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THE DIVERSITY AND STRATIGRAPHIC DISTRIBUTION OF PRE-DINOSAURIAN COMMUNITIES FROM THE TRIASSIC MOENKOPI FORMATION, CAPITOL REEF NATIONAL PARK AND GLEN CANYON NATIONAL RECREATION AREA, UTAH

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Recent discoveries in the Moenkopi Formation (Early Triassic) of Capitol Reef National Park (CRNP), and Glen Canyon National Recreation Area (GCNRA), Utah have revealed important new terrestrial and subaqueous vertebrate track localities. These well-preserved tracks occur on multiple stratigraphic horizons and are the oldest and most laterally extensive track-bearing horizons documented in the Western U.S. Ichnogenera (*Chirotherium*), *(Rhynchosauroides*), and *(Rotodactylus),* are the dominant forms. Rare fish fin drag marks *(Undichna)* and fish skeletal remains have been identified in the Torrey Member and equivalent strata of the Moenkopi Formation.

Tracks are preserved either as positive relief "casts" filling impressions in the underlying mudstones or on plane bed surfaces as negative relief "impressions". Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone has eroded away and in finer grained sediments such as mudstones and siltstones. The Torrey Member represents deposition on a broad, flat-lying coastal delta plain. Both nonmarine (fluvial) and marine (principally tidal) processes influenced deposition. Even-bedded mudstones, siltstones, claystones, and fine grained

Location Map of Glen Canyon National Recreation Area and Capitol Reef National Park

sandstones, containing abundant ripple marks and parallel laminations dominate lithologic types. Ichnites indicating swimming/floating behavior are associated with the walking trackways. The water depth was sufficiently shallow to permit the vertebrates to touch the substrate with manus and pedes when moving through the water.

Tracks form locally dense concentrations of toe scrape marks which sometimes occur with complete plantigrade manus and pes impressions. Well preserved, skin, claw, and pad, impressions are common. Occasional, well developed, tail-drag marks frequently occur in many of the trackway sequences. Fish fin drag marks and fish skeletal material are preserved with tetrapod swim tracks. In addition to vertebrate ichnites, fossil invertebrate traces *Arenicolites*, *Paleophycus*, *Fuersichnus*, *Kouphichnium* (horseshoe crab), centipede, and fossil plants of *Equisetum* are abundant.

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Lateral correlations of the ichnostratigraphic units identified in the Moenkopi Formation throughout Utah's National Parks will aid interpretations about the paleoecology, and diversity of the Western Interior during the Middle Triassic-"the dawn of the dinosaurs".

Significance

- Terrestrial tracks in an apparently marine influenced facies of the Moenkopi Formation

- Distribution of Middle Triassic Pre-Dinosaurian Communities

- Diversity of Middle Triassic Pre-Dinosaurian Communities

There are Three Lines of Evidence of Tidal Influence

- Tidal point bars present

- Presence of mud draped features; pulses of water and suspended load being dropped; an indication of fluctuating currents

- Presence of vertebrate and invertebrate traces

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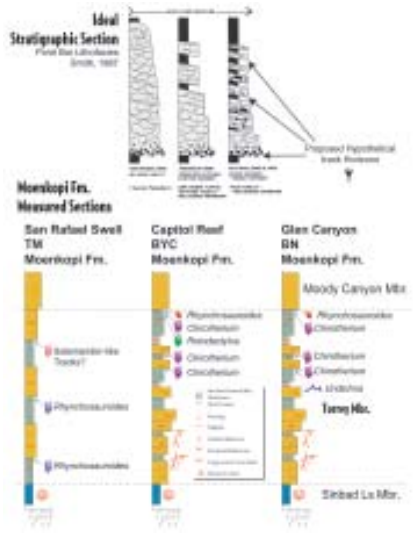
Significance and Three lines of evidence

Geology

The Torrey Member of the Moenkopi Formation has been the subject of investigation for almost 50 years. However, these studies were more broad based regional studies, and only recently has the Torrey Member been studied in stratigraphic detail with emphasis on the extensive tetrapod track-bearing surfaces of pre-dinosaurian communities present within it. At present, the multiple track-bearing horizons are known to extend throughout much of Utah's National Parks. Currently, the Torrey

