Geology of the Blue Mountains Region of Oregon, Idaho, and Washington

Geologic Implications of Paleozoic and Mesozoic Paleontology and Biostratigraphy, Blue Mountains Province, Oregon and Idaho

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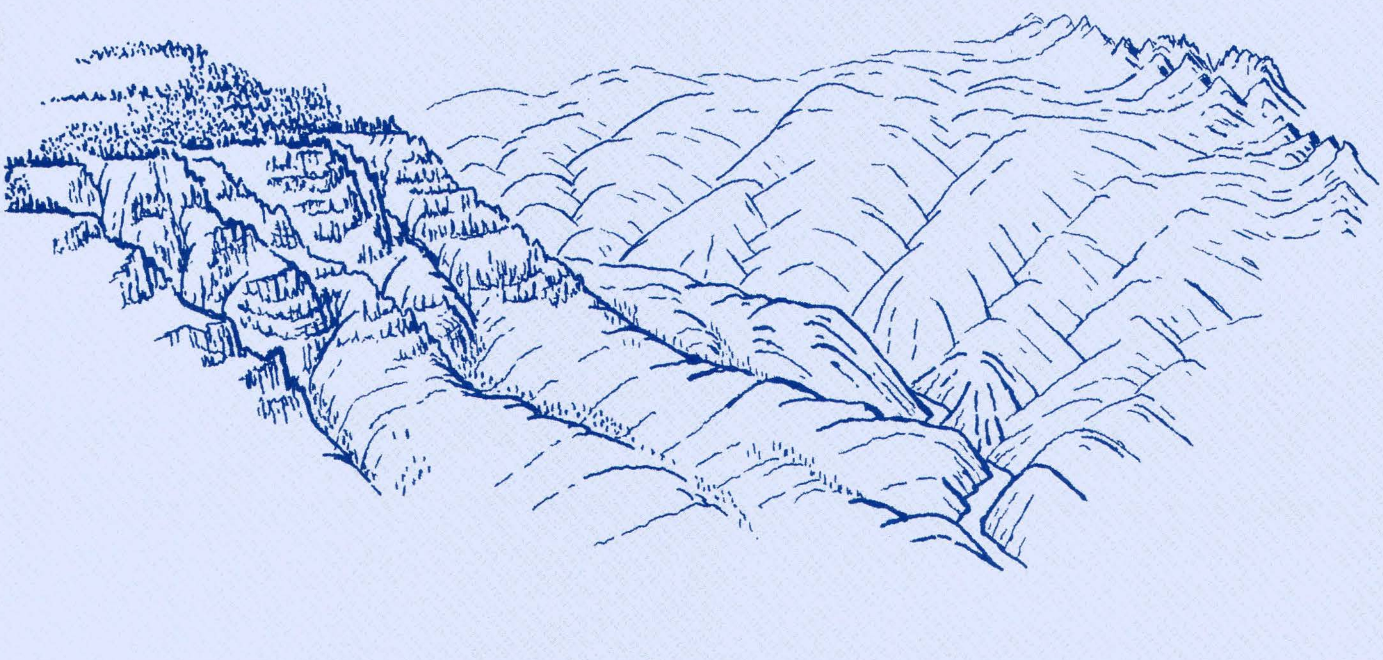

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TRACY L. VALLIER *and* HOWARD C. BROOKS, *editors*

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PREFACE

This U.S. Geological Survey Professional Paper is one volume of a series that focuses on the geology, paleontology, and mineral resources of eastern Oregon, western Idaho, and southeastern Washington. The purpose of this series is to familiarize readers with the work that has been completed in the Blue Mountains region and to emphasize the region's importance for understanding island-arc processes and the accretion of an allochthonous terrane. These professional papers provide current interpretations of a complex island-arc terrane that was accreted to ancient North America in the late Mesozoic Era, of a large batholith that was intruded after accretion had occurred, and of overlying Cenozoic volcanic rocks that were subsequently uplifted and partly stripped off the older rocks by erosion.

Modern island arcs are not well understood, and even less so are ancient arcs that have been deformed, metamorphosed, and subsequently accreted to continents. We have learned that characteristics of modern arcs change significantly both along and across the arcs' axes, and that studies of arc fragments are less than satisfactory because they generally do not characterize an entire arc. For example, the landward trench slopes of arcs can differ greatly, depending on whether materials from the descending slab are being accreted or the slope is being tectonically eroded; which process dominates apparently is related to the volume of sediment in the adjacent trench and the vector of plate convergence. In addition, some arcs (Aleutian) have broad, long, and sediment-filled forearc basins, whereas in others (Tonga-Kermadec) the forearc insular slopes descend precipitously to trench depths and are only interrupted in places by narrow fault-bounded terraces. Moreover, some arcs have erupted primarily tholeiitic igneous products throughout their histories (Tonga-Kermadec) and others (Aleutian) have a long history of both calc-alkaline and tholeiitic eruptive activity. Ridge axes of the arcs may be narrow or broad, and in some arcs (Solomons and Vanuatu) the axial regions have extended to form deep bathymetric and sedimentary basins. Even back-arc basins may have different origins and histories of development. Some (Mariana Trough and Lau Basin) have active spreading ridges, whereas others (Aleutian basin of the Bering Sea) are floored by ancient oceanic crust that was trapped behind the arc.

Because our knowledge of the diverse processes within modern arcs is limited, it becomes even more important to study ancient analogues. Just by the nature of their on-land exposures, ancient arcs can provide insights into sedimentary facies, magmatic evolution, and deep crustal processes that can only be studied in modern arcs by geophysical methods, dredging, and drilling. Few ancient island arcs have exposures as well developed and as extensive as those in the Blue Mountains province. Particularly spectacular and helpful are outcrops provided by intensive stream erosion, which has left some canyon walls more than 2 km deep (Snake River Canyon west of the Seven Devils Mountains).

Most earth scientists who have worked in the Blue Mountains region agree that the pre-Tertiary rocks there form one or more allochthonous terranes. The importance of such terranes in the evolution of circum-Pacific continental margins has been recognized for about a decade, but many complex questions remain. For example, how, when, and where did most of the circum-Pacific allochthonous terranes form? How did they accrete to continents? What are the mechanisms of amalgamation processes during terrane formation and transport? And, perhaps most importantly, what are the effects of these processes on mineral and hydrocarbon resources? While these volumes provide some answers, the data and interpretations contained in them will no doubt raise new and equally intriguing questions for future generations of earth scientists.

CONTENTS

[Numbers designate the chapters]

1. PALEOZOIC AND MESOZOIC FAUNAS OF THE BLUE MOUNTAINS PROVINCE: A REVIEW OF THEIR GEOLOGIC IMPLICATIONS AND COMMENTS ON PAPERS IN THE VOLUME

By TRACY L. VALLIER and HOWARD C. BROOKS[1]

ABSTRACT

This volume contains, besides the present review, seven papers on the biostratigraphy of pre-Tertiary rocks in the Blue Mountains province. Geologic implications of the faunal data are discussed in the context of terrane analyses. Most of the authors agree that the pre-Tertiary rocks of this province were formed in a complex island arc within a low-latitude faunal realm and subsequently moved northward and accreted to the North American continent. The use of different terrane names for parts of the Blue Mountains province by different authors may lead to some confusion. We suggest that future authors use the term "Blue Mountains island arc" for the pre-Tertiary province and, if there is a need for subdivision, that they use the terrane names proposed by Silberling and others (1984).

INTRODUCTION

Papers in this volume discuss the Paleozoic and Mesozoic megafossil and microfossil faunas in the Blue Mountains province of eastern Oregon and western Idaho. We compiled and edited these papers so that new data and interpretations become available, not only to earth scientists who are directly concerned with unraveling the geologic history of the region and determining its resources, but also to those working in other allochthonous terranes that rim the world's oceans (see Jones and others, 1977, 1982; Silberling and others, 1984). The pre-Tertiary rocks of the Blue Mountains province form one large allochthonous terrane. A better understanding of that terrane is the major purpose of this volume and of the companion volumes that are in the process of preparation.

The earlier work of other geologists and biostratigraphers is gratefully acknowledged. Without their pioneering spirit and interpretations, a collection of papers such as this would not now be possible. In particular, the works of Lindgren (1901), Merriam (1901), Pardee and Hewett (1914), Anderson (1930), Gilluly (1937), Ross (1938), Smith and Allen (1941), Merriam (1942), Merriam and Berthiaume (1943), Wagner (1945), Bostwick and Koch (1962), Hamilton (1963), Thayer and Brown (1964), and Buddenhagen (1967) are recognized as important contributions to our understanding of the Blue Mountains region.

In this paper we review the major interpretations of the authors (this volume) and summarize the geologic implications of their conclusions. The approximate areas they discuss are shown in figure 1.1.

ACKNOWLEDGMENTS

We appreciate the reviews of C. Blome, C. Newton, and W. Orr, which substantially improved the manuscript. We thank Juanita Mascardo for assistance with the manuscripts during early stages and Ann Garrett for last-minute typing and the final compilation of the papers. Robin Frisch and Gary Mann helped with drafting.

MAJOR CONCLUSIONS OF PAPERS IN THIS VOLUME

Newton (Chapter 2: Late Triassic bivalves of the Martin Bridge Limestone) describes a rich, well-preserved silicified early Norian invertebrate fauna that was collected from the Martin Bridge Limestone. Analyses indicate that the fossils represent storm lag (tempestite) concentrations. Many of the bivalve species (76 percent) are either new or indeterminate. The faunas in general show hybrid zoogeographic affinities that fit Tozer's (1982) paleogeographic model of central Pacific island arcs with mixed east and west Pacific faunas. Two major lithofacies are rhythmically interbedded in the Spring Creek outcrops, pelbiosparites making up most of the rocks and biopelsparrudites forming lensoid lag concentrations. Most bivalves, Newton reports, are suspension feeders. Some of the bivalve species reflect mixed zoogeographic affinities typical of North America, South America, and Japan. The large bivalve

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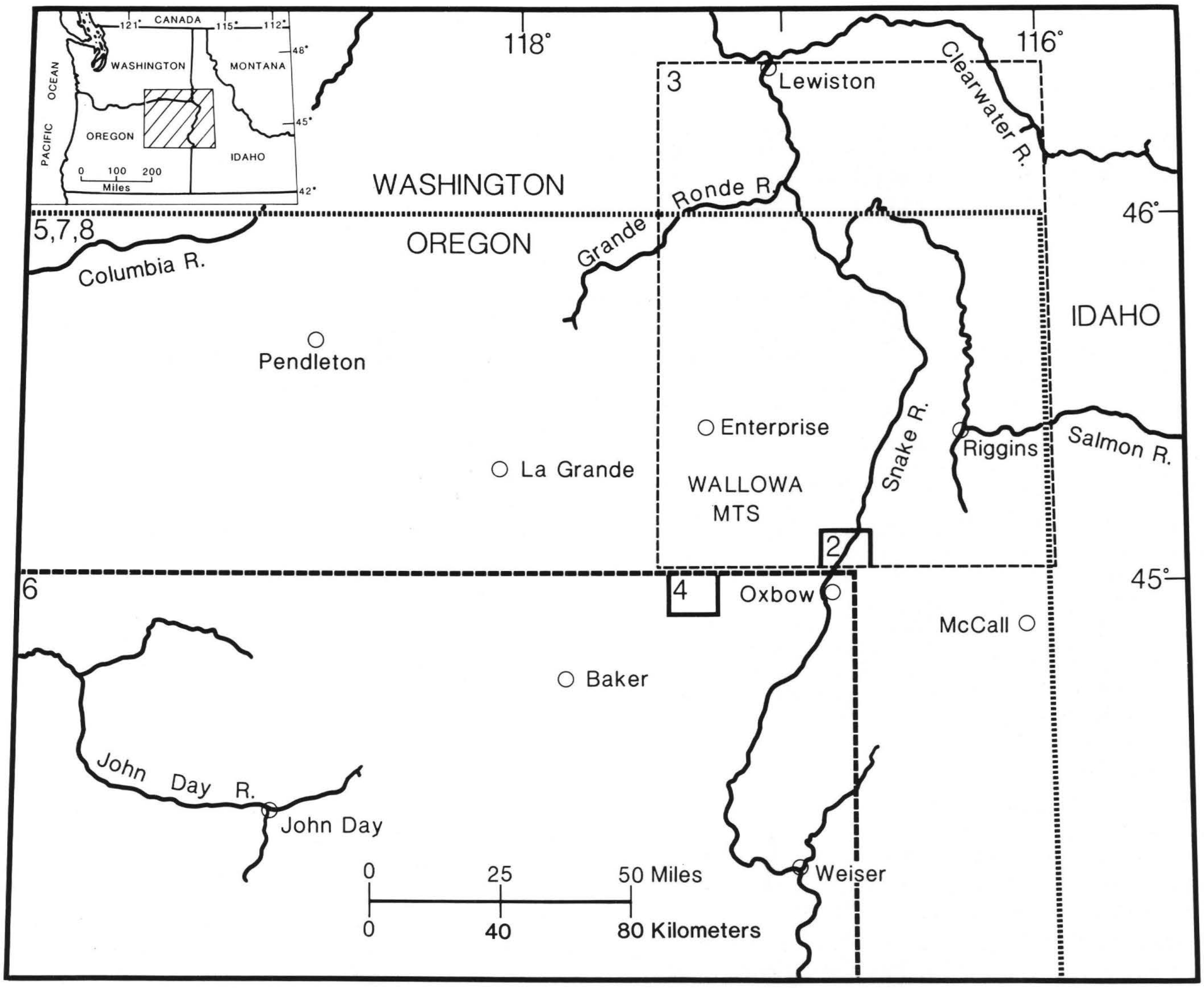

FIGURE 1.1—Index map of eastern Oregon, western Idaho and southeastern Washington, showing the approximate boundaries of areas discussed in this volume. Numbers refer to individual chapters, authored as follows: 2, Newton; 3, Stanley; 4, Orr; 5, Imlay; 6, Morris and Wardlaw; 7, Pessagno and Blome; 8, Blome, Jones, Murchey, and Liniecki.

Mysidioptera cf. *M. williamsi* is of particular significance because it has previously been reported only from cratonal sedimentary rocks of northeastern British Columbia. These findings indicate to Newton that the Hells Canyon area had zoogeographic exchange with the North American continent during the Late Triassic and that the extent of North and South American faunal exchange with Cordilleran allochthonous terranes has been underestimated.

Stanley (Chapter 3: Late Triassic coelenterate faunas of western Idaho and northeastern Oregon) studied coral and spongiomorph taxa from three localities in eastern Oregon and western Idaho and compared them with taxa in the Wrangellia terrane of Alaska and Vancouver Island. He identified 39 different corals and 9 spongiomorphids and determined the following ages: for Hells Canyon, early Norian *Kerri* Zone; for Wallowa Mountains (Eagle Creek), probable early Norian; and for outcrops near Lewiston, Idaho, probable late Norian. The corals in these faunas lived in warm shallow water and are found together with other benthic invertebrates in rich biostromal deposits 1–12 m thick. They display strong Tethyan affinities, fully three-fourths of the fauna being conspecific with distant counterparts in alpine regions of central Europe. Stanley found very little similarity with coeval early Norian collections in North America. This finding necessitates a critical evaluation of Late Triassic paleogeography and perhaps a re-examination of relationships between Wrangellia and the Wallowa-Seven Devils region. He concludes from the significant differences in the coral faunas that during the Late Triassic the Wallowa terrane may have been geographically separated from Wrangellia, at least by a body of water deep enough or one extensive enough to substantially reduce the exchange of coral larvae.

Orr (Chapter 4: A Norian (Late Triassic) ichthyosaur from the Martin Bridge Limestone) relates the fossil animal found in the Wallowa Mountains to those in other localities in the United States and elsewhere. The ichthyosaur is assigned to the genus *Shastasaurus* which previously was known only from Upper Triassic rocks in northern California. Orr suggests that the correlation of this occurrence with localities in northern California, but not with localities on "cratonal" North America, strengthens the accreted-terrane hypothesis for a large part of the Western United States.

Imlay (Chapter 5: Jurassic ammonites and biostratigraphy of eastern Oregon and western Idaho) shows that the major depositional basins formed in the Early Jurassic, particularly in the Hettangian through the Pliensbachian. In the Middle Jurassic, a large depocenter existed in the Izee-Seneca area, where the most complete Jurassic stratigraphic sequence in eastern Oregon is preserved. A much less complete sequence occurs in the Suplee region, indicating that it probably was undergoing erosion during much of the Early and Middle Jurassic. The youngest continuous deposition occurred in the earliest Callovian, but the youngest Jurassic sedimentary rocks thus far discovered in the region are middle Oxfordian strata that crop out along the Snake River Canyon near the Oregon-Washington border. Apparently, the region was largely above sea level during the Hettangian and Oxfordian and entirely so during early Pliensbachian and all of Kimmeridgian and Tithonian times.

Morris and Wardlaw (Chapter 6: Conodont ages for limestones of eastern Oregon) report on new conodont ages from both the Baker and Grindstone terranes and discuss their age implications. Conodont ages range from Devonian through Late Triassic. In the Grindstone (melange) terrane, large blocks of limestone previously yielded Devonian, Mississippian, and Permian fossils, whereas some sandstone blocks yielded Pennsylvanian fossils. Chert between the various limestone blocks contains Permian radiolarians and Early Triassic conodonts. A similar range of ages is shown in the Baker (melange) terrane. For example, within the Miller Mountain melange near Canyon Mountain, Permian limestone blocks and Upper Triassic chert are juxtaposed. Moreover, an arc-related rock assemblage in the Greenhorn Mountains northwest of Baker has Permian fusilinids and conodonts, whereas oceanic assemblages east and southeast of Baker contain conodonts of Middle and Late Triassic age. Pennsylvanian and Permian conodonts in limestone blocks near Baker are associated with fusilinids showing Tethyan affinities. Pennsylvanian conodonts were recovered from a limestone block near Vinegar Hill in the Greenhorn Mountains, and Devonian conodonts were found in a limestone pod farther north. The major conclusions of the authors are that (1) Devonian rocks probably are more abundant than previously thought, (2) geographic subdivision of the melange terrane appears artificial, (3) subdivision into arc-related melange, oceanic melange, serpentinite-matrix melange, and ophiolitic complex seems more reasonable, and (4) exotic blocks in the melange terrane may be accounted for by docking (accreting) a pre-existing terrane into a forearc accretionary prism, or they may have been olistostromal blocks derived from an uplifted older arc.

Pessagno and Blome (Chapter 7: Faunal affinities and tectonogenesis of Mesozoic rocks in the Blue Mountains province) strengthen the conclusions reached earlier by Thayer (1973) and more recently by Vallier and Engebretson (1984) that the various pre-Tertiary terranes of the Blue Mountains may all be parts of a single island arc (Blue Mountains island arc). They suggest that the island arc originated in the eastern Pacific and was subsequently moved northward by a large megashear somewhat analogous to the San Andreas fault. The Blue Mountains island arc apparently was situated in the Central Tethyan Province, either north or south of the paleoequator, during the Late Triassic and Early Jurassic. Interpretations of ammonite and radiolarian data from the John Day inlier show that by early Bajocian time (about 183 Ma, according to the time scale of Palmer, 1983), the Blue Mountains island arc was situated within the Northern Tethyan Province (approximately 15° to 30° north latitude). Subsequent displacement to higher, Boreal latitudes (about 40° north) probably occurred during the Late Jurassic. The authors emphasize that megafossil assemblages in volcanic successions of the so-called Nevadian complex of California and Nevada show the same shift from the Tethyan Faunal Realm to the Boreal Faunal Realm during the course of Mesozoic time: Triassic and Early Jurassic assemblages have strong Tethyan affinities; Upper Jurassic rocks have faunas with both Tethyan and Boreal affinities. Pessagno and Blome use these data to conclude that the so-called Nevadian terrane and the Blue Mountains island arc could be parts of the same island arc complex, which originated at near-equatorial latitudes in the eastern Pacific and was then carried northward along a large megashear.

Blome, Jones, Murchey, and Liniecki (Chapter 8: Geologic implications of radiolarian-bearing Paleozoic and Mesozoic rocks from the Blue Mountains province) use faunal and structural data to recognize five tectonostratigraphic terranes: Grindstone, Izee, Olds Ferry, Baker, and Wallowa. They discuss three of these (Grindstone, Izee, and Baker) in relation to their radiolarian ages. The Grindstone terrane has radiolarians of Early Permian to Early Triassic age. The Baker terrane contains Late Triassic radiolarians in cherts in the southwestern part and both Permian and Late Triassic radiolarians (possibly also some as young as Early Jurassic) in the northeastern part. The authors include the Miller Mountain and Frenchy Butte melange areas in the Baker terrane on the basis of lithologies, identical characteristics of the radiolarian faunas, and the fact that the Grindstone terrane contains no known chert younger than Early Triassic. Though Carboniferous chert is absent from the Grindstone terrane, it occurs as clasts in the conglomeratic rocks within the basal part of the Izee terrane. This indicates that the Grindstone terrane was not the source for Izee terrane detritus; rather, the Baker terrane was the probable source. Moreover, coeval Upper Triassic radiolarian cherts in the Brisbois Member of the Vester Formation, in the herein-revised Rail Cabin Mudstone Member of the Vester Formation, and in the Fields Creek Formation indicate that the Vester Formation was not the source of detritus for the Fields Creek Formation. An important point the authors make is that the abundance of Permian sedimentary rocks in the Baker terrane (ages based on radiolarians, conodonts, and fusilinids) attest that these rocks are not "exotic" blocks. Ages seem to young from west to east in the Baker terrane. The age range of the Elkhorn Ridge Argillite is extended to include the Middle Pennsylvanian to the Late Triassic and possibly the earliest Jurassic.

GEOLOGIC IMPLICATIONS

The terrane concept has greatly helped the interpretation of geologic relationships in the Blue Mountains province, but it has also led to some confusion. Different terrane names have been proposed by several authors (Vallier and others, 1977; Brooks and Vallier, 1978; Dickinson and Thayer, 1978; Brooks, 1979; Dickinson, 1979), and even more recently (see papers in this volume and in Silberling and others, 1984) new names have been proposed for various parts and parcels of the Blue Mountains province. It seems premature to propose formal terrane names in the Blue Mountains region, because sound definitions of island-arc terranes should be tied to the processes that formed them and these processes related to those occurring in modern island arcs. Unfortunately, although our understanding of modern island arcs is rapidly increasing, many questions remain to be answered concerning island arc processes.

Island arcs are major features of the earth's land surface; they are mountain ranges that are mostly submerged. For example, the intra-oceanic part of the Aleutian structural arc is approximately 2,200 km (1,375 miles) long and 200 km (125 miles) wide and has a total area of about 440,000 km^2 (170,000 mi^2). It rises from a depth of 7.3 km below sea level (floor of the Aleutian Trench) to about 3 km above sea level. If the thick sediment accumulation in the trench were removed, the trench would have some depths greater than 11 km (Scholl and others, 1982) and the total relief would be more than 14 km (about 8.75 miles or 46,000 feet). In addition to appreciating the sizes of island arcs, we are gaining insights into sedimentation patterns and formation of major basins within the arcs (see, for example, Scholl and others, 1983, 1985; Katz, 1984). The diverse assemblages of pre-Cenozoic rocks in the Blue Mountains island arc can be compared, both areally and geologically, to assemblages within the present-day intra-oceanic island arcs. At present, however, we do not know how much of the Blue Mountains island arc may have been destroyed by subduction or displaced to other regions by transcurrent faults.

For other workers attempting to unravel the geologic history of the Blue Mountains province, we endorse the suggestion of Pessagno and Blome (this volume) that the pre-Tertiary rocks collectively be referred to as the Blue Mountains island arc. If there are reasons to subdivide, workers are encouraged to use the nomenclature referred to in Blome and others (this volume; terrane names proposed by Silberling and others, 1984).

The original location of the Blue Mountains island arc is not dealt with in detail by the topical papers in this volume. Newton, Stanley, and Pessagno and Blome (all this volume) both imply and suggest an eastern Pacific, near-equatorial initial location for the Blue Mountains island arc. They may agree in part with Dixon (1984), who inferred that terranes in the Pacific moved northwestward by lateral transport during the opening of the Atlantic Ocean. Interpretations by Engebretson (1983) and Vallier and Engebretson (1984) make a western Pacific source region possible, if the Blue Mountains island arc were brought across the Pacific on the Farallon Plate. This would imply a Devonian to Early Jurassic connection with terranes in Australia (for example, New England fold belt), New Zealand, New Caledonia, and New Guinea. Faunal data, however, have thus far not supported such a western Pacific connection.

The suggestion by Imlay (this volume) that there were multiple source areas for Jurassic sediments in the Blue Mountains island arc agrees with our knowledge of processes in modern island arcs, where each basin may have a separate sediment source (for example, see Scholl and others, 1983). The regional uplift of the Blue Mountains island arc that apparently took place in the Late Jurassic may correlate with the beginning of Late Jurassic plutonism. The oldest plutons of the Jurassic and Cretaceous plutonism, which includes the Bald Mountain and Wallowa batholiths, are dated at about 160 Ma (Armstrong and others, 1977) and this age correlates with a Late Jurassic hiatus in sedimentation (beginning of Oxfordian is about 163 Ma, according to the time scale of Palmer, 1983). Collision of the Blue Mountains island arc with the North American continent probably took place after the Late Jurassic (Callovian) because no continental detritus has yet been reported in the Jurassic sedimentary rocks. The formation of the depocenters and source-region highlands can be explained by normal island arc processes.

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2. LATE TRIASSIC BIVALVES OF THE MARTIN BRIDGE LIMESTONE, HELLS CANYON, OREGON: TAPHONOMY, PALEOECOLOGY, PALEOZOOGEOGRAPHY

By Cathryn R. Newton[1]

ABSTRACT

Richly fossiliferous lenses of silicified shells in the Norian Martin Bridge Limestone of Hells Canyon represent "windows" of unusually excellent preservation through which can be read the taphonomy, paleoecology and paleozoogeography of Late Triassic bivalves of the Wallowa Mountains-Seven Devils Mountains volcanic arc terrane of northeastern Oregon. Taphonomic, petrographic, and stratigraphic analysis of the shell beds discloses that they represent storm lag concentrations formed by processes of winnowing and local transport of shells. Despite the inferred transport, however, the autecology of 38 bivalve species is remarkably uniform, suggesting an epifaunal, suspension-feeding association that inhabited peloidal carbonate sediment. Many of these epifaunal bivalve species (74 percent) are either new or indeterminate on the basis of present collections.

Because of the high frequency of new or indeterminate species, zoogeographic conclusions based on species are necessarily preliminary. Those species that have been previously described from other areas are of varied zoogeographic affinities; *"Septocardia"* sp. and *Mysidoptera williamsi* are North American forms; *Mysidiella* cf. *M. americana* and *Tutcheria densestriata* are closely allied to species from South America; and *Parallelodon* cf. *P. monobensis* and *"Chlamys"* cf. *"C." mojsisovicsi* resemble Japanese bivalves. This perplexing assortment of zoogeographic affinities can best be understood in terms of Tozer's (1982) paleogeographic model of central Pacific island arcs with mixed East and West Pacific faunas. It should be emphasized, however, that Norian bivalve species of both the North American craton and the suspect terranes along its margins are at present imperfectly documented.

INTRODUCTION

Diverse silicified benthic macroinvertebrates of Late Triassic age from the Hells Canyon region of northeastern Oregon have significance both for paleoecological reconstructions of early Mesozoic tropical island arc biotas and for tectonic reconstructions of early Mesozoic suspect terranes. This report describes the bivalve taphonomy, paleoecology, and paleozoogeography of silicified shell beds from the lower Norian part of the Martin Bridge Limestone north of Spring Creek on the western flank of Hells Canyon (fig. 2.1). At this site the Martin Bridge consists of shallow-water carbonate rocks in depositional contact with underlying arc volcanic rocks of the Seven Devils Group (Vallier, 1967, 1974, 1977; Sarewitz, 1983).

Previous paleoecologic studies of early Mesozoic molluscan communities have focused on rifted-margin sedimentary basins, such as that of the Cassian Formation of the southern Alps (Fursich and Wendt, 1977; Wendt and Fursich, 1980), or on latest Norian - earliest Hettangian arc-related mixed carbonate and clastic sedimentary rocks (Laws, 1982). In contrast, this study is an examination of the taphonomy and autecology of the biota in early Norian pure carbonate sediments that are of tropical island-arc origin (Hillhouse and others, 1982). Such habitats are the loci for the most diverse and

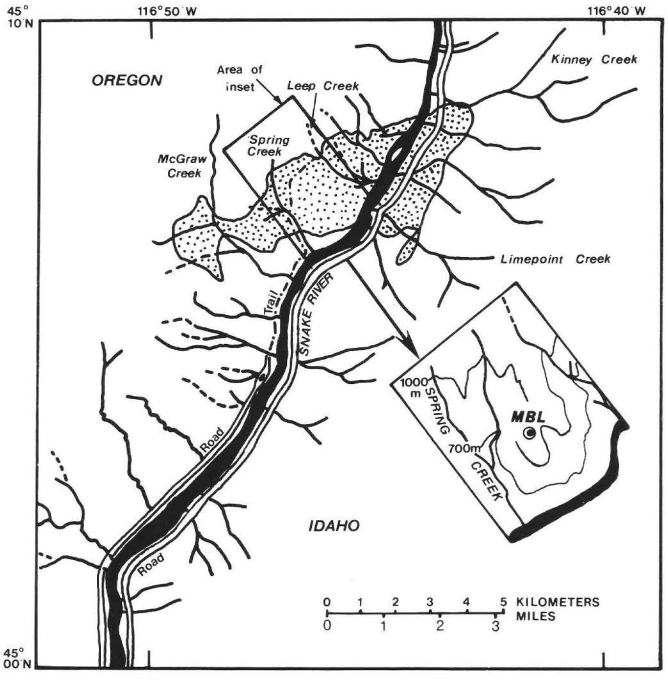

Figure 2.1.—Index map of part of Snake River canyon, showing location of measured fossiliferous carbonate section (MBL) north of Spring Creek, Oregon. Stippling indicates outcrop area of the Martin Bridge Limestone, after Vallier (1974). Quaternary sediment locally covering the Martin Bridge is not indicated.

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most rapidly evolving marine invertebrate faunas in the modern world ocean (Vermeij, 1978).

Assessment of the paleobiogeographic affinities of the Spring Creek fauna also allows refinement of existing paleogeographic models for the Hells Canyon region during the early Mesozoic. Application of the tectonostratigraphic terrane concepts (for example, Jones and others, 1972, 1977, 1978, 1982, 1983; Jones and Silberling, 1979; Coney and others, 1980) to tectonic interpretation of the Hells Canyon area has spawned controversy regarding the kinship of the Wallowa Mountains-Seven Devils Mountains volcanic arc terrane of Brooks and Vallier (1978) to larger "suspect" terranes. Whether the arc formed in close proximity to North America during the Middle and Late Triassic, or instead occupied part of the demonstrably allochthonous Wrangellia terrane, has been a matter of dispute in the recent literature (Jones and others, 1977; Hillhouse and others, 1982; Sarewitz, 1983; Silberling, 1983). Jones and others (1977) first recognized the intriguing resemblance between the early Norian shelly faunas of Wrangellia and those of the Hells Canyon region. Newton (1983) found that similarities, for bivalve genera, of the Norian faunas of Hells Canyon and the Wrangell Mountains exceeded those of any other pair of cratonal or "suspect" terrane localities of North America (Simpson similarity coefficient = 77; Sørenson similarity coefficient = 0.65). This paper considers the Hells Canyon bivalves at the specific level and attempts to use their ecology and zoogeography as tools for reconstructing Late Triassic depositional environments and paleogeography of the Wallowa Mountains-Seven Devils Mountains volcanic arc terrane.

A prerequisite for any discussion of Mesozoic paleozoogeography of western North America is a clear definition of which regions are to be considered cratonal, *sensu stricto,* and which regions are to be termed tectonically "suspect". The only bivalve-rich Upper Triassic rocks deemed to have clear tectonic affinities to cratonal North America are the Pardonet Formation of northeastern British Columbia (McLearn, 1940, 1941a,b; Tozer, 1965, 1982) and the upper part of the Star Peak Group and the lower part of the Auld Lang Syne Group in Nevada (Silberling, 1961; Silberling and Wallace, 1969; Burke and Silberling, 1973; Nichols and Silberling, 1977). In other plate-bound areas of North America, such as the Sverdrup Basin of Arctic Canada, marine Norian strata are present but are not rich in shelly benthic faunas (Tozer, 1982). The numerous other Upper Triassic Cordilleran lithostratigraphic units with rich bivalve faunas occur west of the belt of plate-bound rocks and will herein be considered "suspect" (Coney and others, 1980); many of these units are clearly of allochthonous origin.

ACKNOWLEDGMENTS

The assistance of Tracy Vallier in the planning of fieldwork in Hells Canyon is much appreciated. I also thank Léo Laporte for help in the design and execution of this study and David Jones and Norman Silberling for valuable discussions and for the loan of bivalve specimens. Andrzej Gazdzicki kindly examined the benthic foraminifers in my Spring Creek samples. Denise Mungioli and Joel Thompson were tireless field assistants, and Pat and Dixie Wilmarth were of great help with field logistics. I thank David Delalla for assistance with the acid-bath preparation of samples. K. Sakamoto and P. Jones assisted greatly in the photography of fossil specimens.

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PREVIOUS WORK

Ross (1938) formally proposed the name Martin Bridge Formation (subsequently revised to the Martin Bridge Limestone by Vallier, 1977) for a massively bedded carbonate unit that crops out in the Wallowa Mountains of northeastern Oregon, though the term had appeared in print already years earlier (Chaney, 1932; Gilluly and others, 1933). Vallier (1967, 1974) extended this name, on the basis of stratigraphic and faunal resemblance, to patches of Norian limestone that occur on the ridges flanking Hells Canyon. Other stratigraphic studies of the Martin Bridge Limestone in northeastern Oregon and western Idaho include those of Laudon (1956), Cannon (cited in Hamilton, 1963), Nolf (1966), and Stanley (1979a).

The most complete section of the Martin Bridge in Hells Canyon is at Kinney Creek, where Vallier (1967) measured 530 m of sparites, biomicrites and micrites intercalated with carbonate breccia. The top of the formation is not exposed at Kinney Creek, so that its total thickness at that site remains uncertain. As described by Vallier, the Kinney Creek rocks are relatively unfossiliferous; he reported only a single bed of bivalves and scattered bivalve fragments in the lower part of the section.

Numerous other workers have reported bivalves from the Martin Bridge Limestone (Lindgren, 1901;

Smith, 1927; Ross, 1938; Smith and Allen, 1941; Laudon, 1956; Hamilton, 1963; Nolf, 1966; Stanley, 1979a), but the bivalve faunas have never before been examined in detail. Whereas most of the forms mentioned in the literature are halobiid bivalves that characterize pelagic carbonate facies (Hallam, 1981), the rich shelly faunas discussed here represent shallow-water benthic associations.

The Spring Creek locality was first discovered by Vallier (1967). An early Norian age for the Martin Bridge Limestone there was inferred on the basis of N.J. Silberling's identification of *Tropiceltites columbianus* in the shell beds (Vallier, 1967, p. 246-247). *T. columbianus* is typical of the lowermost Norian *Mojsisovicsites kerri* zone (Silberling and Tozer, 1968).

In addition to bivalves and ammonoid cephalopods, a host of other invertebrates are found in the Spring Creek silicified shell beds: benthic foraminifers, sponges, spongiomorphs, scleractinians, serpulids, articulate brachiopods, ?scaphopods, gastropods, and echinoderms. A. Gazdzicki is currently examining the free-living and encrusting foraminifera. Montanaro Gallitelli and others (1979) and Stanley (this volume) have presented systematic treatments of the scleractinian corals and the spongiomorphs. The *Spondylospira*-like articulate brachiopods are the focus of a monograph in preparation by P. Hoover, and I have forwarded echinoderm specimens from my collections to P. Kier for further study. These investigations of the rich Spring Creek fauna will considerably improve our knowledge of early Norian arc biotas.

MATERIALS AND METHODS

The material that forms the basis for this study is from U.S. Geological Survey Mesozoic collection M2672, made by Tracy Vallier in 1964, and from my own field collections made in 1982 and 1983. The U.S. Geological Survey collections comprise 677 fossil invertebrate specimens (excluding articulate brachiopods and scleractinian corals), of which 538 are bivalves and gastropods. My collections from the Spring Creek locality include more than 5000 macroinvertebrate specimens.

The silicified macroinvertebrates were freed from the calcareous matrix using dilute hydrochloric acid. The M2672 samples were prepared in this manner at the U.S. Geological Survey in Denver by Norman Silberling. My collections were prepared in 7-percent HCl.

Because of folding and pervasive recrystallization of the carbonate rocks it is difficult to construct an accurate composite section of the entire Martin Bridge Limestone at Spring Creek. A short section of part of the Martin Bridge containing the silicified shell beds was measured (fig. 2.2).

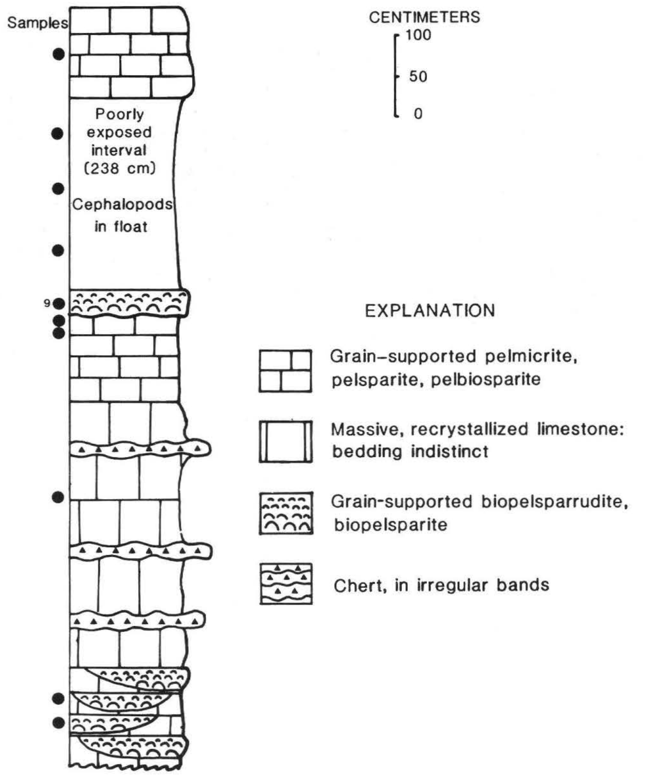

FIGURE 2.2.—Measured section of part of the Martin Bridge Limestone at the Spring Creek locality. Dots to the left of column indicate lithologic samples collected for this study in 1982.

I also examined 90 thin sections and 20 acetate peels from the fossiliferous carbonate rocks at Spring Creek in order to reconstruct the depositional and diagenetic history of the silicified shell beds. Positions of these samples in the measured section are shown in figure 2.2.

RESULTS

STRATIGRAPHY AND PETROGRAPHY

The measured section at Spring Creek consists of two alternating lithofacies defined by the relative abundance of skeletal allochems. The first lithofacies, which constitutes most of the section at the Spring Creek locality, consists of grain-supported fossiliferous pelbiosparites with local pelbiomicrites (fig. 2.3*B*). Nonskeletal allochems include peloids and a variety of coated grains, some of which approach ooids in regularity of outline and evenness of coating (fig. 2.3*B*). Fossils are sparse; those seen in thin section include free-living and encrusting foraminifers (?*Tolypammina;* fig. 2.3*B*), brachiopods and bivalves. In hand specimen and outcrop, echinoderms, bivalves, and gastropods were also observed. The cement in this lithofacies is predominantly sparry, with only minor patches of interstitial micrite. These micrite patches

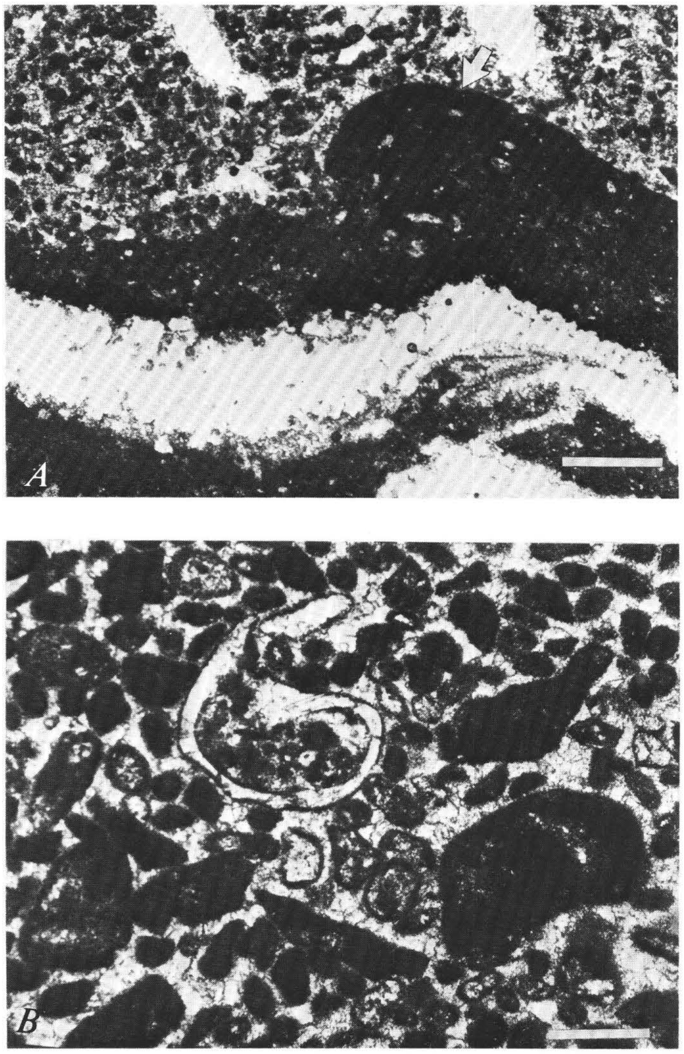

FIGURE 2.3.—Photomicrographs showing lithofacies of the Martin Bridge Limestone at Spring Creek. *A*, Silicified biopelsparrudite of the shell lenses. Arrow marks an encrusting foraminifer (?*Tolypammina*) coating a silicified bivalve. Elongate white patches are skeletal allochems that have been replaced by quartz. *B*, Biopelsparite of the interbedded, sparsely fossiliferous carbonate rocks. Scale bars are 1 mm.

may not represent original cement; many of them are probably the product of degradation of skeletal allochems.

The other lithofacies, represented by the richly fossiliferous shell beds, consists of grain-supported biopelsparrudites with subordinate biopelmicrudites (fig. 2.3*A*). Mollusks (bivalves and gastropods) are the predominant skeletal allochems. Other skeletal allochems evident in thin section include brachiopods, echinoderms, free-living benthic foraminifers, and encrusting foraminifers. In hand specimen and outcrop, inozoan sponges, spongiomorphs, scleractinian corals, serpulids and ?scaphopods were also found. The coarse sand- to gravel-sized skeletal clasts occur together with fine sand- to silt-sized peloids and coated grains of varied outlines. Within the shell lenses, umbrella structures and other grain-sheltered patches are common; sediment in these patches consists of peloids and coated grains.

The two major lithofacies are rhythmically interbedded; the pelbiosparites constitute most of the measured section, whereas the biopelsparrudites form lensoid lag concentrations (averaging 25–30 cm in thickness and 10–15 m across) within the peloidal sand deposits. The bases of the biopelsparrudite lenses are marked by scoured surfaces (fig. 2.4), and the lower part of the skeletal sand concentrations commonly exhibits small-scale cross bedding. Many biopelsparrudite lenses also show normal grading, and their upper contacts are generally more gradational than their bases. The sedimentary rhythmite produced by the intercalation of the two lithofacies is thus marked by a basal scour, which forms the lower boundary of the shell bed, overlain by normally graded bioclastic carbonate sediment with predominantly disarticulated fossils (fig. 2.5), succeeded by peloidal carbonate sediment that exhibits small-scale crosslamination.

