Seilacher, 1962)  
Plate 2, Figure 3  
*Polytholosia astoma* Seilacher, 1962, p. 760, pl. 3, figs. 1-5.
Fania astoma, (Seilacher), Senowbari-Daryan, 1990, p. 83, Pl. 25, figs. 4-5.

Material.- Specimens in bioclastic packstone matrix collected as float from the Norian carbonate interval ERNO-2795.

Description.- Each specimen is characterized by spherical to subspherical chambers stacked one on top of the other. Some chambers are filled with granular or tubular filling structure. Chamber walls are perforated by numerous pores. Most of the chambers are filled with micrite and sparry cement.

Discussion.- This material agrees closely with the material illustrated by Senowbari-Daryan (1990). Senowbari-Daryan in (Stanley and Senowbari-Daryan, in press) notes that F. astoma has previously been documented only in the Luning Formation, Pilot Mountains, Walker Lake terrane (Paradise subterrane, Silberling et al., 1987) and the Eaglenest Reef, Takla Group, Quesnel terrane. The recognition of F. Astoma from the Antimoniio terrane extends the geographic distribution of this taxa and adds to a growing taxonomic list which links these three terranes.

Occurrences.- F. astoma is known from the Luning Formation, Pilot Mountains (Luning allochthon) in Nevada, and the Eagle Nest Reef in the Quesnel terrane.
Genus NEVADATHALAMIA Senowbari-Daryan, 1990

Type species.— Polytholosia cylindrica Seilacher, 1962

NEVADATHALAMIA CYLINDRICA (Seilacher, 1962)
Plate 2, Figures 1, 2
Polytholosia cylindrica, Seilacher, 1962, p. 765, Pl. 5, figs. 1-5
Polytholosia cylindrica dilatata, Seilacher, 1962, p. 765, Pl. 5, fig. 1
Nevadathalamia cylindrica, (Seilacher), Senowbari-Daryan, 1990, p. 82, Pl. 24, fig. 1
Nevadathalamia cylindrica, (Seilacher), Senowbari-Daryan and Stanley, 1992, p. 187, figs. 5, 6, 8.1-8.3

Material.— Two specimens were collected as float from the Norian carbonate interval at Sierra del Alamo.

Description.— Specimens are generally cylindrical and composed of ring-like chambers, chambers are pierced by a well developed spongocoel, except for oldest chambers. Older chambers are filled with granular or tubular filling structure.

Discussion.— ERNO-2794 (Plate 2, Figure 2) agrees closely with the material described by Senowbari-Daryan (1990) in both chamber size and type of filling structure. However, the second specimen, ERNO-2793 (Plate 2, Figure 1)
is conical in shape reaching a maximum diameter of 13.5 cm. This is much larger than any of the material identified in the synonomies, bar P. *cylindrica dilatata* Seilacher. This morphology closely parallels the material illustrated by Seilacher (1962) p. 765, Pl. 5, fig. 1. However, Senowbari-Daryan (1990) places Seilacher's specimen under *Fanthalamia astoma*. It is my opinion this material belongs to the genus *Nevadathalamia* rather than *Fanthalamia*.

*Occurrences.*—This taxa also occur in the Luning Formation, Pilot Mountains (Luning allochthon), and the Lime Peak Reef in Stikinia.

**Corals**

Order SCLERACTINIA Bourne, 1900

Suborder PACHYTHECALIINA Eliásová, 1976

Superfamily VOLZEIOIDEA Cuif, 1977

Family GABLONZERIIDAE Roniewicz, 1989

Genus GABLONZERIA Cuif, 1976

*Type species.*—*Isastraea profunda major* Frech, 1890

GABLONZERIA PROFUNDA (Reuss, 1854)

Plate 3, Figure 1a,b

*Isastraea profunda* (Reuss). Frech, 1890, p. 21, Pl. 5, figs. 1-3;

*Isastraea profunda* (Reuss). Smith (part), 1927, p. 128, fig.
8, Pl. 112, figs. 5, 6, Pl. 114, figs. 1, 3.

*Pamirastraea profunda* (Reuss). Melnikova, p. 101, Pl. 19, fig. 1.

*Elysastraea profunda* (Reuss). Stanley, 1979, Pl. 3, fig. 8.


*Gablomzeria profunda* (Reuss). Roneiwicz, 1989, p. 33, Pl. 4, fig. 1.

**Material.**—One colonial fragment in packstone matrix, ERNO-2797. Collected from float from the middle portion of the Norian carbonate interval, Package 1, Sierra del Alamo.