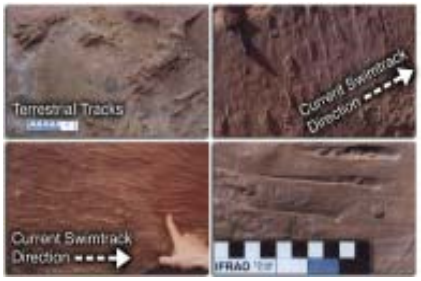


Stratigraphic measured sections of GCNRA and CRNP and Smith's Model of "Meandering River Estuarine Systems ".

Member vertebrate tracks are the oldest and most laterally extensive megatracksite horizons ever recorded.

Following the deposition of the Sinbad Member in a clear shallow sea, a change in tectonic and/or climatic conditions caused the progradation of a major delta succession into Utah. This delta complex is preserved as the Torrey Member.

Basal deposits of the Torrey Member include interbedded siltstones, dolomites, and very fine-grained sandstones that were laid down in advance of the prograding delta. This sequence grades upwards into ledge-forming coarser grained sandstones and interbedded siltstones. Several track-bearing horizons are present within this delta-plain facies. The facies includes channel deposits of large-scale trough cross bedded fine to medium grained



Vertebrate tracks of *Chirotherium*. Known to occur at Glen Canyon National Recreation Area and Capitol Reef National Park.

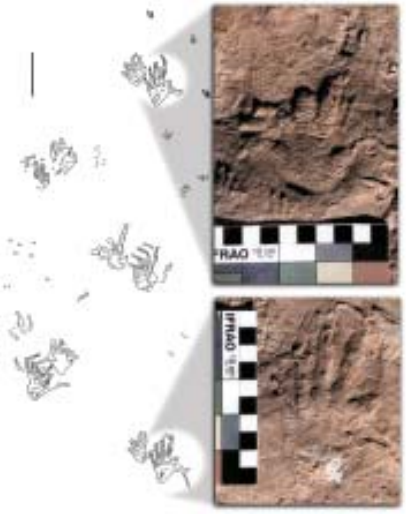
sandstone that was deposited within the fluvial-dominated reaches of the upperdelta-plain. Multiple tetrapod track horizons have been identified within these deposits.

Channel bodies dominated by ripple to large-scale trough cross bedded sandstones and interbedded mudstones are organized into inclined heterolithic packages. Also present within these sandstone and mudstone-dominated channels are large-scale soft sediment deformational features and clay-draped ripple- and dune-scale bedforms. Tetrapod tracks and fish-fin drag marks are typically associated with these deposits. These inclined barforms are likely pointbar deposits that experienced tidal influence and may represent the more seaward lower delta-plain expression of the sandstone-dominated fluvial channels.

A threefold lithofacies classification model produced by Smith (1987) was adapted to describe depositional environments of the Torrey Member delta-plain channels. Outcrop measured sections (a west to east trend) are similar to Smith's, (1987) lithofacies classification for meandering river estuarine systems.

Vertebrate Ichnology

Chirotherium Tracks: Relatively narrow, quadrupedal trackways indicating the normal tetrapod walking gait; in the walking gait a small pentadactyl manus impression regularly occur immediately in front of, but never overlapped by a much larger, pentadactyl pes which generally resembles a reversed human hand. Manus and pes are digitigrade, and in large forms the pes tends to be plantigrade; digits I-IV point more or less forward, manus digits IV is always



Vertebrate tracks of *Rotodactylus*. Known to occur at Capitol Reef National Park.

shorter than III being largest; the footprints may or may not show specialized metatarsal pads. Clear impressions often show a granular or beaded skin surface (skin impressions). Associated swim tracks are common and often indicate current flow directions and water depths**.**