BIVALVE PALEOECOLOGY AND PALEOZOOGEOGRAPHY

Epifaunal suspension feeders are dominant among the 38 species of bivalves in the Spring Creek fauna; 79 percent of the species and 76 percent of the individuals are epifaunal, and 97 percent of the species and 99.5 percent of individuals are suspension feeders. Twenty-eight of the species (74 percent) are either new or indeterminate (table 2.1).

True oysters and oysterlike bivalves are the most common bivalves in the Spring Creek shell beds. Taxonomic assignment of many of these forms is rendered extremely difficult by the paucity of well-preserved muscle scars. True oysters of the genera *Lopha* and *Liostrea* (and possibly also *Gryphaea*), and oysterlike bivalves such as *Plicatula* (pl. 2.1, figs. 16–19), have been recognized.

The inequivalve pterioid *Cassianella* cf. *C. angusta* (pl. 2.1, figs. 1–5) constitutes one of the most abundant bivalve taxa at Spring Creek. *Cassianella* was a suspension feeder that probably lived with its lower, highly convex valve partially sunk into the sediment, and the small upper valve just above the sediment-water interface. A frequent constituent of shallow-water, soft-sediment benthic marine associations of the Late Triassic, *Cassianella* is the dominant bivalve genus in the *Ampullina* association of the Alpine Formation, and is also common in the *Tutcheria* association of the Gabbs Formation of Nevada (Fursich and Wendt, 1977; Laws, 1982). *Cassianella* has a very broad paleozoogeographic

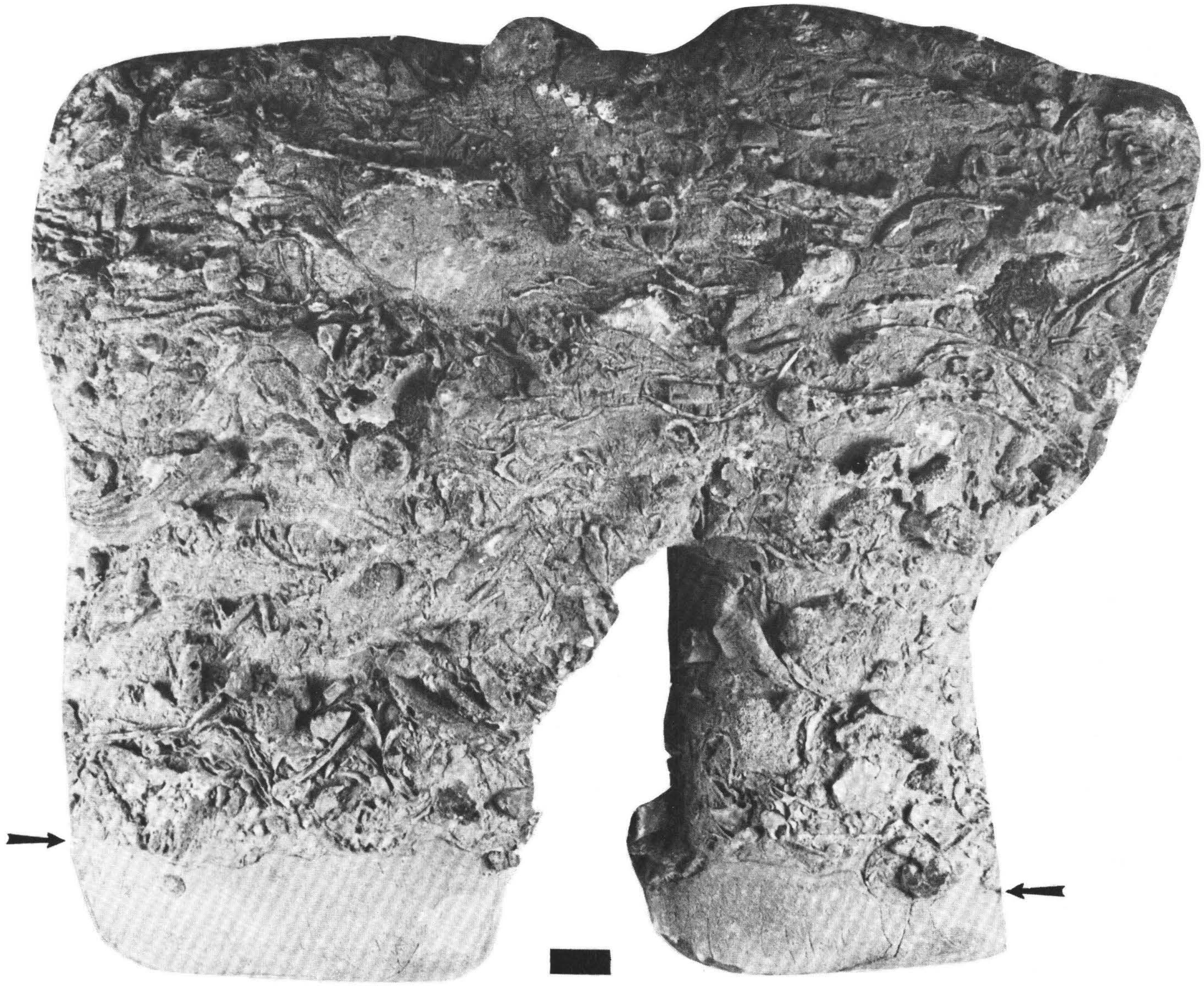

FIGURE 2.4.—Slab of the Martin Bridge Limestone, showing face perpendicular to bedding. Photograph shows the lower part of silicified shell bed and the upper part of the shell-rich layer; the contact is indicated by arrows. Slab has been naturally etched by fresh water; hence, silicified skeletal allochems have weathered out of the calcareous peloidal matrix. Scale bar represents 1 cm.

distribution. It is found both in high paleolatitude sediments of Bear Island (Böhm, 1904) and at numerous localities in low-latitude habitats of the Palaeotethys (*sensu* Sengor, 1979). Its longitudinal range is also very broad, extending from western Europe to cratonal North America. Hence, the genus *Cassianella* is not useful as a biogeographic indicator of provenance for the North American suspect terranes.

Bivalves of the genus *"Septocardia"* are common at Spring Creek (pl. 2.1, figs. 12–13). The specimens are unusual representatives of the genus in having an elongate, subquadrate outline with a distinct postero-dorsal carination, so that in external view they bear a close resemblance to the carditid *Palaeocardita*. The presence of a conspicuous anterior myophorous buttress on valve interiors suggests, however, that these specimens should be assigned to *Septocardia,* based on the broad redefinition of this genus proposed by Keen (1980). The buttress is a diagnostic feature of *Septocardia* (Hall and Whitfield, 1877; Silberling, 1959, 1961; Cox and others, 1969; Keen, 1980), whereas no buttress is mentioned in A. Chavan's description of *Palaeocardita* in the *Treatise on Invertebrate Paleontology* (Cox and others, 1969, p. 554). A further resemblance to the genus *Septocardia* is indicated by the tuberculate nature of the posterior lateral teeth in the Spring Creek specimens; as noted by Silberling (1961), tuberculiform laterals are more typical of *Septocardia,* whereas *Palaeocardita* has elongate,

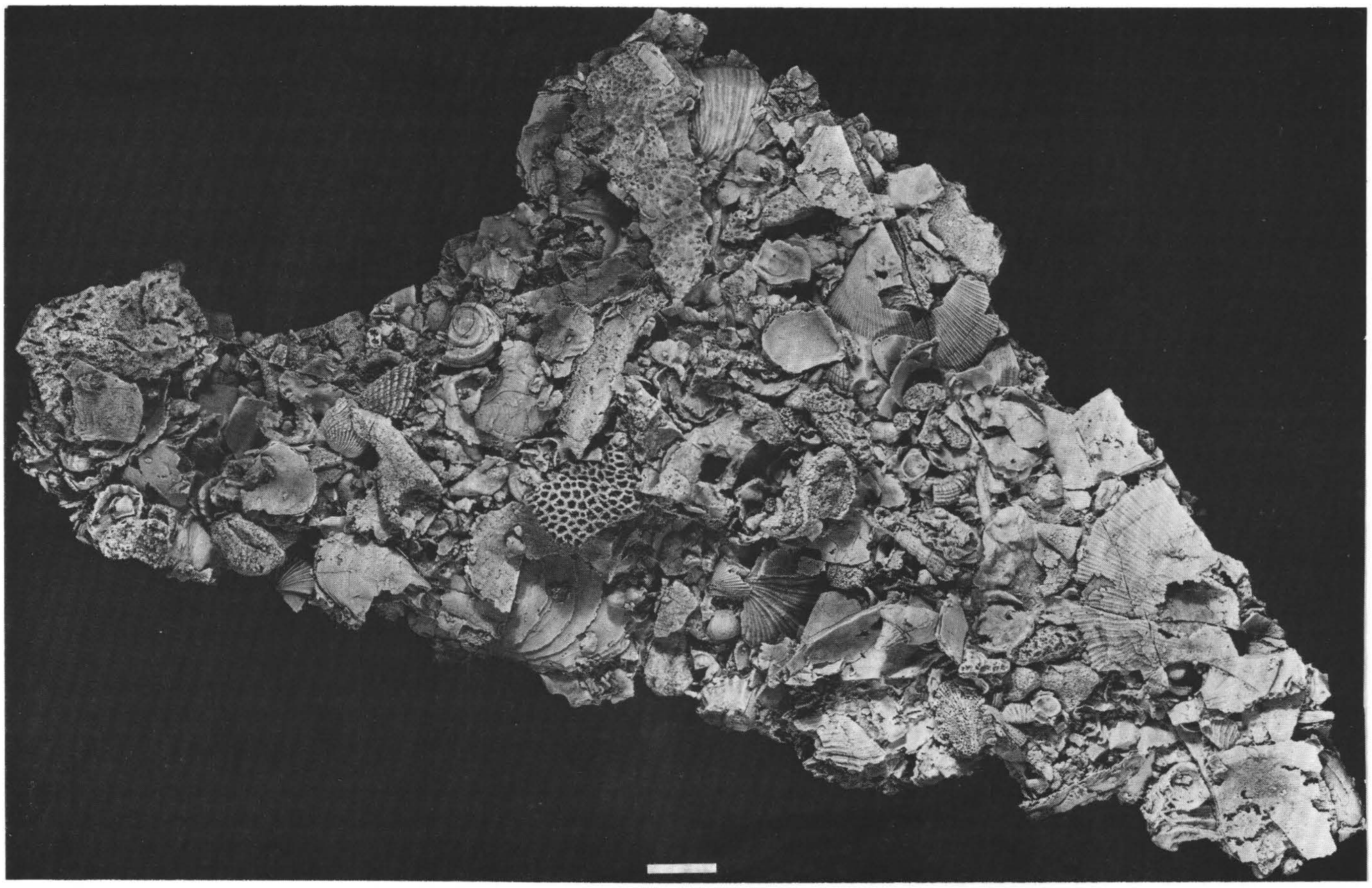

FIGURE 2.5.—Acid-etched slab of the Martin Bridge Limestone, Spring Creek, Hells Canyon, Oregon. Surface shown is parallel to bedding. Note incipient fragmentation of fossils along fractures; thus, some of the comminuted skeletal debris seen in insoluble residues may be an artifact of sample preparation. Scale bar represents 1 cm. Photograph by R.E. Burkholder.

laminate lateral teeth (Cox, 1949). Certainly the Spring Creek specimens, along with other Late Triassic examples of *"Septocardia"* from North America, merit further study as possible transitional forms between the bivalve superfamilies Cardiacea and Carditacea.

Septocardia is best categorized as an infaunal suspension-feeding bivalve, by comparison with the living habits of modern cardiids (Stanley, 1970). Corroboration for this interpretation comes from the Gabbs Formation of Nevada, where Laws (1982) has reported *Septocardia* in apparent life orientation, with the plane of commissure perpendicular to bedding, and the posterior margins of the valves oriented upward. Like many modern cardiids (Stanley, 1970), *Septocardia* was probably a shallow burrower.

Septocardia of typical morphology and the unusual forms assigned to *"Septocardia"* are both restricted in paleozoogeographic distribution to cratonal North and South America, and to the belt of Cordilleran suspect terranes (Hall and Whitfield, 1877; Cox, 1949; Silberling, 1959, 1961, and cited in Muffler, 1967; Nolf, 1966; Hayami and others, 1977; Stanley, 1979a; Laws, 1982; Newton, 1983). Thus, the presence of *"Septocardia"* at Hells Canyon has important paleozoogeographic implications for the Spring Creek fauna.

The large, flat pterioid *Mysidioptera williamsi* (pl. 2.1, figs. 14–15), another distinctive element of the Spring Creek bivalve fauna, is interpreted as an epibyssate suspension feeder. The specimens from Spring Creek closely resemble the holotype of *M. williamsi* in overall shape, occurrence of postero-dorsal emargination and mucronation, and presence of wavy concentric ridges.

This species is of paleozoogeographic significance, having been reported previously only from the craton-bound sediments of northeastern British Columbia (McLearn, 1941a). The discovery of *Mysidoptera williamsi* at Spring Creek indicates that the Hells Canyon area had zoogeographic exchange with the North American continent during the Late Triassic. The Spring Creek occurrence also suggests an extended biostratigraphic range for this species, from the upper

TABLE 2.1.—*Bivalves from the U.S. Geological Survey collection M2672, Hells Canyon, Oregon*

[Data from 203 individuals represented by 274 specimens. n = number of individuals identifiable at least to ordinal level. P = proportion of identifiable individuals in the sample; ES = epifaunal sessile; EB = epifaunal byssate; EC = epifaunal cementer; IM = infaunal mobile; S = suspension feeder; D = deposit feeder; H = Shannon-Wiener diversity index; E = observed equitability]

Genus and species	Abundance rank	n	P	Life habit	Feeding type
Cassianella cf. *C. angusta*	1	47	0.2435	ES	S
"*Septocardia*" sp.	2	23	.1192	IM	S
Mysidioptera williamsi	3	13	.0674	EB	S
Lopha sp. 2	4,5	10	.0518	EC	S
?Pachycardiidae, gen. uncertain	do	10	.0518	I?M	?S
Plicatula hekiensis	6	9	.0466	EC	S
Mysidiella cf. *M. americana*	7	7	.0363	EB	S
Antiquilima n. sp. 2	8,9	6	.0311	EB	S
?*Lopha* sp. 1	do	6	.0311	EC	S
Trigoniidae, new gen. 1	10	5	.0259	IM	S
Pseudolimea naumanni	11	4	.0207	E?B	S
Parallelodon cf. *P. monobensis*	12-20	3	.0155	EB	S
Gervillia (*Cultriopsis*) *angusta*	do	3	.0155	EB	S
Pteriidae, sp. 2	do	3	.0155	EB	S
"*Chlamys*" cf. *C. mojsisovicsi*	do	3	.0155	EB	S
Pectinid B	do	3	.0155	EB	S
Pectinid C	do	3	.0155	EB	S
Pectinid D	do	3	.0155	EB	S
Antiquilima n.sp. 1	do	3	.0155	EB	S
?*Tutcheria* sp.	do	3	.0155	IM	S
Arcoid indet.	21-28	2	.0104	EB	S
Pteriidae, sp. 1	do	2	.0104	EB	S
Pectinid A	do	2	.0104	EB	S
Mysidioptera spinigera	do	2	.0104	EB	S
Plicatula sp. 1	do	2	.0104	EC	S
"oyster" sp. 1, indet.	do	2	.0104	EC	S
Tutcheria densestriata	do	2	.0104	IM	S
?Fimbriidae indet.	do	2	.0104	IM	S
Nuculoid indet.	29-38	1	.0052	IM	D
Pteriacean indet.	do	1	.0052	EB	S
?*Antiquilima* sp.	do	1	.0052	EB	S
Antiquilima ? sp. 3	do	1	.0052	EB	S
Liostrea sp.	do	1	.0052	EC	S
?*Gryphaea* sp.	do	1	.0052	ES	S
Limacean indet.	do	1	.0052	EB	S
"oyster" sp. 2, indet.	do	1	.0052	EC	S
Bakevilliidae, indet.	do	1	.0052	EB	S
Trigoniidae, gen. 2	do	1	.0052	IM	S
Bivalve indet.		9			

H= 1.2915*
Hmax= 1.5798
E= 0.8175

(calculated $H = -\sum_{i=1}^{S} P_i \log P_i$)

Karnian in northeastern British Columbia (Tozer, 1965) to the lowermost Norian in Hells Canyon.

Plicatula hekiensis is a spinose, oysterlike bivalve (pl. 2.1, figs. 16–19) that is inferred to have been an epifaunal suspension feeder. The Spring Creek specimens differ from the species as described by Nakazawa (1955) in having a highly convex left valve in early stages of growth, becoming more flattened in adult specimens.

Newton (1983) considered the presence of *Plicutala hekiensis* to suggest Japanese zoogeographic influence on the Hells Canyon fauna; however, this form is now known to occur also in Late Triassic faunas on the North American craton in the Canadian Arctic Archipelago (T. Tozer and C. Newton, personal observations, 1983). It is therefore clear that *P. hekiensis* was also part of the North American cratonal fauna during Late Triassic time.

The epibyssate mytiloid *Mysidiella* cf. *M. americana* (pl. 2.1, figs. 6–7, 10-11) and the shallow infaunal burrower *Tutcheria densestriata* (pl. 2.1, figs. 8–9), which are suspension feeders representing epibyssate and infaunal burrowing habits, respectively, are typical of Norian assemblages of central and northern Peru (Korner, 1937; Cox, 1949; C. Newton, personal observations of American Museum of Natural History collections, 1983). These two species also occur in the Norian carbonate rocks of the Chitistone Limestone in the Wrangell Mountains of Alaska (Newton, 1983).

An unusual aspect of the early Norian silicified fauna of Hells Canyon is the occurrence of smooth trigoniaceans with trigoniid-grade dentition (usage of Newell and Boyd, 1975). Although many of the available specimens are fragmented, the Hells Canyon forms apparently have subrounded outlines, in contrast to smooth trigoniaceans with trigonal to cuneiform outlines described by Freneix and Avias (1977) from the Triassic rocks of New Caledonia. Smooth trigoniaceans with advanced-grade dentition have not previously been reported from the lower Mesozoic rocks of North America.

DISCUSSION

GENESIS OF THE SHELL BEDS

The silicified shell beds at Spring Creek are interpreted as the product of storm winnowing and local transport of skeletal material. The shell beds conform well to the idealized proximal carbonate tempestite sequence proposed by Aigner (1982). Similarities include the presence of a basal scour surface, predominance of disarticulated bioclasts oriented generally parallel to bedding, overall normal grading of beds, relative thickness of bioclastic beds, prevalence of ripple cross-lamination in upper parts of the sequence, and the presence of umbrella structures and other grain-sheltered patches.

The main distinction between the Muschelkalk storm shell beds of southwestern Germany as described by Aigner (1977, 1982) and the bioclastic lenses discussed here is the nature of the background sedimentation. Fair-weather sediments of the Muschelkalk reflect low-energy sedimentation in an epicontinental nearshore zone subject to fluctuating salinity and temperature, whereas the sand-sized and winnowed fair-weather sediments at Spring Creek represent an agitated, shallow subtidal oceanic environment.

Storm sequences of the Upper Jurassic coquinoid quartz sandstones of Wyoming and Montana may provide a more fitting hydrodynamic analogue for the Spring Creek shell beds, as the energy levels in the fair-weather sedimentary regimes are more similar. Brenner and Davies (1973) described three types of storm deposits that punctuate moderate- to high-energy marine bar facies from this region: *swell lags, channel lags,* and *storm lags. Swell lags* are composed largely of articulated fossils embedded in a muddy matrix, whereas channel lags and storm lags typically lack muddy matrix and are interbedded with sandstones. The *channel lags,* which are composed of bivalve fragments, are 1–3 m thick and exhibit both planar and festoon cross-stratification. The *storm lag* concentrations, which are most similar to the Spring Creek lenses, have erosive bases, thicknesses of 3–30 cm, normal grading, and a geometry described as "sheetlike lens". Fossils observed in the Jurassic storm lags include brachiopods, pectinacean bivalves, oysters, and crinoids (Brenner and Davies, 1973). Thus, despite lithologic contrasts, the Jurassic storm lag concentrations of Wyoming and Montana compare very favorably with the Triassic shell beds at Spring Creek.

Several properties of the storm-influenced stratigraphic sequence at Spring Creek readily distinguish it from basin-margin sequences containing sediment gravity flow deposits. Perhaps the most striking of these is the absence of lime mudstones of periplatform-ooze origin that are typically intercalated with gravity flow deposits in basin-margin settings (Cook and Mullins, 1983). In the Spring Creek sequence the background sediment is winnowed carbonate sand rich in both peloids and coated grains, including ooids. This sandy background sediment is very similar in allochem composition to the peloidal, fine sand- to silt-sized matrix of the shell beds. The pelbiosparites between shell beds contain a sparse benthic fauna generally similar to that of the shell beds, in contrast to the pelagic, deep-water fauna of ammonoid cephalopods and halobiid bivalves expected on basin-margin slopes (see Hallam, 1981). Other features considered typical of basin-margin environments, such as debris flows, modified grain flows, slumps, slides, and large-scale truncation structures (Cook and Mullins, 1983), have also not been observed in the Martin Bridge at Spring Creek. All available biotic, petrographic, and stratigraphic evidence points, therefore, to a shallow-water origin for this sequence.

TAPHONOMIC AND PALEOECOLOGIC IMPLICATIONS

Although storm shell lags clearly cannot be analyzed as *in situ* representations of living benthic communities, the skeletal debris is not allochthonous in the sense of being derived from a distant source. Storm accumulations composed of fragmented shells are most properly considered as parautochthonous deposits (Aigner, 1982; Seilacher, 1982;) that sample all skeletons with sufficient mechanical strength and hydrodynamic properties over a geographic radius defined by the magnitude of the storm. In a particularly severe storm, such as hurricane Carla in 1961, shells can be displaced into water depths that vary as much as 25 m from the original habitat, and mixing of several benthic communities is frequent (Hayes, 1967). Breakage, abrasion, and disarticulation of bivalved skeletons are typical in very severe storms, and these characteristics can be used to define such events in the stratigraphic record.

The high frequency of disarticulation (>99 percent) of bivalves in the Spring Creek fauna indicates substantial postmortem, preburial physical transport and/or biological reworking of skeletal material. A further indication that bivalve shells may have had long residence times above the sediment-water interface is the presence of oyster encrustations on valve interiors and exteriors of *Mysidioptera*. An oysterlike bivalve found cemented to the upper surface of a spongiomorph colony similarly indicates that the colony remained upright above the sediment surface for a considerable time after death.

Generalizations concerning the paleoecology of the communities sampled by the Spring Creek storm events are rendered possible by the relative ecologic homogeneity of the bivalve fauna. The Spring Creek bivalve fauna is an epifaunal, suspension-feeding assemblage whose ecological characteristics indicate a warm-water habitat. Spinose species are present (pl. 2.1, figs. 16–19) and cemented bivalves are common (table 2.1); modern bivalve species having these characteristics are confined to marine waters with annual minimum temperatures no lower than 10 °C and most commonly the minimum temperature for such forms is 20 °C (Nicol, 1967, 1978).

A number of authors have made reference to reeflike structures in the Martin Bridge Limestone (for example, Nolf, 1966; Vallier, 1967). The relatively small proportion of scleractinian corals and spongiomorphs, and the absence of lithoclasts of coralline biolithite, indicate that the shell beds at Spring Creek were not derived from a major reef complex. Instead, the Spring Creek assemblages are the transported relics of level-bottom communities that were dominated by mollusks, but which also included isolated coral colonies or thickets. This is in agreement with the observation of Stanley (1979a,1979b) that most occurrences of Norian scleractinians in North America repesent small coral thickets rather than ecologic reefs.

ZOOGEOGRAPHIC IMPLICATIONS

Zoogeographic analysis of the Hells Canyon bivalves assigned to taxa previously described from other regions suggests a mixture of American and Japanese species. *Septocardia, Mysidioptera williamsi, Mysidiella americana,* and *Tutcheria densestriata* are unknown from continents other than the Americas, whereas *Parallelodon monobensis* and *"Chlamys" mojsisovicsi* are species hitherto reported only from Japan (Kobayashi and Ichikawa, 1949; Nakazawa, 1952, 1955; Ichikawa, 1954; Tokuyama, 1960; Hayami, 1975). This faunal mixture among bivalves lends support to the paleogeographic reconstructions of Tozer (1982), who noted that archipelagoes in the Panthalassic ocean could have formed zoogeographic dispersal routes. As a result, the former archipelagoes that now constitute North American suspect terranes would preserve faunas of mixed zoogeographic affinities (Tozer, 1982).

However, the dearth of adequate taxonomic information on early Mesozoic cratonal North American bivalves suggests caution in making such zoogeographic interpretations. No up-to-date taxonomic information is available, in particular, regarding Norian cratonic representatives of the families Pectinidae and Parallelodontidae, and it is hazardous to assume that *"C." mojsisovicsi* and *P. monobensis* do not occur in North America. Illustrating this point, *Plicatula hekiensis* is reported in the literature only from Japan (Nakazawa, 1955; Hayami, 1975), but E.T. Tozer and I have recently (1983) observed it in underscribed samples from the Canadian Arctic Archipelago. Because American Triassic bivalve faunas have received much less taxonomic attention than those of other regions such as Japan (Hallam, 1981), the overall resemblance of the Spring Creek assemblage to cratonal North and South American faunas has probably been underestimated.

SUMMARY AND CONCLUSIONS

Richly fossiliferous lenses of early Norian silicified macrofossils found at the Spring Creek locality of the Wallowa Mountains-Seven Devils Mountains volcanic arc terrane formed in response to storm events that interrupted fair-weather sedimentation in an agitated, warm, shallow marine environment. Though transported, the Spring Creek bivalves uniformly indicate an epifaunal, suspension-feeding association that dwelled on a peloidal sand substrate during fair weather conditions. A large proportion (74 percent) of the bivalve species are new or indeterminate. The few bivalve species previously described from other regions reflect mixed zoogeographic affinities; species typical of cratonal North America, South America, and Japan are present. Such diverse affinities tend to support the early Mesozoic paleogeographic model of Cordilleran suspect terranes advanced by Tozer (1982): island archipelagoes positioned in central portions of ocean basins would be expected to have faunas of mixed zoogeographic alliance. I speculate, however, that the extent of North and South American faunal exchange with Cordilleran suspect terranes has likely been underestimated because of the impoverished state of the literature on cratonal American bivalves.

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PLATE 2.1

[Contact photograph of the plate in this chapter is available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

PLATE 2.1.

[Figures natural size unless otherwise indicated. All specimens coated with ammonium cloride]

FIGURES 1–5. *Cassianella* cf. *C. angusta* Bittner. USGS Mesozoic loc. M2672
1. Left valve interior.
2. Left valve exterior.
3. Fragmentary right valve exterior (×1.5).
4. Left valve interior (ventral periphery and posterior broken).
5. Left valve exterior (ventral periphery and posterior broken).

6, 7, 10, 11. *Mysidiella* cf. *M. americana* Körner. USGS Mesozoic loc. M2672.
6. Left valve exterior of fractured specimen.
7. Left valve interior of fractured specimen (part of hinge-covering plate on anterior margin is broken away).
10. Left valve interior with unbroken hinge area.
11. Left valve exterior.

8, 9. *Tutcheria densestriata* (Körner). USGS Mesozoic loc. M2672.
8. Right valve exterior (periphery broken) (×1.5).
9. Right valve interior (periphery broken) (×1.5). Note denticulation of inner shell margin.

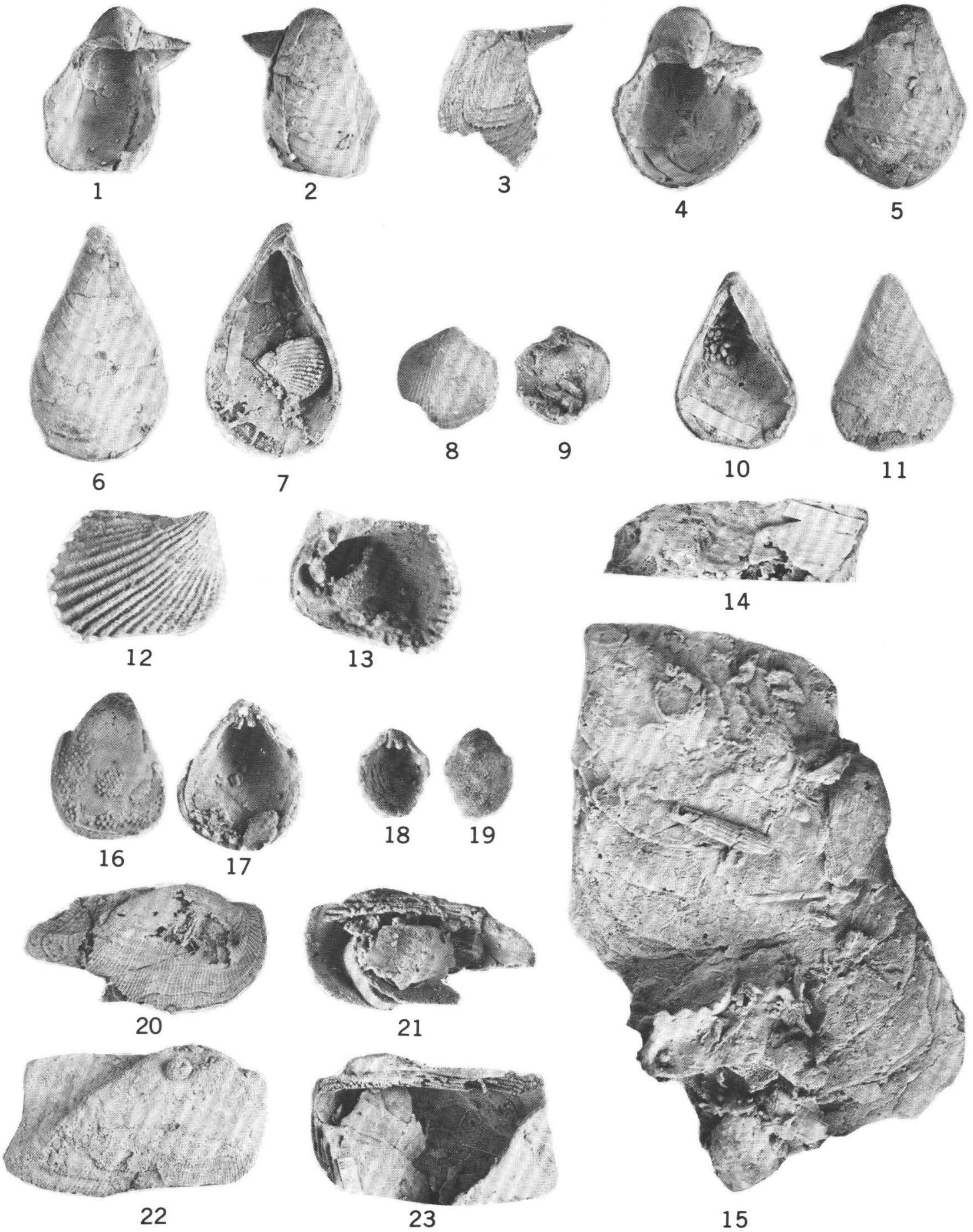
12, 13. *"Septocardia"* sp. USGS Mesozoic loc. M2672.
12. Right valve exterior (×2).
13. Right valve interior (×2).

14, 15. *Mysidioptera williamsi* (McLearn). USGS Mesozoic loc. M2672.
14. Detail of left hinge, illustrating single ligament pit.
15. Left valve exterior (anterior, ventral margin broken). Note fragments of cemented oysterlike bivalve in central posterior region; echinoid spine cemented to center of valve; and left valve of *Parallelodon* on mid-posterior part of shell.

16–19. *Plicatula hekiensis* Nakazawa. USGS Mesozoic loc. M2672.
16. Left valve exterior (×1.5). Spinose outer shell layer absent over much of valve.
17. Left valve interior (×1.5).
18. Left valve interior (×1.5).
19. Left valve exterior (×1.5).

20, 21. *Parallelodon* aff. *P. monobensis* Nakazawa. USGS Mesozoic loc. M2672.
20. Right valve exterior (×1.5).
21. Right valve interior (×1.5).

22, 23. *Parallelodon* cf. *P. monobensis* Nakazawa. USGS Mesozoic loc. M2672.
22. Right valve exterior.
23. Right valve interior.



CASSIANELLA, MYSIDIELLA, TUTCHERIA, "SEPTOCARDIA," MYSIDIOPTERA, PLICATULA, PARALLELODON

3. LATE TRIASSIC COELENTERATE FAUNAS OF WESTERN IDAHO AND NORTHEASTERN OREGON: IMPLICATIONS FOR BIOSTRATIGRAPHY AND PALEOGEOGRAPHY

By George D. Stanley, Jr.[1]

ABSTRACT

Rich collections of Late Triassic corals and spongiomorphs provide useful new data for biostratigraphic and paleogeographic studies of western Idaho and northeastern Oregon. The systematic standing of some of the corals is clarified and a new species, *Cyathocoenia squiresi,* is designated. The identification and stratigraphic distribution of 49 taxa of scleractinian corals and spongiomorphs from the Wallowa Mountains, Hells Canyon, and a locality near Lewiston, Idaho, allow comparison with faunas from Vancouver Island, British Columbia, and the Wrangell Mountains, Alaska. These data show a differentiation of early and late Norian faunas. Certain characteristic coral species are useful, in the absence of more diagnostic fossils, in recognizing the Kerri and Crickmayi Zones in the Upper Triassic rocks.

The coelenterate faunas occur in distinct horizons and are clearly of warm shallow- water origin. Although true reef structure is absent, the corals locally form rich biostromal deposits 1–12 m thick, in association with a variety of other benthic invertebrates including molluscs and echinoderms.

Strong Tethyan affinities of the coelenterates are clearly evident at some localities, as much as 75 percent of the fauna are conspecific with distant counterparts in alpine regions of central Europe. Dispersal of corals within the Triassic Panthalassa Sea was probably facilitated by the presence of numerous small continental and volcanic islands which were probably scattered throughout the ancestral Pacific. Distances between these islands and the presence of intervening bodies of deeper water may explain marked differences between coelenterate faunas from widely distributed terranes now part of North America.

Comparisons with presumably contemporaneous early Norian coelenterate faunas from other regions show surprisingly little similarity. Such findings necessitate critical evaluation of Late Triassic paleogeography and perhaps a re-examination of relationships between Wrangellia and the Wallowa terrane.

INTRODUCTION AND PAST WORK

Triassic coelenterate faunas of North America have, until recently, received relatively little study. They were first made known by Smith (1912), who discussed the occurrence of Late Triassic coral reefs in the Wallowa Mountains of Oregon, western Nevada, and Alaska. Smith's idea of an early Norian north-south coral reef belt quickly caught the attention of geologists the world over. Dacque (1915) referred to it in his textbook on paleogeography and Koppen and Wegener (1924) used it in the context of newly emerging ideas on continental drift. Smith (1927) described and illustrated the coral and hydrozoan taxa and noted the striking similarities to counterparts in reef sequences of the Alps. Few details of the so-called reefs were given, but nevertheless the idea of a coral reef belt, widely distributed with respect to latitude along the western margin of North America, became firmly rooted in the minds of stratigraphers, paleoclimatologists, and paleogeographers (Opdyke, 1962; Schwarzbach, 1974; Dott and Batten, 1976). Major problems revolved around explaining the high latitude occurrences of these "reefs" as well as the high levels of similarity with distant counterparts in Europe (Smith, 1927).

Stanley (1979) conducted regional studies of some important localities in California, Nevada, Oregon, Idaho, Canada, and Alaska and established that few if any of these occurrences are true reefs in the ecologic sense of living counterparts. Most of the limestone sequences are small in scale compared with alpine counterparts, and the coral deposits that occur in these sequences are thin and laterally restricted. In addition to corals and hydrozoans, a variety of other groups including sponges, brachiopods, molluscs, and echinoderms are present. The coral deposits are locally thin and do not form extensive organic frameworks, and where they are the principal components of fauna, they show little evidence of having developed in high-energy wave environments. The localities range in age from Ladinian to latest Norian and thus cannot all be assigned to a single lower Norian coral zone such as that envisioned by Smith (1927). In terms of their stratigraphic and paleoecologic settings, the corals bear little resemblance to the well- developed reef sequences of the Alps (Stanley, 1980). In terms of their taxonomic composition, however, much similarity exists.

Most coral localities in the Western United States, Canada, and Alaska are Norian in age (Stanley, 1982), but because shalllow-water sequences commonly lack the ammonites and halobiid and monotid bivalves

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characteristic of open or deeper water, precise dating and chronostratigraphic correlations have been difficult. As discussed below, some coral taxa hold potential for resolving biostratigraphic correlations.

The development of the concept of displaced terrane and its application to widely distributed rocks of western North America (Jones and others, 1982) has provided a new way to explain the present distributions of the coral faunas. Careful evaluation of these faunas and other Triassic benthic invertebrates from diverse terranes provides a basis for assessing ideas on the origins and subsequent tectonic displacements of these allochthonous units. Although the shallow-water benthic faunas have long been known, they have received relatively little attention and have not been utilized on any large scale for paleogeographic studies. Current work by Peter Hoover (Paleontological Research Institute, Ithaca) on brachiopods, Cathryn Newton (Syracuse University) on molluscs, and Porter Kier (Smithsonian Institution) on echinoids, promise additional fruitful contributions to the paleogeographic issues.

This paper discusses some of the coral faunas that are unique to northeastern Oregon and western Idaho. Many of these faunas are silicified and thus well preserved and are among the richest coral faunas in North America. Upper Triassic corals discussed in this paper come from three principal areas: (1) the southern Wallowa Mountains, along Eagle Creek in northeastern Oregon, (2) the Nez Perce Indian Reservation south of Lewiston, Idaho, on Mission Creek, and (3) Hells Canyon, near the Snake River between Oregon and Idaho (fig. 3.1). The first two areas have been previously studied (Stanley, 1979) and I have recently examined the Hells Canyon locality. The rich faunas of these areas may be compared not only with each other but also with more distant faunas. Data generated from such comparisons provide powerful tools for solving biostratigraphic and paleogeographic problems.

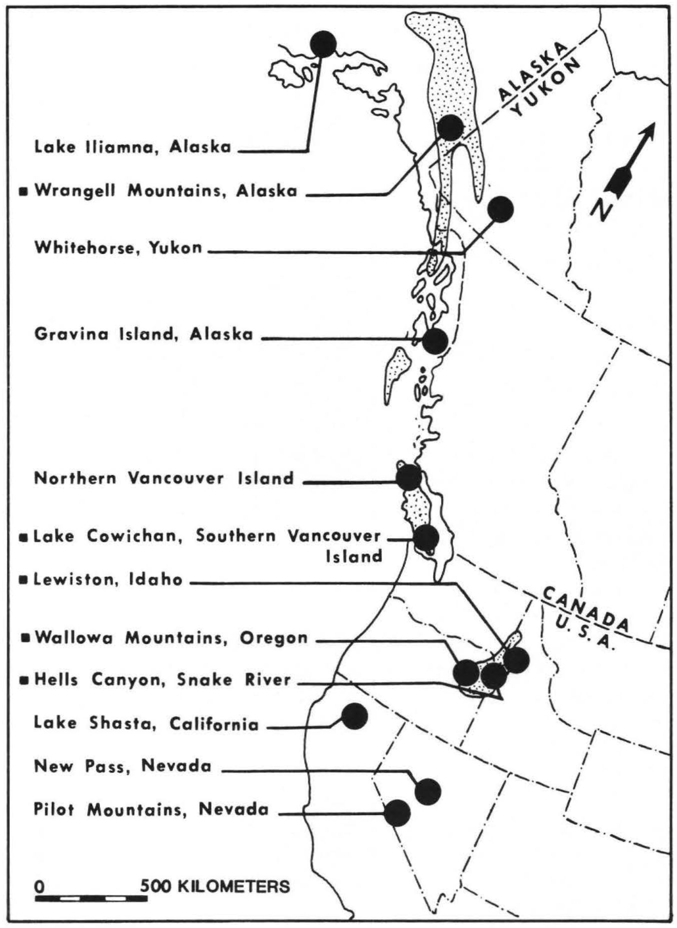

FIGURE 3.1.—Locations of important Late Triassic coelenterate faunas in western North America. The stippled region indicates the general extent of the postulated Wrangellia terrane (Jones and others, 1977). Squares to the left of locality names show localities discussed in this report.

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STRATIGRAPHY AND PALEOECOLOGY OF THE CORALS

The Triassic corals reported by Smith (1912, 1927) come from the type section of the Martin Bridge Limestone (Vallier, 1977) on Eagle Creek in the southern Wallowa Mountains, Oregon. As described by Ross (1938), the strata are interbedded massive and thin-bedded limestone and shale about 460 m thick. The lower part of the sequence is characteristic of turbiditic sedimentation (Follo, 1985). The corals occur within a thin- bedded limestone about 12 m thick and their early Norian age is established by *Halobia* species that occur above and below these coral beds (Smith, 1927). A reinvestigation of calcareous argillaceous beds below the coral limestone, with rich ammonite and halobiid bivalve faunas (J. A. Grant-Mackie, in preparation) suggests that they span the Karnian- Norian boundary through the base of the Kerri zone. In this respect these beds could be unique to North America, yielding a biostratigraphic boundary previously unrecognized. Solitary, branching, and encrusting corals dominate. Unfortunately, the fossiliferous section containing the corals described and collected by Smith (1927, p. 10) has been covered by the construction of a road high on the east side of the creek. Coral collections were made from surrounding areas (Stanley, 1979); but owing to lack of silicification, large numbers of specimens are not available. In the northern Wallowa Mountains near Joseph, Oregon, similar Upper Triassic limestone has been correlated with the Martin Bridge Limestone (Nolf, 1966), but structural complications and metamorphism of the rocks, coupled with their isolation from Martin Bridge outcrops to the south, partially obscure the relationships. Nolf (1966) established a stratigraphic sequence in the northern Wallowa Mountains which is generally similar to that of the type locality on Eagle Creek, but he recognized various members not distinguishable at the type locality. My preliminary observations of the fossils and rock types at the type locality, suggest that this sequence, relative to that of the southern Wallowas, represents a deeper water, more distal shelf setting than that at the northern Wallowa locality. In both localities, corals are concentrated in thin biostromal beds 1–12 m thick. Although this paper deals mostly with corals from the Eagle Creek locality, silicified coral faunas from the northern Wallowa Mountains are now under study, and preliminary findings support the early Norian age assigned by Smith (1927) for both localities.

On Mission Creek, near Lewiston, Idaho, the limestone in an isolated quarry was reported by Cooper (1942) to be richly fossiliferous. This locality contains at least 150 m of limestone. Thin horizons near the base and top of the quarry have yielded a wealth of silicified Late Triassic fossils. The limestone is an inlier surrounded by extensive Upper Tertiary basalts, so physical correlations outside the outcrop area have not been possible. The coral fauna from this quarry was first studied by Squires (1956). Stanley (1979) illustrated some of the rich silicified sponge, coral, and bivalve taxa that indicated a late Norian age. The recrystallized limestone is lithologically similar to the Martin Bridge Limestone. Silicified fossils form thin beds at several horizons. The locality is unique in having such a rich silicified benthic invertebrate fauna of Late Triassic age. It is also the easternmost exposure of marine Upper Triassic limestone known in the United States, lying about 50 km east of the easternmost outcrop of known Upper Triassic limestone assigned to the Martin Bridge.