**Description.**—Lamellate cerioid growth form, colony dimensions 35 mm x 25 mm and 3 mm thick. Calicies are well defined by strong coralite wall, shapes vary from polygonal to round to ovoid depending on surrounding coralites, diameters range between 2.8 and 4 mm. S1 are generally thick and reach near the coralite center. S2 are slightly shorter and much thinner. S3 are shorter sill and do not exceed more than half the length of S1. S4 not observed. Septa are connected by well developed endothecal dissepiments.

**Discussion.**—This material compares well with Roneiwicz's descriptions. However, this specimen has been subjected to significant post-mortem transportation. This action has eroded the calicular surface so that the "strongly depressed endotheca" embedded in Roneiwicz's description is
not present in this material.

Occurrence.—This is an extremely wide spread taxa occurring in both the Tethyan realm and in North America.

Suborder CARYOPHYLLIINA Vaughn and Wells, 1943
Superfamily REIMANIPHYLLIOIDEA Melnikova, 1975
Family REIMANIPHYLLIIDAE Melnikova, 1975
Subfamily REIMANIPHYLLIINAE Melnikova, 1975
Genus DISTICHOPHYLLIA Cuif, 1975

Type species.—Montlivaltia norica Frech, 1890

DISTICHOPHYLLIA NORICA (Frech, 1890)
Plate 3, Figure 3
Montlivaltia norica, Frech, 1890, p. 39, Pl. 3, figs. 8, 9,
Pl. 10, figs. 1-5, Pl. 18, fig. 17.
Montlivaltia gosaviensis, Frech, 1890, p. 41, Pl. 11, fig. 7.
Montlivaltia norica, (Frech). Smith, 1927, p. 126, Pl. 111,
fig. 6.
Reimoniphyllia gosaviensis, (Frech). Melnikova (part), 1975,
p. 87, Pl. 15, fig. 1.
Montlivaltia norica, (Frech). Stanley, 1986, p. 29, Pl. 3.1,
figs. 4-6.
6, figs. 2-4.
Distichophyllia norica, (Frech). Stanley, 1994, p. 87, Pl. 4, figs. 3, 4.

Material. - ERNO-2799 was collected in a packstone matrix, from the middle part of the Norian carbonate interval.

Description. - ERNO-2799 is a specimen measuring 37 mm in diameter. S1 are thick and reach the coralite center or "axial fissure," where a feeble columella may be present. S2 are thinner than S1 but equal in length. S3 reach two thirds the length of S1. S4 are very thin and rarely reach a length of one half of S1. Granulations are present on high order septa.

Discussion. - This material is significant because it represents the first solitary coral known from the Antimonio Formation. Stanley (1994) points out that North American forms are smaller than Alpine specimens. This material fits in the expected North American size range and agrees with his assertion. He continues by stating that the North American forms often display evidence of budding. This has not been observed in the Sonoran material.

Occurrence. - D. norica occurs in both the Tethyan realm and American Cordillera.

Genus RETIOPHYLLIA Cuif, 1967
Type species.— *Thecosmilia fenestrata* Reuss, 1854 *in* Frech 1890

RETIOPHYLLIA OPPELI (Reuss, 1865)

Plate 3, Figure 2a,b

*Calamophyllia opelli*, Reuss, 1865, p. 160, Pl. 4, figs. 1.

*Thecosmilia opelli*, (Reuss). Frech, p. 10, Pl. 2, figs. 18-20,24, Pl. 3, figs. 4A-E.

Material — Several colonies of different preservational quality were collected from the Norian interval. ERNO-2798 was illustrated because it was least affected by recrystallization.

Description.— Phaceloid colonies, frequently branching at acute angles with numerous connecting processes. Coralites are 3.0-4.5 mm in diameter, and generally round to ovoid in transverse section. Septa number from 40-56 and occur in three discernable orders. S1 and S2 are subequal in length but S1 are generally thicker. S3 are approximately half the length of S1. Endotheca is concave and occupied by numerous dissepiments.

Occurrence.— *R. oppeli* occurs in both the Tethyan realm and American Cordillera.

Suborder ARCHAEOCOENIINA Alloiteau, 1952
Family ACTINASTRAEIDAE Alloiteau, 1952

Genus CHONDROCOENIA Roneiwicz, 1989

Type species.—Prionastraea schafhaeutli Winkler, 1861

CHONDROCOENIA sp. B (Roneiwicz, 1989)

Plate 4, Figure 1a,b

Chondrocoenia sp. B, Roneiwicz, 1989, p. 108, Pl. 33, fig. 4

Material.—One small colony, ERNO-2789, collected as float from the Lower Portion of the Norian carbonate interval.

