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LUNGFISH BURROWS IN THE UPPER TRIASSIC CHINLE AND DOLORES FORMATIONS, COLORADO PLATEAU[1]

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ABSTRACT: Vertical-to-inclined, cylindrical trace fossils that occur in the Upper Triassic Chinle and Dolores Formations on the Colorado Plateau are interpreted to be the casts of lungfish burrows. The casts, which are as much as 11 cm in diameter and as much as 1.6 m long, were formed by passive siliciclastic and carbonate sedimentation into apparently abandoned lungfish burrows. Locally, the burrow fillings are overwhelmingly abundant, and many intersect and have destroyed former burrow fillings. Superposition of bioturbation episodes has obliterated most primary sedimentary structures. This bioturbation has contributed to the mottled coloration and the knobby-weathering texture of the rocks. The burrow-fillings occur ubiquitously in three lithofacies, comprising 1) purple- and white-mottled, silicified sandstone and siltstone, 2) red and brown siltstone and mudstone, and 3) pink and green limestone. These strata were deposited in a continental environment that included fluvial channels and floodplains, sand sheets and playa mudflats, and lacustrine basins, marshes, and deltas.

The identification of the trace fossils as the positive casts of lungfish burrows is based on their morphologic similarity to previously identified lungfish burrows and to available hand specimens.

The widespread occurrence of the lungfish burrows in the Chinle and Dolores Formations attests to the extensive habitat that supported lungfish in the Late Triassic and to conditions favorable for burrow preservation. Analogy with the environments that support modern lungfish populations suggests that the Late Triassic climate in the study area provided sufficient moisture to support large populations of lungfish and that this climate was probably punctuated by seasonally dry periods.

INTRODUCTION

Fossil lungfish (Dipnoi) burrows were first described from the Lower Permian Clear Fork Group of Texas (Romer and Olson 1954; Olson and Bolles 1975). The identification was based on the external morphology of natural cylindrical burrow casts and the included disarticulated skeletal remains of the dipnoan genus *Gnathorhiza* within several of the burrows. Other similar burrow casts attributed to lungfish have been reported from a number of Paleozoic stratigraphic units in North America (Table 1). Well-preserved, articulated skulls, and skeletons of *Gnathorhiza* in a presumed tail-down, aestivating (dry-season-dormant) position in the burrows have been documented only from the Lower Permian Wellington Formation of Oklahoma (Carlson 1968); other identifications have been based on the morphologic similarity of the burrow casts to the first-described Permian specimens.

Sedimentologic studies of the Upper Triassic Chinle Formation and the Upper Triassic Dolores Formation on the Colorado Plateau have disclosed abundant, vertical-to-inclined, cylindrical burrow casts in rocks that were deposited in a complex fluvial-lacustrine system. The external morphology of the Chinle and Dolores burrow casts is very similar to the initial Permian lungfish burrow description and other subsequent literature descriptions, and to available hand specimens of lungfish burrows. This evidence, and the fact that many burrow casts contain clastic material of larger grain size than the surrounding matrix, suggests that the casts were produced by passive siliciclastic and carbonate infilling of abandoned lungfish burrows. Although the morphology of the lungfish burrows in the Triassic rocks is very similar to that of lungfish burrows reported from other strata, the overwhelming abundance of burrows in the Triassic rocks contrasts markedly with the sparse numbers of specimens reported from most other stratigraphic units.

The presence of lungfish burrows, combined with sedimentologic data, provides additional control on the depositional environments and the Late Triassic climate that prevailed at the time of deposition of the Chinle and Dolores Formations. In addition, burrows that extend from the basal units of the Chinle Formation into the underlying Early and Middle(?) Triassic Moenkopi Formation and the mixing of Moenkopi and Chinle sediments by lungfish bioturbation provide insight into the nature of the Chinle-Moenkopi unconformity and the relative time of lithification of the Moenkopi Formation.

Blodgett (1980, 1984) and Dubiel (1983, 1984a, b) mentioned briefly the occurrence and interpretation of the lungfish burrows in the Dolores and Chinle Formations, respectively. This report describes in greater detail

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the morphology of the burrow casts, their stratigraphic distribution, and the sedimentologic and climatic implications of their occurrence.

REGIONAL STRATIGRAPHIC SETTING

The Upper Triassic Chinle Formation and the, in part, laterally equivalent Upper Triassic Dolores Formation were deposited over a large part of the Colorado Plateau and adjacent areas. In the study area (Fig. 1), the Chinle Formation unconformably overlies the Early and Middle(?) Triassic Moenkopi Formation, and the Dolores Formation unconformably overlies the Permian Cutler Formation. Locally, both the Chinle and Dolores Formations overlie rocks older than Permian. In this area, the Chinle Formation is overlain by the Upper Triassic Wingate Sandstone and locally by the Middle Jurassic Entrada Sandstone, while the Dolores Formation is overlain by the Entrada Sandstone. The Dolores Formation appears to correlate with portions of the Chinle Formation of the Colorado Plateau and, in addition, with the lower member of the Wingate Sandstone in Arizona and New Mexico (Fig. 2). However, there is little lithologic or paleontologic evidence to establish correlations between the lower half of the Dolores Formation and specific members of the Chinle Formation in Utah, Arizona, and New Mexico. The Chinle Formation has a maximum thickness of about 500 m in the study area, and the Dolores Formation varies in thickness from 30 m to 150 m.

