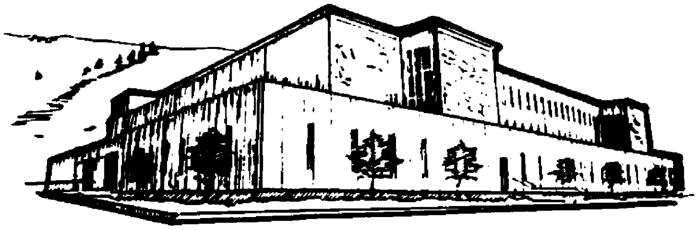
1990

Systematic paleontology stratigraphic occurrence and paleoecology of halobiid bivalves from the Martin Bridge Formation (Upper Triassic) Wallowa Terrane Oregon

Christopher A. McRoberts
The University of Montana

Recommended Citation

McRoberts, Christopher A., "Systematic paleontology stratigraphic occurrence and paleoecology of halobiid bivalves from the Martin Bridge Formation (Upper Triassic) Wallowa Terrane Oregon" (1990). *Graduate Student Theses, Dissertations, & Professional Papers*. 7438.
https://scholarworks.umt.edu/etd/7438



SYSTEMATIC PALEONTOLOGY, STRATIGRAPHIC OCCURRENCE, AND PALEOECOLOGY OF HALOBIID BIVALVES FROM THE MARTIN BRIDGE FORMATION (UPPER TRIASSIC), WALLOWA TERRANE, OREGON

By

Christopher A. McRoberts

B.S. University of Wyoming, 1987

Presented in partial fulfillment of the requirements
for the degree of
Master of Science
University of Montana
1990

Approved by

Chairman, Board of Examiners

Dean, Graduate School

May 30, 1990
Date

McRoberts, Christopher, A., M.S., May, 1990 Geology

Systematic paleontology, stratigraphic occurrence, and paleoecology of halobiid bivalves from the type Martin Bridge Formation (Upper Triassic), Wallowa Terrane, Oregon (156 pp.)

Director: George D. Stanley, Jr.

The form-genus "*Halobia*" probably represents several different *Posidonia* and *Daonella* descendants. Species-level systematic survey of Martin Bridge *Halobia* results in synonymy of previously described species from the same locality, and discovery of halobiid species new to the Wallowa terrane. Re-examination of type material suggests *Halobia ornatissima* is a junior synonym for *H. superba*, *H. dilatata* a junior synonym for *H. halorica*, and *H. dalliana*, and *H. symetricia* are junior synonyms for *H. radiata*.

Geologic mapping revealed the Martin Bridge stratotype is broken by thrust and high-angle faults. From the stratotype, five structurally isolated blocks were identified for stratigraphic analysis. The blocks consists of dark, finely laminated shale, finely-bedded limestone, and limestone conglomerate.

Limited biostratigraphic resolution was possible. The presence of *Discotropites*, *Anatropites*, *Halobia oregonensis* and *H. superba* low in the section indicates an Late Carnian age, whereas, higher up, *H. halorica* indicates a Early-to-Middle Norian age. The occurrence of *H. beyrichi* and *H. austriaca* indicates proximity to the Carnian-Norian stage boundary, although faulting has obscured its exact stratigraphic position.

Halobiids from the section primarily occur in shell beds within a dark, finely-laminated calcareous shale, probably deposited in an anaerobic or dysaerobic basin. The shell beds are interpreted to be a result of increased biogenic deposition rather than a decrease in background sedimentation or erosional lag deposit. Apart from *Chondrites*, the halobiid-bearing sediments are devoid of any benthos and evidence of bioturbation.

Previous arguments for the life-habit of *Halobia* as endobyssate, reclining or swimming are reconsidered. Morphologic evidence suggests a loosely-nestling epibyssate habit. Evidence for halobiid attachment sites is lacking. Possible attachment to an algal substrate, either rooted or floating, is suggested. *Halohia* was probably opportunistic. A long-lived larval stage along with possible attachment to floating algae may explain their unusual facies and broad geographic distributions.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURE

LIST OF TABLES

TABLE

ACKNOWLEDGEMENTS

I am greatly indebted to my thesis committee chair, George D. Stanley, Jr., for his initiation of the project and continual advice and encouragement throughout its evolution. I also give thanks to my other committee members Donald Winston, Ken Dial, and Fred Allendorf for their supportive comments and critical review along the way.

Special thanks are given to Cathy Newton, Syracuse University; Norm Silberling, US Geological Survey; and Tim Tozer Canadian Geological Survey, who assisted with identification of non-halobiid taxa and provided access to their libraries and collections. Tom Waller, Smithsonian Institute, allowed access to collections at the National Museum, and shared his views of the systematic position of halobiids. My thanks also go to Mike Orchard, Geological Survey of Canada, for identifying the conodonts; to Hamish Campbell, New Zealand Geological Survey, and Jack Grant-Mackie University of Auckland, for information regarding halobiid studies; and to Paul Wignall, Leeds University, and Erle Kauffmann, University of Colorado, who shared their ideas on "flat clam" paleoecology. For geological matters and locality information, I thank Tracy Vallier, U.S. Geological Survey.

I give my sincerest thanks to Mariane Farr, Ginny Bolton, and the staff of the Interlibrary Loans for their exhaustive searches, and securing the varied and obscure halobiid literature.

Acknowledgement is also given to Helge Gonnermann, Due Yue, and Trish Weaver for translations, to Sherri Lierman and John Cuplin who assisted with the photography, and to Steve Balogh for making the thin-sections. Finally, I give my sincerest thanks to all those who have read and edited various parts of the manuscript, especially Pat Renolds, Jacqueline Scallan, Tom Waller, and Dave Alt.

Parts of this study were funded by the Department of Geology, University of Montana, and through NSF grants to George Stanley. Without this help this study would not have been possible.

CHAPTER I

INTRODUCTION

"Halobia", a pteriacean bivalve form-genus, has long been known from the Upper Triassic, where it occupies a wide variety of marine facies. Halobiid bivalves are known for their very thin shells and narrow widths; often informally categorized as a "flat clam". Halobia, and several other "flat clams" (e.g. Posidonia and Monotis) are unique among bivalves in that they frequently occur in lithologic facies typical of anaerobic or dysaerobic environments, often to the exclusion of a normal benthic fauna. Their morphology and facies occurrence suggests they were opportunists with a life-mode very different from other bivalves. Furthermore, in addition to being very cosmopolitan, their taxonomic turnover was rapid; with origination and extinction rates almost as high as the ammonites. As such, halobiids embody the prime aspects of good zonal fossils.

Smith (1927) described four species of Halobia from a measured section of limestone and shale near Martin's Bridge in the southern Wallowa Mountains of northeast Oregon. Subsequently, Ross (1938) named this section the Martin Bridge Formation. Halobia is important because its species are the primary fossils for dating the Martin Bridge, and because they offer insight into the paleoecology and sedimentary environments during Martin Bridge deposition.

This study reanalyzes the halobiid-bearing rocks of the Martin Bridge Formation (Ross, 1938) from its type locality (the same section previously described by Smith, 1912; 1927) in northeastern Oregon (Figure 1.1).

The "*Halobia*" problem and Triassic biostratigraphy.

As a generic concept, "*Halobia*" is in a state of flux. Recently, several workers have divided *Halobia* into several different genera: *Zittelihalobia* Polubotko,1984, *Indigirohalobia* Polubotko, 1984, *Perihalobia*, Gruber, 1976, and *Parahalobia* Yin and Hsu 1938. Although division of such a large genus is desired, the morphologic and phylogenetic basis for subdivision remains sceptical.

Most systematic work on *Halobia* was conducted in the early part of this century when systematicists employed the typological species concept. It was during this time that Smith (1927) described the North American halobiids, and like his contemporaries, such as E. Kittl (1912), E. Mojsisovics (1874), and C. Deiner (1908), they did not seem to have an understanding of morphologic variation in *Halobia*. Often slight, intra-populational variation was sufficient cause to erect new species. Because the current species concept (Mayr, 1963) now accepts intra-populational variation, the systematic validity of many, if not most, species of *Halobia* is in question. From the Martin Bridge collection, and elsewhere from North America, Smith's (1927)

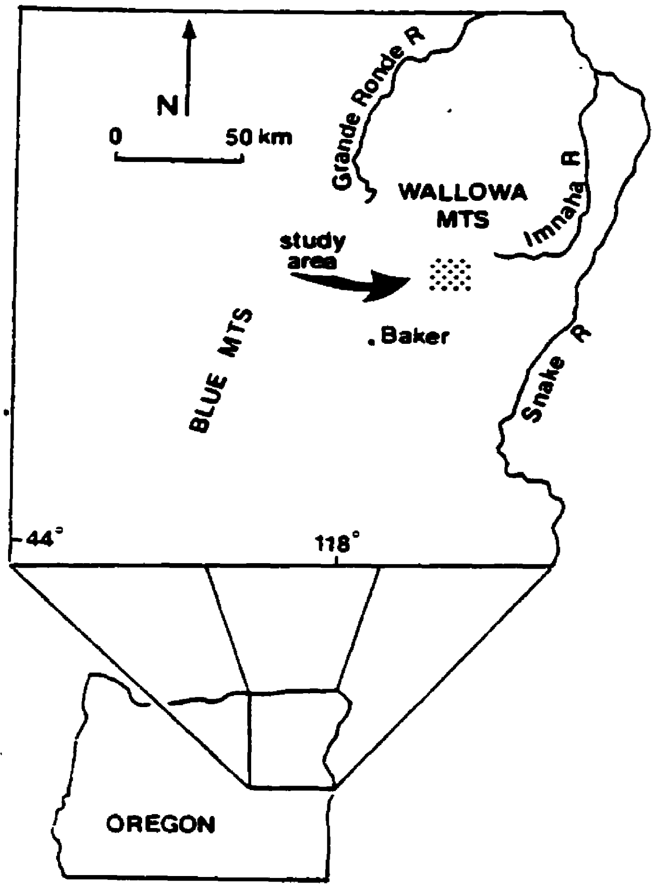


Figure 1.1. Location map of study area, situated in the southern Wallowa Mountains of northeast Oregon. Refer to Figure 2.3 for coverage of stippled area.

systematic treatment of Halobia is considered inadequate in that many species he assigned to Halobia are probably conspecific and in need of revision. Recently, this early trend of taxonomic splitting has been reversed (e.g. Gruber, 1976; Cafiero and De Capoa Bonardi, 1980; Polubotko, 1984). The resulting systematic refinement has increased the temporal resolution of Halobia species to the benefit of biostratigraphers of the Upper Triassic.

As in the former Tethyan region of Europe and Asia, the western Pacific margin, and the North American Cordillera, ammonite and halobiid associations have been instrumental in developing and refining the Late Triassic time scale (e.g. Silberling and Tozer, 1968; De Capoa Bonardi, 1984). However, many problems still remain with the definition, limits, and applicability of the various zonal schemes of the above regions.

Problems with the biostratigraphic zonation of the Upper Triassic rocks can be catagorized into two main types. The first type is that the original designations of stages and zones in Europe lack stratotypes and have not been clearly defined. Some of the original European zones were described in the reverse sequence, constructed from mixed faunal elements representing different stages. The second type of problem is that many faunal elements used in zonal schemes have a limited geographic distribution, making correlation between distant regions difficult and sometimes impossible. Like their European counterparts, halobiids from the Martin Bridge come from structurally isolated outcrops rendering zonation difficult.

The Martin Bridge problem.

Several problems have limited the identification and sequencing of the faunal and lithic characters of the Martin Bridge Formation. Some problems have been introduced by improper use of stratigraphic nomenclature, while others result from inadequate geologic interpretation of the different lithologic facies in the Formation across the region. Most of the short-comings of the Martin Bridge Formation are expressed at its type section.

Smith (1912: 1927) described the fossil succession of the Martin Bridge stratotype and correlated these fossils to other localities in the North American Cordillera. The Martin Bridge stratotype was revisited by Kristan-Tollmann and Tollmann (1983) who described several species of *Halobia* along with Foraminifera and crustacean (anomuran) microcorprolites. Stanley (1986) reported corals and spongiomorphs from the Martin Bridge stratotype, and Orr (1986) described an icthyosaur. Although these fossil occurrences remain important, the sampling was from stratigraphically and structurally isolated horizons limiting their biostratigraphic veracity.

Biostratigraphic studies of the Martin Bridge outside the type section have offered limited correlation potential. Nolf (1966) described the fossil succession from the Martin Bridge and Hurwal Formations of the northern Wallowa Mountains. The Martin Bridge of the northern Wallowa Mountains contains a shallow-water fauna very different from that of the southern parts of the range where deeper-water faunas dominate. Due to these facies constraints, Nolf (1966) was not able to correlate the Martin Bridge between these two areas. Newton (1986), Newton and others (1987), and Stanley and Whalen (1989) studied the fossils from the Martin Bridge in Hells Canyon. These fossils are also shallow-water forms offering little correlation potential to the type section.

The main problem with correlating the Martin Bridge outside its type area is due to facies changes represented by other outcrops, and the inability to physically trace other exposures to the stratotype. This is further compounded by the conflicts of nomenclatural usage for the Martin Bridge. The early descriptive studies by Gilluly and others (1933), Ross (1938), and Smith and Allen (1941) are confusing because the term "Martin Bridge" is used as both a lithostratigraphic and a chronostratigraphic unit. Moreover, Hamilton (1963) informally changed the name from the Martin Bridge Formation to the Martin Bridge Limestone even though the type section is mostly shale. In this study, the name Martin Bridge Formation (sometimes shortened to

Martin Bridge) is retained not only because of priority, but because the type section is mostly shale, not limestone.

Recent studies on the Martin Bridge have increased our understanding of the sedimentologic processes operating on the Wallowa terrane, and its relationship to adjacent terranes and the North American craton (Nolf, 1967; Follo, 1986, and in press; Whalen, 1985, 1988). With the exception of Follo, these workers have failed to satisfactory demonstrate the equivalency of "Martin Bridge" strata to the type section in the southern Wallowa Mountains. The shortcomings of the above studies stem from a failure to understand Triassic facies patterns and depositional systems on the Wallowa terrane. Interpretations of the Martin Bridge are further obscured by regional plutonism and metamorphism, structural displacement, and extensive burial by the Miocene Columbia River Basalt Group.

Focus of this study.

This study introduces new concepts of halobiid systematics. The systematic scheme used in this study differs from many previous schemes by employing intergrated morphologic analysis as species-level criteria. This work also proposes several paleobiological hypothesis regarding halobiid life-habits in an attempt to explain their occurrence in varied litho and biofacies and the broad geographic distributions of many species of Halobia.

A better understanding of halobiid biostratigraphy is important in that species of _Halobia_ equal, if not exceed, ammonoid species as zonal indices of the Late Triassic. This study identifies three useful biostratigraphic units from the Martin Bridge stratotype which can be recognized across the Wallowa and other Cordilleran terranes, the Tethyan realm, and the circum-Pacific. Of particular significance is the identification of the Carnian-Norian boundary in type Martin Bridge (first recognized by J. Grant-Mackie, pers. comm., 1986), and previously undescribed from North America.

A sedimentologic and paleontologic study of the type Martin Bridge Limestone is long overdue. The type section has been only superficially described; its fossil content and sedimentology and has not, until now, received the detailed attention it deserves.

CHAPTER II

TECTONIC AND STRATIGRAPHIC SETTING

Pre-Tertiary rocks of the Blue Mountain geomorphic province of northeast Oregon and adjacent states are west of the Sr 87/86 > 0.704 line of Armstrong and others (1977), designating them as part of the collage of displaced terranes which make up the North American Cordillera (Silberling et al., 1984). The terranes of the Blue Mountain province are interpreted to be a complex system of oceanic crust, once active island arcs and intervening basins. As part of the Blue Mountain province, the Lower Permian and Upper Triassic- to Jurassic rocks of the Wallowa terrane (Wallowa-Seven Devils terrane of Brooks and Vallier, 1978) represent a nearly 5 km thick package of volcanic and sedimentary rocks. Exposures of the Wallowa terrane are limited to outcrops in the southern and northern Wallowa Mountains, along the Snake River at Hells Canyon, in the Seven Devils Mountains near Riggins Idaho, possibly near Lewiston Idaho, and at the mouth of the Grande Ronde River in southeastern Washington (Figure 2.1). The exposures occur as small inliers through the extensive Miocene, Columbia River Basalt, blanketing the region.

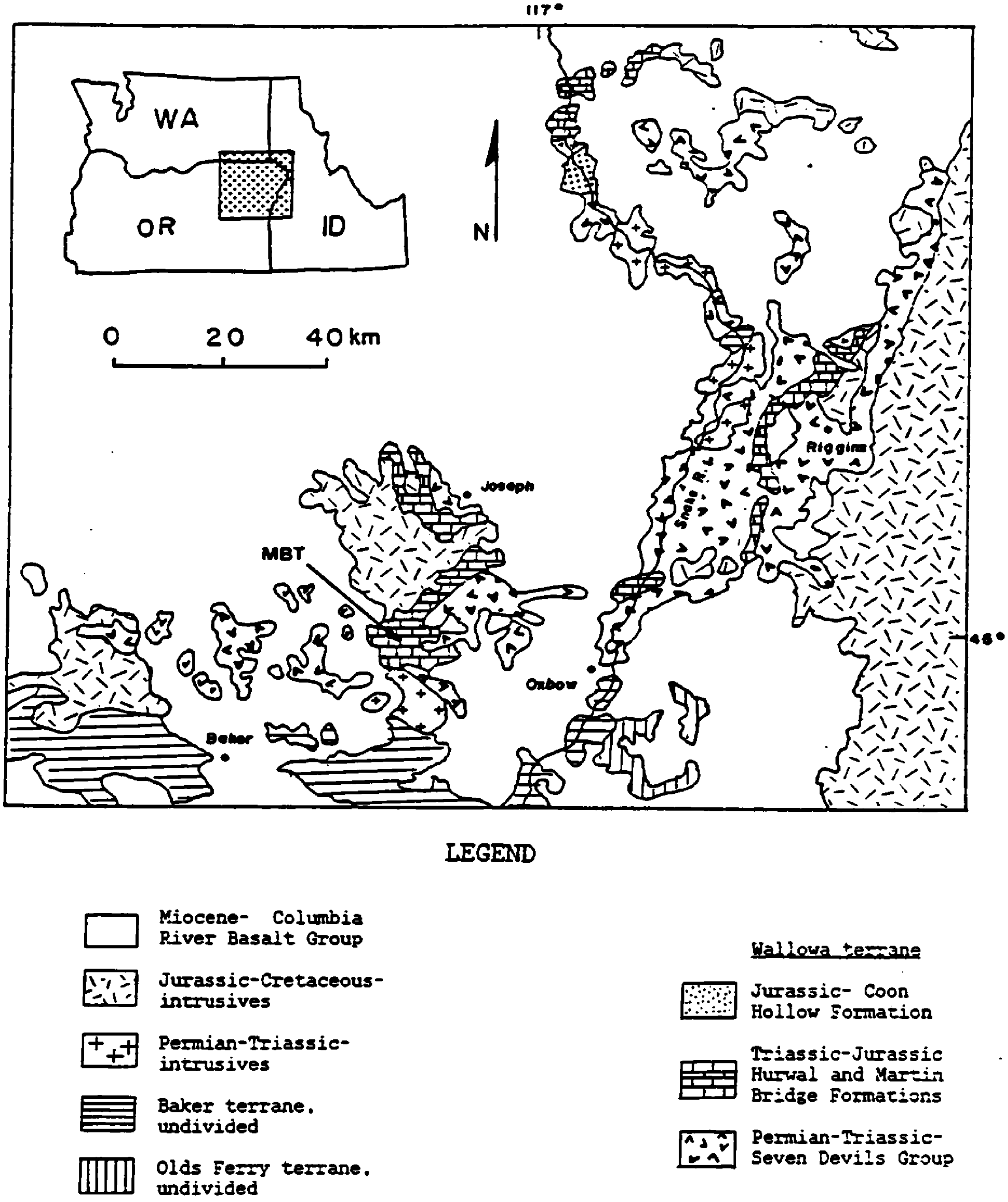


Figure 2.1. Generalized geologic map of the Wallowa and adjacent terranes. MBT indicates the type locality for the Martin Bridge Formation. Compiled from Follo (in press), Brooks and Vallier (1978), and Walker (1977).

Tectonostratigraphy

Based on gross stratigraphic and faunal similarities, rocks from the Blue Mountain geomorphic province were suggested to be a southern fragment of the tectonostratigraphic terrane of Wrangellia (Jones et al. 1977, Coney et al., 1980). The lithologic, paleomagnetic, and faunal characteristics of the Blue Mountain province suggests a history apart from North America, with the paleomagnetic position of volcanogenic rocks from the Wallowa terrane deposited 18 (± 4) degrees north or south of the Late Triassic (Carnian) paleoequator (Hillhouse et al., 1982). This position contrasts with a paleolatitude of about 23 degrees north of the Upper Triassic equator for adjacent cratonic rocks. Revised Late Triassic paleopole data by May and Butler (1986) suggests a slightly lower (14 ± 4 degrees) paleolatitude for the Wallowa terrane. When compared to a revised cratonic paleopole, May and Butler suggest no significant difference between the paleolatitudes of the Wallowa terrane and cratonic North America.

Since its inception, the concept of the Wallowa terrane has undergone revisions. The name Wallowa-Seven Devils Volcanic Arc terrane, first used by Brooks and Vallier (1978), gave the terrane its own identity. Sarewitz (1983), Stanley (1987; 1988), and Silberling and others (1984) have supported the distinctiveness of the Wallowa terrane, apart from Wrangellia. Others (Jones, et al., 1977; Hillhouse et al., 1982; Newton, 1987, 1988; Wernicke and Klepack, 1988; and Follo, in press) maintain that Wrangellia was linked to the Wallowa terrane, at least until the Early Jurassic. Based on volcanic petrologic similarities, Mortimer (1986), and more recently McGroder and Umboefer (1989), suggested that the Wallowa terrane is best correlated with the Canadian Stikine terrane rather than Wrangellia.

The Wallowa terrane is surrounded, at least on three sides, by Late Paleozoic and Early Mesozoic terranes of the Blue Mountains Island Arc assemblage (Brooks and Vallier, 1978). Figure 2.1 shows that the Baker and Olds Ferry terranes border the Wallowa terrane on the south and southeast, and that the Idaho Batholith and suture zone, east of Oxbow Oregon, border the Wallowa terrane on the east (Brooks and Vallier, 1978; Strayer, et al, 1989). The terranes of the Blue Mountain province form a 150 km northeastwardly trend across much of northeastern Oregon. Although the northern and western extent of the Wallowa terrane is buried beneath the Tertiary basaltic cover, it probably extended well into Washington State and further west into north-central Oregon (Brooks and Vallier, 1978).

Stratigraphic setting

The Late Paleozoic and Early Mesozoic stratigraphy of the Wallowa terrane illustrates the complex interactions between volcanic arc, platform and deeper-water basinal settings. The stratigraphic composition for the Wallowa terrane has been adequately addressed by Brooks and Vallier (1978), and except for the Martin Bridge Formation, is reviewed below. Figure 2.2 illustrates the Mesozoic stratigraphic correlation between regions of the Wallowa terrane.

The Martin Bridge Formation is underlain by the volcanic and volcaniclastic rocks of the Seven Devils Group. In ascending order, the Seven Devils Group is comprised of the Lower Permian and Upper Triassic Clover Creek Greenstone (Guilluly, 1937) and the Gold Creek Greenstone (Ross, 1938) in the Wallowa Mountains, and the Wild Sheep Creek Formation in the Hells Canyon Region (Vallier, 1977; Brooks and Vallier, 1978). These units are in turn overlain by the Upper Carnian siliceous mudstone and shale of the informally named "Lower Sedimentary Series" (Smith and Allen, 1941). In Hells Canyon, the uppermost unit of the Seven Devils Group, and a possible "Lower Sedimentary Series" correlative, is the siliceous shale and mudstone of the Doyle Creek Formation (Vallier, 1977).

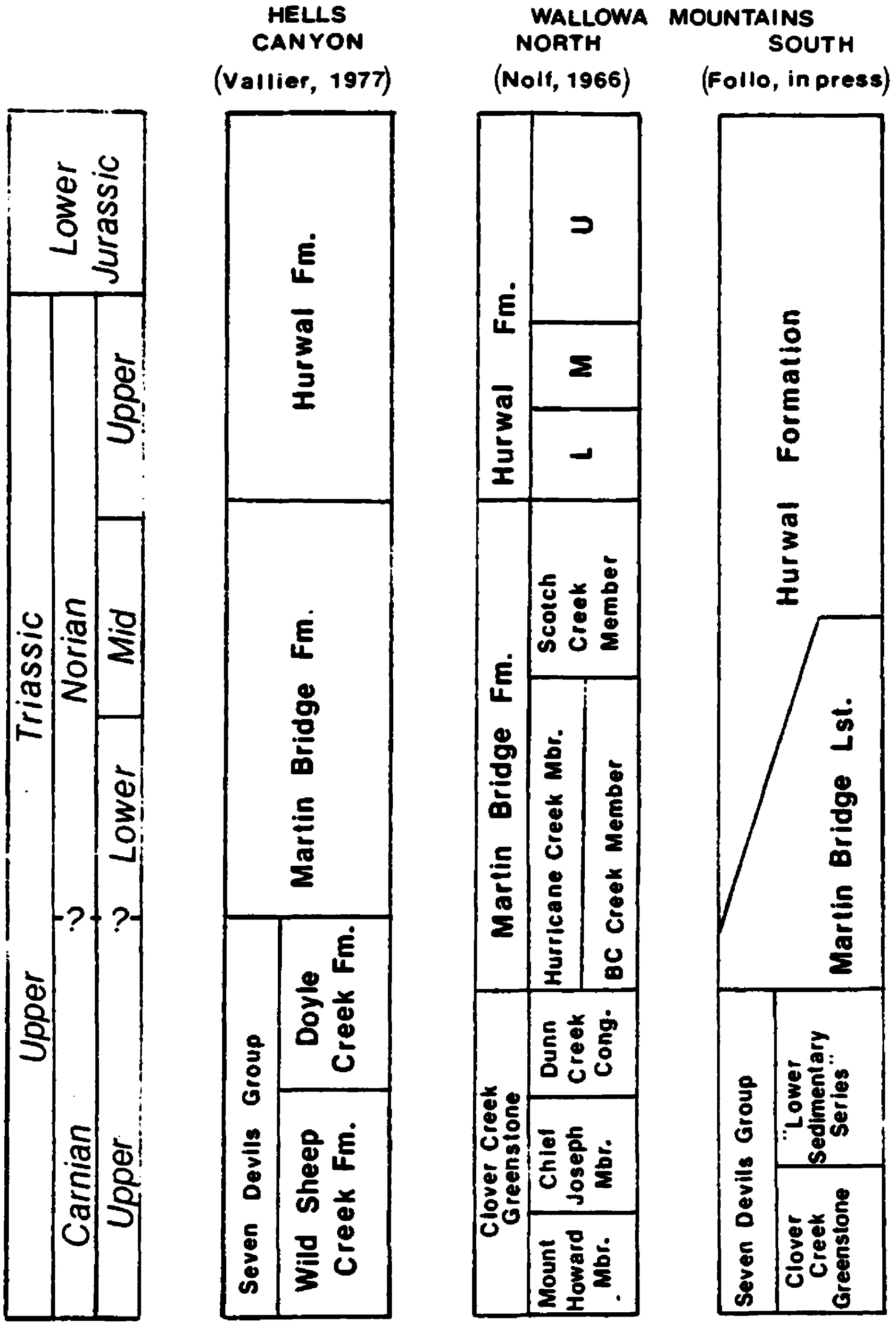


Figure 2.2. Stratigraphic correlation of the three principal Upper Triassic areas of the Wallowa terrane. This study follows closely that of Follo (in press), except that the Hurwal does not extend down into the Carnian, and the term Martin Bridge Formation is used instead of Limestone.

In both the northern and southern Wallowa Mountains the Martin Bridge Formation conformably overlies the "Lower Sedimentary Series". Martin Bridge lithologies vary considerably across the terrane; a shale facies dominates in the southern Wallowa Mountains, whereas, limestone is more common in the northern parts of the range and in Hells Canyon. The Martin Bridge is discussed in more detail in the following section.

In the northern and southern Wallowa Mountains the Martin Bridge Formation is overlain by, and intercalated with, the shale and minor limestone and conglomerate beds of the Norian-to-Early Jurassic Hurwal Formation (Smith and Allen, 1941). In places the Hurwal appears to be compositionally identical to the Martin Bridge making the two Formations difficult to distinguish from each other. Although younger Mesozoic sediments were either not deposited or are missing from the Wallowa Mountains, at Pittsburg Landing and further north in Hells Canyon, a Middle to Upper Jurassic (Callovian-Oxfordian) sequence of shallow marine and terrestrial deposits were named the Coon Hollow Formation (Morrison, 1964; White et al., in press).

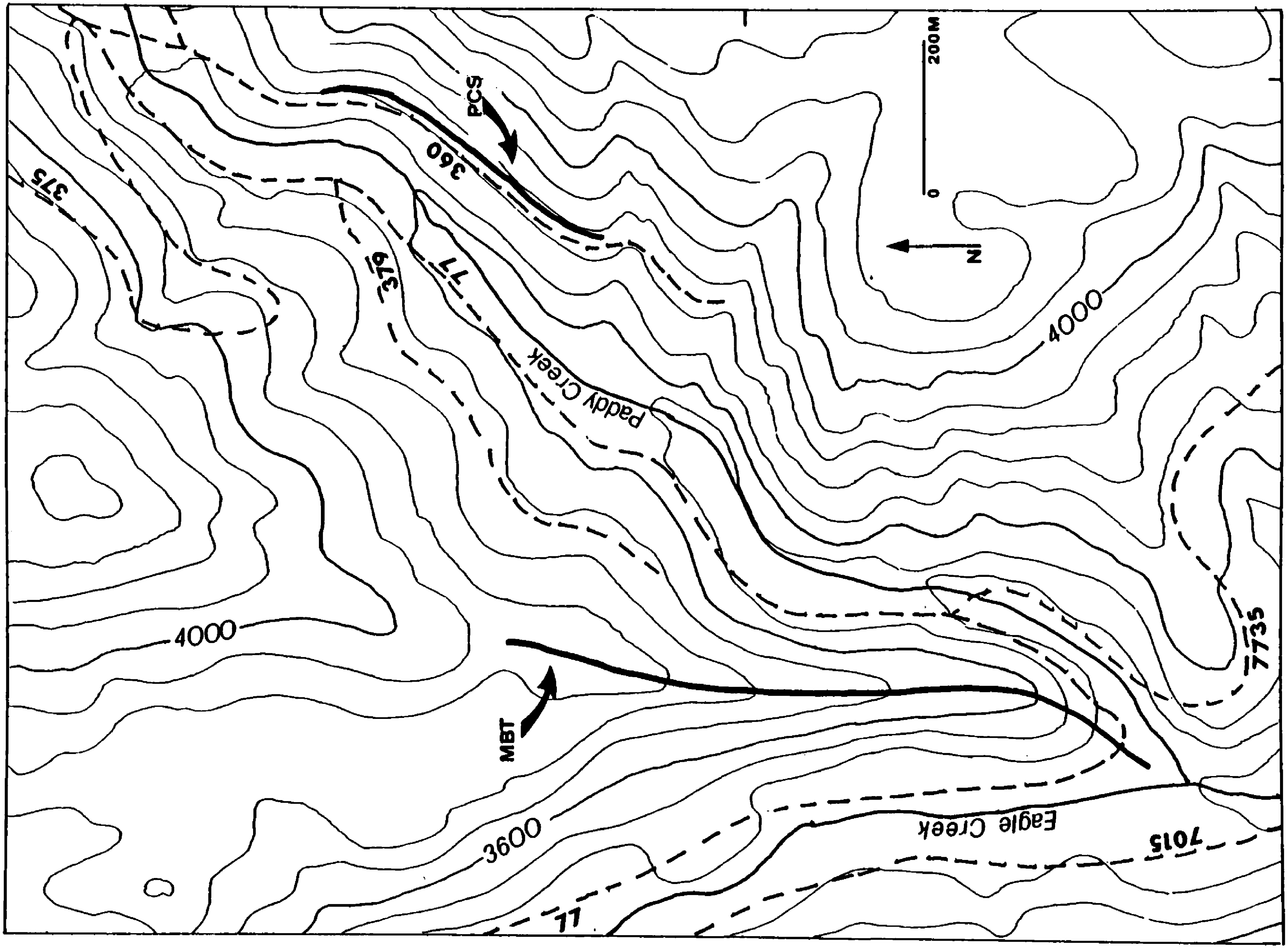
Martin Bridge Formation.

The name "Martin Bridge" was first published as a locality by Smith (1912; 1927), who described a measured section including 192 meters of shale, bedded limestone, and massive limestone interpreted as an coral reef. Ross (1938) formally named the formation, designating Smith's (1912; 1927) section near the confluence of Eagle and Paddy Creeks as the stratotype. Referring to the type section Ross (1938) described its location as "... from the bridge across Eagle Creek, near which the best preserved fossils were found". This section is assumed to be the prominent north-trending ridge separating Eagle and Paddy Creeks (Figure 2.3).

Confusion as to the correct usage of the name Martin Bridge results from the earlier geologic reports from the region. Without reference, Chaney (1933) used the name to include all Upper Triassic rocks of central and eastern Oregon, including volcanic and argillaceous sedimentary rocks. Likewise, Guilluly and others (1933) assigned all Upper Triassic rocks from the Wallowa Mountains, regardless of rock type, to the Martin Bridge, attributing the name to a forthcoming paper by C. Ross. In the northern Wallowa Mountains, Smith and Allen (1941) restricted its usage to the prominent limestones and marbles, although much attributed by them to the Martin Bridge has since been assigned to other formations.

Vallier (1977) is often cited as changing the name Martin Bridge Formation to the Martin Bridge Limestone (Stanley, 1986; Newton, 1986). The name change also has been attributed to Hamilton (1963) (Vallier, 1977).

Figure 2.3. Locality map showing Martin Bridge stratotype (MBT) and Paddy Creek section (PCS), situated in the N/2 of Section 21 and the S/2 of Section 16, T7S, R44E, modified from U.S.G.S. 7.5 minute Sparta Quadrangle. Dashed lines indicate numbered U.S. Forest Service roads.



200 M
0
N
PCS
360
375
379
77
Paddy Creek
4000
4000
7735
MBT
3600
Eagle Creek
7015
77

Although Hamilton (1963) was first to use the lithologic designation Limestone, apart from Formation, it appears to have been in a casual sense, for no mention of a formal nomenclature change was stated or implied. Subsequently, the name Martin Bridge Limestone has been extensively used in recent literature (e.g. Whalen, 1988; and the series of papers in Vallier and Brooks, 1986). For nomenclatural priority, and because the type locality is mostly shale, the term Martin Bridge Formation is reinstated for use in this study.

