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EDITED BY PAUL KARL LINK AND BART J. KOWALLIS

V O L U M E 4 2 • 1 9 9 7

PART **2** TWO

MESOZOIC TO RECENT GEOLOGY OF UTAH

Edited by

Paul Karl Link and Bart J. Kowallis

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Editor

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Cover photos taken by Paul Karl Link.

Top: Upheaval Dome, southeastern Utah.

Middle: Lake Bonneville shorelines west of Brigham City, Utah.

Bottom: Bryce Canyon National Park, Utah.

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Preface

Guidebooks have been part of the exploration of the American West since Oregon Trail days. Geologic guidebooks with maps and photographs are an especially graphic tool for school teachers, University classes, and visiting geologists to become familiar with the territory, the geologic issues and the available references.

It was in this spirit that we set out to compile this two-volume set of field trip descriptions for the Annual Meeting of the Geological Society of America in Salt Lake City in October 1997. We were seeking to produce a quality product, with fully peer-reviewed papers, and user-friendly field trip logs. We found we were bucking a tide in our profession which de-emphasizes guidebooks and paper products. If this tide continues we wish to be on record as producing "The Last Best Geologic Guidebook."

We thank all the authors who met our strict deadlines and contributed this outstanding set of papers. We hope this work will stand for years to come as a lasting introduction to the complex geology of the Colorado Plateau, Basin and Range, Wasatch Front, and Snake River Plain in the vicinity of Salt Lake City. Index maps to the field trips contained in each volume are on the back covers.

Part 1 "Proterozoic to Recent Stratigraphy, Tectonics and Volcanology: Utah, Nevada, Southern Idaho and Central Mexico" contains a number of papers of exceptional interest for their geologic synthesis. Part 2 "Mesozoic to Recent Geology of Utah" concentrates on the Colorado Plateau and the Wasatch Front.

Paul Link read all the papers and coordinated the review process. Bart Kowallis copy edited the manuscripts and coordinated the publication via Brigham Young University Geology Studies. We would like to thank all the reviewers, who were generally prompt and helpful in meeting our tight schedule. These included: Lee Allison, Genevieve Atwood, Gary Axen, Jim Beget, Myron Best, David Bice, Phyllis Camilleri, Marjorie Chan, Nick Christie-Blick, Gary Christenson, Dan Chure, Mary Droser, Ernie Duebendorfer, Tony Ekdale, Todd Ehlers, Ben Everitt, Geoff Freethy, Hugh Hurlow, Jim Garrison, Denny Geist, Jeff Geslin, Ron Greeley, Gus Gustason, Bill Hackett, Kimm Harty, Grant Heiken, Lehi Hintze, Peter Huntoon, Peter Isaacson, Jeff Keaton, Keith Ketner, Guy King, Mel Kuntz, Tim Lawton, Spencer Lucas, Lon McCarley, Meghan Miller, Gautam Mitra, Kathy Nichols, Robert Q. Oaks, Susan Olig, Jack Oviatt, Bill Perry, Andy Pulham, Dick Robison, Rube Ross, Rich Schweickert, Peter Sheehan, Norm Silberling, Dick Smith, Barry Solomon, K.O. Stanley, Kevin Stewart, Wanda Taylor, Glenn Thackray and Adolph Yonkee. In addition, we wish to thank all the dedicated workers at Brigham Young University Print Services and in the Department of Geology who contributed many long hours of work to these volumes.

Paul Karl Link and Bart J. Kowallis, Editors

Triassic and Jurassic macroinvertebrate faunas of Utah: Field relationships and paleobiologic significances

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ABSTRACT

Analysis of marine faunas from understudied strata of the Triassic and Jurassic of the western United States have made contributions to our understanding of the Mesozoic, a critical time period in the history of life on earth. Paleobiological study of the Lower Triassic Sinbad and Virgin Members of the Moenkopi Formation have provided significant information on the pace and style of ecological recovery after the Permian-Triassic mass extinction. The Middle Jurassic Carmel Formation has yielded some unique hard-substrate assemblages as well as low-diversity soft-substrate paleocommunities which have been used to evaluate paleocommunity evolution in the Jurassic western interior seaway. This field trip will allow participants to visit several significant exposures of marine Triassic and Jurassic strata in southern Utah.

INTRODUCTION

The Mesozoic is considered to be a critical transitional period in the history of life on Earth as faunas recovered and proliferated after the Permian-Triassic mass extinction, the largest extinction in Earth history when 90% of marine genera were estimated to have gone extinct (Erwin, 1993). Many globally significant oceanographic and biological events occurred through the Mesozoic. Biologically, the Mesozoic was a time of rapidly increasing faunal diversity which occurred with the origination of many major groups of organisms (e.g., heart urchins, planktonic foraminifera, 1981). During this time interval, organisms of the "Modern Fauna" (i.e., bivalves, gastropods) replaced the "Archaic Fauna" of the Paleozoic (i.e., crinoids, bryozoans) (Sepkoski, 1981). These ecological changes have been referred to as the "Mesozoic Marine Revolution" which was brought on by escalation of the "arms race" between predators and prey (Vermeij, 1977).

While Cretaceous marine strata of the western United States have received a great deal of paleontological research, marine Triassic and Jurassic faunas of the U.S. have been largely neglected. Thus, recently renewed paleoecological and paleobiological research on these faunas provides much insight into the recovery after the Permian-Triassic extinction as well as evolutionary patterns during the Mesozoic Marine Revolution.

GEOLOGICAL SETTING

Mesozoic rocks in the southwestern United States generally overlie the Late Permian Kaibab Formation unconformably. During intervals of Triassic and Jurassic time, the western interior was the site of marine, marginal marine, and non-marine deposition; at times, southwestern Utah was the site of marine deposition along the edge of the epicontinental seaways (Caputo et al., 1994). Strata deposited in this region include shallow normal-marine, marginal-marine, sabhka, erg, and fluvial facies. Although the Triassic and Jurassic western interior seaways were mixed carbonate-siliciclastic depositional systems, the Lower Triassic and Middle Jurassic fossiliferous strata examined during this field trip will all be limestones which were deposited during times of major transgressions within the seaway; however Triassic and Jurassic siliciclastic fluvial and erg deposits will be seen in Zion and Capitol Reef National Parks as well as surrounding areas.

PALEOBIOLOGY AND PALEOECOLOGY

Both the Early Triassic and Middle Jurassic benthic marine faunas in southern Utah are characterized by low diversities and fairly simple paleoecological structure. The depauperate nature of the faunas within the Lower Triassic Moenkopi Formation is thought to reflect the slow, pro-

longed faunal recovery after the Permian-Triassic mass extinction (see Bottjer and Schubert, this volume). The Sinbad Member contains predominantly bivalves and gastropods while the younger Virgin Member exhibits a slightly more diverse and complex association with the addition of regular echinoids and the oldest known articulate crinoid.

In the Middle and Upper Jurassic of the western interior seaway, the regional (gamma) diversity of trace fossils and benthic marine organisms is low compared to other Jurassic faunas (Wilson and Palmer, 1994; Tang, 1996). In addition, both hard- and soft-substrate assemblages exhibit fairly low diversities within paleocommunities (alpha diversity) and between paleocommunities (beta diversity, i.e., low differentiation between communities) (Tang, 1996; Tang and Bottjer, 1996). The faunas are heavily dominated by bivalves although gastropods, crinoids, echinoids, bryozoans, corals, and serpulids are present as well.