Near the Snake River in Hells Canyon, along the border of Idaho and Oregon, Upper Triassic limestone about 500 m thick lies above the Triassic part of the Seven Devils Group (Vallier, 1974, 1977). Most of the limestone is recrystallized, but some thin beds yield an abundant silicified fauna especially rich in molluscs. Corals and spongimorphs are present in one such mollusc bed north of Spring Creek (USGS locality M2672), which is interpreted as a subtidal storm deposit (Newton, this volume). The corals were described by Montanaro Gallitelli and others (1979), and the specimens illustrated by them are now in the United States National Museum. Coelenterates are not a very significant component of the fauna, with corals and spongiomorphs occurring mainly as debris. Most of the corals have sheet-like growth forms, and some appear to have encrusted the molluscan shell material. There is no organic framework structure, even of small size. Characteristics of the carbonate rocks at Hells Canyon, as well as the general stratigraphic relationships, are similar to those of the Martin Bridge Limestone in the Wallowa Mountains. Fossils at both localities occur in thin beds of silicified, highly concentrated invertebrates separated by thick intervals of recrystallized limestone, seemingly barren of fossils.

Details of the paleoecology of Triassic corals were given by Stanley (1979, 1980). Late Triassic coral faunas from both western North America and the Alps occur in a variety of rock types indicating a great range of depositional environments. These include shallow lagoon, reef, and deeper, basinal shelf-slope environments. The coral taxa are remarkably undifferentiated with respect to the various environments (Stanley, 1979, 1980, 1982). In terms of their ecologic preferences, corals of the Triassic do not appear to have been as closely adjusted to specific habitats as their Cenozoic and living counterparts (Stanley, 1981).

Rather than inhabiting high-energy, shelf-edge environments, such as found on crests of modern coral reefs, most Triassic corals appear to have preferred lower energy, more protected or quieter environments, such as lagoon, protected shoal, and deeper shelf slope within a broad carbonate platform. Rather than a gently sloping reef, the ramp model proposed by Armstrong and others (1969) for Alaska, appears more applicable to the bedded Upper Triassic limestone of Oregon and Idaho. Thus, no true Triassic coral reefs were thought to be present in North America. This idea has now been challenged by the discovery of a massive-bedded, coral-dominated reef in the southern Wallowa Mountains, near the Martin Bridge type locality at Eagle Creek (Stanley and Senowbari-Daryan, 1986). Sedimentological and paleontological characteristics are strikingly similar to the Upper Triassic Dachstein Reef Limestone of the Austrian and German Alps (Zankl, 1971) and contrast markedly with Wrangellian sequences.

THE COELENTERATE FAUNAS

A total of 40 coral and 9 spongiomorph taxa are known from the Upper Triassic localities of northeastern Oregon, western Idaho, Vancouver Island, and the Wrangell Mountains of Alaska (fig. 3.1 and table 3.1). While some of these coelenterates are endemic to North America, a large number also occur in alpine reef sequences of central Europe. Considering all 49 taxa, 55 percent are conspecific with Late Triassic alpine forms from the Tethys region of central Europe. Most of those come from the Norian Zlambach beds of Austria (Frech, 1890).

Of the nine spongiomorph taxa recognized (table 3.1) only two are known outside North America. Although subordinate to the corals, spongiomorphs are also important elements of the fauna in Hells Canyon and the Wallowa and Wrangell Mountains. Some branching forms such as *Spongiomorpha ramosa* resemble dendroid corals, and if the limestone matrix is strongly recrystallized, they might be confused with branching corals such as *Retiophyllia*. At the Lewiston locality, however, spongiomorphs are rarer and corals are much more important.

The names of the scleractinian coral taxa listed in table 3.1 are based on a number of systematic studies (Smith, 1927; Squires, 1956; Montanaro Gallitelli and others, 1979). The generic and specific names reflect major new revisions that have taken place through systematic studies of Triassic corals by French and Russian workers (Cuif, 1965, 1972, 1974a,b, 1975, 1976; Melnikova, 1967, 1968, 1971, 1972, 1975). The affinities of the spongiomorph taxa listed in table 3.1 are currently the subject of discussion (Flügel, 1981). Instead of the traditional view as hydrozoans, some workers today regard them as stromatoporoid sponges. Although occurring with corals, these fossils are not corals and may not even be true coelenterates. However, they are discussed with the corals in this paper. Further work is needed to clarify their systematic standing.

Many of the North American corals are certainly conspecific with alpine taxa. The Norian alpine species are numerous and exquisitely preserved, mostly in original aragonite (Frech, 1890). The major problem arising in the systematic classification of North American corals is that before they can be precisely identified, they must be compared with the classic Norian types. These have been re-evaluated by Cuif (1965, 1972, 1974a,b, 1975, 1976), who, from details of their microstructure, has proposed many major revisions at generic and family levels. The Late Triassic corals of North America can certainly be considered well preserved because of their silicified nature, which reveals good surface details. Microstructural details, so important for comparison with the type species, are not present. Consequently many workers have adopted different approaches (Melnikova, 1971, 1972, 1975; Roniewicz, 1974). The only practical and objective way to classify silicified North American corals is to justify observable macroscopic characteristics by use of the better preserved alpine materials, incorporating the newly proposed names where appropriate. A new study of the alpine Norian coral types, currently underway by Dr. E. Roniewicz (Warsaw), may produce some changes, but the integrity of the individual coral taxa recognized herein should not be greatly affected.

Based on published information on localities in Oregon and Idaho, the Lewiston site, where 18 taxa are known, has the highest coelenterate diversity. The lowest diversity is in the Wallowa Mountains (12 taxa) and Hells Canyon, where 15 taxa are present. The coelenterate taxa described by Montanaro Gallitelli and others (1979) come from Hells Canyon (table 3.1). Significant parts of the carbonate sequence are so recrystallized as to make recognition of original fossils, textures, and microfacies types difficult, and therefore silicified intervals provide the bulk of information on the fauna. Equally rich silicified coral faunas occur within carbonate rocks in other areas such as Vancouver Island, where 15 taxa are known, and in the Wrangell Mountains of Alaska (U.S.G.S. locality M1708), where 15 taxa are present.

Applying Odum's (1971) index of similarity to the data in table 3.1, comparison of the presence-absence data from the various localities shows few striking examples of high similarity (table 3.2). The highest value (0.67) occurs between Lewiston and Vancouver Island. Lower levels are found between silicified faunas of Hells Canyon and the Wrangell Mountains (0.33), and Lewiston and Hells Canyon (0.24). No similarity exists between the Wallowa Mountains and Hells Canyon. Chronostratigraphic control based on fossils at these localities, is not continuous, but the corals occur mostly in thin beds dated as early Norian. It is difficult to assess the validity of Smith's (1927) proposed universal lower Norian coral zone. Certainly many examples are early Norian in age, and these may very well occur at consistent stratigraphic horizons. However, Karnian examples and one Ladinian (Middle Triassic) example are

TABLE 3.1.—*Coral and spongiomorph species at localities in northeastern Oregon, western Idaho, southern Vancouver Island and the Wrangell Mountains with occurrences in the Tethys region of Europe and Turkey*

[X, occurrence, based on published reports of Smith (1972), Squires (1957), Stanley (1979), Montanaro-Gallitelli and others (1979), and this paper with synonymization of generic and specific names with more recent systematic revisions. Tethyan occurrences only shown for those species reported from North American localities; all specimens on which this table is based are housed in the U.S. National Museum, University of Kansas Museum of Invertebrate Paleontology, and the University of Montana Museum of Paleontology]

Species	Oregon - Idaho			Canada - Alaska		
	Wallowa Mountains	Lewiston	Hells Canyon	Vancouver Island	Wrangell Mountains	Tethys Region
CORALS						
Actinastraea (?) sp. M. Gallitelli and others					X	
Ampakabastraea aff. *nodosa* Cuif					X	X
Andrazella sp. M. Gallitelli and others			X			
Astraeomorpha crassisepta Reuss		X	X	X		X
A. confusa (Winkler)	X					X
A. confusa var. *minor* Frech				X		X
Coccophyllum acanthophorum Frech		X		X		X
Coccophyllum sp. M. Gallitelli and others			X			
Cyathocoenia idahoensis (Squires)		X		X		
C. cf. *C. juvavica* (Frech)	X					X
C. schafhaeutli (Winkler)		X		X		X
C. squiresi n. sp.		X		X		
Cyathocoenia (?) sp. M. Gallitelli and others			X			
Distichophyllia norica (Frech)	X	X		X	X	X
D. melnikovae (M. Gallitelli)					X	
Gablonzeria major (Frech)		X		X		X
G. profunda (Reuss)	X	X		X		X
Guembelastraea cowichanensis (Clapp and Shimer)				X		
G. vancouverensis (Clapp and Shimer)				X		
G. whiteavesi (Clapp and Shimer)				X		
Margarastraea pulchra (M. Gallitelli)			X			
Margarosmilia zieteni (Klipstein)			X			X
Opelismilia zitteli (Frech)		X				X
Pamiroseris meriani (Stoppani)			X			X
P. smithi (Squires)		X	X	X		
Pinacophyllum parviseptum Squires		X	X		X	
Retiophyllia caespitosa (Frech)			X			X
R. dawsoni (Clapp and Shimer)		X	X	X	X	X
R. delicatula (Frech)	X					X
R. fenestrata (Reuss)	X					X
R. norica (Frech)	X					X
R. oppeli (Reuss)			X		X	X
R. suttonensis (Clapp and Shimer)		X		X		
R. wrangelliana (Russo)					X	
Retiophyllia sp. (M. Gallitelli and others)			X		X	
Stylina norica Frech		X				X
Stylophyllopsis zitteli Frech	X					X
Stylophyllum paradoxum Frech		X				X
Thamnasteriomorpha frechi (Volz)			X		X	X
Tricycloseris sp. M. Gallitelli and others			X			
SPONGIOMORPHS						
Heptastylis aquilae Smith	X					
H. oregonensis Smith	X					
Heptastylis sp. M. Gallitelli and others					X	
Spongiomorpha gibbosa Frech	X				X	X
S. ramosa Frech		X			X	X
S. tenuis (Smith)	X	X				
Stromatomorpha californica Smith					X	
Stromatomorpha sp. M. Gallitelli and others					X	
Stromatomorpha sp.		X				
Total Number of Taxa	12	18	15	15	15	

Table 3.2.—*Similarities between Late Triassic (Norian) coelenterate faunas from localites in northeastern Oregon and western Idaho*

[Odum's (1971) index of similarity: $2C/N_1 + N_2$, C = number of taxa common to two localities, N_1 and N_2 + number of taxa in each respective sample being compared. Data calculated from table 3.1 using published species occurrences; 0.000 indicates no species in common; 1.00 indicates identical faunas; for each locality shown at left, the percent of species found also in the Alps and central Europe and of those found only in North America are indicated at the right]

	Wallowa Mountains	Lewiston	Hells Canyon	Vancouver Island	Wrangell Mountains	Percent Alpine Species	Percent North American Species
Wallowa Mountains	1.00	0.20	0.00	0.15	0.15	75	25
Lewiston	--	1.00	0.24	0.67	0.24	61	39
Hells Canyon	--	--	1.00	0.20	0.33	47	53
Vancouver Island	--	--	--	1.00	0.13	53	47
Wrangell Mountains	--	--	--	--	1.00	47	53

also known in North America (Stanley, 1979). The coelenterate faunas from the different localities (table 3.1) show a great number of Tethyan species (46–75 percent; see table 3.2). This is especially true for the Wallowa Mountains where all the corals are known from the Alps. Interestingly, only two of the spongiomorphs at these localities have alpine affinities (table 3.1). The Hells Canyon and Wrangell Mountains localities show the lowest percentage of Tethyan taxa (47 percent) and more endemic taxa (53 percent) than any other locality.

SYSTEMATIC PALEONTOLOGY

Order SCLERACTINIA Bourne 1900
Suborder ASTROCOENIINA Vaughan and Wells 1943
Family ASTROCOENIIDAE Koby 1890
Genus CYATHOCOENIA Duncan 1867

Cyathocoenia cf. C. juvavica (Frech)

Plate 3.1, figure 7

Stephanocoenia juvavica Smith, 1927, pl. 112, figs. 7–10, p. 132.
Actinastaea juvavica (Frech). Stanley, 1979, pl. 1, fig. 7.

Remarks.—Details of the specimen fit well the descriptions given by both Frech and Smith. Distinctive features are in the septal arrangement and columnella. Based on the study of Melnikova (1968), Frech's species must be placed in the Genus *Cyathocoenia* Duncan.

Occurrences.—Wallowa Mountains (Eagle Creek); Lake Shasta, California; Pilot Mountains, Nevada; Gravina Island, Alaska; Zlambach beds, Austria.

Repository.—University of Montana Museum of Paleontology, UMP 7286.

Cyathocoenia schafhaeutli (Winkler)

Plate 3.1, figure 11

Prionastraea schafhaeutli Winkler, 1861, p. 488, pl. 8, fig. 11.
Stylina savii Stoppani, 1858-67, p. 101-102, pl. 24, figs. 9–12.
Isastraea suessi Reuss, 1864, p. 165, pl. 2, fig. 4.
Stephanocaenia schafhaeutli (Winkler). Frech, 1890, p. 37, text and fig.
Cyathocoenia schafhaeutli (Winkler). Melnikova, 1968, pl. 3, fig. 1-4.

Remarks.—The specimen from Lewiston fits well the description and illustrations in Winkler and Frech as well as that by Smith.

Squires (1956, text figs. 1–3) illustrated and described *Astrocoenia schafhaeutli* (Winkler) from Lewiston. However, as Montanaro Gallitelli and others (1979) pointed out, those specimens are not similar to Winkler's type. Melnikova (1968) put *Stephanocoenia juvavica* Frech in synonomy with *Cyathocoenia schafhaeutli* (Winkler), with which I do not agree. Features presented by Frech, such as number and regular arrangement of the septa, support considering *C. schafhaeutli* as a distinct species, it must be so regarded until detailed study of the type material can be made.

Occurrences.—Lewiston, Idaho; Vancouver Island (Lake Cowichan); Zlambach beds, Austria; southeastern Pamirs, USSR; southern Alps, Italy; Apennines.

Repository.—U.S. National Museum of Natural History, USNM 252707.

Cyathocoenia squiresi n. sp.

Plate 3.1, figure 10

Astrocoenia schafhaeutli (Winkler), Squires, 1956, fig. 1-3.
Actinastraea schafhaeutli (Winkler), Stanley, 1979, pl. 1, fig. 2.
Actinastraea ohmanni (Frech), Stanley, 1979 (not Frech). pl. 1, figs. 3–5.

Description.—Incrusting, nodular, or slender branching colonies. Broad, open corallites 1.0-2.0 mm diameter with a sunken calical pit 1 mm diameter. Septa number 23–27 and are generally straight and nonconfluent with those of adjacent corallites. Some septa curve about strongly where they intersect septa of adjacent corallites. The calical pit contains a slender, stelliform columnella, with 4–8 palli arranged symmetrically about it.

Remarks.—This species was well illustrated by Squires (1956, figs. 1–3) but as Montanaro Gallitelli and others (1979) pointed out, the size of the corallites and other characteristics set these specimens apart from *Cyathocoenia schafhaeutli* (Winkler) to which Squires assigned his material.

Occurrences.—Lewiston, Idaho; Vancouver Island (Lake Cowichan).

Repository.—University of Montana Museum of Paleontology, UPM 7287.

Family THAMNASTERIIDAE Vaughn and Wells 1943

Astraeomorpha crassisepta Reuss, 1854

Plate 3.1, figure 12

Astraeomorpha crassisepta Reuss, 1854, p. 127, pl. 16, figs. 5–7; Pratz, 1882, p. 103, pl. 14, figs. 13, 14; Haas, 1909, p. 153.

Thamnastrea borealis Smith, 1927, p. 131, pl. 115, figs. 6–10.

Astraeomorpha bulbosa Wilkens, 1937, p. 184, pl. 9, figs. 3–4.

Thamnasteria (Astraeomorpha) cuneata Squires, 1956, p. 15, figs. 11–13.

Astraeomorpha crassisepta Reuss, Melnikova, 1971, p. 162, pl. 1, fig. 1-2.

Astraeomorpha crassisepta Reuss, Roniewicz, 1974, p. 113, pl. 9, fig. 4-5.

Astraeomorpha crassisepta Reuss, Cuif, 1975, p. 117, pl. 17, fig. 1-7.

Astraeomorpha crassisepta Reuss, Montanaro Gallitelli and others, 1979, p. 142, pl. 2, fig. 5-6.

Thamnasteria smithi Squires, Stanley, 1979 (not Squires, pl. 1, fig. 10).

Remarks.—Squires (1956) described *Thamnasteria (Astraeomorpha) cuneata* as a new species from Lewiston, Idaho, and placed *Thamnastrea borealis* Smith in synonomy. However, I concur with Montanaro Gallitelli and others (1979) that both Squires' type and Smith's holotype are best referred to as *Astraeomorpha crassisepta* Reuss. This reduces by two the number of endemic North American species known.

Occurrences.—Lewiston, Idaho, Hells Canyon; Gravina Island, Alaska; southeastern Pamirs, USSR; Lombardi, Italy; Zlambach beds, Austria; Kothalp, Austria; Tatra Mts., Poland.

Repository.—University of Kansas Museum of Invertebrate Paleontology, KUMIP 113705.

Suborder FAVIINA Vaughan and Wells 1943

Superfamily STYLOPHYLLICAE Volz 1896

Family STYLOPHYLLIDAE Volz 1896

Genus STYLOPHYLLUM Reuss 1854

Stylophyllum paradoxum Frech 1890

Plate 3.1, figures 1–3

Stylophyllum paradoxum Frech, 1890, p. 45, pl. 14, figs. 1–24, pl. 15, fig. 12; Squires, 1956, p. 17, figs. 14–17; Cuif, 1972, p. 227, fig. 9; Cuif, 1977, pl. 1, figs. 1–3, pl. 2, figs. 1-2.

Remarks.—This species was well described by Squires (1956), who correctly related it to Frech's species from the Zlambach beds of Austria. It is a very common species at the Lewiston locality.

Occurrences.—Lewiston, Idaho; Zlambach beds, Austria.

Repository.—University of Montana Museum of Paleontology UPM 7288, 7289, 7290.

Genus COCCOPHYLLUM Reuss 1865

Coccophyllum acanthophorum Frech 1890

Plate 3.1, figures 8, 9

Coccophyllum acanthophorum Frech, 1890, p. 89, pl. 29, figs. 4–11; Squires, 1956, figs. 19–21; Stanley, 1979, pl. 2, figs 3, 5–7.

Remarks.—This species from Frech was well described by Squires (1956) and has also been recognized from Vancouver Island by Stanley (1979). Although microstructural features are missing because of the silicification, other surface features are adequate enough to relate the North American species to the Alpine species of Frech (1890).

Coccophyllum (?) sp. Montanaro Gallitelli and others (1979) is different, especially in having very large corallites, and thus cannot be related to *C. acanthophorum* Frech.

Occurrences.—Lewiston, Idaho (Mission Creek); Vancouver Island (Lake Cowichan); Zlambach beds, Austria.

Repository.—U.S. National Museum, USNM 252710; University of Montana, Museum of Paleontology, UMP 7291.

Superfamily FAVIICAE Gregory 1900

Family DISTICHOPHYLLIIDAE Cuif 1977

Distichophyllia norica (Frech)

Plate 3.1, figures 4–6

Montlivaltia norica Frech, 1890, p. 34, pl. 3, fig. 9a,b, pl. 10, figs. 1–5, pl. 13, figs. 1–7, pl. 18, figs. 17, 17a; Smith, 1927 (as *Montlivaultia*), p. 126, pl. 111, fig. 6; Squires, 1956, p. 21, figs. 32–47.

Stylophyllopsis mojsvari Frech. Smith, 1927, p. 127, pl. 118, fig. 10.

Montlivaltia sp. cf. *M. norica* Frech. Kanmera, 1964, p. 120, pl. 12, figs. 6–10.

Distichophyllia norica (Frech). Cuif, 1974a, p. 304, figs. 2–6; 1977, pl. 3, fig. 4-8.

Montlivaltia norica Frech. Stanley, 1979, pl. 2, figs. 8–10.

Disticophyllia cf. *norica* (Frech). Montanaro Gallitelli and others, 1979, p. 149, pl. 4, fig. 9a,b.

Remarks.—Cuif (1972a) re-evaluated the microstructural details of Frech's species as well as other corals assigned to *Montlivaltia* and concluded that this genus cannot be present in the Triassic. He therefore proposed a new family, Distichophylliidae, establishing *Montlivaltia norica* Frech as the type species. The specimens that Squires assigned to *Montlivaltia norica* most certainly belong to this species, although the microstructure is not present.

Occurrences. Wallowa Mountains, Oregon (Eagle Creek); Lewiston, Idaho; Pilot Mountains, Nevada; Vancouver Island (Lake Cowichan), Canada; Wrangell Mountains, Alaska; Zlambach beds, Austria.

Repository.—University of Montana, Museum of Paleontology, UMP 7292, 7293.

Family TROPIPHYLLIDAE Beauvais 1980
Genus GABLONZERIA Cuif 1976

Gablonzeria profunda (Reuss) 1854

Plate 3.1, figures 13, 14

Isastraea profunda Reuss, 1864, p. 116, pl. 9, figs. 5-6; Frech, 1890, p. 21, pl. 5, figs. 1–3a; Smith, 1927, p. 128, pl. 105, fig. 8, pl. 112, figs. 5- 6, pl. 114, figs. 1–3.

Elysastraea profunda (Reuss) Stanley, 1979, pl. 3, figs. 6, 8.

Isastraea profunda Reuss. Cuif, 1976, p. 116, pl. 11, figs. 1–8.

Remarks.—Squires (1956) placed his specimens in the Genus *Elysastraea* Laube, describing them as *E. profunda*. These were previously regarded as *Isastraea* in the older publications. Detailed microstructural studies on the Alpine types were conducted by Cuif (1976, p. 118), who proposed the new genus *Gablonzeria* for some species assigned to *Isastraea,* such as *I. profunda* and *I. norica*. Although diagnostic microstructural features have not been found in the North American specimens, they are in all likelihood assignable to Cuif's *Gablonzeria* rather than *Elysastraea* Laube.

Occurrences.—Lewiston, Idaho; Pilot Mountains, Nevada; Lake Shasta, California (Brock Mt.); southern Wallowa Mountains, Oregon (Eagle Creek); Vancouver Island (Lake Cowichan); Gravina Island, Alaska; Lake Iliamna, Alaska; Zlambach beds, Austria; Japan.

Repository.—University of Montana Museum of Paleontology UMP 7294, 7295.

Class HYDROZOA Owen 1843
Order SPONGIOMORPHIDA Alloiteau 1952
Family SPONGIOMORPHIDAE Frech 1890
Genus SPONGIOMORPHA Frech 1890

Spongiomorpha tenuis Smith 1927

Plate 3.1, figure 15

Spongiomorpha (Heptastylopsis) tenuis Smith, 1927, p. 133, pl. 118, fig. 3.

Spongiomorpha tenuis Stanley, 1979, pl. 6, figs. 1-2.

Remarks.—Smith described *Spongiomorpha (Heptastylopsis) tenuis* from the Lake Shasta area. The subgenus *Heptastylopsis* cannot be maintained, as pointed out by Flügel and Sy (1959).

Occurrences.—Lewiston, Idaho; southern Wallowa Mountains (Eagle Creek); Lake Shasta, California (Squaw Creek).

Repository.—University of Kansas Museum of Invertebrate Paleontology, KUMIP 113662.

Spongiomorpha ramosa Frech 1890

Plate 3.1, figure 16

Spongiomorpha (Heptastylopsis) ramosa Frech, 1890, p. 76, figs. a-c; Smith, 1927, p. 133, pl. 120, figs. 4-5, pl. 121, figs. 10–13.

Spongiomorpha ramosa Frech. Haas, 1909, p. 155, pl. 5, fig. 16a,b, pl. 6, fig. 1; Renz, 1912, p. 77; Kolosvary, 1966, p. 179; Montanaro Gallitelli and others, 1979, pl. 6, fig. 6a,b; Stanley, 1979, pl. 4, fig. 11, pl. 6, fig. 4.

Remarks.—This species was described by Smith (1927) and recognized by Montanaro Gallitelli and others (1977). Characterized by a branching coenosteum and strong trabecular elements, it is a widespread and common species in the Norian.

Occurrences.—Lewiston, Idaho; Gravina Island, Alaska; Iliamna Lake, Alaska; Wrangell Mountains, Alaska; Zlambach beds, Austria, Greece; Czechoslovakia.

Repository.—University of Montana Museum of Paleontology, UMP 7296.

Genus STROMATOMORPHA Frech 1890

Stromatomorpha sp.

Plate 3.1, figure 17

Remarks.—Because of the surface structure, composed of simple vertical elements, and the lack of any trabecular elements organized into radial patterns, this specimen is referrable to *Stromatomorpha* Frech. It differs in surface organization from *Stromatomorpha* sp. Montanaro Gallitelli and others (1979, pl. 6, fig. 7a,b). Internal details necessary for species assignments are not available.

Occurrence.—Lewiston, Idaho (Mission Creek).

Repository.—University of Montana Museum of Paleontology, UMP 7297.

AGE OF CORAL DEPOSITS

There are still uncertainties, as mentioned above, about the age of some of the coral faunas. Occurrences of characteristic ammonites or bivalves stratigraphically close to the coralline beds help establish Norian ages. Presence of the ammonoid, *Trophiceltites* cf. *T. columbianus* indicates that the coral fauna of the Wrangell Mountains belong to the lower Norian Kerri Zone and faunal similarities suggest the same for the Hells Canyon locality (Silberling and Tozer, 1968). *Monotis* species referenced by Smith (1927) from the Eagle Creek locality also indicate an early Norian age, but diagnostic ammonoids were not mentioned. The Lewiston locality is clearly Late Triassic in age but no stage-diagnostic fossils are present. On the basis of the brachiopod *Spondylospira,* however, Cooper (1942) suggested a Norian age, as was also concluded by Squires (1956). The rich gastropod fauna of this locality suggested a Norian-Rhaetian age (Haas, 1953), but re-evaluation of the coral faunas by Stanley (1979) indicated a late Norian age for the Lewiston outcrop.

The rare Late Triassic ammonites reported from the coral locality at Lake Cowichan, Vancouver Island (Silberling and Tozer, 1968) allow assignment of that interval to the uppermost Norian Crickmayi Zone (Stanley, 1979). The coral locality in the Chitistone Limestone (U.S.G.S. locality M1708) in the Wrangell Mountains, Alaska, contains *Halobia brooksi* (Silberling and Tozer, 1968), which indicates an age also roughly equivalent to the lower Norian Kerri Zone. The indicated ages of the coelenterate faunas at the various localities are presented in figure 3.2.

Three of the localities (Hells Canyon, Wallowa Mountains, and Wrangell Mountains) thus seem clearly to be early Norian in age. The faunas from these three localities are considered equivalent in age and represent the lower Norian Kerri Zone (fig. 3.2). The Vancouver Island localities on Lake Cowichan are well established as latest Norian. The Lewiston locality is more likely Norian but lacks diagnostic fossils for precise chronostratigraphic assignment; however, the corals suggest correlation with the Vancouver Island locality. The Lewiston coral fauna is, therefore, most probably late Norian in age. Comparison of the faunas from Vancouver Island and the other localities shows significant similarity only between the Lewiston and Vancouver Island localities, where a relatively high value of 0.67 was found (table 3.2). This unusually high similarity value is evidence that the Lewiston coral faunas are late Norian and thus approximately time-equivalent to the Vancouver Island fauna. In addition, these two localities share species known nowhere else (*Cyathocoenia idahoensis, C. squiresi* n. sp. pl. 1, fig. 10; *Retiophyllia suttonensis*). They also share the occurrence of the coral *Coccophyllum acanthophorum* (pl. 1, figs. 8, 9), known also from Lake Iliamna, Alaska, and from the Norian of central Europe (Frech, 1890).

Series	Stage	Substage	Zone	Wallowa Mountains	Lewiston	Hells Canyon	Vancouver Island	Wrangell Mountains
UPPER TRIASSIC	NORIAN	Upper Norian	*Choristoceras crickmayi*		●		●	
			Cochloceras amoenom					
			Gnamohalorites cordilleranus					
		Middle Norian	*Himavatites columbianus*					
			Drepanites rutherfordi					
		Lower Norian	*Juvavites magnus*					
			Malayites dawsoni					
			Mojsisovicsites kerri	●		●		●
	KARNIAN	Upper Karnian	*Klamathites macrolobatus*					
			Tropites welleri					
			Tropites dilleri					

FIGURE 3.2.—Ages of the Late Triassic coelenterate faunas from western North American localities, showing recognized biostratigraphic zones based mostly on ammonoids and monotid bivalves (Tozer, 1967, 1980). The basis for the age determinations at each locality is discussed in the text.

DISPLACED TERRANES AND PROBLEMS IN PALEOGEOGRAPHY

Jones and others (1977) defined Wrangellia, which is now one of the best known of the many displaced terranes recognized in the northwestern United States, Canada, and Alaska. The Wrangellia stratigraphic succession consists of a thick sequence of Permian and Middle and Upper Triassic basalts and volcaniclastic rocks overlain by shallow-water platform carbonate rocks of Karnian and Norian age. Jones and others (1977) cited general similarities in the paleomagnetic, volcanic, and stratigraphic attributes of widespread localities from the Wrangell Mountains of Alaska to Vancouver Island in British Columbia, with possible extensions in Hells Canyon and the Wallowa Mountains. Thus, all of the coral faunas discussed in this paper are from areas recognized or suspected to be part of the Wrangellia terrane. According to current ideas, this terrane was accreted to the craton of North America sometime in the late Mesozoic and was later tectonically dislocated. Remnants are believed to be distributed throughout an extensive part of western North America, from Alaska to Idaho and Oregon.

Accumulating paleomagnetic evidence, coupled with the general characteristics of the rich faunas of shallow-water benthic invertebrates, indicates that all of Wrangellia originated at low latitudes, generally about 16°, north or south of the Triassic equator (Jones and others, 1982). Triassic rocks of the Wallowa and Snake River region are part of the volcanic arc terrane of Brooks and Vallier (1978). Silberling and others (1984) have recently termed these rocks the Wallowa terrane, and that terminology will be used in the following discussion. Paleomagnetic studies by Hillhouse and others (1982) demonstrated that Triassic rocks of the Wallowa terrane originated at approximately 18° from the paleoequator and had undergone significant rotation. Their findings tended to support the idea of Jones and others (1977) that these rocks were part of the extensive Wrangellia terrane.

The importance of the faunas in assessing terrane movements was emphasized by Tozer (1982), who relied mostly on open-ocean pelagic or deepwater taxa and treated the shelly benthos as a single association of low-latitude origin. His paleogeographic reconstruction (Tozer, 1982; fig. 2) places Wrangellia in a warm-water setting south of the Triassic equator, far from the craton of Pangaea, and east of the postulated Triassic spreading center, ancestral to the East Pacific Rise. Similarities of benthic invertebrate faunas from Upper Triassic carbonate rocks of Wrangellia and of the Wallowa terrane were noted by Jones and others (1977), who suggested that the latter was a southern extension of Wrangellia.

Newton (1983) assessed these apparent paleogeographic relationships in a more detailed approach based on analysis of numerous bivalve genera. She placed Wrangellia in an east-west orientation between 15° and 18° latitude. This seems totally in agreement with the paleomagnetic data. At the generic level, Newton found significant similarity between the Wrangell Mountains and Hells Canyon, also believed to belong to the Wrangellia terrane, and less similarity between these and faunas from Puale Bay and Keku Strait, Alaska, thought to belong to terranes different from Wrangellia. Because of the lack of detailed systematic work on the molluscs, a more refined analysis using species was not possible.

The similarity coefficients presented in table 3.2 are based on an analysis of 49 coelenterate species. Compared to genera, these species should be more sensitive indicators of biogeographic variations. It is clear from table 3.1 that if genera only are used the results will be quite different, because many genera have numerous species and are widely distributed.

The Hells Canyon fauna at the U.S.G.S. locality M2672 has been recollected by Michael Whalen (University of Montana, M.S. thesis, 1985). The results are expected to be published later in a systematic study now underway. Preliminary identifications of 11 coelenterate taxa from the fossil bed at the Hells Canyon locality show a number of discrepancies with the data of Montanaro Gallitelli and others (1979). The major discrepancy is in the preponderance of spongiomorphs which appear to make up a major component of the Hells Canyon fauna but were reported by Montanaro Gallitelli and others (1979) only from the Wrangell Mountains. Further results show that some taxa reported only from the Wrangell Mountains occur instead in Hells Canyon. The possibility therefore exists that earlier collections from these two localities were mixed up by these authors or perhaps their material was not representative of the whole coelenterate fauna.

Coefficients of similarity may be recalculated on the basis of new species collected from Hells Canyon, but they still show low similarity with other localities, especially the Wallowa Mountains. The new data, not yet published, yield a similarity of 0.31 with the Wrangell Mountains, a value not so different from that originally calculated (table 3.2). Before unequivocal comparisons between these two are possible, new collections from the Wrangell Mountains must be studied.

Paleomagnetic data clearly establish the segments of Wrangellia present in Alaska and the Canadian northwest as having been formed at low latitudes, an inference substantiated by the general character of the invertebrate faunas. The importance of detailed systematic studies is readily apparent here because not until paleontological studies of the benthic faunas are complete can accurate comparisons of them be made and relative placement of the original longitudinal positions of various terranes be inferred. It is still not clear whether the isolated Wallowa terrane segment in northeastern Oregon and Idaho actually belongs to the Wrangellia terrane. More detailed paleontologic studies of the benthic elements of the faunas are necessary to clarify the paleogeography of Wrangellia, as defined by

Jones and others (1977), and its relationship to other volcanic terranes such as those of Oregon and Idaho.

CONCLUSIONS

The Late Triassic coelenterate faunas of Oregon, Idaho, Vancouver Island, and the Wrangell Mountains have been differentiated into early and late Norian assemblages. This work shows that the corals can, in the absence of other more diagnostic fossils, be useful in biostratigraphic studies. While some commonly occurring corals such as *Distichophyllia norica* (pl. 3.1, figs. 4–6), *Retiophyllia dawsoni,* and *Gablonzeria profunda* (pl. 3.1, figs. 13, 14) seem to be little differentiated through the Triassic, whereas other taxa such as *Coccophyllum acanthophorum, Cyathocoenia idahoenis, C. squiresi* n. sp., and *Retiophyllia suttonensis* are distinct from taxa in older rocks and assist in recognizing the latest Triassic (Crickmayi Zone). The spongiomorph taxa do not appear to be as useful as the corals in biostratigraphic studies.

The high degree of similarity between Alpine faunas of the former western Tethys region and faunas of Oregon and Idaho supports the idea that the Panthalassa Sea connecting with the Tethys and surrounding Pangaea contained numerous seamounts and islands of volcanic and continental origins (Tozer, 1982). Coral larvae could use these islands as stepping stones for their dispersal across this sea. Various distances between islands and the presence or absence of intervening deep sea between continents, islands, or island clusters would contribute to substantial differences in the overall composition of coral faunas.

All the localities studied in this paper are suspected to be part of Wrangellia (Jones and others, 1977). With the refinement of the age relationships now possible (fig. 3.2), one would expect that contemporaneous coelenterate faunas of Wrangellia would show high levels of similarity to each other and be different from faunas of other unrelated terranes. This is, however, not the case with the coral faunas. With the exception of the two late Norian faunas of Vancouver Island and Lewiston, the faunas do not have much similarity with one another (table 3.2). For example, comparisons of Wallowa coral faunas with those of the Wrangell Mountains show extremely low similarity values. No similarity at all exists between the Wallowa fauna and that of Hells Canyon, only a short distance away (table 3.2), although both are of the same age according to Montanaro Gallitelli and others (1979). Previous similarity data of Stanley (1979) showed that early Norian corals of the Wallowa Mountains bear much higher levels of similarity to other, supposedly unrelated, terranes (fig. 3.1), such as Gravina Island, which belongs to the Alexander terrane (Berg, 1973), and the Luning Formation in the Pilot Mountains, Nevada. The latter may be related to the Sonomia terrane of Speed (1979). Coelenterate faunas from these rocks show significantly higher levels of similarity with the Wallowa terrane than with the "type locality" of Wrangellia in the Wrangell Mountains. Dissimilarities between the Wallowa locality and the nearby Lewiston site can be explained because these faunas are of different ages, separated by at least six biostratigraphic zones (fig. 3.2). Considerable evolution is thus represented among the coral faunas, which by latest Triassic time were beginning to increase their rates of diversification (Stanley, 1981).

The problem of separating local environmental influences on the composition of the coral faunas from real paleogeographic differences can be partly overcome by recognizing the broad ecologic tolerances that characterized many of the coral taxa. As previously pointed out, Triassic corals appear not to have been so closely controlled by environment as their more recent descendents. There are definite problems in relating the Wallowa terrane to Wrangellia. Admittedly, the two localities bear much stratigraphic similarity (Silberling, 1983). In spite of these superficial similarities, however, Sarewitz (1983) concluded, on the basis of differences in the geochemistry of the volcanic rocks and contrasting geologic histories, that these two terranes are quite distinct from one another. The data from coelenterate faunas generally tend to corroborate this conclusion, but high similarities link late Norian faunas of Lewiston and Vancouver Island, which may have been in closer proximity than the early Norian faunas. Fifteen coral taxa listed from the Wrangell Mountains (table 3.1) were described by Montanaro Gallitelli and others (1979). Eight of these are known only from North America, and four others (a species of *Actinastraea, Distichophyllia melnikovae, Margarastraea pulchra,* and *Retiophyllia wrangelliana*) are found only in the Wrangell Mountains (table 3.1).

Current workers envision Wrangellia in early Norian time as a subsiding volcanic-island terrane on which a thick series of carbonate sediments was deposited within platforms or shoals. Paleomagnetic and paleontological evidence shows that Wrangellia was situated in a low-latitude, warm-water setting, most likely in the southern hemisphere. The coral fauna of such a setting, like those demonstrated for present-day groups of islands in the Carribean or Indo-Pacific regions (Wells, 1954; Newell, 9171; Rosen, 1975), would be expected to display a great deal of commonality in genera and even in species. The degree of commonality is especially strong when such an island group is oriented in an east-west direction, because such orientation promotes uniform conditions for marine life. However, significant differences in the coral faunas suggest that during the Late Triassic the Wallowa terrane was separated from Wrangellia by a body of water deep or extensive enough to substantially reduce the exchange of coral larvae. After volcanic activity ceased, distant terranes could have developed similar stratigraphic sequences by similar responses to sea level changes induced by the mechanisms of sea-floor spreading and the accompanying subsidence normally affecting volcanic atolls and seamounts.

Although preliminary, the paleontological data presented here provide a stimulus to explore further the paleogeographic issues. They necessitate rethinking on ideas about the inclusion of northeastern Oregon and adjacent Idaho in the Wrangellia terrane and even question the coherence of a single Wallowa terrane. Continued structural, petrographic, and stratigraphic studies should be made, in concert with detailed paleontological studies. Independent studies of the rich brachiopod, mollusc, echinoid, and crinoid faunas would allow cross-checks of paleogeographic conclusions. Some of the Late Triassic benthic faunas may have been craton-bound or at least postaccretional and thus would be indigenous to North America. Faunas of this type include those of the Sonomia (Speed, 1979) in Nevada, the Pardonet Formation of northeast British Columbia (Tozer, 1967), and possibly the Alexander terrane (Hillhouse and Grommé, 1980). Future studies must ultimately rely on these autochthonous, craton-bound fossils for the necessary paleobiogeographic controls. Careful and detailed study of such endemic benthic fossils of North and South America and comparisons with counterparts from various exotic terranes should eventually clarify details of the Triassic geography with a precision not currently available from the open-water and deeper water molluscan faunas.

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PLATE 3.1

[Contact photograph of the plate in this chapter is available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

PLATE 3.1

Late Triassic corals and spongiomorphs from western Idaho and northeastern Oregon

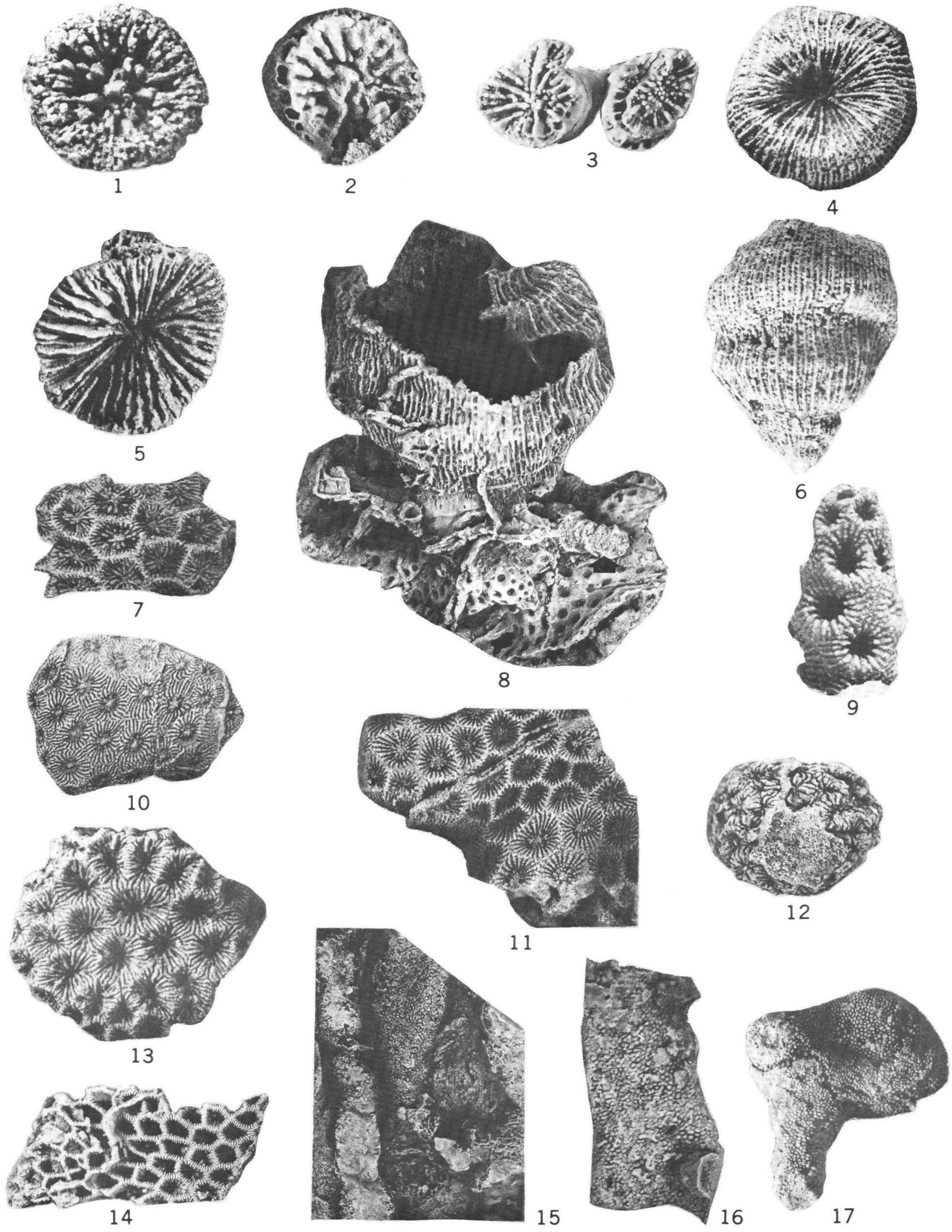
FIGURES 1–3. *Stylophyllum paradoxum.*

1. Calical view, UMP 7288, ×3, Lewiston.
2. Calical view of another specimen, UMP 7289, ×3, Lewiston.
3. Calical view of a budded individual, UMP 7290, ×1.5, Lewiston.

4-6. *Distichophyllia norica.*

4. Calical view of somewhat weathered specimen, UMP 7292, ×2.25, Lewiston.
5. Natural view of calyx showing pustulate surfaces of septa, UMP 7293, Lewiston.
6. Side view of specimen in figure 4. Thin epitheca is absent, UMP 7292, ×2.25, Lewiston.