Lithologies.-- Martin Bridge lithologies vary considerably across the Wallowa terrane reflecting the paleogeographic positioning of the arc-basin configuration during Martin Bridge deposition. The three principal areas where the Martin Bridge is well exposed and has been studied are: the southern Wallowa Mountains (Prostka, 1963; Follo, in press; this study); the northern Wallowa Mountains (Smith and Allen, 1941; Nolf, 1966); and the Hells Canyon region (Vallier, 1977; Whalen, 1988).

From the southern Wallowa Mountains, Follo (in press) has subdivided the Martin Bridge into three end-member lithofacies. Follo's lithofacies include: 1) Facies A-- fine-grained laminated carbonates, calcareous shale, and black shale, 2) Facies B-- well-bedded carbonate grainstone and packstone, and 3) Facies C-- limestone conglomerate.

The shales of facies A are considered identical in composition and laterally equivalent to the Hurwal Formation (Follo, in press). Although Prostka (1963) interpreted these shales as a shallow-water back-reef lagoon, they probably represent normal background sedimentation on a proximal carbonate slope and in basinal environments. The bedded limestones of Facies B are graded with bouma-like sedimentary structures, probably representing allochthonous deposition of turbidite style originating from a carbonate platform to the north. Although facies C was originally interpreted as a limestone breccia by Ross (1938), who thought they were parallochthonous accumulations of reef debris, and Smith (1912; 1927) as coral reefs, they more likely represent large debris sheets shed from the platform edge situated to the north (Follo, in press).

Five kilometers from the type Martin Bridge, at Summit Point, Stanley and Senowbari-Daryan (1986) described a small, Norian patch reef which may actually represent part of the in situ platform edge. These authors suggested this reef may correlate with the upper part of the Martin Bridge.

In the northern Wallowa Mountains, Nolf (1966) identified three informal members belonging to the Martin Bridge (Figure 2.2): the BC Creek and laterally equivalent Hurricane Creek members, and the overlying Scotch Creek member. The Hurricane Creek member is a grey-to-white massive limestone. Although Nolf (1966) believed this member to be a reef facies, Follo (in press) proposes that it more likely represents a shallow-water, sandy shoal facies situated on an open platform edge. The BC Creek member includes finely-crystalline grainstone and packstone which Nolf (1966) and Follo (in press) interpret to represent a shallow subtidal to supratidal environment. Lithologies of the Scotch Creek Member are varied, but mostly consist of bioclastic grainstone, and several limestone breccia lenses. Nolf (1966) suggested a deeper-water carbonate ramp environment with periodic down-slope transport for the Scotch Creek member.

In the northern Wallowa Mountains, at the Black Marble Quarry, Smith and Allen (1941) attributed an isolated outcrop of dark limestone to the Martin Bridge Formation. Stratigraphic position would place this limestone block in the lower, or middle Hurwal Formation (Nolf, 1966), and it has so been mapped by Laudon (1956). Except for exotic clasts within the Deadman Lake Breccia (Nolf, 1966), lithologically similar rocks are unknown from the Hurwal. Although an Upper Carnian fauna (Smith and Allen, 1941) suggests affinity with either the lower Martin Bridge or, more probably, the Clover Creek Greenstone (Nolf, 1966; Stanley, 1979), S. Ashbough (in prep.) has found Norian Foraminifera indicating limestones of the Black Marble Quarry may belong to the middle or upper Martin Bridge.

In Hells Canyon at Spring Creek, Whalen (1988) described the lithology of the Martin Bridge as a package of lime mudstone, pelloidal wackestone, packstone, and grainstone. He interpreted the sequence of carbonate rocks from Spring Creek to indicate a deepening-upward sequence on a drowning carbonate platform (Whalen, 1988).

Formation contacts.-- Confusion has also been introduced because of the lack of any clearly defined boundaries for the Martin Bridge and the similarities between it, the "Lower Sedimentary Series" and the Hurwal Formation. This confusion was introduced because neither the lower boundary of the Martin Bridge with "Lower Sedimentary Series", nor the upper boundary with the Hurwal Formation are exposed at the stratotype.

In the southern Wallowa Mountains, the basal contact with the "Lower Sedimentary Series" has been described as conformable (Prostka, 1963; Mirken, 1986), and as a plane of minor structural dislocation (Follo, in press). The criteria used by Prostka (1963) for this contact was the first massive limestone overlying the calcareous argillite of the "Lower Sedimentary Series". Others take it to be the lowest calcareous beds, either shale or limestone, above the non-calcareous beds of the "Lower Sedimentary Series" (Mirken, 1986). The upper contact of the Martin Bridge with the Hurwal has not been identified from the southern Wallowa Mountains; although it is presumed to be vertically gradational (Prostka, 1963; Mirken, 1986), and possibly laterally equivalent (Follo, in press). In fact, Follo (in press) was unable to distinguish the shaley facies of the Martin Bridge from that of the Hurwal.

In the northern Wallowa Mountains, the Martin Bridge is reported to grade conformably from the siliciclastics of the underlying Dunn Creek Conglomerate (Nolf, 1966). This contact is also reported as a plane of minor structural discontinuity (Follo, in press). The upper contact with the overlying Hurwal is also considered gradational, and is taken to be the first argillaceous beds above the last massive limestone or marble (Nolf, 1966).

In Hells Canyon, the lower contact of the Martin Bridge with the underlying Doyle Creek Formation (Figure 2.2) has been described as unconformable (Vallier, 1977), and as a plane of minor structural discontinuity (Follo, in press). Elsewhere in Hells Canyon, the upper boundary of the Martin Bridge is unconformable with the Miocene Columbia River Basalts or a modern erosional surface (Whalen, 1988).

Near the Riggins area, Hamilton (1963) described the upper contact of recrystallized Martin Bridge as conformable with the Lucile Slate, a possible Hurwal equivalent.

CHAPTER III

THE MARTIN BRIDGE STRATOTYPE

GEOLOGY, STRATIGRAPHY, AND FAUNA

As discussed in the previous two chapters, past stratigraphic and biostratigraphic studies of the Martin Bridge Formation have achieved only limited success. By complimenting previous works, this chapter contributes not only to the understanding of the geology of the southern Wallowa Mountains and the stratigraphy of the Martin Bridge stratotype, but also to the stratigraphic occurrence of halobiid bivalves. Although others have addressed related problems regarding the sedimentology (Follo, 1986, in press) and structural geology (Mirken, 1986) of the southern Wallowa Mountains, this is the first analysis of the geology and biostratigraphy of the Martin Bridge Formation at its type locality since the work of Smith (1912; 1927).

This chapter is divided into two main parts: 1) the local geology of the type area, and 2) astratigraphic analysis. Through geologic mapping, the first part identifies and addresses aspects of the structural geology and lithologic units of the type area, and their bearing on stratigraphic succession of the Martin Bridge stratotype. The second part analyzes the stratigraphic succession of the Martin Bridge stratotype, its varied lithology and faunal content.

Early in this study it became evident that interpretations of the stratigraphy and structural geology of the area were inter-related. Since neither aspect has received sufficient attention, it was deemed necessary first to map, in a reconnaissance fashion, the structure and broadly defined lithofacies for the Martin Bridge type area. This information aided in identifying structural blocks isolated for stratigraphic analysis. Finally, the lithic and faunal characteristics of each structural block helped in working out further the structure of the region.

Local geology.

Geologic mapping and stratigraphic analysis of the Martin Bridge stratotype and surrounding area revealed complex geologic structures throughout. Rocks of the type area have been subjected to intense faulting and folding in addition to intrusive igneous and metamorphic events. A detailed geologic outcrop and structure map was made of the type area at a scale of 1:6000 (1"=500'). The coverage of this map (Figure 3.1) includes about two square kilometers centered on the stratotype between Eagle and Paddy Creeks. The geologic map shown in figure 3.2 was constructed on an enlarged topographic base map (U.S. Geological Survey Sparta 7.5' Quadrangle). Location was made by brunton compass and altimeter methods.

Figure 3.1. Topographic index (same coverage as Figure 2.3) to geologic map (Figure 3.2). Heavy lines indicate location of structural blocks (Figures 3.3-3.8).

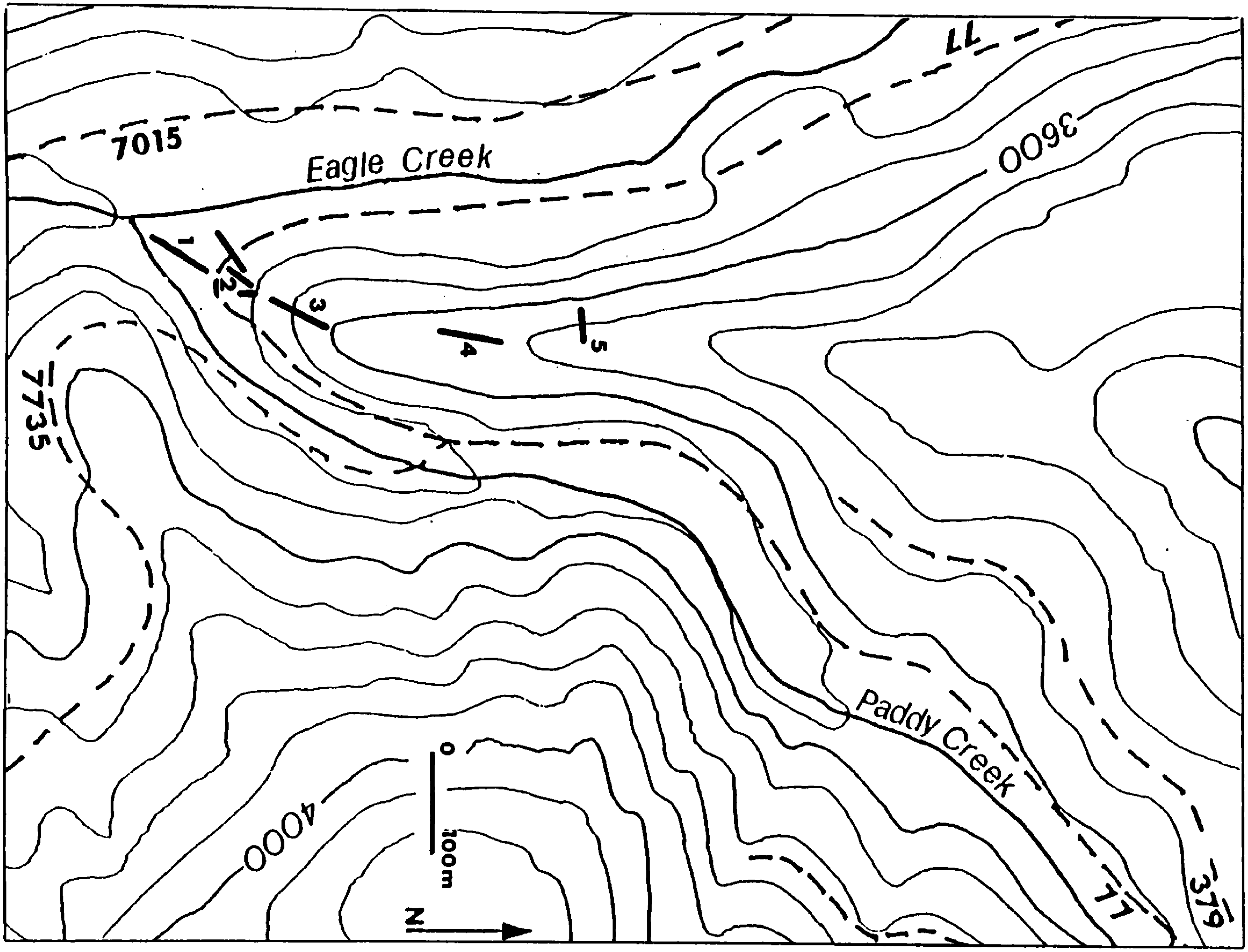

7015
Eagle Creek
77
3600
1
2
3
4
5
7735
Paddy Creek
0
100m
N
4000
77
379

Figure 3.2. Outcrop and structural geologic map of type area.

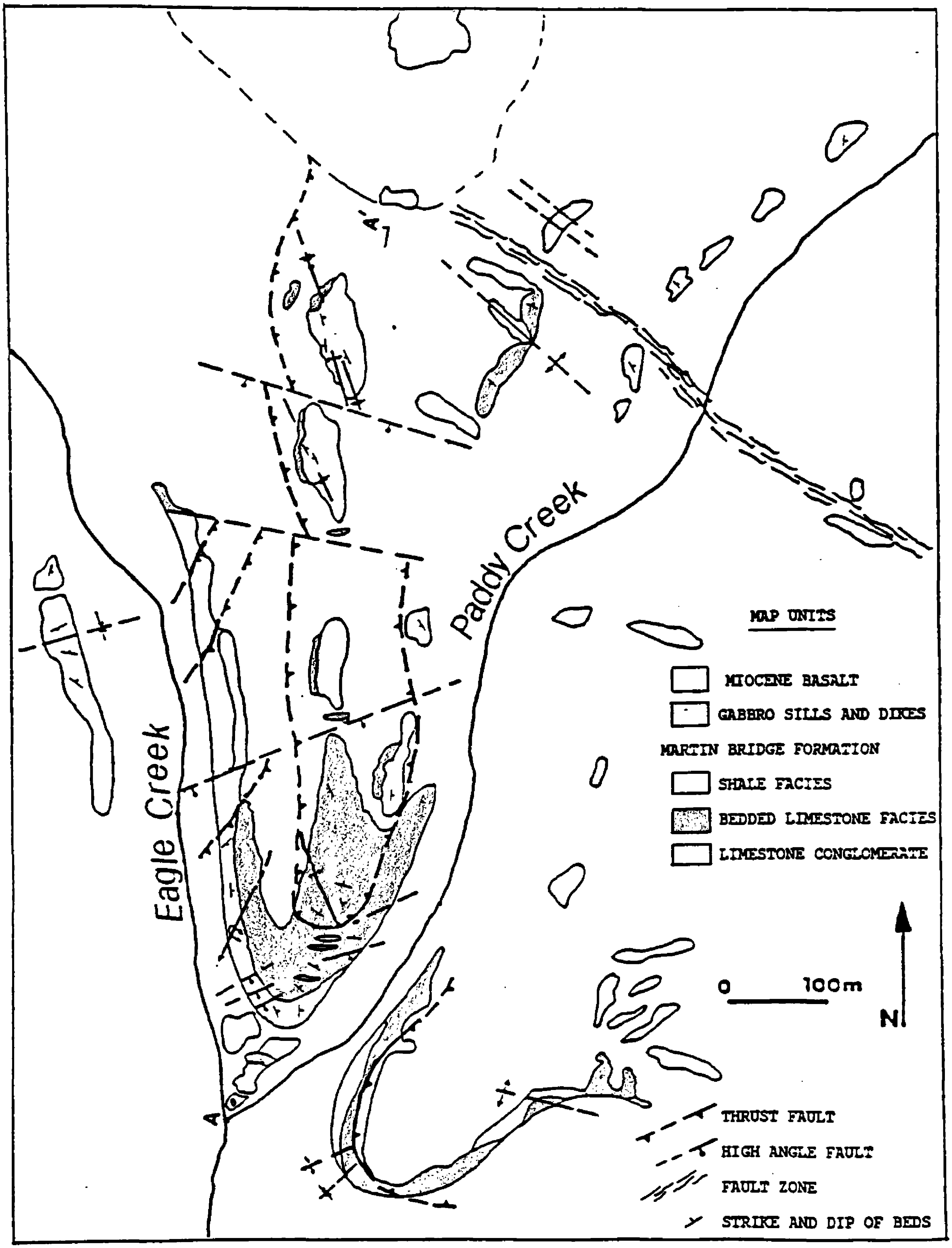
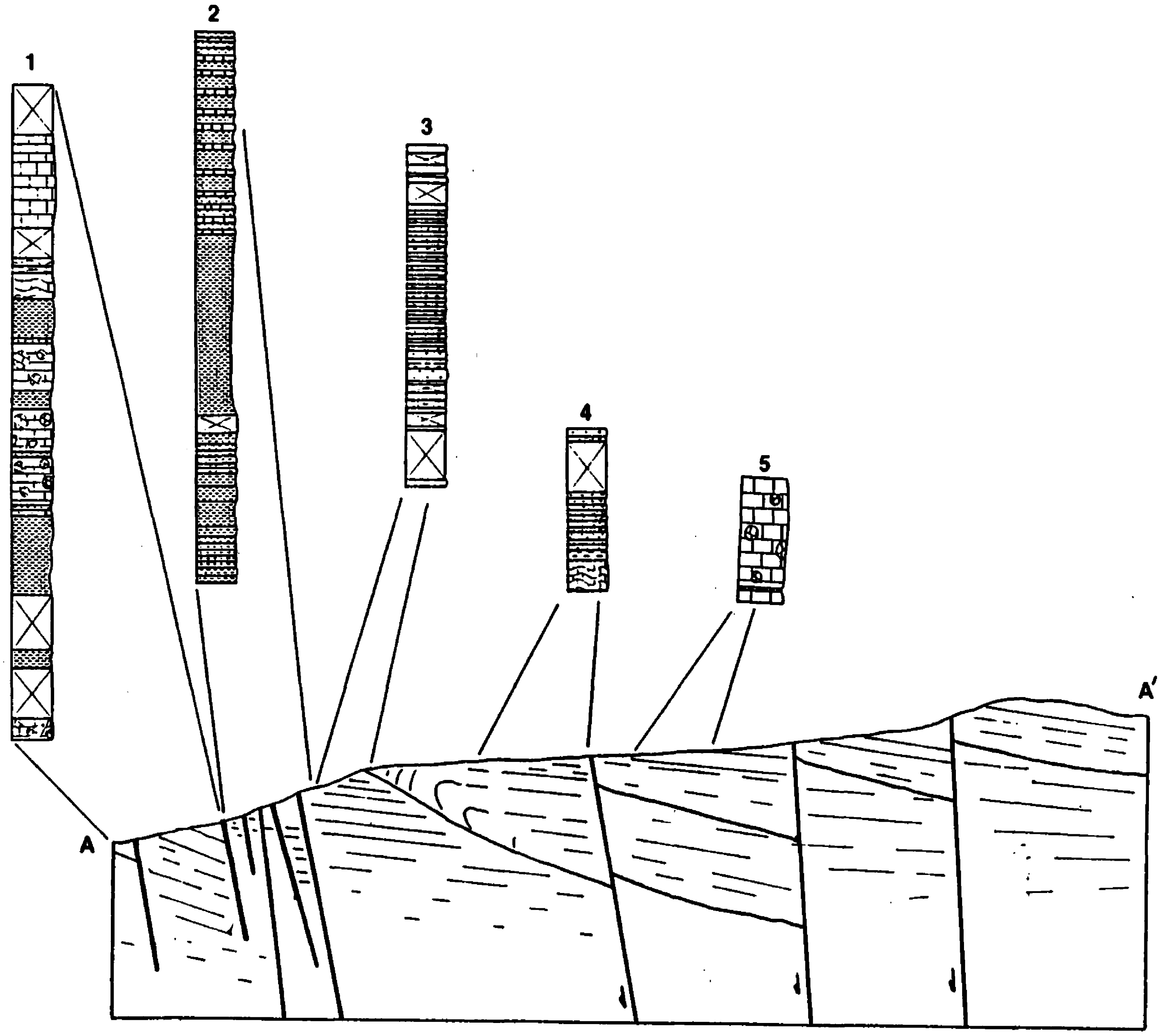

A'
Paddy Creek
Eagle Creek
A
MAP UNITS
MIOCENE BASALT
GABBRO SILLS AND DIKES
MARTIN BRIDGE FORMATION
SHALE FACIES
BEDDED LIMESTONE FACIES
LIMESTONE CONGLOMERATE
0
100m
N
THRUST FAULT
HIGH ANGLE FAULT
FAULT ZONE
STRIKE AND DIP OF BEDS

Figure 3.3. Generalized longitudinal cross section along ridge through A-A′ (Figure 3.2) showing approximate location of structural blocks (block descriptions Figures 3.4-3.8, and discussed in text), and faults (heavy lines)


1
2
3
4
5
A
A′

Lithofacies.-- For mapping purposes, three principal sedimentary lithofacies were identified from the Martin Bridge Formation. These lithofacies include: shale, bedded limestone, and limestone conglomerate. Similar to those described by Follo (in press), these broadly construed lithofacies are strictly map units and do not imply any stratigraphic relationship.

The shale lithofacies includes calcareous and non-calcareous shale and mudstone with varying amounts of volcaniclastic siltstone. The limestone conglomeratic facies includes conglomerates with varying proportions of limestone and volcaniclastic matrix and clasts, and several outcrops of massive limestone, where recrystalization destroyed the conglomeratic texture.

Although other pre-Tertiary sedimentary units were not found in the mapped area, igneous rocks were commonly encountered. Mapped as separate units were basalts belonging to the Miocene Columbia River Group, and a chlorite-rich gabbro, forming sills and dikes throughout the map area.

Structure.-- Structural features identified in the type area include thrust faults, high-angle reverse and normal faults, chevron, tight, and isoclinal folds, intense areas of cleavage, and a broad synform (Figure 3.2). Because complex, small-scale geologic structures are overwhelmingly abundant in the type area, only those deemed sufficiently large, or significant to stratigraphic analysis are included on the map (Figure 3.2). Not included are many small-scale, high angle faults whose displacement could be determined, and most bedding attitudes, which would confuse the reader.

Although much of the outcrop of Martin Bridge in the type area appears to be relatively flat-lying, local intense folding is common. Most of the folds are chevron type, although overturned and isoclinal folds are common. Many of the tight, reclining folds are associated with, or pass into, thrust faults. Hanging-wall anticlines, and foot-wall drag folds commonly occur with thrust and high-angle faults. Regionally, the map area is centered on a broad syncline as mapped by Prostka (1963),

Thrust faults in the area are numerous. At least five individual thrust sheets have been identified in the type area. This number is probably conservative because most of the map area is heavily forested and covered by coluvium. The thrust planes are normally horizontal, and appear to verge northwest. Each of the massive limestone conglomerates on the ridge between Eagle and Paddy Creeks are mapped as upper plates of one or more thrust faults. In most cases, neither the lateral nor stratigraphic displacement of the thrusts could be determined. However, because all the observed thrusts in the type area are found within the Martin Bridge, their stratigraphic displacement could not be very large. The small-scale thrusts in the type area may be splays coming off the Clover Creek thrust fault exposed two kilometers south and southeast of the map. As mapped by Prostka (1963), the large Clover Creek thrust fault puts Permian and Upper Triassic Seven Devils Group over the Upper Triassic Martin Bridge and Hurwal Formations. The thrusts in the map area may also be splays from a larger buried thrust.

High-angle normal and reverse faults commonly occur in the type area. These faults normally strike northwest and east-northeast, and are mostly down-thrown to the southwest in the northern part of the map area, and to the southeast in the southern part. The throw on the reverse faults is small, normally less than several meters. In several places, the high-angle faults cross-cut the thrust faults.

A large fault zone, possibly more than 20 meters wide, trends west-northwest across Paddy Creek in the northern part of the map area (Figure 3.2). The fault zone is characterized by highly fractured and cleaved rocks. Marking this fault zone are slikensides, massive calcite veining, chlorite-rich gabbro intrusives, and intense chloritic (propylitic) alteration of the Martin Bridge country rock. This fault zone may have served as a feeder structure for the Miocene basalts cropping-out on the zone's western extent.

The geologic mapping provided sufficient structural data to construct a generalized cross-section for the type area (Figure 3.3). The mapping also allowed identification of structural blocks from the type section, a starting point for stratigraphic analysis. The blocks are typically bound by observable faults with unknown displacement, or are separated by covered intervals where faults are suspected. Although seven structural blocks were identified from the ridge between Eagle and Paddy Creek, only five were considered sufficiently undisturbed for stratigraphic measurement and analysis.

A thick, well-exposed section of the shale facies was identified to the northeast of the map area, on the east side of Paddy Creek (Figure 2.3). This section appears to be adequately complete, and is included in stratigraphic analysis.

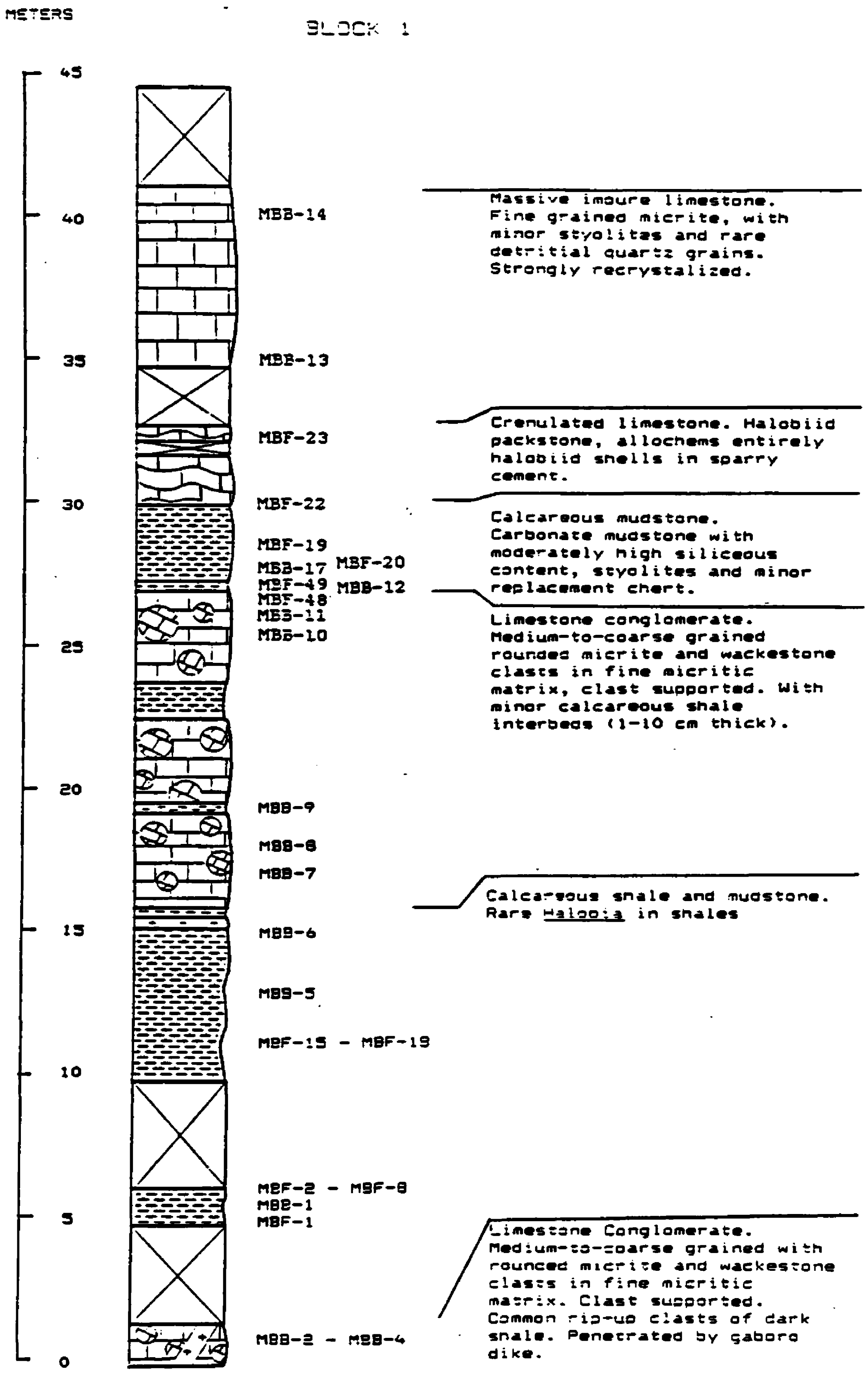
Stratigraphic analysis.

Each structural block was analyzed separately. Measurement was by Jacob staff, with footage markers painted directly on the outcrop. Lithologic samples were taken for each major rock type. Fossil samples were collected from each fossil-bearing bed, although cleavage and metamorphism limited the quality of many specimens.

Block lithologies and faunal content.-- Lithologies vary considerably within and between each structural block. Fugures 3.4-3.8 graphically illustrate the lithologies for each block and the Paddy Creek section. The fossil taxa recovered from each structural block of the Martin Bridge stratotype and the Paddy Creek section are illustrated in Figures 3.9 and 3.10. The age determinations for the fossil data are given in the chapter on biostratigraphy (Chapter 4) and systematics (Chapter 5).

The block at the base of the stratotype (Block 1) is mostly comprised of slightly-calcareous shale and mudstone (Figure 3.4). A limestone conglomerate bed occurs at the base of the block and near its middle. A crenulated *Halobia*-limestone occurs below a massive recrystallized limestone near the top of the block. In ascending order, Block 1 contains the bivalves *Halobia radiata*, *Halobia superba*, and *Halobia beyrichi* (Figure 3.9). Both *Halobia radiata* and *H. superba* are probable Upper Carnian species, whereas *Halobia beyrichi* is known from Upper Carnian and Lower Norian rocks.

Conodonts from Block 1 give different ages. From collections made by G. Stanley in 1986, the Upper Carnian-Lower Norian conodont *Epigondolella primitia* was reported from the middle of the block and the Middle Norian conodont *E. postera* was found higher up in the block (B. Wardlaw, U.S.G.S. report to G.D. Stanley, 1990). The exact stratigraphic levels of Stanley's collections are not known,



Massive impure limestone. Fine grained micrite, with minor styolites and rare detritial quartz grains. Strongly recrystalized.

Crenulated limestone. Halobiid packstone, allochems entirely halobiid shells in sparry cement.

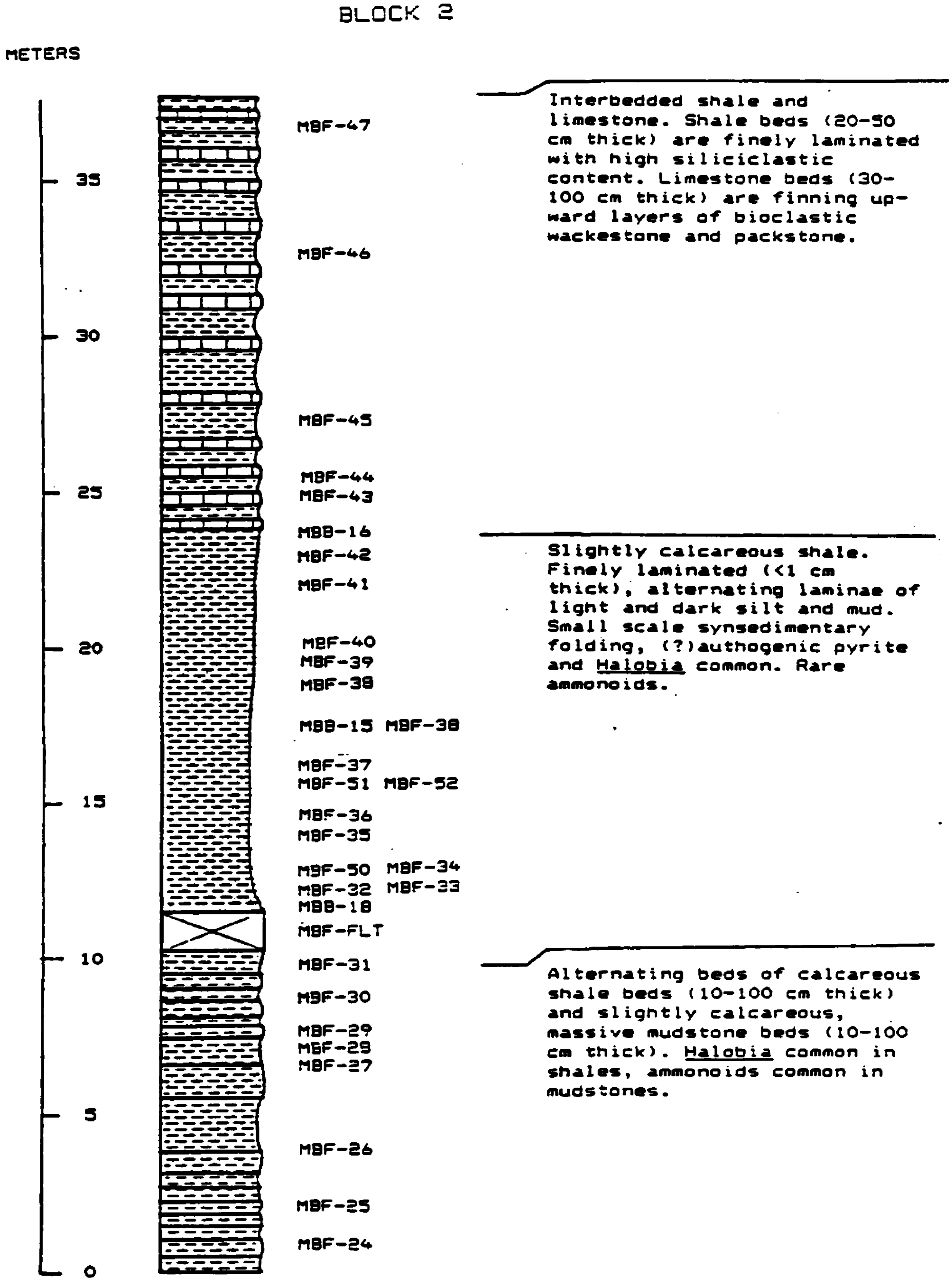
Calcareous mudstone. Carbonate mudstone with moderately high siliceous content, styolites and minor replacement chert.

Limestone conglomerate. Medium-to-coarse grained rounded micrite and wackestone clasts in fine micritic matrix, clast supported. With minor calcareous shale interbeds (1-10 cm thick).

Calcareous shale and mudstone. Rare *Halobia* in shales

Limestone Conglomerate. Medium-to-coarse grained with rounded micrite and wackestone clasts in fine micritic matrix. Clast supported. Common rip-up clasts of dark shale. Penetrated by gabbro dike.

Figure 3.4. Stratigraphic column, structural block 1.