The low-diversity nature of some level-bottom paleocommunities within the Middle Jurassic Carmel Formation may reflect their deposition within marginal marine environments. For example, the Carmel Formation hardground associations found near Gunlock Reservoir exhibit much lower diversities and complexities than do those from comparable hardgrounds in other parts of the world, possibly due to their deposition under marginal marine conditions (Wilson and Palmer, 1994; Wilson, this volume). However, the presence of crinoids and other echinoderms associated with other low-diversity assemblages—such as those found at Mount Carmel Junction—indicate that low-diversity paleocommunities were common in normal marine settings as well (see Tang and Bottjer, this volume). Thus, the low-diversity of Middle Jurassic marine faunas of southern Utah is probably the result of many factors including biogeography, oceanographic conditions, the level of environmental disturbance, the restricted nature of the seaway, and the abundance/patchiness of suitable environments for colonization.

ROAD LOG

This field trip will go south out of Salt Lake City to St. George before heading northeast to Green River through Zion, Bryce Canyon, and Capitol Reef National Parks (fig. 1). There will be a total of nine geological stops of which five will be paleontological in nature.

<u>Stops</u>	<u>Mileage</u>	<u>Mileage</u>	<u>Description and directions</u>
	<u>(cumul)</u>	<u>interval</u>	
Day 1			
	0		Salt Lake City. Junction of Interstates 15 and 215. Go south on 15.
	84.4	84.4	Third Nephi exit.

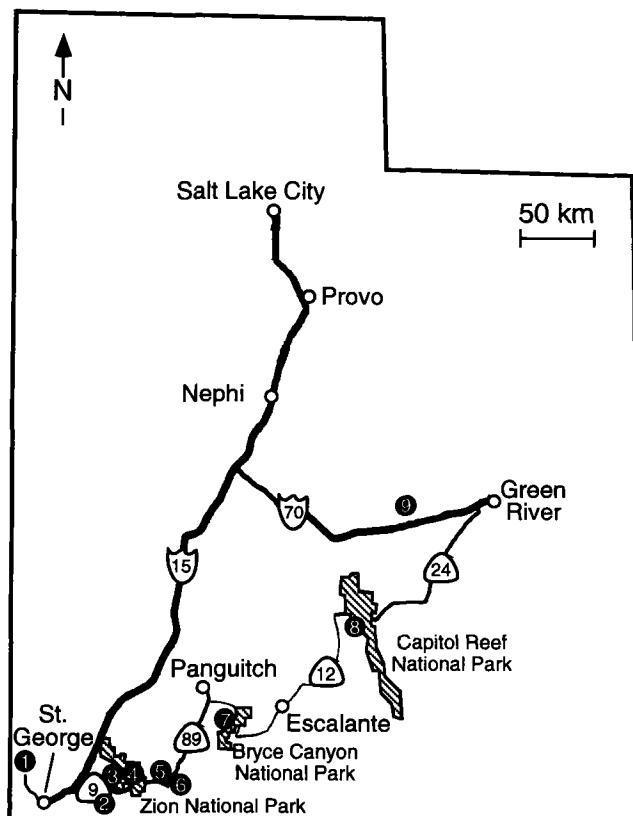


Figure 1. Route of this field trip through Utah. Stop 1: Gunlock reservoir—Carmel Formation. Stop 2: Hurricane Cliffs—Virgin Limestone Member of Moenkopi Formation. Stop 3: Zion National Park. Stop 4: Checkerboard Mesa—Navajo Formation. Stop 5: Mount Carmel Junction, west—Carmel Formation. Stop 6: Mount Carmel Junction, east—Carmel Formation. Stop 7: Bryce Canyon National Park—Clarion Formation. Stop 8: Capitol Reef National Park. Stop 9: San Rafael Swell—Sinbad Member of Moenkopi Formation.

119.1	34.7	(Exit for Scipio and US Highway 50.)
160.5	41.4	(Interstate 70.)
166	5.5	Rest Area.
205.1	39.1	Rest Area.
248.7	43.6	Rest Area.
253.3	4.6	(Kolob Canyon entrance of Zion National Park.)
284.8	31.5	St. George Boulevard exit. Exit and proceed northwest.

Day 2

0		Intersection between Bluff Street and St. George Boulevard. Go northeast on Bluff Street. Zero odometer.
1	1	Sunset Boulevard. Turn left.

	6	5	(Highway 300)		113.4	0.7	(Zion National Park east entrance booth.)
	12	6	Crossroad. <i>Turn right toward Gunlock Reservoir.</i>		113.6	0.2	(Zion National Park boundary.)
	19.4	7.4	BLM dirt road. <i>Turn left and cross Santa Clara River.</i>	Stop 5	126.1	12.5	Mount Carmel Junction between Highways 9 and 89. Carmel Formation encrinite is located on the northwest corner of the junction. <i>Pull into RV parking lot or gas station parking lot. Outcrop is located across small gully.</i>
Stop 1	20.1	0.7	Large gully on left side. <i>Pull into gully and turn around. Walk along gully to find Carmel hard-ground surface. Trace fossils and ostreoliths found in exposures of Carmel on right side of gully.</i>				<i>Pull out of parking lot onto Highways 9 and 89 east. Go straight through intersection on Highway 89 south east past Thunderbird resort and golf course.</i>
	20.1		<i>Pull out of gully and turn right on dirt road.</i>		126.1		
	20.7	0.6	Santa Clara River. <i>Cross river.</i>				
	20.8	0.1	Intersection with paved road. <i>Turn right.</i>				
	28.2	7.4	Intersection. <i>Turn left.</i>		126.5	0.4	Dirt road leading to highway maintenance yard and gravel pit. <i>Turn left and cross Virgin River.</i>
	39.2	11	Bluff Street. <i>Turn right.</i>				
	40.2	1	St. George Boulevard. <i>Turn left.</i>				
	42.2	2	Interstate Highway 15. <i>Take 15 north-east.</i>		126.6	0.1	Maintennance yard and gravel pit. <i>Turn left at the end onto paved road.</i>
	49.6	7.4	Highway 9. <i>Take 9 east.</i>				
	59.3	9.7	Junction with Highways 17 and 59. <i>Take 59 east.</i>	Stop 6	126.7	0.1	Extensive outcrop of Carmel Formation. <i>Turn vans around and park near end of paved road near river.</i>
	62.7	3.4	BLM dirt road. <i>Turn right.</i>				
	63.7	1	(Cattleguard.)				
	64.8	1.1	(Ostrich Farm.)		126.8	0.1	<i>Turn right off paved road onto dirt road.</i>
	65.8	1	Fork in road. <i>Bear right toward Arizona border.</i>		126.9	0.1	Highway 89. <i>Take 89 Northwest by turning right.</i>
Stop 2	68.7	2.9	Virgin Limestone Member is exposed in cliff along right side of road. Road is on a bedding plane full of bivalves and occasional crinoid stems. <i>Turn around and park along the road.</i>		127.5	0.6	Mount Carmel Junction. <i>Continue on Highway 89 north by taking a right turn.</i>
					150.1	22.6	(Intersection with Highway 14.)
					170.8	20.7	(Intersection with Highway 12.)
	71.6	2.9	Fork in road. <i>Bear to the left.</i>		177.8	7	Panguitch.
	74.7	3.1	End of dirt road onto highway 59. <i>Turn left on 59.</i>	Day 3	0	0	Panguitch.
					7	7	Highway 12. <i>Take 12 East by turning left.</i>
	78.1	3.4	Junction between Highways 9, 59, and 17. <i>Go north on Highways 17 and 9 by turning right.</i>		20.7	13.7	State Road 63 to Bryce Canyon National Park. <i>Turn right to go south on 63.</i>
	80.8	2.7	Crossroads. <i>Continue east on 17 and 9 toward Zion.</i>	Stop 7	26.2	5.5	Fairyland viewpoint. <i>Park.</i>
	100.8	20	(Entering Zion National Park.)		31.7	5.5	Highway 12. <i>Turn left.</i>
Stop 3	102.1	1.3	Zion National Park visitors' center. <i>Park.</i>		43.9	12.2	(Turnoff to Kodachrome Basin State Park.)
	103.1	1	Intersection with Zion Canyon Road. <i>Bear right to continue east on Zion-Mt. Carmel Highway.</i>		76.3	32.4	(Escalante Petrified Forest State Park.)
					78.6	2.3	(Escalante.)
	106.6	3.5	(Zion Tunnel.)		101.9	23.3	(Intersection with Hell's Backbone Road.)
	107.6	1	(Exit Zion Tunnel.)				
Stop 4	112.7	5.1	Checkerboard Mesa Viewpoint. <i>Park in parking lot.</i>		105.7	3.8	(Anasazi Indian Village State Park.)