Rotodactylus Tracks: Long-striding, trackways of a medium pentadactyl reptile are well preserved with rare skin and claw impressions. These tracks commonly occur with smaller *Rhynchosauroides* footprints. The manus is always closer to the midline and in some cases overstepped even in the walking gait by the much larger pes in a moderately narrow trackway pattern; pace angulation (pes) as high as 146 degrees in a running trackway and as low as 93 degrees in a walking trackway. The pes impression indicates a foot with an advanced digitigrade posture, and with a strongly developed but slender digit V rotated to the rear where it functioned as a

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rotated backward but it has a propping function. Digit IV on both manus and pes is longer than III; digit I may fail to impress; claws are evident and distinct on digits I-IV. Scaly plantar surface (well defined skin impressions) are often preserved in exquisite detail and is characterized by transversely elongate scales on the digit axis bordered by granular scales.

Rhynchosauroides Tracks: Dense concentrations of *Rhynchosauroides* tracks are commonly associated with the trackways of *Chirotherium* and *Rotodactylus*. These small lacertoid footprints are generally characterized by deeply impressed manus and a faintly impressed pes. Trackways exhibit a relatively wide pattern with pentadactyl footprint relatively distant from the midline. The pace angulation is low, below 90 degrees – 100 –120

Vertebrate tracks of *Undichna* (fish fin drag marks). Known to occur at Glen Canyon National Recreation Area.

degrees if figured from the manus pattern. Most often only 3 to 4 digits are preserved with occasional tail drag marks. The digits are slender and relatively longer in the pes than in the manus and both sometimes exhibit distinct claw impressions. Swim tracks are common.

Undichna Fish Trails: The Moenkopi Formation is known for its exceptional vertebrate fossil record. Fish are rare and have been little studied in detail, and fish trails (fish fin drag marks) have never been recorded. The purpose of this study is to describe the first known occurrence of fish trails (fish fin drag marks), *Undichna* from the Early Triassic Torrey Member of the Moenkopi Formation. This ichnogenus has been reported in abundance from the Late Paleozoic, Permian, Cretaceous, and more recently from the Eocene. *Undichna* from the Torrey Member of the Moenkopi Formation represents the first and only known occurrence of fish trace fossils in the Triassic in the Western U.S.

The fish fin trace fossils are preserved as convex hyporelief sandstone casts with filled imprints preserved in underlying mudstone. Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone eroded away. *Undichna* commonly occur with locally dense concentrations of swim traces of *Chirotherium*.

Occurring in clusters, one isolated fish fin trace consists of a single, slightly-asymmetrical, sinusoidal trail. The trace is 56 cm. Long and includes 6.5 cycles with wavelengths varying from 9 to 10 cm and amplitudes of 3.5 to 4.5 cm.

The trails were most likely produced by a fish with a large caudal or anal fin able to reach the sediment without any other fin doing so. The low wavelength to amplitude ratio is most consistent with a caudal fin. This occurrence of *Undichna* is similar to other previous descriptions and it confirms that the preservation of these trails are favored in fine-grained sediments. Importantly, these traces coupled with *Chirotherium*, and *Rhynchosauroides*, swim tracks, all indicate fluctuating water depths.

Invertebrate Ichnology

Fuersichnus, *Palaeophycus*, and *Arenicolites*: The Torrey Member of the Moenkopi Formation assemblage studied is considered herein as an example of the *Glossifungites* ichnofacies and commonly occur with vertebrate swim tracks. This ichnofacies has been restricted to firm but unlithified nonmarine and marine surfaces. The *Glossifungites* ichnofacies is characterized by low diversity and high density assemblages which include *Fuerichnus*, *Palaeophycus*, *Arenicolites*, and *Skolithos.*

The ichnogenus *Fuersichnus* is a relatively rare trace fossil that has been documented from Triassic and Jurassic nonmarine deposits and only recently documented in marine deposits from the Upper Cretaceous . The ichnogenus consits of horizontal to subhorizontal, isolated of loosely clustered, U-shaped, curved to banana-like burrows, characterized by distinctive striations parallel to the trace axis. It is interpreted as a

Invertebrate trace fossils of *Fuersichnus*, *Palaeophycus*, *Arenicolites*. Known to occur at Glen Canyon National Recreation Area and Capitol Reef National Park.

dwelling structure probably produced by crustaceans or polychaetes.