Stratigraphic relationships and nomenclature, which have evolved through the years, reflect the complexity of the continental depositional systems in the Chinle (Stewart et al. 1972a, b) and Dolores (Blodgett 1984) Formations. In the study area (Fig. 1), six members of the Chinle Formation are recognized—the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock Members, in ascending order. The Dolores Formation is divided into three members, referred to informally as lower, middle, and upper. All of the members are not present at every locality because of lateral and vertical facies changes (Stewart et al. 1972a) and the nature of the sedimentary valley-fill sequence at the base of the Chinle and Dolores Formations (Gubitosa 1981; Dubiel 1983; Blodgett 1984). The Chinle and Dolores Formations comprise relatively thin, lithologically homogeneous sandstone and conglomerate units such as the Shinarump Member, the Moss Back Member, and the lower member of the Dolores Formation. They also contain relatively thick, heterogeneous sandstone and mudstone units such as the Monitor Butte Member, the Petrified Forest Member, the Owl Rock Member, the Church Rock Member, and the middle and upper members of the Dolores Formation. Contacts between members are complex, gradational, and often difficult to pick on the outcrop.

LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS

The Chinle and Dolores Formations were deposited by a succession of fluvial systems and adjacent floodplain,

TABLE 1.—*Descriptive data on reports of fossil lungfish burrows*

Author(s)	Age	Locality	Dispersion	Bones	Diameter	Length	Orientation	Top	Termination	Authors' Attribution
Romer and Olson 1954	Early Permian	Texas	grouped	yes	5.5–10.0 cm	28.0–45.0 cm	vertical	—	rounded	lungfish
Gabelman 1955	Permian(?)	Colorado	grouped	no	1.2–20.0 cm	≤120 cm	vertical	—	rounded	spring action
Langston 1963	Permo-Carboniferous	Canada	solitary	no	8.0–10.0 cm	28.0 cm	vertical	—	rounded	lungfish
Abdel-Gawad and Kerr 1963	Late Triassic	Colorado	grouped	no	2.5–5.0 cm	—	vertical	—	—	hydrothermal alteration
Vaughn 1964	Early Permian	New Mexico	grouped	no	4.5–6.5 cm	23–28 cm	~vertical	dilated	rounded, enlarged	lungfish
Carroll 1965	Middle Pennsylvanian	Michigan	solitary	no	15.0 cm	≤41.0 cm	vertical	—	—	lungfish
Carlson 1968	Permian	Oklahoma	grouped	yes	1.0–10.0 cm	—	~vertical	—	rounded	lungfish
Woodrow and Fletcher 1968	Late Devonian	Pennsylvania	grouped and solitary	no	5.0–15.0 cm	≤52.0 cm	vertical	—	rounded	lungfish
Olson and Bolles 1975	Early Permian	Texas	grouped	yes	1.0–10.0 cm	≤50.0 cm	~vertical	—	rounded	lungfish
Blodgett 1983	Late Triassic	Colorado	grouped	no	2.0–9.0 cm	≤130.0 cm	~vertical	—	—	lungfish
Dubiel 1984a, b	Late Triassic	Utah, New Mexico	grouped	no	3.6–11.0 cm	25.0–168.5 cm	~vertical	—	rounded	lungfish
This paper	Late Triassic	New Mexico, Utah, Colorado, Arizona	grouped	no	3.6–11.0 cm	25.0–168.5 cm	~vertical to inclined	dilated	rounded, some enlarged	lungfish
T. M. Bown, unpubl. data	Early Oligocene	Egypt	grouped	no	4.0–8.5 cm	33.0–62.0 cm	vertical to ~inclined	—	rounded	lungfish