	141.9	36.2	Intersection with Highway 24. <i>Turn right to go east on 24.</i>
Stop 8	151.9	10	Capitol Reef National Park Visitors' Center. <i>Park and view exhibits, book store, and the Castle.</i>
	160.9	9	Exiting Capitol Reef National Park.
	189.5	28.6	Hanksville. Intersection with Highway 95. <i>Turn left and continue north on 24.</i>
	233.5	44	Junction with Interstate Highway 70. <i>Take 70 west.</i>
	235.3	1.8	(Pass over San Rafael River.)
	236.7	1.4	(Rest Area. Note San Rafael Swell flatirons/hogbacks.)
	251.3	14.6	Exit #129, Farm Road. <i>Exit highway, bear right (north) onto Frontage Road, a graded BLM road.</i>
	253.7	2.4	(Cattleguard.)
	255.2	1.5	(Dirt road to Hyde Draw.)
	257.4	2.2	(Dirt road to Jackass Benches.)
Stop 9	264.1	6.7	Outcrop of Sinbad Member on east side of graded road. <i>Turn around, pull off road, and stop.</i>
	276.9	12.8	Interstate Highway 70. <i>Take 70 west.</i>
	291.9	15	Rest Area at Exit 114.
	351.9	60	Highway 50. <i>Exit freeway, go north on 50.</i>
	356.4	4.5	(Salina.)
	383	26.6	Junction with Interstate Highway 15. <i>Take 15 north.</i>
	502.1	119.1	Junction between Interstate Highways 15 and 215.

BRIEF DESCRIPTIONS OF FIELD TRIP STOPS

Detailed descriptions of the stratigraphy, sedimentology, fauna and paleobiological significances of Stops 1, 2, 4, 5, and 8 are found in the following chapters in this volume. Several good references for Mesozoic depositional systems within the western interior can be found within Caputo et al., (1994).

Stop 1 Carmel Formation—Gunlock Reservoir Locality

We will examine outcrops of the marine and marginal-marine strata of the Middle Jurassic Carmel Formation with emphasis on (1) a horizon of extensive hardground development with abundant *Liostrea strigilecula* encrusters and *Gastrochaenolites* borings; (2) facies with abundant

trace fossils, especially those of *Gyrochorte* and *Neonereites*; and (3) ostreoliths ("oyster balls") which are spherical accumulations of free-rolling *Liostrea* colonies. Wilson (this volume) provides a more detailed account of the facies and faunas found in this section of the Carmel Formation ("Member D").

Stop 2 Virgin Limestone Member Hurricane Cliffs Locality

We will examine one laterally-extensive outcrop and bedding plane of the Early Triassic Virgin Limestone Member of the Moenkopi Formation which contains numerous bivalves and occasional crinoid stems from *Holocrinus? smithi*, the oldest-known articulate crinoid. This deposit represents the one of the first examples of the re-development of relatively complex paleocommunities following the Permian-Triassic mass extinction. A more detailed discussion is contained within Bottjer and Schubert (this volume).

Stop 3 Zion National Park Visitors' Center

In addition to several natural history displays, the visitors' center affords a good view of some of the Mesozoic sandstone formations such as the Kayenta and Navajo Formations which make up Zion and which will be visible during our drive through the park. The fossil-bearing marine and marginal marine Carmel Formation can also be seen capping some of the taller structures in the park.

Stop 4 Checkerboard Mesa Viewpoint

Excellent view of Checkerboard Mesa which exhibits jointing, cross-bedding, and trough cross-bedding in Lower Jurassic erg sandstones of the Navajo Formation.

Stop 5 Carmel Formation—Mount Carmel Junction Locality, northwest

An outcrop of shallow-water, nearshore carbonates of the Co-op Creek Member of the Carmel Formation contains one of the youngest crinoidal limestones in the fossil record. The encrinite is composed of partially-articulated stems of *Isocrinus nicoleti*, the first non-endemic crinoid identified in the Jurassic western interior (Tang et al., in prep). Fairly abundant and well-preserved examples of the bryozoan *Eurystrotos duofluvina* can be found from units just above the encrinite. More information is included in Tang and Bottjer (this volume).

Stop 6 Carmel Formation—Mount Carmel Junction, northeast

A laterally-extensive exposure of the Carmel Formation underlain by the Temple Cap Member of the Navajo For-

mation can be found along the northside of Highway 89. The dominant fossils are bivalves which can be well-preserved and include *Liostrea*, *Lina*, and *Camptonectes*, but a number of other rare taxa such as gastropods, echinoids, serpulids, and crinoids can be found as well. The trace fossil *Gyrochorte* can be found on bedding planes. Details about this locality are provided in Tang and Bottjer (this volume).

Stop 7 Bryce Canyon National Park Fairyland Viewpoint

Fairyland Viewpoint is the northernmost viewpoint within the park and offers a view of the Pink Cliffs and the Aquarius Plateau in the distance. Bryce Canyon is not a canyon but a series of amphitheaters eroded from the Paunsaugunt Plateau. The colorful hoodoos and spires are a result of erosion of the Paleogene Claron Formation (formerly referred to as the Wasatch Formation).

Stop 8 Capitol Reef National Park Visitors' Center

The visitors' center contains a small geological display and offers a picturesque view of "The Castle" eroded from the Triassic Wingate Formation (fig. 2). Other Mesozoic formations exposed through the park in the Waterpocket Fold include the Moenkopi, Chinle, Kayenta, Navajo, Carmel, Entrada, and Curtis Formations.

Stop 9 Sinbad Member—San Rafael Swell Locality

We will examine Early Triassic gastropods and bivalves from the Sinbad Limestone Member of the Moenkopi Formation. The gastropods, originally described by Batten and Stokes (1987), are good examples of Early Triassic "Lazarus taxa." More information can be found in Bottjer and Schubert (this volume).

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We would like to thank Drs. J. Schubert, M.A. Wilson, GSA Field Trip Coordinator Edna Collis, and 1997 GSA



Figure 2. "The Castle," eroded from the Triassic Wingate Formation, can be viewed from the Capitol Reef National Park visitor's center (Stop 8).

Field Trip Co-chairs P. K. Link and B. J. Kowallis for their assistance.

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Trace fossils, hardgrounds and ostreoliths in the Carmel Formation (Middle Jurassic) of southwestern Utah

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INTRODUCTION

The Middle Jurassic Carmel Formation in southwestern Utah is a diverse unit with a fascinating array of sedimentary facies. It is approximately 250 meters thick in the area north of St. George, and is particularly well exposed just north of the Gunlock Reservoir. Here the most paleontologically and stratigraphically interesting portion is "Member D" (*sensu* Nielson, 1990), which is a shallowing-upward sequence of ooid-rich carbonate shoal deposits, lagoonal muds, and intertidal and supratidal carbonate and siliciclastic sands, silts and clays. The low diversity, mollusk-rich fossil assemblage in Member D supports the hypothesis that this area was a marginal marine environment at the southern end of the Carmel-Twin Creek Seaway in the Middle Jurassic (Imlay, 1980; Nielson, 1990). These restricted conditions led to the development of a unique and diverse set of trace fossils, along with extensive carbonate hardgrounds and unusual free-rolling oyster assemblages termed ostreoliths, or colloquially as "oyster balls." This contribution introduces these elements of the marine portion of the Carmel Formation and places them within a stratigraphic and regional context.