The ichnogenus *Palaeophycus* a common trace fossil that has been documented from Pre-Cambrian to Holocene nonmarine and marine deposits. Branched, and irregularly winding, cylindric or subcylindric tubes, that sometimes cross-cut one another. These horizontal galleries most often have vertically striated lined burrows or rarely nearly smooth surface textures. *Palaeophycus* represents passive sedimentation within an open dwelling burrow constructed by a predaceous or suspension-feeding animal.

The ichnogenus *Arenicolites* are simple U-tubes (paired tubes) without spereite, perpendicular to bedding plane; usually varying in size, tube diameter, distance of limbs, and depth of burrows; limbs rarely somewhat branched, some with funnel-shaped opening; walls commonly smooth. A common trace fossil documented from Triassic to Cretaceous from marine and nonmarine deposits. The Torrey *Arenicolites* are very consistent in size, shape, and distance apart from each other and are interpreted as made by annelid worms.

Summary

- Occurrence of terrestrial and sub-aqueous tracks in the Moenkopi Formation.

- Tracks occur in marine influenced environments.

- Implication is that these animals may have tolerated brackish water conditions.

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Discussion

Several important discoveries have been made during the course of this research in GLCA and CARE. The Torrey Member of the Moenkopi Formation trackways are first described in detail from this stratigraphic unit and suggest a great potential for finding other footprint sites in this Formation. This unit is widely exposed not only in Capitol Reef, and Glen Canyon Recreation Area, but also, Zion, Canyonlands, and Arches, National Parks. Lateral correlations in Utah's National Parks of the Moenkopi's extensive track bearing horizons provide a good basis for correlation with the entire region.

As a non-renewable resource on public lands, fossil footprints provide an opportunity for public education, scientific research, monitoring programs, and an administrative opportunity and challenge for both scientists and land management authorities.

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What Is Ichnology?

Fossils can be divided into body fossils, preserved parts of the plant or animal, and trace fossils, indirect evidence of their presence. **Ichnology** is the study of plant and animal traces. The implication of this definition is that the traces made by plants and animals reflect some sort of behavior or in the case of animals their mode of locomotion. The best known trace fossil are tracks but burrows, nests, and gnaw marks on bones or plants are also types of trace fossils.

Ichnology can be divided into two major subdivisions: **paleoichnology** (the study of ancient traces) and **neoichnology** (the study of modern traces). Most ichnologists are involved in paleoichnology but a considerable number also study neoichnology for the comparison of modern equivalents (and their trace makers) to ancient traces. Technically speaking, wildlife biologists or ecologists who study tracking (identification of animals and their behavior on the basis of their tracks and feces) are neoichnologists, although they probably would not recognize such an designation if you told them.

http://www.emory.edu/COLLEGE/ENVS/research/ichnology/

Discovery of Cretaceous Marine Reptiles at Glen Canyon National Recreation Area

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Ninety million years ago dinosaurs ruled the land on a globe that had been inundated by rising sea level. The North American continent had become two islands separated by an inland seaway that isolated eastern North America from western North America. That shallow sea became home for a myriad of sea-going animals and plants that we now find as fossils in the shales and limestones that accumulated in the Cretaceous Inland Sea. During the past five years, paleontologists from the Museum of Northern Arizona and our colleagues have discovered a variety of new and sometimes spectacular marine vertebrates from the Tropic Shale, which represents the accumulation of muds and siltstones in that warm, tropical sea. The most abundant are the plesiosaurs, giant marine predators that competed with sharks as the dominant terrors of the Cretaceous sea.

Our field investigations have focused on the Cretaceous vertebrate fauna of southern Utah in Glen Canyon National Recreation Area (National Park Service) and Grand Staircase-Escalante

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Paleontologists from the Museum of Northern Arizona answer questions about the plesiosaur during an open house at Glen Canyon National Recreation Area

The plesiosaur, *Trinacromerum*, as it was found at Glen Canyon National Recreation Area.