7. *Cyathocoenia* cf. *C. juvavica,* UMP 7286, ×3.75, Eagle Creek, southern Wallowa Mountains.
8. *Coccophyllum acanthophorum,* showing sheetlike growth. Incrusted by large solitary *Distichophyllum norica* and a smaller thamnasteriid *Pamiroseris smithi* (arrow), USNM 252710, ×1.25, Lewiston.
9. *Coccophyllum acanthophorum,* small tip of a branching colony showing the deeply sunken corallites, UMP 7291, ×3.75, Lewiston.
10. *Cyathocoenia squiresi* n. sp., showing details of corallite surface, KUMIP 7287, X3.75, Lewiston.
11. *Cyathocoenia schafhaeutli,* surface of corallum, USNM 252707, ×3.75 Lewiston.
12. *Astraeomorpha crassisepta,* small nodular colony illustrating fungiform corallites, KUMIP 113705, ×2.25, Lewiston.
13. *Gablonzeria profunda,* natural surface view of the corallum, UMP 7294, ×3, Lewiston.
14. *G. profunda,* a deeply weathered specimen revealing deep open calices, UMP 7295, ×1.5, Lewiston.
15. *Spongiomorpha tenuis,* details of a small branching coenosteum, KUMIP 113662, ×1.5, Eagle Creek, southern Wallowa Mountains.
16. *Spongiomorpha ramosa,* part of a branching coenosteum showing the irregularities of the surface, UMP 7296, ×2.25, Lewiston.
17. *Stromatomorpha* sp., details of the surface of coenosteum, UMP 7297, ×1.5, Lewiston.



STYLOPHYLLUM, DISTICHOPHYLLIA, CYATHOCOENIA, COCCOPHYLLUM, ASTRAEOMORPHA, GABLONZERIA, SPONGIOMORPHA, STROMATOMORPHA

4. A NORIAN (LATE TRIASSIC) ICHTHYOSAUR FROM THE MARTIN BRIDGE LIMESTONE, WALLOWA MOUNTAINS, OREGON

By William N. Orr[1]

ABSTRACT

Ichthyosaur fossils of the genus *Shastasaurus* were recovered from the Martin Bridge Limestone (Norian Stage, Upper Triassic) of northeastern Oregon. Ichthyosaurs are known only from scattered localities worldwide in the interval from the Middle Triassic to the Late Cretaceous. The occurrence of this aquatic reptile in the Oregon Triassic is consistent with, but not conclusive evidence for, recent paleotectonic hypotheses suggesting that parts of western North America, including areas of eastern Oregon, are composed of exotic accreted terranes.

INTRODUCTION

One of the most striking marine reptiles of the Mesozoic Era was the streamlined fish-like ichthyosaur. Fragmentary skeletal remains of these reptiles have been described from scattered localities around the world in the time interval from the Middle Triassic to the latest Cretaceous. Ichthyosaur remains have been reported from every continent except Africa and Antarctica. Their distribution may reflect the effects of global tectonics in the interval prior to and during the break-up of Gondwanaland in the Mesozoic. Some of the most complete and best preserved ichthyosaur fossils known are from Jurassic localities in England and Germany, where well-preserved articulated specimens have been found in a variety of rocks including shale, mudstone, and limestone. Isolated ichthyosaur centra (vertebrae) have turned up in many marine Mesozoic sequences in America, but major North American areas for ichthyosaur remains are limited to Triassic rocks in the Shoshone Range of Nevada and in Shasta County of northern California, Jurassic rocks in Alberta, Canada, and Cretaceous rocks in Wyoming.

Much of the research carried out on ichthyosaurian paleontology in the United States was by John C. Merriam of the University of California near the turn of the century. Several new taxa were described by Merriam from localities in Nevada and the Pacific slope area of northern California (fig. 4.1). His work was summarized in a series of monographs that still stand as the prime American references to the group. One of the most spectacular ichthyosaur finds in North America was only recently described by Camp (1980). Triassic (Karnian) rocks of the Luning Formation exposed in the Shoshone Range, Nye County, Nevada, have yielded about 40 articulated ichthyosaur skeletons. Several of the skeletons are displayed in place in a series of quarries at the Ichthyosaur State Park, Nevada.

Although marine Mesozoic sedimentary rocks are exposed over wide areas of southwestern, central and northeastern Oregon, ichthyosaurs in that region are rare. Merriam and Gilmore (1928) described and figured two cervical vertebrae collected by Earl Packard from the Cretaceous Hudspeth Formation in Wheeler County, north-central Oregon. The bones were associated with Albian Stage molluscs. Because of the limited material, it was not possible to assign even a generic name to the find. Marsh (1895) briefly noted a single ichthyosaur vertebra found in the Blue Mountains but

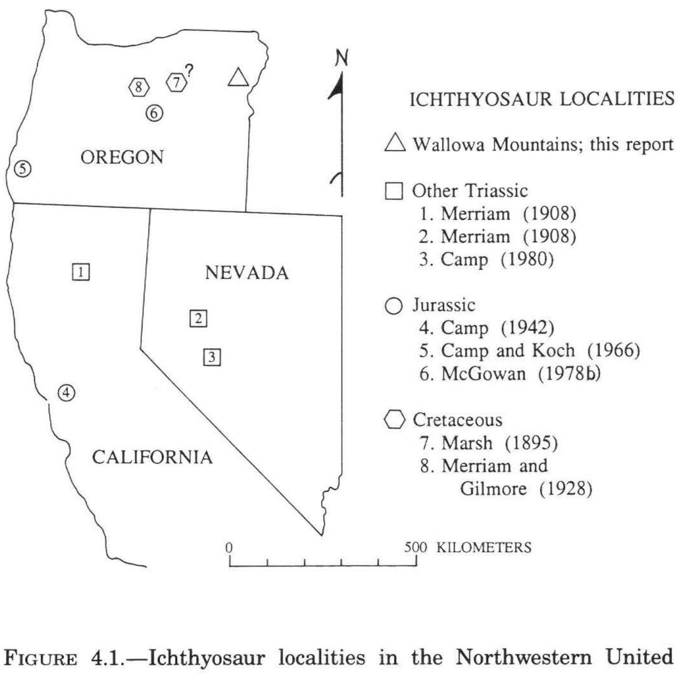


Figure 4.1.—Ichthyosaur localities in the Northwestern United States. The age of rocks at locality 7 is uncertain.

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did not illustrate or assign an age to this specimen. In 1961 Norman Peterson, working in southwest Oregon, collected an ichthyosaur rostrum and well-preserved teeth. This fine specimen from the Otter Point Formation in the Klamath Mountains province was later described by Camp and Koch (1964) and identified as the species *Ichthyosaurus californicus*. They assigned the material to the Late Jurassic (Tithonian) on the basis of molluscs in the same strata. The only other ichthyosaurian material reported from Oregon to date was noted by McGowan (1978b) who recognized vertebral centra from the Nicely Formation of Early Jurassic (Pliensbachian) age in east-central Oregon. As with the Cretaceous material described by Merriam and Gilmore (1928), McGowan (1978b) did not attempt to make a generic assignment but stated that the centra are consistent with *Ichthyosaurus*. This genus is also known from the Lower Jurassic of England and the Lower Jurassic Nordegg Formation of Alberta.

The specimens reported in this paper from Baker County, Oregon, are from Norian (Upper Triassic) rocks of the Martin Bridge Limestone. In comparison with the rest of the Mesozoic, there is a notably high diversity of ichthyosaurs in the Late Triassic (six known genera). In spite of this, previously described fossils of these reptiles in this time interval are known only from areas in Italy, Nevada, and California.

The fossils reported here represent the largest volume of ichthyosaur bone material recovered to date in Oregon. They comprise 23 articulated vertebrae, neural arches and ribs. These elements are assignable to the genus *Shastasaurus*, known until now only from Upper Triassic rocks in northern California.

ACKNOWLEDGMENTS

Kurt Katsura and the 1981 University of Oregon summer field party are thanked for collecting the specimens used in this study. William Kelley of the University of Oregon Museum of Natural History performed much of the preparation of the bone material. Howard Brooks, Tracy Vallier, Cathryn Newton and Norm Silberling kindly reviewed the manuscript.

GEOLOGY AND STRATIGRAPHY

Fossil bone specimens described here are all from the Martin Bridge Limestone (Vallier, 1977) at its type section in the southern Wallowa Mountains of northeastern Oregon (fig. 4.2). The Martin Bridge is up to 600 meters thick and consists of well-indurated fossiliferous massive to thin-bedded limestones with lesser amounts of shale. The Martin Bridge Limestone unit is overlain by the Upper Triassic and Lower Jurassic Hurwal Formation and underlain by the Permian and Upper Triassic Clover Creek Greenstone (fig. 4.3; Ross, 1938; Prostka, 1962)

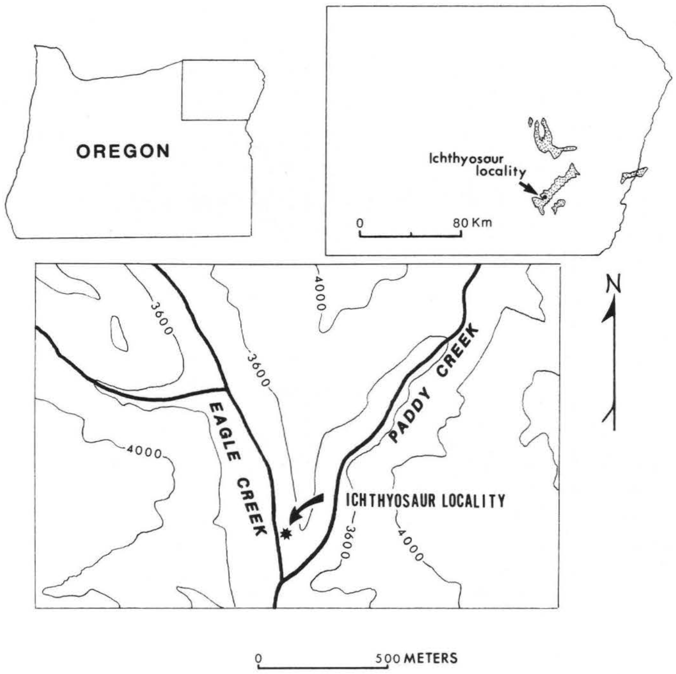

FIGURE 4.2.—Location of ichthyosaur locality in Wallowa Mountains, Oregon. Distribution of Martin Bridge Limestone (stippled) after Vallier (1967). Contours in feet.

The pre-Cretaceous rocks of northeast Oregon have been divided into four terranes believed to represent allochthonous oceanic and island arc material that was accreted to the North American plate during the Mesozoic (Vallier, 1977; Brooks and Vallier, 1978; Brooks, 1979; Dickinson, 1979). Eastern Oregon at that time may have resembled a convergent plate boundary region

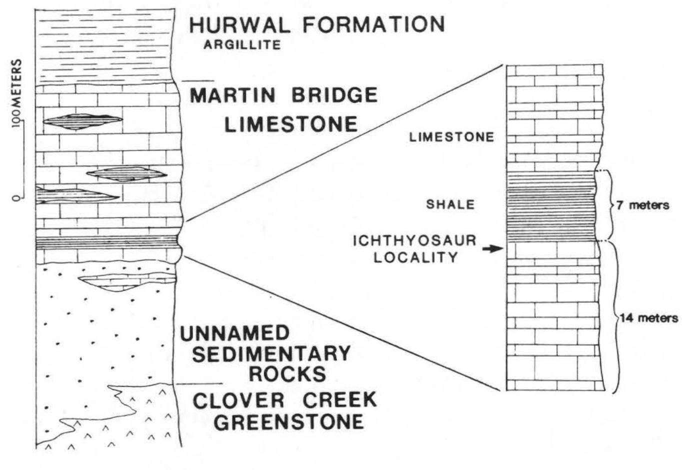

FIGURE 4.3.—Partial stratigraphic column for southern Wallowa Mountains, Oregon, showing position of the ichthyosaur locality.

similar to present-day complex volcanic island arcs like the Marianas of the western Pacific. The Martin Bridge Limestone is part of the Wallowa-Seven Devils arc terrane of Mullen and Sarewitz (1983). This terrane may have been accreted to the continent sometime during the Late Triassic to Middle Cretaceous. Within the Wallowa-Seven Devils arc terrane Permian and Triassic volcanic rocks and sediments 6,000 meters thick represent typical volcanic island-arc constituents. The Martin Bridge Limestone, consisting of platform carbonate rocks and shales, has yielded conodonts of Norian age (Sarewitz, 1982) and cephalopods of early and middle Norian age (Silberling and Tozer, 1968). Newton (1982 and this volume) described Norian benthic invertebrate faunas from the Martin Bridge in Hells Canyon. Her reconstruction of the Martin Bridge paleoenvironment suggests a current-swept shallow marine shelf edge.

LOCALITY

Fossil ichthyosaurian bones were collected by the University of Oregon 1981 summer camp field party from roadcut exposures in the Wallowa-Whitman National Forest along Eagle Creek at the intersection with Paddy Creek in the NW¼ sec. 21, T. 7 S., R. 44 E. Seven meters of massive limestone interbedded with black calcareous shales are exposed here along the road. Smith (1912) measured a 200-meter section of the Martin Bridge in this immediate vicinity. Vertebrate fossil material at the locality is readily visible owing to the dark color of the bone against the matrix of gray limestone. The resistant bone material also stands out in relief above the more easily eroded limestone. Fossils described here were all collected from immediately below a prominent shale layer very near the base of the Martin Bridge Limestone. Associated with the ichthyosaur bones is a diverse assemblage of marine invertebrates dominated by cephalopods and pelecypods.

PALEONTOLOGY

Twenty-three intact vertebrae with attached neural arches and associated ribs were collected from two sites at nearly the same stratigraphic level. The material consists of cervical and anterior dorsal centra and is all assignable to the genus *Shastasaurus* Merriam. The vertebrae, particularly in the dorsal series, are comparatively large for a Triassic form and indicate an individual on the order of 2 meters long. Centra were found arranged in echelon in opposite directions from a break in the vertebral column. A similar imbricate orientation of centra has been reported by Kauffman (1981) in Jurassic ichthyosaurs preserved in the Posidonienschiefer sequence of Germany. He interpreted the echelon orientation of the centra as a taphonomic artifact of carcass decay penecontemporaneous with burial.

Shastasaurus Merriam

Plate 4.1, figures 1–8

Shastasaurus Merriam, 1895, Amer. Jour. Sci., v. 5, p.56.
Shastasaurus osmonti Merriam, 1902, Univ. Calif., Publ. Geol. Sci., v. 3, p. 93, pls. 3, 9, 10, 11.
Shastasaurus cf. *S. osmonti* Merriam

Description.—Vertebrae centra circular, greatest diameter of centrum faces average 40 mm on the cervicals and 64 mm on the dorsals. Greatest thickness through the vertebra averages 22 mm on cervicals and 32 mm on the dorsals. Vertebrae bi-concave with a distinctive hour-glass cross section flared all the way from the periphery of the centrum face (fig. 4.4). Parapophyses well developed in the anterior (cervical) series but disappearing gradually in the posterior dorsal series.

Diapophyses abbreviated at anterior end of vertebral column. Toward posterior of series, diapophyses elongate to accommodate the missing parapophyses. The excavation on the centra below the neural arch is a broad shallow groove split by a low median ridge. Neural arches elongate, well-developed and round in cross section, displaying slight lateral compression. Neural arches are all free and the arch pedicels extend laterally. Ribs doubleheaded only in the anterior part of the vertebral column. Anterior double-headed ribs are flattened with a shallow longitudinal groove. Rib cross section in double-headed series markedly dumbbell shaped at the proximal end to circular or slightly ovoid at the distal end.

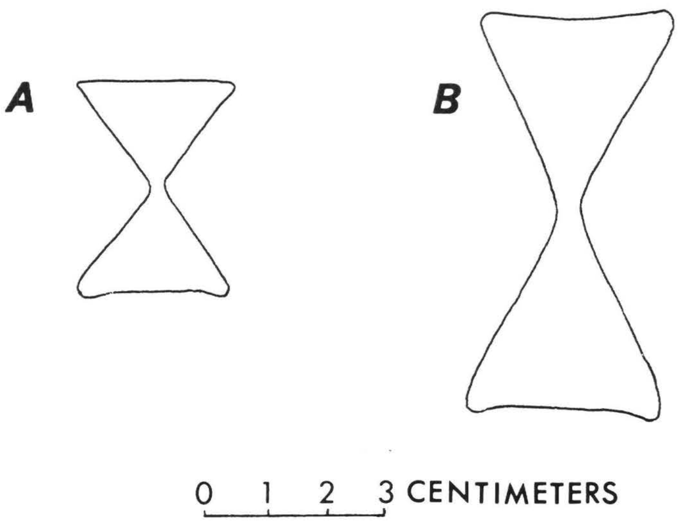

FIGURE 4.4—Cross sections of centra of *Shastasaurus* from Wallowa Mountains, Oregon. *A*, Centrum from cervical region. *B*, Centrum from anterior dorsal region.

Discussion.—The genus *Shastasaurus* is characterized by Merriam (1902) as having biconcave centra with concave even surfaces beginning close to the centrum's periphery. Longitudinal diameter of the centra is much shorter than the vertical or transverse except in the caudals. Wallowa material includes only cervical and dorsal elements. Cervical vertebrae, according to Merriam, are somewhat broader than high and this is shown by the Wallowa material. Rib morphology in the anterior vertebrae is one of the most distinctive features of the genus. Two sets of articular surfaces, the diapophyses and parapophyses, are apparent on the cervical series, but the latter gradually decrease in size posteriorly and disappear at about the fifteenth vertebra. Cervical ribs fit the vertebrae articulation, displaying a well-developed tubercule and diminished capitulum. As the parapophysis disappears at about one-fourth of the length of the vertebral column, the rib capitulum is also lost. Merriam suggest that *S. osmonti* had about 50 vertebrae. Wallowa specimens compare very well with Merriam's type specimen of *S. osmonti,* particularly in the critical details of rib articulation and corresponding morphology of cervical and dorsal centra. One significant departure is in height of the neural arches. Wallowa specimens compare well in this measurement in the cervicals, but in the dorsals they are 15 to 20 mm taller than the type specimen of *S. osmonti* or any other shastasaurid (table 4.1).

TABLE 4.1.—*Dimensions of centra of* Shastasaurus *cf.* S. osmonti *Merriam from the Martin Bridge Limestone, Wallowa Mountains, Oregon*

[All figures in millimeters. Figures in parentheses are estimates or projections made because bone is fractured or distorted. Blank spaces indicate structure not present or preserved]

		Dimensions of centrum			Heights of individual features		
	Vertebra	Height	Width	Length	Diapophysis	Parapophysis	Neural arch
	Series 1						
Cervicals	1st	39	41	22	19	(8)	54
Cervicals	2nd	38	40	21	20	9	(52)
Cervicals	3rd	(40)	(45)	(23)	(20)	(11)	(51)
Cervicals	4th	40	46	20	20	10	52
Cervicals	5th	41	48	21	(19)	(9)	(52)
Cervicals	6th	43	48	23	20	11	(51)
Cervicals	7th	44	50	(22)	(21)	8	(50)
Cervicals	8th	45	50	24	23	7	(52)
Cervicals	9th	(47)	(52)	(26)	(27)	(5)	54
Dorsals	10th	48	51	27	26	2	54
Dorsals	11th	50	51	29	29	(2)	(67)
Dorsals	12th	54	53	29	(33)		
Dorsals	13th	55	52	28	32		
	Series 2						
Dorsals	1st	75	72	33	47		83
Dorsals	2nd	77	75	32	47		84
Dorsals	3rd	(75)	(71)	(30)	(48)		(90)
Dorsals	4th	(74)	73	31	(47)		(87)
Dorsals	5th	(76)	75	35	50		(85)
Dorsals	6th	75	73	34	(51)		86
Dorsals	7th	76	77	33	55		(83)

ICHTHYOSAUR DISTRIBUTION

Ichthyosaur remains are known worldwide in the interval from the Middle Triassic to the latest Cretaceous (fig. 4.5). In the Middle Triassic only four genera are known: *Pessosaurus, Possopteryx, Cymbospondylus,* and *Mixosaurus*. The first three genera are known only from single localities in Spitzbergen and Nevada, but species of *Mixosaurus* have been reported from a striking range of environments and areas including Timor, China, Switzerland, Spitzbergen, the Canadian Arctic, Alaska and Nevada. Because of the difficulties of making species assignments to many ichthyosaurian remains, discussions here are confined to the generic level.

In the Late Triassic, the Ichthyosauria appear to be more provincial than in the Middle Triassic, but this may be only a reflection of the meager fossil record. All six genera reported from the Upper Triassic are known only from single localities. Although it is cosmopolitan in the Middle Triassic, *Mixosaurus* is reported from a single Upper Triassic locality in Italy. The five other Late Triassic genera, *Merriamia, Delphinosaurus, Toretoenemus, Shastasaurus* and *Shonisaurus* are known from single localities in California and Nevada.

Triassic ichthyosaurs are readily distinguished morphologically from Jurassic and Cretaceous forms. Halstead (1968, p. 136-138) has suggested that Triassic forms were fish predators, whereas Jurassic ichthyosaurs fed predominantly on cephalopod molluscs. In this regard, Pollard (1968) has published a fascinating detailed study of the stomach contents of an Early Jurassic ichthyosaur from England wherein he records an abundance of preserved cephalopod remains.

Despite their reported rapid evolution (McGowan, 1972a) and the local abundance of material, early Lias (Jurassic) ichthyosaurs are known from three general geographic areas in Canada, Germany, and England, The genus *Stenopterygius* is reported from the latter two areas, but the genera *Leptopterygius* and *Temnodontosaurus* are known only from England. In the early Lias interval, Icthyosaurus is known from England and Alberta, Canada. Material from the Jurassic Nicely Formation in Oregon may be of this genus. Early Lias forms include only two genera, and they are confined to England and Germany. *Stenopterygius* occurs in both areas, whereas *Eurhinosaurus* is known only from Germany. The Late Jurassic form *Ophthalomosaurus* is cosmopolitan and has been reported from England, the

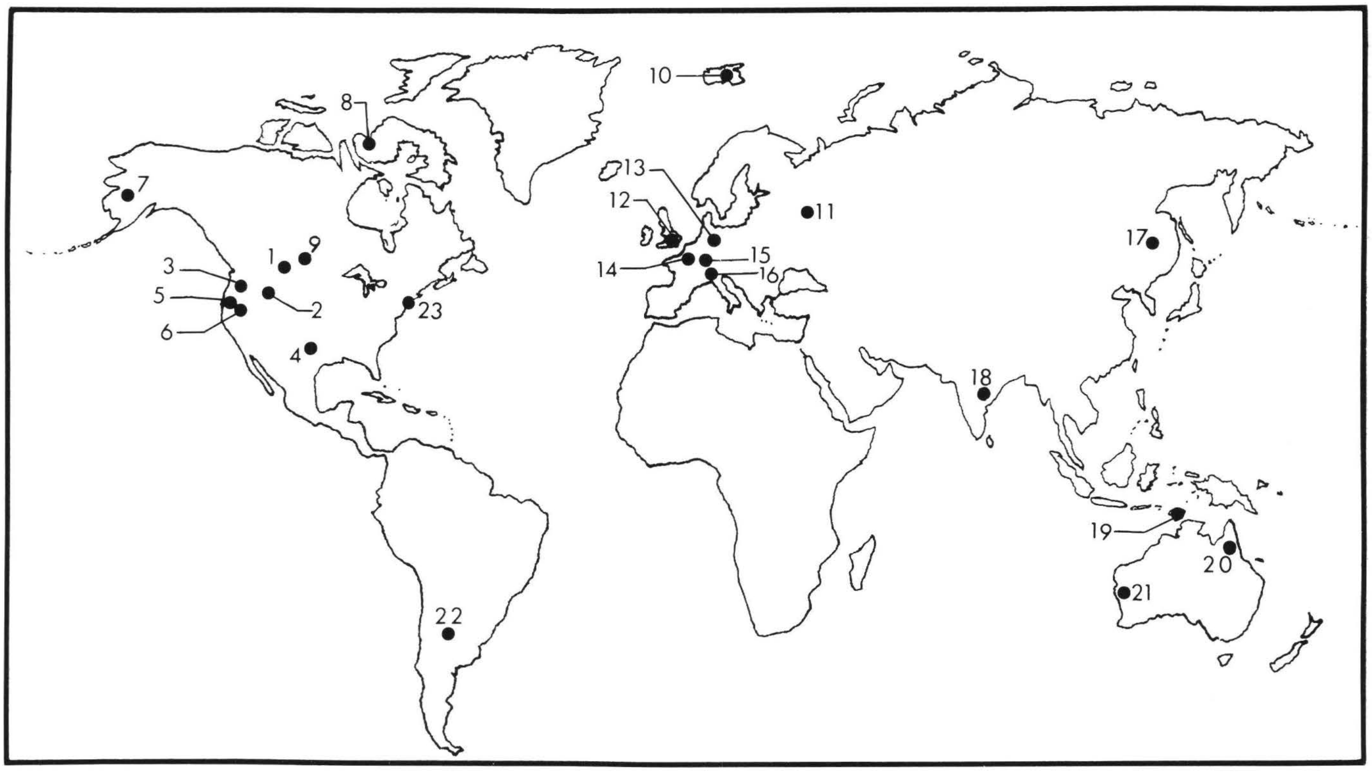

FIGURE 4.5.—Global distribution of major ichthyosaur localities. 1. Alberta, Canada (McGowan, 1978b) (Jurassic); 2. Wyoming (Nace, 1939, 1941; Romer, 1968b) (Cretaceous); 3. Oregon (Merriam and Gilmore, 1928; McGowan, 1978b; this paper) (Triassic, Jurassic, Cretaceous). 4. Texas (Slaughter and Hoover, 1963, McNulty and Slaughter, 1962) (Cretaceous). 5. California (Camp, 1942; 1980; Merriam, 1908) (Triassic, Jurassic). 6. Nevada (Camp, 1980; Merriam, 1908) (Triassic). 7. Alaska (McGowan, 1978b) (Triassic). 8. Canadian Arctic (McGowan, 1978b) (Triassic, Jurassic). 9. Saskatchewan (McGowan, 1978b) (Cretaceous). 10. Spitzbergen (Hulke, 1872; Wiman, 1910, 1916, 1929) (Triassic). 11. Russia (McGowan, 1972b) (Cretaceous). 12. Britain (McGowan, 1974a, 1976) (Jurassic). 13. Germany (McGowan, 1974a, 1979) (Jurassic). 14. France (Lennier, 1870) (Cretaceous). 15. Switzerland (Kuhn-Schnyder, 1964) (Triassic). 16. Italy (Kuhn-Schnyder, 1964) (Triassic) 17. China (Young, 1965) (Triassic). 18. India (McGowan, 1972b) (Cretaceous) 19. Timor (Von Huene, 1936) (Triassic). 20. Australia (Teichert and Matheson, 1944) (Cretaceous). 21. Australia (W.) (Teichert and Matheson, 1944) (Cretaceous). 22. Argentina (Rusconi, 1948) (Jurassic). 23. New Jersey (McGowan, 1978a) (Cretaceous).

Canadian Arctic, western North America and Argentina. Early Cretaceous forms are comparable to those from the Middle Triassic in their worldwide distribution. A single genus, *Platypterygius* is known from Australia, India, Russia, England, Germany and North and South America. *Ophthalomosaurus* has been reported from Lower Cretaceous rocks at a single locality in Britain. Late Cretaceous occurrences are rare, but the fossil record has been expanding rapidly in the past decade as new forms are unearthed. The genus *Platypterygius* has been reported from the Upper Cretaceous of Australia, England, and Saskatchewan, Canada. The youngest ichthyosaur remains known to date are an unassigned taxon from the Maastrichtian Stage in New Jersey.

The present state of the ichthyosaur fossil record may be summarized into three segments by time periods. The Triassic interval shows comparatively high diversity, but most of the taxa are provincial and known from single localities. Only the genus *Mixosaurus* is cosmopolitan in the Triassic. Jurassic rocks have yielded some of the best preserved and studied ichthyosaur fossils, but most of the forms are provincial except for Late Jurassic ones. Cretaceous ichthyosaurs fall into only two genera, yet one of these, *Platypterygius,* is the most cosmopolitan taxon known. In a very general way, therefore, ichthyosaur diversity and geographic distribution appear to be inversely related.

The widespread distribution of the Triassic genus *Mixosaurus* suggests that even early Mesozoic ichthyosaurs may be too cosmopolitan to group taxa into geographic areas. A major anomaly in this regard is the absence of *Mixosaurus* in Camp's (1980) highly fossiliferous Triassic locality in Nye County, Nevada. One explanation for this might be paleoenvironmental. Camp (1980) reported that the Nevada ichthyosaurs are preserved in shaley limestone and mudstone. Localities of Triassic forms elsewhere in western North America described by Merriam (1908) are almost exclusively from carbonate rocks.

In a report of the first record of the genus *Stenopterygius* from the early Lias of England, McGowan (1978b) discussed the global distribution of ichthyosaurs. The rapidly growing number of finds prompted his conclusion that these reptiles will eventually be shown to be both spatially and temporally widespread. As evidence he cites the cosmopolitan genera *Mixosaurus, Ophthalmosaurus, Ichthyosaurus,* and *Platypterygius* and attributes the limited known distribution of ichthyosaurs to the paucity of good fossil-bearing exposures. On the other hand, the easy recognition of exotic forms as summarized in this paper suggests that ichthyosaurs might have been as provincial as they appear.

Ichthyosaur morphology resembles that of modern open-ocean nektonic forms. Colbert (1980, p. 166–169) compares the hydrodynamics of ichthyosaurs to that of the speediest of modern fish such as mackerel and tuna. His view of the ichthyosaur is of a powerful fast swimmer, quite at home in the wide expanses of the Mesozoic seas. Romer (1968a) suggests the ichthyosaurs were as highly adapted to marine life as modern porpoises or dolphins.

The diversity of entombing matrices from which ichthyosaurs have been recovered also implies that they ranged over broad areas including the open seas at considerable distances from land. In this regard, a quote from Camp (1980) is interesting. In discussing the distribution of genera found in Nye County, Nevada, Camp notes that only a short distance away in northern California and at nearly the same stratigraphic interval Meriam (1908) reported a markedly different suite of ichthyosaurs. Camp (1980, p. 141) wrote:

> Strangely enough, the California ichthyosaurs included in four genera described by John C. Merriam (1908) lived at nearly the same time and in the same large embayment of the Pacific as the three species here re-covered from a sequence of some 160 meters of strata in Nevada. One of the youngest and latest of the species from the Upper Triassic of northern California, namely the lesser-known *"Shastasaurus" careyi,* is the largest species assigned to that genus and is possibly related to our Nevada forms. Yet the differences between the genera from the two regions are noteworthy and seem to indicate a rapid change in the ichthyosaur populations of the Nevada-California seaways.

Merriam (1902, p. 87) also had noticed the provincial characteristics of the northern California taxa and wrote in this regard:

> That a group of marine reptiles with the characters of *Shastasaurus* would be confined within very narrow geographic limits is improbable, particularly as the occurrence of its remains points toward a fairly deep and open sea as its habitat.

The anomalous occurrences and distributions noticed by both of the above authors may well be eventually explained by long-distance transport of accreted terranes.

CONCLUSIONS

The Oregon occurrence of the Triassic ichthyosaur *Shastasaurus* may have some significance for the tectonic history of western North America. The locality in the Wallowa Mountains is a few hundred kilometers north of the Nevada and California Triassic localities, but the fossil material is evidently closely affiliated only with the northern California ichthyosaur fauna. Known diversities and biogeographic distributions do not yet permit use of ichthyosaurs as markers for allochthonous terranes. On the other hand, the occurrence of *Shastaurus* in the Martin Bridge Limestone is consistent with other evidence of an allochthonous origin for the Wallowa-Seven Devils arc terrane. Because the genus *Shastasaurus* is known elsewhere only from northern California, the paleolatitude range for the form cannot be determined at present.

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PLATE 4.1

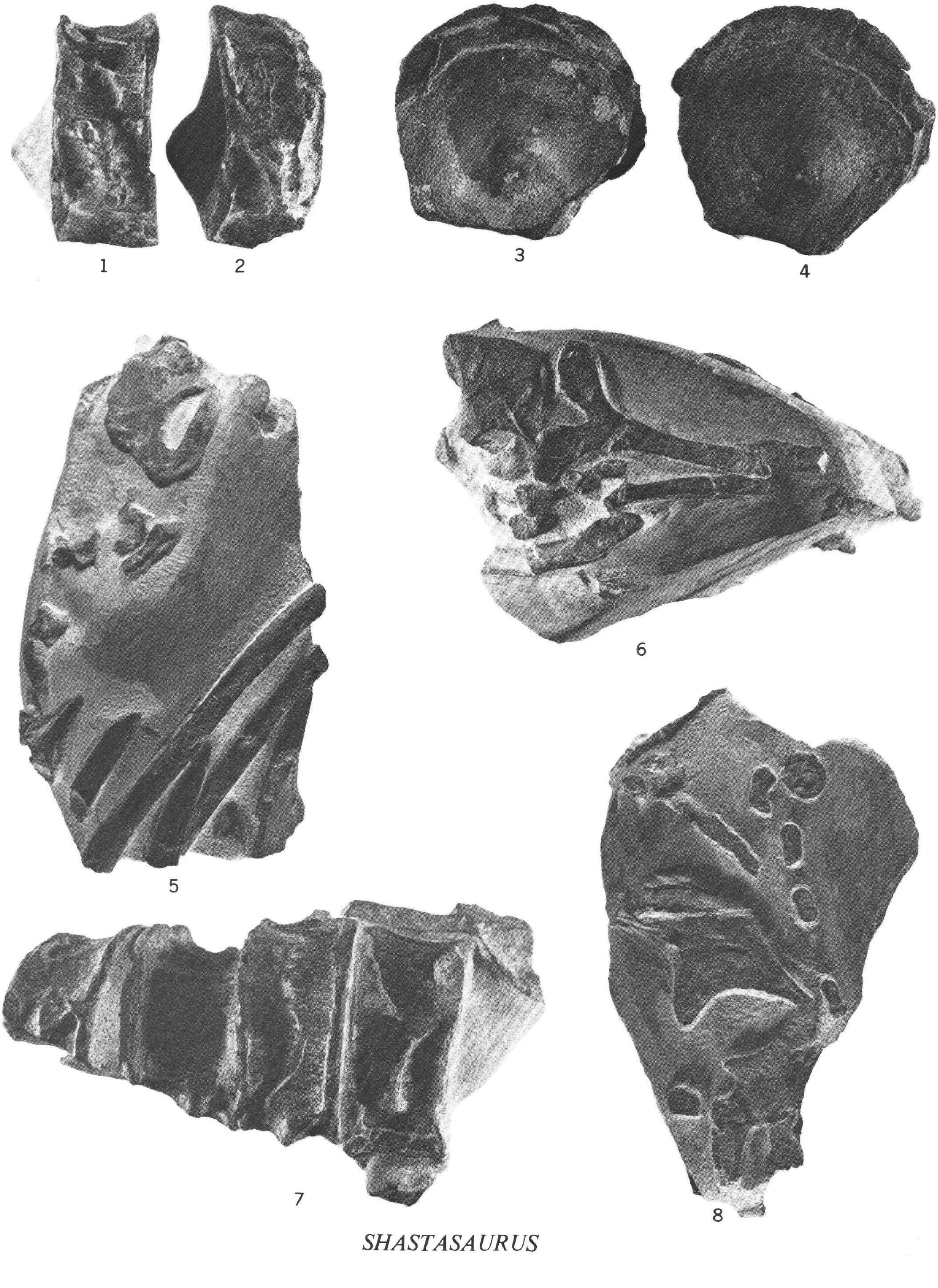
[Contact photograph of the plate in this chapter is available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

PLATE 4.1

[All figures × 0.65]

FIGURES 1–8. *Shastasaurus* cf. *S. osmonti* Merriam from the Martin Bridge Limestone, Wallowa Mountains, Oregon.

1–2. Anterior dorsal centra in lateral view.
3–4. Anterior dorsal centra in face view.
5. Cervical vertebra and rib fragments, showing grooved rib structure.
6. Neural arch in cross section.
7. Anterior dorsal centra in lateral view, showing echelon arrangement.
8. Cervical vertebra in cross section and rib cross sections in a proximal area, showing rib grooves.



SHASTASAURUS

5. JURASSIC AMMONITES AND BIOSTRATIGRAPHY OF EASTERN OREGON AND WESTERN IDAHO

By Ralph W. Imlay

ABSTRACT

Jurassic clastic sedimentary rocks in the Blue Mountains region of eastern Oregon and western Idaho have furnished ammonites ranging from Hettangian to Oxfordian age. Jurassic beds are included in the Izee, Olds Ferry, and Wallowa terranes of Silberling and others (1984).

The thickest, most complete, and best preserved Jurassic sequence is in the Izee terrane, where ammonite genera of Hettangian age are well represented. The Sinemurian and Pliensbachian stages are represented in the Izee, Olds Ferry, and Wallowa terranes. Toarcian and Bethonian ammonites have been found only in the Izee-Seneca area, whereas fauna of the intervening Bajocian are widespread in both the Izee and Olds Ferry terrances. The Bajocian genera include forms that are characteristic of the East Pacific realm. The Callovian is well represented in the Izee terrane and to a very limited extent in the Olds Ferry and Wallowa terranes. Some of the Callovian genera represent the Boreal Realm.

The only known occurrence of the early Oxfordian ammonite *Cardioceras (Scarburgiceras)* found in the Western United States is on the Idaho side of Snake River near the southeast corner of Washington.

INTRODUCTION

The Jurassic sedimentary rocks in the Blue Mountains region of eastern Oregon and western Idaho have furnished ammonites ranging from Hettangian to early Oxfordian age. Jurassic beds are included in the Izee, Olds Ferry, and Wallowa terrances of Silberling and others (1984). The Jurassic sequences consist mostly of graywacke, shale, and siltstone but locally include considerable volcanic material and minor amounts of limestone and conglomerate.

The thickest and most complete Jurassic stratigraphic sequence is in the Izee terrane. The rocks there are only weakly metamorphosed and deformed, and fossils are abundant. The section has been divided into more than 10 formations. The sequence has a total thickness of 7,700 meters in the area between Izee and Seneca but thins westward to about 2,090 meters near Suplee. In the Suplee-Izee area, the Jurassic sequence is marked by unconformities (1) between the Upper Triassic and Sinemurian beds (except in the Izee area), (2) at the base of the lower Pliensbachian beds, (3) at the base of the Callovian beds, and (4) at the top of the uppermost Callovian beds. Except for the area between Suplee and Izee the Jurassic beds change considerably laterally, and dating and correlation are based mostly on the ammonites present.

Jurassic beds in the Olds Ferry terrane comprise the Weatherby Formation (Brooks, 1979) in the eastern part of the terrane and unnamed beds of equivalent lithology and age in the western part. The sequence may be as much as 7,000 meters thick near the Snake River. Little variation in lithology is recognized throughout the exposure belt. The rocks are folded and cut by pervasive axial plane cleavage and are weakly metamorphosed. Ammonite fossils from those rocks have been collected from about 25 widely separated localities.

In the Wallowa terrane, Lower Jurassic beds are represented in the upper 600 meters of the Hurwal Formation in the Wallowa Mountains south of Enterprise, Oregon. Early Oxfordian beds occur in the Coon Hollow Formation in Snake River Canyon near the Washington border.

In previous papers (Imlay, 1964, 1968, 1973, 1981) I have described ammonites from eastern Oregon and western Idaho ranging in age from Pliensbachian to Oxfordian. The Hettangian and Sinemurian ammonites from that area have not yet been described. The ammonites studied were collected by many geologists, listed and acknowledged in the papers cited above. Their collections show that well-preserved ammonites occur in concretions obtained from shales, and that crushed or fragmentary ammonites mostly occur on bedding planes in soft shales. Some shales in which no megafossils can be seen on weathered surfaces actually contain identifiable fossil mollusks in the fresh rock.

BIOSTRATIGRAPHIC SUMMARY

The basal part of the Jurassic sequence in the Izee terrane (fig. 5.1) is present in the Izee-Seneca area and represented by the Graylock Formation and the Murderers Creek Graywacke (fig. 5.2), which are in different structural blocks. They are, respectively, 120 m and 915 m thick and contain ammonite genera of Hettangian age (Muller and Ferguson, 1939, p. 1612-1613; Hallam, 1965, p. 1490-1491). Those ammonites include

Waehneroceras and *Psiloceras* in the lower parts of the formations and *Schlotheimia, Caloceras* and *Alsatites* in the upper parts (Imlay, 1971, p. 713; 1980, p. 19-20).

The conformably overlying Keller Creek Shale in the Izee-Seneca area is about 1,525 m thick. Ammonites from this unit include *Arnioceras* of early Sinemurian age and *Eoderoceras* and *Crucilobiceras* of latest Sinemurian age (Imlay, 1971, p. 713). The Keller Creek is overlain unconformably by the Robertson Formation of late early Pliensbachian age (Lupher, 1941, p. 235, 245–247; Imlay, 1980, p. 20, 55). In the Huntington area farther east an unfossiliferous conglomerate 9–244 m thick is overlain by beds that contain the ammonites *Arnioceras* and *Crucilobiceras,* respectively of middle and late Sinemurian ages (Imlay, 1980, p. 56, 64). In the Wallowa Mountains near Enterprise, Oregon, the lower 90 m of the Lower Jurassic part of the Hurwal Formation contain ammonites of latest Sinemurian age (Smith and Allen, 1941, p. 6, 13, 14; Imlay, 1968, p. C7; Imlay, 1980, p.65) and some ammonites that are probably of early Sinemurian age.