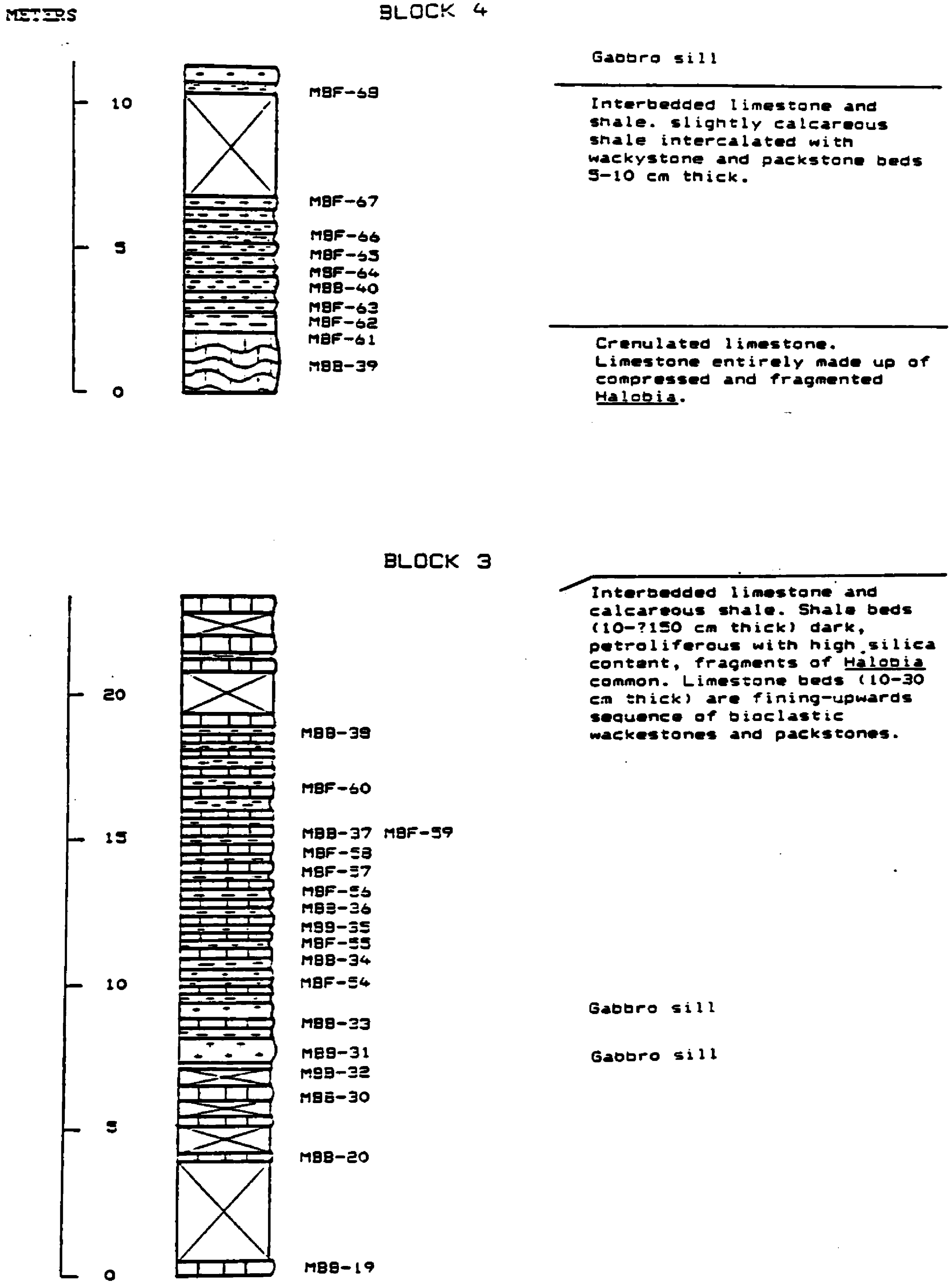


Interbedded shale and limestone. Shale beds (20-50 cm thick) are finely laminated with high siliciclastic content. Limestone beds (30-100 cm thick) are finning upward layers of bioclastic wackestone and packstone.

Slightly calcareous shale. Finely laminated (<1 cm thick), alternating laminae of light and dark silt and mud. Small scale synsedimentary folding, (?)authogenic pyrite and <u>Halobia</u> common. Rare ammonoids.

Alternating beds of calcareous shale beds (10-100 cm thick) and slightly calcareous, massive mudstone beds (10-100 cm thick). <u>Halobia</u> common in shales, ammonoids common in mudstones.

Figure 3.5. Stratigraphic column, structural block 2.



Gabbro sill

Interbedded limestone and shale. slightly calcareous shale intercalated with wackystone and packstone beds 5-10 cm thick.

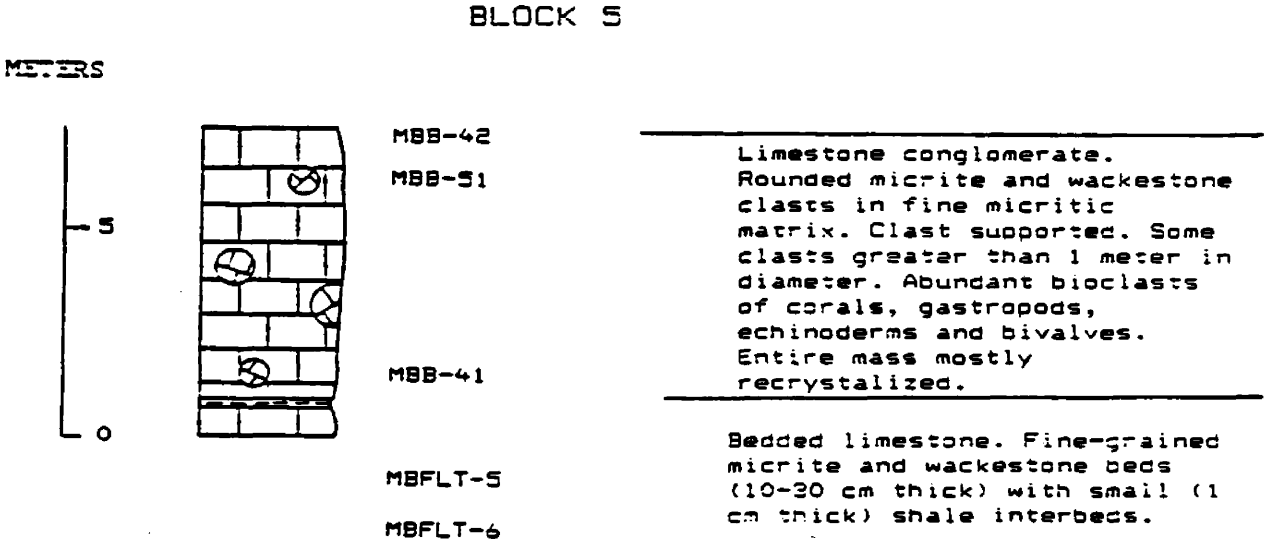
Crenulated limestone. Limestone entirely made up of compressed and fragmented *Halobia*.

Interbedded limestone and calcareous shale. Shale beds (10-?150 cm thick) dark, petroliferous with high silica content, fragments of *Halobia* common. Limestone beds (10-30 cm thick) are fining-upwards sequence of bioclastic wackestones and packstones.

Gabbro sill

Gabbro sill

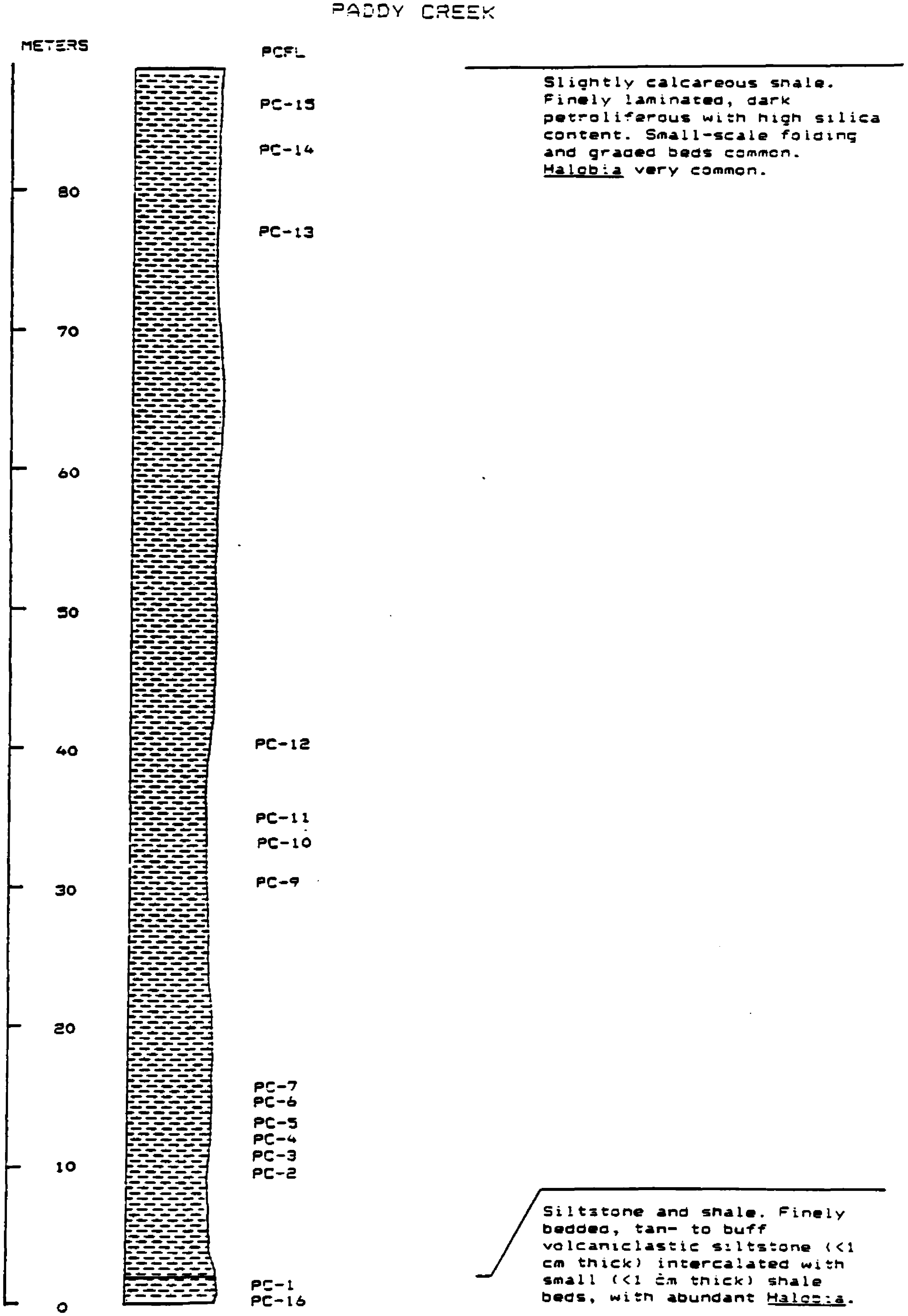
Figure 3.6. Stratigraphic column, structural blocks 3 and 4.



Limestone conglomerate. Rounded micrite and wackestone clasts in fine micritic matrix. Clast supported. Some clasts greater than 1 meter in diameter. Abundant bioclasts of corals, gastropods, echinoderms and bivalves. Entire mass mostly recrystalized.

Bedded limestone. Fine-grained micrite and wackestone beds (10-30 cm thick) with small (1 cm thick) shale interbeds.

Figure 3.7. Stratigraphic column, structural block 5.



Slightly calcareous shale. Finely laminated, dark petroliferous with high silica content. Small-scale folding and graded beds common. *Halobia* very common.

Siltstone and shale. Finely bedded, tan- to buff volcaniclastic siltstone (<1 cm thick) intercalated with small (<1 cm thick) shale beds, with abundant *Halobia*.

Figure 3.8. Stratigraphic column, Paddy Creek section.

but probably, the conodonts come from levels illustrated in Figure 3.9. On the other hand, M. Orchard (pers. comm., 1990) reported only Upper Carnian conodonts (generic and specific determinations unavailable) from localities at, or near, those of Stanley (Figure 3.9)

Block 2 is dominantly calcareous mudstone and shale overlain by a sequence of bedded limestone and shale (Figure 3.5). The fauna of Block 2 is fairly diverse (Figure 3.9), containing the bivalves *Halobia superba* and *H. oregonensis* and *H. beyrichi*. The ammonoids *Discotropites* sp., *Anatropites* sp., and *Arieltceltites* sp. were found low in Block 2. At the top of Block 2, the Middle Norian conodont *Neogondolella* sp. occurs (B. Wardlaw, U.S.G.S. report to G.D. Stanley, 1990). This fauna, except *Neogondolella* sp. and possibly *Halobia beyrichi*, is typical of the Upper Carnian.

The third block is comprised of limestone beds intercalated with shale (Figure 3.6). Chlorite-bearing gabbro sills are common at several stratigraphic positions in Block 3. The fauna of Block 3 (Figure 3.10) is not diverse, containing the following taxa low in the block: Upper Carnian-Lower Norian *Halobia beyrichi*, and an Upper Carnian conodont (generic and specific determination unavailable, M. Orchard, pers. comm., 1990). In the middle of the block, G.D. Stanley (pers. comm., 1989) found the

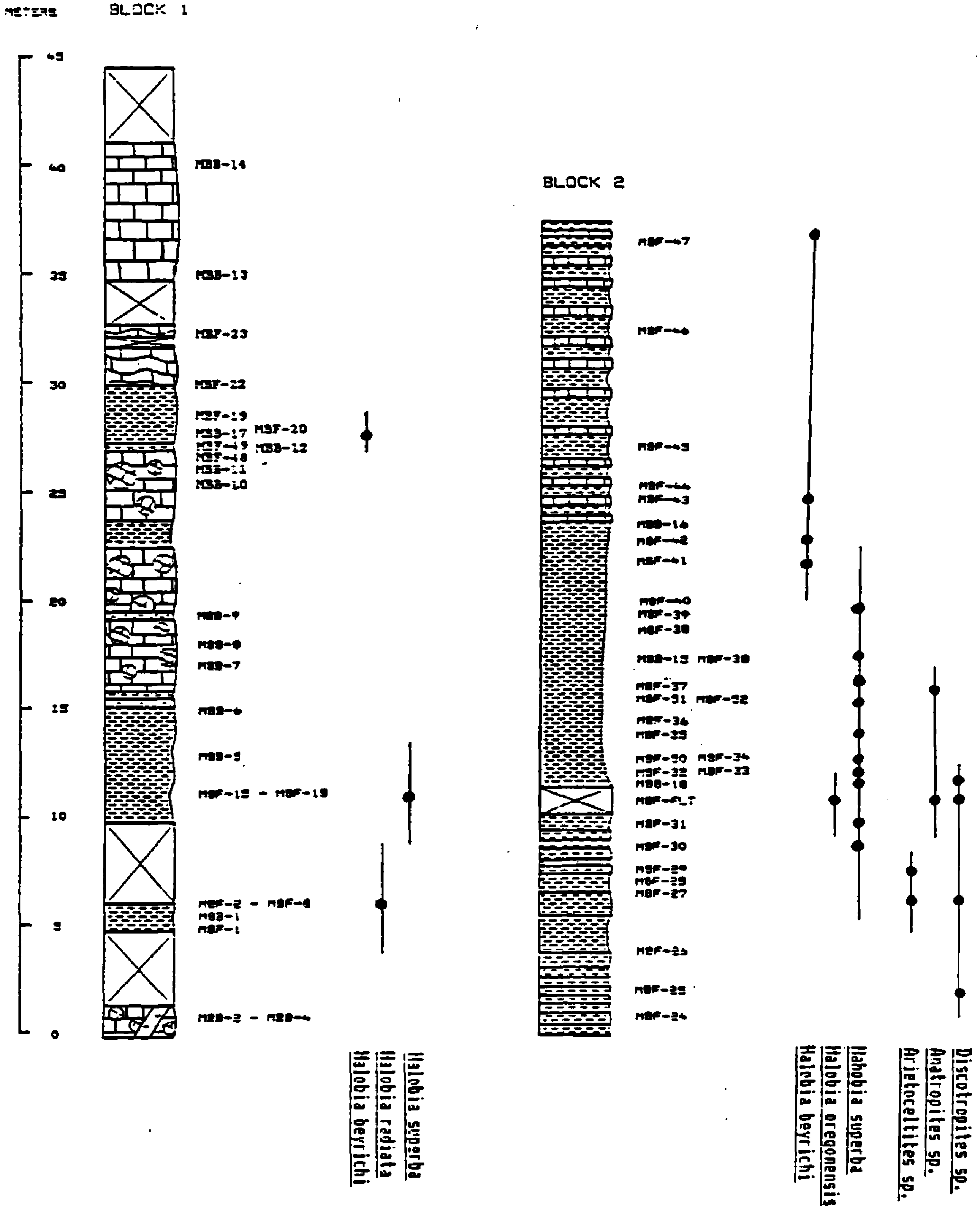


Figure 3.9. Fossil occurrences, Blocks 1 and 2.

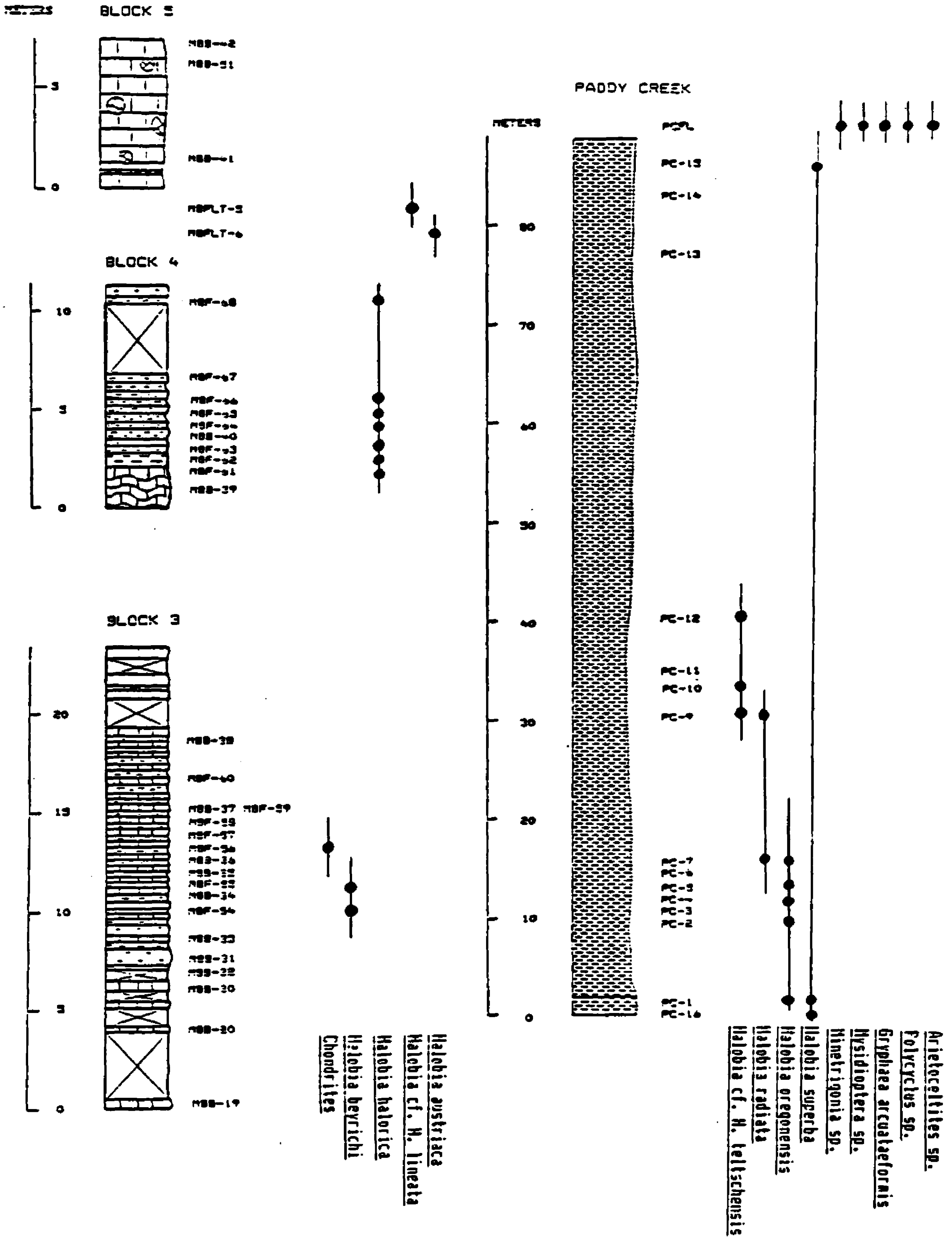


Figure 3.10. Fossil occurrences, Blocks 3, 4, 5, and Paddy Creek section.

coral Retiophyllia norica, commonly recognized in Norian rocks of Europe. Chondrites, the trace of an unknown organism, and not age diagnostic, was found in shale in the middle part of Block 3.

Block 4 is mostly dark brown to black shale with packstone/grainstone interbeds resting conformable above a crenulated limestone (Figure 3.5). The fauna of this block is monospecific, containing Halobia halorica, an upper Lower and Middle Norian species.

Block 5 consists mainly of limestone conglomerate, although a thin-bedded limestone occurs at the base (Figure 3.7). Within the limestone conglomerate, the Norian coral Distichophyllia norica was found. In float below Block 5, both Halobia austriaca and Halobia cf. H. lineata were recovered. The age of these halobiids is probably Early Norian.

The Paddy Creek section is mostly shale, except for its base where tan, volcaniclastic siltstone and shale occurs (Figure 3.8). The Upper Carnian bivalves Halobia superba, H. oregonensis, and H. radiata occur in the shales of the Paddy Creek section. A slightly calcareous mudstone occurs in structural isolation above the top of this section. Occurring in this mudstone is a diverse Upper Carnian ammonoid and benthonic bivalve fauna containing Gryphaea arcuataeformis, ?Mysidioptera, Minetrigonia sp., Arietoceltites, and Polycyclus.

Block sequencing.-- The structural blocks are sequenced by using lithologic similarities, stratigraphic position, structural extrapolation, and faunal content. The use of different correlation and sequencing criteria results in three different solutions (options A-C) for sequencing the Martin Bridge stratotype and Paddy Creek sections (Figure 3.11). Correlation lines are typically drawn on the first occurrence of taxa.

All three sequencing arrangements (Figure 3.11) are similar in that they have Blocks 2,3,5,and 4 in ascending order. The three options differ in the positions of Blocks 1 and 2, and the Paddy Creek section. Of the three alternatives, option C (Figure 3.11) is favored because it is the most supported, with both fossil and lithologic data. Because the conodont data provided by M. Orchard and B. Wardlaw are conflicting, and the temporal ranges of ammonoids and halobiids are usually smaller than those of conodonts (e.g. De Weaver, et al., 1979), conodonts are given only limited weight in resolving the sequence.

In option A, Block 1 is below Block 2, and the Paddy Creek section correlates with all of Block 1 and the lower part of Block 2. In this case, correlation is based upon Halobia radiata and the mudstone bed with Arietoceltites. The main problem with this option is that Halobia beyrichi of Block 1 would be below H. superba and other Carnian taxa of Block 2. Furthermore, the limestone conglomerate at the base, and near the top, of Block 1 can not be correlated with the Paddy Creek section. Additionally, the shales of the Paddy Creek section, bearing *Halobia superba* can not be correlated to the similar shales of Block 2.

Option B requires Block 1 to correlate to the upper part of Block 2. The primary correlation criteria relies on *Halobia beyrichi*. In this case, the Paddy Creek section is mostly below Block 2 with a correlation level based upon *Arietoceltites*, and in part correlative with Block 1 based on *Halobia radiata*. Like the first option, correlation cannot be made with the limestone conglomerate of Block 1, nor can the shales of the Paddy Creek section bearing *Halobia superba* and Block 2 be correlated.

The third alternative (option C) requires correlation of the Paddy Creek section to most of Block 2 and the lower part of Block 1. This option also correlates the upper part of Block 1 to the upper part of Block 2. In this case, correlation of the Paddy Creek section to Block 2 relies on the occurrence of *Halobia superba* and on the lithologic similarities of the shale found in each block. Correlation of Block 1 to the Paddy Creek section relies upon the occurrence of both *Halobia superba* and *H. radiata*. The similar occurrence of *Halobia beyrichi* in Blocks 1 and 2 offers another correlation level. This option is favored for several reasons: 1) it is supported by more correlation levels than the other two options, and 2) *Halobia superba* is

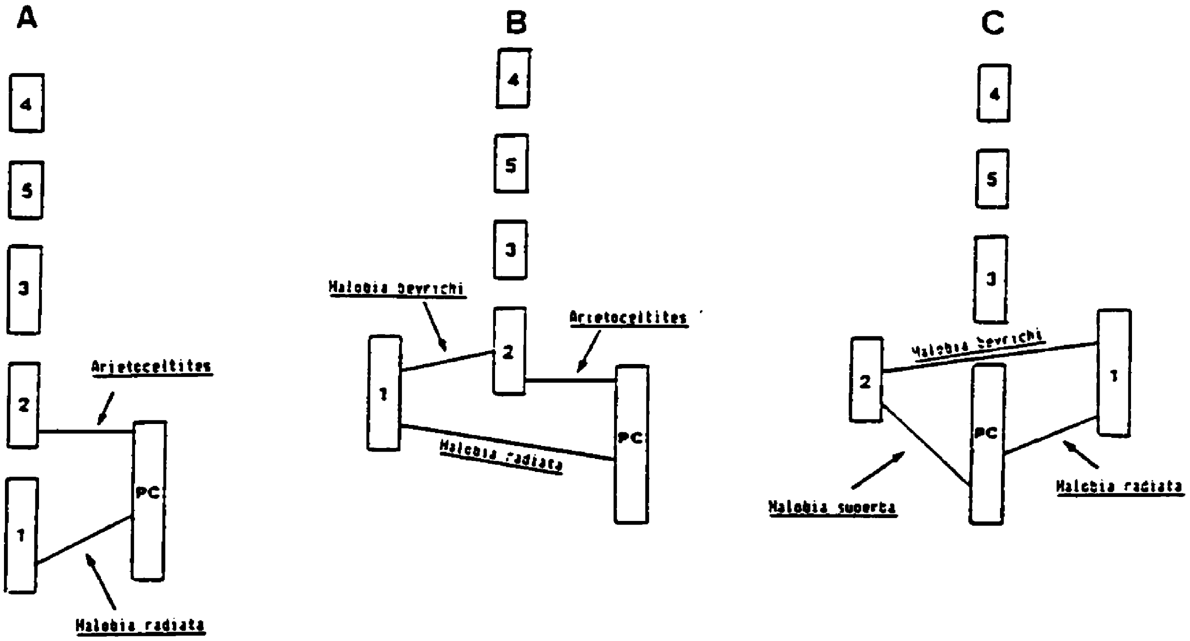


Figure 3.11. Block sequencing. Showing three alternative schemes to correlate and sequence the Martin Bridge stratotype and the Paddy Creek section into a composite section. Note that stratigraphic columns are not drawn to scale.

always below *H. beyrichi*, a succession observed within each block and elsewhere the two species occur in succession. The massive mudstone at the top of the Paddy Creek section with *Arietoceltites* may be fault-bounded and correlate to the base of Block 2; therefore, belonging lower in the composite section.

Interpretations of the stratigraphic succession for the remainder of the section rests on firmer ground. Block 3 is believed to rest conformable above Block 2. The lithology of the upper part of Block 2 and the lower part of Block 3 appear to be similar, suggesting no significant sedimentary break, even though the contact between the two is buried. The occurrence of *Halobia beyrichi* in both the upper part of Block 2 and the lower part of Block 3 also suggest the two blocks are conformable. Furthermore, *Halobia beyrichi* from Block 2 and the lower part of Block 3 suggests that it underlies Blocks 4 and 5.

Block 5 is believed to be stratigraphically above Block 3 and below Block 4. To the east of Block 4, a partially covered sequence of bedded limestone, similar to Block 4, is conformable underlain by limestone conglomerate indistinguishable from Block 5. Although no particular age-diagnostic fossils were recovered from the limestone conglomerate, *Disticophyllia norica* has a total Norian (?uppermost Carnian) range and could be older than the halobiid-bearing beds of Block 4. Furthermore, *Halobia* austriaca, found in float below Block 5 and above Block 4, suggests a Early Norian age for Block 5, an age older than the Mid Norian age established for the Halobia halorica of Block 4.

Discussion.-- Lithologic and faunal differences within and between correlated blocks can be attributed to rapid facies changes, lateral and stratigraphic transport by faults, and structural omission. Thrust faults between, and possibly undetected within blocks may have moved contemporaneous rocks from widely separated areas into stratigraphic juxtaposition.

Throughout the type area, most outcrops of limestone conglomerate appear to be lithologically correlative to Block 5. All are approximately 10 meters thick, and underlain by bedded limestone similar to Block 3. The shales and bedded-limestones of Blocks 2 and 3 act as the sole of the thrusts. Follo (in press) interpreted the limestone conglomerates to represent different debris sheets from separate down-slope events. All of the limestone conglomerate beds have same thickness and lithic character and are mapped as structural repetitions of the same marker bed. An exception may be the limestone conglomerate of Block 1 which, although may be fault bounded, appear to be conformable with adjacent beds.

The volcaniclastic shales and siltstones low in the Paddy Creek section pose another problem of interpretation. Nowhere in the Martin Bridge stratotype are there any tan volcaniclastic siltstones resembling those found at Paddy Creek. Perhaps they represent the lowest part of the Martin Bridge exposed in the type area. The volcaniclastics at the base of the Paddy Creek section maybe correlative to lithologically similar beds described from the base of the Martin Bridge at the Spring Creek locality in Hells Canyon (Whalen, 1988). Vallier (1977) and Follo (in press) state that volcanic activity was progressively shut off during Martin Bridge deposition, further corraborating the volcaniclastics at the bas of the Paddy Creek section.

With few exceptions, the stratigraphic sequence of the Martin Bridge, described herein, agrees well with the original description given by Smith (1912, 1927). Apart from the limestone conglomerate, the shale and mudstone at the base of Block 1 correlates well with the halobiid-bearing shales at the base of Smith's section. The upper part of Block 1 may correlate to Smith's unfossiliferous limestone. Although now known to contain a diverse fauna, Block 2 probably represents the 300 feet termed "barren shale" described by Smith (1927, p.10). The upper part of Block 2 and all of Block 3 probably correlate to the bedded, coraline-limestone described by Smith. Block 4 corresponds with Smith's argillaceous shales with _H. halorica_. Block 5 corresponds to the 60 feet of massive limestone that Smith described as barren of fossils.

CHAPTER IV

BIOSTRATIGRAPHY

The previous chapter has sequenced the fossils recovered from the Martin Bridge stratotype; this chapter builds on that succession by correlating the fossils from the Martin Bridge stratotype to other localities on the Wallowa terrane, other Cordilleran terranes, and elsewhere from the Upper Triassic. This chapter is divided into three parts. In the first part, the halobiid and ammonite occurrences described in the preceding chapter are assigned stratigraphic position, based on similar occurrences from other localities. Secondly, the stratigraphic position is then calibrated to existing zonal schemes by similar occurrences of halobiids, ammonoids, and conodonts. Thirdly, biostratigraphic units are identified by assemblage taxa from the Martin Bridge stratotype, and correlated to other Upper Triassic localities.

Halobia and the Triassic time scale

The historical development of the Late Triassic time scale has been adequately discussed by Tozer (1985) and needs only to be reviewed here when pertinent to halobiid biochronology.

Although Wissmann (1847, cited in Tozer, 1984) first recognized Halobia as a Triassic genus, it was not until 1874 that Mojsisovics published the first zonation of Halobia species. Like his ammonoid zonations (1875-1902), Mojsisovics' halobiid zonation was constructed with fossils from the Hallstatt region of the Northern Calcareous Alps. The fossils used for his zonation came from mixed, condensed and structurally isolated localities. Like his ammonoid schemes, he incorrectly placed the Carnian above the Norian Stage.

Kittl (1912) published a more substantial zonation for halobiid species. Although many of Kittl's Halobia species have been synonymized, his scheme remains relatively intact. Kittl's scheme correctly placed the Norian above the Carnian.

Smith (1927) described the Halobia succession from North America. Special note to Smith's work (1927) should be taken in that the fossils collected from the Martin Bridge stratotype were instrumental in constructing his scheme. From the Martin Bridge, Smith recognized three Upper Triassic "Zones"; Upper Carnian beds with Halobia oregonensis, overlain by the Lower Norian coral zone, overlain by the Middle Norian Pseudomonotis Zone. The zone of Halobia oregonensis he correlated with the Tropites subbulatus Zone of California, and beds with Halobia superba from Alaska. Smith believed both the coral and Pseudomonotis Zones could be recognized everywhere in North

American marine Triassic. The *Pseudomonotis* Zone he correlated to beds from Alaska, California, British Columbia, and Nevada containing *Monotis* (=*Pseudomontis*) *subcircularis*, and the ammonoids *Rhabdoceras*, *Halorites*, and *Arniotes*. Like his European contemporaries, Smith's collections had poor stratigraphic control, leaving the exact stratigraphic succession poorly understood. Although part of Smith's scheme remains useful, most of it (e.g. the *Tropites subbulatus* and coral Zones) has been emended or abandoned by subsequent workers (e.g. Tozer, 1967; Silberling and Tozer, 1968; Stanley, 1979).

Tozer (1967), and Silberling and Tozer (1968) included halobiids in their ammonoid zonation of the Upper Triassic. Although slight modifications have been added to the original scheme (Tozer,1971, 1974), it has remained relatively unchanged. The utility of the "North American Standard" is shown by its use by all North American and most European workers. Silberling and Tozer (1968) defined their zones as assemblage zones, admitting that zonal correlation often relies on one, or only a few, species. Unlike their European counterparts, these zones have stratotypes where they were originally described and defined. Thus, they satisfy the requirements as chronstratigraphic units of Hedberg (1976) and as chronozones of Harland and others (1982). Of the eleven zones identified by Silberling and Tozer (1968) for the Upper Triassic, only six are considered here in detail.

More recent work on the chronology of halobiids come from Caferio and De Capoa Bonardi (1980, 1982), who described the halobiid succession from Sicily, Yugoslavia, Greece and Turkey. Gruber (1976) illustrated a halobiid zonation from the Alpine Triassic, which, like the earlier works from the Hallstatt, are deficient in stratigraphic control, the sequence being mostly inferred. Polubotko (1984) illustrated a halobiid zonation from northeastern USSR, along with compilations of previously published halobiid chronologies from around the world. As will be discussed later (pg.xx), Polubotko introduced an error in her sequencing of Oregon halobiids.

Basis for age and stratigraphic position

The determination of age and stratigraphic position of the Martin Bridge faunas are considered separate from their correlation or recognition abroad. Complete sequences where the succession of faunas can be objectively demonstrated should be compared. Relatively few sections are available for this type of analysis. In North America, several sections in the Brooks Range of Alaska, Peace River Foothills of British Columbia, and in the Humbolt and Shoshoni Mountains of Nevada are available for such study. Several sections from Sicily, Yugoslavia, Greece are sufficiently intact, contributing to a reliable sequence of halobiids, ammonoids, and conodonts. Sequences from the Hallstatt region are only now becoming understood (e.g. Krystyn, 1980) and will offer more reliable data concerning Mojsisovics' and Kittl's localities. Northeastern Asia, particularly the northeast Soviet Union has begun to provide important localities and will contribute significant information on the succession of halobiid faunas.