National Monument (Bureau of Land Management) where continuous exposures of the Tropic Shale offer unparalleled opportunity for studies on biodiversity of the final stages of the Age of Dinosaurs. Plesiosaurs seem to be the most abundant, and certainly the largest of the Cretaceous marine predators in the Tropic Shale fauna. From several partial, but nevertheless spectacular skeletons, we have pieced together enough to display one example of the genus *Trinacromerum*, a short-neck plesiosaur with the ability to swim at astounding velocity, by some calculations as fast as 30 miles per hour or more. That mounted skeleton was on display at the Museum of Northern Arizona from April 2003 until May 2004. It is now scheduled to become a year-long exhibit in 2004 and 2005 at the John Wesley Powell Museum of Page, Arizona, the town closest to the field area in Glen Canyon National Recreation Area.

That mounted skeleton is about 20 feet long, with a skull and jaws more than four feet long and containing about 100 piercing teeth. It is a composite

Paddle of the plesiosaur during excavation.

from two individuals, one from Glen Canyon National Recreation Area, the other from Grand Staircase-Escalante National Monument, making this exhibit an interagency display. During the 2003 field season we completed the excavation of another partial skeleton from an individual that was twice as long: at least 40 feet in length and several tons in total weight. Although we did not recover bones from the head, we can estimate that the skull and jaws were nearly eight feet long. And that's not the largest: we have discovered incomplete skeletons, mainly vertebrae, from a variety that's even larger.

Some say the Age of Dinosaurs was a dangerous time to live on land. We say that the Cretaceous Sea during the Age of Dinosaurs was the *most* dangerous place to live!

Denali Geologist's Name Graces Fossil

While any employee of the National Park Service can names lots of fringe benefits of working in parks, one of the more unusual ones is to have a fossil named after you. The recipient of this rather unusual claim to fame is Phil Brease, an NPS geologist at Denali National Park and Preserve. A fossil Devonian brachiopod from the park was described as a new species of *Myriospirifer*, *M. breasei* by Jenaro L. García-Alcalde and Robert B. Blodgett in the Journal of the Czech Geological Society. Blodgett is a geologist with the United States Geological Survey in Anchorage, Alasaka that specializes in brachiopods. The brachiopod was found by Blodgett, Brease, and Pam Sousanes during a research trip in the park in July 1996. A member of the subfamily Eospiriferinae, this genus of brachiopod was widespread within Gondwana and Baltica during the Devonian. Its presence in Alaska is interpreted as being the result of transport on accreted terrane rifted from Sibera and joined to North America during the late Mesozoic.

Answer to name the fossil and the park. This is a portion of a fossil termite burrow preserved in the Navajo Sandstone at Glen Canyon National Recreation Area.

***Myriospirifer breasei* Dorsal view**

Phil Brease, geologist at Denali National Park

García-Alcalde, J.L. and R.B. Blodgett. 2001. New lower Devonian (upper Emsian) *Myriospirifer* (Brachiopoda, Eospiriferinae) species from Alaska and northern Spain and the paleogeographic distribution of the genus *Myriospirifer*. Journal of the Czech Geological Society 46(3-4):145-154.

Brachiopod or Bivalve?

While brachiopods and bivalves (also known as pelecypods) look superfically similar because they have two external shells, they are quite different. In fact they are placed in two seperate phyla, with brachiopods in their own phylum and bilvalves are placed within the phylum Mollusca. One way to tell a brachiopod from a bivlave is the plane of symmetry - where the line goes that divides the animal into mirror images. In the brachiopods the plane of symmetry is at a right angle to the shell, while in in a bivalve the plane of symmetry passes between the two valves of the shell so each half of the shell is the mirror image of the other.

Brachiopods also have a structure known as a pedicle which they use to attach to rocks while bivalves have a muscular foot. Bivalves breath and gather food using gills while a brachipod does this with a structure known as a lophophore.