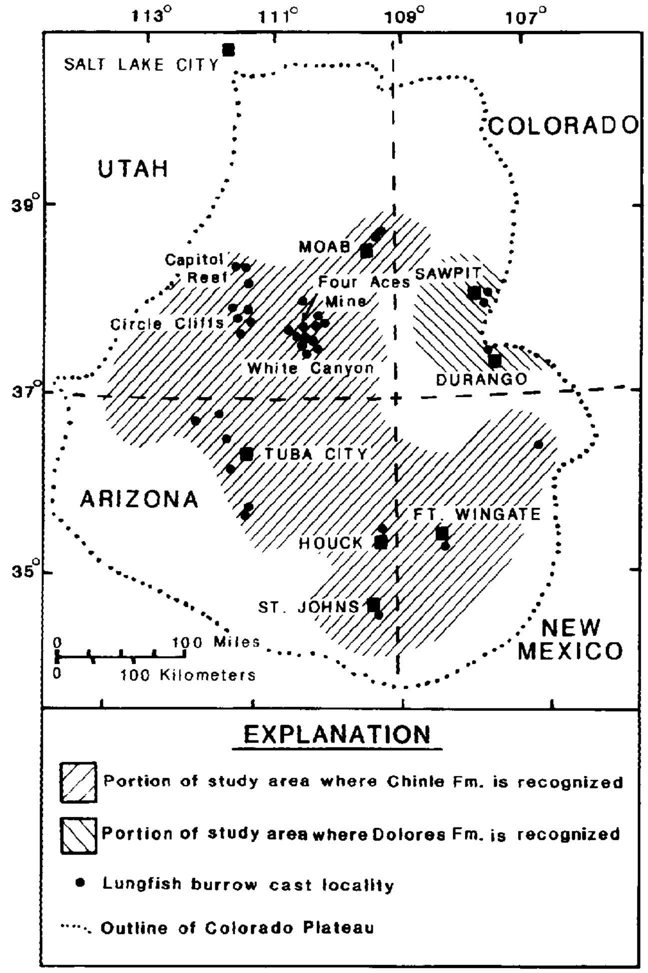

FIG. 1.—Location of study area, lungfish burrow cast localities, and geographic features referred to in the text.

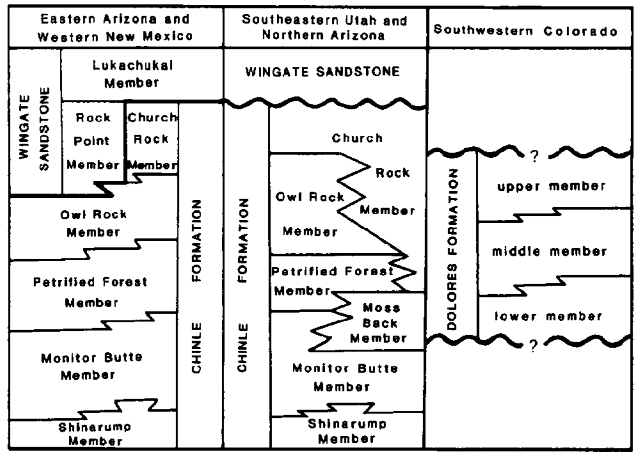

FIG. 2.—Correlation of the Upper Triassic Dolores Formation with members of the Upper Triassic Chinle Formation and the Wingate Sandstone based on facies relationships (modified from Blodgett 1984).

lacustrine, sand sheet, and continental sabkha environments (Stewart et al. 1972a; Gubitosa 1981; Blakey and Gubitosa 1983; Dubiel 1983; Blodgett 1984). Laterally extensive, coarse-grained to conglomeratic sandstones are common in the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock Members of the Chinle Formation and the lower member of the Dolores Formation. Medium- to fine-grained sandstones are present in all members of the Chinle Formation, and in the middle and upper members of the Dolores Formation. Mudstones and siltstones are common in each member of the Chinle Formation and in the middle and upper members of the Dolores Formation. These lithologies compose a major portion of the Monitor Butte, Petrified Forest, and Owl Rock members of the Chinle Formation and the middle and upper members of the Dolores Formation. Limestones are a minor component of the Monitor Butte Member and a major component of the Owl Rock Member of the Chinle Formation.

Vertical and horizontal lithofacies relationships, sedimentary structures, paleocurrent indicators, and regional relationships have been used to interpret the depositional environments and history of the Chinle (Stewart et al. 1972a; Blakey and Gubitosa 1983; Dubiel 1983, 1984a, b) and Dolores (Blodgett 1983, 1984) formations. In general, coarse-grained and conglomeratic sandstones were deposited by both meandering and braided fluvial systems. Medium- and fine-grained sandstones were deposited in a variety of fluvial, lacustrine, deltaic, floodplain, sand sheet, and continental sabkha environments. Mudstones and siltstones were deposited on fluvial floodplains and in abandoned fluvial channels, on lacustrine and sabkha mudflats, and in lacustrine marshes and basins. Limestones were deposited in parts of lacustrine basins that did not receive a large supply of clastic detritus.

BIOGENIC STRUCTURES

Cylindrical structures are common in the Chinle and Dolores Formations at many localities in the study area (Fig. 1). Excellent outcrop examples of these structures occur in the Chinle Formation throughout the White Canyon, Capital Reef, and Circle Cliffs areas, Utah; near Houck, St. Johns, and Tuba City, Arizona; and near Ft. Wingate, New Mexico. In the Dolores Formation, the structures are well represented in outcrops near Sawpit and Durango, Colorado. Specific locality information may be obtained from the authors.

Description

The lungfish aestivation burrows from the many localities in the Upper Triassic Chinle and Dolores Formations (Fig. 1) are similar in size and shape and are discussed together. Though several examples of one or a few burrows occurring in isolated circumstances are known, the majority of the specimens occur grouped together in clusters. It is a common attribute of their dispersion that the margins of these clusters of burrow casts have a lesser density of specimens, and it is thereby uncertain if the more isolated specimens represent isolated instances of burrowing or if they are on the margins of an unexposed cluster of burrow casts. Within the clusters, the burrow casts typically overlap and intersect one another through several meters of section and along the line of outcrop for several hundred meters. Many thousands of burrow casts are preserved at some localities (Fig. 3A).