This section will consider each age-diagnostic taxon recovered from the Martin Bridge stratotype and compare it to known sequences where the sucession has adequately been worked out.

The lower part of the Martin Bridge contains the *Discotropites* sp., *Halobia superba*, *H. oregonensis*, and *H. radiata*. *Halobia oregonensis* is an endemic species with no known occurrences anywhere outside of the Wallowa terrane; thus, is helpful for determining stratigraphic position only in a local region.

Halobia superba is cosmopolitan and has a temporally wider range than most halobiid species. At the Martin Bridge stratotype, the upper limit of *Halobia superba* occurrs below and with the ammonoid *Anatropites* and probably below *Halobia beyrichi*, while the lower limit is unknown. From the Pardonet Formation of northeast British Columbia, Tozer (1967) described forms regarded as *Halobia* cf. *H. superba* with the ammonoid *Dicotropites* as belonging to the Welleri and Dilleri Zones, and with the ammonoid *Anatropites* from the Macrolobatus Zone. From the Otuk Formation of the Brooks Range, Bloom and others (1988) found Halobia superba below H. cordillerana and attributed it to the Upper Carnian (Dilleri-Macrolobatus Zones). From European sections, Halobia superba is mostly considered an Upper Carnian species (Caferio and De Capoa Bonardi, 1980, 1982) primarily because it is found below H. styriaca and H. austriaca. Exact ranges however, have not been determined satisfactorily.

From the Martin Bridge, Halobia radiata is found both above and below beds with H. superba and H. oregonensis. It is confined to beds below Anatropites. Halobia radiata is not known from any other section in North America where succession can be demonstrated. In European sections from Budva area, Yugoslavia (Caferio and De Capoa Bonardi, 1980) and the Sicana and Imerese basins, Sicily (Caferio and DeCapoa Bonardi, 1982) Halobia radiata is almost always found below forms regarded as H. superba, but sometimes co-occurs with that species.

The ammonite Discotropites is usually found in beds below Anatropites and is believed to occur in beds typical of the Welleri and Dilleri Zones from Nevada, California, and Alaska (Silberling, 1959, Silberling and Tozer, 1968), and in northeastern USSR (Polubotko, 1984). Although the sequence of Discotropites below Anatropites has been found in several sections in Europe (e.g. De Weaver et al., 1979),

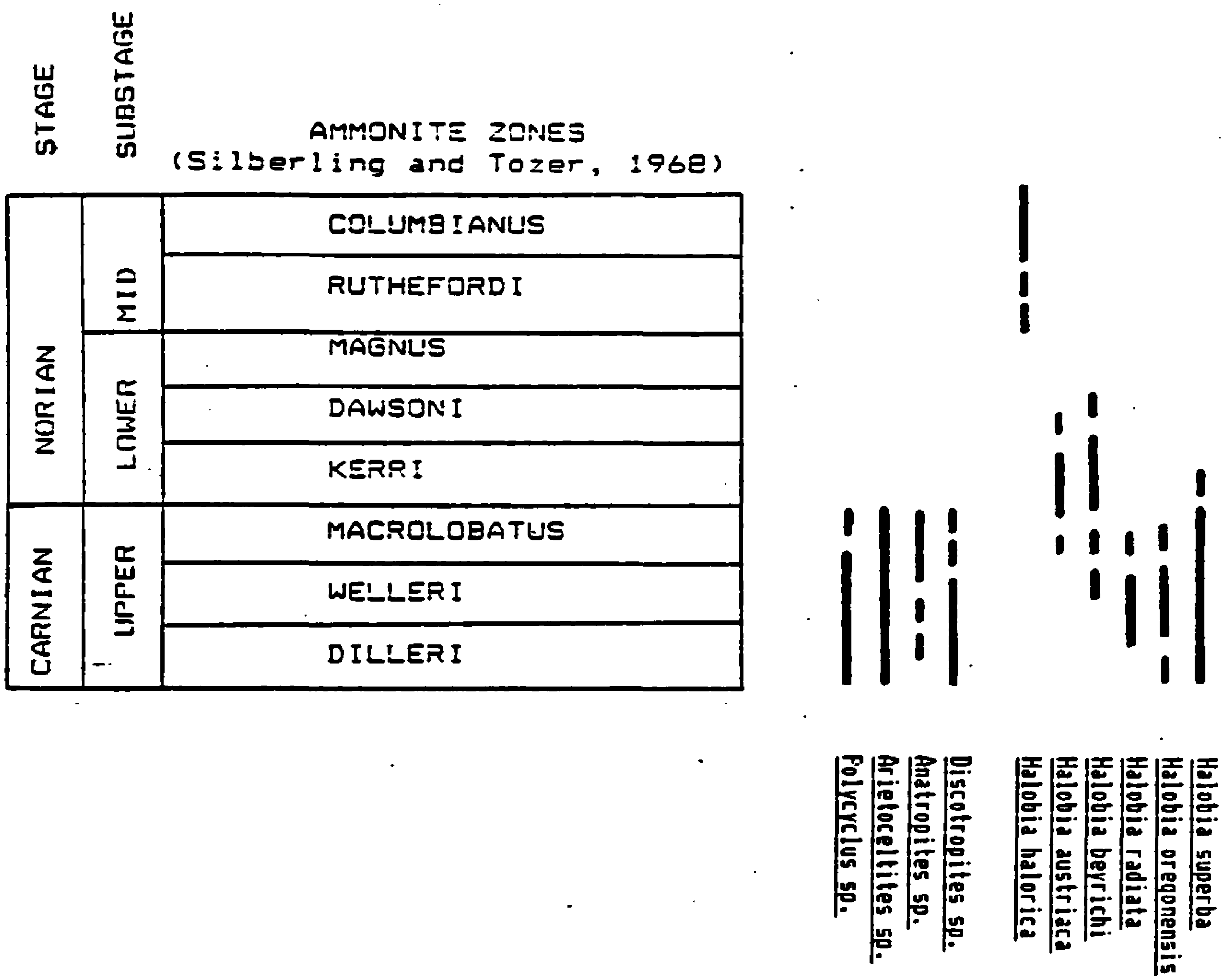


Figure 4.1. Range chart of Halobia species and ammonoids recovered from the Martin Bridge Formation. Compiled from many sources discussed in text.

other sections yield both genera from the same bed, where they occur in uppermost Carnian rocks (Krystyn, 1980, 1982). *Anatropites* is probably restricted to the Macrolobatus Zone, and *Discotropites* ranges through most of the Upper Carnian.

Halobia beyrichi has been reported only from a few sections in Europe where it is found at, or very near, the Carnian Norian boundary. In most of the sections (e.g Yugoslavia, Gruber, 1975), it is associated with, or found below *H. styracia*, a key species in halobiid chronology. In earlier reports from the southwest Pacific, *H. stryacia* was thought to occur in the Lower Carnian (e.g. Kobayashi and Mansanti, 1968). More recent studies from sections in Yugoslavia (Caferio and De Capoa Bonardi, 1980) have *Halobia beyrichi* placed in either the uppermost Carnian, below *H. styriaca* and *H. halorica*, and coinciding with *H. austriaca* and *H. superba*, or more commonly in the Lower Norian, above these two species. Re-interpretation of the Yugoslavian section, and others in Sicily, suggest that *H. styriaca* and *H. beyrichi* are Lower Norian (Caferio and De Capoa Bonardi, 1982). This sequence is also confirmed from the section in Turkey (De Weaver et al., 1979). When combined with conodont data, the sections in Sicily and Turkey indicate that *Halobia styracia* (probably also *H. beyrichi*) occurs at approximately the same stratigraphic horizon in the lowest Norian, Lacian 1 zone (De Capoa Bonardi, 1984). As previously mentioned, *Anatropites*, is confined to the

Macrolobatus Zone and is found below *H. beyrichi*. This occurrence, *Halobia beyrichi* above *Anatropites* sets the lower limit for *H. beyrichi* as within or above the Macrolobatus Zone. The upper limit probably lies in the Kerri Zone.

The stratigraphic position of *Halobia halorica* seems well-established in the upper part of the Lower Norian and throughout the Middle Norian. From Turkey and Sicily, De Weaver and others (1979) reported *H. halorica* below *H. lineata* and above the ammonoid *Malaysites*, an upper Lower Norian genus. The same study associated *Halobia halorica* with the conodonts *Epigonoella abneptis*, a Lower-Middle Norian form, and *E. postera*, strictly a Middle Norian form. From Sicily, Caferio and De Capoa Bonardi (1982) reported the same sequence from the Middle Norian (Aluanian 2). From the Brooks Range, Bloom and others (1988) reported *Halobia* cf. *halorica* above *H.* cf. *cordillerana*, an uppermost Carnian -to- mid-Norian species, and below *H.* cf. *plicosa* also suggesting a similar stratigraphic position and age.

The faunal sequence from the Martin Bridge stratotype is given in Figure 4.1. It is apparent that a large span of time is missing from the section, mainly the Magnus and Dawsoni Zones of the Lower Norian. The following discussion explain this gap.

Biostratigraphic Units

Three informal biostratigraphic units have been identified from the Martin Bridge stratotype. The units should be considered biostratigraphic rather than biochronologic units because they are defined solely on biological terms. They are comprised of a characteristic fossil assemblages which can be correlated to the chronozones of Silberling and Tozer (1968) and to other fossil assemblages containing similar faunas. Each of these assemblages is considered to represent a different age, and do not overlap. Three biostratigraphic units, BU-1 through BU-3, are defined below. They are correlated by either recognition of a similar taxa or recognition of taxa of inferred similar age.

Because of the wide temporal span of most genera and species reported herein, these units are broader than the zones described by Silberling and Tozer (1968). In most cases, the boundaries of these units can not be discerned because of structural displacement or because they are separated by beds where fossils have not been recovered. The chronologic position of these biostratigraphic units are given in Figure 4.2, where they are broadly compared to the chronostratigraphic scheme of Silberling and Tozer (1968).

BU-1.-- The lowest biostratigraphic unit contains the following species as found at the Martin Bridge stratotype

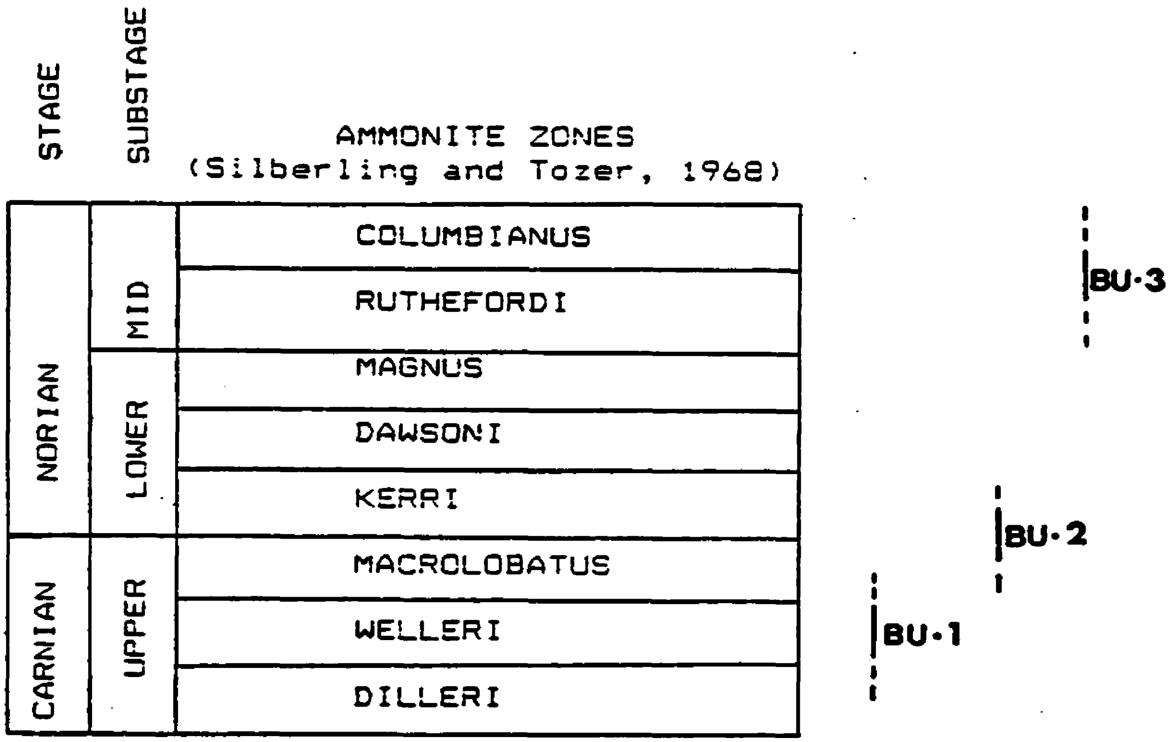


Figure 4.2. Biostratigraphic units constructed from halobiids and ammonoids recovered from the Martin Bridge stratotype. Note, these biostratigraphic units are only loosely correlated to the ammonoid zonal scheme of Silberling and Tozer (1968).

and Paddy Creek sections: _Halobia superba_, _H. oregonensis_, _H. radiata_, _Discotropites_ sp., and _Arietelceltites_ sp.. From the Martin Bridge stratotype, BU-1 is found in the lower part of Block 1 and the lower half of Block 2. The entire Paddy Creek section is believed to be contained in BU-1. The age of BU-1 is Late Carnian, and is believed to fall within the Welleri and Macrolobatus Zones of Silberling and Tozer (1968).

_BU-2_.-- Biostratigraphic unit 2 contains the following 2 species: _Halobia beyrichi_ and _Anatropites_ sp. The one occurrence of _Halobia austriaca_, obtained from float (?Block 5) belongs in BU-2. The upper part of Block 2 from the Martin Bridge Stratotype contains BU-2. The age of BU-2 is believed to be latest Carnian and earliest Norian, spanning the upper part of the Macrolobatus into the Kerri Zones of Silberling and Tozer (1968).

_BU-3_.-- The third biostratigraphic unit contains _Halobia halorica_. _Halobia_ cf. _H. lineata_ was found in float near below Block 5 and belongs to BU-3. All of Block 4 is believed to lie within BU-3. The age of BU-3 lies within the upper part of the Rutherfordi and within the Columbianus Zones of the Middle Norian.

Correlations

Unlike the process of determining stratigraphic position, fossil occurrences may be correlated to localities where the stratigraphic succession is unknown or poorly understood. This is of considerable importance because most of the Upper Triassic localities in the alpine areas of Europe, the North American Cordillera and elsewhere in the circum-Pacific come from strata of unknown or poorly understood sequences. Correlations are of two types: 1) direct correlation by similar taxa, and 2) inferred correlation to localities containing related taxa, or other taxa of an inferred similar age. This section concentrates on the first type, as the second type is subjective and open to interpretation.

With few exceptions, The Martin Bridge stratotype can be correlated with the marine Triassic sequences where halobiids have been found. Only localities deemed important for interregional correlations are considered here. For additional localities, the reader is referred to the extensive synonymies and occurrences listed for each species in Chapter 6.

Many localities in the North American Cordillera can be correlated with the Martin Bridge stratotype. From Hells Canyon, _Halobia_ _austriaca_ has been found below the Lower Norian bivalve shell beds reported by Newton and others

(1987) (T. Fleming, pers. Comm., 1989), and correlated to BU-2. In the northern Wallowa Mountains, *Halobia oregonensis* and *H. superba* occur in the Martin Bridge and Hurwal Formations (Nolf, 1966) and can be correlated to BU-1. Correlations with the Shasta region of California rely mainly on data obtained from Smith (1927), including *Halobia superba* and *H. austriaca* suggesting correlation with BU-1 and BU-2 of the Martin Bridge stratotype.

Numerous localities in Alaska can be correlated with the Martin Bridge stratotype. Apart from the described occurrences from the Otuk Formation of the Brooks Range (Bloom et al., 1988), the Peninsular, Alexander, and Wrangell terranes can be correlated to all three biostratigraphic units, where *Halobia superba*, *H. austriaca*, and *H. halorica* are locally abundant (Smith, 1927; Silberling, 1963; C.R. Newton, unpublished data).

Although similar halobiid occurrences are known from the western Pacific terranes of Asia, one locality deserves special mention. From the Korayak terrane of northeastern Soviet Union, Mel'enkova and Bychkov (1986) report a fauna containing: *Halobia* ex. gr. *austriaca*, *H.* aff.*ornatissima* (=*H. superba*), *H.* aff. *brooksi* (=?*H. austriaca*) , *Anatropites* sp. and *Discotropites* sp.. This fauna is more similar to the Martin Bridge stratotype than to other Soviet localities further west in the Kolma, Yana, and Indigiro River Basins (Kiparisova, et al., 1966; Polubotko, 1980,

1984) which seem to represent an endemic fauna. It is intereseting that Stanley and Whalen (1989) reported coral species known only from the Koryak and Wallowa terranes.

Discussion

From the described biostratigraphic units it is clear that the halobiid succession here reported from the Martin Bridge stratotype generally conforms to that proposed by Smith (1927); the exception being *Halobia salinarum* which he reported from low in the section. During this study, *Halobia salinarium* was never recovered from the Martin Bridge stratotype. *Halobia salinarum* is restricted to the mid Norian (e.g. Gruber, 1976), and does not agree with the ammonoid or halobiid ages for Block 1. It is unlikely Smith would mistake *H. radiata* for *H. salinarum* (his original material was re-studied, and clearly the two species are different). It is suggested here that the specimens reported as *H. salinarum* were from a different locality than that described by Smith. This species may have come from higher up in the section (Block 4, BU-3) where a similar species, *H.* cf. *H. lineata* was recovered from float.

In her biochronologic compilation of Oregon *Halobia*, Polubotko (1984) introduced an error by listing *Halobia oregonensis* in the mid-Norian. She may have tried to correct the age discrepancy between *H. salinarum* and *H.*

oregonensis, to which Smith (1927) placed in the Upper Carnian. Because *Halobia oregonensis* is unquestionably Carnian, as correctly pointed out by Smith, Polubotko's error can easily be resolved by disassociating Smith's *H. salinarum* from *H. oregonensis*, and placing it in the Middle Norian where it belongs.

A large span of time represented by the Magnus-Dawsoni Zones was not identified in rocks between BU-2 and BU-3. This gap may be represented by the upper parts of Block 3 and Block 5 in its entirety. The corals mentioned in the preceding chapter, *Disticophyllia norica* and *Retiophyllia norica*, are mostly known from the Lower-Middle Norian (Smith, 1912, 1927; Stanley 1979, 1986), and may belong in this interval. Further sampling may reveal age diagnostic fossils from the upper part of Block 3 and Block 5 which may allow recognition of an additional biostratigraphic unit.

Of interest is the absence of *Halobia cordillerana* from the Martin Bridge stratotype. *Halobia cordillerana* is known from the Hurwal Formation at Excelcior Gulch five kilometers from the Martin Bridge stratotype (Silberling, cited in Follo, in press). The range of *Halobia cordillerana* from Macrolobatus to ?Dawsoni Zones would fall within the gap in the upper part of the Martin Bridge stratotype. This discrepency could be explained on facies grounds if the limestone conglomerate of Block 5 represents a very localized event, or on structural grounds, if the strata containing *Halobia cordillerana* is deleted by faulting.

Although fossil evidence indicates Martin Bridge deposition occurred between the Welleri (?Dilleri) and Columbianus Zones, the definite time constraints for all of Martin Bridge deposition remains a question. The lowest fossiliferous beds from the Martin Bridge type area are probably represented at the Paddy Creek section by the volcaniclastic siltstones containing *Halobia superba* and *H. oregonensis*. Beds with *Halobia halorica* of Block 4 are Middle Norian and set the upper limit for the Martin Bridge in the type area.

CHAPTER V

PALEOECOLOGY OF HALOBIA

As mentioned in Chapter 1, the morphology of halobiid bivalves and their occurrence in varied bio and lithofacies suggests a life-habit and ecology very different from other extant and extinct bivalves. This chapter proposes answers to some of the paleobiological and paleoecological questions raised by their morphology, and broad geographic and facies occurrence.

Numerous authors have suggested three general life-modes for Halobia: 1) benthonic, 2) pseudoplanktonic, and 3) nektonic. Within the benthonic class, a reclining, endobyssate or epibyssate habit have been suggested. An epibyssate habit is inferred for all pseudoplanktonic interpretations. Figure 5.1 illustrates the possible life-habits for Halobia.

This study adopts the position that all species of Halobia were epibyssate and pseudoplanktonic, meaning they were passive plankton, attached to floating objects. Although support for this life-mode primarily relies on deductive logic and functional analogy, positive evidence comes from halobiid morphology and sediment and biological associations. In this regard, the methodology used for this study is similar to that of Jefferies and Minton (1965), Gruber (1976), and Campbell (1985b). The methodology used in this study differs from

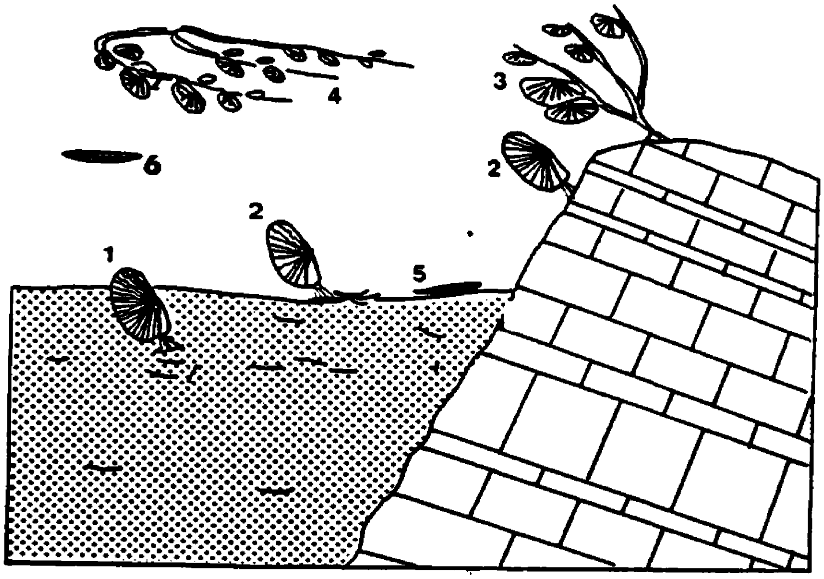


Figure 5.1. Reconstruction of possible halobiid life-habits. 1) benthic, endobyssate; 2) benthic, epibyssate; 3) benthic, epibyssate on rooted alga; 4) pseudoplanktonic, epibyssate on floating alga; 5) benthic, reclining; 6)necktonic.

most other studies in which conclusions on halobiid life-habits were made by crude analogy with other bivalves, occasionally without apparent reference or reason. For example, both Kobayashi and others (1966) and Wignall (1988) offer no supporting evidence for their interpretation of halobiids as mud-loving benthic animals (1, 2, 5, Figure 5.1).

Halobiid functional morphology.

Figure 5.2 illustrates the morphological features of Halobia. These features were adequately described by Campbell (1985b), and need only be reviewed in the following section. Special note of Campbell's work should be taken, in that he was the first to recognize the anterior byssal tube, apart from the anterior auricle (Figure 5.2). He also demonstrated variability in the halobiid ligament, encompassing both alvincular and multivincular types. As discussed in the following chapter, recognition of the byssal tube and variable ligament grades questions some of the higher-level systematics for the genus.

Morphologic and structural features used to infer mode-of-life are restricted mostly to the exterior of the shell. They include the size and outline of the shell, the auricle and byssal apparatus, and the strength, position and course of costae and rugae. Valve interiors sometimes show size and position of musculature, which,

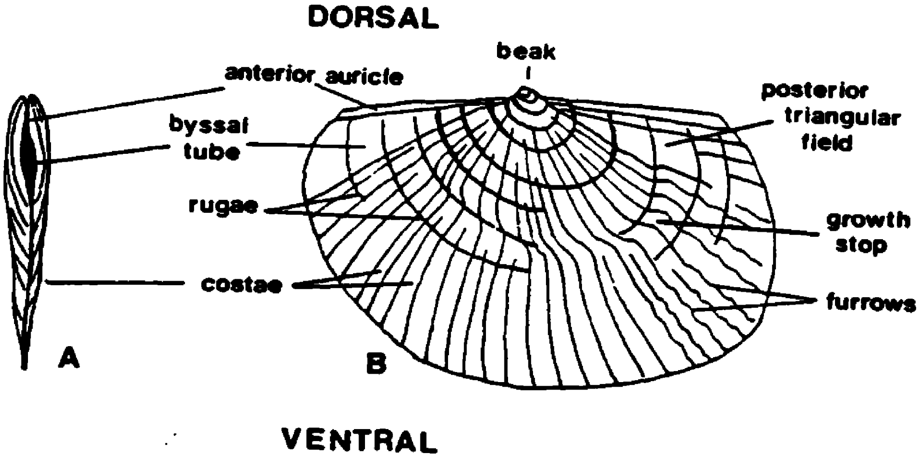


Figure 5.2. Morphological features of <u>Halobia</u>. Illustrated is A) anterior view showing very narrow width and byssal tube aperture (byssal gape); and B) left valve showing morphologic features discussed in text.

when observed, may be used to infer a life-mode.

The most striking feature of halobiids is their very thin shells. Although the shell of Halobia is reported to range from 15 to 60 microns thick (Krumbeck, 1924), one specimen measured during this study was more than 100 microns thick. The adaptive significance of an extremely thin shell is unclear. E.G. Kauffman (pers. comm., 1988) suggested that the large surface-to-volume ratio and extremely thin shells of many "flat clams" may aid in oxygen absorption through the shell, allowing them to live in oxygen deficient environments. Although this argument may seems plausible, direct or indirect evidence is lacking. The thin shells of Halobia probably weighed little, and may have allowed the animals to pack densely on an extended or floating plant or algal frond without sinking it.

Halobiids also have very compressed valves. Measurements taken during this study indicate that the width of two closed valves would be no greater than five millimeters. The narrow width of halobiid valves greatly restricts the little volume of the visceral mass, and may have several functions. The narrow valve width may have acted as a streamlining function, minimizing friction from currents, and/or achieving stabilization. Additionally, the narrow widths of halobiid shells may have allowed dense packing.

Campbell (1985b) departed from previous interpretations by recognizing the difference between the auricle and byssal tube of Halobia. Earlier workers considered both structures together as the "Halobia ear". The true auricles of halobiids are very reduced, usually no greater than two millimeters in width (Figure 5.2). Structurally, the auricles function as a flattened hinge between the two valves. The auricles may also act as small rudders, aiding in keeping the shell perpendicular to its substrate.

Rather than a byssal notch or sinus, halobiids have a byssal tube (Figure 5.2). This tube is considered a developmental necessity for housing the byssal threads. Campbell (1985b) interpreted thread-like structures attached on the byssal tube interior as fossilized byssal threads. The angular breadth and gape of the byssal tube probably allowed the animal to swing loosely on its byssal threads in response to changing current velocity and direction.

The general outline of halobiid shells vary between, and to a lesser extent within, species. Shell outlines fall into three easily recognizable types: Type I-- equant with the height:width ratio (H/L) greater than 1 (e.g Halobia austriaca, Figure 6.6.9), Type II-- equant with the H/L less than 1 (e.g. Halobia halorica, Figure 6.6.1), and Type III-- posteriorly elongate with the beak sub-central (typically anteriorly) and H/L usually less than 1 (e.g. Halobia oregonensis, Figure 6.3). Types II and III usually exhibit long straight hinge margins.

Many species of Halobia are elongated posteriorly (Type III). Posterior elongation has been described as nearly a universal feature among epifaunal bivalves with the sagittal plane vertical (Stanley, 1970). Elongation of the bivalve shell may have served two purposes: 1) to aid in keeping the shell from overturning, and 2) to elevate the exhalent aperture to avoid blockage (Stanley, 1968, Gruber, 1976). Posterior elongation is also a suitable morphology for an endobyssate habit where the sagittal plane is vertical. Pinna and several species of Mytilus and Modiolis are examples of endobyssate bivalves with posterior elongations. The morphologies of endobyssate species of Mytilus and Modiolis greatly differ from Halobia; they are wider, and more elongate. Although both Mytilus and Modiolis are byssate, for species that live in soft mud, their width enables them to "float" in the sediment with their dorsal margin inclined. Pinna, on the other hand, are extremely elongated posteriorly with the dorsal margin oriented vertically; an orientation improbable for halobiids. Although differing slightly in morphology, especially in regard to the auricle areas, Pteria may serve as a better analog. Like Halobia, most species of Pteria are also elongated posteriorly, are equivalved, and have a very thin shells with narrow valve inflation. In life, Pteria is epibyssate with the sagittal plane oriented vertically and the dorsal margin slightly inclined.

Jefferies and Minton (1965) suggested, by analogy with *Posidonia*, that the musculature and posterior gape of *Halobia* indicate a nektonic mode-of-life. Gruber (1976), appealing to musculature and shell symmetry as evidence, concurred at least for *Halobia subreticulata*, a type I halobiid. This argument fails upon close scrutiny of characters. More probably, the posterior gape on halobiids is an aperture requirement for exhalent currents. The disturbance of costae on the posterior field of *Halobia* probably reflects the exhalant path (S.Stanley, pers. comm., 1990). The musculature of *H. subreticulata* (Gruber, 1976) appears to be smaller than that of extant swimming bivalves (Stanley, 1970). More convincingly, most swimming bivalves are inequivalved, with a strongly convex lower (left) valve (Stanley, 1970). Because halobiids are equivalved, it is unlikely they were nektonic.

Through analogy with *Inoceramus* and other thin-shelled pteriomorphs, Kauffman (1988) suggested that halobiid shell morphology is evidence of expanded gills, and may have used bacterial chemosymbionts allowing them to live as benthos in oxygen-starved environments. Although several extant bivalves use chemosymbiotic bacteria (e.g. *Calyptogena magnifica*, *Bathymodiolus thermophylus* and several species of *Tridacna*), they live exclusively in hydrothermal vent or shallow-water hypersaline environments. This argument fails for lack of any tangible evidence of gill structure or symbiotic relationship in halobiids. It would seem that the small volume enclosed by compressed valves would limit gill size. Furthermore, halobiids are not associated with sediments indicative of vent or hypersaline environments.

The morphologic evidence documented here and cited by Campbell (1985b) indicates that halobiids were byssate, equivalved and non-pleurothetic. Their extremely thin shells were probably tough but flexible. Their exterior shape is streamlined. As Campbell (1985b) recognized, such morphology would be regarded by Stanley (1970, 1972) as evidence of a nestling, epibyssate mode, with the shell pendently suspended in the water column. On the same morphological grounds, Kauffman (1969) would regard Halobia and its allies as free-swinging byssate organisms. Because byssal threads almost never fossilize (although see Campbell (1985b) for a possible exception), a halobiid found fossilized in its original life position is unlikely. After death, the byssal threads and ligament would decompose leaving the disarticulated valves to settle on the sea floor.

Shell beds and sedimentary environments.

Most inferences concerning halobiid life-habits rely on their occurrence in a particular rock and biofacies. While halobiids have been found associated with nearly all marine rock types (eg. Kobayashi et al.,1966), most occur in organic-rich black shales, including much of the Martin Bridge stratotype. Such shales are finely-laminated with high organic carbon contents, indicative of anaerobic or dysaerobic environments (cf. Rhoads and Morse, 1971). At the Martin Bridge stratotype, halobiids were also found in slightly-calcareous siltstones and shales of probable volcanic origin, in moderately-to-highly calcareous mudstones, and concentrated in small, crenulated halobiid limestone lenses composed entirely of compressed shells. Similar occurrences of halobiids in crenulated limestones have been reported only from Yugoslavia (Jurkovesk, 1985).

In the Martin Bridge stratotype, halobiids locally occur in shell beds with their valves covering entire bedding surfaces, or as isolated constituents in otherwise barren sediments. The shell beds are numerous and intermittently spaced throughout the section, normally separated by several centimeters of barren sediments.

The lower boundaries of the shell beds are frequently gradational; whereas, the upper surfaces are typically abrupt, or more rarely, gradational (Figure 5.3). The sharp upper boundaries of the shell beds are not erosional surfaces. This condition (Type I of Kidwell, 1985), could represent decreasing sedimentation rates, followed by an increase of clastic input. An alternative to Kidwell's (1985) interpretation invokes a halobiid population expansion or immigration. Increasing and subsequently

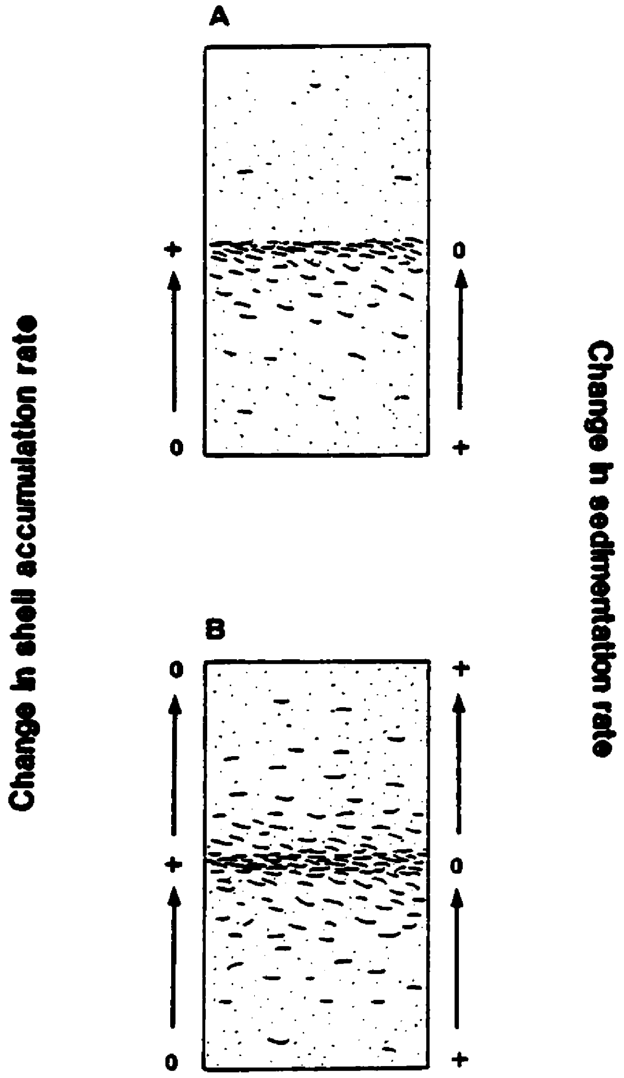


Figure 5.3. Diagrammatic genetic classification of shell beds. A) Upper shell bed surface bound by sharp discontinuous surface, depicting mass-mortality or slow down and cessation of clastic input. B) Gradational upper and lower surface of shell bed illustrating slowing and subsequent increase of clastic input, or increase of deposition (immigration) and subsequent decrease (emigration) of shelly organisms. Modified from Kidwell (1985).

decreasing the biogenic shell deposition rate would produce the same pattern as changing sedimentation rates. Changing biogenetic deposition seems a more reasonable alternative for formation of these shell beds because the abrasion and dissolution (corrasion) of shell material long exposed on the sea floor was not observed. In modern environments, even small shell bed accumulations require unusually high organic production (Davies, et al., 1989).