TRACE FOSSILS

Trace fossils are abundant and diverse in the carbonates and fine-grained siliciclastic units in Member D of the Carmel Formation in southwestern Utah. Only a few geologists have examined this ichnofauna. Blakey et al., (1983) and Nielson (1990) briefly noted some of the prominent soft-sediment burrow systems, and Wilson and Palmer (1992, 1994) described the bivalve and phoronid borings in the carbonate hardgrounds and their associated shelly fauna. Smail and Wilson (1993) presented the most extensive analysis of the ichnofauna in a study which continues.

The ichnogenera identified in Member D of the Carmel Formation include, in alphabetical order: *Asteriacites* (Fig. 3), *Chondrites*, *Gastrochaenolites*, *Gyrochorte*, *Lockeia*, *Monocraterion*, *Neonereites*, *Palaeophycus*, *Planolites*, *Skolithos*, *Taenidium*, *Talpina*, and *Teichichnus*. These traces are for the most part very well preserved, especially as

hypichnia on the soles of thin-bedded carbonate units. The most prominent ichnofossil is *Gyrochorte comosa* Heer (1865), which is a sinuous, bilobate intrastratal trackway preserved as both convex epichnia and concave hypichnia in oolitic and peloidal siltstones and grainstones formed in a shallow lagoon. Heinberg (1970, 1973) interpreted *Gyrochorte* as the product of an elongate worm, such as a polychaete, which tunneled obliquely through the sediment. Fürsich (1974) considered *Gyrochorte* to be a tunnel produced by a burrowing amphipod. *Gyrochorte* is common to abundant in Jurassic shallow-water carbonate and siliciclastic sequences around the world, including west-central India (Howard and Singh, 1985; Kulkarni & Ghare, 1991; Fürsich et al., 1991), eastern Greenland (Heinberg & Birkelund, 1984), and western Europe (Fürsich, 1974, 1975).

The marine facies in Member D of the Carmel Formation have distinct ichnological assemblages. The oolitic shoal deposits represent the highest environmental energy in the member. These coarse grainstones and packstones contain relatively few trace fossils, which is probably a function of preservation. The trace fossils present in this facies include *Lockeia*, *Palaeophycus* and *Taenidium*. The lagoonal sediments (mostly peloidal and ooid-rich siltstones and grainstones) have the highest diversity and abundance of trace fossils, including *Asteriacites*, *Chondrites*, *Palaeophycus*, *Monocraterion*, *Teichichnus*, and the especially abundant *Gyrochorte* and *Neonereites*. The carbonate hardgrounds are most common in this facies; their trace fossils are covered below. The subtidal and intertidal facies (represented primarily by calcareous mudstones) contain *Planolites*, *Chondrites* and *Skolithos*. No trace fossils have been found in the supratidal sediments (siltstones and mudstones with desiccation cracks, anhydrite nodules and halite crystal casts), almost certainly because these evaporative conditions did not support much life.

Smail and Wilson (1993) suggested that the more basinward facies of Member D, include the seaward sides of the lagoons, contained ichnogenera generally larger in size and deposit feeders usually working the strata parallel to bedding. More vertically-oriented and domichnial forms characterize the landward lagoonal and intertidal environments.



Figure 3. *Asteriacites lumbricalis* von Schlotheim, 1820. Trace fossil of a burrowing ophiuroid echinoderm from Member D, Carmel Formation, near Gunlock, Utah. Natural size.

HARDGROUNDS

Carbonate hardgrounds and their associated fossils are prominent in the lagoonal facies of the Carmel Formation's Member D. Hardgrounds are syndimentarily lithified carbonate sea-floors that became hardened *in situ* by the precipitation of a carbonate cement in the primary pore spaces (Wilson and Palmer, 1992, p. 3). They are found in the rock record from the Cambrian through the Recent, most abundantly in the Cambrian and Jurassic (Palmer, 1982; Wilson and Palmer, 1992). The intervals of common hardground formation coincide with the "Calcite Seas" postulated by Sandberg (1975, 1983). During Calcite Sea times, low magnesium calcite was the primary inorganic precipitate from seawater, and hence the most common hardground cement.

Several hardground horizons are present in Member D of the Carmel, but one described in detail by Wilson and Palmer (1994) is very extensive and seen over several kilometers. It is between 110 and 120 meters above the base of the Carmel in the Gunlock area. The hardground is at the base of a regressive sequence; it probably formed during a brief sea level highstand. This hardground varies in its composition from an interbedded silty micrite and sandy oolitic grainstone, with only occasional mollusk shell fragments and micritic intraclasts, to a packstone with thin intraclasts of silty micrite and abundant ooids and bioclastic debris. The hardground was formed in a lagoonal complex, from ooid-rich shoals seaward to a subtidal shelly facies landward.

The most extensive Carmel hardground in the Gunlock area is often heavily encrusted by the oyster *Liostrea strigilecula* (White, 1877), with minor numbers of the cementing bivalve *Plicatula* sp. The boring *Gastrochaenolites lapi-*

dicus Kelly and Bromley (1984) is very common in the hardground upper surfaces. The mytilid bivalve *Lithophaga* is sometimes preserved inside the *Gastrochaenolites* excavations, which it apparently produced. The mytilid bivalve *Modiolus subimbricatus* (Meek, 1873) is also occasionally found in the borings, most likely as a nestler. Wilson and Palmer (1994) also described a rare bioimmuration of the soft-bodied bryozoan *Arachnidium* which encrusted the hardground upper surface and was covered by oysters. Some Carmel hardgrounds were undermined by currents while on the seafloor, producing shallow cavities beneath the cemented horizon as uncemented sediments below were removed. These small caves had their own cryptic hardground fauna, including the common *Gastrochaenolites*, thecidean brachiopods, cyclostome bryozoans, and serpulid worm tubes.

The Carmel hardgrounds resemble most other carbonate hardgrounds in the Jurassic, especially those of western Europe. For example, a Bathonian hardground in England described by Palmer and Fürsich (1974) is very similar; from the carbonate petrography to the differences between the exposed fauna on the upper surfaces to the cryptic faunas below. The Carmel hardgrounds are unusual, though, in their lack of encrusting echinoderms and cementing foraminiferans. This may be due to the restricted marine conditions under which the Carmel hardgrounds formed.

OSTREOLITHS

Two horizons in Member D of the Carmel Formation in the Gunlock area contain some unusual fossils which are worth special notice. They are radial accumulations of oysters which formed around a nucleus and rolled freely on the seafloor (Fig. 4). Nielson (1990) was the first to describe them, calling them "oyster colonies" and "oyster boundstones." Wilson et al., (1997) prefer the term "ostreolith," and have interpreted their formation in detail. Ostreoliths such as these have not been described from anywhere else.

The Carmel ostreoliths are made primarily of left valves of the oyster *Liostrea strigilecula*, the same species which is the most common encruster on the Carmel hardgrounds. The most common ostreoliths average about 15 cm in diameter and have a calcite-filled cast of a formerly aragonitic bivalve (such as *Isognomon* or *Astarte*) as a nucleus, and then sequential layers of *Liostrea*. Other encrusters are rare, but they include *Plicatula*, and the cyclostome bryozoan *Eurystrotois duofluwina* (Cuffey and Ehleiter, 1984). The oyster framework is frequently penetrated by *Gastrochaenolites lapidicus*, sometimes with the nestler *Modiolus subimbricatus* in place. A less common but larger group of ostreoliths (up to 50 cm in diameter) has similar borers and encrusters (along with the inarticulate brachiopod *Disciniscia*), but has pieces of carbonate hardground as the nuclei.