At all localities, the burrow casts are generally straight and are vertical or near vertical in orientation (Figs. 3A, C, D, E, F, 4), and a few other specimens are inclined 45° or less to the horizontal bedding (Fig. 3B, F). A few relatively sinuous examples are also known. Cross sections normal to the long axes of the casts are generally circular to somewhat oval and, in different specimens, vary in mean diameter from about 2.0 cm to 11.0 cm. In individual specimens, diameters varied as much as 15 percent along the vertical reach of the casts, and there is a marked tendency in most specimens for the cross-section diameters to decrease somewhat from top to bottom. This decrease has also been described by Langston (1963), Carroll (1965), Carlson (1968), and Olson and Bolles (1975).

No complete burrow casts have been recognized from the Chinle or Dolores Formations, and it is therefore difficult to arrive at an idea of the range in length of original, undamaged burrows. It is likely that the burrowing represents the activity of lungfish at all growth stages, and the burrow cast sizes vary accordingly. The smallest casts are about 2.0 cm in diameter and up to 15.0 cm in length. The longest specimen (from the Chinle Formation, near the Four Aces Mine, Fig. 1) is 168.5 cm and has a maximum diameter of 8.2 cm; however, most specimens have a preserved length of 25–70 cm. In only two specimens, one each from the Chinle and Dolores Formations, were the recognizable tops of the burrow casts preserved. In each example, the upper reach of the burrow cast is dilated (Fig. 3D), widening to as much as twice or more the average diameter of the remainder of the cast (up to 18.0 cm) and causing the upper part of the structure to resemble a funnel. Similar dilated tops of lungfish burrow casts were described by Vaughn (1964). Preserved lower terminations were noted in only seven burrow casts from the Chinle Formation and in one from the Dolores Formation. In the Chinle examples, the lower reach of the cast is clearly narrower in diameter than the upper reach and terminates in a rounded, unenlarged, convex-downward base (Fig. 5). One Chinle specimen (Fig. 3E) preserves a fist-sized, bulblike termination, much like in specimens described by Vaughn (1964).

The burrow casts occur in sandstone, sandy siltstone or mudstone, and limestone and are generally filled with these lithologies. Some of the sandy burrow fillings are laminated (Fig. 3F), indicating incremental passive filling of an open burrow, whereas most others are filled with structureless (though commonly bioturbated) mud and silt. Many of the specimens in the Chinle Formation are silicified. Two specimens collected from the Petrified Forest Member of the Chinle Formation southwest of Tuba City are silicified and contain abundant rhizoliths (root casts) not seen in the host sediment. Although several hundred burrow casts from both formations were broken and examined in the field, none of the specimens were found to contain skeletal material. Additional slabbing of several specimens in the laboratory failed to reveal any bone. The casts are well cemented by calcite, dolomite, silica, hematite, and clay minerals that preclude any attempt at disaggregation.

The burrow casts are typically more resistant than the host sediment due to this increased carbonate, silicate, authigenic clay, and/or iron oxide or oxyhydrate cementation. In outcrop, they are therefore preserved in bas-relief as adhesive trace fossils (Figs. 3A, E, F, 4), or as discrete trace fossils (readily separable from host rocks; Fig. 3B, C, and D; see Bown 1982; and Bown and Kraus 1983). In siltstones and mudstones, in which there has been considerable mobility of clay minerals and metallic oxides (plasma constituents) probably associated with soil genesis, the casts are differentially pigmented (mottled) with hydrated or dehydrated iron oxides. In other instances, iron pigmentation is more restricted to the peripheries of the burrow casts and/or the host sediment in the immediate vicinity (within a few centimeters) of the casts. Carlson (1968) and Olson and Bolles (1975) observed that some of their burrow casts are composed of a "core," around which is developed an outer shell containing packed scales and bones of lungfish. None of the Chinle and Dolores burrow casts possess this compound structure, believed by those authors to result from packing of the walls of the burrow by the lungfish during burrow construction.

Lungfish burrow casts occur in several different members and lithofacies of the Chinle and Dolores Formations that represent a variety of depositional environments (Fig. 6). The burrows are most common in a distinctive, purple- and white-mottled, silicified, coarse-grained sandstone to siltstone facies of the Monitor Butte Member of the Chinle Formation (Figs. 3A, 4). The burrows themselves are commonly white to light tan and contrast in color with the enclosing unit. Most primary sedimentary structures have been obliterated by the bioturbation. These facies are interpreted as fluvial-channel and levee deposits (Dubiel 1983) that were alternately submerged and exposed due to seasonal flooding. The bioturbation and the pedogenic mottling reflect the influence of alternating wet and dry floodplain conditions. The lighter coloration of the burrow casts may reflect a redistribution of iron resulting from alternating reducing and oxidizing conditions produced by the fluctuating seasonal water table and the oxidation of lungfish-secreted mucus that formed the aestivation cocoon (Johnels and Svensson 1955).

The burrows are present to a lesser extent in red and brown siltstones and mudstones of the middle member of the Dolores Formation (Fig. 3B, D), and the Petrified Forest and Owl Rock Members of the Chinle Formation. The burrows in the mudstones and siltstones are commonly difficult to discern because the grain size of the burrow fill closely approximates that of the surrounding matrix. These mudstones and siltstones are interpreted to have been deposited on floodplain, lacustrine, and marsh mudflats.