Description.—ERNO-2800 is a small domate colonial fragment measuring 9 mm by 8 mm and 3 mm thick. Colony is plocoid with well developed thick costae. Coralite diameters range from 0.9-1.6 mm and average 1.2 mm. Septa are arranged in at least two orders and number between 20-26.

Remarks.—The material illustrated by Roneiwicz are thin section photomicrographs, unfortunately my material was limited to one very small specimen which precluded thin section analysis. However, my measurements agree closely with those provided by Roneiwicz and it is on this basis that I made this identification.

Suborder STYLOPHYLLINA Beauvais 1981

Family STYLOPHYLLIDAE Frech 1890
Genus STYLOPHYLLOPSIS Frech 1890

Type species.—*Stylophyllopsis polyactis* Frech, 1890

STYLOPHYLLOPSIS LINDSTROEMI (Frech, 1890)

Plate 4, Figure 2

*Stylophyllopsis lindströmi*, Frech, 1890, p. 53, Pl. 10 figs. 15-20, Pl. 12, fig. 2.

Material.—One specimen in packstone matrix collected from the middle portion of the Norian carbonate interval, ERNO-2801.

Description.—Ovoid solitary coralite (ERNO-2788A), the maximum and minimum calicular diameters measure 22 x 13 mm, respectively. 85 very thin septa are present in at least four orders. S1 nearly reach the center of the coralite; S2 are thinner and slightly shorter than S1; S3 are approximately equally in length to S2; S4 are very thin and 2/3 the length of S2. Septal spines are present on all four orders of septa.

Discussion.—Unfortunately this specimen appears to be a fragment of a larger specimen. The specimen is a very thin transverse section measuring no more than 5 mm thick. The limited nature of the material precluded any serial sections or thin section analysis. However, the ovoid shape of the coralite, number and character of the septa agree closely
with the material described and illustrated by Roniewicz (1989).

**Occurrence.**—According to Roniewicz (1989) this Tethyan taxa has not been previously reported from North America.

**Genus Meandrostylis Frech, 1890**

*Type species.*—*Stylophyllum (Meandrostylis) irregulare* Frech, 1890

**MEANDROSTYLIS FRECHI (Haas, 1909)**

Plate 4, Figure 3a,b,c

*Stylophyllum (Meandrostylis) (Frech).* Haas, 1909, p. 150, Pl. 5, fig. 10.

**Material.**—One small colony was found from the Norian carbonate interval at Sierra del Alamo, ERNO-2802.

**Description.**—Cerio-meandroid colonies with deep calicities, wall is relatively well developed. Coralite diameter vary between 9-12 mm. Septa are well developed in three orders. S1 are thickest.

**Discussion.**—The small size of this specimen prevents preparation of longitudinal sections. Thus the recognition of the characteristic discontinuous septa developed on dissepiments has not been observed. However, the cerio-
meandroid nature of the coralites and their diameter agree closely with the material illustrated by Roniewicz (1989). This material is also quite similar to *M. grandisephtus* illustrated by Stanley and Whalen (1989), however, their description outlines that *M. grandisephtus* is exclusively cerioid. Thus, I do not align the Sonora specimen with this North American generic counterpart. This genus was also reported from the Antimonio Formation by Stanley and González-León (1997).

Occurrence.—According to Roniewicz (1989) this Tethyan taxa has not been previously reported from North America.

Phylum uncertain

Class uncertain

Order SPONGIOMORPHIDA Alloiteau 1952

Family SPONGIOMORPHIDEA Frech 1890

Genus SPONGIOMORPHA Frech 1890

Type species.—*Spongiomorpha acyclica* Frech, 1890

SPONGIOMORPHA RAMOSA (Frech, 1890)

Plate 5, Figure 1a,b

*Spongiomorpha (Heptastylopsis) ramosa* Frech, 1890, p. 76.

*Spongiomorpha (Heptastylopsis) ramosa* (Frech). Smith, 1927, p. 133, Pl. 120, figs. 4,5, Pl. 121, figs. 10-13.

*Spongiomorpha ramosa* (Frech). Stanley, 1979, Pl. 4, fig. 11.
Spongiomorpha ramosa (Frech). Stanley and Whalen, 1989, p. 815, Pl. 8, figs. 1-4, 7,8.

*Material.* - Several specimens from the norian carbonate interval of both Sierra del Alamo and Barra los Tanques were encountered in thin section, ERNO-2803.

*Description.* - Specimens are generally nodular to branched. In all specimens longitudinal sections display characteristic meandering pillars. Transverse sections reveal net like fabric. All examples are small and do not exceed a few centimeters in any dimension.

*Occurrence.* - This is an extremely wide ranging taxa occurring throughout the North American Cordillera as well as in the Tethyan realm.