Figure 4. *Ostreolith* made primarily of left valves of the oyster *Liostrea strigilecula* (White, 1877). From Member D, Carmel Formation, near Gunlock, Utah. Natural size.

In the interpretation of Wilson et al., (1997), the Carmel ostreoliths formed in two ways. The smaller ostreoliths formed on a soft, ooid-rich substrate as oysters encrusted loose mollusk valves. The larger ostreoliths developed as oysters accumulated on dislodged blocks of carbonate hardground. *Liostrea* preferred the upward-facing, exposed surfaces of the nuclei, and *Plicatula*, *Eurystrotos* and *Gastrochaenolites* accumulated on the cryptic undersurfaces. The ostreoliths were frequently overturned, allowing the framework oyster *Liostrea* to cover all surfaces, producing the nearly-spherical objects. The form of these ostreoliths is a direct function of the morphology of *Liostrea strigilecula*, especially its rapid growth, deep left valve, and calcitic composition.

The Carmel ostreoliths are found in two laterally extensive horizons in the top half of Member D. Like the hardgrounds, these horizons cross facies boundaries from ooid-rich sediments to otherwise unfossiliferous muds. It appears that the ostreoliths formed in oolitic shoal environments and were later washed into muddy lagoons by large storms.

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Low-diversity faunas of the Middle Jurassic Carmel Formation and their paleobiological implications

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ABSTRACT

Laterally-extensive outcrops of Middle Jurassic normal marine carbonate strata are present at Mount Carmel Junction in southwestern Utah. These fossil-bearing limestones are part of the Co-op Creek Member of the Carmel Formation and include ooid grainstones, crinoidal grainstones, peloidal packstones, and bivalve-dominated packstones. These facies are interpreted to represent deposition in a nearshore, shallow-water lagoon-shoal setting.

The paleocommunities found in this southern end of the Middle Jurassic North American epicontinental seaway are low-diversity and exhibit low levels of complexity and tiering. Soft-bottom macrofossil assemblages are heavily dominated by oysters, limids, and pectens although serpulids, crinoids, echinoids, bryozoans, gastropods, possible stromatolites, and the trace fossil *Gyrochorte* can be found as well. One paleobiologically significant deposit is a crinoidal limestone composed of partially-articulated stems of *Isocrinus nicoleti*, the first non-endemic crinoid reported in the western interior. This deposit represents one of the youngest shallow-water encrinites in the fossil record and may provide evidence for unique conditions in this seaway.

INTRODUCTION

The Jurassic is a time of many significant global changes in the lithosphere, hydrosphere, atmosphere, and biosphere. For example, the breakup of Pangaea and the opening of the Atlantic Ocean first occurred during Jurassic times and greatly influenced oceanographic and climatic patterns. In the biosphere, the Jurassic saw the origination of many significant groups of modern taxa, the rapid increase in familial diversity (Sepkoski, 1981), and many ecological changes of the Mesozoic Marine Revolution (Vermeij, 1977). Thus, the study of the evolutionary paleoecological changes which occurred through this critical time interval may shed light on the response of the biota to global change processes. Surprisingly, despite centuries of intense study of Jurassic fossils in Europe (especially in England) (see Arkell, 1933), the Jurassic marine fauna of North America has been largely ignored. After the initial discovery and identification of Jurassic fossils by federal surveys in the 1800's, most modern paleontological work on this fauna was conducted by Ralph Imlay of the U.S. Geological Survey. Even many of

the theses and dissertations which included paleontological aspects were conducted in consultation with Imlay.

One possible reason for the lack of attention to these faunas may be that these Jurassic marine strata are not highly fossiliferous and are low-diversity in comparison to other Jurassic faunas around the world. In addition, the Jurassic seaway which covered the U.S. western interior was a unique biological province with its own succession of ammonites (Taylor et al., 1984), thus making biostratigraphy and global correlation difficult. Even regional stratigraphic correlations across short distances are difficult due to the general lack of good biostratigraphic fossils and the large variability of rock lithologies resulting from such things as local changes in terrestrial sediment input, sea levels, and topography (Brenner and Peterson, 1994; Peterson, 1994).

PALEOGEOGRAPHIC SETTING

During the Jurassic in the U.S. western interior, a series of marine and marginal marine rocks were deposited in a

shallow seaway during a 20 million year interval from Middle to Late Jurassic times (Imlay, 1980). The seaway was very shallow, probably never deeper than 100 meters, had many topographic highs, and had only one restricted opening to the open ocean in the north (Imlay, 1980) (Fig. 5). The seaway experienced several major sea level changes (reviewed by Brenner and Peterson, 1994; Peterson, 1994). Although much of the strata is fully marine, there are also many deposits indicative of terrestrial, brackish, high salinity, and marginal marine conditions (Brenner and Peterson, 1994; Peterson, 1994). Thus, the Jurassic western interior seaway is a unique system in which to examine ecological and evolutionary changes through the Mesozoic Marine Revolution.

STRATIGRAPHY OF CARMEL FORMATION

The Carmel Formation was first formally described by Gregory and Moore (1931). It was deposited in and adjacent to an epicontinental seaway which formed during a Middle Jurassic transgression across the western interior of the United States (Imlay, 1980). A stratigraphic column is shown in Figure 6. The Carmel Formation overlies Unconformity J-1 and Navajo Formation. In the type area near Mount Carmel Junction where this field trip will stop, the Temple Cap Member of the Navajo Formation underlies the Carmel Formation. The Carmel Formation is laterally equivalent with the Twin Creek Formation of northern Utah, Idaho, and Wyoming and the Arapien Shale of central Utah (Imlay, 1980).

The nomenclature of the members within the Carmel Formation has changed many times and differs among regions; for example, Wilson (this volume) adopts the informal member names used by Nielson (1990). The unit we will examine at Mount Carmel Junction is the limestone unit in the lower section of the Carmel Formation. In the literature, it has been referred to as the lower limestone member (Cashion, 1967), Kolob Limestone (Thompson and Stokes, 1970), Judd Hollow Member (Wright and Dickey, 1962), and most recently, the Co-op Creek Member (Doelling and Davis, 1989). In this discussion, I have adopted the terminology of Doelling and Davis (1989).

The Co-op Creek Member consists of a thin lower unit of non-marine pink and green clastics and a sequence of marine and marginal marine carbonates which are interpreted to have been deposited during a transgression (Peterson, 1994; Taylor, 1981). The Co-op Creek Member has been interpreted to have been deposited in subtidal to supratidal conditions in low- to moderate-energy regimes (Taylor, 1981). The lower Co-op Creek carbonates are composed of thin beds which have been interpreted as possible stromatolites (Taylor, 1981). Most of the fossils found from the Carmel Formation come from the middle carbonate

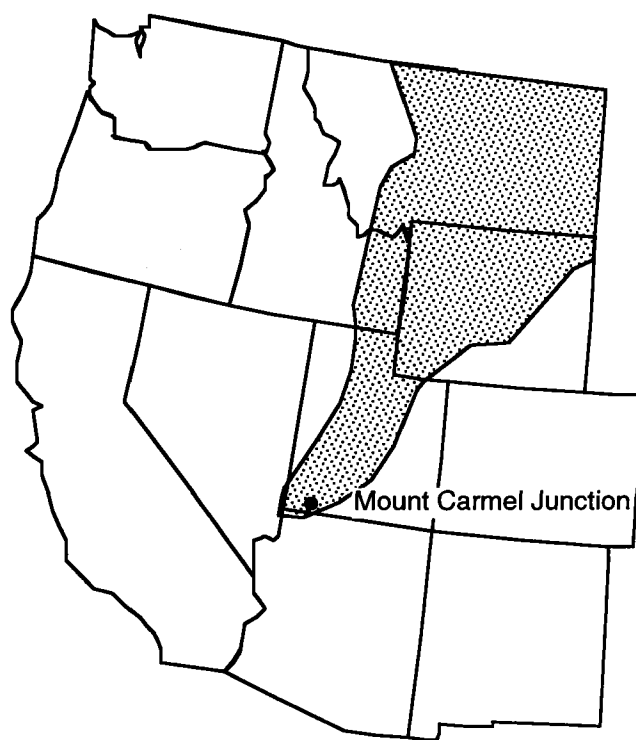


Figure 5. Stippled region represents the extent of the Middle Jurassic western interior epicontinental seaway during deposition of the Carmel Formation. Mount Carmel Junction is the site of Field Trip Stops 5 and 6 on Day 2 where we will examine an encrinite and low-diversity bivalve communities in the Co-op Creek Member of the Carmel Formation. (Modified from Nielson, 1990)

unit of the Co-op Creek Member which is composed of interbedded ooidal grainstones, peloidal packstones, and bivalve packstones representing deposition within a lagoonal-ooid shoal environment. The presence of echinoids and abundant crinoids indicate that these fossiliferous beds were most likely deposited under normal marine salinities.