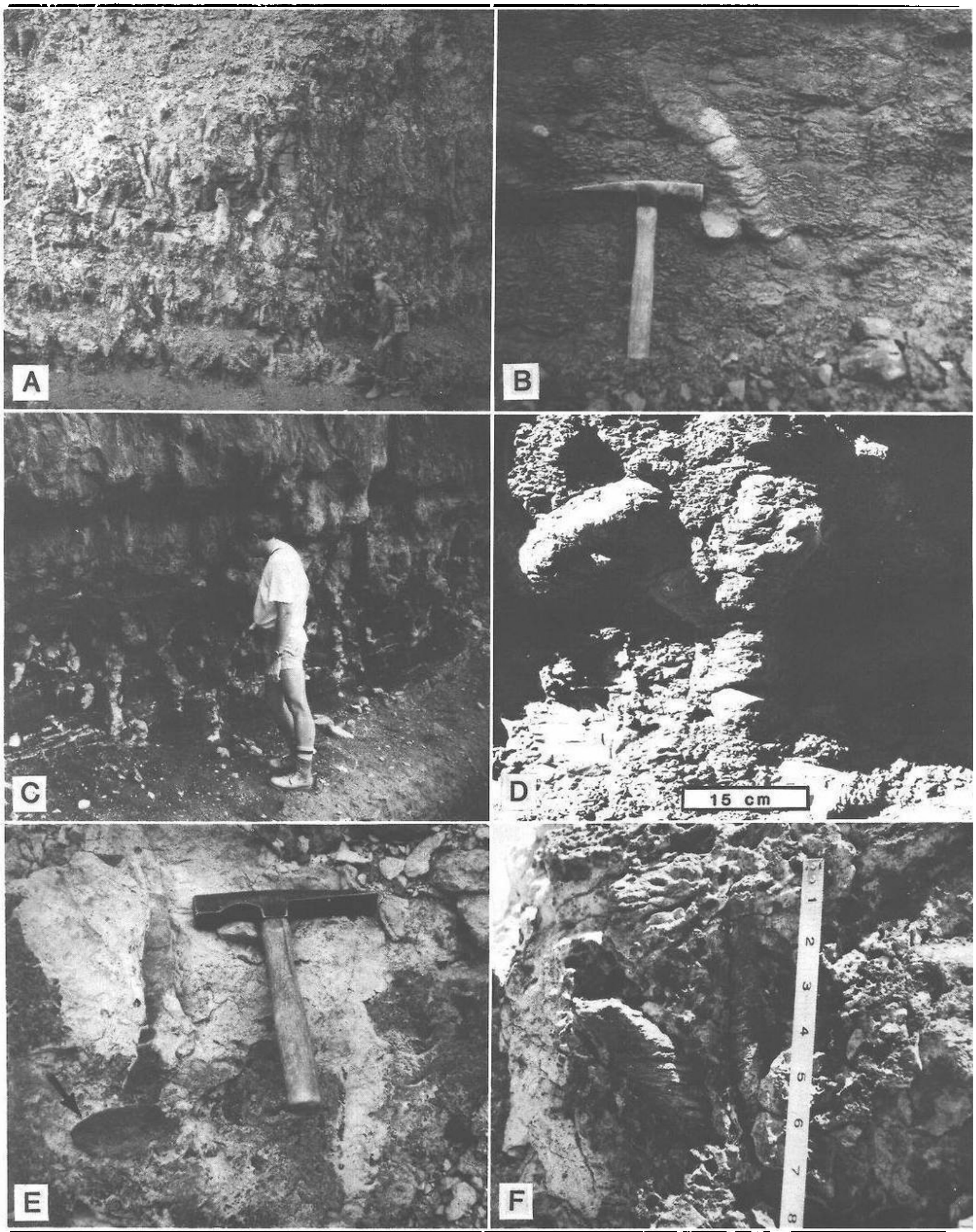

FIG. 3.—Lungfish burrow casts in the Chinle and Dolores Formations. A) Abundant lungfish burrow casts in the flooded fluvial facies of the Monitor Butte Member of the Chinle Formation, Ft. Wingate, New Mexico. Note that the extensive bioturbation has virtually destroyed primary

FIG. 4.—Lungfish burrow casts in flooded fluvial facies, Monitor Butte Member of the Chinle Formation, Ft. Wingate, New Mexico. Note the lighter color of the burrow casts compared to the mottled coloration of the matrix. Hammer, in center, for scale.

The burrow casts are also abundant in the pink and green limestone facies of the Owl Rock Member of the Chinle Formation. These burrow casts are filled with both carbonate cement and siliciclastic grains. The burrows are very distinct where they extend from limestone into the underlying siltstone and are less distinct within the limestones because of the bioturbation. Commonly, only the final episode of burrowing is well preserved; the remainder of the limestone exhibits a knobby-weathered, bioturbated texture. These limestones are interpreted to have been deposited in a lacustrine basin (Dubiel 1983).