The Pliensbachian is represented in the Suplee-Izee area of the Izee terrane by, from bottom to top, the Robertson, the Suplee, and the Nicely Formations. The Robertson Formation consists mostly of volcanic sandstone but includes some limestone units 2–12 m thick and a basal conglomerate 10–25 m thick. It attains a maximum thickness of about 100 m, pinches out eastward, and grades laterally in other directions into the overlying Suplee Formation. It rests unconformably on the Graylock Formation (Hallam, 1965, p. 1489; Dickinson and Thayer, 1978, p. 157) of Hettangian age in the Suplee area and on the Keller Creek Shale of Sinemurian age in the Izee area. The Suplee Formation consists of gray limestone and limy sandstone, ranges in thickness from 9 to 45 m, and grades upward into the Nicely Formation. In its upper third the Suplee is characterized by the late Pliensbachian ammonites *Arieticeras, Prodactylioceras, Leptaleoceras and Paltarpites* (Imlay, 1968, p. C8, Fig. 5 on p. 16; 1980, p.55). The overlying Nicely Formation ranges in thickness from 25 to 90 m and consists of dark gray to black limy siltstone

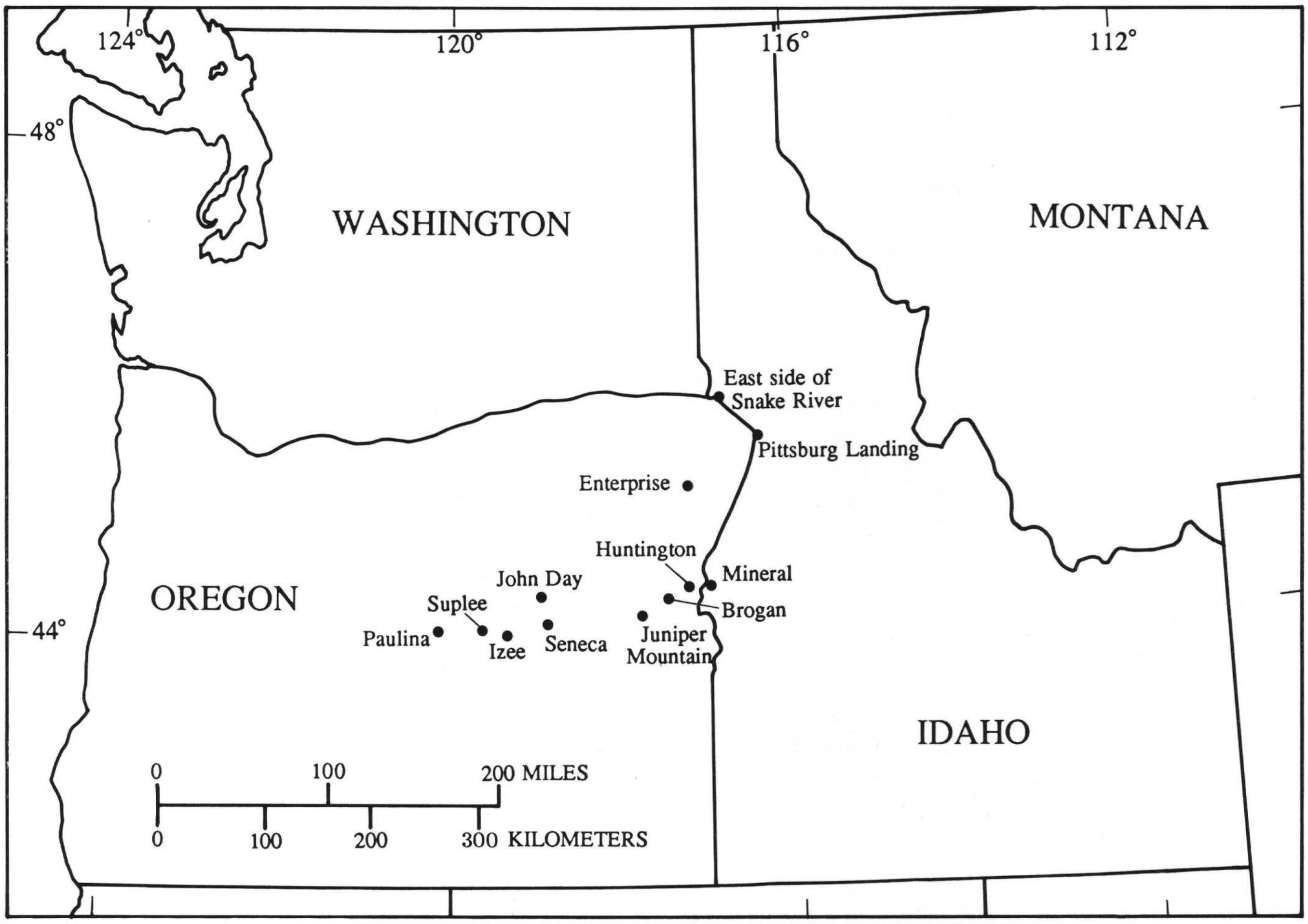
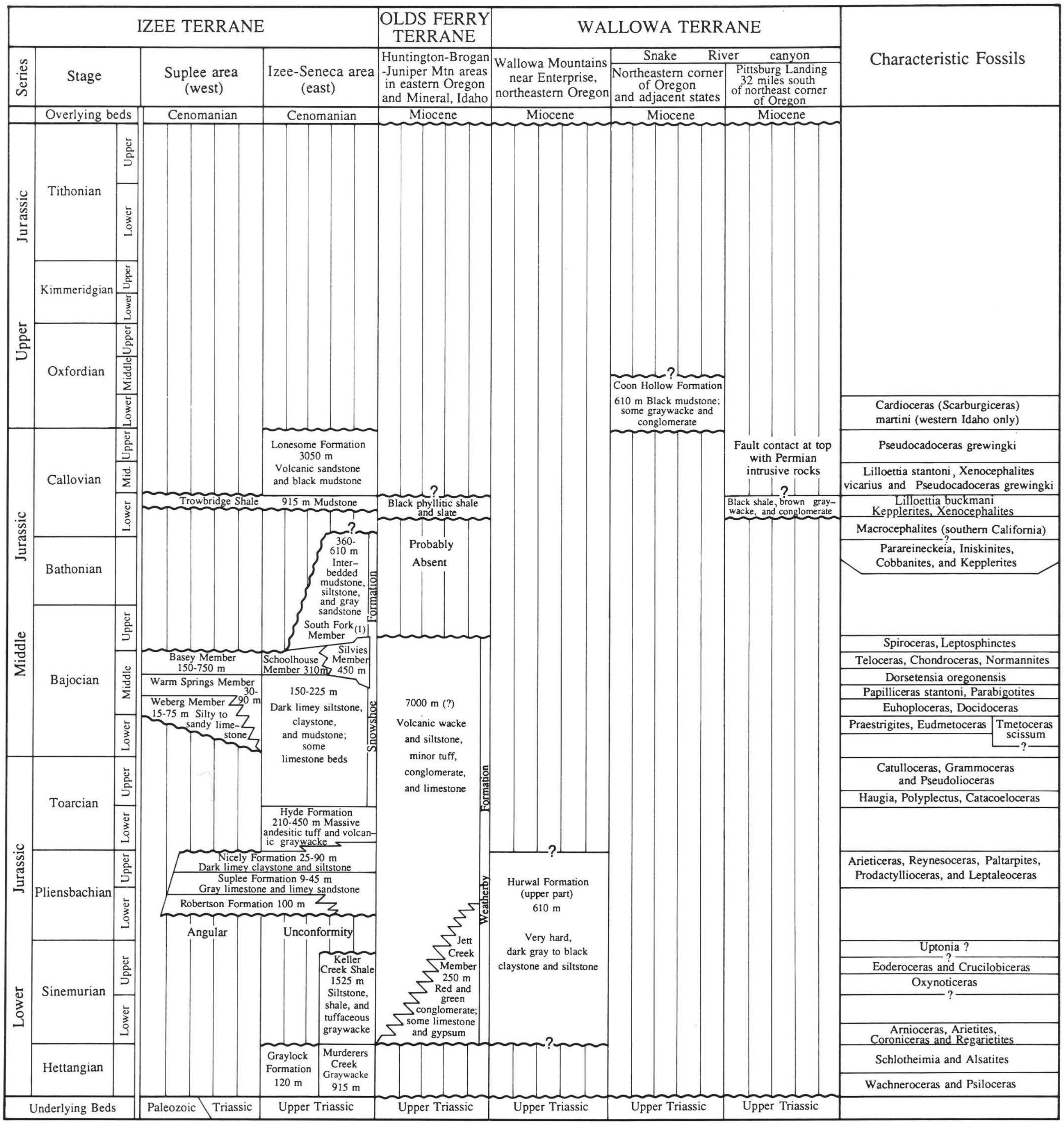


FIGURE 5.1.—Index map showing localities mentioned in text for the general areas in which Jurassic ammonites occur in eastern Oregon and westernmost Idaho.

and claystone. It contains most of the same ammonite genera as the Suplee Formation and is therefore also of late Pliensbachian age.

Late Pliensbachian ammonites have been found also in the upper 189 m of the Hurwal Formation exposed near Enterprise in the Wallowa Mountains (Imlay, 1968, p. C14-C15; 1980, p. 56, 65) of the Wallowa terrane. These ammonites include *Canavaria, Har-*



1) Unit named by Smith (1980).

FIGURE 5.2.—Correlations and comparisons of Jurassic rocks in eastern Oregon and western Idaho. Parallel vertical lines indicate that strata of that age are not present. Wavy lines indicate presence of unconformities or disconformities; jagged lines indicate gradational or indefinite contacts.

poceras, Arieticeras, Prodactylioceras, Protogrammoceras and *Fuciniceras*. Early Pliensbachian ammonites have not yet been found in Oregon or in California.

The Toarcian in the Blue Mountains has been identified faunally only in the Izee-Seneca area where it is represented by the basal 38 m of the Snowshoe Formation. The fauna consists of *Haugia, Polyplectus, Catacoeloceras* and, at a higher level, *Catulloceras, Grammoceras* and *Pseudolioceras*. All of these forms are of late Toarcian age (Imlay, 1968, p. C14, C15, C18; 1980, p. 20). The black shale of the Snowshoe Formation from which these ammonites were obtained contains black limestone concretions and resembles the black shale in the Nicely Formation.

Underlying the Snowshoe Formation is the Hyde Formation, which is about 310 to 450 m thick and consists mostly of thick-bedded to massive sandstone. It grades rather abruptly upward into the Snowshoe Formation and more gradually downward into the Nicely Formation. The Hyde Formation is dated as early Toarcian mainly on the basis of its stratigraphic position, although some shell fragments of ammonites resembling taxa in the Snowshoe Formation have been noted by Lupher (1941, p. 259, 262).

The Bajocian succession in the Suplee area consists of, from bottom to top, the Weberg, Warm Springs and Basey Members of the Snowshoe Formation. These are bounded at top and bottom by pronounced unconformities (Fig. 5.2) and attain a thickness of about 335 m. In the Izee area to the east the Weberg Member changes from a silty or sandy limestone or limy sandstone to soft dark-gray siltstone and claystone that are essentially identical with beds in the Warm Springs Member. The Warm Springs Member thickens eastward into the Izee area and its base becomes older. The Basey Member consists of volcaniclastic sedimentary rocks and some lava in the Suplee area. Correlative beds in the Izee area farther east consist of siltstone, sandstone, and some claystone that have generally been assigned to the middle member of the Snowshoe Formation, but have recently been named the Schoolhouse Member by Smith (1980, p. 1605). Nearly correlative beds cropping out northeast of Izee near the Silvies River are named the Silvies Member and consist of siltstone, coarse-grained sandstone and conglomerates. Both the Schoolhouse Member and the Silvies Member are overlain by Smith's (1980) South Fork Member, which differs from them by containing some thick beds of sandstone. These sequences attain a thickness of at least 800 m in the Izee area and are probably thicker in the Seneca area.

Bajocian ammonites in eastern Oregon occur in five inliers spaced over a distance of 192 km from Paulina on the west to the Snake River on the east (Wagner and others, 1963, p. 687–691, figs. 1, 2; Imlay, 1973, pl. 48). The ammonite succession is essentially the same as the Bajocian succession in southern Alaska (Imlay, 1973, p. 21, 31–33), except that it lacks the genera *Liroxyites, Bradfordia* and *Pseudolioceras*. The succession is also similar to that in Europe (Imlay, 1973, p. 35, 36), but differs from the Bajocian succession in central and southern France by the presence of such forms as *Pseudotoites, Parabigotites, Zemistephanus, Megasphaeroceras* and *Lupherites* which characterize the East Pacific Realm. It differs also by lacking certain ammonite genera that in Europe represent the lowest two zones of the lower Bajocian and the upper two zones of the upper Bajocian.

Bathonian beds have been identified faunally in eastern Oregon only in the Izee area, where they constitute the upper 210 m of the South Fork Member (Smith, 1980, p. 1605) at the top of the Snowshoe Formation (Imlay, 1981, p. 6–10, Figs. 5-6, tables 3-4). The rocks consist of dark gray siltstone and claystone and some fairly thick beds of volcanic sandstone. Faunally they are characterized by the ammonites *Iniskinites, and Cobbanites,* which are not known above the upper Bathonian, and by their association with *Xenocephalites, Kepplerites* and *Torricelliceras,* which are not known below the upper Bathonian and whose lowest occurrences are respectively 190 m, 170 m and 180 m below the top of the South Fork Member. Of these genera *Xenocephalites, Iniskinites,* and *Cobbanites* characterize the East Pacific Realm; *Kepplerites* and *Torricelliceras* are most common in the Boreal Realm. The early Bathonian could be represented by part of the 250-m unfossiliferous section that underlies these fossiliferous beds of late Bathonian age and overlies beds that contain *Leptosphinctes* of early late Bajocian age.

The Callovian is represented in the Izee terrane by the Trowbridge Shale and the conformably overlying Lonesome Formation. These formations crop out in the Izee, Delintment Lake, West Myrtle Butte and Sawtooth Creek quadrangles (Imlay, 1981, p. 11, table 5). The Trowbridge Shale (Imlay, 1981, p. 4-7, fig. 3, 5, table 2) occurs in four small areas in eastern Oregon. It consists of black shale, generally ranges in thickness from 300 m to 1,100 m, thickening northeastward, and rests unconformably on either the South Fork Member or the Basey Member of the Snowshoe Formation. In the Izee area the Trowbridge Shale thins rapidly toward the southwest to only 30 m. Near its middle the unit contains ammonites including *Lilloettia, Kepplerites* and *Xenocephalites*. The presence of *Lilloettia* and the absence of *Cobbanites* and *Iniskinites* indicate an early Callovian age for the Trowbridge Shale.

Black shales that crop out near Pittsburg Landing in the Wallowa terrane and near Mineral, Idaho, in the Olds Ferry terrane contain ammonites similar to those in the Trowbridge Shale and are probably of the same age.

The Lonesome Formation, conformably above the Trowbridge Shale, is overlain unconformably by beds of early Late Cretaceous age (Imlay, 1981, p. 11, fig. 6, table 5). It attains a thickness of about 3,000 m and consists of hard, thin- to thick-bedded massive volcanic rocks and gray to green siltstone and claystone. Ammonites include *Xenocephalites* throughout the lower 2,000 m of the unit, *Lilloettia* 380 m above its base, and *Pseudocadoceras* throughout its upper 2,900 m. The presence of *Pseudocadoceras* shows that the Lonesome Formation is of late early and middle Callovian age. The ammonite genera found in these Callovian sequences, *Lilloettia, Kepplerites* and *Pseudocadoceras,* represent the Boreal Realm.

The early early Oxfordian ammonite *Cardioceras (Scarburgiceras)* is represented in the Pacific Coast region of the United States by five specimens from a locality on the east (Idaho) side of the Snake River near the southeast corner of Washington (Imlay, 1964, p. D7, D11, D15-D16, pl. 2, figs. 4-5). These specimens were collected from hard, black shale about 90 m above an angular unconformity at the top of a Triassic sequence that is more than 1,200 m thick (Morrison, 1961, p. 105–110). This occurrence of *Cardioceras* is several hundred miles south of the nearest other known occurrence of that genus, in British Columbia.

CONCLUSIONS

Evidence of age furnished by ammonites shows that the most complete Jurassic stratigraphic sequence is in the Izee-Seneca area of the Izee terrane. A much less complete sequence occurs in the Suplee area a few miles to the west. Evidently the Suplee area was undergoing a period of nondeposition or erosion during most of the Early and Middle Jurassic, whereas in the Izee-Seneca area deposition was continuous throughout that time interval except during the early Pliensbachian and early Callovian. The Jurassic sequence in the Olds Ferry terrane is about the same age as the Izee-Seneca sequence except that rocks of Hettangian, late Bajocian, Bathonian, and late Callovian age have not been found. In contrast, the Jurassic section in the Wallowa terrane is limited chronologically to rocks of Sinemurian and Pliensbachian age in the Wallowa Mountains and rocks of late early Callovian and early Oxfordian ages in Snake River Canyon.

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6. CONODONT AGES FOR LIMESTONES OF EASTERN OREGON AND THEIR IMPLICATION FOR PRE-TERTIARY MELANGE TERRANES

By Ellen Mullen Morris[1] and Bruce R. Wardlaw

ABSTRACT

Limestone blocks and strata within the Grindstone and Baker terranes of eastern Oregon have been sampled for conodonts. The conodont faunas yield ages from Devonian through Permian in each of these melange terranes. These ages generally agree with the range of ages obtained by other means. Results suggest that (1) Devonian rocks may be more widespread than previously thought, (2) division of the eastern Oregon melange belt into the Grindstone and Baker terranes appears artificial, and (3) lithologies and faunas support division of the melange into oceanic, arc, serpentinite-matrix, and ophiolite rock assemblages. Enclosure of Paleozoic limestones within Mesozoic cherts is a problem deserving further work.

INTRODUCTION

Conodont ages and distribution provide an additional parameter for understanding the complex and varied geology of the pre-Tertiary terranes of eastern Oregon. Ages, structure, and petrology in these terranes suggest either a prolonged history of accretion or the accumulation of a variety of rocks of different ages at the leading edge of an island arc. Radiometric dates range from Pennsylvanian to Early Jurassic (Walker, 1983). Paleontologic ages are from the Middle Devonian to Late Jurassic, with significant absences of dates in the Early Mississippian, Late Pennsylvanian, and early Middle Triassic.

REGIONAL OVERVIEW

Sedimentary and volcanic rocks of Paleozoic and Mesozoic age form the dominant part of the accreted, arc related pre-Tertiary terranes of the Blue Mountains in eastern Oregon. Two arc-related terranes are generally recognized on the basis of lithologic and structural characteristics (Brooks, 1979; Dickinson, 1979; Mullen and Sarewitz, 1983). These accepted terranes (fig. 6.1) are the Seven Devils terrane and the Huntington arc terrane. The Permian and Late Triassic Seven Devils terrane includes basaltic to andesitic volcanic rocks, volcaniclastic rocks, and sedimentary rocks ranging from graywacke and conglomerate to tuffaceous siltstones. Upper Triassic (Norian) limestone (Martin Bridge Limestone) and Upper Triassic and Lower Jurassic fine-grained clastic sediments (lower part of the Hurwal Formation) unconformably overlie the Seven Devils rocks. The Huntington arc terrane is Late Triassic in age and dominantly composed of andesite, volcaniclastic breccia, and a variety of sedimentary rocks ranging from coarse conglomerates to siliceous siltstone. Small differences in age and lithology suggest that the Seven Devils and Huntington arc terranes could be separate terranes.

Also present in the same region is a third terrane known as the central melange terrane (Dickinson, 1979) or the oceanic/melange terrane (Mullen and Sarewitz, 1983), which is a seemingly chaotic mixture of large coherent blocks of oceanic chert and greenstone separated from coherent blocks of arc-derived sedimentary and volcanic rocks by serpentinite-matrix melange that includes clasts and knockers of chert, greenstone, barrositic amphibolite, and fragmented ophiolitic plutonic rocks. This melange terrane also includes two coherent ophiolitic or plutonic complexes: the Canyon Mountain complex and the Sparta complex. Geochemical and mineralogical data from greenstones and plutonic rocks suggest that the melange terrane represents a forearc which may have been coeval with the arc that formed the Seven Devils terrane (Mullen, 1985). Ages reported from the melange terrane are diverse. Fusulinids of Pennsylvanian through Late Permian age have been identified and represent a seemingly random distribution of Tethyan and North American faunas (Nestell, 1983). Radiolarians from cherts are commonly Permain or Late Triassic. Other paleontological ages based upon corals and brachiopods are Devonian (Kleweno and Jeffords, 1962), Mississippian, and Permian (Vallier and others, 1977).

The diversity in ages and rock types within the melange terrane has led to the recent recognition of two possible subterranes (Grindstone and Baker) based largely upon data from oceanic cherts (Blome and others, 1983). Cherts of the Grindstone terrane in the south are dominantly Permian (Leonardian to Ochoan), but some contain Early Triassic conodonts. Cherts in the

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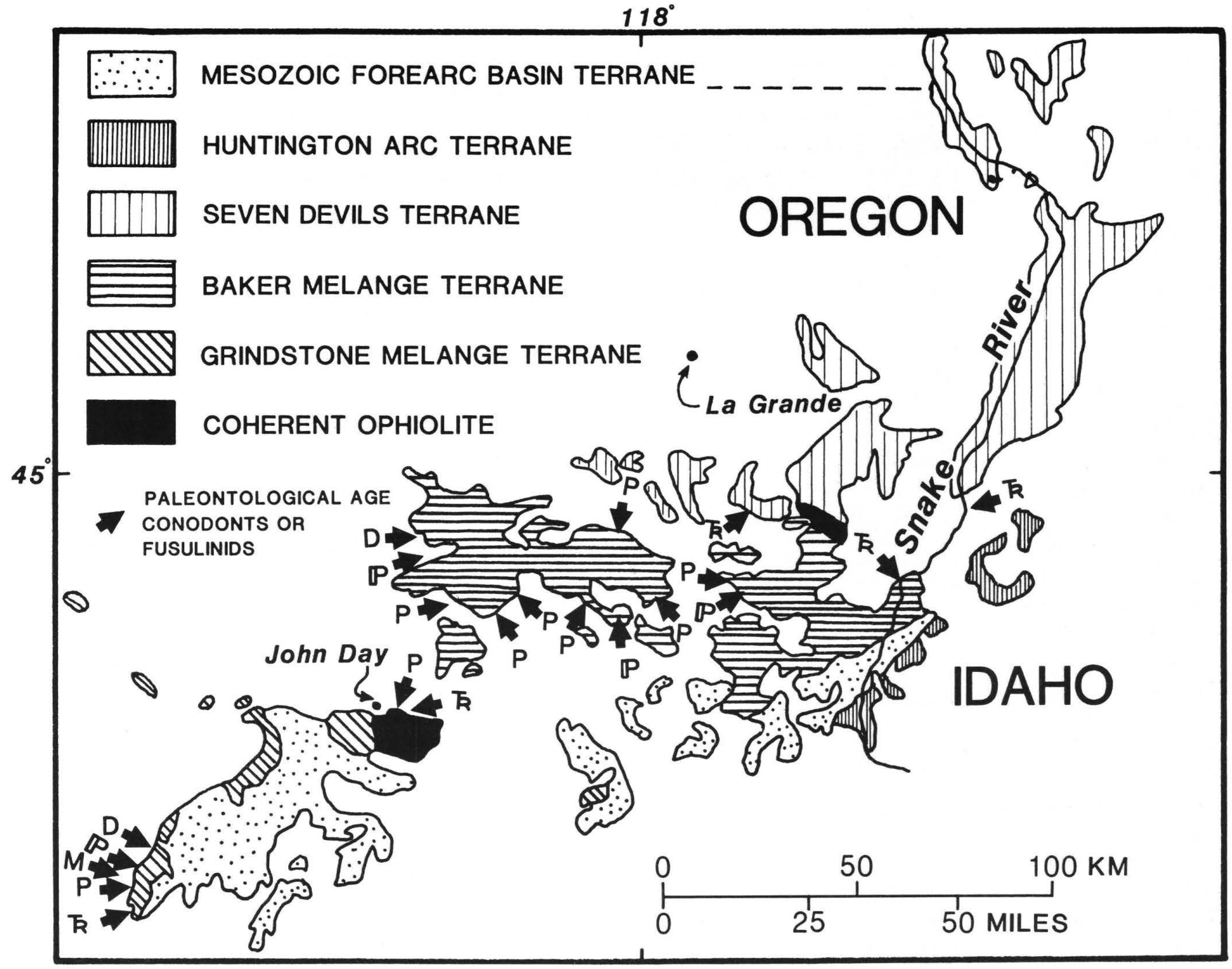

FIGURE 6.1.—Distribution of terranes and conodont and fusulinid faunas in central Oregon. D, Devonian; M, Mississippian; ℙ, Pennsylvanian; P, Permian; ₮, Triassic.

Baker terrane to the north are of Late Triassic (Karnian to Norian) age and contain exotic Permian and Triassic limestone blocks.

The fourth commonly recognized terrane, known as the forearc basin terrane (Brooks, 1979; Mullen and Sarewitz, 1983) is Late Triassic to Late Jurassic in age and unconformably overlies the melange terrane. It is composed of a thick clastic sequence dominated by sandstones and siltstones and incorporates rare basaltic to andesitic volcanic rocks. This sequence was deposited on the subsiding Permian and Triassic arc (Dickinson, 1979). The forearc basin terrane correlates in age with the Triassic sequence that unconformably overlies the Seven Devils terrane, and it is equivalent to the Malheur terrane of Blome and others (1983), which includes Late Triassic radiolarian cherts. Clasts in conglomerate within the Malheur terrane contain Carboniferous radiolarians in chert (Blome and others, 1983) and Permian fusulinids in limestone (Nestell, 1983).

CONODONTS OF THE MELANGE TERRANE

Conodont ages for limestones and limestone blocks within the melange terrane range widely and have ages similar to that of other paleontologic data (fig. 6.2). Because of the tectonic mixture involved in melanges, paleontologic data will be considered separately for blocks of oceanic, arc, and serpentinite-matrix associations. Sample locations and terrane designations of limestone blocks yielding conodont and fusulinid faunas are shown on figure 6.1

GRINDSTONE TERRANE

The faunas and floras of the Grindstone melange have been reasonably well documented (Merriam and Berthiaume, 1943; Dickinson and Thayer, 1978; Wardlaw and others, 1982) and are briefly discussed here.

Arc-related assemblages.—Large blocks of limestone in the southern part of the melange terrane (Grindstone-Twelvemile melange of Dickinson and Thayer, 1978) have yielded abundant Devonian, Mississippian and Permian fossils, whereas cherts between limestone blocks have yielded Permian radiolarians and Early Triassic conodonts. Sandstone blocks containing minor limestone have yielded Pennsylvanian plants, conodonts, and fusulinids. The Permian fusulinid faunas in the limestone blocks have North American affinities.

Oceanic related assemblages.—Permian fusulinids have been recovered from a limestone block near Dog Creek in the northern part of the melange terrane (Miller Mountain melange of Dickinson and Thayer, 1978). Adjacent cherts yield Late Triassic radiolarians and conodonts. The Permian fusulinid fauna shows Tethyan affinities.

BAKER TERRANE

Arc-related assemblages.—In the western area of the Baker melange (fig. 6.1) the southern part of the Greenhorn Mountains is comprised of arc-derived volcanic greenstones and lower greenschist-facies sedimentary rocks. The sedimentary rocks are siltstone, graywacke, and conglomerate that contain clasts of chert, andesitic and basaltic volcanic rocks, and some tuff. Greenstones have major-element, trace-element, and mineral compositions that indicate calc-alkaline island-arc affinities (Mullen, 1985). Limestone lenses, usually less than one meter thick, occur within the clastic sediments. These carbonate rocks are deformed and stretched parallel to the deformation of enclosing sedimentary rocks, and conodont color-alteration indices indicate metamorphism at 300–400 °C.

A limestone which appears to be stratigraphically coherent and interbedded with clastic rocks in the drainage of Granite Boulder Creek yielded a diversified fauna including crinoids, bryozoans, corals, brachiopods, sponge spicules, and fish fragments. Fusulinids were identified as *Pseudofusulinella and Schwagerina,* of probably Early Permian (Wolfcampian)

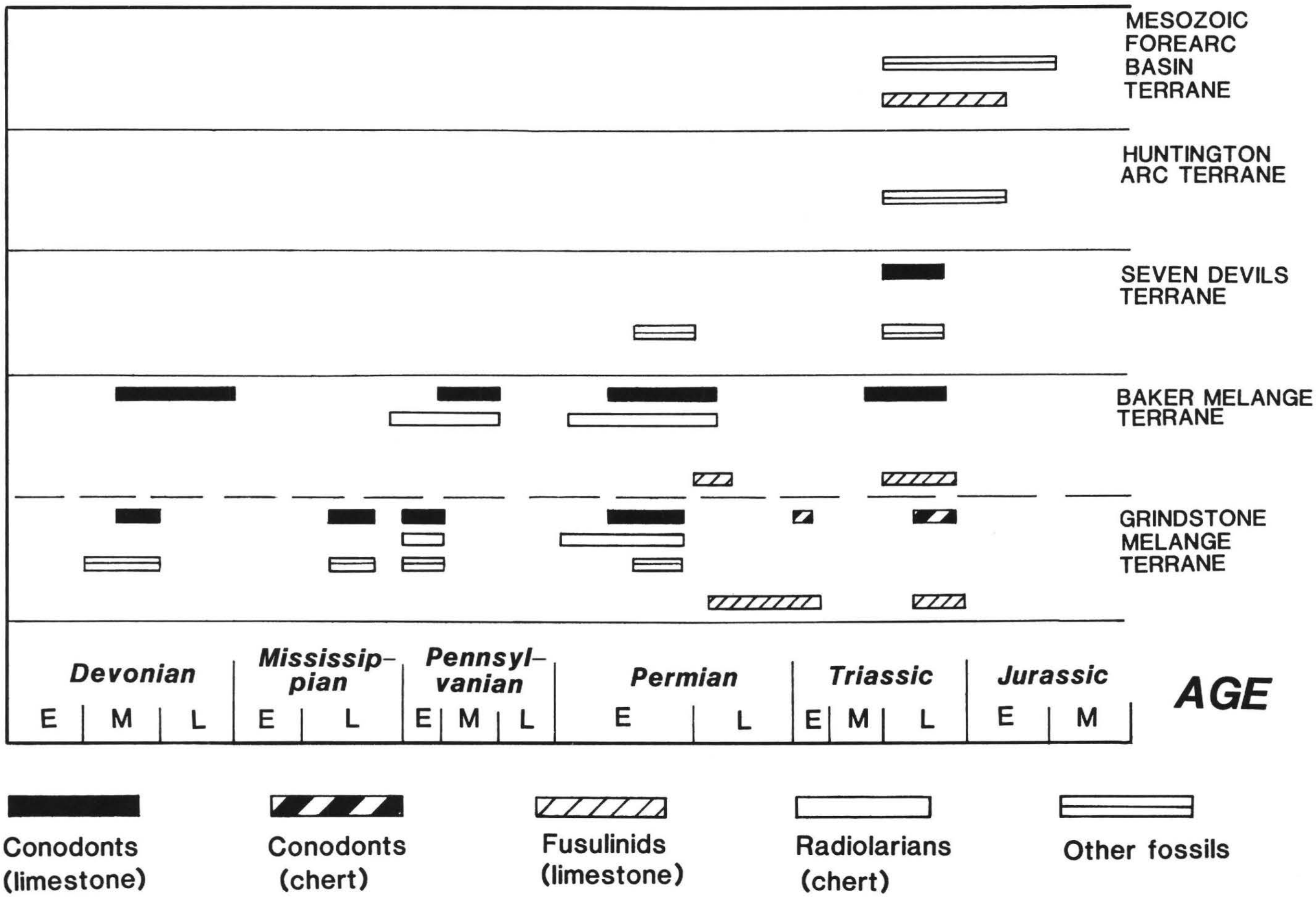

FIGURE 6.2.—Ages derived from various faunas and floras in the terranes (Dickinson, 1979) of central Oregon.

age (D.W. Bostwick, oral commun., 1977) and North American affinities. Conodonts from the same locality are *Neogondolella idahoensis* and *Neostreptognathodus* sp., both of Early Permian (Leonardian) age.

The rocks at the locality reported here are similar to the Coyote Butte Formation described by Wardlaw and others (1982). Both limestone bodies seem stratigraphically coherent and both contain a similar and diverse fossil assemblage. The disparity between conodont Leonardian and fusulinid Wolfcampian ages is present in both. The two localities are lithologically similar, except for the possibly finer grain size of the clastic sedimentary rocks in the Coyote Butte. It seems reasonable to correlate the limestones and clastic sedimentary rocks in the Greenhorns with the Coyote Butte Formation.

Oceanic assemblages.—Large limestone pods occur in an assemblage with cherts and tholeiitic greenstones near the eastern extremity of the Baker terrane. Two conodont localities in these limestones are associated with the Burnt River Schist (greenstone), and a third is associated with siliceous sedimentary rocks that appear to be oceanic.

Along the Burnt River, large pods of partly silicified, clay-rich dolomitic limestone occur within the Burnt River Schist. These rocks are deformed and recystallized, and the term "marble" is more appropriate than "limestone". The associated greenstones have major, trace-element and relict clinopyroxene compositions which indicate affinities to mid-ocean ridge tholeiites (Mullen, 1985). The limestones near French Spring appear to represent several boudinaged beds, although they may have been tectonically emplaced or possibly olistostromal. All units, greenstones and sedimentary rocks, are pervasively sheared, obliterating evidence for the mode of emplacement. The conodont *Neogondolella navicula* of Middle to Late Triassic age occurs in these limestones. Conodonts from the Nelson Marble at Durkee include *N. navicula* and *Xaniognathus* sp. of Middle to Late Triassic age. The extreme deformation of these rocks may be related to the nearby Connor Creek fault, a high-angle reverse fault (Brooks, 1979), or thrust (Roure, 1982) of possible Jurassic age, which juxtaposes forearc basin sedimentary rocks against melange.

Large pods (50 meters in diameter) of limestone occur in a small fenster of pre- Tertiary siliceous sedimentary rocks along the Snake River north of Brownlee, Oregon. The limestone is not strongly deformed, but the contact between limestone and enclosing sedimentary rocks is sheared. Crinoidal hash is the only faunal material visible. The conodont *Neogondolella polygnathiformis* of Late Triassic (Karnian) age was recovered from this limestone.

The conodonts associated with these oceanic assemblages in the eastern-most part of the Baker melange are therefore all Triassic in age. Conodont and fusulinid faunas near Baker in the center of the melange terrane are Pennsylvanian and Permian in age (figure 6.1); the fusulinid faunas show Tethyan affinities.

Melange-related assemblages.—Serpentinite-matrix melange (Ferns and Brooks, 1983), exposed along the crest of Vinegar Hill in the Greenhorn Mountains (Brooks and others, 1983) and extending northwestward toward Olive Lake, separates arc-derived rocks on the south from an ocean/alkalic block to the north. This melange contains cherts and siliceous sedimentary rocks, pillowed and non-pillowed greenstone, and plutonic ophiolitic fragments, including serpentinized harzburgite (Mullen, 1978). Limestone collected from Mullen's unit on the north side of Vinegar Hill contains strained Middle Pennsylvanian (Demoinesian) conodonts including *Adetognathus* sp., *Gondolella* sp., *Idiognathodus* sp., and *Neognathodus* sp. Metagabbro and pillowed greenstone underlie the sedimentary unit that contains the fossiliferous limestone (Brooks and others, 1983).

A second locality recently discovered by James Evans is north of Olive Lake. It is a limestone block in a large exposure of argillite and chert mapped by Evans as part of the Elkhorn Ridge Argillite along the same melange trend. Conodonts recovered from this limestone pod are Middle to Late Devonian *Polygnathus* sp. Devonian rocks have previously been reported in eastern Oregon from the Suplee area (Kleweno and Jeffords, 1962; Savage and Amundson, 1979), 125 kilometers to the southwest along a trend roughly parallel to the possible trace of the subduction zone of the Triassic arc. Rocks adjacent to this melange on the north are probably oceanic. To the northwest, along the North Fork of the John Day River, the pre-Tertiary rocks are so strongly sheared that whether they are plutonic or volcanic is obscure even in thin section. Major- and trace-element geochemistry suggest that volcanic rocks in this deformed terrane have island-arc affinities.

Limestone exposed southeast of Sumpter contains a North American Permian fusulinid fauna. We are unable, however, to place this occurrence in a rock assemblage.

IMPLICATIONS OF CONODONT AGES AND DISTRIBUTION

The first conclusion from the material presented above is that conodont ages corroborate dates obtained by other means throughout eastern Oregon. The restricted geographic distribution of conodont samples makes it undesirable to interpret the conodont data alone. However, the combination of conodont ages and distributions with other geochronologies leads to the following suggestions:

(1) Devonian rocks may be more abundant than previously considered. Limited exposures in the melange terrane make correlation with the Suplee occurrence difficult. The Devonian at Suplee appears to be a large, coherent block within melange.

(2) The division of the melange terrane into the Grindstone and Baker terranes appears artificial.

(3) Division of the melange terrane into arc-related and oceanic rock assemblages, serpentinite-matrix melange, and ophiolite complex seems more reasonable. These rock assemblages cut across the melange terrane boundaries. Arc- related assemblages contain Devonian through Early Triassic fossils with fusulinid faunas of North American affinities and cherts no younger than Early Triassic. Serpentinite- matrix melanges contain Devonian through Permian fossils and fusulinid faunas of both North American and Tethyan affinities. Oceanic assemblages contain Pennsylvanian through Late Triassic fossils with fusulinid faunas of Tethyan affinities and cherts commonly of Late Triassic age. The fusulinid faunas of North American affinities southeast of Sumpter may be an exception, but these rocks could also lie within a general northwest-trending zone of serpentinite-matrix melange.

(4) The absence of upper Lower and Middle Triassic sedimentary rocks, and the enclosure of Paleozoic limestone within Mesozoic cherts are fundamental problems of eastern Oregon geology. A possible explanation for the "exotic" limestones is incorporation of a "docked" terrane into a forearc accretionary prism. However, this solution does not explain why only limestones seem to have anomalous ages, and why there appear to be no recognizable equivalent exotic blocks of other sedimentary lithologies. Another attractive explanation is that limestone blocks were shed from an uplifted, older arc edifice or platform and represent olistostromal deposits.

We must caution that these conclusions are tentative and preliminary because of the complex nature of the problem, the sparsity of conodont data, and the rather poor exposures. We strongly encourage collection of more data.

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7. FAUNAL AFFINITIES AND TECTONOGENESIS OF MESOZOIC ROCKS IN THE BLUE MOUNTAINS PROVINCE OF EASTERN OREGON AND WESTERN IDAHO

By Emile A. Pessagno, Jr.,[1] and Charles D. Blome

ABSTRACT

Paleontologic, paleomagnetic, petrologic, and stratigraphic data from the Blue Mountains province indicate that the Seven Devils terrane, the central melange terrane, the Mesozoic clastic terrane, and the Huntington arc terrane represent dismembered components of a single island-arc complex—referred to herein as the Blue Mountains island arc. Paleontologic evidence (specifically, the presence of *Weyla* Boehm in Lower Jurassic strata) suggests that this terrane originated in the eastern Pacific. Furthermore, it can be established from combined paleomagnetic and paleozoogeographic data that the terranes of the Blue Mountains were situated in the Central Tethyan Province, either north or south of the paleoequator, during the Late Triassic and Early Jurassic.

Both ammonite and radiolarian data (presence of *Parvicingula* Pessagno and abundant, diversified pantanelliids) from the Mesozoic clastic terrane (John Day Inlier) indicate that by middle Toarcian time the Blue Mountains island arc was situated within the Northern Tethyan Province (approximately 15° to 30° north). Pantanelliid diversity and abundance decline during the late Bajocian and drop dramatically during the latest Bathonian and Callovian. The dramatic drop in pantanelliid diversity, together with the presence of *Parvicingula* and a preponderance of Boreal over Tethyan ammonites, indicate that during the latest Bathonian and Callovian this terrane was situated at higher latitudes, within the Southern Boreal Province of the Boreal Realm. Final displacement of the Blue Mountains island arc to even higher boreal latitudes (Late Jurassic paleolatitude, 40° ± north) probably occurred during the Late Jurassic.

INTRODUCTION

Much of the western part of the Cordilleran region of North America appears to be a collage of displaced terranes that have been accreted to the margin of the continental craton during Paleozoic and Mesozoic times. Many such geologic terranes have been displaced hundreds or perhaps even thousands of kilometers from their points of origin.

The brilliant recognition of the first of these displaced terranes—the Wrangellia terrane—by Jones and others (1977) has revolutionized geological thinking pertaining to the evolution of the North American Cordillera, and indeed to the evolution of the entire circum-Pacific margin. Wrangellia is represented primarily by components in the Wrangell Mountains (Alaska), the Queen Charlotte Islands (British Columbia), part of Vancouver Island (British Columbia), and in Hells Canyon along the Idaho-Oregon border. In the first three of these areas the physical stratigraphy is remarkedly similar; however, the fourth area at Hells Canyon shows differences in its physical stratigraphy as well as in the composition of its volcanic rocks (see discussion of the Seven Devils terrane herein). Paleomagnetic data indicate that Wrangellia originated 15° north or south of the Triassic paleoequator, and both the Late Triassic and Early Jurassic megafossil assemblages are Tethyan in character (Jones and others, 1977; Tipper, 1981).

Melange belts inherent to subduction complexes along the circum-Pacific margin show evidence of major displacement of blocks even smaller than terranes such as Wrangellia. For example, the Jurassic and Cretaceous red manganiferous ribbon cherts characteristic of the Franciscan Complex (California Coast Ranges), the Otter Point Formation (coastal southwestern Oregon), and the Pacific Rim complex (west coast of Vancouver Island, British Columbia) all contain radiolarian faunas that are distinctly Tethyan (dominantly Central Tethyan) in character and are similar to those described by Baumgartner and others (1980) from the Mediterranean region and by Tippit (1981) from Oman. On the other hand, adjacent blocks or slabs consisting of flyschoid sandstone and shale with Buchias or of green to black tuffaceous cherts with radiolarians represent Boreal strata.

The tectonic complexity of the western Cordilleran region resulting from displaced terranes and displaced strata (nannoterranes in subduction complexes) is immense. It behooves paleontologists to consider the problems posed by this complexity in their zoogeographic reconstructions and in their attempts to compile meaningful zonal schemes.

The purpose of the present report is to evaluate Triassic and Jurassic paleontologic data from the Blue Mountains province of east-central and northeastern Oregon and to determine, if possible, how these data

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reflect the tectonic history of the region. Before Jones and others (1977) introduced their hypothesis of displaced terranes, most attempts to discuss the Mesozoic faunas of the circum-Pacific region were, at best, chaotic and usually ended in bizarre zoogeographic reconstructions. For example, Holder (1979, p. A391), who was apparently unaware of the displaced terrane hypothesis, described circum-Pacific Jurassic faunas as lacking faunistic uniformity. He even (p. A401) entitled a section of his chapter: "Faunal mosaic of the Pacific Ocean."

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THE TETHYAN AND BOREAL FAUNAL REALMS DURING THE LATE TRIASSIC AND JURASSIC

As noted by Gordon (1974, p. 139), the decline in mean temperature from the equator to the poles is one of the most important determinants of biogeographic distribution (see also Fischer, 1960). Planktonic foraminifers in modern oceans, for example, show a marked decrease in diversity from equatorial latitudes to the Arctic (see Loeblich and others, 1964, p. C126-C127). Furthermore, it can be established that certain taxa such as *Globigerina pachyderma* (Ehrenberg) are cold-water (Arctic- subarctic) indicators whereas others, such as *Sphaeroidinella dehiscens* (Parker and Jones), are warm-water (equatorial) indicators.

Gordon (1974, p. 143), in his excellent report dealing with the distribution of the marine biota during the Jurassic, stated:

> Working in association with density variations such as occur in modern seas, the planetary wind system under the influence of a rotating earth would have produced a system of ocean currents which also would have had similarities with the modern system. Equatorial currents ancestral to those of modern time must have existed, but during most if not all of the Jurassic they would have formed a world-encircling girdle across the central Pacific Ocean and through the Tethys Sea. Within the equatorial west-bound flow an east-bound counter current would have existed just as it does today. In each hemisphere the coriolis force would have induced current gyres and at high latitudes a West Wind Drift would have existed as it does today in the Antarctic Ocean.

Gordon's model for the oceanic surface currents of the Oxfordian (Late Jurassic) is shown in figure 7.1. It is apparent that if this model is correct, most of the western margin of Late Jurassic cratonic North America would be under the influence of a cold-water "paleo-California" current. Stratigraphic studies in east-central Mexico (Cantu Chapa, 1971; Imlay, 1980; Longoria and Pessagno, unpub. data) indicate that the Gulf of Mexico opened in late Bathonian (Middle Jurassic) time. From that time onward during the Jurassic, a direct connection existed between the Pacific, Atlantic, and Mediterranean. Hence, it is inferred that the Gordon model can be applied through the interval from late Bathonian to late Tithonian times. It is likely that the current circulation in the Early and Middle Jurassic Pacific was more similar to modern Pacific circulation than even that in the Late Jurassic.

There is little question that a climatic zonation and latitudinal temperature gradient existed throughout Jurassic time. This is substantiated by both the floral and faunal records (for example, see Gordon, 1974). The Tethyan Realm corresponds to the tropical and subtropical climatic belts in both the Northern and Southern Hemispheres, whereas the Boreal Realm corresponds to the temperate belt in the Northern Hemisphere. The temperature rather than Arctic nature of the Boreal Realm during the Jurassic is indicated by the presence of temperate to warm-temperature conifers at high latitudes (Axelrod, 1963, p. 3258).

In this report, we rely on the global tectonic reconstructions of Smith and others (1981) to interpret the paleolatitudinal positions of boundries between the Tethyan and Boreal Realms. These reconstructions are regarded as being more accurate than others such as those of Irving (1979) because they are consistent with the faunal data. Whereas the paleolatitudinal lines on the maps of Smith and others generally parallel faunal-realm boundries, those of Irving for North America are positioned obliquely to such boundries. Finally, one must keep in mind that during Triassic to Late Jurassic time cratonic North America moved in a northwesterly direction away from the paleoequator. Hence the boundary between the Tethyan and Boreal Faunal Realms shifted progressively southward.