PALEOBIOLOGY AND PALEOECOLOGY

Mount Carmel Junction (northwest corner):

On the west side of Mount Carmel Junction, there is an outcrop of the Co-op Creek middle limestone unit which includes a dense accumulation of partially-articulated crinoid stems measuring about 1 meter in thickness with a restricted lateral extent of about 100 meters. Crinoid columnals identified as *Pentacrinus asteriscus* Meek and Hayden were reported by John Wesley Powell from Jurassic deposits of southern Utah as early as 1876 and by Gregory and Moore in their original descriptions of the type locality of the Carmel Formation (1931). However, current work indicates that the crinoid at Mount Carmel Junction is *Isocrinus nicoleti*, a species described from

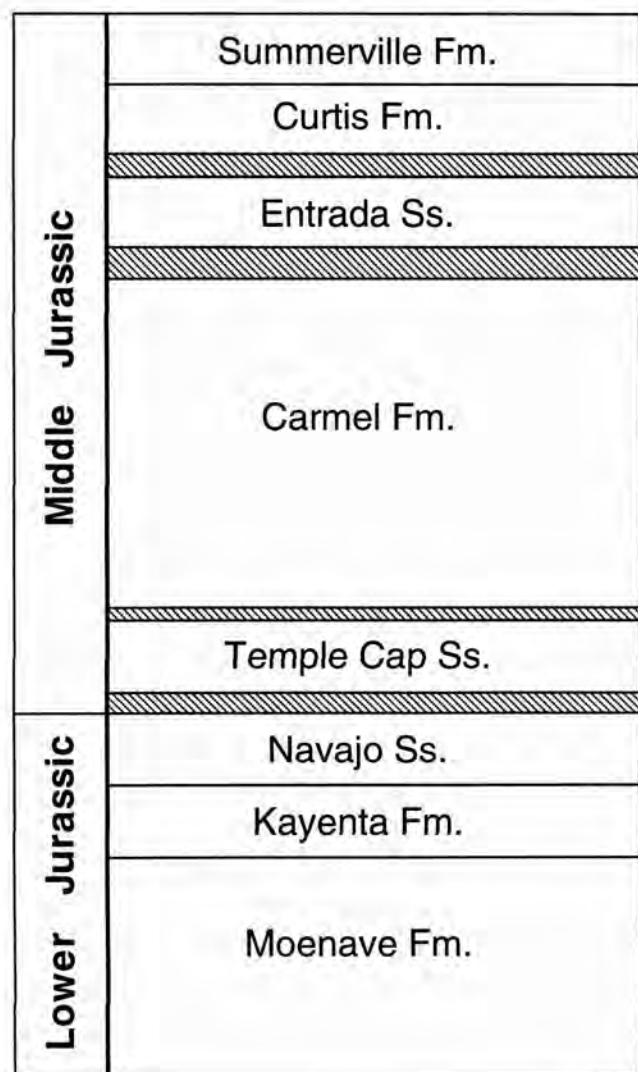


Figure 6. Schematic stratigraphic column depicting the Lower and Middle Jurassic formations of southern Utah.

European Jurassic strata (Tang et al., in prep). This crinoid occurrence in the Carmel Formation would represent the first non-endemic species described from the Jurassic of the U.S. western interior.

Based on sedimentological evidence at outcrop and thin-section scales, the crinoidal limestone has been interpreted as a tidally-influenced deposit, possibly representing accumulation in a tidal channel (Tang et al., 1994; Tang, 1996). The articulated nature of stems (Fig. 7) and some arms indicates that the crinoids experienced little transport after death and were buried fairly rapidly; it appears that these crinoids were living either in a tidal channel or on a tidal bar and used taphonomic feedback mechanisms to colonize a shifting sand-gravel sea floor which excluded most other

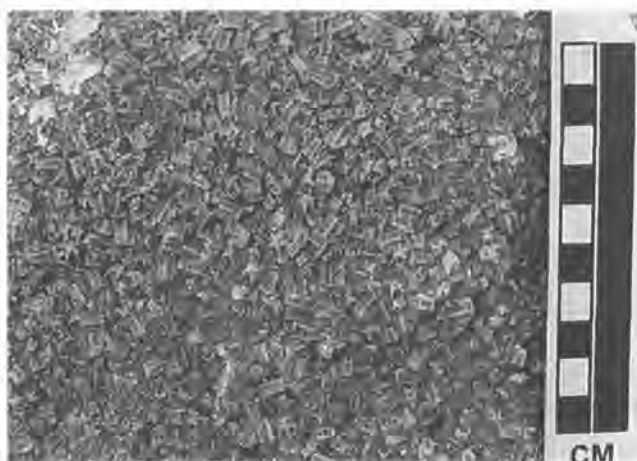


Figure 7. Well-preserved, partially-articulated crinoid columnals are exposed on a bedding plane within the Carmel Formation crinoidal limestone (encrinite) at Mount Carmel Junction (Stop 5). Scale is in centimeters.

organisms. This crinoid accumulation is one of the youngest shallow-water crinoidal limestones (encrinites) in the fossil record. Thus, it represents one of the last "stands" of stalked crinoids in shallow-water environments and may suggest unusual oceanographic and ecological conditions leading to the development of a refugium. If crinoids were excluded from shallow-water environments due to increases in predatory pressures during the Mesozoic Marine Revolution as suggested by Meyer and Macurda (1983), the presence of this encrinite suggests that predatory pressures may not have been intense in this southernmost extent of the Jurassic epicontinental seaway (Tang et al., 1994).

Well-preserved specimens of the cyclostome *Eurystotos duofluvia*—one of a handful of bryozoans described from the Jurassic of the western interior—can be found in wackestones overlying the encrinite. This species was originally described as *Berenicea duofluvia* by Cuffey and Ehleiter (1984) based on rare specimens from the Twin Creek Formation near Kemmerer, Wyoming. They can also be found on Carmel Formation ostreoliths from Gunlock, UT (Wilson, this volume).

Mount Carmel Junction (northeast):

At this locality, we will focus on the two lowermost ledge-forming carbonate units of the Co-op Creek Member (Fig. 8). The lowest resistant unit is composed of thin beds which have been interpreted as stromatolites (Taylor, 1981). However, without detailed study, this interpretation remains unsubstantiated.

Above this first ledge is a talus slope which is capped by a second resistant carbonate unit which is interpreted to have been deposited within a lagoonal-oid shoal environ-



Figure 8. Outcrop of lower section of the Co-op Creek Member of the Carmel Formation at Mount Carmel Junction (Stop 6). At the base, interbedded pink and green siltstones are overlain by the first ledge-forming limestone unit. Fossil-bearing carbonate beds are seen at the top of the photograph.

ment. While most of the beds in this unit are not highly fossiliferous, echinoderm fragments, algae, ostracodes and molluscan fragments can be identified in thin section. Rare spherical colonies of polychaete worms are about 20 cm in diameter and appear to be composed of radially-arranged smooth polychaete worm tubes with diameters of about 1 cm. One bed contains many good examples of the trace fossil *Gyrochorte* which is also found at the Gunlock locality of the Carmel Formation (Wilson, this volume) and in other parts of the world.