Burrows in the Dolores Formation are found in three depositional settings that are characterized by specific lithologies and sedimentary structures. The burrows occur in reddish brown mudstone that exhibits large-scale, lateral-accretion stratification and is bounded by lobe-shaped sandstone bodies. This setting is interpreted to represent floodplain, upper-point-bar, and crevasse-splay facies deposited by a fine-grained meanderbelt system near Sawpit and Durango (Blodgett 1984). Burrows also occur in mudstone that fills a large scour cut into sandstone and is interpreted to represent an abandoned channel fill of the same meanderbelt system. Lastly, the burrows occur in very fine grained sandstone and siltstone that exhibit mud drapes on bedding planes. This unit, which occurs near Sawpit, is interpreted as a pedogenically altered sand-sheet deposit (Blodgett 1984). Burrows in the very fine sandstone and siltstone of the sand-sheet facies, and the presence of mud drapes, suggest that the fish may have invaded this depositional environment during seasonal flooding.

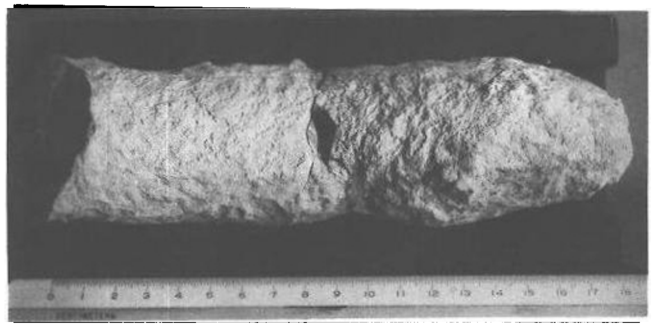

FIG. 5.—Lower portion of lungfish burrow cast from lacustrine basin facies, Owl Rock Member of the Chinle Formation, showing rounded, unenlarged, convex-downward termination (bottom of burrow is to the right). Scale at bottom in centimeters.

In both the Chinle and Dolores Formations, regional lithofacies distribution and sedimentologic interpretation of depositional environments suggest that lungfish burrowing may have been induced by seasonal flooding similar to that which occurs on the modern Yaeres' floodplain (Chari and Logone Rivers) southeast of Lake Chad, in Chad and Cameroon (Welcomme 1979; Beadle 1981). The ecology of living lungfish has been treated at some length by several authors, including Lancester (1894), Kerr (1898), Budgett (1901), Longman (1928), Smith (1931), Johnels and Svensson (1955), and references therein.

Discussion

The cylindrical structures from the Chinle and Dolores Formations almost certainly are the passively filled burrows of lungfish. The vast majority conform well in dispersion, size, orientation, and morphology with burrow casts attributed by several other authors to lungfish (Table 1). The absence of lungfish bones in or associated with the burrows is probably not very significant regarding their origin because physically associated burrow casts, some with bones and some without, are known from other published records (Romer and Olson 1954; Carlson 1968; Olson and Bolles 1975). Most burrow casts attributed to lungfish on other criteria (Table 1) do not have lungfish bones associated with them.

In details of their morphology, the structures at hand

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stratification. B) Inclined, sandstone-filled lungfish burrow cast in mudstone and siltstone floodplain facies, middle member of the Dolores Formation. C) Lungfish burrow casts, Circle Cliffs, Utah, extending from flooded fluvial facies of the Monitor Butte Member of the Chinle Formation down into the Moenkopi Formation. The Chinle-Moenkopi contact is at the level of the geologist's elbow. D) Lungfish burrow cast in the middle member of the Dolores Formation showing the expanded, funnel-shaped top. E) Lungfish burrow cast, Monitor Butte Member of the Chinle Formation, showing rounded termination (arrow). A second, indistinct burrow cast is just right of the hammer handle. F) Two lungfish burrow casts in flooded fluvial facies of the Chinle Formation showing distinctly cross-bedded, passive sedimentary fill. Scale marked in inches.