The shell beds are composed of virtually all single valves; articulated valves are rare. The shells are always found parallel to bedding. Although many of the shells in the concentrations are broken, probably from compaction, many are complete or nearly complete. Table 5.1 shows the frequency among left, right, articulated, and convex-up, concave-up valves from the bedding planes of several slabs collected during this study. The results in table 5.1 indicate little significant preference in the preservation of left and right valves, and no significant difference between convex-up and concave-up orientations.

In other settings, halobiids with their shells convex-up are more common (Kobayashi et al., 1966). N.J. Silberling (pers. comm., 1988) noted however, that many monotiid and halobiid accumulations are concave-up. Studies in modern environments, below wave base, show that shells with a convex-up position have undergone some re-working by currents, and a concave-up orientation reflects deposition in quiet environments (Emery, 1968). Current orientation of valves in the shell beds is not supported by the data (Table 5.1).

TABLE 5.1. Orientation of halobiid valves from select bedding planes. LV= left valve, RV=right valve, ARTIC= articulated left and right valves, INDET= left or right valve, CONC-UP= concave-up, CONV-UP= convex-up.

SPECIMEN	LV	RV	ARTIC	INDET	CONC-UP	CONV-UP	N
UMIP 16042	10	8	1	6	7	18	26
UMIP 16012b	7	13	0	26	19	27	46
UMIP 16041	3	5	0	2	7	3	10
UMIP 16058	5	7	0	2	11	3	14
UMIP 16030	4	4	0	3	6	5	11
TOTALS	29	37	1	39	50	58	224

Since the data in Table 5.1 are inconclusive regarding water velocity regimes, the question remains whether the shells were transported into shell beds or formed in place. The finely-laminated texture of the halobiid-bearing sediments suggests the shells were not transported far. The absence of broken shells, and the occurrence of open articulated valves may also support this view. However, halobiid shells may be stronger than their thinness suggests, and Campbell (1985b) cited evidence that the correlation between articulated valves and low-energy environments may be misleading.

The characters of the shell beds described above offer strong evidence for an epibyssate life-mode for halobiids. The absence of closed, articulated valves, expected for endobyssate bivalves, also support an epibyssate life-mode. The predominance of disarticulated shells, and absence of corresponding left and right valves indicates that halobiids lived in an environment above the substrate.

Biotic associations and oxygen deficiency.

Sedimentary structures, a distinctive mineralogy, and faunal composition are often used to infer oxygen levels of past environments (e.g. Rhoads and Morse, 1971). Evidence for oxygen deficiency is based mostly on negative criteria, relying upon the relative abundance and diversity of benthonic organisms, especially when compared with pelagic faunas. This deductive approach has been applied successfully in several studies (e.g. Rhoads and Morse, 1971; Thompson et al., 1985), and is the primary evidence for anoxia in the Martin Bridge analysis. Besides the lithic characters of many halobiid-bearing rocks of the Martin Bridge, consideration of the presence and absence of other invertebrates provides evidence of oxygen deficiency.

From the Martin Bridge stratotype, halobiids have been found closely associated with ammonites, and rarely with the trace fossil *Chondrites*. Other authors have noted similar associations (e.g. Jefferies and Minton, 1965, Ichikawa, 1958, and Tozer, 1982). The associations described above are striking in that, apart from Chondrites, the halobiid-bearing sediments lack a normal benthonic shelly biota.

Studies by Bromley and Ekdale (1984) and Ekdale and Mason (1988) indicate that Chondrites, the trace of an unknown deposit-feeding animal, may be indicative of either anaerobic or dyaerobic environments. On the other hand, Seilacher (1967) and Wheatcroft (1989) believed Chondrites indicates only deep water and has little or no bearing on the issue of oxygen levels.

Epizoan infestation is extremely rare on halobiid shells; only one example is known from Japan, the polychaete Spirobis encrusting a valve interior (Kobayashi and Aoti, 1943). This is quite unusual, since most fossils and the exoskeletens of living organisms from normally oxygenated waters show some evidence of epizoan infestation or bioerosion. None has been seen among the Martin Bridge halobiids.

Furthermore, in beds stratigraphically adjacent to halobiid-bearing rocks from the Martin Bridge at the Paddy Creek section, a slightly calcareous, massive mudstone contains a benthonic fauna, and bioturbation, more typical of oxygenated environments (Chapter 3, Figure 3.10, locality PCF). The halobiid-bearing shales contrast sharply with the massive mudstone not only in their faunas, but also because authigenic(?) pyrite is common in the shales, possibly a result of increased sulfide production, a typical feature of oxygen-starved environments. Apart from the beds that contain benthic fossils, all of the halobiid-bearing rocks of the Martin Bridge stratotype presumably formed in an oxygen deficient environment.

Most models of anaerobic or dysaerobic basins use the shallow, epeiric sea or Black Sea analog, with restricted circulation. However, increasing evidence (Wignall, in press) shows many black shale environments may represent a deeper-water facies. Although an analog for a black shale setting in a back-arc basin is unknown, Wignall (in press) believes many anaerobic deposits in the open ocean may have formed beneath up-welling areas, and may serve as an alternative to the epieric-sea model. If Wignall is correct, the Martin Bridge stratotype may represent a deeper-water oceanic setting where anoxic conditions prevail.

Halobiid substrates and the epiplanktonic hypothesis.

Suitable substrates for halobiid byssal attachment include hard or soft-sediments, any shelly material either resting on or below the sediment surface, rooted and floating flora and fauna, and other floating debris. By deductive logic which eliminates competing or alternative hypothesis and through analogy, an extended, or floating soft substrate (Figure 5.1) is favored for halobiid attachment.

Hard substrates, resting on, or in the sediment, and firm sediments (e.g. hardgrounds) are unlikely candidates for halobiid attachment sites. An endobyssate attachment mode-of-life is ruled out due to the lack of closed, articulated valves which one would expect if the shells were partially, or wholly, buried. Even though shelly material is locally abundant in halobiid-bearing sediments (halobiid and ammonoid shells), a hard shelly substrate resting on the soft-sediment surface (benthic islands of Seilacher, 1982) is unlikely because there is good independent evidence for anaerobic or dysaerobic conditions near the sediment-water interface. A hardground substrate is also ruled out because synsedimentary, small-scale folding and slumping in many of the halobiid-bearing rocks suggests soft sediment (Figure 3.5).

An alternative to a benthic substrate includes an extended or floating faunal or floral substrate. Although a variety of organisms could have served this role (e.g. corals, stalked echinoderms or arthropods), all but soft-bodied organisms, marine plants or vegetative algae are ruled out because fossilized hard parts of other organisms are absent from most halobiid occurrences. Whether halobiids were byssally attached to algae, either rooted or floating, is hotly debated and discussed below.

Numerous fossil examples of epiplanktonic bivalves attached to wood are known. Nye and others (1975) have shown that a Devonian pterioid, Lunnulacardium curium, attached to floating wood and subsequently sank into the presumably euxinic muds of the Marcellus Shale of New York. Horn (1960) illustrated bivalves attached to once floating wood from the Carboniferous of West Germany. The Posidienschiefer of the German Jurassic is well known for its pseudoplanktonic fauna of epibionts attached to wood and ammonoids (Seilacher, 1982, but see Kauffman, (1981) for an alternative view).

Examples of bivalves attached in situ to algae are rare in the fossil record. McRoberts and Stanley (1989) described the first example from the Mississippian of Montana. This assemblage includes over 100 pterioid bivalves byssally attached along a loosely coiled ?brown algal thallus. The thallus was probably extended, and possibly floated as plankton.

Modern analogs of bivalve-algal associations are quite common. Sargassum, a brown, vegetative alga found in the temperate and subtropical waters of the Atlantic, Pacific, and Indian oceans, commonly is attached to by numerous organisms including bivalves (Fine, 1970; Mukai, 1976; Weis, 1968). Sargassum, recorded several thousands of kilometers from its home range, has been found on the deep-sea floor (Schoener and Rowe, 1970). Jerzmanska and Ktarczyk (1976) proposed the Sargasso community had its origin in the Tethys

Seaway in the earliest Cenozoic time; there is no reason to exclude similar communities before that time.

Although halobiid-algal associations remain to be discovered, many workers believe that such a life-habit could help explain their varied facies and broad geographical distribution (Krumbeck, 1924, Hayami, 1969, Ichikawa, 1958, and Campbell, 1985b; although, see Gruber, 1976 for opposing arguments). Campbell (1985b) observed semi-linear arrangement of halobiid shells on bedding surface and postulated the pattern might reflect mass attachment to algae. Grant-Mackie (1980) postulated a similar life-mode for Monotis, a possible Halobia analog. Like algae and marine plants, driftwood, and even pumice, may have been suitable, albeit rare, attachment sites.

Problems with a pseudoplanktonic mode-of-life for halobiids can be explained by preservation and the inadaquacies of the fossil record. The absence of an in situ life association probably is due to the rapid decomposition of the plant material. The concentration of halobiids in thick, laterally continuous shell beds, require the input of large numbers of shells. The mechanisims for such an episodic input are difficult to explain. If the halobiid shell beds were derived as epibionts on settling algae, the algal mass must have been quite large and densely populated by bivalves. The settling of isolated alga thalli may account for the sometimes scattered occurrences of halobiids in otherwise barren sediments.

Given the epibyssate morphology of halobiids, a probable oxygen-deficient benthic environment, and numerous examples of modern bivalve-algae analogs, an epibyssate, algal-hosted life-mode remains a viable hypothesis to explain halobiid ecology.

Halobiids as fossil opportunists.

MacArthur (1960) distinguished between species that are mostly resource limited (equilibrium species) and those controlled mostly by the physical environment (opportunistic species). MacArthur described opportunistic species as physiological generalists with high numerical abundances maintained by very high fecundity rates and short generation times. Opportunists are typically eurytropic and can live in a variety of environments. Their populations explosively expand when environmental conditions allow, often to the exclusion of equilibrium species.

Levinton (1970) expanded this concept to fossil species, suggesting traits that can aid in the identification of fossil opportunists. These traits include: 1) populations showing rapid fluctuations in abundance, 2) communities with a very low diversity (e.g. monospecific), 3) rapid taxonomic turnover, typically with high extinction and origination rates, and 4) populations found in ecologically unstable, extreme, or newly created paleoenvironments.

Through these criteria, halobiids can be viewed as fossil opportunists, although many opportunistic traits can come from their floating algal substrates. Halobiids show rapid fluctuations in population density as evidenced by the shell concentrations. Most halobiid shell beds are monospecific and laterally extensive. The species composition of successive beds often alternates. The environment proposed for many of the halobiid-bearing rocks seems inhospitable to most benthic invertebrates. Furthermore, the species duration of halobiids is very short, averaging around two million years per species (calculated by comparison of published halobiid range charts (e.g. De Capoa Bonardi (1984) with Harland and others (1982) time scale).

Halobiids can be viewed as physiological generalists becauseheir occurrences in varied lithofacies attest to their ability to adapt to numerous marine habitats. Halobiids need not have been specialist to adapt to a floating substrate. As generalists, they could have fit into many ecologic niches, including floating plants and algae.

Several authors (e.g. Hallam, 1981) commented on the apparent contradiction between the opportunistic aspects of Halobia and the environmental stability previously assumed for many deep-water black shales. This contradiction is resolved if halobiids were attached to floating plants or algae high in the water column, above anoxic bottom waters. The contradiction would also be resolved if the black-shale benthic environment was not stable. Although common in shallow sea settings, Wignall (in press) has shown that many oceanic black shales were probably subject to rapid changes in sea water chemistry and fouling agents. If Wignall is correct, the successive changes in environmental stability may correspond to successive halobiid population expansions or blooms recorded in the shell beds.

Halobiids may only appear to be opportunists because of the opportunistic ecology of their algal substrates. Brown algae and other seaweeds are notorious as opportunists, often rapidly invading unoccupied or unstable environments (Pearse and Hines, 1977). Floating algae, and its attached biota, would not be affected by unstable conditions at, or near the sea floor. If the algae were floating in large mats, as does Sargassum, the dense, monospecific shell beds could be explained by killing off the whole algae population, and in turn, its epibionts. The alternation of halobiid species in successive shell beds could be explained by successive immigrating algal populations.

The lack of any definite evidence of an algal substrate for halobiids precludes assignment of either halobiids or their possible algal they lived on as opportunists. More likely, both would contribute opportunistic traits.

Paleoeographic distribution.

Halobiid bivalves are broadly distributed around the northern hemisphere and southwest Pacific margin. They are known from nearly all Carnian to mid-Norian marine strata. Figure 5.4 shows the distribution of *Halobia* localities extending across the former Tethys Seaway, the circum-Pacific accreted terranes and in the Arctic regions.

Levels of endemism differ between geographic areas and between species. Because most species of *Halobia* are cosmopolitan, it is possible to identify only a few paleobiogeographic provinces. For example, *Halobia austriaca* and *H. superba* occur in the Tethys Realm of Eurasia and the circum-Pacific, making them poor paleobiogeographic indices. Other species, such as *H. oregonensis*, are known only from the Wallowa terrane. *Halobia zitteli* seems to be restricted to the Boreal Province, with occurrences from the Soviet and Canadian Arctic, and Spitsbergen.

Two contrasting hypotheses may be invoked to explain this distribution pattern: 1) dispersal by oceanic currents of vegiler larvae and/or halobiids with a floating ecology, or 2) tectonic displacement. Both models are not mutually exclusive, halobiid distribution probably reflects both.

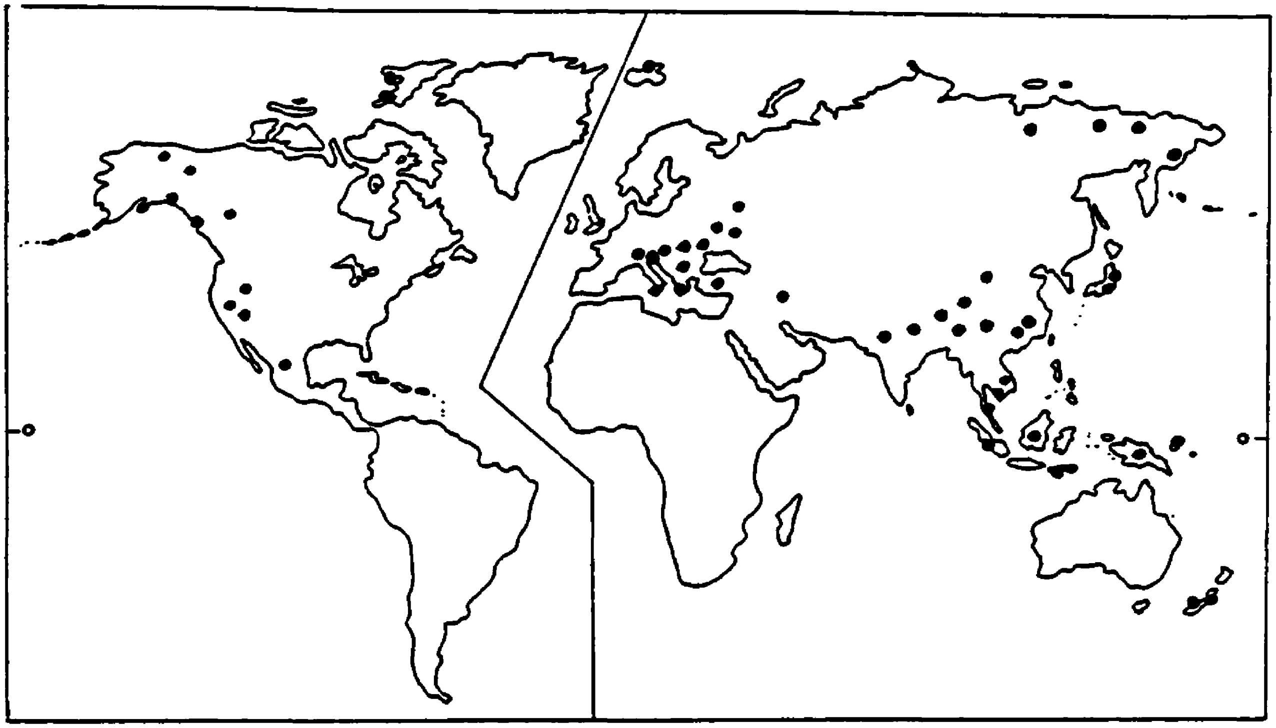


Figure 5.4. Map showing global distribution of <u>Halobia</u>. Note significant occurrences from southern Europe across south-central Asia, the circum-Pacific and Arctic regions. Compiled from many sources.

Oceanic currents may have effectively transported veliger larvae long distances achieving the widespread occurrences of cosmopolitan species of Halobia. Halobia may have had a large fecundity rate, similar to the oyster Crassostrae, where a single discharge may exceed 70 million eggs (Jablonski, 1985). Transport of halobiid veliger larvae by swift currents, similar to those described by Scheltema (1977), could explain the abrubt appearence of Halobia species throughout the marine Triassic. A similar alternative would be dispersal by means of attachment of post-larval halobiids to floating objects such as algae.

Halobiid larval dispersal would have been facilitated if the Triassic seas were dotted with islands that could have served as stepping-stones. Newton (1988) applied this idea to facilitate her steady-state pantropical hypothesis for Norian benthic bivalves from the Wallowa terrane. Plate tectonic transport of any island arcs, seamounts, or other positive relief above the sea floor would complicate any pattern of dispersal by current or island-hopping.

From North American localities, halobiids mostly occur on accreted terranes (Silberling et al., 1984). The halobiid faunal composition should reflect the Upper Triassic paleogeographic position of the terrane on which they occur. Of the two types of fossil assemblages occuring on terranes, Noah's ark and Viking funeral ship faunas (McKenna, 1973), it is probable halobiids display, like corals found on the Wallowa terrane (Stanley and Whalen, 1989; White et al, in press) changes in taxonomic composition as Noah's Ark faunas.

As previously discussed, Halobiid species were very cosmopolitan and for reasons discussed below their usefullness as biogeographic indicators in terrane analysis is limited. Their distribution could be exlained by any of the competing hypotheses of biotic dispersal. The three main problems concerning halobiid distributional patterns and dispersal mechanisms include: 1) taxonomic base, 2) biostratigraphic resolution, and 3) biases in sampling. The largest problem is the taxonomic base, with many halobiids in need of systematic revision. Such revision, when sufficiently advanced, will unquestionably change the levels of inferred endemism. Refinement of halobiid biostratigraphy is necessary before paleobiogeographic analysis becomes meaningful. For halobiid paleobiogeographic analysis, contemporanity between faunas should be established when comparing faunas from different paleogeographic areas. As mentioned in Chapter 4, the ranges of Halobia species are inadequately known; caution is here advised in making statements about the contemporaneous halobiid faunas.

Errors in sampling may also affect halobiid paleobiogeographic analysis. Halobiids are commonly crushed beyond recognition and difficult to remove from rock.

Furthermore, does the absence of a particular halobiid species indicate it did not live there?, or simply that it has not been found yet? Alternatively, new discoveries may increase both the number of Halobia species and the resolution of halobiid provinces.

CHAPTER VI

SYSTEMATIC PALEONTOLOGY

Martin Bridge fauna: overview.

Although this chapter primarily concerns the bivalve *Halobia*, other important fossils have been recovered from the Martin Bridge during the course of this study.

Smith (1927) was the first to describe and illustrate the fauna from the Martin Bridge Formation. From the Martin Bridge stratotype, he reported a diverse bivalve, coral and spongiomorph fauna. Smith (1927) recognized the following taxa:

- bivalves:
    - *Halobia halorica* (=*H. dilatata*)
    - *Halobia oregonensis*
    - *Halobia salinarum*
    - *Pecten* (*Entolium*) *ceruleus*
- corals and spongiomorphs:
    - *Retiophyllia norica* (=*Thecosmilia norica*)
    - *Distichophyllia norica* (=*Montlivaultia norica*
    - *Stylophyllopsis zitteli*
    - *Heptastylis oregonensis*
    - *Heptastylis aquilae*
    - *Spongiomorpha* sp.

In comparison to Smith's fauna, the present study has produced less than half of the species described by Smith. However, sixteen species, out of eighteen total, are here reported for the first time from the Martin Bridge stratotype.

The fauna from the Martin Bridge stratotype is molluscan dominated, and except for the halobiids and ammonoids, is not very diverse. Included in this fauna are 12 species of bivalves and 5 species of ammonoids, two species of corals, an indeterminate number of echinoid species, 4 paraspecies of conodonts, and 1 trace of an unknown organism. Of the bivalve species, 9 belong to the genus _Halobia_, one to _Gryphaea_, one to _Minetrigonia_ and one to ?_Mysidioptera_. The taxa recovered from the Martin Bridge stratotype during this study include:

- bivalves:
  - _Halobia_ _austriaca_
  - _Halobia_ _halorica_
  - _Halobia_ _beyrichi_
  - _Halobia_ _radiata_
  - _Halobia_ _superba_
  - _Halobia_ _oregonensis_
  - _Halobia_ cf. _H._ _teltchensis_
  - _Halobia_ cf. _H._ _lineata_
  - _Gryphaea_ _arcuataeformis_
  - _Minetrigonia_ sp.
  - ?_Mysidioptera_ sp.
- ammonoids:
  - _Discotropites_ sp.
  - _Anatropites_ sp.
  - _Polycyclus_ sp.
  - _Arietoceltites_ sp.
  - indetermininate ammonoid
- other taxa:
  - indeterminate echinoids fragments
  - _Distichophyllia_ _norica_
  - _Retiophyllia_ _norica_
  - _Epigondolella_ _postera_
  - _Epigondolella_ _primitia_
  - _Neogondolella_ sp.
  - indetermininate Upper Carnian conodont
  - Ichnogenus _Chondrites_

The systematic determinations for all halobiids were carried out by the author. For non-halobiid taxa, the identifications were aided by various specialists: C.R.

Newton for non-halobiid bivalves, G.D. Stanley for corals, E.T. Tozer and N.J. Silberling for ammonoids, and M. Orchard and B. Wardlaw for conodonts. The corals, conodonts and trace fossil were not subject to systematic treatment beyond the identifications listed above.

"Halobia" concept and systematics.

Halobiid systematics suffer from two principal problems: 1) lack of any clearly defined generic and specific-level characters, and 2) the earlier halobiid taxonomists use of typological species concepts. It seems both problems are connected, with single-character analysis from one individual often defining the type.

Through the early part of this century, strict application of the typological species concept has resulted in the proliferation new species. This is especially true for Halobia. Often, individual specimens from the same population were designated different species based on slight variations.

Mayr's (1963) biological species concept accepts intrapopulational variation, but relies on observations or deductions as to whether the populations can interbreed. For obvious reasons, Mayr's concept of the biological species can not be applied to fossil populations. As with all fossils, halobiid species are defined by their morphology; as such, they should be termed morphospecies.

Workers do not agree which morphological features are useful in species determinations for Halobia. In the past, specific-level criteria have been restricted to the general outline of the shell, its size, and the nature of costae, rugae and auricle areas. Until recently, morphometric analysis have not been a part of halobiid systematics. These taxonomic ambiguities have led to a proliferation of specific names. In a case of extreme splitting, Kittl (1912) described over 100 species of Halobia, designating 52 as new. The current trend has been to review the morphologic basis for much of the earlier work; resulting in many synonymies (e.g. Caferio and De Capoa Bonardi, 1982).

Criteria for species recognition.-- Gruber (1976), Polubotko (1984,1988) and Campbell (1985b) stressed re-evaluations of specific-level halobiid morphologic characters are in order. They suggest, in addition to the above mentioned characters, consideration of anterior and posterior triangular fields, rib density and shell outline before the costae divide or re-curve. The characters used for this study are slightly altered from those proposed by Polubotko (1984, 1988) and Campbell (1985b). The morphologic characters defined below, and illustrated in Figure 6.1, have proven to be effective in recognizing

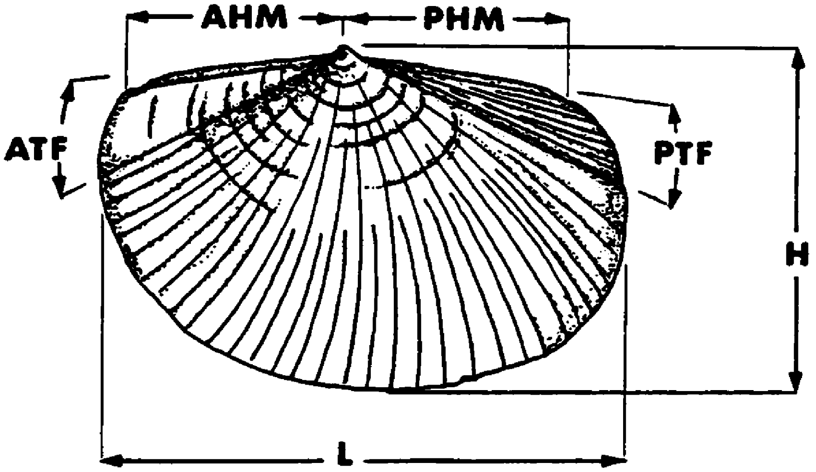


Figure 6.1. Halobia morphologic measurements used in analysis. Showing height (H), length (L), anterior triangular field (ATF), posterior triangular field (PTF), anterior hinge margin (AHM), and posterior hinge margin (PHM).

species closer to a biological concept for Halobia. None of these character traits alone are definitive for species recognition, but when integrated become useful in the subjective "art" of halobiid taxonomy.

The height (H) and length (L) measurements are usually taken from commarginal rugae, presumed to follow increments of shell growth. The beak position (BP), a measure of elongation, is taken as the length of posterior hinge margin (PHM) divided by the anterior hinge margin length (AHM). The anterior triangular field (ATF) includes the combined angular breadth of the byssal tube and anterior auricle. The angular breadth of the posterior triangular field (PTF) includes the region of posterior rib absence, rib disturbance, or differentiation including the angular breadth of the posterior auricle. The rib density (RD) is taken as the number of costae through a specified angular breadth (usually 20 degrees) at a given distance from the beak (usually 1 cm).

Generic concept of "Halobia".-- Debate continues regarding "Halobia" as a natural taxon. Many workers, this author included, believe "Halobia" is comprised of several, separate monophyletic groups, arising from different Posidonia and Daonella ancestors (e.g. Gruber, 1976; Polubotko, 1984, 1988). As such, different genera should be erected to accommodate the distinct lineages. The main problem for dividing "Halobia" is that the generic-level characters are not clearly defined, with many characters resultant from convergence and reversals. Five proposed phylogenies for Halobia are given in Figure 6.2.

Evidence that halobiids, collectively regarded as Halobia belong to different genera is three-fold. Early Carnian halobiid species (e.g. H. zitteli) are morphologically similar to Daonella, differing only by having auricles. Secondly, several Upper Carnian to Lower Norian forms (e.g. H. radiata and H. austriaca) exhibit Posidonia morphology early in ontogeny. Thirdly, ligament types, generally regarded as a conservative feature in bivalve evolution (Newell and Boyd, 1989), may differ between halobiid species. Although the significance of these characters in generic-level determinations has not been adequately demonstrated, they do question the concept of "Halobia" as a natural taxon. Given below are several proposed phylogenies for Halobia and related taxa.

Encheva (1978) was the first to consider the inter and intra-generic evolution of Halobia. She envisioned Halobia as monophyletic, arising from Daonella (Figure 6.2a). Encheva also considered the evolution of groups within Halobia (the same groups put forth by Kittl, 1912). A re-evaluation of Kittl's groups, and the morphologic criteria set forth by Encheva, was conducted by cladistic methods

(PAUP and CLINCH software). Through cladistic analysis, over 100 trees were constructed, none of which appeared intuitively satisfying. Encheva's phylogenetic hypothesis could not be reproduced without more than twenty-five reversals and/or convergences. I conclude that either Kittl's species groups, or the characters used to define them, are unnatural.

Gruber (1976) introduced Perihalobia to accommodate halobiid species lacking the three-fold auricle, common to other halobiid species. Gruber believed Perihalobia was derived from Posidonia, whereas, Halobia arose from Daonella (Figure 6.2b). Morphologically, the concept of Perihalobia does not appear to be valid; species belonging to Halobia (sensu Gruber, 1976) often have an undivided auricle.

Polubotko (1984, 1988) introduced Zittelihalobia and Indigirohalobia. The criteria used by Polubotko was the angle of the anterior auricle; 14-26 degrees for Indigirohalobia, 20-40 degrees for Zittelihalobia. Polubotko places halobiids with straight undivided ribs, including all forms designated as Perihalobia, in Halobia. Polubotko hypothesized Zittelihalobia and Indigirohalobia as arising from separate Daonella ancestors, whereas Halobia was derived from Posidonia (Figure 6.2c). Many exceptions are known where auricle angles vary within a species of a given population, or differ between closely related species

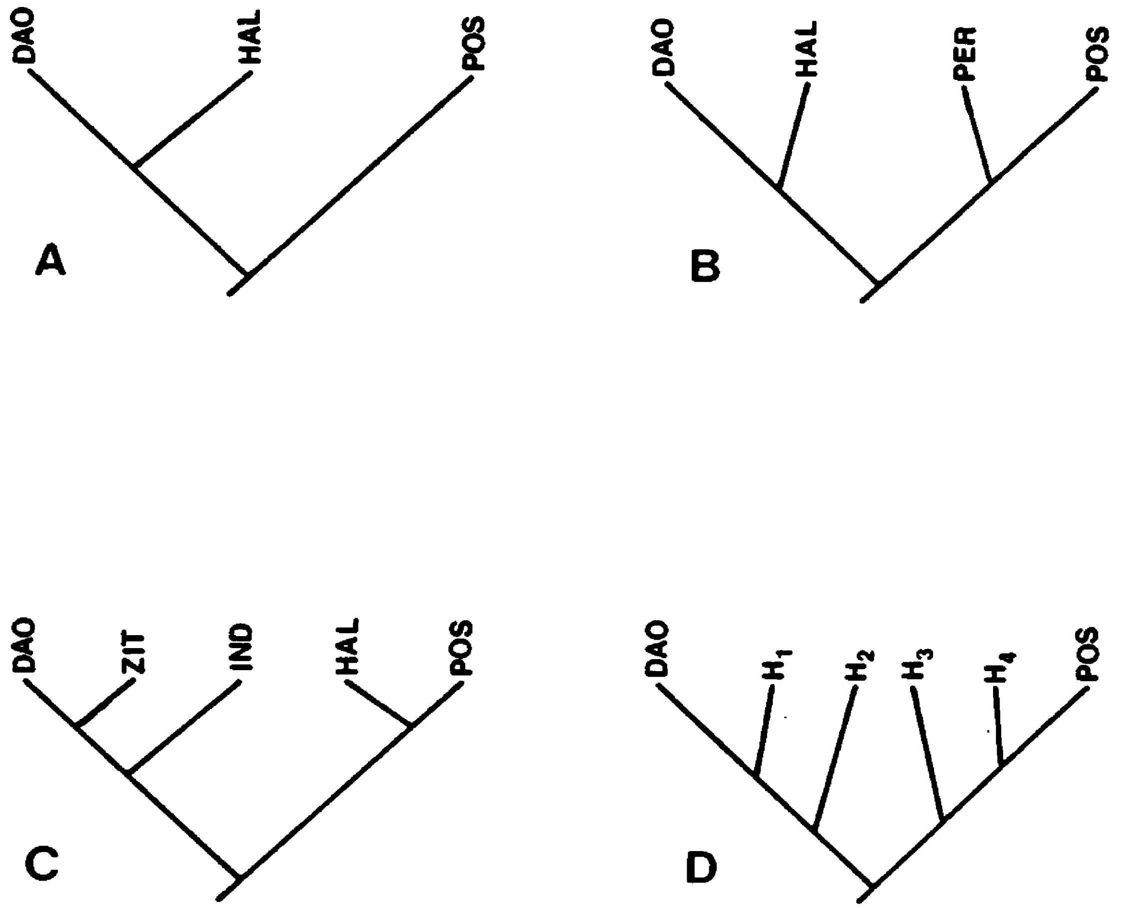


Figure 6.2. Cladograms of proposed phylogeny for halobiids. DAO = *Daonella*, HAL =*Halobia*, ZIT =*Zittelihalobia*, IND =*Indigirohalobia*, PER =*Perihalobia*, H_1-H_4 =morphologically similar taxa regarded here as "*Halobia*". A) from Encheva (1972), B) from Gruber (1976), C) from Polubotko (1984, 1988), D) this study.

(e.g. *H. superba*, and *H. oregonensis*). I believe auricle angle is probably best reserved as a specific-level character, and then, only for some species. Furthermore, the presence of both curved and straight radial ribbing within the same species (e.g. *Halobia austriaca*) may invalidate the distinction between *Zittelihalobia*, *Indigirohalobia* and *Halobia*.

Yin and Hsu (1938, *In* Hayami, 1976) erected *Parahalobia* for halobiid forms lacking radial ornamentation. Objection to this generic distinction is that many species (e.g. *Halobia radiata*) achieve radial ribbing late in ontogeny.

For this study, *Halobia* is retained as a form-genus, and is used to represent all halobiids (H_1-H_4 Figure 6.2d). The genera *Zittelihalobia*, *Indigirohalobia*, *Perihalobia*, and *Parahalobia*, are tentatively suppressed, awaiting more rigorous character analysis.

Preservation of halobiid material.-- Most of the fossils collected for this study has been altered by taphonomy. The Martin Bridge halobiids are preserved in three ways: 1) diagenetically altered shell material; 2) internal molds; and 3) external molds. Silicification has not been a part of the process, although it does affect corals found in limestone high in the section.

The differing states of preservation severely limits the accurate measurements of _Halobia_. Some individuals are wholly, or partially destroyed by compaction, cleavage, and/or strain deformation. Except in special cases (e.g. _Halobia_ cf. _H. lineata_), such specimens were not measured. The most common form of preservation is altered shell material. In this case, the entire shell has recrystallized (neomorphosed) from original aragonite to calcite. Interior and exterior molds are also common, and often preserve the fine detail of the original shell. In most cases, both recrystallization and moldic preservation preserves details of the original shell form sufficiently well to allow accurate measurements.