In this limestone unit, one bed does contain abundant well-preserved fossils and is interpreted to have been deposited in much quieter waters than the other horizons as evidenced by the presence of large amounts of micrite, very large and complete bivalves, unoriented valves, and

other sedimentological, petrological, and taphonomic evidence (Tang, 1996). Based on this information, the fossils are interpreted to represent a para-autochthonous (disturbed neighborhood) assemblage. In this fossiliferous unit, common body fossils are *Liostrea strigilecula*, *Camptonectes stygius*, and *Lima occidentalis*. Less common fossils include *Modiolus*, *Vaugonia*, *Isognomon* and others listed by Imlay (1964).

Paleoecologically, the fauna at Mount Carmel Junction exhibits low within-community (alpha) diversity and low between-community (beta) diversity similar to faunas across the entire Jurassic western interior seaway (Tang, 1996). The trophic nuclei of the Carmel Formation paleocommunities—the taxa which make up 80% of the assemblage—were usually composed of only two species, *Liostrea strigilecula* along with either *Lima occidentalis* or less commonly, *Camptonectes stygius*. However, numerically, *Liostrea strigilecula* individuals dominated almost all soft-bottom assemblages. Non-bivalve taxa are rarely found associated with the bivalve paleocommunities: rare encrusters can be found on bivalve shells and very rare crinoid and echinoid fragments can be present. Thus, these assemblages are heavily dominated by epifaunal suspension-feeding bivalves. Not only are these faunas low-diversity in nature, they also exhibit very low levels of trophic and tiering complexity. The Carmel Formation taxa have been interpreted as being generalists since they do not appear to be greatly partitioning their resources nor exhibiting habitat specialization (Tang, 1996). In this sense, the Carmel Formation fauna is congruent with low-diversity generalist faunas found throughout the entire western interior seaway from Middle to Late Jurassic times (Tang and Bottjer, 1996).

DISCUSSION

Fossiliferous limestones of the Co-op Creek Member of the Carmel Formation provide a glimpse into the paleoecological conditions which existed in the southern end of the Middle Jurassic western-interior epicontinental seaway. The presence of one of the youngest examples of an encrinite in the fossil record suggests that there may have been unique conditions in this area which may have created a short-lived refugium for Mesozoic stalked crinoids.

Paleoecological analyses of soft-bottom, para-autochthonous fossil assemblages indicate that the Co-op Creek Member fauna was heavily dominated by epifaunal suspension-feeding bivalves which formed very low-diversity paleocommunities. The Carmel Formation fauna provides a dramatic example of the generalist nature of the fauna found throughout the entire Jurassic western interior seaway and suggests that this seaway may be a unique laboratory in which to examine the development and evolution of low-diversity generalist taxa and their paleocommunities.

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Paleoecology of Lower Triassic marine carbonates in the southwestern USA

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ABSTRACT

Paleoecologic study of benthic invertebrate faunas from successive Early Triassic seaways reveals that biotic recovery from the end-Permian mass extinction event was slow, and that full recovery did not occur until after the Early Triassic. Simple, cosmopolitan, opportunistic generalists, and low-diversity, low-complexity paleocommunities were characteristic of the entire Early Triassic in the southwestern USA. An increase in guild and taxonomic diversity is observed with the addition of several new higher taxa in the late Early Triassic (Spathian), to the almost exclusively molluscan faunas of the earlier early Triassic (Nammalian). Comparison with data on faunas from the Permian and Triassic suggests that, worldwide, even the most diverse Early Triassic faunas (in the Spathian) were rather low in guild diversity and species richness. These characteristics of genera and paleocommunities in the Early Triassic may be typical of mass extinction aftermaths.

INTRODUCTION

The mass extinction at the Permian-Triassic boundary constitutes the most devastating biotic crisis of the Phanerozoic, and punctuates the transition from Paleozoic to Mesozoic life. Overall, marine families experienced a 49% reduction (Erwin, 1993, 1994), and an estimated 90% of the marine genera present in the late Permian disappeared (Erwin, 1993). A spectrum of causal mechanisms for the Permian/Triassic mass extinction has been proposed, from extensive flood basalt volcanism to abrupt extraterrestrial phenomena, with effects ranging from prolonged climate deterioration, to changes in ocean stratification, circulation and cycling (Erwin, 1993). However, the aftermath of this mass extinction is virtually unknown. Although comprehensive biostratigraphic work has been done, paleoecologic studies examining faunas as a whole are just beginning. This study (first reported in Schubert, 1993; Schubert and Bottjer, 1995) of benthic invertebrate recovery in the Early Triassic of the western USA has as a fundamental goal the identification of characteristics of this post-extinction fauna and its ecology that might be distinctive of mass extinction aftermaths.

STRATIGRAPHIC AND PALEOENVIRONMENTAL CONTEXT

The latest Permian and earliest Triassic are times of emergence and non-deposition in much of the western USA,

with a significant time gap of 1–6 m.y. commonly accepted for the Paleozoic-Mesozoic boundary (Paull and Paull, 1986). In the Early Triassic, both subsidence of the area and global sea level increases caused transgressive pulses from the northwest, bringing marine conditions recorded by fossiliferous limestones (Paull and Paull, 1986). The first of these (Griesbachian) transgressive events is recorded in the north by the Dinwoody Formation (Carr and Paull, 1983) (Fig. 9). The second (Nammalian) transgression is marked by a widespread marine carbonate unit containing ammonoids (*Meekoceras*), which defines the base of the Thaynes Formation (Kummel, 1954) (Fig. 9). This Nammalian transgression was geographically more extensive, and is recorded in south-central Utah by the Sinbad Limestone Member of the Moenkopi Formation (Fig. 9). The third (Spathian) transgression in the Early Triassic is recorded by thick sequences in the field area of the Virgin Limestone member of the Moenkopi (Paull et al., 1989) (Fig. 9).

The Moenkopi Formation in southeastern Nevada and southwestern Utah contains three limestone members (Fig. 9). The lower limestone member, the Timpoweap, is only very sparsely fossiliferous and is primarily a marginal marine deposit (Larson, 1966). The middle Virgin Limestone Member contains limestone units (Fig. 10) deposited under normal marine conditions during the Spathian transgression, intercalated with fine-grained siliciclastics and less common sandstones, representing marginal and subtidal environments (Larson, 1966; Rief and Slatt, 1979). The upper

Age	SE Nevada SW Utah	SE-central Utah	W & N-central Utah, Idaho, Montana & Wyoming
241	MOENKOPI FM		THAYNES FM
SPATHIAN	Upper Red		
	Schnabkaib	Moody Canyon	
	Middle Red		
	Virgin Limestone	Torrey	upper limestone
	Lower Red		
242	Timpoweap	Sinbad Limestone	
NAMMALIAN		Black Dragon	
243.5			
GRIESBACHIAN			DINWOODY FM
245			

Figure 9. Stratigraphy of the Lower Triassic in the Western USA, compiled and simplified from Larson (1966) and Hintze (1973); modified from Schubert and Bottjer (1995).

limestone, the Schnabkaib Limestone, is unfossiliferous and mainly evaporitic.