In the following discussion of Triassic and Jurassic megafossil data, we regard most circum-Pacific occurrences of ammonoids, pelecypods, and gastropods as suspect, particularly where faunal associations or paleomagnetic data are either unknown or not cited. If the displaced-terrane hypothesis is valid for the circum-Pacific region, Tethyan faunas conceivably could occur as far north as Alaska and as far south as Tierra del Fuego. To interpret the faunal data, we utilize megafossil occurrences from terranes which have not been greatly displaced latitudinally (for example, the western interior of North America and the Mediterranean area).

Figure 7.2 shows faunal criteria for separating the Tethyan and Boreal Realms during the Middle and Late Jurassic. It is now apparent from our studies of the North American radiolarian assemblages, as well as radiolarian studies from other regions (for example, Baumgartner and others, 1980), that we can distinguish Tethyan from Boreal radiolarian faunas. Furthermore, it is apparent that at least in the late Early, Middle, and Late Jurassic we can subdivide the Tethyan Realm into a Central Tethyan Province and a Northern Tethyan Province (fig. 7.2). The Central Tethyan Province is characterized by a parvicingulid assemblage that lacks *Parvicingula* Pessagno (sensu Pessagno and Whalen, 1982) but contains *Ristola* Pessagno and Whalen. The Northern Tethyan Province and the Southern Boreal Province possess a parvicingulid assemblage containing both taxa; however, *Parvicingula* is the dominant element in the southern boreal assemblage. In addition, pantanellid diversity remains high throughout the Tethyan Realm, but declines dramatically in the Boreal Realm (Southern Boreal Province). Figure 7.3 shows faunal-realm and province indicators for the Middle and Late Jurassic; it is based on both megafossil and microfossil data. Utilizing the paleolatitudinal reconstructions of Smith and others (1981) and the faunal data, we place the boundary between the Boreal and Tethyan Faunal Realms at approximately 30° north both in Europe and in cratonic North America. Furthermore, using these reconstructions and integrated paleomagnetic and radiolarian data from California (McWilliams and Howell, 1982; Pessagno and Blome, unpub. data), we place the northern and southern limits of our Central Tethyan Province at approximately 22° north and south of the Middle and Late Jurassic paleoequator. There is little question that a direct integration of the radiolarian faunal data with the paleomagnetic data will allow a much more accurate delimitation of faunal-realm and province boundaries in the near future.

MESOZOIC TECTONOSTRATIGRAPHY AND ZOOGEOGRAPHY OF THE BLUE MOUNTAINS PROVINCE

Dickinson (1979) divided the Blue Mountains Province into four major tectonostratigraphic terranes that crop out discontinuously from beneath a cover of Cenozoic volcanic rocks in northeast-trending belts.

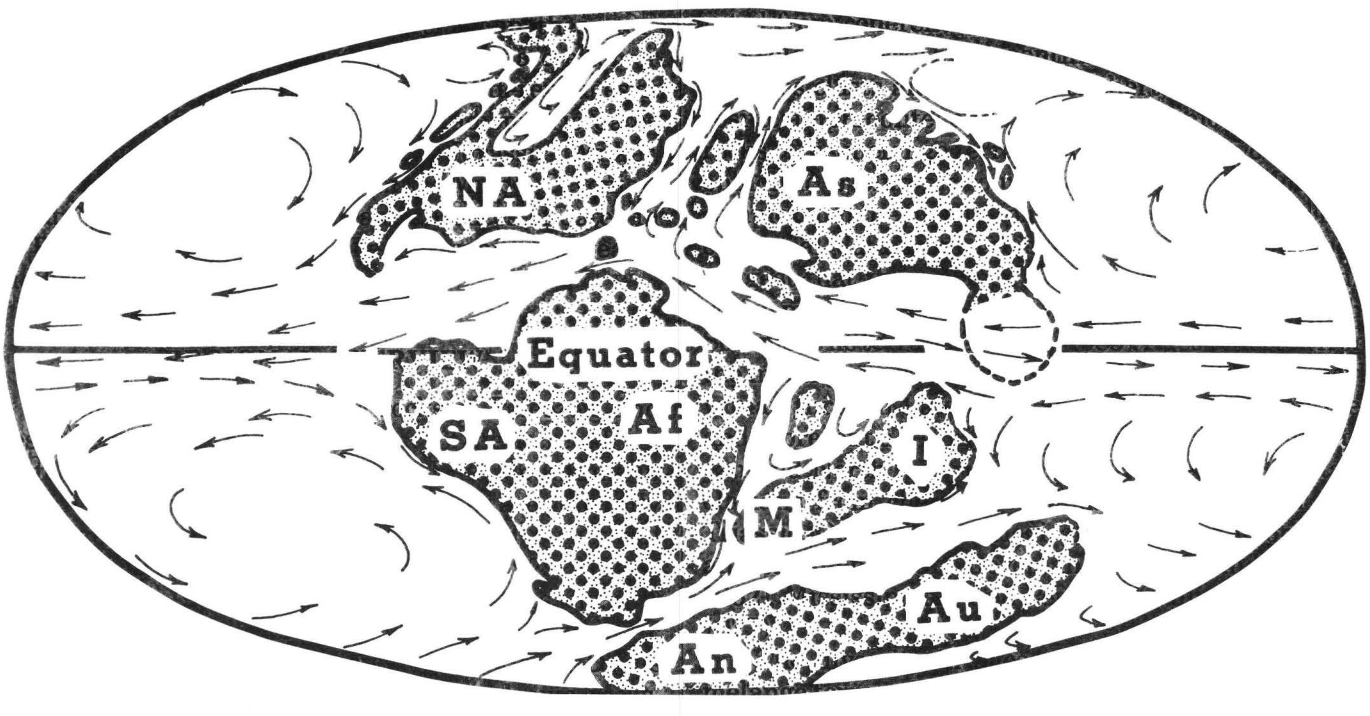
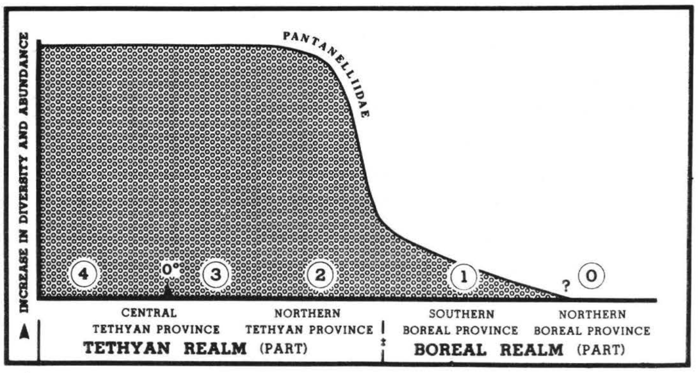


FIGURE 7.1.—Inferred ocean surface currents during Oxfordian times (from Gordon, 1974, fig. 4). This model can be applied to the entire late Bathonian to late Tithonian interval. Stratigraphic evidence from east-central Mexico indicates that the Gulf of Mexico opened up during the late Bathonian (Longoria, 1984). Continental areas (outlines dashed where poorly known): Af = Africa; An = Antarctica; As = Asia; Au = Australia; I = India; M = Madagascar; NA = North America; SA = South America.

From north to south, these terranes are the Seven Devils terrane, the central melange terrane, the Mesozoic clastic terrane, and the Huntington arc terrane (Dickinson, 1979; see fig. 7.4).



A

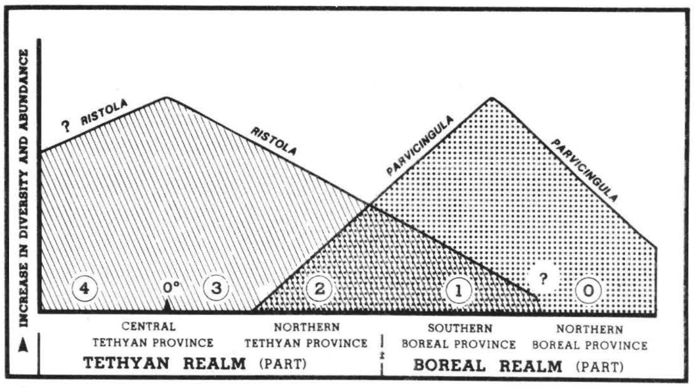


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FIGURE 7.2.—Latitudinal variations during the Middle and Late Jurassic in the diversity and abundance of *A*, pantanelliid radiolarians and *B*, *Parvicingula* Pessagno (sensu Pessagno and Whalen, 1982) and *Ristola* Pessagno and Whalen. Notes on data used: O, data from Alaska [North Slope, Brooks Range (unpublished data) and Puale Bay areas]. At Puale Bay Blome (1984b) recovered well-preserved middle Callovian radiolarians from the same horizon as *Stenocadoceras* Imlay, a high-latitude Boreal ammonite taxon that elsewhere occurs in Russia and Greenland. 1, Data from about the upper half of volcanogenic successions overlying the Coast Range ophiolite, from the overlying Great Valley sequence (California Coast Ranges), and from the Galice Formation, Klamath Mountains, California. 2, Data from the Taman and Pimienta Formations of east-central Mexico, where radiolarian faunas are associated with Tethyan ammonites, pecten (*Aulacomyella* Furlani), calpionellids, and nannoconids. 3, Data from the Mediterranean area, Turkey, Iran, Oman, Tibet, and various Deep Sea Drilling Project legs. No Central Tethyan faunas are known from North America except from displaced terranes and subduction complexes (for instance, Franciscan Complex, California; Pacific Rim Complex, Vancouver Island, British Columbia). 4, No data from southern hemisphere. Our model assumes symmetrical arrangement of faunal provinces and realms north and south of the paleoequator. Boundary between Central and Northern Tethyan Provinces placed at about 22° N. and that between Tethyan and Boreal Realms at about 30° N. (see text).

SEVEN DEVILS TERRANE

Jones and others (1977) tentatively treated the Seven Devils terrane as part of Wrangellia. The same position was maintained by Hillhouse and others, 1982). However, Sarewitz (1983, p. 634–637) noted major differences in the physical stratigraphy and composition of the Seven Devils and Wrangellian rocks. Sarewitz correctly noted that the Triassic volcanic rocks of the Seven Devils terrane are representative of a volcanic arc of probable calc-alkaline affinity, whereas coeval rocks in Wrangellia (sensu stricto) consist of a thick pile of tholeiitic basalts, subaerial basalt flows, and breccias. The tholeiitic character of the basalt in the Karmutsen Formation of Wrangellia was well documented, for example, in the Queen Charlotte Islands by Sutherland Brown (1968, p. 46-47) and at Vancouver Island by Carlisle and Susuki (1974).

In spite of such differences there is little question that the Seven Devils terrane, like Wrangellia proper, was displaced from low latitudes during Triassic and Jurassic times. Paleomagnetic data presented by Hillhouse and others (1982) indicate that the Seven Devils terrane originated 18° (±4°) north or south of the Triassic paleoequator. In addition, Jones and others (1977, p. 2520) found that the upper part of the Martin Bridge Limestone (Vallier, 1977) (Late Triassic: early Norian; Hells Canyon and Wallowa Mountains, Oregon) possesses a highly diversified invertebrate fauna of Tethyan affinities. These workers noted further that in its overall composition this fauna closely resembles that of the same age from the transition beds between the Chitistone Limestone and Nizina Limestone in the Wrangell Mountains of Alaska.

The rocks of the Seven Devils terrane range in age from Early Permian to Late Jurassic (early Oxfordian). A volcanic arc assemblage is represented by the Seven Devils Group of Early Permian and Middle and Late Triassic (late Ladinian and Karnian) age (see Vallier, 1977; Brooks and Vallier, 1978; Sarewitz, 1983). The Seven Devils Group is overlain by the massive, neritic, early Norian (Late Triassic) Martin Bridge Limestone, which is in turn overlain by the bathyal (?) "argillite" (= siliceous mudstone) and limestone of the Hurwal Formation (Late Triassic and Early Jurassic: Norian and late Pliensbachian). It should be noted, however, that only the part of the succession that includes the Martin Bridge Limestone and the Hurwal Formation resembles that of Wrangellia proper. The Martin Bridge Limestone resembles the lower gray limestone member of the Kunga Formation in the Queen Charlotte Islands. The Hurwal Formation is somewhat similar to the bathyal strata of the middle black limestone member

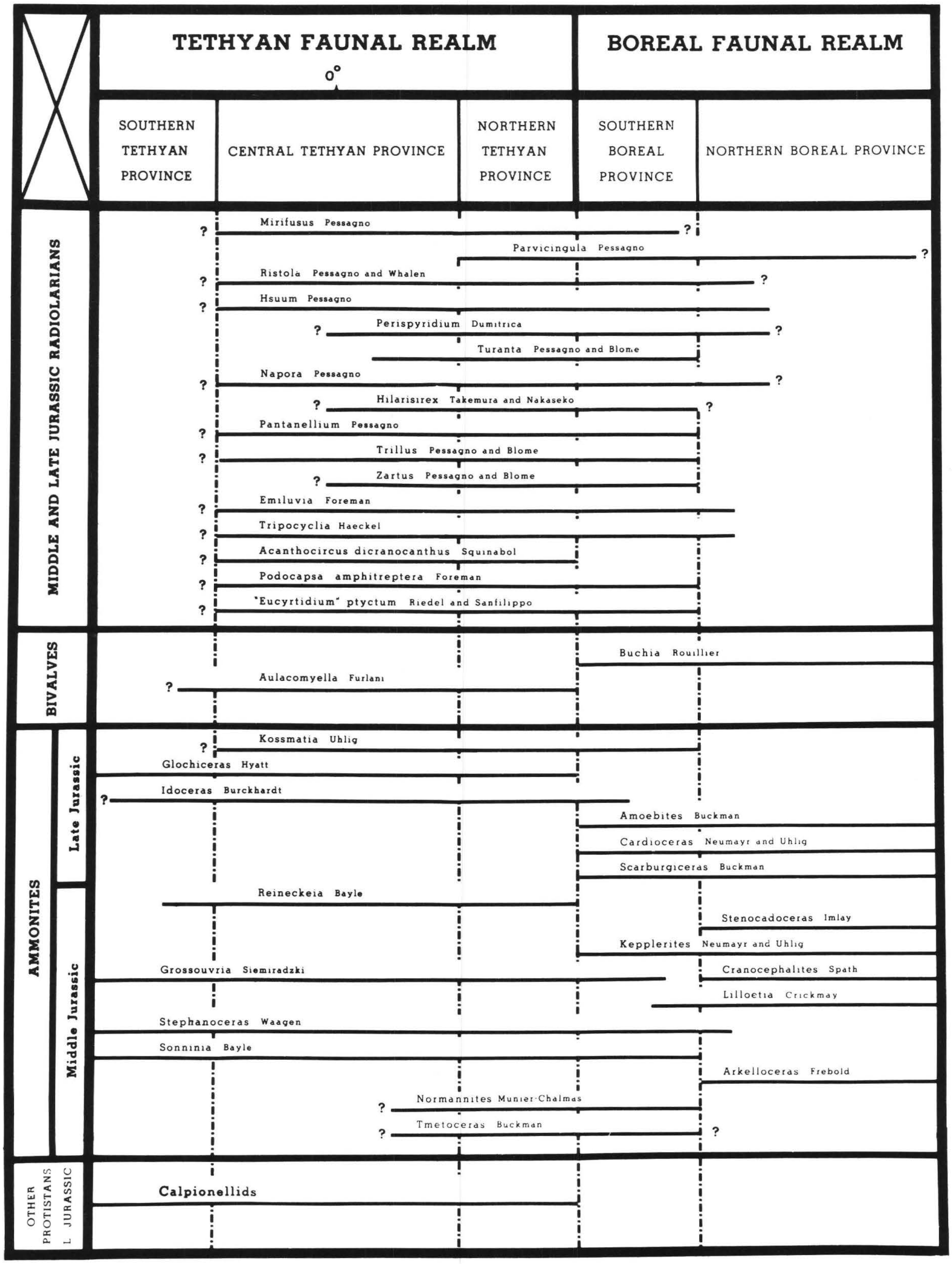

FIGURE 7.3.—Faunal realm and province indicators for the Middle and Late Jurassic. Distribution of selected taxa of radiolarians, other microfossils, and megafossils among the provinces of the Tethyan and Boreal Realms. Boundaries defined as in figure 7.2.

(Karnian and late Norian) and the upper thinly bedded argillite member (Hettangian and Sinemurian) of the Kunga Formation as well as the overlying Maude Formation (late Sinemurian to Toarcian) (see Sutherland Brown, 1968; Pessagno and Blome, 1980, 1982; Pessagno and Whalen, 1982). Finally, it should be noted that Imlay (1968, p. C21) indicated that the late Pliensbachian ammonite assemblage of the Hurwal Formation, like that of the Nicely Formation (Suplee-Izee area; see discussion of the Mesozoic clastic terrane herein) shows strong Mediterranean (Tethyan) affinities.

The Seven Devils Group is overlain with marked angular unconformity by the Coon Hollow Formation (Morrison, 1961, 1964). The Coon Hollow Formation consists of about 600 m of dark gray mudstone, impure limestone, and occasional limestone concretions in the mudstone. It is exposed along Hells Canyon just south of the Oregon-Washington border near Cottonwood Creek and also somewhat farther south near Pittsburg Landing. At both the Cottonwood Creek and Pittsburg Landing localities the base of the Coon Hollow is marked by a conglomerate which includes clasts derived from the underlying Seven Devils Group (Vallier and Hooper, 1976). The Coon Hollow Formation appears to be genetically related to similar flyschoid strata (for example, the Lonesome Formation) exposed near Izee in the Mesozoic clastic terrane to the south.

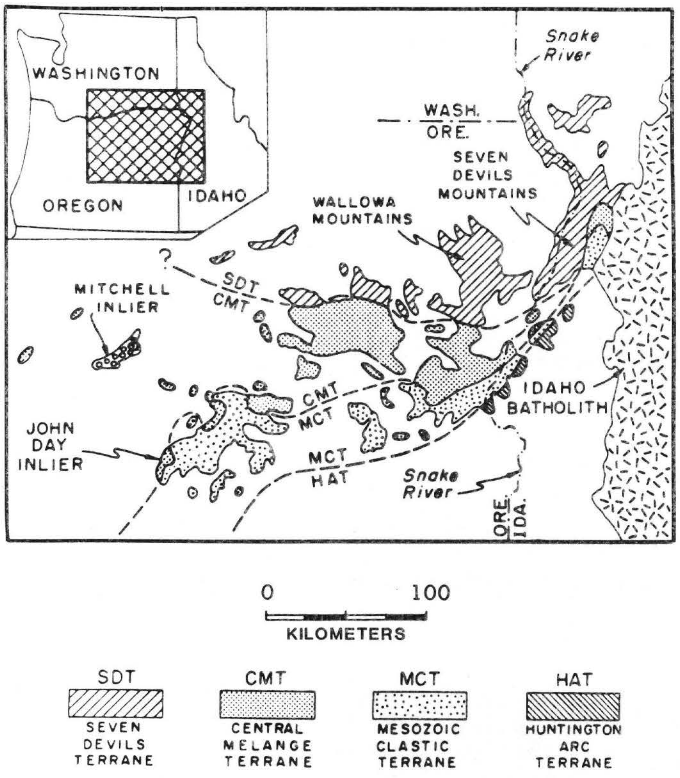

FIGURE 7.4.—Geologic terranes in the Blue Mountains province (from Dickinson, 1979).

At the southern locality near Pittsburg Landing on the Oregon side of Hells Canyon, Imlay (1981, p. 12) recovered early Callovian ammonites from the Coon Hollow Formation. These include *Lilloettia stantoni* Imlay, *Xenocephalites vicarius* Imlay, and *Grossouvria* sp. The genus *Lilloettia* Crickmay appears to be a Boreal eastern Pacific taxon. It is known from Oregon (Imlay, 1981), from the Canadian Rocky Mountains (Fernie Shale, British Columbia; Hall and Stronach, 1982), and from Alaska (Imlay, 1981). *Xenocephalites* Spath, except for its occurrence in Greenland, is predominantly an eastern Pacific taxon. It is known from South America, Mexico, and northern and southern Alaska (Holder, 1979, p. A402). *Grossouvria* Siemradzki is predominantly a Tethyan form (see Arkell and others, 1957, p. L319). However, Imlay (1961, p. D6) noted *Grossouvria* in association with the Boreal ammonite *Kepplerites* Neumayr and Uhlig in the Colfax Formation, Placer County, California. The association of these ammonite taxa in the lower Callovian part of the Coon Hollow Formation suggests that these strata were deposited within the Southern Boreal Province of the Boreal Faunal Realm (fig. 7.3).

At the northern locality near Cottonwood Creek, Imlay (1964, p. D6) recorded early Oxfordian ammonites assignable to *Cardioceras (Scarburgiceras) martini* Reeside from strata (USGS Loc. 28652) occurring about 120 m above the base of the Coon Hollow Formation. In Europe and in tectonically more stable portions of North America (for example, the Western Interior Seaway) both *Cardioceras* Neumayr and Uhlig and its subgenus *Scarburgiceras* Buckman are indicative of the Boreal Faunal Realm (see Imlay, 1980, p. 24-25, fig. 15). In North America both taxa are known only from Wyoming northward to the Canadian Arctic; Upper Jurassic marine strata are generally lacking farther south in the western interior. In northwest Europe these taxa occur as far south as the Paris Basin (see Enay and others, 1971). *Cardioceras* is also known from Poland, European Russia, Siberia, and Greenland (see Arkell and others, 1957, p. L306); *Scarburgiceras* is known from European Russia.

The data from the Seven Devils terrane indicate that (1) the Seven Devils terrane originated 18° (±4°) north or south of the Triassic paleoequator within the Tethyan Faunal Realm, and by Early Jurassic (late Pliensbachian) time it was situated at relatively low latitudes still within the limits of the Central Tethyan Province of the Tethyan Faunal Realm (figs. 7.2 and 7.3); (2) the Tethyan strata of the Seven Devils terrane were first deformed (in a local orogenic pulse characteristic of island-arc complexes such as the Greater Antilles) between Early Jurassic (late Pliensbachian) and Middle Jurassic (early Callovian) time; (3) by Callovian and Oxfordian (Late Jurassic) time, the Seven Devils block, then covered unconformably by the Coon Hollow Formation, was situated at boreal latitudes within the Southern Boreal Province (fig. 7.3); and (4) the strata of the Seven Devils terrane (including the Coon Hollow Formation) were deformed in post-early Oxfordian (Late Jurassic) time (see Vallier and Hooper, 7 1976; Vallier, 1977).

CENTRAL MELANGE TERRANE

The central melange terrane consists of disrupted late Paleozoic oceanic crustal blocks such as the ophiolitic Canyon Mountain Complex, as well as associated deep-marine sedimentary strata (Elkhorn Ridge Argillite) of late Paleozoic and Triassic (and possibly Early Jurassic) age. Extensive bodies of highly deformed but lithologically coherent metamorphic and sedimentary rocks, such as the Burnt River Schist and Nelson Marble, are also present (Brooks and Vallier, 1978). It was originally believed by Dickinson and other workers that the rocks of the central melange terrane ranged in age from Middle Devonian to Middle Triassic (Ladinian). Subsequent investigations have established that younger rocks are also present.

Nestell and MacLeod (personal commun., 1984) recently recovered Late Triassic (late Karnian?; early to late middle Norian) radiolarians assignable to the *Capnodoce* Zone (Pessagno and others, 1979; Blome, 1984a) from the melange belt east of John Day. This radiolarian assemblage is identical to those from the Rail Cabin Mudstone Member of the Vester Formation (Blome and others, this volume) (*Capnodoce* Zone, *Xipha striata* Subzone to *Latium paucum* Subzone; Blome, 1984).

Directly northwest from the town of John Day across Little Dog Creek, chert samples (P–1, P–3) collected by Merlyn Nestell (University of Texas, Arlington) contained a younger fauna of latest Triassic (latest Norian) or possibly Early Jurassic (Hettangian) age (see Blome and others, this volume).

The Middle Triassic (late Ladinian) radiolarian assemblage (originally called Jurassic) recovered by Jones, Pessagno, and Force (1976) from the Miller Mountain melange area near Vance Creek south of John Day bears strong resemblance to radiolarian assemblages figured by Kozur and Mostler (1981) from the Austrian Alps and to assemblages examined from Italy. Other black chert samples (OR 68–71; Blome, 1984a) collected from the same locality also contained similar age Middle Triassic (late Ladinian) or Late Triassic (early Karnian) radiolarians. This radiolarian fauna is interpreted to be of early Karnian age based on the presence of *Gorgansium* Pessagno and Blome (1980), which makes its first appearance in the Karnian.

The eastern part of the central melange terrane is characterized by ophiolite fragments, chert, argillite, siliceous tuff, and rare coarse-grained sedimentary rocks. Most of the eastern part of this terrane has undergone low-grade metamorphism (greenschist facies), and in many areas it includes structurally intermixed plutonic masses.

West of the town of Baker, chert collected by the junior author (see Blome and others, this volume) contained Middle Permian (Guadalupian) radiolarian faunas nearly identical in age and faunal composition to those collected in the southwestern part of the melange terrane near Grindstone Creek. Permian fusulinids from limestones near Suplee were also noted by Dickinson and Vigrass (1965). These workers and also Merriam and Berthiaume (1943) noted that the fusulinid limestones are correlative with limestones in part of the Elkhorn Ridge Argillite in the northeastern part of the central melange terrane (Taubeneck, 1955). According to Wardlaw and others (1982), a chert sample collected near Coyote Butte (southwestern part of the central melange terrane) contained Early Triassic (Scythian) conodonts and radiolarians. Metacherts collected from the Elkhorn Ridge Argillite east of Baker yielded poorly preserved radiolarian assemblages of both middle Permian (Guadalupian) and Late Triassic (early to middle Norian) ages. The Triassic assemblage included in these strata is assignable to the *Xipha striata* to *Latium paucum* Subzones of the *Capnodoce* Zone (Blome, 1984a). The radiolarians collected thus far from the Elkhorn Ridge Argillite indicates that the unit is equivalent in age to the Fields Creek Formation and all but the lower 5 m of the Rail Cabin Mudstone Member of the Vester Formation (Mesozoic clastic terrane).

A sample (BD 816) from the Elkhorn Ridge Argillite submitted to the senior author by Robert I. Coward (Department of Geology, Rice University) was found to contain *Canoptum* sp. and *Canoptum anulatum* Pessagno and Poisson (?). Investigations by Pessagno and Whalen (1982) and by Whalen (unpub. data) indicate that members of the *Canoptum anulatum* group first appear in highest upper Norian strata in western North America and occur throughout the Lower Jurassic (Hettangian to Toarcian). *Canoptum anulatum* s.s. is restricted to the upper Pliensbachian and Toarcian.

It is tempting to postulate a genetic relationship between the Seven Devils terrane and the central melange terrane and to suggest that the two have been associated as part of the same island arc.

Insofar as is known, no paleomagnetic data have been obtained from the central melange terrane.

However, Dickinson (1979, p. 166) and Bostwick and Nestell (1967) indicated that both Tethyan and American fusulinid faunas occur in separate pods in both the eastern and western parts of the melange belt. As already noted, the Middle Triassic radiolarians from cherts near Vance Creek south of John Day are very similar to those figured by Kozur and Mostler (1981) from the Austrian Alps. The Late Triassic radiolarian assemblage is very similar to that of the Brisbois and Rail Cabin Members of the Vester Formation and hence may likewise be Tethyan (see following discussion on the Mesozoic clastic terrane).

MESOZOIC CLASTIC TERRANE

The Mesozoic clastic terrane consists of rocks of Late Triassic (late Karnian) to Middle Jurassic (middle Callovian) age. It lies between the central melange terrane and Seven Devils terrane to the north and the Huntington arc terrane to the south. As noted previously, the Coon Hollow Formation (early Callovian to early Oxfordian), which overlies the Triassic Seven Devils Group with angular unconformity, appears to be genetically related to strata in the Mesozoic clastic terrane (for example, the Lonesome Formation). Furthermore, the Weatherby Formation, which unconformably overlies the Huntington arc terrane to the southeast, appears to be an extension of the Mesozoic clastic terrane (Brooks and Vallier, 1978).

The Mesozoic clastic terrane consists mainly of a somewhat flysch-like volcaniclastic succession, together with spilitic basalt and andesite flows of Late Triassic age (Karnian and late middle Norian; for example, Begg Member of the Vester Formation and Fields Creek Formation), rare andesite flows of Early Jurassic age (in the late Pliensbachian Nicely Formation), andesitic tuff breccias and andesitic flows of Middle Jurassic age (Bajocian; Basey Member of the Snowshoe Formation), and tuffs of the Middle Jurassic (Callovian) Trowbridge Formation (see Dickinson and Vigrass, 1965).

Unfortunately, no detailed paleomagnetic data are yet available for the rocks of the Mesozoic clastic terrane. However, abundant paleontologic data (Imlay, 1964, 1968, 1973, 1981; Pessagno and Blome, 1980, 1982; Pessagno and Whalen, 1982; Blome, 1983, 1984a,b) from the Suplee-Izee area of Dickinson and Vigrass (1965) and from surrounding areas suggest that this terrane, like the Seven Devils terrane to the north and the Huntington arc terrane to the south, originated at low latitudes within the Tethyan Faunal Realm and gradually moved northward to boreal latitudes during Late Triassic, Early Jurassic, and Middle Jurassic times.

SYNTHESIS OF PALEONTOLOGICAL DATA IN THE SUPLEE-IZEE AREA AND IN SURROUNDING AREAS

Late Triassic (late Karnian) ammonites recorded by Dickinson and Vigrass (1965, table 4) from the Brisbois Member of the Vester Formation include *Arcestes* Suess, *Discotropites* Hyatt and Smith, *Gymnotropites* Hyatt and Smith, *Homerites* Mojsisovics, *Juvavites* Mojsisovics, *Parahauerites* Diener, *Paratropites* Mojsisovics, and *Tropites* Mojsisovics. Using the distribution of data presented by Arkell and others (1957), *Arcestes* is seen to be cosmopolitan, whereas *Gymnotropites* and *Parahauerites* are known only from California and are hence suspected to be allochthonous. The remaining taxa occur throughout the Alpine-Himalayan belt and can be regarded as Tethyan, probably Central Tethyan.

The radiolarian assemblage from the Rail Cabin Mudstone Member (late Karnian?, early to late middle Norian) is diverse (see Pessagno and Blome, 1980; Blome, 1983, 1984a). Particularly noticeable in the Rail Cabin assemblage are the abundance and diversity of members of the family Pantanellidae. Pantanelliid diversity is, in part, overprinted by a period of adaptive radiation during the Late Triassic which gave rise to a variety of bizarre forms such as *Capnodoce* DeWever, *Loffa* Pessagno, and *Renzium* Blome among the Capnodocinae; longer ranging genera such as *Gorgansium* Pessagno and Blome include a relatively large number of species-level taxa (named and unnamed). Investigations by the writers over the past seven years indicate that diverse pantanelliid assemblages are characteristic of the Tethyan Faunal Realm. During the Late Jurassic, pantanelliid diversity and abundance decline drastically from the Northern Tethyan Province to the Southern Boreal Province (fig. 7.2).

In the overlying Lower Jurassic formational units, the megafossils, where they are abundant enough to be significant (for example, in the Suplee and Nicely Formations), are likewise Tethyan forms. Imlay (1968, p. C21) noted that the late Pliensbachian ammonite assemblage from the Suplee Formation and the overlying Nicely Formation closely resembled that of the same age from the Mediterranean area (for example, Italy), as shown by the abundance of genera and species among the families Dactylioceratidae Hyatt and Hildoceratidae Hyatt, and by the absence of those of the family Amaltheidae Hyatt. In addition to the ammonites, two bivalve (pelecypod) taxa that occur in the Suplee and Robertson Formations display distributions that have both important latitudinal as well as longitudinal significance. The rudistid-like bivalve *Plicatostylus* Lupher and Packard occurs in the Robertson Formation and in the lower part of the Suplee Formation in association with the dominantly Tethyan gastropod *Nerinea* Defrance (see Imlay, 1968, p. C6). *Plicatostylus* appears to be restricted to the eastern Pacific area; it is only known from California, Nevada, Oregon, and Peru (Cox, 1969, p. 866; Imlay, 1980, p. 53–57). The pectenacid *Weyla* Boehm occurs throughout the Suplee Formation in the Izee area (for example, at Morgan Mountain, west-northwest of Izee). Damborenea and Mancenido (1979), in their excellent analysis of the paleogeographical distribution of *Weyla,* indicated that it occurs in North Africa, Arabia, Madagascar, the Eurasian Tethys, and along the eastern margin of the Pacific from Chile to Alaska. Thus, only in the circum-Pacific region does *Weyla* display an apparent non-Tethyan distribution. It is likely that if one critically examines all of the eastern Pacific high-latitude occurrences of *Weyla,* it will always be found associated with other Tethyan molluscan taxa. Damborenea and Mancenido (1979, p. 88), for example, noted that *Weyla* is present in the Lubbe Creek Formation of the Wrangell Mountains, Alaska. There is little question that this high-latitude occurrence is due to the northward displacement of Wrangellia from low (Tethyan) latitudes. The occurrence of *Weyla* both in the Lower Jurassic strata of Wrangellia and of the Mesozoic clastic terrane suggests that both terranes originated in the Tethyan eastern Pacific.

Imlay (1968, p. C14) recovered the following late Toarcian ammonites from the lower part (equivalent to the Warm Springs Member; see Smith, 1981) of the Snowshoe Formation in the area near Izee: *Haugia* Buckman, *Polyplectus* Buckman, *Grammoceras* Hyatt?, *Catulloceras* Gemmellaro, and *Dumortiera* Haug. Most of these genera appear to be widespread Central Tethyan to Southern Boreal forms; *Catulloceras,* however, appears to be dominantly Tethyan (see Arkell and others, 1957; Gabilly and other, 1971; Sapunov, 1971).

The Early Jurassic radiolarian assemblage of the Nicely, Hyde, and Snowshoe Formations is also diverse and contains many elements (for example, *Praeconocaryomma parvimamma* Pessagno and Poisson, *Orbiculiforma mclaughlini* Pessagno, *Canoptum anulatum* Pessagno and Poisson) in common with Tethyan faunas. Pantanellid diversity and abundance remain high. However, the first occurrence of *Parvicingula* Pessagno in the middle Toarcian part of the Warm Springs Member (Snowshoe Formation) is noteworthy. This taxon is restricted to the Northern Tethyan Province (Tethyan Faunal Realm) and the Boreal Faunal Realm (see discussion below).

The diverse Middle Jurassic ammonite assemblage of the Suplee-Izee area and adjoining areas has been monographed by Imlay (1973, 1981). Except for a few endemic Pacific genera, most of its Aalenian (equivalent to early Bajocian as used by the U.S. Geological Survey but not the International Subcommission on Jurassic Stratigraphy) and Bajocian genera occur throughout the Tethyan Faunal Realm and in the Southern Boreal Province of the Boreal Faunal Realm. In contrast, the late Bathonian and Callovian ammonite assemblage is less diverse and contains genera such as *Torricelliceras* Buckman, *Kepplerites* Neumayr and Uhlig, and *Pseudocadoceras* Buckman, which are mostly restricted to the Boreal Faunal Realm (see Imlay, 1981, p. 12-13). Together with these forms there are genera such as *Lilloetia* Crickmay that are known only from the boreal eastern Pacific, and others such as *Parpatoceras* Spath that are predominantly Tethyan. Missing are Callovian genera such as *Reineckeia* Bayle which, exclusive of the circum-Pacific area of suspect and displaced terranes, occurs in east-central Mexico (Imlay, 1980), North Africa, and in the Alpine-Himalayan belt (Arkell and others, 1957).

Middle Toarcian to Bajocian strata of the Snowshoe Formation contain a rich and diverse radiolarian assemblage. This assemblage is characterized by the abundance and diversity of species of *Parvicingula* Pessagno (sensu Pessagno and Whalen, 1982), *Hsuum* Pessagno, *Turanta* Pessagno and Blome, *Perispyridium* Dumitrica, and Pantanelliid genera such as *Zartus* Pessagno and Blome, *Pachyonchus* Pessagno and Blome, *Gorgansium* Pessagno and Blome, and *Pantanellium* Pessagno (figs. 7.2, 7.3). In general, the composition of the radiolarian assemblage remains much the same from middle Toarcian (Early Jurassic) until early Hauterivian (Early Cretaceous) time (base of Zone 1 to top of Zone 5, Pessagno and others, 1984).

The presence of *Pavicingula* Pessagno in the middle Toarcian to Bajocian assemblage is particularly significant. This taxon is restricted to the Northern Tethyan Province of the Tethyan Faunal Realm during this age interval (figs. 7.2, 7.3). Central Tethyan deposits of Middle and Upper Jurassic red manganiferous ribbon chert and limestone from the Mediterranean area (Baumgartner and others, 1980), Iran, Oman, Tibet, Puerto Rico, and the circum-Pacific region are characterized by their total lack of *Parvicingula* Pessagno; *Parvicingula* is replaced instead by species of *Ristola* Pessagno and Whalen (figs. 7.2, 7.3). It should be noted that pantanelliid diversity is high in all well-preserved Central Tethyan samples.

The Upper Jurassic (Kimmeridgian to upper Tithonian) Taman Formation in east-central Mexico (Pessagno and Longoria, unpub. data) contains abundant radiolarians associated with ammonites, the pectenacid *Aulacomyella* Furlani, calpionellids, and nannoconids (fig. 7.3). The presence of calpionellids, coupled with a molluscan assemblage of strong Mediterranean affinities, indicates that this area was part of the Tethyan Faunal Realm (see Cantu Chapa, 1971; Imlay, 1980, p. 38). The radiolarian fauna is characterized by the presence of *Parvicingula* Pessagno (sensu Pessagno and Whalen, 1982) and by a diverse assemblage of pantanelliids. Species of Pantanellidae are considerably more abundant and diverse than they are in strata of Kimmeridgian or Tithonian age in the Boreal Faunal Realm (for example, the Galice Formation, Northern California, and the upper half of the volcanogenic-pelagic succession overlying the Coast Range ophiolite at Point Sal and Stanley Mountain). There are three to five times more species-level taxa (named and unnamed) present in the Taman assemblage than there are in Boreal strata of the same age in California (fig. 7.2). In addition, it should be noted that the upper Tithonian part of the Taman Formation contains Tethyan species such as *Acanthocircus dicranocanthos* Squinabol (Tithonian to lower Hauterivian) that have never been observed in the Boreal California faunas. *A. dicranocanthos* also occurs in red ribbon cherts from the Mediterranean area, Oman, the Franciscan Complex of California, the East Indies (Sarawak), Japan, and other areas; it is known as well from numerous central Tethyan Deep Sea Drilling Project samples of Late Jurassic to Early Cretaceous age (for example, DSDP Leg 1, Site 5A, Blake-Bahama Basin; DSDP Leg 32, Sites 303–307; DSDP Leg 62, Site 463, Mid-Pacific Mountains; see Pessagno, 1969; Foreman, 1975; Schaaf, 1981). The Taman radiolarian assemblage from east-central Mexico thus seems to link the assemblage of the Central Tethyan Province with that of the Southern Boreal Province. Considering also the Tethyan nature of the associated mollusks, calpionellids, and nannoconids, this indicates that east-central Mexico is representative of the Northern Tethyan Province of the Tethyan Faunal Realm.

In the late Bathonian fauna of the Snowshoe Formation (South Fork Member of Smith, 1980) at Izee, there is a dramatic drop in pantanelliid diversity, but *Parvicingula* species are abundant and diverse. This indicates that by latest Bathonian time the Mesozoic clastic terrane was in Boreal latitudes. The ammonite assemblage shows a mixture of both Boreal and Tethyan elements (predominantly Boreal, see above), suggesting that the Mesozoic clastic terrane was situated in the Southern Boreal Province by this time. The shift of the Mesozoic clastic terrane from lower (Tethyan) to higher (Boreal) latitudes is reflected in even a crude analysis of pantanelliid diversity. There appears to be a progressive drop in pantanelliid diversity from the early Bajocian (equals middle Bajocian as used by Imlay, 1973; Pessagno and Blome, 1980) onwards. Twenty plus species-level taxa (named and unnamed) are present in Aalenian and lower Bajocian Snowshoe samples, seven in upper Bajocian Snowshoe samples; two in uppermost Bathonian Snowshoe samples; and only one in Callovian samples from the Lonesome Formation (the upper Bajocian strata are included in the *rotundum* Zone of Hall and Westermann, 1980). Pantanelliids are virtually absent in radiolarian faunas from higher Boreal latitudes. For example, well-preserved middle Callovian faunas from the Shelikof Formation of Alaska contain *Parvicingula* and other elements in common with the Oregon uppermost Bathonian and Callovian, but they totally lack pantanelliids (Blome, 1984b). The Shelikof radiolarian assemblage is significant in that it occurs at the same horizon with *Cadoceras (Stenocadoceras)* (identifications by R. W. Imlay, U.S. Geological Survey). *Stenocadoceras* Imlay is a high-latitude Boreal taxon, which occurs also in Russia and Greenland.

In summary, the paleontological data indicate that the Mesozoic clastic terrane originated at low latitudes (Central Tethyan Province) during the Late Triassic (Karnian) and was still at relatively low latitudes (Central Tethyan Province) in the Early Jurassic (late Pliensbachian). By Toarcian, Aalenian, and Bajocian times, this terrane appears to have been at somewhat higher latitudes but still within the Tethyan Faunal Realm. The presence of abundant *Parvicingula* in the middle Toarcian to Bajocian faunas suggests a latitudinal position within the Northern Tethyan Province. Declining pantanelliid diversity through the Bajocian may reflect a gradual northward shift of this terrane within the Northern Tethyan Province. The dramatic drop in pantanelliid diversity by latest Bathonian to middle Callovian, coupled with an ammonite assemblage possessing Boreal taxa together with some Tethyan taxa, suggests a latitudinal position in the Southern Boreal Province (figs. 7.2, 7.3). The Mesozoic clastic terrane probably was displaced to even higher latitudes during the Late Jurassic. Unfortunately, no Upper Jurassic strata are exposed; if present, they are covered by Cenozoic volcanic rocks. Finally, the presence in the Mesozoic clastic terrane of bivalves, such as *Weyla* and *Plicatostylus,* which are known in the circum-Pacific region only from the eastern Pacific, suggests that this terrane originated in the eastern Pacific.

HUNTINGTON ARC TERRANE

Hillhouse and others (1982) indicated that the calc-alkaline volcanic rocks of the Upper Triassic Huntington Formation (Brooks, 1979) formed 18° ($\pm$4°) north or south of the Triassic paleoequator. The Huntington Formation is overlain unconformably by the Jurassic

Weatherby Formation (Sinemurian and Callovian; see Brooks, 1979; Imlay, this volume). Dickinson (1979, p. 166) included the Huntington Formation in his Huntington arc terrane and the overlying Weatherby Formation in his Mesozoic clastic terrane. The Weatherby Formation contains Early and Middle Jurassic ammonite faunas that are similar to those of the Suplee-Izee area and adjoining areas in the John Day Inlier (see Imlay, 1973, this volume). Hence, these faunas seem to reflect the same latitudinal shift from the Tethyan Faunal Realm to the Boreal Faunal Realm during Early and Middle Jurassic times.

CONCLUSIONS

A major stumbling block to interpreting the relationships of the various tectonostratigraphic terranes in the Blue Mountains Province has been the correlation of the Seven Devils terrane with Wrangellia. If "the Wrangellian fly is removed from the soup," tectonostratigraphic relationships between the various terranes appear to be clearer.