The two sides of the shell are not mirror images of each other. Gruber (1976) and Campbell (1985b) recognized, morphologic differences between valve interiors and exteriors. Such differences were considered during systematic study.

MOLLUSCAN SYSTEMATICS

In addition to field specimens, published and non-published specimens were studied from the U.S. National Museum, U.S. Geological Survey, Denver, the Canadian Geological Survey in Ottawa. I have attempted to critically evaluate published specimens for possible synonymy. However, the often poor quality of illustrations and their reproduction severely limited such an endeavor. For more complete synonymies, the reader is referred to Gruber (1976; In Kristan-Tollmann and Tollmann, 1983; In Kristan-Tollmann et al., 1987), Caferio and De Capoa Bonardi (1980, 1982), and De Capoa Bonardi (1984).

Specimen numbers with the USNM prefix are U.S. National Museum of Natural specimens housed in Washington, D.C.. Those with a UMIP prefix are curated in the University of Montana paleontological collections. Specimens with an (a) or (b) suffix refer to part and counterpart of the same slab.

Class BIVALVIA Linne, 1758
Subclass PTERIOMORPHIA Beurlen, 1944
Order PTERIOIDA Newell, 1965
Suborder PTERIINA Newell, 1965
Superfamily PTERIACEA Gray, 1847
(emend. Waller, 1978)

Discussion.-- There has been some disagreement as to the placement of the genera "*Halobia*" and *Daonella* and Family Posidoniidae (cf. Halobiidae Kittl) to Superfamily. Most workers have abandoned Newell's (1969) designation of this family in the Pectinacea, and following Stanley's (1972) suggestion, place it in the Pteriacea. In contrast, Campbell (1985b) described a middle homogeneous (aragonitic?) shell layer from a Spitsbergen <u>Daonella</u>, and suggested a new superfamily should be erected, Daonellacea, arising from a common Ostreina and Pectinina stock (sensu Waller, 1978). Homogeneous calcitic shell structure is limited to the Limacea, and homogeneous aragonite to other distantly related groups (Taylor et al. 1969; Waller, 1978). The significance of these shell structure types in higher level taxonomy has not yet been demonstrated. In addition to the two layered shell structure described by Freneix (1972), consideration of halobiids being non-pleurothetic, byssate, equivalved, and having a multivincular (and possibly alvincular) ligament, suggests placement of the halobiids in the Pteriacae.

Stanley (1972), on morphological grounds, and Encheva (1978) in her phylogenetic hypothesis, proposed the Posidoniidae arose from a Carboniferous pteriacean ancestor, <u>Cayenella</u>. If this evolutionary pathway is inferred correctly, the Posidioniidae must be placed in the Pteriacea.

Family POSIDONIIDAE Frech, 1909

<u>Diagnosis</u>-- Thin shelled, ovate to subround, equivalved,

non-pleurothetic, byssate Pteracean. Ligament multivincular (and possibly alvincular) and amphedetic. Shell microstructure comprises both a simple prismatic outer layer and an inner lamellar or nacreous layer. Characterized by long straight hinge margin, with or without the development of auricles. Shell usually shows development of both commarginal rugae and radial costation, although strength and density vary inter and intraspecifically, and absent in some members.

Discussion-- Various authors (e.g. Polubotko, 1988, and Campbell, 1985b) have placed Daonella and Halobia in the Halobiidae Kittl 1912. It is probable that" Halobia" and Daonella have their origins from several different Posidonia ancestors by reiterative evolution. The question of a polyphyletic origin for members of "Halobia" from different Posidiona and Daonella ancestors precludes such placement in a separate family. The Halobiidae is thus considered a junior synonym of Posidoniidae. Although departing from Campbell's (1985b) interpretation, I concur with him that the Posidioniidae appears to be a "convenience" family for thin shelled pteriomorphs. Revision is desired for most of this family, especially for "Halobia" and its possible generic derivatives.

Genus HALOBIA Bronn, 1830

Perihalobia Gruber, 1976, p.192; *Indigirohalobia* Polubotko, 1984, p.42; *Zittelihalobia* Polubotko, 1984, p.42; *Parahalobia* Yin and Hsu, 1938 (*In* Hayami, 1976).

Type species.-- *Halobia salinarum* Bronn, 1830.

Diagnosis.-- Shells very thin, small to large, ovate to sub-round, oblique to equant. Anterior auricle, byssal tube, and posterior auricle present to varying degrees in all members. Usually, commarginal rugae and radial costae.

Discussion.-- Traditionally, recognition of *Halobia* apart from *Daonella* has been based on the presence of the anterior auricle. This feature is maintained as the deciding criterion in delimiting these two closely related genera. As previously discussed, several genera, similar in many regards to *Halobia* (e.g. *Perihalobia* Gruber, *Zittelihalobia* Polubotko, and *Ingigirohalobia* Polubotko), have been recognized by various authors on account of differences in the nature of costae and auricles. To account for these similar genera, Kittl (1912), Ichikawa (1958), Gruber (1976), and Gruber et al. (1980) have suggested polyphyletic origins for "*Halobia*"; with possible *Daonella* and *Posidonia* ancestors. As correctly pointed out by Gruber and others (1980), if polyphyly has indeed occurred (as evidence suggests), separate genera should be erected to accommodate the distinct lineages. Unfortunately, the current understanding of generic-level characters, and identifying apomorphic from plesiomorphic characters precludes any attempt at division at the generic rank. Campbell (1985b) and Polubotko (1988) have introduced new and revised subgenera for Halobia. Although such division of such a large genus seems acceptable, again, the problem of characters has not been adequately addressed. Because of the uncertainties in our understanding of Posidoniidae morphometrics, and those of the halobiid derivitives, establishment of new genera and subgenera is premature.

HALOBIA AUSTRIACA Mojsisovics, 1874

Figure 6.6.9

Halobia austriaca Mojsisovics, 1874, p. 26, pl.4, fig.1-3; pl.5, fig.14; Arthaber, 1906, pl.45, fig.2; Kittl, 1912, p.101, pl.6, fig.11-14; Krumbeck, 1924, p.143, pl.9, figs.13-23; Smith, 1927,p.113, pl.99, fig.10-13; Kiparisova, 1937, p.21, pl.2, figs. 13, 15; Kiparisova, 1938, p.23, pl.5, figs.4-8; De Capoa Bonardi, 1970, p.64, pl.12, fig.1-12; pl.13, fig.1-13; Encheva, 1972, p.66, pl.18, fig.7; pl.19, fig.3; pl.23, fig.4; Allasinaz et al., 1974, pl.1, fig.2; Gruber, 1975, p.128, pl.3, fig.1-4; Gruber, 1976, fig.1, 4a-b;

Chernov, 1981, p.37, fig. 5-9; Cafiero and De Capoa Bonardi, 1982, p.42, pl.4, fig.14-16; Chen and Ba, 1986, pl.1, figs. 1, 2, 6; Gruber *In* Kristan-Tollmann et al., 1987, p.261, pl.4, fig.1.

Halobia cf. *austriaca* Chen, 1964, pl.1, figs. 7, 12; Chen, 1974, p.216, pl.34, fig,26.

Halobia *subaustriaca* Kittl, 1912, p.101, pl.6, fig.15-16.

Lectotype.-- Original specimen of Mojsisovics (1874, pl.4, fig.3)

Material.-- One fairly well preserved right valve: UMIP 16040.

Diagnosis.-- Shell moderate to small, broad, round-topped ribs generally running straight. RD less than one. ATF variable in breadth: well developed

Discussion.-- The specimen illustrated bears a strong resemblance to rugate forms of *H. halorica* but differs from that species in its broader, round-topped ribs, and more pronounced anterior triangular field. *H. austriaca* is similar to *H. styriaca*, but the former is smaller and has finer, more numerous, rounded topped costae. Additionally, the hinge margin and auricles are not reduced in length as in *H. styriaca*. *H. austriaca* could also be compared to *H. brooksi* Smith, but lacks the growth-stop found in that species. Futher study may prove that *H. austriaca* and *H.*

brooksi are conspecific.

Occurrence.-- Very rare at Martin Bridge stratotype, locality MBFLT-6. This species has also been found from the Upper Carnian of Alaska (Silberling, 1963), Japan (Hayami, 1976), and the upper Ganzi region of China (Chen, 1964). It also has been reported from the Lower Norian of the northeast Soviet Union (Polubotko, 1984), and from several biostratigraphically useful sections from the Alpine and Mediterranian Triassic, keyed into the following zonal scheme, Upper Carnian- to Lower Norian H. lenticularis - H. mediterranean Zones (=Tuv 3-Lac 1) (De Capoa Bonardi, 1984).

TABLE 6.1. Measurements of Halobia austriaca.

SPECIMEN	H/L	RD	ATF	BP
UMIP 16062	0.57	0.61	25	0.25
USNM 14190*	0.90	0.50	20	0.20
USNM 14190!	0.70	0.78	13	0.20

* Smith (1927, pl.99, fig.10); ! Smith (1927, pl.99, fig.11)

HALOBIA BEYRICHI (Mojsisovics, 1874)

Figures 6.6.10, 6.6.11

Daonella beyrichi Mojsisovics, 1874, p.11, pl.1, fig.7
Gruber (1975) pl.3 fig.5.

Halobia beyrichi (Mojsisovics), Kittl, 1912, p.96, pl.1, fig. 30-31, pl.6, fig.10; Gruber, 1975, pl.3, fig.5.

Halobia dilatata Kittl, Smith, 1927 pl.100, figs.1-4.

Perihalobia *berichi* (Mojsisovics) Gruber, 1976, p. 194, pl.6, fig.5

Lectotype.-- Original specimen of Mojsisovics (1874, pl.1, fig.7).

Material.-- Numerous left and right valves on slabs UMIP 16023, UMIP 16024, and UMIP 16030, not illustrated are UMIP 16030 containing 10 left and seven right valves, all fairly well preserved.

Diagnosis.-- Shells medium sized, straight, or slightly anteriorly-sloping, fine costae of equal strength except on posterior triangular field.

Discussion.-- Similar to *H.* *halorica*, but has more numerous, narrower, flat-toped costae, than that species. Gruber (1976), has synonymized with this species several specimens of *H.* *dilatata* Smith 1927 (pl.100, figs.1-4) from the Wallowa Mountains. Measurements from Smith's original USNM material also support this synonymy.

Occurrence.-- Common at Martin Bridge stratotype localities MBF-17, MBF-41, MBF-42, MBF-43, MBF-47, MBF-54, MBF-55. Elsewhere, reported from the Lower Norian, *H.* *styriaca* Zone (= Lac 1 = Kerri) from Sicilian sequences (De Capoa Bonardi, 1984), and lower Norian from other Alpine sequences (Gruber, 1976).

TABLE 6.2. Measurements for <u>Halobia</u> <u>beyrichi</u>.

SPECIMEN	H/L	ATP	BP	RD
UMIP 16024	0.85	17	1.22	0.75
UMIP 16030	0.84	--	1.50	0.55
UMIP 16023	0.68	13	1.33	0.70
USNM 316094*	0.55	--	--	0.55

* <u>Halobia</u> <u>dilatata</u> (Smith, 1927, pl.100, fig.2)

HALOBIA HALORICA Mojsisovics, 1874

Figures 6.6.2-6.6.6, 6.6.8

<u>Halobia</u> <u>halorica</u> Mojsisovics, 1874, p.33, pl.5, fig.1- 2; Kittl,1912, p.116, fig.25; Smith, 1927, p.116, pl.95, fig.3,4; Allasinaz et al., 1974, pl.2, figs.1-3; Gruber, 1976, fig.1; Cafiero and De Capoa Bonardi, 1980, p.190, pl.5, fig.4-6; Cafiero and De Capoa Bonardi, 1982, p.54, pl.8, fig.14-17; pl.9, fig.1-8.

<u>Halobia</u> <u>dilatata</u> Kittl, 1912, p.115, pl.8, fig.; Smith,1927, p.115, pl.95, fig.5; Kiparisova, 1938, p.22, pl.5, figs.10-14.

<u>Halobia</u> <u>dilatata</u> var. <u>tetyochensis</u> Kiparisova, 1938, p.22, pl.5, fig.15.

<u>Monotis</u> <u>limaeformis</u> Montanari and Renda, 1977, p.737, fig.2(6), 3(4).

<u>Lectotype</u>.-- Original specimen of Mojsisovics (1874, pl.5, fig.1)

Material.-- Thirty eight, fairly well preserved valves representing at least 26 individuals.

Diagnosis.-- Shells small to medium, equant and slightly wider that high. Flat-topped radial ribs dividing into two's and three's, sometimes bundled, but running straight. PTF well developed (around 18 degrees) with longitudinal ridges. Presence of rugae common in some forms early in ontogeny.

Discussion.-- There seems to be a lot of variation within this species which sometimes exhibit commarginal rugae, varying even from the same population. Like Gruber (1976) I consider *H. dilatata* Kittl a junior synonym of *H. halorica*, as published specimens of *H. dilatata*, including the type, are indistinguishable from *H. halorica*.

Occurrence.-- Very common high in the Martin Bridge stratotype, localities MBF-61 through MBF-66, and MBF-69 (and see Smith, 1927). Elsewhere, Smith (1927) reports this species from the Lower Norian from the Yukon, and Kiparisova (1938) for northeastern U.S.S.R. Additionally, it has been reported from the Middle Norian, *H. halorica* Zone (= Alau 2) from Mediterranean sequences and Turkey (De Capoa Bonardi, 1984).

TABLE 6.3. Measurements of Halobia halorica.

SPECIMEN	H/L	ATF	PTF	RD
UMIP 16040	0.56	--	17	0.56
UMIP 16039	--	--	19	0.50
UMIP 16072	0.62	--	19	0.40
UMIP 16049	0.71	20+	18	0.40
USNM 306103	0.70	18	--	0.25
USNM 74151	0.70	--	18+	0.40

HALOBIA RADIATA Gemmellaro, 1882

Figures 6.5.1-6.5.3

Halobia radiata Gemmellaro, 1882, pl.1, fig.9-12.

Halobia daltoni Kittl, 1912, p.143, pl9, fig.33-34.

Halobia dalliana Smith, 1927, p.119, pl.98, figs.5-6.

Halobia septentrionalis Smith, 1927, p.118, pl.98, fig.1-4.

Halobia symmetrica Smith, 1927, p.119, pl.98, figs.7-8.

Halobia radiata radiata Gemmellaro, Cafiero and De Capoa Bonardi, 1980, p.196, pl.3, fig.1,2; Cafiero, and De Capoa Bonardi, 1982, p.64, pl.3, figs.1-10; Gruber In Kristan-Tollmann and Tollmann, 1983, p.244, pl.17, fig.3; Gruber In Kristan-Tollmann et al., 1987, p.265, pl.4, fig.2-4.

Lectoypes.-- Gemmellaro's original specimens.

Material.-- Two right valves UMIP 16054, and two articulated valve pair UMIP 16029a and UMIP 16052. Not illustrated are numerous specimens on UMIP 16031.

Diagnosis.-- Shell moderate to small, nearly equilateral, with very fine, closely-spaced radial ribs (RD>1), often beginning several mm from beak.

Table 6.4. Measurements of Halobia radiata.

SPECIMEN	H/L	BP	ATP	RD
UMIP 16054	0.72	1.42	12+	1.40
UMIP 16029a	0.67	1.83	12	--
UMIP 16031	0.75	2.18	16	--
USNM 74181*	0.62	2.72	--	--
USNM 74182!	0.61	1.20	11	1.40

* Halobia dalliana Smith holotype; ! Halobia symetrica Smith holotype.

Discussion.-- Several subspecies have been introduced for H. radiata by De Capoa-Bonardi (1980), however, the forms illustrated here can not be placed in any of these subspecies because preservation has destroyed much of the fine detail. H. radiata closely resembles H. beyrichi, but can be easily distinguished by absence of ribbing in early growth and the extremely fine ribbing characteristic of later growth stages.

Occurrence.-- Common from Upper Carnian/ Lower Norian beds from the Martin Bridge stratotype localities MBF-2, MBF-4, MBF-7 and Paddy Creek section locality PC-7 and PC-9. Also noted from the Upper Carnian, H. lenticularis Zone (=Tul 3) (De Capoa Bonardi, 1984). Lower Norian, U.S.S.R. (Polubotko, 1984)

HALOBIA cf. H. LINEATA (Muenster), 1833

Figure 6.6.7

Monotis lineata Muenster, 1833 p.140, pl.121, fig. 3.

Halobia lineata (Muenster) Mojsisovics, 1874, p.29, figs.2,3; Allasinaz et al., 1974, pl.2, figs.4-6.

Halobia cf. lineata Krumbeck, 1924, p.162, pl.12, fig.4.

Material.-- Four poorly preserved specimens.

Discussion.-- The illustrated specimens (UMIP 16060) is assigned tentatively to this species. Measurements were not reliable because of strain deformation of specimens. Its long, straight and closely spaced costae, however, is sufficient to warrant species assignment.

Occurrence.-- The specimens were recovered only from float high in the Martin Bridge stratotype (MBFLT-5). Smith (1927) reports this species from the ?Upper Carnian and Lower Norian of Alaska. In Europe Turkey and Timor, however, this species is only known from the Lower to Middle Norian (De Capoa Bornardi, 1984; Krumbeck, 1924).

HALOBIA SUPERBA Mojsisovics, 1874

Figures 6.4, 6.5.6-6.5.8, 6.7.6

Halobia superba Mojsisovics, 1874, p. 30, pl. 4 fig. 9, 10; Diener, 1890, p. 94, pl.16, fig. 7; Renz, 1906, p.35, pl.3, fig.5; Kittl, 1912, p.151, pl.7, fig. 17, 18; Smith, 1927, p.118, pl.93, fig.1-5; pl.94, fig.7, pl.97, fig.1-3; Chen, 76, p.219, pl.36, figs.7, 8; Chen and Ba, 1986, pl.3, figs.4, 7, 13.

Halobia superba var. timorensis Krumbeck, 1924, p.171, pl.12, figs.14-17.

Halobia cf. superba Kiparisova, 1936, p.97, pl.3, figs.2, 6; Kiparisova, 1938, p.26, pl.6, figs.4-7.

Halobia ?presuperba Kittl, 1912, p.150, pl.7, fig.15-16.

Halobia gigantea Smith, 1927, p.116, pl.93, fig.6,7; pl.94, fig. 1-3.

Halobia ornatissima Smith, 1927, pl.94, figs.4-6, pl.97, fig.8.

Halobia oregonensis Smith, 1927, pl.95, fig.2 (not fig.1).

Lectotype.-- Mojsisovics' original specimen (1984, pl.4, fig.10)

Material.-- Over 100 specimens, some well preserved.

Diagnosis.-- Shells medium to large, equant to high. Ribbing running straight until kink or multiple kinks at about 15 mm from umbo. ATF around 19 degrees.

Discussion.-- Many other species bear close similarities to *H. superba* and without doubt intergrade with this species. *H. ornatissima* Smith and *H. gigantea* Smith are here considered to be conspecific with *H. superba* and probably represent intraspecific variation as many authors have suggested (see Gruber, 1976, and Campbell, 1985b). Measurements of *H. ornatissimsa* fall well within the range of variation of *H. superba*, as does the paratype of *H. oregonensis* Smith. *H. gigantea* Smith is considered a large variant of *H. superba*. *H. superba* is similar to *H. oregonensis* Smith, but can be distinguished by its narrower anterior triangular breadth and by its growth stop at a greater distance from the beak.

Occurrence.-- Common in Upper Carnian beds from the Martin Bridge stratotype (localities MBF-16, MBF-17, MBF-30 - MBF-33, MBF-35, MBF-37, MBF-39, MBF-44, MBF-50, MBF-52), and from the Paddy Creek section (localities PC-1, PC-15, PC-16). *H. superba* is known from the Upper Carnian Korkodon and Omolon River Basins of northeast U.S.S.R. (Kiparisova, 1936), and from the Upper Carnian to Lower Norian *H. lenticularis* to *H. styriaca* and possibly *H. mediterranean* zones (Tuv 3- to Lac 1 and ?Lac 2) (De Capoa Bonardi, 1984). Smith (1927) reported this species from several Upper Carnian (Subbulatus Zone) localities from California, Alaska and the Yukon.

Table 6.5. Measurements of *Halobia superba*.

SPECIMEN	H/L	BP	ATF	RD
UMIP 16041	0.86	1.48	20	0.55
UMIP 16042a	0.90	1.25	19	0.50
UMIP 16042b	0.75	1.33	20	0.50
UMIP 16042c	0.80	1.11	21	0.45
UMIP 16064	0.75	1.60	18	0.50
UMIP 16012b	0.91	1.33	20	0.45
UMIP 16025	0.82	1.50	20	0.55
USNM 16116	0.65	1.19	20	--
USNM 74139#	0.66	1.33	18	0.50
USNM 74178!	0.67	1.21	18	0.45
USNM 316109!	0.78	1.33	18	0.45
USNM 316105*	0.59	1.50	18	0.45

Halobia ornatissima Smith holotype; ! *Halobia ornatissima* Smith; * *Halobia oregonensis* Smith, paratype.

HALOBIA OREGONENSIS Smith, 1927

Figure 6.3.1-6.3.5, 6.7.6

Halobia oregonensis Smith, 1927, p.117, pl.95, fig.1. (not fig.2)

Holotype.-- USNM 74150 (Smith, 1927, pl.95, fig.1)

Material.-- Six well preserved left and right valves and many fragments representing at least 20 individuals.

Diagnosis.-- Shell medium to large size, longer than high, ribs strong, dividing into two's and three's, and irregularly wavy on posterior triangular field. PTF seperated from rest of shell by multiple, longitudnal ridges. Growth-stop less than 1 cm from beak. ATF around 30 degrees.

Discussion.-- *H. oregonensis* bears close similarities to *H. superba* but the former may be characterized by an increase in growth stops to produce wavy appearance, especially along posterior margin and by the greater breadth of the ATF. The paratype of *H. oregonensis* is considered conspecific with *H. superba*, and differes from the holotype by its smaller ATF. *H. oregonensis* is also closely related to *H. cordillerana* Smith but differs from that species by having radiate ridges seperating the posterior triangular field from the rest of the shell.

TABLE 6.6. Measurements of *Halobia oregonensis*.

SPECIMEN	H/L	BP	ATF	RD
UMIP 16075b	0.94	1.25	28	0.80
UMIP 16059	0.66	--	32	0.60
UMIP 16037	0.72	1.33	30	0.70
UMIP 16065	0.82	1.20	32	0.40
UMIP 16057	0.79	1.25	34	0.35
USNM 74150*	0.82	1.42	30	0.45

* *Halobia oregonensis* Smith Holotype.

Occurrence.-- Common from Upper Carnian of the Martin Bridge Paddy Creek section (localities PC-1, PC-2, PC-4, PC-5, PC-7) and rare from the Martin Bridge stratotype (MBF-FLT).

HALOBIA cf. H. TELTSCHENESIS (Kittl, 1912)

Figure 6.5.5

Daonella teltschenesis Kittl, 1912, p.33, pl.1, figs.18-19.

Lectotype.-- Kittl's original specimen (1912, pl.1, fig.18)

Material.-- Several bedding surfaces containing numerous individuals, all fairly well preserved.

Diagnosis.-- Shells small, oblique, and posidoniaform. Rugae of nearly equal strength and spacing. Hinge-line, straight and generally sloping.

Discussion.-- These specimens could be placed in Parahalobia Yin and Hsu (1938, In Hayami, 1976) because of the absence of ribbing. The specimens may be juveniles, as were probably those used to erect Parahalobia, for which ribbing is evident later in ontogeny. Additionally, differentiation of anterior triangular field require placement in the genus. The forms illustrated appear to correspond to Daonella teltschensis illustrated by Kittl (1912) and are only tentatively placed in this species awaiting further study. These specimens differ from H. salinarum Bronn described by Smith from presumably the same stratigraphic horizon, by lacking the prominate ridges typical of that species.

Occurrence.-- Associated with H. superba, and H. ornatissima at the Martin Bridge Paddy Creek section, localities PC-9, PC-10, PC-12. Probably Upper Carnian in age.

TABLE 6.7. Measurements of _Halobia teltschensis_.

SPECIMEN	L	H	ATF	BP
UMIP 16056	12.0	7.0	--	0.42
UMIP 16058	14.0	8.5	15	0.47

Order OSTEROIDA Waller 1978

Superfamily OSTREACEA Rafinesque 1815

Family GRYPHAEIDAE Vyalov 1936

Genus GRYPHAEA Lamarck 1801

GRYPHAEA ARCUATAEFORMIS Kiparisova, 1936

Figure 6.7.1-6.7.3

Gyrphaea arcuataeformis Kiparisova 1936, pl.4, fig.1-10; Vyalov, 1946, p.29, pl.2, fig.1-7; Kiparisova et al. 1966, p.157, pl.27, fig.14-17.

Gryphaea chalkii McLearn 1937, fig.8.

Type-- None designated

Material.-- Six well-preserved left valves.

Diagnosis.-- Left valve highly convex, height far greater than length. Umbo strongly coiled posteriorly, well developed sulcus and corresponding posterior lobe. Right valve unknown.

Discussion.-- This species is similar to the Lower Liassic species G. arcuata Lamarck by its consistantly smaller size. As Westermann (1962) noted, G. chalkii McLearn is of comparable size and is indistinguishable from G. arcuataeformis.

Occurrence.-- Recovered from one bed of slightly calcareous, non-bedded mudstone (locality PCF). This is the first reported occurrence from the Wallowa terrane, and as such, the only occurrence from a low paleolatitude. G. arcuataeformis is also known from the Canadian (Tozer, 1961; Tozer and Thorsteinsson, 1964) and Soviet (Kiparisova, 1936; Kiparisova et al., 1966) Arctic in beds with sparse Carnian and Norian Halobia, and from the Carnian and Norian Shublick Formation of the Brooks Range Alaska (N.J. Silberling, pers. comm., 1990).

Order LIMOIDA Waller 1978

Family LIMIDAE Rafinesque 1815

Genus MYSIDOPTERA Salomon 1865

?MYSIDOPTERA sp. indet.

Figure 6.7.4

Material.-- One well preserved right valve.

Discussion.-- The large specimen illustrated in Figure

6.6.4 exhibits a elongated posterior, and a long straight hinge margin. The central inflated conical region and concentric ornamentation characterize this specimen as a possible Mysidioptera, and apart from Girviella, since internal hinge structures can not be discerned, this assignment remains tentative.

Occurrence.-- Only one bed from the Martin Bridge at the Paddy Creek Section (locality PCF), probably Upper Carnian in age.

Order TRIGONIODA Dall, 1889

Superfamily TRIGONIACEA Lamarck, 1819

Family MINETRIGONIIDAE Flemming, 1982

Genus MINETRIGONIA Kobayashi and Katayama 1938

MINETRIGONIA sp.

Figure 6.7.7

Material.-- One external mold of a right valve from locality PCF.

Discussion.-- The external mould of the right valve is trigonally suboval with concentric ornament on main part of disc with longitudinal ridges parallel to main anterior ridge. Hinge and dentition unknown. This specimen is different from Minetrigonia suttonensis (Smith) in being less elongated, thus, probably representing a new species.

Occurrence.-- Martin Bridge Paddy Creek section, locality

PCF. Probably Upper Carnian.

Class CEPHALOPODA Cuvier, 1797
Order AMMONOIDA Zittel, 1884
Suborder CERATITINA Hyatt, 1884
Superfamily TROPITACEA, Mojsisovics, 1875
Family TROPITIDAE Mojsisovics, 1875
Genus DISCOTROPITES Hyatt and Smith, 1905
DISCOTROPITES sp. indet.
Figure 6.8.4

Material.-- Five incomplete specimens.

Discussion.-- The several specimens recovered from the Martin Bridge stratotype are all compressed. The best specimen, UMIP 16002, is involute and shows the rib curvature near the ventral margin typical of this genus. Because sutures could not be discerned, specific assignment could not be made.

Occurrence.-- Common from the Martin Bridge stratotype (localities MBF-25, MBF-29, MBF32, and MBFLT), where it is the first reported occurrence from the Wallowa terrane. This genus is only known from Upper Carnian rocks, placed in the Dilleri and Macrolobatus zones (Silberling and Tozer, 1968).

Genus ANATROPITES Mojsisovics, 1893

ANATROPITES sp. indet.

Figure 6.8.5

Material.-- Two incomplete specimens.

Discussion.-- The specimens (UMIP 16013, UMIP 16011) are evolute having umbilical spines or nodes and well developed keels along the ventral margin characteristic of *Anatropites* to which it is placed. The fragmented specimens precludes assignment to species.

Occurrence.-- This is the first reported occurrence from the Wallowa terrane where it is found in Upper Carnian rocks of the Martin Bridge stratotype (MBF-37, MBFLT). Elsewhere it is known from uppermost Carnian in North America (Silberling and Tozer, 1968) and Europe (Krystan, 1982).

Genus POLYCYCLUS Mojsisovics 1889

POLYCYCLUS sp. indet.

Figure 6.8.3

Material.-- Only one specimen.

Discussion.-- The one specimen (UMIP 16006b) is small, evolute having straight, equally spaced ribs. It is similar to *Polycyclus nodifer* described by Hyatt and Smith (1905) and later by Smith (1927), but specific level details can not be discerned.

Occurrence.-- A first occurrence for the Wallowa terrane, the one specimen (UMIP 16006b) has been recovered from the Martin Bridge at the Paddy Creek section (locality PCF) from the Upper Carnian. Elsewhere this genus is known from the Carnian of the Shasta Region of California (Smith, 1927).

Family TROPICELTITDAE Spath, 1951

Genus ARIETOCELTITES Diener, 1916

ARIETOCELTITES sp. indet.

Figure 6.8.1

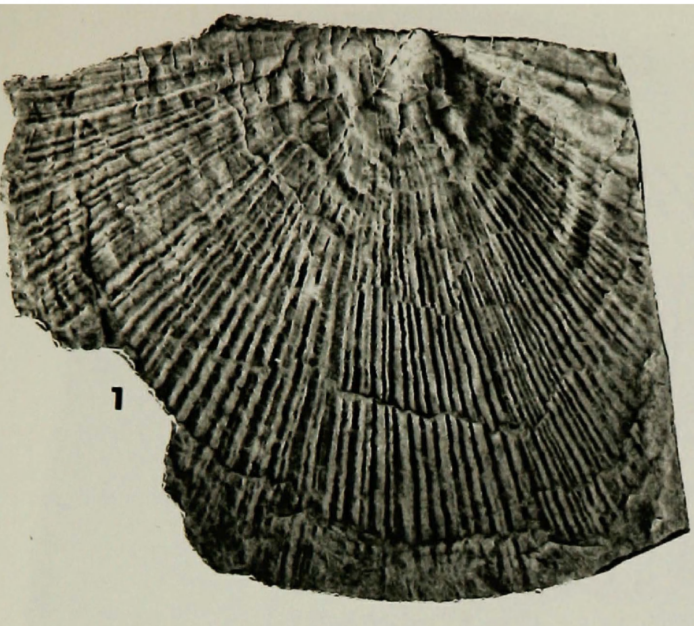
Material.-- Six fairly-well preserved specimens.

Discussion.-- The large specimen illustrated (UMIP 16006a) shows the adorally curved ribs and flattened keel typical of this genus. Species-level characters could not be discerned. Also of interest are the six bivalves attached along one quarter of the ventral margin.

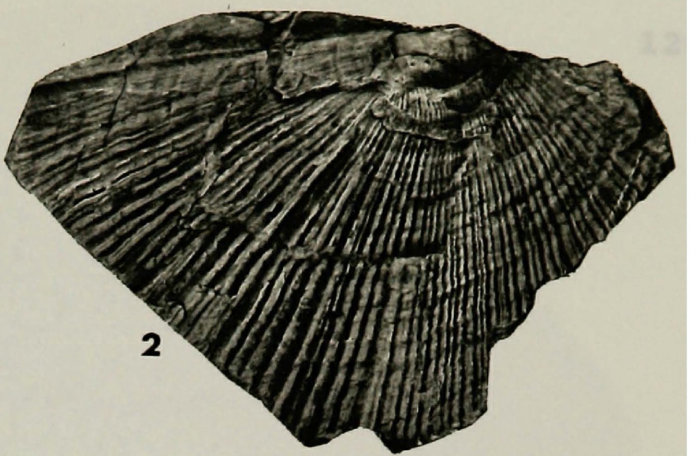
Occurrence.-- Very common from the Martin Bridge stratotype (locality MBF-27) and at the Paddy Creek section (locality PCF) probably Upper Carnian.

Figure 6.3. Halobia oregonensis Smith. 1) right valve exterior UMIP 16057, x1.5; 2)right valve exterior UMIP 16037, x1.5; 3)left valve exterior UMIP 16075a, x1.5; 4)left valve exterior UMIP 16065, x1.5; 5) left valve exterior UMIP 16075b, x1.5; 6)left valve slightly crushed exterior UMIP 16077a, x1.5.