An Unlikely Giant in Capitol Reef National Park

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The discovery of giant stromatolite fossils in the Navajo Sandstone is part of a growing body of research challenging some long-held assumptions about the paleoenvironment of the Navajo erg.

The Navajo Sandstone, a prominent and well-exposed rock unit in the Colorado Plateau, was once an enormous, arid sea of blowing sands (called an erg) often compared to the present Sahara Desert. This early Jurassic dune field covered close to half a million square kilometers and reached thicknesses in excess of 700 meters making it one of the largest dune fields in the history of Earth.

Although the Navajo erg is generally thought to have been an expansive and lonely desert, new fossils found in Capitol Reef National Park suggest otherwise. During an extended backpacking trip, the senior author stumbled across what he described looked "almost like a giant haystack" or "a giant limestone onion slowly being peeled." This turned out to be the serendipitous discovery of the first known stromatolite in the Navajo Sandstone and possibly the first stromatolite within an erg setting. Eisenberg, an independent geology consultant, spent the next several years researching the occurrence and the discovery was reported in the February, 2003 issue of *Geology*.

During the roughly 15 million years in which the Navajo was deposited it spread out over seven states, reaching its maximum thickness in what is today Zion National Park.

Stromatolites are bizarre fossils whose biological origins were debated until only a few decades ago. Today, scientists generally agree that stromatolites are layered colonial structures predominately formed by cyanobacteria. Stromatolites are the oldest fossils on earth, dating back to more than three billion years ago. They were the dominant life form on earth for over 2 billion years and are thought to be primarily responsible for the oxygenation of the atmosphere. Living and fossil stromatolites are usually no more than half a meter tall and are found in marine environments. In contrast, the Capitol Reef Stromatolites are up to five meters in height and appear in thin carbonate beds associated with interdune deposits.

The most important implication of the fossils is the suggestion of large bodies of standing water necessary to sustain the towering stromatolites. "We need to reevaluate the whole paleoenvironment," David Loope of the University of Nebraska-Lincoln says. "Until we had the stromatolites the general picture was hyper-arid," he says. Dr. Marjorie Chan of the University of Utah agrees, saying that despite the dry and dusty impression of the Navajo erg, "it in fact had water and lakes."

This is a dramatically different picture of the Navajo than previously thought. The Navajo erg "may not be analogous to the present Sahara" in that it had the "potential for heavy rain and long lived episodes of water," Loope says. Long lived episodes of water would also translate into extended periods of erg stabilization.

Researchers have long "suspected that the Navajo must have stabilized at some point," although this is the first direct evidence of such stabilization. Modern ergs are known to periodically stabilize, a recent example being the "greening period" of the Sahara between four to ten thousand years ago. Using growth rates for modern stromatolites, it can be determined that the fossil stromatolites grew over a period of a few thousand to over ten thousand years, putting them "right in the ballpark, …in the thousands of years range," with the duration of the Sahara stabilization.

The Capitol Reef Stromatolites stand out like "haystacks" from the surrounding rock because they are composed of limestone, which is more resistant to weathering in a desert environment than the surrounding sandstone.

If the Navajo erg stabilized for thousands of years, it would mark a major stratigraphic boundary within the Navajo Sandstone. Right now, "the

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What Are Stromatolites?

A stromatolite is produced by cyanobacteria. The distinctive layers are produced as calcium carbonate is precipitated over the growing mat of bacterial filaments. Photosynthesis in the bacteria depletes carbon dioxide in the surrounding water and makes it less acidic thus initiating the precipitation of the calcium carbonate. The minerals, along with grains of sediment precipitating from the water become trapped within the sticky layer of mucilage that surrounds the bacterial colonies. As the colony continues to grow upwards through the sediment a new layer is formed. As this process occurs over and over again, the layers of sediment are created.

Navajo is a big pile of sand and it's hard to know where you are stratigraphically,"

"The next step is the "correlation of these scattered outcrops" to help "unravel the internal geometry and history of the Navajo erg."

Further correlation of interdune carbonate deposits could also suggest a regional climatic event, helping to improve climatic models of the Early Jurassic.