We suggest that the Seven Devils terrane, the central melange terrane, the Mesozoic clastic terrane, and the Huntington arc terrane are all components of a single island arc complex, the Blue Mountains island arc, and that this entire complex originated in the eastern Pacific central Tethys at paleolatitudes about 18° north or south (Hillhouse and others, 1982) during the Triassic. The combined paleomagnetic and paleontological data from the Seven Devils, Mesozoic clastic, and Huntington arc terranes of the Blue Mountains island arc indicate that this terrane had been displaced to Northern Tethyan latitudes by middle Toarcian to Bajocian time and to Southern Boreal latitudes by the latest Bathonian to middle Callovian. Subsequent displacement to higher boreal latitudes probably occurred during the Late Jurassic.

It is important to note that the megafossil assemblage in volcanic successions of the so-called Nevadian complex of California and western Nevada reflects the same shift from the Tethyan Faunal Realm to the Boreal Faunal Realm during the Mesozoic. Triassic units in related calc-alkaline successions in western Nevada contain megafossils having strong Tethyan affinities. In western Nevada the Candelaria, Excelsior, Grantsville, Luning, and Gabbs Formations contain mollusks, reef corals, and brachiopods of central Tethyan aspect (see Muller and Ferguson, 1939; Silberling, 1959). For example, Muller and Ferguson (1939, table 4, p. 1609) noted that the cephalopod fauna of the Gabbs Formation is typically Mediterranean. Their extensive list of taxa includes forms such as *Stenoarcestes* Mojsisovics, *Cladiscites* Mojsisovics, *Paracladiscites* Mojsisovics, *Pinacoceras* Mojsisovics, and *Placites* Mojsisovics. These forms occur outside the circum-Pacific region, in the Alpine-Himalayan belt (Arkell and others, 1957). It is also significant to note that reef-building corals occur in the Luning Formation (see Muller and Ferguson, 1939, p. 1599-1600). Silberling (1959, p. 20-21) noted that a late Karnian assemblage of ammonites similar to that described by Mojsisovics (1893) from the Hallstatt region of the Austrian Alps occurs in the Hosselkus Limestone in the Taylorsville area (Shasta County, California). Furthermore, Muller and Ferguson (1939, p. 1600) noted that Norian strata in Shasta County, California (presumably in the Hosselkus Limestone) contained an assemblage of reef-building corals that is similar to that of the Luning Formation.

The Tethyan character of the molluscan assemblage in so-called Nevadian rocks is likewise reflected in Early Jurassic successions related to calc-alkaline volcanism in the Sierra Nevada and in western Nevada. For example, Imlay (1968) noted that the late Pliensbachian ammonite assemblage of the Sailor Canyon Formation (Sierra Nevada) exhibits strong Mediterranean affinities like those of the Nicely and Hurwal Formations in the Mesozoic clastic terrane of the Blue Mountains island arc. It is also worth noting that the Tethyan bivalve *Weyla* Böhm occurs in the Potem Formation of north-central California and in the Hardgrave Sandstone of the Taylorsville area in northern California (see Imlay, 1980, p. 57, 61). Furthermore, *Plicatostylus* Lupher and Packard, which is associated with *Weyla* in the lower part of the Suplee Formation in Oregon, occurs in the Sunrise Formation of western Nevada and in the Thompson Limestone of the Taylorsville area in northern California (Imlay, 1980, p. 53, 57). The Middle Jurassic ammonite assemblage of the Sierra Nevada, though not as well known, contains many of the same faunal elements as that of Oregon. Middle Jurassic (Bajocian) radiolarians are unknown from so-called Nevadian rocks except at one locality near the Consummes River. A sample of tuffaceous chert (Sample DO3–11 from Philip Behrman, University of California, Berkeley) from this locality was found to contain a Central Tethyan radiolarian assemblage including *Ristola* Pessagno and Whalen, *Zartus* Pessagno and Blome, *Pantanellium* Pessagno, and *Pachyoncus* Pessagno and Blome (figs. 7.2, 7.3).

The Callovian ammonite assemblage of the western part of the Sierra Nevada, like that in the Blue Mountains island arc of Oregon, shows a mixture of Boreal with Tethyan to Southern Boreal elements (see Imlay, 1961, p. D18). Boreal elements include *Cadoceras* Fischer, *Paracadoceras* Crickman, *Pseudocadoceras* Buckman, and *Kepplerites* Neumayr and Uhlig; Tethyan to Southern Boreal elements include such forms as *Choffatia* Siemiradzki, *Reineckeites* Buckman, and *Grossouvria* Siemiradski (see Imlay, 1961, p. D6, D18). Oxfordian and Kimmeridgian strata in this area are characterized by the abundance of the Boreal bivalve *Buchia concentrica* (Sowerby), in association with ammonites that are strictly Boreal, such as *Amoeboceras* Hyatt, or that are predominantly Tethyan, such as *Idoceras* Burckhardt. Kimmeridgian radiolarian faunas from the lower part of the Galice Formation in northern California are characterized by the presence of *Parvicingula* Pessagno (sensu Pessagno and Whalen, 1982) and a pantanellid assemblage of low diversity.

These data, together with those from the Blue Mountains island arc, suggest that the so-called Nevadian terrane and the Blue Mountains island arc were part of the same island arc complex, which originated at near-equatorial latitudes in the eastern Pacific. We suggest that this island arc complex was carried northward along a megashear system analogous to the present day San Andreas fault. Such a megashear may have been related to those well documented by Longoria (1984) in east-central and northeastern Mexico, and therefore to the rifting and subsequent sea-floor spreading which formed the Gulf of Mexico and moved North America away from South America (Buffler and others, 1980; Dickinson and Coney, 1980).

We further suggest that island-arc volcanism in the Blue Mountains island arc occurred in two phases: (1) a Permian to Late Triassic near-axis phase (Seven Devils Group, Huntington Formation, Begg Member of the Vester Formation, Fields Creek Formation) and (2) an Early Jurassic (late Pliensbachian) and Middle Jurassic (Callovian) off-axis phase (Nicely, Snowshoe, Trowbridge, and Weatherby Formations). The central melange terrane component of the Blue Mountains island arc (Paleozoic to Late Triassic; Early Jurassic?) may represent a subduction complex associated with the earlier phase of island-arc volcanism noted above. The rocks in the Mesozoic clastic terrane component of the Blue Mountains island arc reflect a second phase of island-arc development, which began in the Early Jurassic (late Pliensbachian) and continued at least until the Middle Jurassic (early Callovian). The position of the axial zone of the Jurassic arc that produced the sporadic tuffs, andesitic tuff breccias, and andesitic flows in the Mesozoic clastic terrane component of the John Day Inlier is, at present, enigmatic and may never be known because of the cover of Cenozoic volcanic rocks. However short lived, comparatively simple island-arc complexes, such as the Greater Antilles, yield some important inferences concerning the position of the axial zone of island-arc volcanism. In Puerto Rico, for example, island-arc volcanism occurred from Early Cretaceous (Aptian? and Albian) to early middle Eocene time along a northwest-southeast axis, which gradually shifted northwards (see Christman, 1953; 1973: Lesser Antilles). The youngest plutonic rocks are batholiths of quartz monzonite and quartz diorite (Utuado and San Lorenzo batholiths), which were emplaced in the axial zone of early middle Eocene volcanism during or subsequent to a major orogeny that culminated island-arc volcanism and intensely folded and faulted all early middle Eocene and older rocks (Weaver, 1958; Berryhill and others, 1960; Mattson, 1960; Pessagno, 1960, 1961, 1962; Glover, 1971). There appears to be a shift in "granitic" plutonic activity in eastern Oregon and western Idaho from west to east during late Triassic to early Tertiary time, and a corresponding shift in the axial zone of island-arc volcanism may be suggested (see Hamilton, 1978).

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8. GEOLOGIC IMPLICATIONS OF RADIOLARIAN-BEARING PALEOZOIC AND MESOZOIC ROCKS FROM THE BLUE MOUNTAINS PROVINCE, EASTERN OREGON

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ABSTRACT

The Blue Mountains province can be described as a collage of tectonic blocks or "terranes," some of which have been displaced from their original site of formation. Five such tectonostratigraphic terranes are now recognized in the province: the Grindstone, Izee, Olds Ferry, Baker, and Wallowa terranes. The ability to determine the ages of late Paleozoic and early Mesozoic radiolarian-bearing rocks in the southwestern part of the Blue Mountains province provides critical evidence for unraveling the province's stratigraphic and structural history.

Most cherts from the Grindstone terrane are Early Permian to Early Triassic in age. Cherts from the southwestern part of the Baker terrane are Late Triassic, whereas those in the northeastern part are of both Permian and Late Triassic age. A few Baker terrane cherts may even be as young as Early Jurassic. The absence of cherts of Late Triassic age in the Grindstone terrane, its general lack of volcanic and volcaniclastic rocks, and its low regional metamorphic grade, all indicate that the Grindstone terrane is a separate tectonic block from the juxtaposed Baker and Izee terranes.

Upper Triassic cherts collected from sedimentary units throughout the Izee terrane prove that some units are facies equivalents and provide new insight into their provenances. A Carboniferous age for a chert clast from the basal part of the Izee terrane and the Permian and Early Triassic ages established for cherts in the Grindstone terrane make it unlikely that the Grindstone was the sole source for Izee detritus. Permian and Triassic sedimentary and volcaniclastic units in the Baker terrane are an obvious source for detritus in the sedimentary units of the Izee terrane, as well as for the Jurassic flysch in the Olds Ferry terrane.

INTRODUCTION

Pre-Cenozoic rocks within the Blue Mountains province occur in a belt trending northeast from the area near the town of Suplee to near Grangeville, Idaho (fig. 8.1). Numerous inliers or windows of Paleozoic and Mesozoic (Devonian to Cretaceous) rocks in this belt are surrounded by Tertiary lavas and sedimentary rocks of continental origin (Brooks and Vallier, 1978). These inliers contain the only pre-Tertiary outcrops known between British Columbia and northernmost Washington on the north, and southern Oregon on the south (Dickinson and Thayer, 1978).

The varied terminology used for the structural units within the Blue Mountains province of northeastern Oregon and southwestern Idaho can be confusing. For consistency and simplicity, the terrane map constructed by Silberling and others (1984) is used here. They divide the east-central Oregon area, starting in the southwest, into five distinct tectonostratigraphic terranes: Grindstone, Izee, Olds Ferry, Baker, and Wallowa (fig. 8.1).

The Grindstone terrane was first termed the Paleozoic shelf terrane by Vallier and others (1977) because of the presence of shallow-water Devonian rocks in its western part. This tectonic block was also termed the melange terrane by Dickinson and Thayer (1978), and it represents the southwesternmost part of the dismembered oceanic terrane of Brooks and Vallier (1978).

The Izee terrane contains abundant clastic rocks and includes the western half of Vallier and others' (1977) oceanic terrane, the western half of Dickinson's (1979) Mesozoic clastic terrane, and the western half of the forearc basin terrane of Brooks (1979a).

The rocks included in the Olds Ferry terrane were originally considered to form the southern part of the oceanic terrane and the southern part of the volcanic arc terrane as described by Vallier and others (1977). These rocks later included the Jurassic flysch terrane and Juniper Mountain-Cuddy Mountain volcanic arc terrane of Brooks and Vallier (1978). The Olds Ferry terrane also represents the eastern half of Dickinson's (1979) Mesozoic clastic terrane and was included as part of the forearc basin as described by Brooks (1979a).

The Baker terrane was originally defined as the oceanic terrane by Vallier and others (1977) because it consisted of structurally dismembered blocks of oceanic origin. It was later termed the dismembered oceanic terrane by Brooks and Vallier (1978) and the central melange terrane by Dickinson and Thayer (1978).

The Wallowa terrane was originally considered the northern part of the volcanic arc terrane of Vallier and others (1977). It has also been termed the Wallowa

Mountains-Seven Devils Mountains volcanic arc terrane by Brooks and Vallier (1978) and the Seven Devils terrane by Dickinson (1979). The Wallowa terrane is considered by Jones and others (1977) to represent a possible detached block of the Wrangellia terrane, known mainly from Alaska and British Columbia.

Although the general geology of the various terranes is known, critical stratigraphic and structural relationships between juxtaposed terranes are yet to be resolved, in part because of inadequate paleontologic dating. Radiolarian biostratigraphy has proven helpful in resolving stratigraphic problems in volcanic-arc and ophiolite assemblages (Blome and Irwin, 1985) and in tectonically disrupted units such as melanges or olistostromes (Blome, 1984). The purposes of this paper are to ascertain the age relationships of radiolarian-bearing rocks within some of the terranes defined by Silberling and others (1984) and, as far as possible, to establish depositional relationships within each individual terrane, as well as structural relationships between adjacent terranes.

GRINDSTONE TERRANE

The Grindstone terrane contains the oldest rocks within the Blue Mountains province. This olistostrome-

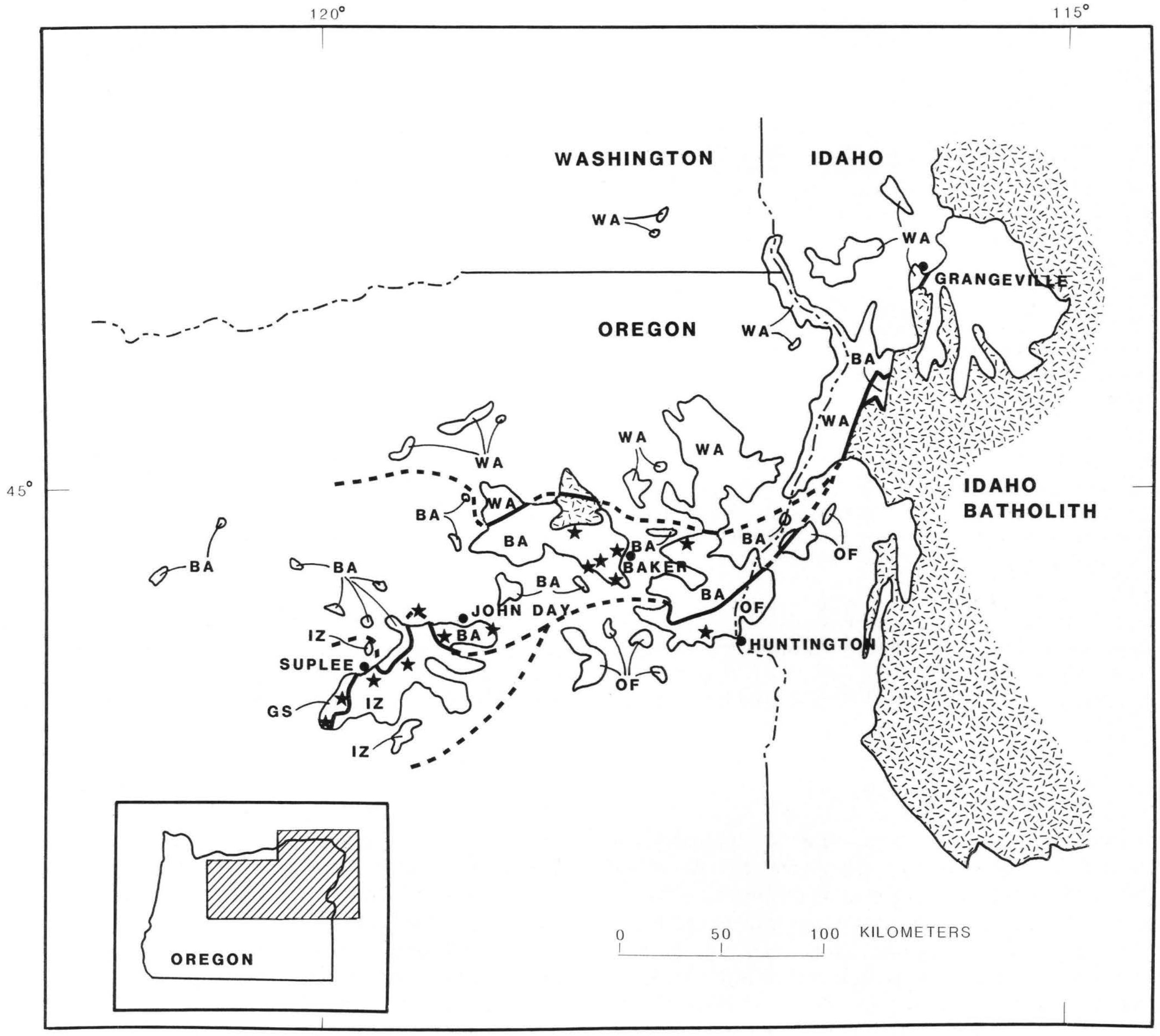

FIGURE 8.1.—Distribution of pre-Tertiary rocks with generalized terrane boundaries for the southwestern part of the Blue Mountains province: WA = Wallowa terrane; BA = Baker terrane; IZ = Izee terrane; OF = Olds Ferry terrane; and GS = Grindstone terrane (after Silberling and others, 1984). Star symbols indicate radiolarian collecting localities.

rich terrane is exposed along the southwestern border of the province (fig. 8.1) and contains a tectonically disrupted assemblage of (1) Middle Devonian limestone interstratified with cherty sandstone, chert, and argillite; (2) Mississippian argillite, sandy limestone, calcareous sandstone, and conglomeratic sandstone (Coffee Creek Formation); (3) Pennsylvanian mudstone, sandstone, and conglomerate containing plant remains (Spotted Ridge Formation); (4) Permian partly fusulinid-bearing, partly feldspathic, and sandy limestone (Coyote Butte Formation); and (5) Permian radiolarian-bearing red, black, and green chert. The first four of these units were first described by Merriam and Berthiaume (1943).

According to Dickinson (1979), both Tethyan and American fusulinid faunas occur within this terrane. Fossiliferous limestones have yielded a variety of faunas ranging in age from Devonian to Permian (Merriam and Berthiaume, 1943; Kleweno and Jeffords, 1961; Dickinson and Vigrass, 1965). Devonian limestones containing stromatoporoids and other shallow-water invertebrates were first reported in the northwestern part of the terrane by Kleweno and Jeffords (1961). Permian fusulinids from limestones near Suplee were also noted by Dickinson and Vigrass (1965), and both they and Merriam and Berthiaume (1943) inferred that these fusulinid limestones are correlative with limestones in part of the Elkhort Ridge Argillite near the town of Sumpter (located approx 30 mi northwest of Baker, Oregon; Taubeneck, 1955). According to Wardlaw and others (1982), the Coyote Butte Formation contains conodonts, fusulinids, and brachiopods of Early Permian (Leonardian) age and is similar in age, fauna, and sedimentology to limestone near Quinn River Crossing, Nevada.

Siliceous rocks within the Grindstone terrane include abundant blue-black, green, and red chert, cherty graywacke, tuff, tuffaceous breccia and chert breccia, as well as chert-pebble conglomerate (Dickinson and Thayer, 1978). Chert exposures predominate over limestone in the north and represent sparsely exposed, lenticular pods, most of which are elongate in a north-south direction. These chert exposures are generally red and green and are most continuous in the north near the Weberg Ranch and along the North Fork of Trout Creek (fig. 8.2). Chert exposures to the south between Grindstone and Twelvemile Creeks are smaller, less continuous, and more varied in color. Almost all the chert exposures, no matter what the internal color, weather to blue-black. Most of the chert, even where poorly exposed, exhibits well-developed bedding structure, in contrast to the massive metachert within the Elkhorn Ridge Argillite to the east. Cherty breccia, tuff, and recrystallized (tectonized) tan chert and white limestone form more prominent exposures than the less diagenetically altered red and green chert and buff limestone. In the northern part of the Grindstone terrane, chert and limestone occur on the topographic highs, whereas tuff, chert breccia, and conglomerate occur on the ridge flanks.

Structurally discontinuous tuffaceous red and green chert was collected for radiolarians in the Suplee quadrangle due west of the Robertson Ranch. Two thinly bedded blocks of chert (82CB–106, –108; see fig. 8.2 and locality descriptions) contained radiolarian faunas which are probably Early Permian (late Wolfcampian or early Leonardian) and are characterized by *Pseudoalbaillella scalprata* Holdsworth and Jones, 1980 and by *P. longicornis* Ishiga, Kito, and Imoto, 1982b.

Discontinuous belts of chert, limestone, cherty breccia, and conglomerate continue farther south and southwest into the Delintment Lake quadrangle and the eastern half of the Twelvemile Reservoir quadrangle. Just north of Grindstone Creek in the northwest corner of the Delintment Lake quadrangle, these rocks are more metamorphosed (greenschist to amphibolite facies). Chert samples (82CB–105 and –111; see fig. 8.2 and locality descriptions) collected just north of an unnamed reservoir along Grindstone Creek contained middle Permian (late Leonardian or early Guadalupian) radiolarian faunas (plate 8.1). Characteristic species include *Parafollicucullus fusiformis* Holdsworth and Jones, 1980, *Pseudoalbaillella longicornis* Ishiga, Kito, and Imoto, 1982b, *P. globosa* Ishiga, Kito, and Imoto, 1982b, *Latentifistula* sp., and other undescribed genera of the superfamily Latentifistulidea Nazarov and Ormiston, 1983. At present, this fauna appears older than the Lamar Limestone of Guadalupian age (Ormiston and Babcock, 1979).

Chert samples collected approximately 1 mi north of 82CB–105 yielded an equally well-preserved Permian radiolarian fauna of similar age. This fauna is correlative with the *Follicucullus monocanthus* assemblage in Japan, which Ishiga and others (1982b) consider to be late Leonardian or early Guadalupian in age. Samples of tuffaceous green chert (82CB–109A to C; see fig. 8.2 and locality descriptions) collected from a block of chert breccia in the same vicinity yielded a Late Permian (late Guadalupian or Ochoan) radiolarian fauna. Although these faunas remain largely undescribed, they do contain *Angulobracchia, Latentifistula,* and other distinct cross-axon forms described by Takemura and Nakaseko (1981), as well as undescribed mammelate spheroidal spumellarians (plate 8.1).

Samples of well-bedded chert (82CB–114A to C; see fig. 8.2 and locality descriptions) collected south of Twelvemile Creek, near Three Buttes (also known as Coyote Butte and designated the type locality of the

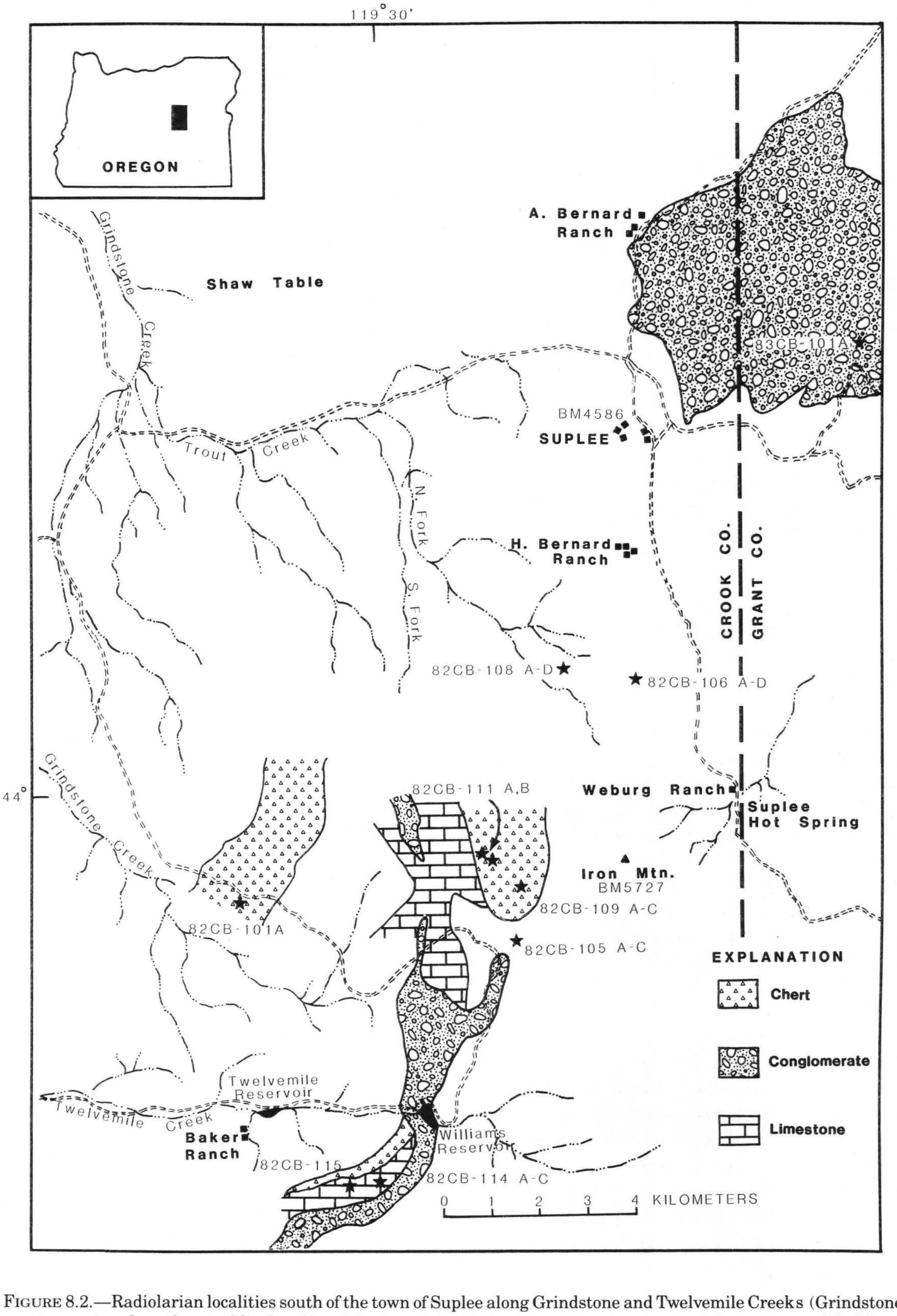

FIGURE 8.2.—Radiolarian localities south of the town of Suplee along Grindstone and Twelvemile Creeks (Grindstone terrane) and northeast of Suplee (Begg Member of the Vester Formation, Izee terrane), Oregon (modified from Merriam and Berthiaume, 1943; and Buddenhagen, 1967). Stars indicate radiolarian collecting localities.

Coyote Butte Formation by Merriam and Berthiaume, 1943), contained radiolarians largely correlative with those collected to the north of Grindstone Creek. Elements of this fauna include *Pseudoalbaillella* aff. *P. globosa* Ishiga, Kito, and Imoto, 1982b, *P. longicornis* Ishiga, Kito, and Imoto, 1982b (plate 8.1), *Follicucullus* aff. *F. scholasticus* Ormiston and Babcock, 1979, *Albaillella asymmetrica* Ishiga, Kito, and Imoto, 1982b, and *Latentifistula* cf. *L. crux* Nazarov and Ormiston, 1983. A float sample of black chert (82CB–115; see fig. 8.2 and locality descriptions) of Late Permian (late Guadalupian or Ochoan) age was also collected along the northwestern flank of Three Buttes and contained *Neoalbaillella* aff. *N. grypus* Ishiga, Kito, and Imoto, 1982a, as well as open-faced, cross-axon forms *(Latentibifistula)* described by Takemura and Nakaseko (1981).

Chert and limestone clasts were collected from a block of coarse, chert-pebble conglomerate between Wade Butte and Grindstone Creek in the northeast corner of the Twelvemile Reservoir quadrangle. A distinct radiolarian fauna extracted from the black chert clasts (83CB–101A; see fig. 8.2 and locality descriptions) possessed simple spheroidal spumellarians which have yet to be described. This conglomerate locality corresponds closely to Merriam and Berthiaume's (1943) site 21, which contained Permian fusulinids *(Triticites)* in limestone pods within the conglomerate. A previously collected chert sample from near Three Buttes (sample 7 in Wardlaw and Jones, 1980) contained Early Triassic conodonts and radiolarians.

According to Wardlaw and others (1982), most of the chert exposed near Three Buttes is of Triassic age. The abundant biostratigraphic data yielded by radiolarian-bearing cherts near Three Buttes, as well as in other parts of the Grindstone terrane, indicate that the Grindstone cherts are mostly of Permian (late Wolfcampian or early Guadalupian and late Guadalupian or Ochoan) age. At present, the southern and western areal extent of the Grindstone terrane remains undefined.

According to Dickinson and Thayer (1978), uplift and subsequent erosion of the Grindstone terrane provided all the detritus for the chert- and limestone-rich conglomerates of the Begg Member of the Late Triassic Vester Formation (Izee terrane). If this interpretation were valid, one would expect most or all of the chert clasts within the Begg chert-pebble conglomerates to be of Permian age. However, as shown below, the Begg chert conglomerate contains radiolarians of Carboniferous age.

IZEE TERRANE

The Izee terrane contains a thick, mainly flyschoid sequence of clastic sedimentary rocks, along with subordinate limestones, and volcanic and volcaniclastic rocks, which range in age from Late Triassic (Karnian) through Middle Jurassic (Callovian). Complex stratigraphic relationships and local unconformities indicate tectonic instability during deposition. The terrane includes Upper Triassic turbidite sequences, with minor finer grained basinal deposits, that lie depositionally atop the Grindstone terrane. The northward-trending Poison Creek fault divides the Upper Triassic and Lower Jurassic sedimentary rocks of the Izee terrane into two distinct stratigraphic units (fig. 8.3). Upper Triassic rocks west of the fault are represented by the Vester Formation, which includes the Begg and Brisbois Members, as well as the overlying Rail Cabin Argillite (Dickinson and Vigrass, 1965). The Rail Cabin Argillite was later renamed the Rail Cabin Mudstone by Blome (1984) and is herein revised as the Rail Cabin Mudstone Member of the Vester Formation. Triassic rocks east of the fault include the Late Triassic Fields Creek Formation and the Late Triassic(?) Laycock Graywacke of the Aldrich Mountains Group (Thayer and Brown, 1960).

The Begg Member unconformably overlies the predominantly Paleozoic rocks of the Grindstone terrane and represents the oldest rocks within the Izee terrane. This unit is characterized by chert-grain sandstone, chert-pebble conglomerate, volcaniclastic rocks, and sedimentary breccia, intercalated with equal or greater amounts of mudstone and siltstone. The precise age of the Begg Member is not known, as only a sparse invertebrate fauna has been found in the unit thus far. The unit has been questionably assigned by Dickinson and Vigrass (1965) to the Karnian Stage, below the late Karnian *Tropites subbullatus* Zone of Smith (1927), although the basal part of the member could possibly extend down into the Middle Triassic.

Clasts of black chert were collected from the Begg chert-pebble conglomerates along the southeast limb of the Little Bear anticline over a three-year period in the hope of determining both the age and provenance of the chert detritus. One sample (82CB–101A; see fig. 8.3 and locality descriptions) contained fragments of the radiolarian genus *Latentifistula* Nazarov and Ormiston, 1983 (plate 8.2), as well as other undescribed taxa of the superfamily Latentifistulidea Nazarov and Ormiston, 1983, and the family Entactiniidae Riedel, 1967. Although *Latentifistula* has a stratigraphic range of early Carboniferous (Mississippian) to Permian, the taxa from sample 82CB–101A are significantly different from Permian Latentifistulids collected in both the Grindstone and Baker terranes, and are therefore interpreted to be pre-Early Permian in age. Within the Begg conglomeratic beds, limestone blocks containing Mississippian and Permian fossils have also been reported

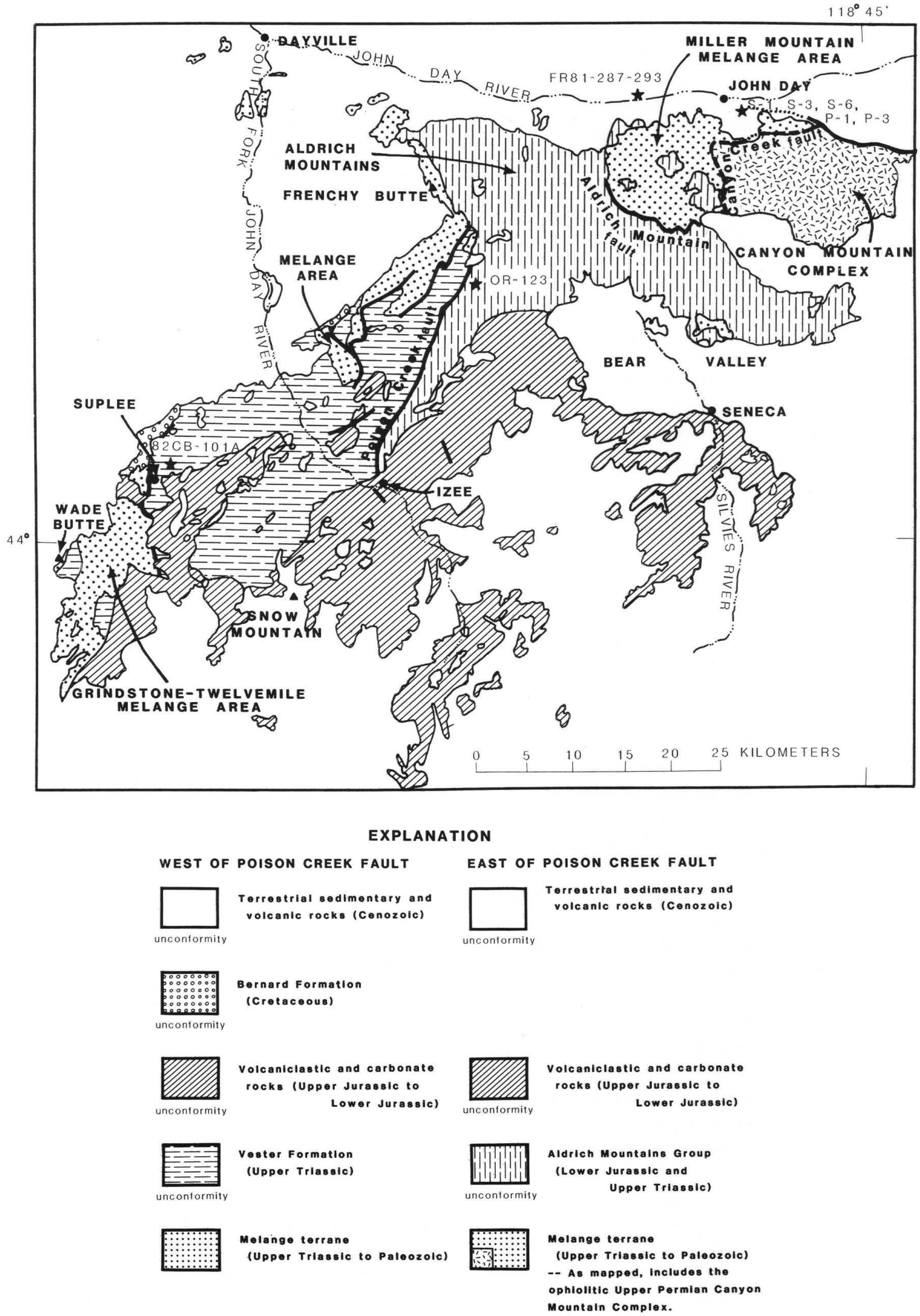

FIGURE 8.3.—Generalized geologic map of the John Day inlier both east and west of the Poison Creek fault (modified after Dickinson and Thayer, 1978). Star symbols indicate radiolarian collecting localities.

by Dickinson and Thayer (1978). Northwest of Suplee, Merlynd Nestell (written commun., 1983) reported well-preserved Permian fusulinid faunas from redeposited limestone pods within the Begg conglomerates.

All the radiolarian-bearing chert collected thus far from the Grindstone terrane has been of Permian age. The Carboniferous (or earliest Permian?) age of the single chert clast from the Begg conglomerates makes it doubtful that the Grindstone terrane to the west and southwest represents the only chert source for these chert-pebble conglomerates.

The Brisbois Member of the Vester Formation consists of thin-bedded, gray to black siliciclastic sandstone and sandy calcarenite intercalated within a more abundant, thin-bedded, soft mudstone matrix. The calcarenite beds consist of shallow-water brachiopod, pelecypod, gastropod, and crinoid fragments and were interpreted by Dickinson and Vigrass (1965, p. 23) to be bioclastic in origin. Other pelecypods (*Halobia* sp.) and ammonites collected throughout this formation are regarded as being from displaced limestone blocks. The ammonites collected from the Brisbois Member are all indicative of the upper Karnian *"Tropites subbullatus"* Zone (Dickinson and Vigrass, 1965). Specimens of *Halobia* cf. *H. ornatissima* Smith, of late Karnian age, were reported by Blome (1984) from the upper part of the Brisbois Member (locality V177 in Dickinson and Vigrass, 1965) .

The Rail Cabin consists predominantly of thinly bedded radiolarian-rich, dark-gray to black siliceous mudstones and cherts. Lenticular masses of gray-brown bioclastic limestone containing displaced shallow-water invertebrates occur sporadically throughout the unit. Minor amounts of thinly bedded, dark-gray to black (weathering to brown) calcilutites occur within its upper part.

At the type locality of the Rail Cabin north of Morgan Mountain, a sharp lithologic break exists between the underlying Brisbois Member of the Vester Formation and the harder siliceous mudstones of the Rail Cabin. This contact was interpreted by Dickinson and Vigrass (1965, p. 28) to be unconformable because of the markedly divergent bedding attitudes exhibited above and below the contact at Graylocke Butte.

The Rail Cabin is well exposed along the slopes of Morgan Mountain, located directly northwest of the town of Izee. Siliceous mudstone samples collected from 110 m (360 ft) of section near Elkhorn Creek contained well-preserved radiolarian faunas of Late Triassic (late Karnian?; early through late middle Norian) age (Blome, 1984). Although Dickinson and Vigrass (1965) interpreted the contact between the Brisbois Member of the Vester and the overlying Rail Cabin as being unconformable, a gradational contact was observed at this locality. Mudstones from the uppermost part of the Brisbois Member approximately one km southwest of Morgan Mountain contained radiolarian faunas essentially identical to those in the lower part of the Rail Cabin to the northeast (Blome, 1984).

The lithostratigraphic and biostratigraphic evidence collected from the Brisbois and Rail Cabin indicates that the lower part of the Rail Cabin and the upper part of the Brisbois Member, especially south and west of Morgan Mountain, are sedimentary facies equivalents (Blome, 1984). On the basis of this facies equivalency, the Rail Cabin Mudstone is reduced in rank and assigned as the upper member of the Vester Formation. Additionally, a 110-m. (360-ft) section near Elkhorn Creek (U.S. Geological Survey Izee 15′ quad. NW ¼SE ¼ sec. 14, T. 17 S., R. 27 E., west side of unnamed drainage west of Elkhorn Creek) is herein designated as a reference section for the Rail Cabin.

The predominantly siliceous Rail Cabin represents a period of pelagic sedimentation in a lower-slope depositional environment relatively free from terrigenous input. The minor occurrence of calcilutite (containing ammonites) in the upper part of the member may represent an intermittent lowering of the carbonate compensation depth (CCD). The partly contemporaneous, intertonguing Brisbois Member of the Vester Formation is interpreted as hemipelagic middle- and upper-slope deposits diluted by displaced calcarenite debris originally deposited in shallower water.

East of the Poison Creek fault, the Triassic rocks include the Upper Triassic Fields Creek Formation and the Upper Triassic(?) Laycock Graywacke (fig. 8.3). The Fields Creek Formation rests unconformably on the Begg Member of the Vester Formation near the northern end of the Poison Creek fault (Dickinson and Thayer, 1978).

The Fields Creek Formation is characterized by massive beds of dark mudstone and minor intercalations of graded sandstone. The basal part of this formation is largely composed of slide blocks of various lithologies, presumably derived from the melange areas to the northwest (Dickinson and Thayer, 1978).

Until recently, the only known fossils from the Fields Creek Formation were Norian megafossils from redeposited limestone blocks. These transported limestone blocks, collected from the basal part of the formation, contained middle or late Norian *Halorella* (Brown and Thayer, 1977). A siliceous mudstone sample (OR–123C; see fig. 8.3 and locality descriptions) collected from this olistostromal basal section contained a well-preserved radiolarian fauna (plate 8.3) of Late Triassic (early Karnian) age (Blome, 1984). This radiolarian fauna is identical to the radiolarian fauna from chert blocks in the Miller Mountain area near Vance

Creek. The paleontologic evidence agrees with Dickinson and Thayer's (1978) concept that the basal part of the Fields Creek Formation represents tectonic blocks displaced from uplifted nearby melange areas, and it also indicates that melange formation continued in the Izee terrane until Late Triassic time.

Other radiolarian-bearing mudstone samples (OR–123A,B; see locality descriptions) collected very near OR–123C, contained early Norian to late middle Norian radiolarian faunas essentially equivalent to those reported by Cheng (1982) from the stratigraphically higher middle and upper parts of the Fields Creek Formation. According to Dickinson and Thayer (1978, p. 156), the Vester Formation (Karnian and younger) was uplifted and contributed detritus to the thicker Aldrich Mountains Group (Norian and younger). The Norian age for the Fields Creek and the facies relationship established between the upper part of the Brisbois Member and the Rail Cabin Member west of the Poison Creek fault both suggest a different source for the Fields Creek detritus.

The Laycock Graywacke conformably overlies the Fields Creek Formation and consists of a mixture of mudstone and graywacke, along with minor amounts of cherty sedimentary breccia and boulder conglomerate. The unit is unfossiliferous but is considered to be of Late Triassic(?) age because of its stratigraphic position beneath the Lower Jurassic Murderers Creek Graywacke.

OLDS FERRY TERRANE

The Olds Ferry terrane typically contains Upper Triassic mafic and intermediate volcanic and volcaniclastic rocks of the Huntington Formation described by Brooks (1979b), overlain by Lower Jurassic (and possibly uppermost Triassic) limestone and coarse-grained volcaniclastic rocks, and Lower and Middle Jurassic coarse- to fine-grained sedimentary rocks of the Weatherby Formation. According to Brooks (1979b), the varyingly metamorphosed Upper Triassic volcanic rocks are largely andesitic in composition but range from basalt to rhyolite. Except for rare pods of limestone, the interlayered sedimentary rocks are entirely volcaniclastic or tuffaceous. Ammonites and pectenacid bivalves *(Halobia)* of Late Triassic (late Karnian to middle Norian) age are known from widely scattered localities. Upper Triassic strata are associated with small bodies of quartz diorite or granodiorite, one of which yielded a U-Pb age of 234 Ma (Walker, 1983). Generally faulted over these Upper Triassic rocks, but originally overlying them unconformably (and included within the Olds Ferry terrane), is the Jet Creek Member of the Weatherby Formation of Brooks (1979b). This member consists of shallow-marine limestone and gypsum and intercalated volcaniclastic conglomerate and sandstone of Early Jurassic (Sinemurian to late Pliensbachian) age. The rest of the Weatherby Formation is made up of Lower Jurassic (lower Sinemurian) and Middle Jurassic (lower Callovian) sandstone and argillite.

Paleomagnetic data from the Upper Triassic basalts of the Olds Ferry terrane agree with those from Triassic rocks in the Wallowa terrane, both data sets indicating a paleolatitude of about 18° N. or S., as well as a large clockwise rotation (Hillhouse and others, 1982).

Upper Triassic cherts (FR80–A to C; see fig. 8.4 and locality descriptions) of Elkhorn Ridge lithology containing Late Triassic (Karnian and Norian) radiolarians were collected 16 mi due west of the town of Huntington. According to Vallier and others (1977), outcrops of Elkhorn Ridge Argillite and Burnt River Schist appear locally within the area containing flyschlike rocks of the Olds Ferry terrane, either because they underlie part of the Olds Ferry and are exposed at structural windows, or because pieces of the oceanic Baker terrane were incorporated within the Olds Ferry as fault slices. Brooks and Vallier (1978, p. 140) note the presence of serpentinite and chert clasts in the Jurassic Weatherby sandstones in the northern part of the Olds Ferry terrane. This evidence would indicate that the Baker terrane is a probable source of detritus for the juxtaposed Olds Ferry.