The Moenkopi changes in both lithology and nomenclature from southwestern Utah to the southeast-central part of the state, where the Lower Triassic section is dominated by terrigenous red and yellow siliciclastics (Blakey, 1974; Dean, 1981). Four members are recognized (Fig. 9), the Black Dragon, the Sinbad Limestone, the Torrey Member, and the Moody Canyon Member, which represent a range of environments, including bar, beach, delta, lagoon and shallow subtidal (Blakey, 1974; Dean, 1981). The Sinbad Limestone, deposited during the Nammalian transgression, is considered to be a major southern tongue of the lower Thaynes Formation (Kummel, 1954). The Sinbad Limestone is a thin yellow silty fossiliferous marine limestone and dolomite (Blakey, 1974; Dean, 1981). Sinbad depositional environments produced evaporitic tidal flat deposits, intertidal oolites, and subtidal and lagoonal pelletal mudstones as well as bioturbated skeletal wackestones from lagoon, tidal channel, and sub-wave-base shelf settings (Dean, 1981).

METHODS OF STUDY

Paleoecologic and paleoenvironmental data were collected at selected sites of the Lower Triassic in the south-



Figure 10. The Virgin Limestone Member is exposed at the top of a cliff near Hurricane, Utah (Stop 2). Person is standing on the bedding plane pictured in Figure 11. (Photo by C. Tang)

western United States (Schubert and Bottjer, 1996). In particular, study was made of localities of the Virgin Limestone in the Hurricane Cliffs area (Figs. 10,11), as well as localities of the Sinbad in the San Rafael Swell area, the two stops to be visited during this field trip. Collection of bulk sample faunal data involved removal of about 8000 cm³ of rock from intervals 15 cm or less in thickness. Fossils freed from the matrix and exposed on broken surfaces were identified and counted. Paleocommunities were defined from tallies of generic abundance of Virgin and Sinbad samples based upon cluster analysis (Schubert and Bottjer, 1996). Paleoecologic studies also included an analysis of the adaptive strategies of organisms in these paleocommunities. Bambach (1983) introduced this approach, and each of the major adaptive strategies that he defined have been termed "Bambachian megaguilds" (Droser et al., 1997).

PALEOCOMMUNITY ANALYSIS

Characteristics of the paleocommunities in these Lower Triassic strata indicate that ecologic recovery from this mass extinction was not achieved in the Early Triassic (e.g., Schubert and Bottjer, 1995; Bottjer et al., 1996). Diversity at high taxonomic levels is very low; only bivalves, crinoids, plus in some cases, echinoids, gastropods, and brachiopods, are represented. Diversity at low taxonomic levels is low as well; most of these groups are represented by only one species (e.g., crinoids and echinoids) or a few species (e.g., brachiopods). Bambachian megaguild diversity is relatively low and few taxa are represented in each megaguild. Examination of the nature and timing of recovery throughout the Early Triassic of the western USA reveals that it was slow and uneven.



Figure 11. A bedding plane of the Virgin Limestone with numerous cross-sections of bivalves and occasional columnals of the crinoid *H. smithi* (Stop 2, near Hurricane, Utah). (Photo by C. Tang)

Nammalian Sinbad Limestone paleocommunities exhibit a greater diversity at higher and lower taxonomic levels than the older Dinwoody Formation to the north (Schubert and Bottjer, 1995); a larger variety of bivalves and several species of microgastropod are typically present. The increase in taxic diversity also signals an increase in megaguild diversity, particularly the addition of grazing/detritovore and predatory life habits represented by the gastropods. However, relatively few tiers (e.g., Bottjer and Ausich, 1986), or levels of vertical space, are occupied in these Sinbad paleocommunities. Suspension-feeding bivalves, as well as the microgastropods, lived at the sediment surface, semi-infaunally, and as shallow burrowers (*Arenicolites*, observed in the Sinbad, also records shallow burrowing). None of the organisms represented by body fossils found in these paleocommunities lived elevated above the sediment surface, or burrowed deeply within it.

Sinbad paleocommunities can be very high in dominance, with one or two species of microgastropod or bivalve extraordinarily numerous, and a relatively small number of individuals of other species present. These microgastropods are typical of and limited to the Nammalian Sinbad Limestone (Batten and Stokes, 1987), and are neither abundant nor diverse in faunas of the Spathian Virgin Limestone. This waxing and waning of microgastropods may represent volatility in the process of ecologic recovery. Possibly, ecologic rebound cannot be described as an increasing linear function, but is in part a fitful unpredictable process. The boom/bust behavior exhibited by the microgastropods, which were extremely abundant in the Sinbad, but almost unknown from seemingly similar environments of the Virgin, could also be a function of the kinds of genera that are characteristic of mass extinction aftermaths: opportunists known for blooms and crashes in their population dynamics.

Although bivalves remain dominant in Spathian Virgin paleocommunities (Fig. 11), different bivalve genera occur in different relative abundances than in Nammalian Sinbad paleocommunities. A more diverse assemblage of higher taxa is known from the Spathian. For example, Virgin paleocommunities are characterized by the first appearance (in the western USA) of representatives of important Mesozoic clades, *Holocrinus* (?) *smithi* (crinoids) and *Miocidaris utahensis* (echinoids). *H. smithi* is the earliest known member of its clade and served as the stem group for all post-Paleozoic crinoids. Representing the brachiopods is one terebratulid genus. Because the terebratulids and rhychonellids are the only articulate orders to persist into the present, these two genera are important as a link between Permian and Triassic brachiopods, and as potential ancestral stock for post-Paleozoic brachiopods.

The presence of these taxa in the Spathian of the western USA is also of ecologic significance, since it represents the re-appearance of life habits previously absent from the dominantly molluscan paleocommunities of earlier Triassic settings. Shallow infaunal, semi-infaunal, and epifaunal suspension-feeding bivalves were prominent members of Griesbachian, Nammalian, and Spathian invertebrate paleocommunities in the western USA (Schubert and Bottjer, 1995). The stemmed crinoid represents the addition in the Spathian of not only a new guild but also a new tier in the vertical space partitioning of the community, since its feeding activity occurs above the substrate at the raised calyx. As a mobile epifaunal grazer and detritovore, the Spathian echinoid also belongs to a different guild. Though more complex than paleocommunities in the Sinbad, these Spathian paleocommunities are still simple in structure and vary little in terms of dominant genera over the vast geographic area of the Early Triassic Virgin seaway; the same handful of bivalves and a single crinoid species recur in paleocommunities throughout the western USA (Schubert and Bottjer, 1995).

CONCLUSIONS

Paleoecologic study of invertebrate faunas from successive Early Triassic seaways in the southwestern USA reveals that biotic recovery from the end-Permian mass extinction event was slow and incomplete. Simple, cosmopolitan, opportunistic generalists, and low-diversity, low-complexity paleocommunities were characteristic of the entire Early Triassic throughout this region (Schubert and Bottjer, 1995). An increase in guild and taxonomic diversity was observed with the addition of other higher taxa in the late Early Triassic (Spathian) to the almost exclusively molluscan faunas of the earlier Early Triassic (Nammalian). Comparison with data on faunas from the Permian and Triassic suggest that even the most diverse Early Triassic faunas (in the Spathian)

were rather low in megaguild diversity and species richness (Schubert and Bottjer, 1995).

A remarkable aspect of the ecology and biota of the Early Triassic aftermath is the apparent small part played by radiation during this 4–5 m.y. time period. Groups such as crinoids, echinoids, and articulate brachiopods that eventually appeared in Spathian paleocommunities probably did not evolve there. Rather, this most probably simply reflects their migration into the area, and does not represent much evolutionary innovation. These Spathian taxa, like the Lazarus taxa for which the Triassic is so noted (e.g., Hallam, 1991), are groups that vanish from the fossil record of the western USA during the mass extinction interval and reappear later in the Triassic without being much (if at all) different from those in the Paleozoic. They must have persisted, or originated from very similar forms, in unknown refuges. What we see here is a slow trickling back of survivors, scattered over megaguilds and taxa, that would serve as the basis for radiations that occurred, not in the Early Triassic, but much later in the Triassic and Jurassic.

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