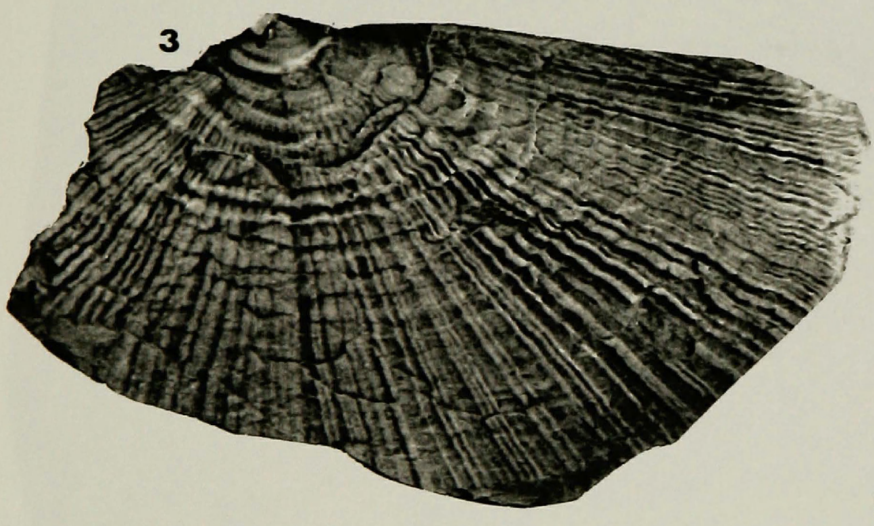
1



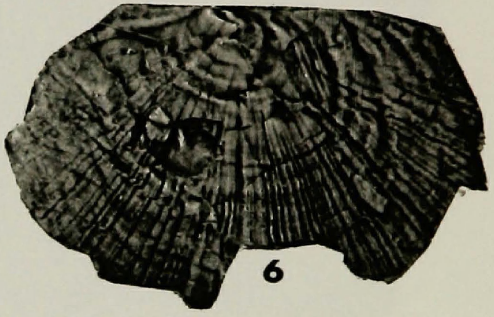
2



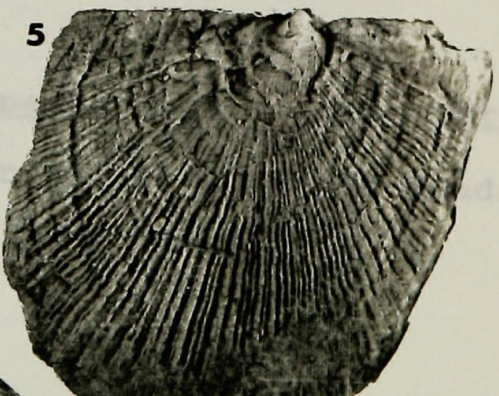
3



6



5



4

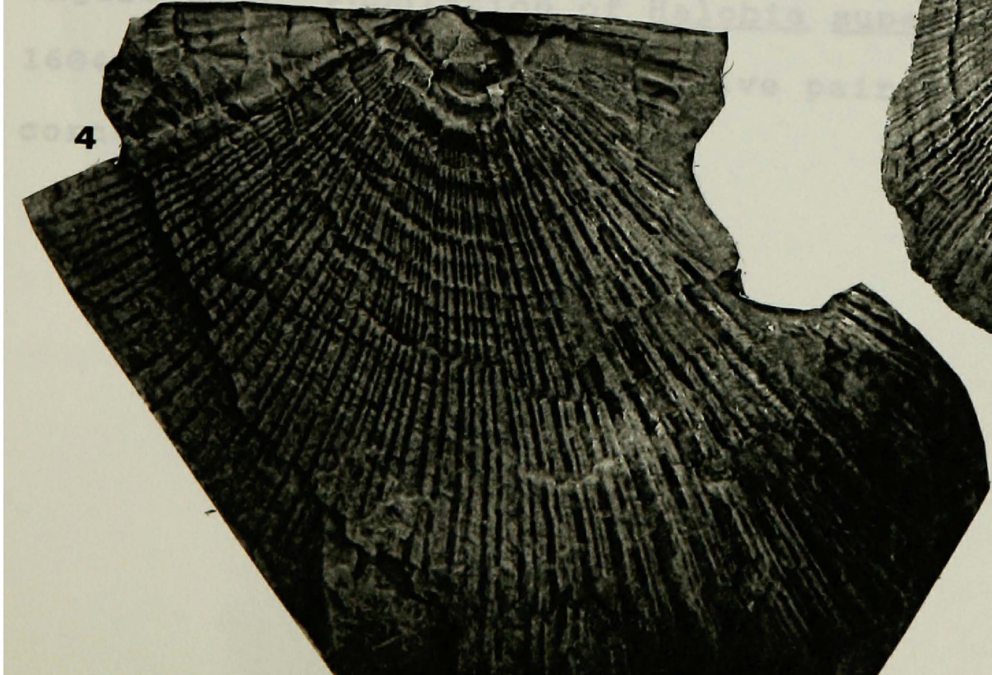
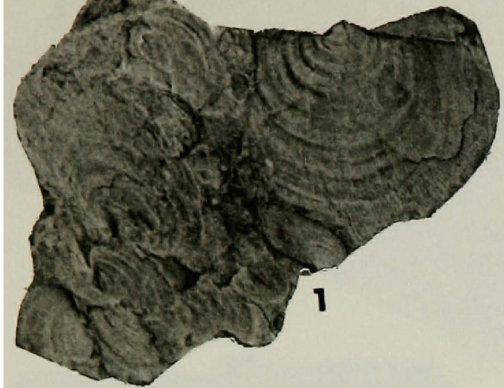
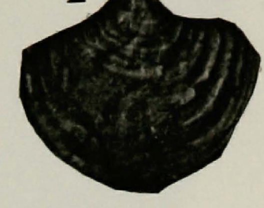
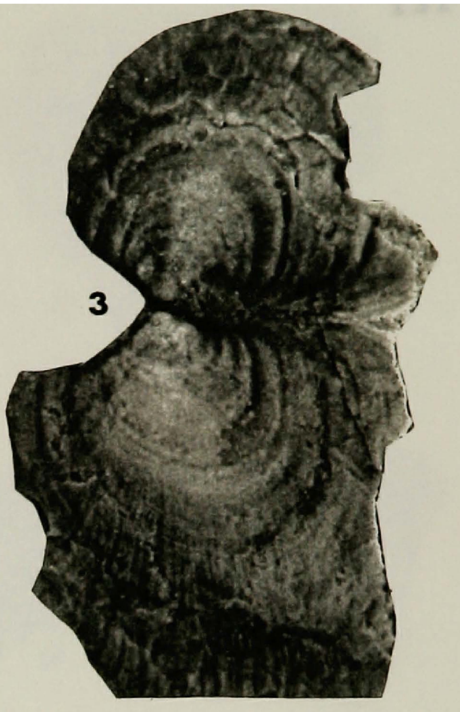


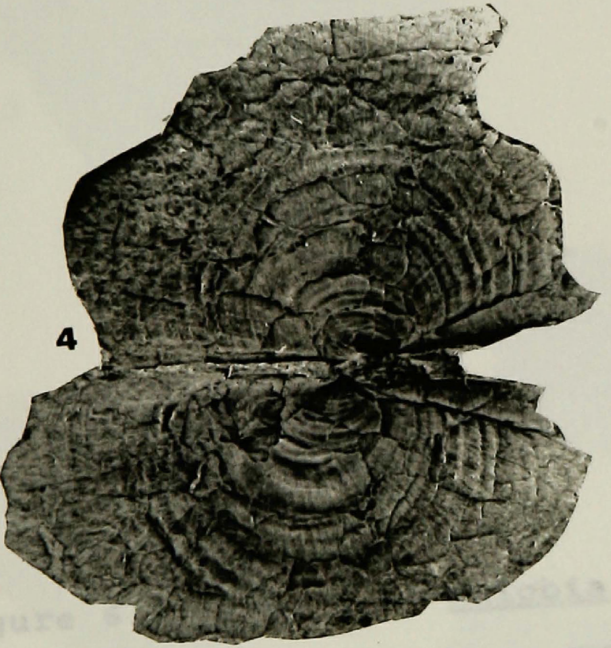
Figure 6.4. Population of _Halobia_ _superba_ Mojsisovics. UMIP 16042, x2. Note articulated valve pair in upper, right-hand corner.

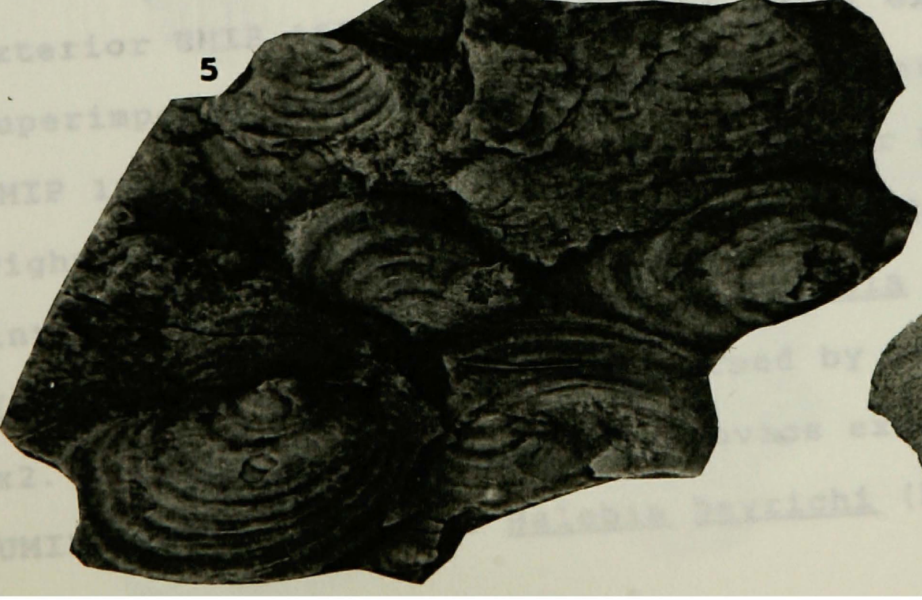
Figure 6.5. 1-3 -- Halobia radiata Gemm. 1) right valve exterior UMIP 16054, x2; 2) ?right valve exterior UMIP 16xx, x2; 3) articulated valve pair, UMIP 16029a, x4; 4) ?Halobia beyrichi articulated valve pair, internal UMIP 16031, x1.5; 5) population of Halobia cf. H. teltschenesis (Kittl). UMIP 16058, x2.5; 6-8 Halobia superba Mojsisovics.

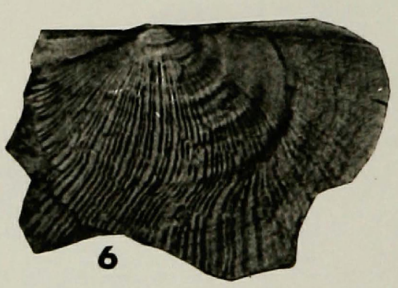

1


2


3


4

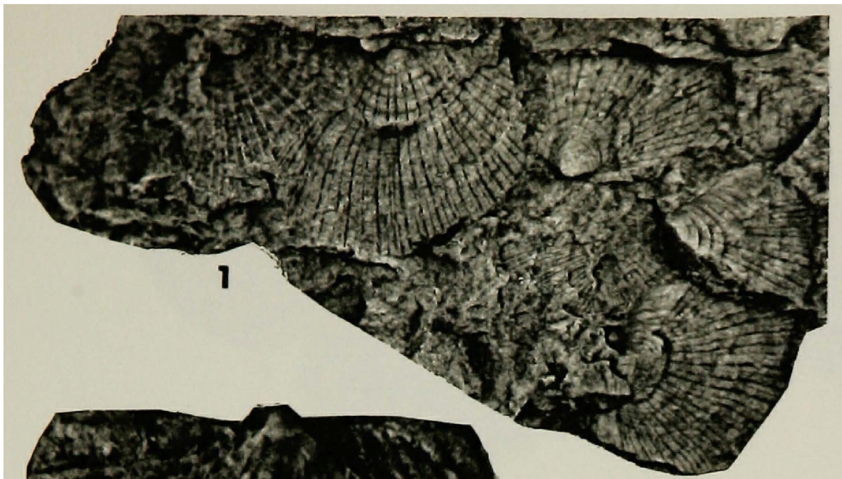

5

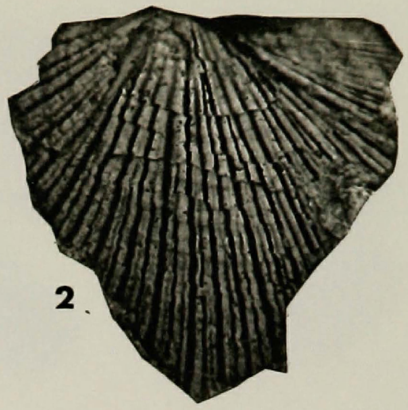

6

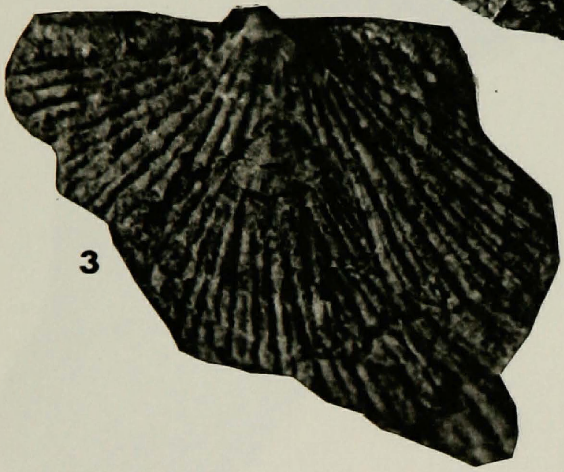

7

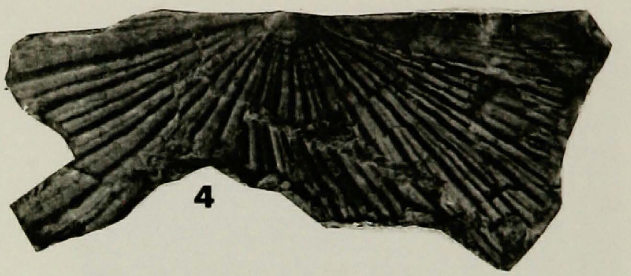

8

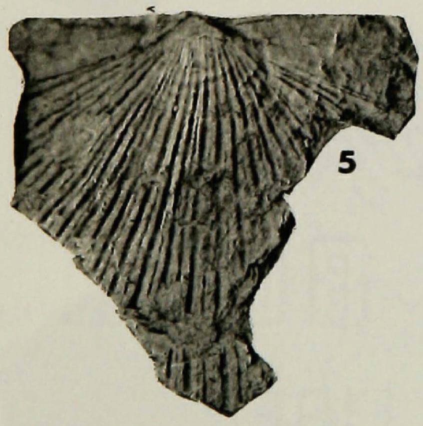
Figure 6.6. 1-6, 6 -- *Halobia halorica* Mojsisovics 1) population of rugate forms UMIP 16066, x2; 2)left valve exterior UMIP 16039, x2; 3) right valve exterior with superimposed juvenile UMIP16036, x3; 4)left valve exterior UMIP 16072, x1.5; 5) left valve exterior UMIP 16049, x2; 6) right valve rugate form UMIP 16066, x2; 8) ?left valve, internal mold UMIP 16040, x2; 7) *Halobia* cf. *H. lineata* (Muenster) two individuals deformed by strain UMIP 16060, x2. 9) *Halobia austriaca* Mojsisovics exterior right valve UMIP 16062, x2; 10-11 *Halobia beyrichi* (Mojsisovics).

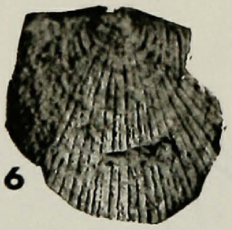

1

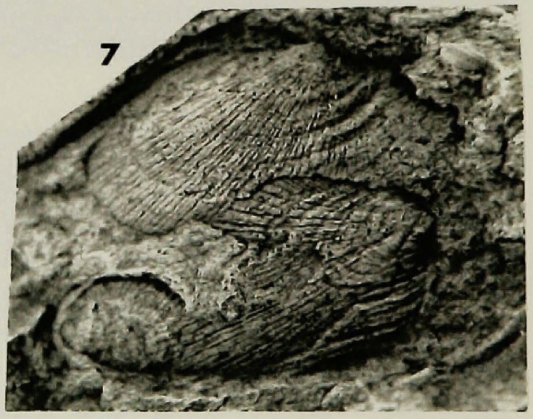

2


3

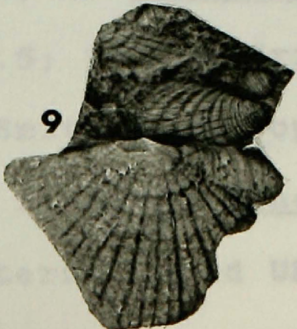

4

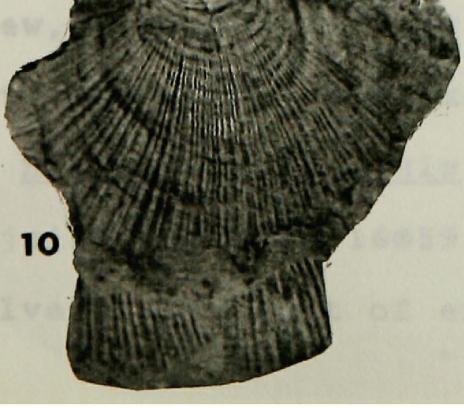

5


6


7


8


9


10

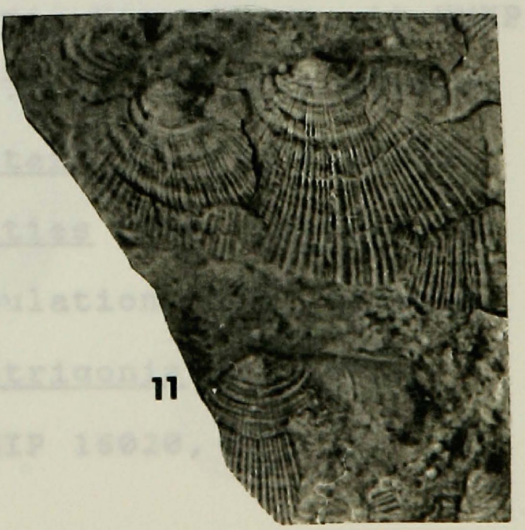
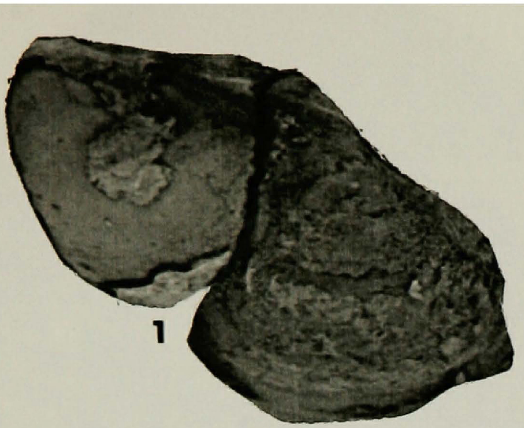
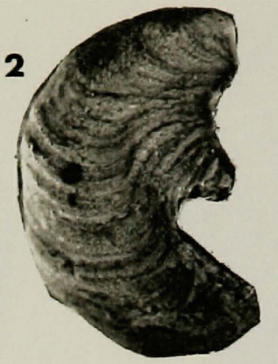
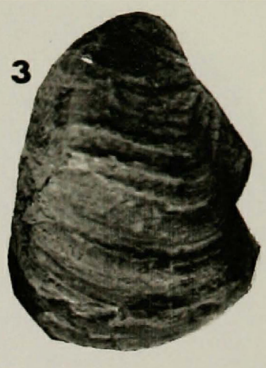
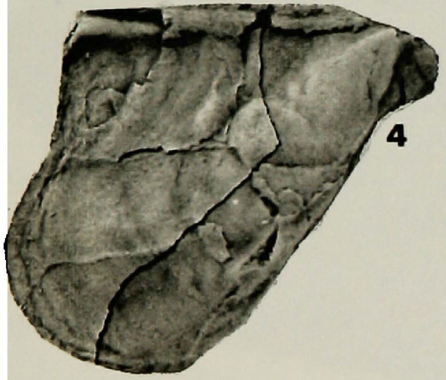

11

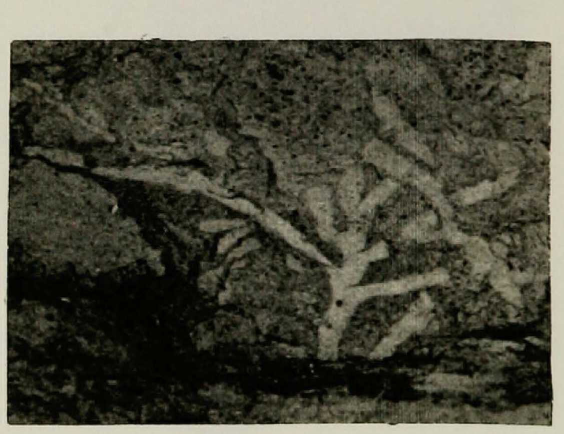
Figure 6.7. 1-3 *Gryphaea arcuataeformis* Kiparisova, 1) UMIP 16017d, x1.5; 2) left valve UMIP 16017b, x1.5; 3) posterior view, same specimen as 2; 4) *Mysidioptera* sp. right valve exterior UMIP 16018, x1.5; 5) *Chondrities* UMIP 16048, x1.5; 6) *Halobia oregonensis* Smith in a population of *H. superba* Mojsisovics UMIP 16059, x1.5; 7) *Minetrigonia* sp. left valve, latex cast of external mold UMIP 16020, x2.

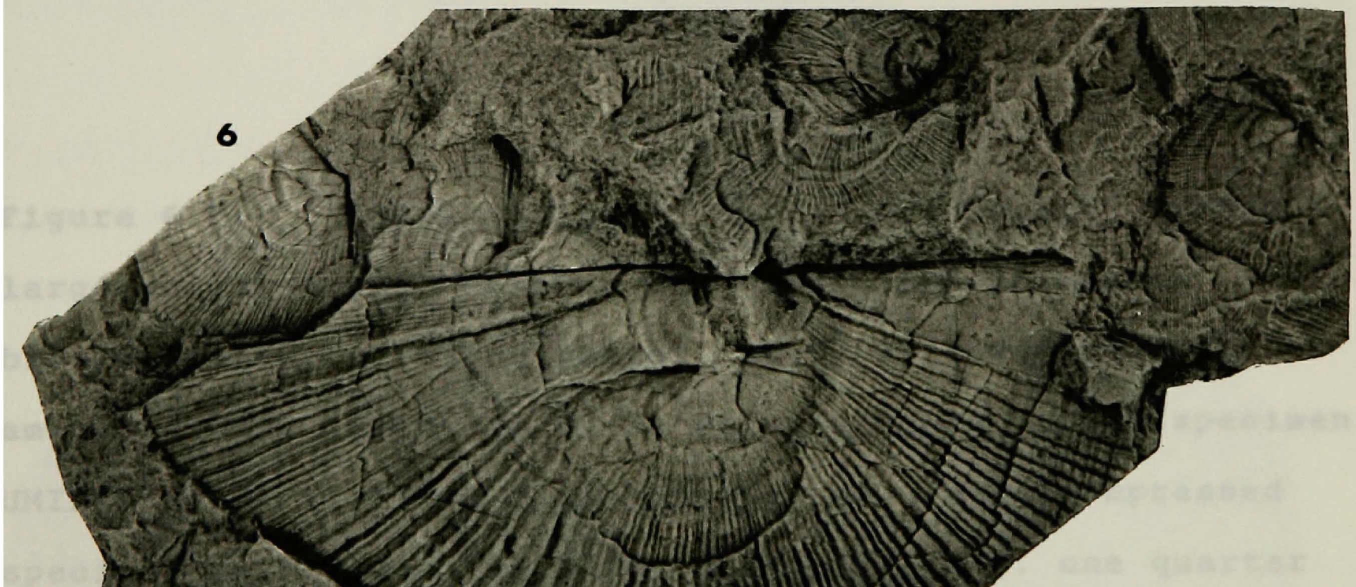

1


2


3


4


5

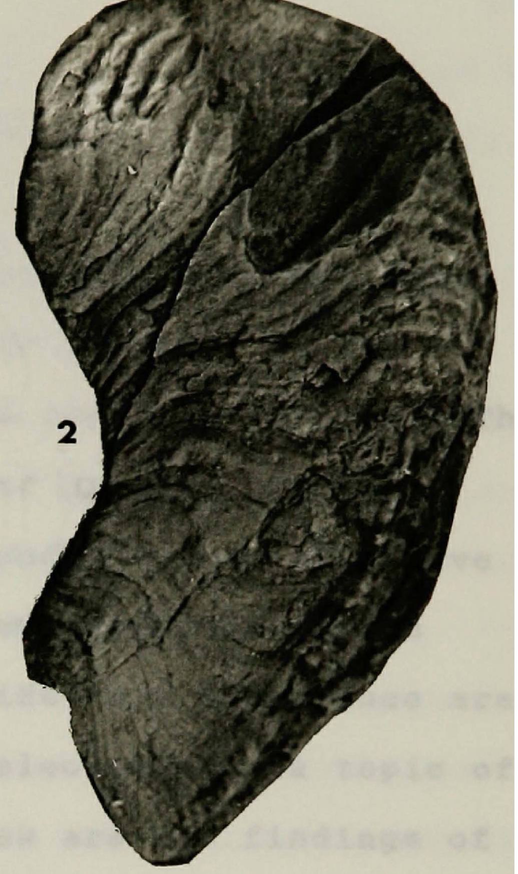

6


7

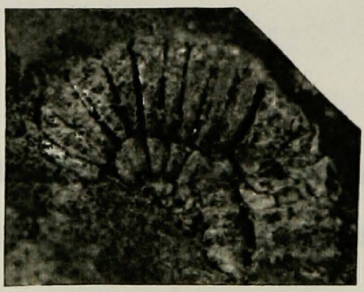
Figure 6.8. 1) *Arietoceltites* sp., cross section through large specimen UMIP 16006a, note small indeterminate bivalves attached along venter, x1.5; 2) indeterminate ammonoid UMIP 16003, x1.5; 3) *Polycyclus* sp. small specimen UMIP 16006b, x1.5; 4) *Discotropites* sp. large compressed specimen UMIP 16002, x1.5; 5) *Anatropites* sp. one quarter whorl, UMIP 16013, x2.

1

2

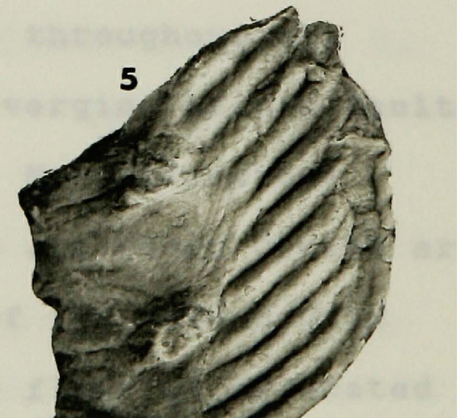


3



4

5



CHAPTER VII

SUMMARY AND CONCLUSIONS

This study documents several important findings from detailed paleontlogical and geological analysis of the Martin Bridge Fromation stratotype in northeast Oregon. The systematic revision of many species of Halobia and the identification of numerous ammonoid and conodont taxa have aided in solving geologic and biostratigraphic problems overlooked by past studies. Of considerable importance are the conclusions regarding halobiid paleoecology, a topic of considerable debate. Summerized below are the findings of this study.

Martin Bridge stratotype, geology and stratigraphy.

Although previous studies suggest a largly intact section, geologic mapping and stratigraphic analysis identified numerous structural problems throughout the Martin Bridge type section. Northwest-verging thrust faults disrupt the section in several places. Most limestone conglomerate on the ridge between Eagle and Paddy Creeks are believed to be structural repetitions of the same bed by thursting, rather than different debris flows as advocated by Follo (in press). Northeast and northwest striking high-angle reverse and normal faults are also common, and cross-cut thrust fault structures. The type area was subjected to intense folding associated with the thrusting. Some folds, however, are determined to be post-thrusting and are associated with high-angle faults and regional deformational events.

Mapping revealed five isolated structural blocks which were stratigraphically analyzed. The lithologic succession agrees well with the original description of the stratotype given by Smith (1912; 1927). The lithologic and fossil occurrences within and between each block provide criteria for the block sequencing and correlation. At least three different interpretations of the block sequence are possible based on the occurrences of different fossil halobiid and ammonoid taxa as sequencing criteria. Of the three, one alternative places the lowest structural block (Block 1) in part coeval with the next highest (Block 2) and the Paddy Creek section and is favored because it relies upon three biostratigraphically important taxa (_Halobia beyrichi_, _H. radiata_, and _H. superba_) as well as lithologic similarities as criteria.

Systematic classification and biostratigraphy of Halobia.

Systematic revision of most, if not all, halobiids is desired. Members within the form-genus "_Halobia_" are probably descendant from multiple _Posidionia_ and _Daonella_ ancestors. A polyphyletic origin for _Halobia_ requires supression of the Family Halobiidae Kittl as a junior synonym for the Family Posidoniidae Frech. The morphology of _Halobia_ and possession of a two-layered shell microstructure suggest placement of the Posidoniidae in the Superfamily Pteriacea.

Generic and subgeneric characters are poorly understood. Division of "_Halobia_" at the generic and subgeneric rank is desired, but considered premature. Species-level characters are also poorly understood, but new concepts provide a working systematic scheme. By employing multi-character analysis, specimens recovered from the Martin Bridge were given species rank, often by synonomizing many of the earlier described species. Eight species of _Halobia_ were identified. Of considerable importance, is that _Halobia_ _ornatissima_ is here thought of as a junior synonym for _Halobia_ _superba_. A similar species, _Halobia_ _oregonensis_, remains valid, although the paratypes designated by Smith (1927) probably belong to _Halobia_ _superba_.

Although additional species are reported here, the faunal succession of the Martin Bridge stratotype closely correspond to the original descriptions of Smith (1912; 1927). Of the halobiid species discussed in this study, _Halobia_ _beyrichi_, _H._ _radiata_, _H._ _austriaca_, _H._ cf. _H._ _teltchenses_, and _H._ cf. _H._ _lineata_ are reported for the first time from the Wallowa terrane. The ammonoids

Discotropites, *Anatropites*, *Polycyclus*, and *Arietoceltites* are also reported for the first time from the Wallowa terrane.

When compared to key stratigraphic sections in Europe and Alaska, the halobiid and ammonoid succession from the Martin Bridge can be related to the ammonoid zones of Silberling and Tozer (1968). Three biostratigraphic units (taxon range zones) can be identified from the Martin Bridge: 1) *Halobia superba*, *H. oregonensis*, *H. radiata*, and *Discotropites* belong to the earliest biostratigraphic unit (BU-1) and is believed to fall within the Upper Carnian Welleri and Macrolobatus Zones, 2) BU-2 contains *Halobia beyrichi*, *H. austriaca*, and *Anatropites* and believed to correspond to the upper part of the Macrolobatus (Upper Carnian) and into the Kerri (Lower Norian) Zones, and 3) The highest biostratigraphic unit (BU-3) contains *Halobia halorica* and is correlated to the Middle Norian Rutherfordi and Columbianus Zones. Key taxa representive of the Kerri-Rutherfordi Zones is missing from the Martin Bridge stratotype but may lie with the unfossiliferous beds between the middle of Block 2, and Block 5. Thus, the deposition of Martin Bridge at its type locality took place between the Welleri and Columbianus Zones.

Paleoecology of Halobia.

Morphologic evidence requires an epibyssate life-mode for most, if not all, species of Halobia. Rather than being a response to substrate preference (Gruber, 1976), the general outline and thinness of the halobiid shell are considered constructional and functional responses to streamlining in different water velocity regimes. Suitable attachment sites must have included any available firm substrate either lying on or above the soft sediment surface. Lack of a suitable benthonic substrate and sedimentological evidence of an oxygen deficient bottom, an extended substrate, such as algae, is preferred.

Shell concentrations of Halobia can be explained by extremely high rates of shell deposition rather than decreased sedimentation, non-deposition, or erosion. Extensive post-mortem transport is ruled-out for most shell beds because of the presence of articulated valves, lack of corraded valves and evidence of deposition in quiet water.

The high density and monospecific composition of most halobiid shell beds, along with their wide-spread geographic distribution suggest that halobiids were opportunists and not limited primarly by resources. A long-lived planktotrophic larval stage, along with their postulated attachment to floating algae may explain the rapid appearance and cosmopolitan distribution of many halobiid species. Furthermore, if halobiids were attached floating or rooted algae, their population fluctuations might be attributed to the populations of their algal substrates. By analogy with modern seaweed distributions, population fluctuations, and their attached epibionts, an algal-hosted, epibyssate life-mode is deduced for most species of _Halobia_.

REFERENCES

ALLASINAZ, A., M. GUTNIC, and A. POISSON. 1974. La formation de l'Isparta Cay: Calcaires a Halobies, Gres a plantes et Radiolarites d'age Carnien(?)-Norien (Taurides-Region d'Isparta-Turquie),p.11-21, In H. Zapfe, (ed.) The stratigraphy of the Alpine-Mediterranean Triassic. Schrifenreihe Erdwiss. Komm. 2. Springer-Verlag, Berlin.

ARMSTRONG, R.L., W. TAUBENECK, and P. HALES. 1977. Rb-Sr and K-Ar geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho. Geological Society of America Bulletin. 88:397-411.

ARTHABER, G. 1906. Die alpine Trias der Mediterranan-Gebietes. Lethaea geognostica II. Teil, Mesozoicum Band I. 472p. Stuttgart.

BEURLEN, K. 1944. Beitrage zur Stammesgeschichte der Muscheln. Bayer. Akad. Wiss. Sitzungsber., no. 1-2, p.133-145.

BITTNER, 1899. Himalayan fossils: Trias Braciopoda and Lamellibranchiata. Memoirs Geologocal Survey of India. Palaeontologia Indica. Series 15, 3:1-76.

BLEAHU, M., C. TOMESCU, and S. PANIN. 1974. Contributii la biostratigrafia depozitelor Triasice din Platoul Vascau (Muntii Apuseni). Dari Seama Sed. Inst. geol. Rom. 58(3)(1971)1972:5-25, 11 pls.

BLOME, C.D., K.M. REED, and I.L., TAILLEUR. 1988. Radiolarian biostratigraphy of the Otuk Formation in and near the National Petroleum Reserve in Alaska. U.S. Geological Survey Professional Paper 1399. p.725-776.

BROMLEY, R.G. and A.A. EKDALE. 1984. Chondrites: A trace fossil indicator of anoxia in sediments. Science, 224:872-874.

BRONN, H. 1830. Ueber die Muschel-Versteinerungen des sud-Deuschen Steinsalzgebirges, welche bisher unter dem Namen Pectines salinarius zusammenbegriffen wurden. Leonhard und Bronns Jahrb. f. miner., 1:279-285, 4 pls. Heidelberg.

BROOKS, H.C., and T.L., VALLIER. 1978. Mesozoic rocks and tectonic evolution of eastern Oregon and western Idaho, p.133-145. In D. Howell and K. McDougall (eds.), Mesozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium 2. Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles, California.

CAFIERO, B. and P., DE CAPOA BONARDI. 1980. Stratigraphy of the pelagic Triassic in the Budva-Kortor area (Crna-Gora, Montenegro, Yugoslavia). Bollettino della Societa Paleontolgica Italiana, 19:179-204.

_________, and _________. 1982. Biostratigrafia del Trias pelagico della Sicilia. Bollettino della Societa Paleontolgica Italiana, 21:35-71.

CAMPBELL, H.J. 1985a. The stratigraphic significance of the Triassic bivalves Daonella and Halobia in New Zealand and New Caledonia. New Zealand Geologic Survey, Record 9, Hornibrook Symposium, Extended Abstracts. p. 21-23.

_________. 1985b. Stratigraphic significance of the Triassic bivalves Daonella and Halobia in New Zealand and New Caledonia. Unpublished Ph.D Thesis, University of Cambridge, Cambridge. 185p.

CHANEY, R.W. 1932. Central Oregon: International Geological Congress, 16th, Washington, D.C., 1933, Guidbook 21, Excursion C-2, 14p.

CHEN, CHU-CHEN. 1964. On the occurrence of Halobia fauna from the Ganzi region, western Sichuan (Szechuan) and its significance. Acta Paleontologica Sinica. 2:68-78. Peking.