BAKER TERRANE

The Baker terrane is represented by disrupted late Paleozoic oceanic crustal blocks, associated deep-marine sedimentary rocks of late Paleozoic and Triassic age (for example, the Elkhorn Ridge Argillite), and tectonically mixed blocks of various rock types. Extensive zones of melange exist in the southwestern part of the terrane, whereas more coherent rock slices occur in the northwestern and eastern parts. Large bodies of highly deformed but lithologically coherent metamorphic and sedimentary rocks, such as the Burnt River Schist and Nelson Marble, are also present (Silberling and others, 1984).

Lawsonite-bearing blueschist, associated with strongly sheared chert, quartzite, marble, and mafic metavolcanic rocks, are represented among the more western outliers of the Baker terrane in central Oregon. Near Mitchell, Oregon, these rocks have yielded an ^{40}Ar-^{39}Ar age of about 223 Ma (Hotz and others, 1977).

MILLER MOUNTAIN AREA

Blocks of serpentinite, siliceous shale, chert, assorted metamorphosed (greenschist grade) clastic

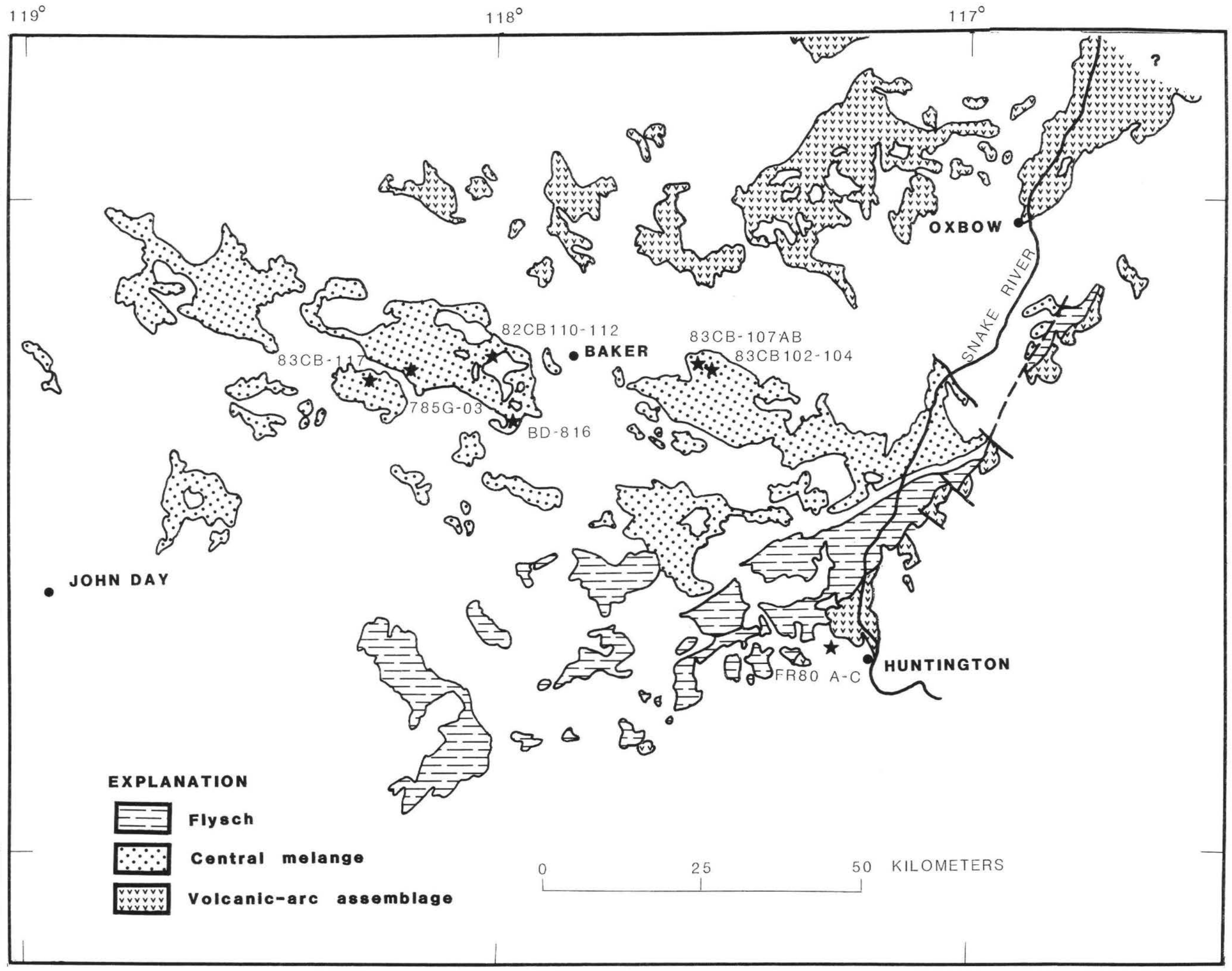

FIGURE 8.4.—Distribution of pre-Tertiary volcanic-arc rocks, melange, and Jurassic flysch between John Day, Oregon, and the Snake River (modified after Vallier and others, 1977). Star symbols indicate radiolarian collecting localities.

sedimentary rocks, greenstone, and varied volcaniclastic rocks make up a melange area in the Miller Mountain area, forming part of the Baker terrane. This melange is separated from the Canyon Mountain Complex (Brown and Thayer, 1966) by the Canyon Creek fault on the east and from the Aldrich Mountains Group of the Izee terrane by the Aldrich Mountain Fault (fig. 8.3). The Canyon Mountain Complex, which is well exposed southeast of the town of John Day (Brown and Thayer, 1966; Avé Lallemant, 1976) represents the basement rocks for the melange (Vallier and others, 1977).

The rocks in this melange area are largely unfossiliferous, particularly in its western part, but Early Permian fusulinids and middle Permian conodonts have been reported from limestone pods east and southeast of John Day (Dickinson and Thayer, 1978). Dickinson and Thayer (1978, p. 152) also reported Middle Triassic (late Ladinian) radiolarians in chert cropping out near Vance Creek. Black chert samples (OR68–71; see fig. 8.3 and locality descriptions), subsequently collected near Vance Creek, contained radiolarian faunas of similiar Middle (late Ladinian) or Late (early Karnian) Triassic age (Blome, 1984). These radiolarian faunas we now interpret to be of early Karnian age because of the presence of *Gorgansium* Pessagno and Blome (1980), a genus that makes its first appearance in the earliest part of the Karnian Stage.

FRENCHY BUTTE AREA

Composed almost entirely of serpentinite and metavolcanic rocks, the Frenchy Butte area is located north of the town of Izee, between the Fields Creek Formation (of the Aldrich Mountains Group) and the South Fork of the John Day River (fig. 8.3). Although unfossiliferous, this melange area was presumed by Dickinson and Thayer (1978) to be Permian and (or) Triassic in age.

ROCKS NORTH OF MILLER MOUNTAIN AND FRENCHY BUTTE

Chert similar to that in the Elkhorn Ridge Argillite occurs north of the Aldrich Mountains and northeast of the city of Mount Vernon. Samples of this chert (FR81–287 to –293; fig. 8.3 and locality descriptions) contained Late Triassic (early and middle Karnian) radiolarian faunas (plate 8.3). These faunas consist mainly of those taxa described by Nakaseko and Nishimura (1979) and include *Pseudostylosphaera helicatum, Triassocampe annulata, T. japonica,* and *Yeharaia elegans,* as well as ?*Tripocyclia* cf. *T. acythus* De Wever, 1979. This radiolarian assemblage differs slightly from the early Karnian fauna of the Miller Mountain melange area in that it contains abundant species of *Yeharaia* Nakaseko and Nishimura, 1979, a genus mostly restricted to Karnian age rocks.

Directly east of Canyon City and just north of the ophiolitic Canyon Mountain Complex, chert samples were collected by Merlynd Nestell (Univ. of Texas, Arlington) from two separate chert blocks. One set of these samples (S–1, S–3, and S–6; fig. 8.3 and locality descriptions) contained Late Triassic (early to late middle Norian) radiolarian taxa (see Plate 8.3) identical to those from the uppermost part of the Brisbois and the Rail Cabin Mudstone Members of the Vester Formation and from the Fields Creek Formation (Blome, 1984). A short distance to the northwest, across Little Dog Creek, chert samples (P–1, P–3; see fig. 8.3 and locality descriptions) yielded a younger radiolarian faunal assemblage of latest Triassic (latest Norian) age. This distinctive faunal assemblage contained taxa incorporated in Yao and others (1982) *Canoptum triassicum* Assemblage Zone of latest Norian age, as well as elements of the Upper Triassic (upper Norian) *Betraccium deweveri* Subzone described by Blome (1984). Nassellarians similar to Jurassic (Hettangian) forms described by Pessagno and Whalen (1982) were also present.

EASTERN PART OF THE BAKER TERRANE

Late Paleozoic and early Mesozoic rocks in the eastern part of the Baker terrane near Baker, Oregon, include abundant chert, argillite, and siliceous tuff and rare coarse-grained sedimentary rocks. Incorporated in this part of the terrane are argillite, chert, tuff, and limestone of the Elkhorn Ridge Argillite (fig. 8.3), thin-layered phyllitic quartzite, greenstone, and marble of the Burnt River Schist (Gilully, 1937), and basalt flows and volcaniclastic rocks. Most of this terrane has undergone severe structural deformation and metamorphism (greenschist to amphibolite facies), and in many areas it is structurally intermixed with plutonic bodies.

To the north and northeast, the Baker terrane is bounded by Lower Permian and Middle and Upper Triassic metavolcanic and volcaniclastic rocks, which are overlain by Upper Triassic and Lower Jurassic carbonate rocks and clastic sequences of the Wallowa terrane (Silberling and others, 1984; fig. 8.1). Late Permian through Middle Triassic sedimentary rocks are absent in the Wallowa terrane.

The Elkhorn Ridge Argillite was named by Gilully (1937) for a thick succession (565 m) of argillite, tuff, chert, and minor amounts of limestone and greenstone exposed on Elkhorn Ridge, which trends northwest-southeast and lies mostly within the Elkhorn Peak quadrangle (Baldwin, 1979). The major part of the Elkhorn Ridge Argillite is of Permian age, but it ranges from Middle Pennsylvanian to Late Triassic in overall age. Permian fusulinids have been reported both by Pardee and Hewett (1914) and by Bostwick and Koch (1962), who state that the fusulinid-bearing limestone pods within the Elkhorn Ridge Argillite correlate, at least in part, with the Coyote Butte Formation, which forms part of the Grindstone terrane of Silberling and others (1984). Bostwick and Koch (1962) also report Late Permian fusulinids from limestone pods east of Baker. Bostwick later reported Middle Pennsylvanian (Desmoinesian) fusulinids and Triassic(?) hexacorals from rocks mapped as the Elkhorn Ridge Argillite (Brooks and others, 1976).

The geology due west of the town of Baker, near Elkhorn Ridge in the Bourne quadrangle, is characterized by a metamorphosed Paleozoic igneous complex containing mostly gabbro, but with lesser amounts of diorite, quartz diorite, and contemporaneous metavolcanic rocks composed of basaltic lava flows and volcaniclastic rocks (Brooks and others, 1982). Metamorphosed sedimentary rocks in this area include the Elkhorn Ridge Argillite (Gilully, 1937), comprising dark argillite and chert with minor amounts of limestone, tuff, sandstone, and conglomerate. Siliceous rocks range from soft argillite to hard, indurated, uniformly bedded chert.

Metacherts collected from the Elkhorn Ridge Argillite near Elkhorn Ridge in the Bourne quadrangle (83CB–110 to –112; see fig. 8.4 and locality descriptions) were all barren of radiolarians, probably because of metamorphism related to emplacement of the Late Jurassic and Early Cretaceous Bald Mountain batholith. Other chert samples collected by Howard Brooks (Oregon Department of Mineral Industries, written commun., 1983) produced the same negative results. Although further collecting may be warranted, the possibility of obtaining datable radiolarians from the cherts near Elkhorn Ridge seems doubtful. Brooks and others (1982) note that Pennsylvanian, Permian, and Triassic fossils have all been found in the Elkhorn Ridge Argillite outside the Bourne quadrangle.

Farther west of Elkhorn Ridge, in the Bates and Greenhorn quadrangles, crustal rocks include Permian and Triassic(?) serpentinite, serpentinized melange, metamorphosed gabbro and diorite, as well as Permian greenstones, pillow basalts, tuffs, volcaniclastic rocks, conglomerate, and breccia (Ferns and others, 1983). These, like similar rocks to the east, are associated with the sedimentary rocks of the Elkhorn Ridge Argillite, and also with the clastic sedimentary sequence, unit "TrPa" of Ferns and others (1983). The "TrPa" unit contains argillite, siltstone, and sandstone, with minor amounts of conglomerate, chert, and limestone and differs from the Elkhorn Ridge Argillite by possessing more coarse clastic detritus, as well as being less siliceous.

Permian to Triassic age fossils have been reported from the Elkhorn Ridge Argillite within the Greenhorn quadrangle (Ferns and others, 1983), and in the Bates quadrangle in the sequence mapped as "TrPa". The fossils include both Early Permian (Leonardian) conodonts along with Early Permian (Wolfcampian) fusulinids from limestone blocks (Mullen, 1978). Ferns and others (1983) acknowledge the possibility that these Early Permian fossils may be exotic to the "TrPa" unit and were derived from the underlying melange by redeposition of limestone blocks.

Chert samples collected from the Greenhorn quadrangle were all barren of radiolarians, with the exception of a float pebble (78SG–03; see fig. 8.4 and locality descriptions) collected by N.J. Silberling near Olive Creek in the northwestern corner of the quadrangle. This float sample contained an early Late Permian (Guadalupian) radiolarian fauna characterized by *Follicucullus scholasticus* Ormiston and Babcock, 1980, and *Follicucullus ventricosus* Ormiston and Babcock, 1980. Other samples collected from well-bedded green and black chert nearby (83CB–120A–C; see fig. 8.4 and locality descriptions) were all barren of radiolarians and the provenance of Silberling's float sample remains unknown.

A chert sample (83CB–117; fig. 8.4 and locality descriptions) collected from outcrops in a gravel pit along Granite Boulder Creek in the central part of the Bates quadrangle contained early Late Permian (Guadalupian) radiolarians almost identical to those from Silberling's pebble locality. Characteristic taxa include *Follicucullus scholasticus* Ormiston and Babcock, 1980, *Follicucullus ventricosus* Ormiston and Babcock, 1980, and *Pseudoalbaillella* cf. *P. sakmarensis* (Kozur) 1982. In addition, another chert sample (83HB–703; see fig. 8.4 and locality descriptions) collected by Howard Brooks from the southwestern part of the Bates quadrangle (Brooks and others, 1984) yielded well-preserved early Late Permian (Guadalupian) radiolarians. Characteristic taxa again include *Follicucullus scholasticus* Ormiston and Babcock, 1980, and *F. ventricosus* Ormiston and Babcock, 1980, as well as undescribed *Pseudoalbaillella* sp.

The Permian age given by these radiolarian faunas and by the conodonts and fusulinids in the limestones disagree with those implied by the correlations of Brown and Thayer (1966b). They also suggest that the blocks of Permian limestone are probably indigenous to the "TrPa" unit and not reworked from the underlying melange.

South of Elkhorn Ridge, in the northeastern corner of the Beaverdam Creek quadrangle, a sample (BD–816; see fig. 8.4 and locality descriptions) of chert collected by Robert Coward yielded a poorly preserved radiolarian fauna containing *Canoptum*(?) *analatum* Pessagno and Poisson, 1979, and *Canoptum* sp. (Emile Pessagno, written commun., 1983). According to Pessagno and Whalen (1982) and Whalen (written commun., 1983), the multichambered *Canoptum anulatum* species group ranges in age from the very latest Norian through the Early Jurassic (late Pliensbachian or Toarcian). Multichambered species of *Canoptum* have also been reported by Yao and others (1982) from latest Triassic rocks in Japan.

East of Baker, isolated blocks of metamorphosed chert and limestone occur in the eastern half and northwestern quarter of the Oxman quadrangle. Although both the chert and limestone occur as individual blocks of varied sizes, they do form an arcuate belt extending northeast to southwest, which is in agreement with the regional structural trend suggested by Vallier and others (1977, p. 461).

In the more metamorphosed eastern part of the Baker terrane, cherts exhibit varying metamorphic grades, and some are distinctly foliated. The Elkhorn Ridge Argillite and Burnt River Schist are both very quartz-rich, but the latter unit has undergone a higher degree of metamorphism. Ashley (1967) proposed that the quartz-rich phyllites in the Burnt River Schist may have been derived from metamorphosed fragments of the Elkhorn Ridge Argillite. Metamorphosed cherts in the Oxman quadrangle represent another likely protolith for the phyllites of the Burnt River Schist.

Black chert (83CB–107A, B; see fig. 8.4 and locality descriptions) collected from the northwestern part of the Oxman quadrangle north of Second Creek contained age-diagnostic Permian (late Leonardian?; Guadalupian) radiolarians. Typical Guadalupian taxa include *Follicucullus scholasticus* Ormiston and Babcock, 1980, *F.* aff. *F. ventricosus* Ormiston and Babcock, 1980, and ?*Pseudoalbaillella* cf. *P. sakmarensis* (Kozur) 1982. Well-preserved Permian fusulinids were recently collected from nearby limestone pods by Merlynd Nestell (written commun., 1983).

Poorly preserved radiolarian faunas of Late Triassic (early to middle Norian) age were extracted from cherts (83CB–102, –103A,B, and –104; see fig. 8.4 and locality descriptions) collected in the eastern half of the Oxman quadrangle. Late Triassic genera include *Capnodoce* De Wever, 1979, and *Xipha* Blome, 1984. The Permian and Triassic radiolarian data, although preliminary, indicates a younging from west to east within the suggested northeast-southwest structural belt.

CONCLUSIONS

Radiolarian biostratigraphy has established that cherts from the Grindstone terrane are Permian (late Wolfcampian to late Guadalupian or Ochoan) in age. In the Baker terrane, Late Triassic (early Karnian) cherts occur in the Miller Mountain area and represent a southwestern extension of the Elkhorn Ridge Argillite. Other Baker terrane cherts near John Day range in age from Karnian to latest Norian and some may be as young as earliest Jurassic (Hettangian). Cherts typical of the Elkhorn Ridge Argillite near Baker are of both Permian (Leonardian to Guadalupian) and Late Triassic (Karnian to latest Norian) ages, and one sample may possibly be as young as Early Jurassic.

The Miller Mountain and Frenchy Butte melange areas should be placed within the Baker terrane for the following reasons: (1) Both these areas possess volcanogenic rock assemblages of greenschist metamorphic grade similiar to volcanic assemblages of the Baker terrane and (2) Late Triassic (Karnian) radiolarian faunas from the Miller Mountain area are nearly identical to those from the southwestern extension of the Elkhorn Ridge Argillite east and west of John Day.

Although equivalent-age Permian (Leonardian and Guadalupian) cherts occur in both the Grindstone and Baker terranes, the Grindstone terrane has no Middle or Upper Triassic cherts, generally lacks volcanic and volcaniclastic rocks, and also has a lower regional metamorphic grade. These differences indicate that the Grindstone terrane represents a separate tectonic block from the Baker terrane.

The Grindstone terrane may not be the sole chert source for the Karnian-age Begg conglomerates of the Izee terrane. The only dated chert clast from the Begg Member is Carboniferous or earliest Permian, an age unrepresented in either the Grindstone or the Baker terrane. The Late Triassic age for chert in the Miller Mountain melange area, and the Late Permian and Late Triassic ages for the rest of the Baker terrane chert appear to preclude the Baker terrane from being a source for Begg chert detritus.

Correlation of radiolarian faunas shows that the upper part of the Brisbois Member of the Vester Formation is locally a facies equivalent of the lower part of the heretofore-designated Rail Cabin Mudstone. The Rail Cabin has subsequently been revised herein as the upper member of the Vester Formation.

Identical Late Triassic (early Karnian) radiolarian faunas from both the olistostromal basal part of the Fields Creek Formation (Izee terrane) and the Miller Mountain melange area (Baker terrane) substantiate the interpretation that redeposited blocks in the basal part of the Fields Creek were derived from the Baker terrane to the north.

Late Triassic (late Karnian to middle Norian) radiolarian cherts collected from the Brisbois Member of the Vester Formation, the Rail Cabin Mudstone Member, and the Fields Creek Formation are coeval, indicating that the Fields Creek detritus could not have been derived from the uplift and erosion of the Vester Formation as was originally suggested.

The age of the Elkhorn Ridge Argillite in the Baker terrane is extended up to at least latest Triassic time by the discovery of latest Triassic and possibly Early Jurassic radiolarian faunas in cherts near John Day and east of Baker. The Baker terrane thus contains rocks slightly younger than the Triassic siliciclastic rocks of the Izee terrane.

Chert clasts in the Jurassic sandstones of the Weatherby Formation in the northern part of the Olds Ferry terrane, west of the town of Huntington, are of Elkhorn Ridge lithology and yield Late Triassic (Karnian and Norian) radiolarian faunas. This indicates that the Elkhorn Ridge Argillite and associated units in the Baker terrane may have provided some of the detritus for the Weatherby Formation, in much the same manner as the Frenchy Butte and Miller Mountain melange areas of the Baker terrane provided detritus for the Fields Creek Formation and possibly the Vester Formation in the Izee terrane.

Radiolarian biostratigraphy has shown that the Baker terrane contains cherts of Permian, Late Triassic, and possible Early Jurassic age. These are therefore, essentially coeval with the Permian and Triassic metavolcanic and volcaniclastic rocks, and the Late Triassic and Early Jurassic carbonate and clastic sequences of the Wallowa terrane to the north and northwest.

LOCALITY DESCRIPTIONS

78SG–03 (USGS MR 0515). Float block of dark green chert from the Elkhorn Ridge Argillite, Baker terrane. Sample collected by Norm J. Silberling (USGS, Denver). USGS Greenhorn quad. (7.5′): T. 9 S., R. 35 E., SE¼SW¼ sec. 35, west side of road, in creek debris.

82CB–101A (USGS MR 4578). Black chert clast collected from chert pebble conglomerate of the Begg Member of the Vester Formation. USGS Suplee quad. (7.5′): T. 17 S., R. 26 E., NW¼NE¼ sec. 20, east side of Bull Creek.

82CB–105A–C (USGS MR 4591-4593). Red chert in Grindstone terrane. USGS Delintment Lake quad. (15′): T. 18 S., R. 25 E., SW¼SW¼ corner sec. 27, north side of unnamed reservoir.

82CB–106A–D (USGS MR 4596-4599). Red chert in Grindstone terrane. USGS Suplee quad. (7.5′): T. 18 S., R. 25 E., NW¼SE¼ sec. 11, top of butte.

82CB–108A–D (USGS MR 4605-4608). Green chert in Grindstone terrane. USGS Suplee quad. (7.5′): T. 18 S., R. 25 E., SE¼NW¼ sec. 10, top of butte.

82CB–109A–C (USGS MR 4609-4611). Green tuff bed from cherty breccia in Grindstone terrane. USGS Delintment Lake quad. (15′): T. 18 S., R. 25 E., NW¼NW¼ sec. 27.

82CB–111A,B (USGS MR 4613-4614). Thinly bedded red chert in Grindstone terrane. USGS Delintment Lake quad. (15′): T. 18 S., R. 25 E., SW¼SE¼ sec. 21.

82CB–114A-C (USGS MR 4619-4621). Red chert in the Grindstone terrane. USGS Twelvemile Reservoir quad. (7.5′): T. 19 S., R. 25 E., NW¼NW¼ sec. 17, 0.2 mi NE.of eastern extension of Three Buttes.

82CB–115 (USGS MR 4622). Black chert float in the Grindstone terrane. USGS Twelvemile Reservoir quad. (7.5′): T. 19 S., R. 25 E., SW¼NE¼ sec. 18, northern flank of Three Buttes.

83CB–101A (USGS MR 4084). Black chert pebbles from chert pebble conglomerate, Grindstone terrane. USGS Twelvemile Reservoir quad. (7.5′): T. 18 S., R. 24 E., SW¼NE¼ sec. 25, approximately same location as Merriam and Berthiaume's loc. 21.

83CB–103A,B (USGS MR 4086 and 4087 respectively). Light green chert interbedded with light brown tuff, from the Elkhorn Ridge Argillite, Baker terrane. USGS Oxman quad. (7.5′): T. 10 S., R. 42 E., NE¼NE¼ sec. 26, farthest east fork of Holman Creek.

83CB–104 (USGS MR 4088). Thinly bedded, dark green chert from the Elkhorn Ridge Argillite, Baker terrane. USGS Oxman quad. (7.5′): T. 10 S., R. 42 E., SW¼NE¼ sec. 11, along north fork of Pritchard Creek.

83CB–107A,B (USGS MR 4092 and 4093 respectively). Green and black chert from the Elkhorn Ridge Argillite, Baker terrane. USGS Oxman quad. (7.5′): T. 9 S., R. 42 E., NE¼NW¼ sec. 33, approx. 450 ft south of the boundary between secs. 28 and 33.

83CB–110–112 (USGS MR 4096 to 4098 respectively). Black siliceous mudstone samples from the Elkhorn Ridge Argillite in the Baker terrane. USGS Bourne quad. (7.5′): T. 9 S., R. 37 E., NW¼NW¼ sec. 30, south side of sharp bend in road.

83CB–117 (USGS MR 4111). Black chert samples from the Elkhorn Ridge Argillite (or unit "TrPa" of Ferns and others, 1983), Baker terrane. USGS Bates quad. (15′): T. 10 S., R. 34 E., NE¼NE¼ sec. 32, north end of gravel pit.

83CB–120A–C (USGS MR 4116 to 4118 respectively). Green chert samples from the Elkhorn Ridge Argillite, Baker terrane. USGS Greenhorn quad. (7.5′): T. 9 S., R. 35 E., SE¼SW¼ sec. 35, east side of road.

BD–816. Thin-bedded black chert from northwest-trending chert block, Baker terrane. USGS Beaverdam Creek quad. (7.5′): T. 11 S., R. 38 E., SW¼SW¼ sec. 14, directly north of Big Creek and dirt road.

FR80–A–C (USGS MR 2804 to 2806 respectively). Samples from chert blocks in Jurassic flysch, Olds Ferry terrane. Collected by Francois Roure. USGS Bridgeport quad. (15′): T. 14 S., R. 42 E., northern half of boundary between secs. 14 and 15.

FR81–287–293 (USGS MR 2819 to 2824). Chert in the Elkhorn Ridge Argillite, Baker terrane. Collected by Francois Roure. USGS Mt. Vernon quad. (15′): T. 12 S., R. 30 E., SW¼SW¼ sec. 6, west side of U.S. Route 395.

83HB–703 (USGS MR 4406). Black chert from the Elkhorn Ridge Argillite. USGS Bates quad. (15′): T. 12 S., R. 34 E., SW¼ sec. 9, east side of Dads Creek road.

OR–123A–C. Samples from a chert block near the base of the Fields Creek Formation, Izee terrane, along Fields Creek road, approximately 11.3 miles south of the intersection of Hwy. 26 and Fields Creek Road. USGS Aldrich Mt. quad. (15′): T. 14 S., R. 29 E., SE¼NE¼ sec. 5.

OR68–71. Black chert in the Miller Mountain melange area, now considered part of the Baker terrane. USGS Mt. Vernon quad. (15′): T. 14 S., R. 30 E., NE¼SW¼ sec. 5, approximately 0.2 miles north of Vance Creek.

P–1 and P–3 (USGS MR 2536 and 2538 respectively). Samples collected from a block of chert resembling the Elkhorn Ridge Argillite, Baker terrane. Samples collected by Merlynd Nestell. USGS John Day quad. (7.5′): T. 3 S., R. 32 E., NW¼NW¼ sec. 32, directly south of road leading due west from Little Dog Creek.

S–1, S–3, and S–6 (USGS MR 2550, 2552, and 2555 respectively). Samples collected from a block of chert resembling the Elkhorn Ridge Argillite, Baker terrane. Samples collected by Merlynd Nestell. USGS John Day quad. (7.5′): T. 13 S., R. 32 E., NE¼SE¼ sec. 32, east of road along Little Dog Creek.

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PLATES 8.1–8.3

[Contact photographs of the plates in this chapter are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

PLATE 8.1

Scanning electron photomicrographs of Permian radiolarians from cherts in the Grindstone terrane, east-central Oregon.

FIGURE 1, 2 *Pseudoalbaillella lanceola* Ishiga, Kito, and Imoto. Loc. 82CB–105, × 420 and × 350, respectively.

3–6. *Pseudoalbaillella fusiformis* (Holdsworth and Jones). Loc. 82CB–105, × 240, × 250, × 350, and × 360; respectively.

7, 8. *Pseudoalbaillella* aff. *P. longicornis* Ishiga, Kito, and Imoto. Loc. 82CB–105, × 420, and × 390, respectively.

9, 10. *Pseudoalbaillella longicornis* Ishiga, Kito, and Imoto. Loc. 82CB–105, × 420, and × 420, respectively.

11. *Pseudoalbaillella fusiformis* (Holdsworth and Jones). Loc. 82CB–105, × 350.

12. *Pseudoalbaillella* aff. *P. fusiformis* (Holdsworth and Jones). Loc. 82CB–105, × 360.

13. *Latentifistula*(?) sp. Loc. 82CB–105, × 300.

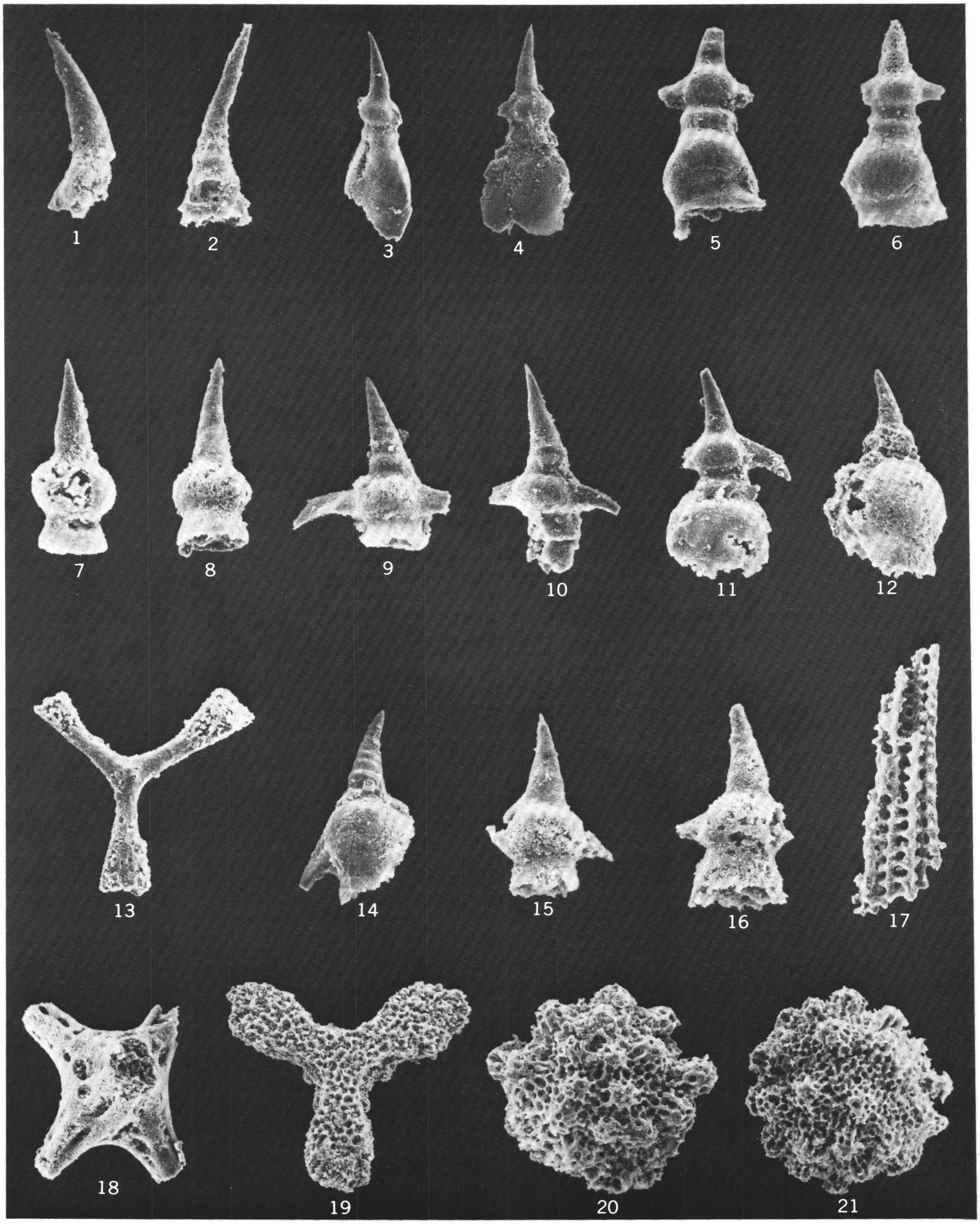
14–16. *Pseudoalbaillella* aff. *P. longicornis* Ishiga, Kito, and Imoto. Loc. 82CB–105, × 275, × 400, and × 425, respectively.

17. *Latentibifistula*(?) fragment. Loc. 82CB–105, × 260.

18. *Quinqueremis*(?) sp. Loc. 82CB–105, × 360.

19. *Latentifistula crux* Nazarov and Ormiston. Loc. 82CB–105, × 225.

20, 21. Undescribed mammelate spumellarians. Loc. 82CB–105, × 300 and × 325, respectively.



PSEUDOALBAILLELLA, LATENTIFISTULA, LATENTIBIFISTULA, QUINQUEREMIS (?)

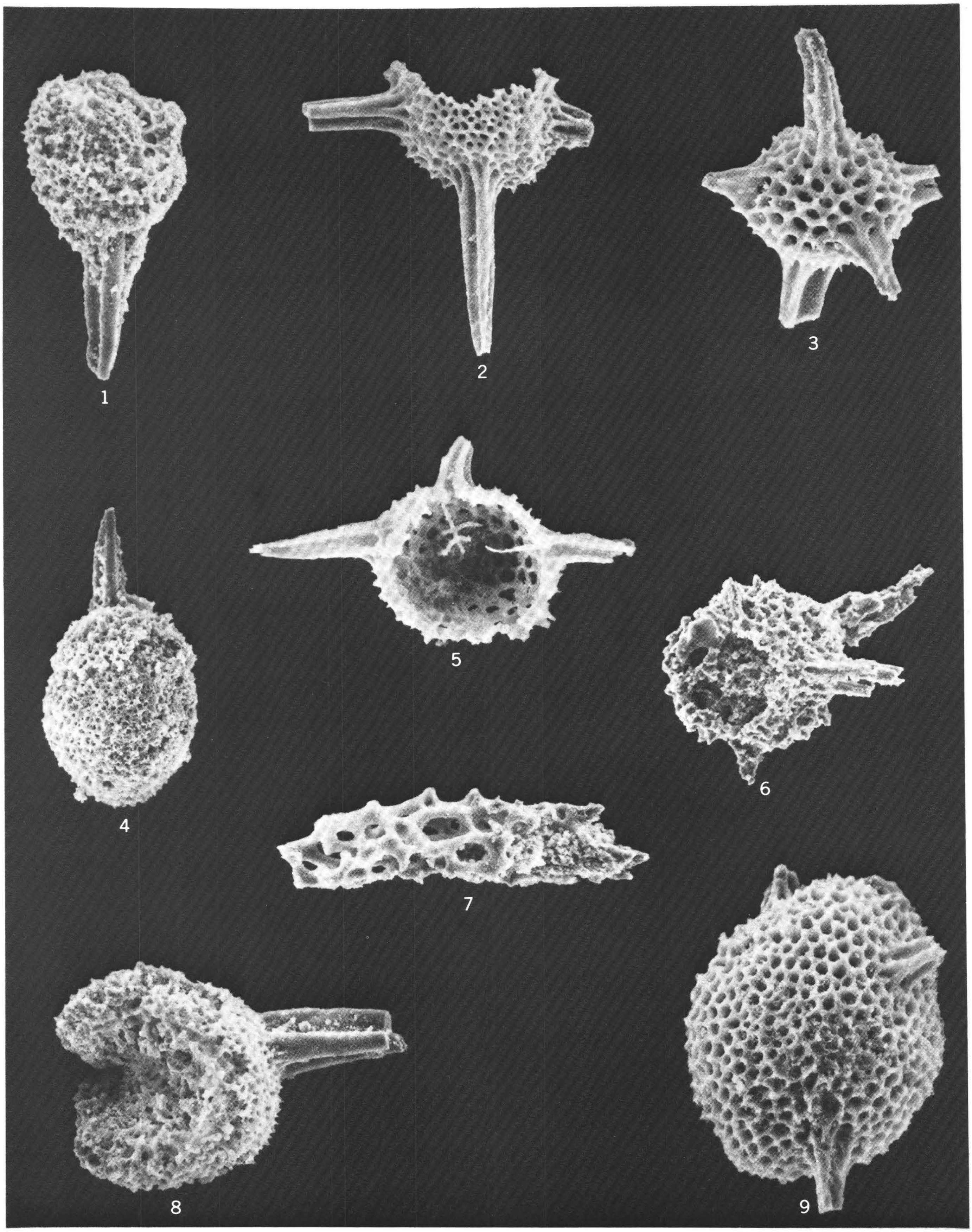
PLATE 8.2

Scanning electron photomicrographs of Carboniferous radiolarians from cherts in the Begg Member of the Vester Formation, Izee terrane, east-central Oregon.

FIGURE 1–6. Undescribed Late Paleozoic forms of the family Entactiniidae. Loc. 82CB–101A, × 300, × 260 × 390, × 330, × 500, and × 330, respectively.

7. *Latentifistula* fragment. Loc. 82CB–101A, × 360.

8, 9. Undescribed Late Paleozoic forms of the family Entactiniidae. Loc. 82CB–101A, × 390 and × 450, respectively.

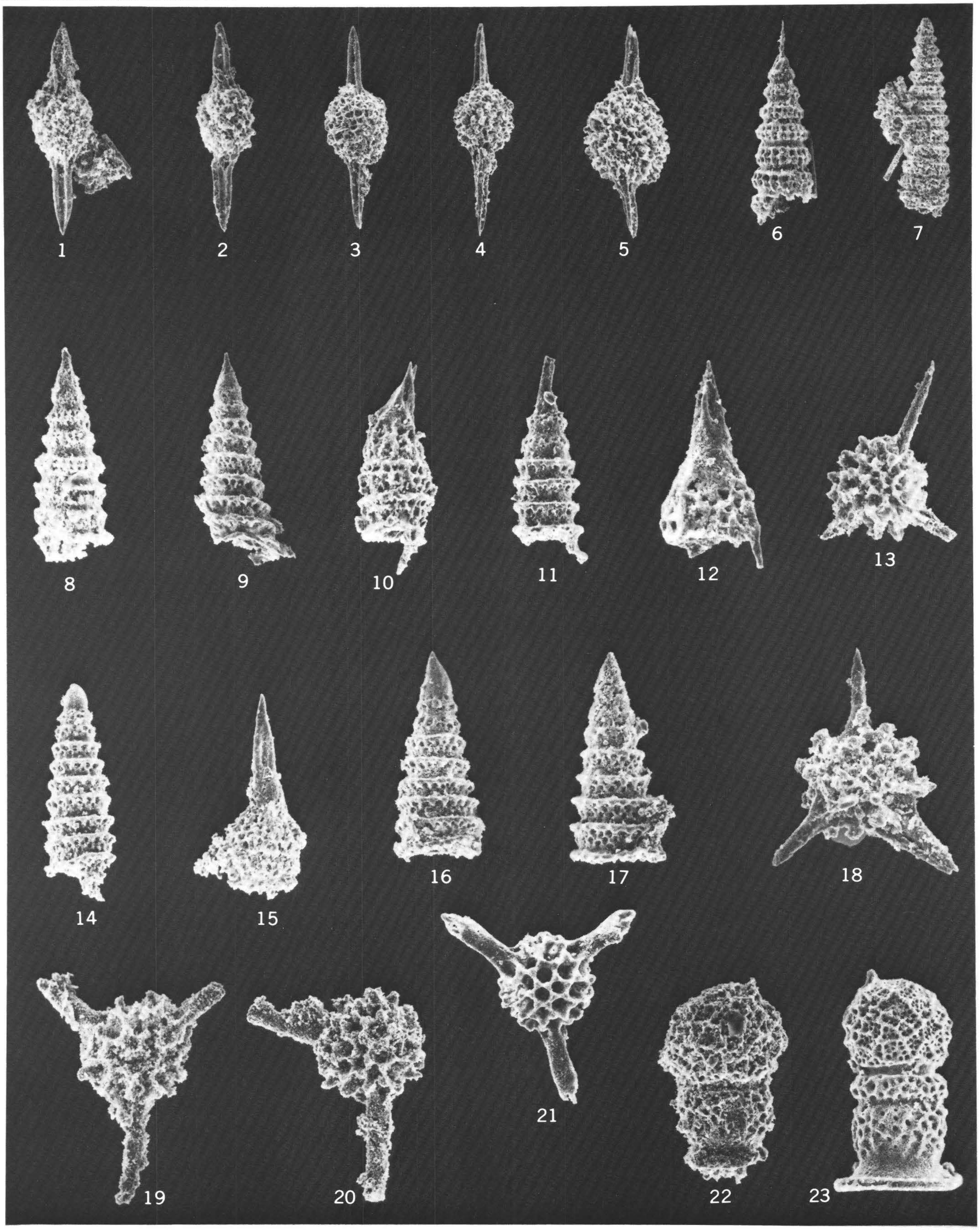


LATENTIFISTULA

PLATE 8.3

Scanning electron photomicrographs of Late Triassic radiolarians from the Izee and Baker terranes, east-central and eastern Oregon.

FIGURE 1. *Pseudostylosphaera japonica* (Nakaseko and Nishimura). Loc. FR18–292, × 225.
2. *Pseudostylosphaera japonica* (Nakaseko and Nishimura). Loc. FR18–290, × 240.
3–5. Undescribed *Pseudostylosphaera* sp. Loc. FR81–290, × 165, × 170, and × 240, respectively.
6. ?*Trilonche annulata* (Nakaseko and Nishimura). Loc. FR81–292, × 360.
7. *Triassocampe*(?) *pulchra* Kozur and Mostler. Loc. FR81–292, 170.
8. *Triassocampe japonica* (Nakaseko and Nishimura). Loc. FR81–290, × 330.
9. *Triassocampe japonica* (Nakaseko and Nishimura). Loc. FR81–292, × 360.
10. Undescribed *Triassocampe* sp. Loc. FR81–290, × 400.
11. *Triassocampe annulata* (Nakaseko and Nishimura). Loc. FR81–292, × 330.
12. *Eonapora* sp. Loc. FR81–290, × 400.
13,18. ?*Tripocyclia japonica* Nakaseko and Nishimura. Loc. FR81–292, × 360 and 360, respectively.
14. *Triassocampe deweveri* (Nakaseko and Nishimura). Loc. S–6, × 300.
15. Proximal portion of ?*Yeharaia* sp. Loc. FR81–290, × 360.
16,17. *Triassocampe* aff. *T. japonica* (Nakaseko and Nishimura). Loc. FR81–292, × 330 and × 360, respectively.
19. *Capnodoce* cf. *C. angusta* Blome. Loc. FR81–292, × 325.
20. *Capnodoce traversi* Pessagno. Loc. FR81–292, × 260.
21. *Capnodoce antiqua* Blome. Holotype (USNM 205819), Loc. OR–6 (in Blome, 1984, p. 60), Rail Cabin Mudstone Member of the Vester Formation, × 350.
22. *Quasipetasus disertus* Blome. Loc. FR81–292, × 325.
23. *Quasipetasus insolitus* Blome. Holotype (USNM 305963), Loc. OR–143 (in Blome, 1984, p. 61), Rail Cabin Mudstone Member of the Vester Formation, × 350.



PSEUDOSTYLOSPHAERA, ? TRILONCHE, TRIASSOCAMPE, EONAPORA, ? TRIPOCYCLIA, ?YEHARAIA, CAPNODOCE, QUASIPETASUS

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