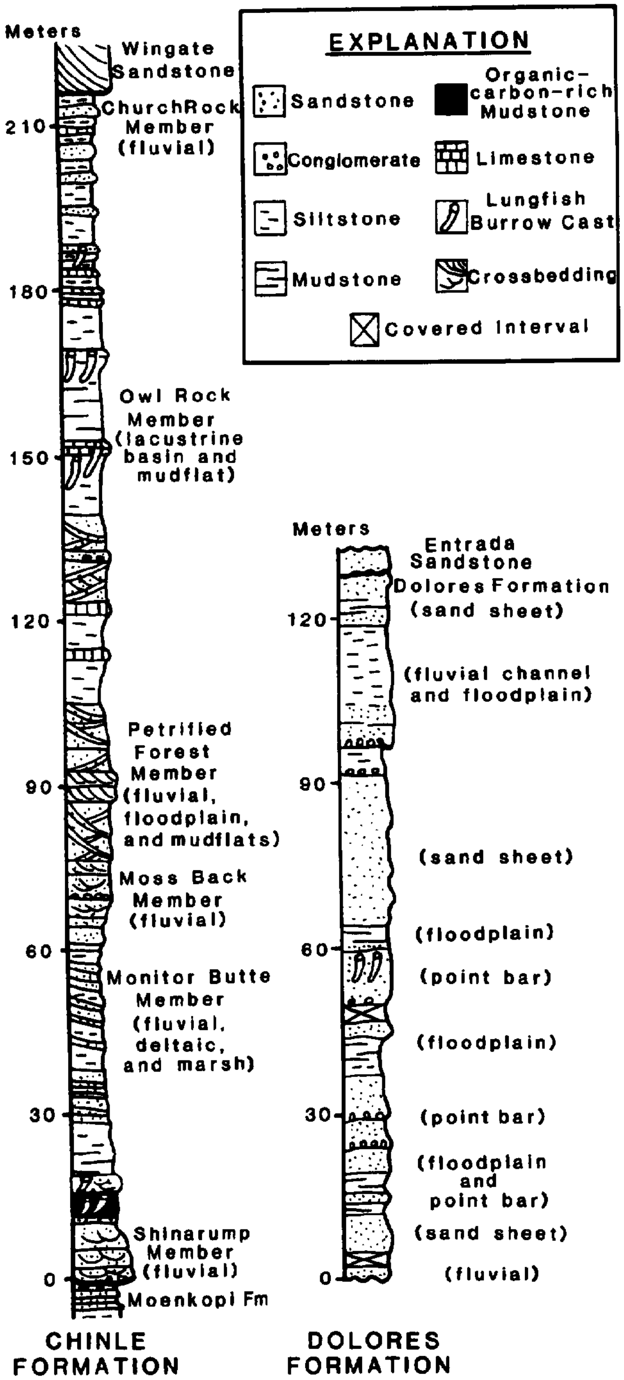

FIG. 6.—Measured stratigraphic sections of the Chinle Formation at Blue Notch, White Canyon area, San Juan County, Utah, and the Dolores Formation near Vanadium, San Miguel County, Colorado, showing typical lithofacies and stratigraphic occurrence of lungfish burrows.

do not resemble cylindrical pith casts of the horsetail *Neocalamites* from Upper Triassic rocks of western Colorado (Holt 1947), New Mexico (Ash 1967), or Arizona (Ash 1972), and their peculiar dispersion, lack of branching, and top and bottom termination morphologies rule out a rhizolith origin (Klappa 1980; Bown 1982). Decapods are the only nonmarine invertebrates large enough to have possibly constructed these burrows. The oldest of the fresh-water decapods are the Family Astacidae (crayfish), which date back to the Late Jurassic or Early Cretaceous in Eurasia but only to the early Eocene in North America (Glaessner 1969). Burrows of extant Astacidae always have chambers at the base (Pennak 1953), in contrast to the straight terminations of the Chinle and Dolores burrows. Olsen (1977) reported an Erymidae crayfish from lacustrine facies of the Upper Triassic Chatham Group of North Carolina, but the Chinle and Dolores burrows are two to eleven times larger than a burrow that would be constructed by this crayfish. In addition, decapod burrow casts have a characteristic external structure (Bown and Kraus 1983) not seen in any of the Chinle or Dolores examples. There are no certain records of other vertebrate burrows from rocks of this antiquity except for the amphibian *Lysorophus* (Olson and Bolles 1975), whose burrow is dissimilar.

Cylindrical sandstone-plugged pipes in the Old Red Sandstone, originally thought to be fluid-escape structures (Allen 1961), were reinterpreted (Allen and Williams 1981) as the trace fossil *Beaconites antarcticus* (Gevers et al. 1971). The structures described herein do not exhibit the long lateral reaches and conspicuous internal menisci (Gevers et al. 1971; Allen and Williams 1981) typical of *Beaconites*. Other cylindrical structures in sandstone have been interpreted as being the results of spring action (for example, Hawley and Hart 1934; Gabelman 1955) or to have been caused by the downward movement of unconsolidated sand above fissures (for example, Dietrich 1952). The morphology and sedimentologic contexts of the Chinle and Dolores structures are inconsistent with these origins in that there is no known inorganic mechanism for producing cylindrical structures with convex-downward terminations, as described here. Simpson (1936) gave several insightful reasons against origins by spring action for similar enigmatical cylindrical structures in the Paleocene of Argentina. Moreover, there are no deposits containing such structures in recent or ancient sediments in which their origin is known to be due to spring action. The shape, scale, and lithologic setting within sandstone beds of pillar, or water-escape, structures (Lowe and LoPiccolo 1974) contrast markedly with the Chinle and Dolores structures.

Nonetheless, the size and orientation of some of the Chinle and Dolores burrow casts deviate somewhat from other records of lungfish burrows. The longest specimen previously reported had a length of 50 cm, but in the Chinle many specimens exceed a meter in length and one specimen is 168 cm long. The significance of this large size is unknown because there is no information available on the adult body length of the fish that probably produced the structures. Living Australian *Epiceratodus* (a nonburrowing lungfish) and burrowing African *Protopterus* have body lengths of at least 210 cm (Longman 1928; Smith 1931). Moreover, the pronounced sinuosity evidenced in some of the Chinle burrow casts, as well as the common tendency to have a relatively shallow angle with bedding, differs from the essentially straight, vertical casts that typify most lungfish burrows. In both formations, burrows in mud or muddy silt tend to be more sinuous and inclined than burrows intruded into sandstone. It is possible that it was easier for the fish to excavate straight, vertical burrows in sand; however, the more sinuous structures might even have been produced by a different organism.