"There is variability that we never realized that was there," Chan says. "Just when you think you know it all, we discover there's a lot we didn't know." The stromatolites in Capitol Reef National Park have renewed interest in the Navajo Sandstone and provide insight into the biology and environmental history of the Navajo erg, all from a walk in the Park.

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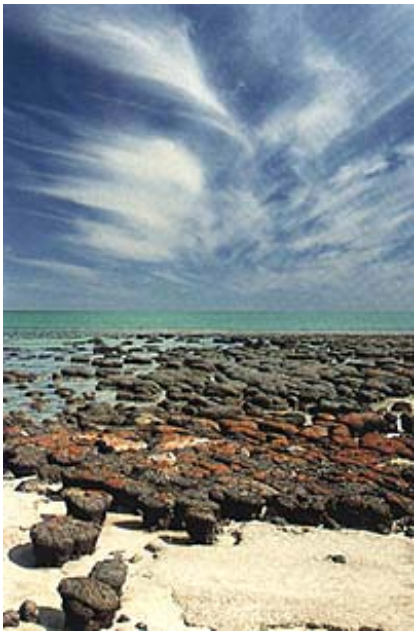
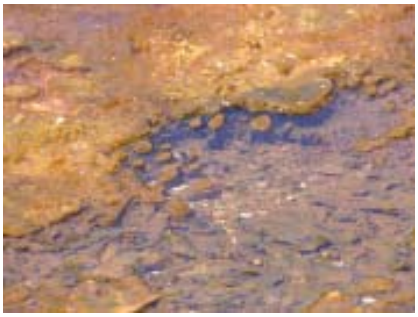


The best modern analogues to fossil stromatolites can be found in Shark Bay, Australia (above). Similar organisms, identical in form and structure, can be found in the outlet channel of Octopus Springs in Yellowstone National Park (below). Living stromatolites are rare today and are usually only found in hyper-saline waters.



PLEASE NOTE

The fossil stromatolites at Capitol Reef are not easily accessible and somewhat hard to find. If you're up for a long day-hike or an overnighter, one of the best locations to see the stromatolites is located along Cottonwood wash in the central-eastern section of the Park. Always check in with the park staff beofre going on any overnight or extended trips into the back country of the park. As always, removal or vandalism of any fossil is strictly prohibited.

Fossils from Glen Canyon NRA Travel to France

Glen Canyon National Recreation Area has a wide variety of fossils. While those associated with the Jurassic Navajo Sandstone are perhaps the best known, fossils at Glen Canyon also includes remains from the Ice Age. The dry arid environment of the region helps preserve soft tissue and organic material including skin, horn and hoof coverings and dung that is not often preserved in the fossil record. Often the preservation is just as spectacular as the better known frozen fossils of Siberia and Alaska. The same Navajo Sandstone that includes dinosaur tracks and termite nests often weathers to form sandstone overhangs or alcoves. During the Ice Age animals, including mammoths, shrub oxen and ground sloths often used these alcoves for shelter and evidence of their presence is indicated by not only their preserved remains but their dung as well.

The Muséum National d'Histoire Naturelle Paris, France has recently opened an exhibit entitled **"Au Temps des Mammouths"**, (The Time of the Mammoths" which will be open from March 17, 2004 to January 10, 2005. The exhibit is in The Grande Gallerie de l'Evolution. 36, rue Geoffroy Saint-Hillaire. Among the various fossils included in the exhibit is dung of the extinct Columbian Mammoth from Glen Canyon National Recreation Area on loan from the park to the museum. Arrangement of the loan was done through Chris Kincaid, curator at the park and Linda Clement, Staff Curator for the Rocky Mountain Region working with Jim Mead of Northern Arizona University. Dr. Mead along with Dr. Larry Agenbroad of the university was involved in the original excavation or the site and its scientific study. Study of the dung has shown it is composed of 95 % grasses and sedges and has provided important information about the diet of these extinct animals.

The web site for the exhibit
http://www.mnhn.fr/mammouths/

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Name the fossil and the park. Hint: The park contains a large artificial lake named for a geologist. Answer on page 5.