_______. 1976. Lamellibranch fossils of China. Nanking Inst. Geol. and Paleon. Acad. Sin. (eds) Science Press. Peking,. PRC. 522p.

CHEN, J-h, and D-z BA. 1986. Halobia fauna from Zedang of Xizang with a discussion on the Halobia assemblages in China. Acta Palaeont. Sin. 25(1):1-9.

CHERNOV, V.G. 1981. Bivalvia from the Upper Triassic deposites of the Soviet Carpathians. Paleontologiczni Sbornik, 1981, no. 18, p.36-42, 1 pl. Lvov.

CONEY, P.J., D.L. JONES, and J.W.H. MONGER. 1980. Cordilleran suspect terranes. Nature, 288:329-333.

COX, L.R., and N.D. NEWELL. 1969. Family Posidoniidae Frech, 1909. p. N342-N344. In R.C. Moore, (ed.) Treatise on Invertebrate Paleontology, Part N, Mollusca 6, Bivalvia, Volume 1. The Geological Society of America and University of Kansas Press, Larwence.

CUVIER, G.L.C. 1797. Tableau elementaire de l'histoire naturelle des animaux. 710p. Paris.

DALL, W.H. 1889. On the hinge of pelecypods and its development with an attempt toward a better subdivision of the group. American Journal of Science, Ser. 3, 38:445-462.

DAVIES, D.J., E.N. POWELL, AND R.J. STANTON. 1989. Relative rates of shell dissolution and net sediment accumulation- a commentary: can shell beds form by the gradual accumulation of biogenic debris on the sea floor? Lethaia, 22:207-212.

DE CAPOA BONARDI, P. 1970. Le Daonelle e le Halobie della serio calccareo-silico-marnosa della Lucania (Appenio Meridionale). Studio paleontologico e biostratigrafico. Memoire. Societa Naturali Napoli, Suppl. Bollettino 78 (1969). p. 1-127. 19 pls. Napoli.

_________, 1984. Halobia zones in the pelagic Late Triassic sequences of the central Mediterranean area. Bollettino della Societa Paleontologica Italiana, 23:91-102.

DE WEVER, P., A. SANFILIPPO, W. RIEDEL, and B. GRUBER. 1979. Triassic radiolarians from Greece, Sicily and Turkey. Micropaleontology, 25:75-110, pls. 1-7.

DEUSER, W.G., AND E.H. ROSS. 1980. Seasonal change in the flux of organic carbon to the deep Sargasso Sea. Nature, 283:364-365.

DIENER, C. 1908. Ladinic, Carnic, and Noric faunae of Spiti. India Geological Survey Momoirs, Palaeontologia Indica Ser.15, v.5, mem.3.

_________. 1916. Untersuchungen uber die Wohnkammerlange als Grundlage einer nauturlichen systematik der Ammoniten. K. Akad. Wiss. Wien, math-naturwiss. Kl. Sitzungsber., Abt.1, 125:253-309.

________. 1923. Fossilium Catalogs I. Animalia, part 19: Lamellibranchiata Triadica. W. Junk, Berlin, 257p.

________. 1925. Leitfossilien der Trias, Wirbellose Tiere und Kalkalgen. Borntraegen, Berlin. 119p.

ELKDALE, A.A., and T.R. MASON. 1988. Characteristic trace-fossil associations in oxygen-poor sedimentary environments. Geology 16:720-723.

_________, and _________. 1989. Reply to R.A. Wheatcroft. Geology, 17:674-675.

EMERY, K.O. 1968. Positions of empty pelecypod valves on the continental shelf. Journal of Sedimentary Petrology, 38:1264-1269.

ENCHEVA, M.G. 1972. Les fossiles de Bulgarie. II. Les Trias. Acad. Bulg. Sciences, pp.56-152, 44pls. Sofia.

_________. 1978. Phylogenetic development of the family Posidoniidae and the Genera Daonella and Halobia (Bivalvia; Triassic). Geologica Balcanica, 8(2):55-67.

FINE, M.L. 1970. Faunal variation on pelagic Sargassum. Marine Biology, 7:112-122.

FLEMING, C.A. 1982. The family name for radial ribbed Trigoniacea (Bivalvia). Journal of Paleontology, 56:820-821.

FOLLO, M.F. 1986. Sedimentology of the Wallowa terrane, northeastern Oregon. Unpublished Ph.D thesis, Harvard University, Cambridge, Massachusetts.

_________. (in press) Sedimentology and stratigraphy of the Martin Bridge Limestone and Hurwal Formation (Late Triassic-Early Jurassic) from the Wallowa terrane, Oregon. U.S. Geological Survey Professional Paper.

FRECH, F. 1909. Lethaea geognostica. Das Mesozoicum 1: die Trias. Stuttgart, 632 p.

FRENEIX, S. 1972. Le test de Daonella indica Bittner. Haliotis, 2:167-173.

FRUSICH, F.T. and J. WENDT. 1977. Biostratinomy and paleoecology of the Cassian Formation (Triassic) of the southern Alps. Paleogeography, Paleoclimatology, Paleoecology. 22:257-322.

GABB, W.M. 1864. Description of the Triassic fossils of California and adjacent territories. Geol. Surv. Calif. Paleont. 1:19-35.

GEMMELLARO, G. 1882. Sul Trias regione occidentale della Sicilia. Accedemia Nazionale del Lincei. Memoire 12, 3D ser. p.451-473. 5 Tav. Rome.

GRANT-MACKIE, J.A. 1980. Mode of life and adaptive evolution in the cosmopolitain Triassic bivalve Monotis. Journal of the Malacological Society of Austraila, 4:242-243.

GRAY, J.E. 1847. A list of the genera of Recent Mollusca, their synonyms and types. Zoological Society of London, Proceedings, 15:129-219.

GRUBER, B. 1975. Unternorische Halobien (Bivalvia) aus Bosmien Jugoslavian. Sitzungsberichte ost. Akad. Wiss (Abt.1) 183(4-7)119-130.

_________. 1976. Neue Ergebnisse auf dem Gebiete der Okologie, Stratigraphie und Phylogenie der Halobien (Bivalvia). Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Osterreich, 23:181-198. Wien.

_________, 1985. Die Gattungen Halobia Bronn, 1830, und Perihalobia Gruber, 1976, (Posidoniidae, Bivalvia) in der alpin-mediterranen Tethys und Nordamerika. Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Osterreich, 31:241-248. Wien.

_________, R. LEIN, and M. SEEGER. 1980. Ein karnischerTisovec- Kalk mit Halobia (?) clari n. spec. aus den St. Pauler Bergen. Mitteilungen der Gesellschaft der Geolgie- und Bergbaustudenten in Osterreich, 26:167-177. Wien.

GILLULY, J. 1937. Geology and mineral resources of the Baker Quadrangle, Oregon. U.S. Geological Survey Bulletin 897, 119p.

_________, J.C. REED, and C.F. PARK. 1933. Some mining districts of eastern Oregon. U.S. Geological Survey Bulletin 846, 140p.

HALLAM, A. 1981. The end-Triassic bivalve extinction event. Paleogeography, Paleoclimatology, Paleoecology, 35:1-44.

HAMILTON, W. 1963. Metamorphism in the Riggins region, western Idaho. U.S. Geological Survey Professional Paper 438. 95p.

HAYAMI, I. 1969. Notes on Mesozoic "planktonic" bivalves. Journal of the Geological Society of Japan, 75:375-385. (English Abstract).

_________. 1975. A systematic survey of the Mesozoic Bivalvia from Japan. The University Museum, The University of Tokyo Bulletin no. 10, p.64-68.

HARLAND, W., A.V. COX, P.G. LLEWELLYN, C.A.G. PICKTON, A.G. SMITH, and R. WALTERS. 1982. A geologic time scale. Cambridge University Press, London. 131 p.

HYATT, A. 1884. Genera of fossil Cephalopods. Boston Society of Natural History, Proceedings, 22:273-338.

_________, and J.P. SMITH. 1905. The Triassic Cephalopod genera of America. U.S. Geological Survey Professional Paper 40, pp.1-394, pl.1-85.

HEDBERG., H.D. 1976. International stratigraphic guide. John Wiley and Sons, New York. 200 p.

HILLHOUSE, J.W., C.S. GROMME, and T.L. VALLIER. 1982. Paleomagnetism and Mesozoic tectonics of the Seven Devils volcanic arc in northeastern Oregon. Journal of Geophysical Research, 87:3777-3794.

HORN, M. 1960. Die zone Eumorphoceras pseudobilingur im Sauerland. Fortschr. Geol. Rheinld. u. West. 3:303-342.

ICHIKAWA, K. 1958. Zur Taxonomie und Phylogenie der triadischen ,, Pteriidae'' (Lamellibranch.), mit besonderer Berucksichtigung der Gattung Claria, Eumorphotis, Oxytoma und Monotis. Palaeontographica, A 3, p.131-212.

JABLONSKI, D. 1985. Molluscan development. p.33-50. In T.W. Broadhead (ed.) Mollusca, notes for a short course. University of Tennesee Studies in Geology 13. University of Tennesee, Knoxville.

_________, and R.A. LUTZ. 1983. Larval ecology of marine benthic invertebrates: paleobiological implications. Biological Reviews. 58:21-89.

JEFFERIES, P.S., and P. MINTON. 1965. The mode of life of two Jurassic species of Posidonia (Bivalvia). Paleontology, 8:156-185.

JERZMANSKA, A., AND J. KOTLARCZYK. 1976. The beginnings of the sargasso assemblage in the Tethys? Paleogeography, Paleoclimatology, Paleoecology, 20:297-306.

JOHNSON, A., and M.J. SIMMS. 1989. The timing and cause of Late Triassic marine invertevrate extinctions: evidence from scallops and crinoids. p. 174-194. In S.K. Donavan (ed.) Mass extinctions: Processes and evidence. Bellhaven, London.

JONES, D.L., N.J. SILBERLING, and J. HILLHOUSE. 1977.

Wrangellia-- a displaced terrane in northwestern North America. Canadian Journal of Earth Science, 14:2565-2577.

JURKOVESK, B. 1985. Bivalves from the family Halobiidae: Important fossils for establishing the age of Triassic strata. Proteus, 47(7):243-247.

KAUFFMAN, E.G. 1969. Form, function and evolution. p.N129-N205. In R.C. Moore (ed.) Treatise on Invertebrate Paleontology, Part N, Mollusca 6, Bivalvia Volume 1. The Geological Society of America and the University of Kansas Press, Larwence.

_________. 1981. Ecological reappraisal of the German Posidienschiefer (Toarcian) and the stagnant basin model, p.311-381. In J. Gray, A.J. Boucot, and W.B.N. Berry (eds.), Communities of the past. Hutchinson Ross Publishing, Stroudsburg.

_________. 1988. The case of the missing community: low-oxygen adapted Paleozoic and Mesozoic bivalves ("flat clams") and bacterial symbiosis in typical Phanerozoic seas. Abstracts with Programs, v. 20, no. 7, 1988 Annual Meeting The Geological Society of America. Denver, Colorado. no.27931.

KIDWELL, S.M. 1985. Palaeobiological and sedimentological implications of fossil concentrations. Nature, 318:457-460.

KIPARISOVA, L.D. 1936. Upper Triassic pelecopods from the Kolyma-Indigirla Land. Transactions of the Artic institute, 30:71-136.

_________. 1937. Fauna triasovykh otlozheniy vostochnoy chasti Sovetsky arktiki (fauna from the Triassic sediments of the northern part of the Soviet arctic). Trudy Arktich 91:135-156.

_________. 1938. Pelecopoda of the Triassic System of USSR. Central Geological and Prospecting Institute, Paleontology of USSR Monographs, 47:42p.

________, Y.M. BYCHKOV, and I.V. POLUBOTKO. 1966. Upper Triassic bivalve molluscs from the northeast USSR. Vsesoyuznyy nauchno-issledovatel'skii instituta (VSEGEI). Magadan. 312 p.

KITTL, E. 1907. Die Triasfossilien vom Heureka Sund. Report of the second Norwegian artic expedition in the "Fram" 1898-1902. no.7. Vedenskabs-Selskabet I Kristianai.

_________. 1912. Materialen zu einer Monographie der Halobiidae und Monotidae der Trias. Resultate der Wissenschaftl Erforschung des Balatonsees. I Band, I Teil. Paleontologie Anhang. p.1-229. Wien.

KOBAYASHI, T. 1935. Einige neue Triadische Bivalven aus der innenzone sudwest-Japans. Japanese Journal of Geology and Geography, 12:27-32, pl. 7.

_________. 1963. Halobia and some other fossils from Kedah, northwest Malaya. Japaneese Journal of Geology and Geography. 34(2-4):113-128, pl.6.

_________, and AOTI. 1943. Halobiae in Nippon. J. Sigenkagaku Kenkyusho, 1(2):241-255.

_________, C.K. BURTON, A. TOKUYAMA, and E.H. YIN. 1966. The Daonella and Halobia facies of the Thai-Malay Peninsula compared with those from Japan. Contributions to the Geology and Palaeontology of Southeast Asia. 3:98-122.

_________, and T. ISHIBASH. 1970. Halobia styriaca, Upper Triassic pelecypod, discovered in Okinawa-Jima, the Rynkyu Islands. Transactions, Proceedings Paleontological Society of Japan, 77:243-248.

_________, and M. KATAYAMA. 1936. Trigonia from the Miya Series. Journal of the Geological Society of Japan. 43:331-335.

_________, and K. MANSANTI. 1968. Upper Triassic Halobia (Pelecypoda) from North Sumatra with a note on the Halobia facies of Indonesia. Japaneese Journal of Geology and Geography 39(2-4):113-123, 1pl.

_________, and M.TAMURA. 1968. Upper Triassic pelecypods from Singapore. Contributions to the Geology and Palaeontology of Southeast Asia, 5:135-150.

_________, and _________. 1984. The Triassic Bivalvia of Malaysia, Thailand and adjacent areas. Contributions to the Geology and Palaeontology of Southeast Asia, 25:201-220.

_________, and A.TOKUYAMA. 1959. The Halobiidae from Thailand. Journal of the Faculty of Science, University of Tokyo. 12:27-20, Section 2, Part 1.

KRISTAN-TOLLMANN, E., S. BARKHAM, and B. GRUBER. 1987. Potschenschichten, Zlambachmergel (Hallstatter Obertrias) und Liasfleckenmergel in Zentraltimor, nebst ihren Faunenelementen. Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Osterreich, 80:229-285, 5 pls. Wien.

KRISTAN-TOLLMANN, E, and A. TOLLMANN. 1983. Tethys-Faunenelemente in der Trias der USA. Mitt. Osterr. Geol. Ges. 76:213-272.

KRUMBECK, L. 1921. Die brachiopoden, lamellibranchiaten und gastropoden der Trias von Timor: I. Palaontologie von Timor X. 142 p.

_________. 1924. Die brachiopoden, lamellibranchiaten und gastropoden der Trias von Timor: II. Palaontologie von Timor XXII. 275 p.

KRYSTYN. L. 1980. Trriassic conodont localities of the Salzkammergut region (Northern Calcareous Alps). Abhandlungen der Geologischen Bundesanstalt, 35:61-98.

_________. 1982. Obertriassische ammonoideen aus dem Zentralnepalesischen Himalaya. Abhandlungen der Geologischen Bundesanstalt, 36:1-63, 18 pls.

LAMARCK, J. B. 1801. Systeme des animaux sans vertebres. 432p. Paris.

_________. 1819. Extrait du cours de zoologie du Museum d'Histoire Naturelle, sur les animaux sans vertebres. 127p. Paris.

LAUDON, T.S. 1956. Stratigraphy of the Upper Triassic Martin Bridge Formation and "Lower Sedimentary Series" of the northern Wallowa Mountains, Oregon. Unpublished Masters thesis, University of Wisconson, Madison.

LEVINTON, J.S. 1970. The paleoecologic significance of opportunistic species. Lethaia, 3:69-78.

LINDGREN, W. 1901. The gold belt of the Blue Mountains of Oregon. U.S. Geological Survey, 22nd Annual Report, Part 2, p.551-776.

LINDSTROEM,G.1865. Om Trias- och Juraforsteningar fran Spetsbergen. Kungl. Svenska Vetenskaps-Akademiens Handlingar. v.6, no.6, p.1-20.

LINNAEAS, C. 1758. Systema naturae per regna tria naturae. 842 p. edit. Decima (Holmiae).

McGRODER, M.F., and P.J. UMHOEFER. 1989. Comment on "Escape hypothesis for the Stikine block". Geology 17:1161-1162.

McKENNA, M. 1973. Sweepstakes, filters corridors, Noah's Arks, and Beached Viking Funeral ships in palaeogeography. p.295-308. In D.H. Tarling, and S.K. Runcorn (eds.) Implications of contenental drift to the Earth sciences. Academic Press, London.

McLEARN, F.H. 1937. New species from the Triassic Schooler Creek Formation. The Canadian Field Naturalist, 51:95-98.

_________. 1940. Preliminary study of some Triassic pelecypods and ammonoids from the Peace River foothills, B.C. Canadian Field Naturalist 54:111-116, 4 pls.

McROBERTS, C.A., and G.D. STANLEY, Jr. 1989. A uniquie bivalve-algal life assemblage from the Bear Gulch Limestone (Upper Mississippian) of Central Montana. Journal of Paleontology. 63:578-581.

MACARTHUR, R. H. 1960. On the relative abundance of species. American Naruralist, 94:25-36.

MARWICK. 1953. Divisions and faunas of the Hokonui System (Triassic and Jurassic). New Zealand Geological Survey Pal. Bull. 21, pp. 1-142.

MAY, S.R., and R.F. BUTLER. 1986. North American Jurassic apparent polar wander: implications for plate motion, paleogeography and Cordilleran tectonics. Journal of Geophysical Research, 91:11519-11544.

MAYR, E., 1963. Populations, Species and Evolution. Harvard University Press. 453 p.

MEL'NIKOVA, G.K., and Y.U. BYCHKOV. 1986. [Late Triassic scleractinians from the Kenkeren Range (Koryakskoe highland), pp.63-81, In Y.D. Zakharov, and Y.U. Onoprienko (eds.) Correlation of Permo-Triassic deposits of the east of the USSR.] Biol-pochv. in-t. DVNTs AN SSSR. 128p. Vladivostok.

MIRKIN, A.S. 1986. Structural analysis of the East Eagle Creek area, southern Wallowa Mountains; northeastern Oregon. Unpublished Masters thesis, Rice University, Houston. 116p.

MOISSIEV, A.S. 1926. Sur les Halobia des schistes argilleux de la Crimee. Bull. du Comite Geol. Leningrad. 43(7):755:758, Abb 25-26. Taf 23 Leningrad.

MOJSISOVICS, E. 1874. Uber Die Triadischen

Pelecypoden-Gattungen Daonella und Halobia. Abhundlungen der k. k. geologischen Reichsanstalt, 7:1-35, pls. 1-5.

_________. 1873-1902. Das Gebirge um Hallstatt I: Die Cephalopoden der Hallstatter Kalke. Abhundlungen der k. k. geologischen Reichsanstalt, Band 6, Heft 1, 2; Band 1 Suppl. Heft, p. 1-356, pl. 1-70 and 1-23 (Heft 1, p.1-82, published in 1873; Heft 2, p. 83-174, pl.33-70, in 1875; suppl. Heft, p.175-356, pl.1-23, in 1902); p.1-835, pl.71-200, 1893.

MONTANARI, L., and P. RENDA. 1977, Biostratigrafia del Trias di M.Triona (Sicani). Bollettino Societa Geologico Italiana. (1976) 95:725-744, 6 fig. Roma.

MORRISON, R.F. 1964. Upper Jurassic mudstone unit named in Snake River Canyon, Oregon-Idaho boundary. Northwest Sciences, 38:83-87.

MORTIMER, N. 1986. Late Triassic, arc-related, potassic igneous rocks in the North American Cordillera. Geology, 14:1035-1038.

MUESTER, G. 1838. in A. Goldfuss. Abbidungen und Beschreibungen der Pterfacten Deutschlands und der anganzenden Lander. Petrefacten Germaniae 2. Dusseldorf, 150p.

NYE, O.B., J.C. BROWER, AND S.E. WILSON. 1975. Hitchhiking clams in the Marcellus Sea. Bulletins of American Paleontology,67:287-299.

NEWELL, N.D. 1965. Classification of the Bivalvia. American Museum, Novitates, 2206:1-25.

_________. 1969. Superfamily Ptectinacea Rafinesque, 1815. p.N333-N383. In R.C. Moore (ed.), Treatise on Invertebrate Paleontology, Part N, Mollusca 6, Bivalvia, Volume 1. The Geological Society of America and University of Kansas Press, Larwence.

_________, and D.W. BOYD. 1987. Iteration of ligiment structures in Pteriomorphian bivalves. Novitates, 2875:1-11.

_________, and _________. 1989. Phylogenetic implications of shell microstructure in the Pseudomonotidae, extinct Bivalvia. Novitates, 2933:1-12.

NEWTON, C.R. 1983. Paleozoogeographic affinities of Norian bivalves from the Wrangellian, Peninsular, and

Alexander terranes, western North America. p.37-48. In C. Stevens (ed.) Pre-Jurassic rocks in western North America suspect terranes. Society of Economic Paleontologists and Mineralogists, Pacific Section.

__________. 1986. Late Triassic bivalves of the Martin Bridge Limestone, Hells Canyon, Oregon: taphonomy, paleoecology, paleozoology. p. 7-22 In T.L. Vallier, and H.C. Brooks (eds.) Geology of the Blue Mountains Region of Oregon, Idaho, and Washington. U.S. Geological Survey Professional Paper 1435.

__________. 1987. Biogeographic complexity in Triassic bivalves of the Wallowa terrane, northwestern United States: Oceanic islands, not continents, provide the best analogues. Geology, 15:1126-1129.

__________. 1988. Significance of "Tethyan" fossils in the Cordillera. Science, 242:385-391.

__________, and M.T. WHALEN, J.B. THOMPSON, N. PRINS, and D. DELALLA. 1987. Systematics and paleoecology of Norian (Late Triassic) bivalves from a tropical island arc: Wallowa Terrane, Oregon. The Paleontological Society Memoir 22. 83 p.

NOLF, B.O. 1966. Structure and stratigraphy of part of the northern Wallowa Mountains. Unpublished Ph.D thesis, Princeton University, Princeton, New Jersey. 135p.

ORR, W.N. 1986. A Norian (Late Triassic) ichthyosaur from the Martin Bridge Limestone, Wallowa Mountians, Oregon. pp 41-47. In T.L. Vallier, and H.C. Brooks (eds.) Geology of the Blue Mountains regions of Oregon, Idaho, and Washington. U.S. Geological Survey Professional Paper 1435.

PEARSE, J.S., and A.H. HINES. 1979. Expansion of a California kelp forest following the mass mortality of sea urchins. Marine Biology, 51:83-91.

POLUBOTKO, I.V. 1980. Early Carnian Halobiidae of northeast Asia. Paleontological Journal, no.1, 34-41.

__________. 1984. Zonal and correlation significance of Late Triassic halobiids. Sovetskaya Geologiya, 6:40-51. (in Russian).

__________. 1988. On the morphology and systematics of the Late Triassic Halobiidae (bivalve mollusks). Annual of the all-union Paleontological Society, 31:90-103.

PROSTKA, H.J. 1962. Geology of the Sparta quandrangle, Oregon. Oregon Department of Geology and Mineral Resources. Geological Map Ser. 1.

PULEC, M. 1965. Neue fossilien in den Lunzer Schichten. Geol. prace Bratisl. 34:209-216. in Czech.

RAFINESQUE, C.S. 1815. Analyse de nature: 225p. (Palermo).

RENZ, C. 1906. Uber Halobien und Daonellen aus Griechland, nebst asiatischen Vergleichsstucken. N. Jahrb. Mineral., 1906/1:27-40, Stuttgart.

RHOADS, D.C., and I.W. MORSE. 1971. Evolutionary and ecologic significance of oxygen-deficient marine basins. Lethaia, 4:413-428.

ROSS, C.P. 1938. The geology of part of the Wallowa Mountains. Oregon Department of Geology and Mineral Resources Bulletin no.7, 74p.

SALOMON, W. 1895. Geologische und palaeontologische Studien ueber die Marmolata. Palaeontographica, 42:1-210.

SAREWITZ, D. 1983. Seven Devils terrane: is it really a piece of Wrangellia? Geology, 11:634-637.

SCANDONE, P. and P. DE CAPOA BONARDI. 1966. Sulla posizione stratigrafica e l'eta dei livelli a Daonella e ad Halobia in Lucania. Boll. Soc. Natur. Napoli, 75:30-39, 7pls., Napoli.

SCHELTEMA, R.S. 1977. Dispersal of marine invertebrate organisims: paleogeographic and biostratigraphic implications, p.73-108. In E. Kauffman, and J. Hazel (eds.) Concepts and methods of biostratigraphy. Dowden, Hutchinson, and Ross. Stroudsburg.

SCHOENER, A. AND G.T. ROWE. 1970. Pelagic Sargassum and its presence among the deep-sea benthos. Deep-Sea Research, 17:923-925.

SEILACHER, A. 1967. Bathymetry of trace fossils. Marine Geology, 5:413-428.

_________. 1982. Ammonite shells as habitates in the Posidinia shales of Hollzmaden- floats or benthic islands? N. Jb. Palaeont. Min. 152(2):98-114.

_________. 1984. Constructional morphology of bivalves: evolutionary pathways in primary verses secondary sort-bottom dwellers. Palaeontology, 27:207-237.

SENOWBARI-DARYAN, B., and G.D. STANLEY, Jr. 1988. Triassic sponges (Sphinctozoa) from Hells Canyon, Oregon. Journal of Paleontology, 62:419-423.

SILBERLING, N.J. 1963. Field guide to halobiid and monotid pelecypods of the Alaskan Triassic. U.S. Geological Survey open-file report, 9p.

__________. 1985. Biogeographic significance of the Upper Triassic bivalve Monotis in circum-Pacific accreted terranes. In D.G. Howell (ed.), Tectonostratigraphic terranes of the Circum-Pacific region. Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, no. 1, p. 63-70.

__________, and E.T. TOZER. 1968. Biostratigraphic classification of the marine Triassic in North America. The Geological Society of America Special Paper Number 110. 63p.

__________, D.L. JONES, M.C. BLAKE, and D.G. HOWELL. 1984. Lithotectonic terrane map of the western contimerous United States, In Silberling N.J. and D.L. Jones (eds.) Lithotectonic terrane maps of the North American Cordillera. U.S. Geological Survey Miscellaneous Field Studies Map MF-1874.

SKWARKO, S.K. 1973. On the discovory of Halobidae (Bivalvia, Triassic) in New Guinea. Commonwealth Austral., Bur. Miner Resour. Geol. Geophys. Bull. Austral., no. 126, pp. 51-54.

SMITH, D.W., and J.E. ALLEN. 1941. Geology and physiography of the northern Wallowa Mountains, Oregon. Oregon Department of Geology and Mineral Resources Bulletin no. 12, 75p.

SMITH, J.P. 1912. The occurrence of coral reefs in the Triassic of North America. American Journal of Science, 33:92-96.

__________. 1927. Upper Triassic Marine invertebrate faunas of North America. U.S. Geological Survey Professional Paper 141. 262 p., 121 pls.

SMITH, P.L. 1988. Paleobiogeography and plate tectonics. Geoscience Canada, 15:261-279.

SPATH, L.F. 1951. Catalogue of the fossil Cephalopoda in the British Museum (Natural History), Part 5, The Ammonoidea of the Trias (11). London. p.1-228.

STANLEY, G.D., Jr. 1979. Paleoecology, structure and distribution of Triassic coral buildups in western North America. The University of Kansas Paleontological Contributions, Artical 65, 68 p.

_________. 1981. The early history of sceractinian corals and its geological consequences. Geology, 9:507-511.

_________. 1986. Late Triassic Coelentrate faunas of western Idaho and northeastern Oregon. p.23-40. In Vallier, T.L and H.C. Brooks (eds.) Geology of the Blue Mountains Region of Oregon, Idaho, and Washington. U.S. Geological Survey Professional Paper 1435.

_________, and B. SENOWBARI-DARYAN. 1986. Upper Triassic Dachstein-type reef limestone from the Wallowa Mountains, Oregon: first reported occurrence in the United States. Palaios, 1:172-177.

_________, and M.T. WHALEN. 1989. Triassic corals and spongiomorphs from Hells Canyon, Wallowa terrane, Oregon. Journal of Paleontology, 63:800-819.

STANLEY, S.M. 1970. Relation of shell form to life habits in the Bivalvia (Mollusca). Geological Society of America Memoir 125, 296p.

_________. 1972. Functional morphology and evolution of byssal attached bivalve molluscs. Journal of Paleontology, 46:165-212.

STEFANOV, S.A. 1963. Vertreter der Familie Halobiidae aus dem Ladin von Golo Bardo (SW Bulgarien). Tr. geol. Balgarija, ser. Paleontol., n.5, p.89-107, 5pls. Sofia.

STRAYER, L.M., D.W. HYNDMAN, and J.W. SEARS. 1989. Direction and shear sense during suturing of the Seven Devils-Wallowa terrane against North America in western Idaho. Geology, 17:1025-1028.

TAMURA, M. 1959. Carnic pelecypods from Matsukuma in central Kyushu Japan. Mem. Fac. Educ. Kumamoto Univ. 7:219-224. Kumamoto.

TAYLOR, J.D., W.J. KENNEDY, and A. HALL. 1969. Shell structure and mineralogy of the Bivalvia. Bulletin of the British Museum of (Natural History) Zoology. Supplement, 3:1-125.

THOMPSON, J.B., H.T. MULLINS, C.R. NEWTON, AND T.L. VERCOUTERE. 1985. Alternative biofacies model for dysaerobic communities. Lethaia, 18:167-179.

TOLLMANN, A., and E. KRISTAN-TOLLMANN. 1985 Paleogeograpgy of the European Tethys from Paleozoic to Mesozoic and the Triassic relations of the eastern part of the Tethys and Panthalassa. pp.3-22. In K. Nakazawa and J.M. Dickins (eds.) The Tethys; her paleogeography and paleobiogeography from Paleozoic to Mesozoic. Tokai University Press, Tokyo.

TOZER, E.T. 1961. Triassic stratigraphy and faunas Queen Elizabeth Islands. Geological Survey of Canada Memoir 316, 116p.

_________. 1965. Upper Triassic ammonoid zones of the Peace River foothills, British Columbia, and their bearing on the classification of the Norian Stage. Canadian Journal of Earth Sciences, 2:216-226.

_________. 1967. A standard for Triassic time. Geological Survey of Canada Bulletin 156, 103p.

_________. 1971. Triassic time and Ammonoids: problems and proposals. Canadian Journal of Earth Sciences, 8:989-1031.

_________. 1974. Definitions and limits of Triassic stages and substages: suggestions prompted by comparisions between North America and the Alpine-Mediterranean region. p. 195-206. In H. Zapfe (ed) The stratigraphy of the Alpine- Mediterranean Triassic. Schrifenreihe Erdwiss. Komm. 2. Springer-Verlag, Berlin.

_________. 1982. Marine Triassic faunas of North America; their significance for assessing plate and terrane movements. Geologische Rundschau, 7:1077-1104.

_________. 1984. The Trias and its ammonoids: the evolution of a time scale. Geological Survey of Canada, Miscellaneous Report 35, 171p.

TOZER, E.T., and R. THORSTEINSSON. 1964. Western Queen Elizabeth Islands, Arctic Archipelago. Geological Surver of Canada Memoir 332, 224p.

TSOFLIAS, P. 1975. Donees nouvelles sur la stratigraphie (Trias Superieur) de l'ile de Tilos (Dodecanese). Annales geol Pays hell 25(1974):467-473.

VALLIER, T.L. 1977. The Permian and Triassic Seven Devils Group, western Idaho and northeastern Oregon. U.S. Geological Survey Bulletin 1437. p.1-58.

VRIELYNCK, B. 1986. Conodontes du Trias Perimediterraneen.

Systematique, Stratigraphie. Documents du Laboritorie Geologie du Lyon. Number 97, 301 p.

VYALOV, O.S. 1936. Sur la classification des huitres. Acad. Science URSS, Comptes rendus (Doklady), new ser. 4(13):17-20.

_________. 1946. Triasovi ustritsi SRSR [Triassic oysters from SRSR]. Lvovskogo Derzaunogo Univ. Ivana Franka naukovi zapiski vol.2, ser. geol. no.3, p.22-54.

WALKER, G.W. 1977. Geologic map of Oregon east of the 121st meridian. U.S. Geological Survey Miscellaneous Series. Map 1-902, scale, 1:500,000.

WALLER, T.R. 1978. Morphology, morphoclines and a new classification of the Pteriomorphia (Mollusca: Bivalvia). Philisophical Transactions, Royal Society of London, 284:345-365.

WEISS, J.S. 1968. Fauna associated with pelagic Sargassum in the Gulf Stream. The American Midland Naturalist, 80:554-558.

WERNICKE, B., and D.K. KLEPACKI. 1988. Escape hypothesis for the Stikine block. Geology, 16:461-464.

WESTERMANN, G.E.G. 1962. Succession and variation of Monotis and the associated fauna in the Norian Pine River Bridge section, British Columbia (Triassic, Pelecypoda). Journal of Paleontology, 36:745-792.

WHALEN, M.T. 1985. The carbonate petrology and paleoecology of Upper Triassic limestones of the Wallowa terrane, Oregon and Idaho. Unpublished Masters thesis, University of Montana, Missoula, 151p.

_________. 1988. Depositional history of an Upper Triassic drowned carbonate platform sequence: Wallowa terrane, Oregon and Idaho. Geological Society of America Bulletin, 100:1097-1110.

WHEATCROFT, R.A. 1989. Commont on "Characteristic trace-fossil associations in oxygen-poor sedimentatry environments". Geology 17:674.

WHITE, J.D, D.L. WHITE, T. VALLIER, G.D. STANLEY, and S. ASH. (in press). Geologic evolution and paleoenvironments of a intra-arc summit basin in the Blue Mountains Island Arc, Oregon and Idaho. Geological Society of America Bulletin.

WIGNALL, P.B. 1988. Paper Pectens - a black shale enigma? (Abstract), Palaeontological Association Annual Conference, Aston. p. 17-18.

_________. (in press) Observations on the evolution and classification of dysaerobic communities. Chapter 8, In W. Miller (ed.) Paleocommunity temporal dynamics. Paleontological Society Special Publication 10.

_________, AND K.J. MYERS. 1988. Interpreting benthic oxygen levels in mudrocks: a new approach. Geology, 16:452-455.

ZITTEL, K.A. 1884. Handbuch der Palaeontologie. Abt.1, Band 2, 893p. (cephalopods, p.329-522).