All described Permian lungfish burrows have been attributed to *Gnathoriza* (Romer and Olson 1954; Vaughn 1964; Carlson 1968; Olson and Bolles 1975), and three of these records (Romer and Olson 1954; Carlson 1968; Olson and Bolles 1975) are based on associated bones of that animal in the burrows. Carroll (1965) believed that the Middle Pennsylvanian burrows that he studied were formed by *Gnathoriza* because its bones occur in slightly younger overlying rocks (Romer and Smith 1934). Though no lungfish body fossils are known from the Dolores Formation, lungfish toothplates of a form referred to *Ceratodus* sp. are known from the Chinle Formation in Arizona (Colbert 1972; Jacobs and Murray 1980) and were collected from the Chinle Formation in Utah during this study. *Gnathoriza*, though unknown from the Chinle and Dolores Formations, apparently survived into the Triassic (Rykov and Minikh 1969).

Locally, casts of lungfish burrows extend from the purple- and white-mottled facies of the Monitor Butte Member into the underlying Moenkopi Formation (Fig. 3C). Moenkopi strata have been mixed across the unconformity into the lowermost portion of the Chinle (Fig. 3C). Modern lungfish excavate their burrows by biting off pieces of the substrate with their teeth, chewing the pieces with water in their mouths, and expelling the mixture through their gills (Johnels and Svensson 1955). This presumed method of bioturbation by Triassic lungfish and the observed mixing of Chinle and Moenkopi strata indicate that the affected portions of the Moenkopi Formation were not yet extensively lithified at the time of burrowing.

Abdel-Gawad and Kerr (1963) reported an occurrence of silicified "pipes" as much as 8 cm in diameter within mottled strata of the Chinle Formation located about 17 km northeast of the Colorado River bridge at Moab, Utah. They attributed these pipes to hydrothermal alteration associated with nearby uranium mineralization in the Chinle. The mottled strata were identified in a field check of this locality, and the "pipes" were observed to be identical to the burrow fillings described in this report. The passive fill of these burrows consists of coarse-grained to granular sand and is the coarsest fill observed in any of the Triassic burrow cast localities. The similarity to other Triassic lungfish burrow casts and the distinct difference in grain size between the burrow fills and the surrounding rock suggests that these "pipes" should similarly be interpreted as lungfish burrow casts.

CONCLUSIONS

Vertical, cylindrical structures occurring in purple- and white-mottled, silicifed sandstone and siltstone, red siltstone and mudstone, and pink and green limestone of the Upper Triassic Chinle and Dolores Formations are interpreted to have been produced by the passive siliciclastic and carbonate filling of burrows produced by lungfish. This identification is based on the morphologic similarity of the structures to previously identified Permian lungfish burrows (Table 1) and available hand specimens. The present distribution of the burrowed Chinle and Dolores strata (Fig. 1) suggests that the environments and climatic conditions necessary to sustain lungfish and to preserve their burrows were present over a large portion of the Colorado Plateau during the Late Triassic.

The overwhelming numbers of the lungfish burrow casts in the Upper Triassic strata indicate that optimum conditions existed for their preservation. Our observations of outcrops in many localities, the intense bioturbation of the beds that contain abundant burrow casts, and the presence of many individual burrows of varying size show that there was a significant resident population of lungfish at any one time and place. This evidence, and the occurrence of lungfish burrow casts throughout the stratigraphic column of the Chinle and Dolores Formations (Fig. 6), suggests that the depositional environments and Late Triassic climate were relatively stable for the duration of deposition of the Chinle and Dolores Formations. Lungfish burrows found in sandstone, siltstone, mudstone, and limestone and the sedimentologic interpretation of depositional environments indicate that the life habitat of the lungfish ranged from flooded and ponded fluvial in-channel and floodplain systems to lacustrine basins and marshes. If Triassic lungfish burrowed in response to the same environmental stress of seasonal dryness that influences the modern African lungfish (*Protopterus*), then the burrow abundance and the inferred depositional environments indicate that the Late Triassic climate provided sufficient moisture to form streams, lakes, and marshes but that it was also probably punctuated by seasonally dry periods. A similar climate has been postulated for the Chinle Formation in the Petrified Forest National Park (Daugherty 1941; Bown et al. 1983) and in southeastern Utah (Dubiel 1984a).

Lungfish burrows that extend from the basal units of the Chinle Formation into the underlying Moenkopi Formation and mixing of Moenkopi sediments into the lowermost Chinle units by lungfish bioturbation indicate that the affected portions of the Moenkopi Formation were not extensively lithified at the time of deposition of the basal units of the Chinle Formation. This identification of lungfish burrows in the Chinle and Dolores Formations extends their known geologic range into the Upper Triassic, and it is already well known as far back as the Devonian (Table 1).

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