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VERTEBRATE PALEONTOLOGICAL RESOURCES OF DEATH VALLEY NATIONAL PARK, CALIFORNIA

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INTRODUCTION

Death Valley National Park (DEVA), California, is administered by the National Park Service and was originally proclaimed as a national monument by President Hoover on February 11, 1933. The park boundary was expanded by 1,200,000 acres and redesignated a national park on October 31, 1994 with the passage of the California Desert Protection Act. Death Valley National Park is the largest unit in the National Park System in the lower 48 states consisting of more than 3.6 million acres, much of which is designated wilderness. The park preserves a low-elevation desert ecosystem, almost completely surrounded by high mountain ranges. As the lowest point in North America, the park has also been designated a Biosphere Reserve. The park includes Scotty's Castle and the remnants of gold and borax mining.

Death Valley National Park has a rich paleontological record consisting of fossil plants, invertebrates, vertebrates, and trace fossils. The vertebrate paleontological resources documented from Death Valley National Park consist of conodonts, fish, birds, and mammals (both body fossils and ichnofossils). Although this field guide is intended to focus on the vertebrate paleontology of Death Valley National Park, other significant non-vertebrate fossils which are known to occur from within the park are discussed briefly in the paleontology section of this field guide. The field trip to Death Valley National Park will include scheduled stops at three fossil vertebrate localities in the park. The first stop will examine the Copper Canyon Formation which preserves approximately 1800 m (5905 feet) of basin fill fluvial to lacustrine sediments containing rich and diverse mammal and bird ichnofossils. The second stop will visit another vertebrate track locality of similar age and depositional environment as the Copper Canyon Formation. The third and final stop of the field trip will examine a classic vertebrate collecting locality in the Titus Canyon Formation which has yielded an assemblage of Eocene fossil mammals.

PHYSIOGRAPHY

Death Valley National Park lies in the extreme western portion of the Basin and Range physiographic province and also exhibits some of the most extreme topographic relief within this province. The Basin and Range Province is one of the largest and most extensive provinces in the United States. It extends from southeastern Oregon through Nevada and eastern California, southern Arizona, and New Mexico into western Texas. The province is characterized by uplifted and tilted fault blocks that form longitudinal, asymmetric mountain ranges separated by broad intervening valleys or basins. The overall structure of these mountain ranges and valleys is generally northwest-southeast.

The western boundary in southern California is the Sierra Nevada crest. The Garlock fault separates the province from the Mojave province to the south (Norris and Webb 1976). In Death Valley National Park the northwest-southeast trending ranges include the Panamint, Saline, Last Chance, Cottonwood, Grapevine, Funeral, Greenwater, Black, Amargosa, and Owlshead Mountains and part of the Inyo Range on the northwest boundary. The intervening valleys include Death Valley, Greenwater Valley, Amargosa Valley, Saline Valley, Eureka Valley and part of the Panamint Valley. Relief within the park is dramatic, from the highest point at Telescope Peak 3,368 m (11,049 feet) to the lowest point at Badwater -86 m (-282 feet). As with much of the Basin and Range, drainage is internal.

GEOLOGIC HISTORY

Nearly all major divisions of geologic time are represented in the rock record of this portion of the Basin and Range Province. The summary below is not intended to provide a comprehensive summary for the complex geologic history of Death Valley, rather a very basic overview.

Proterozoic - The oldest rocks are lower Proterozoic (Archean) gneiss, schist and quartzite probably all of sedimentary origin. Some units of this metamorphic basement complex have been dated as 1.8 billion years old (Norris and Webb 1976). Mafic to felsic granitic rocks were also emplaced during the Archean Eon. Following emplacement of the basement complex, there was a long interval of uplift. The surface of the region was above sea level and deeply eroded.

In the late Proterozoic, downwarping resulted in the land surface of the region subsiding below sea level (Wright et al. 1953). A shallow sea transgressed across the region and deposited up to 1,800 m (6,000 feet) of sediments. These shallow marine sedimentary sequences of conglomerate, sandstone, shale, limestone, and dolomite represent the earliest deposits of the Cordilleran geosyncline and are known as the Pahrump Group (Norris and Webb 1976). The pattern of the late Proterozoic to Cambrian sediments suggests that the depositional environment was a well defined, north-northwest striking trough, tributary to the main Cordilleran geosyncline. Large diabase sills were intruded into the lower portion of these geosynclinal sediments. Diabase emplacement is thought to have been prior to lithification of the sediments, and probably before deposition of the upper half of the Pahrump Group (Wright et al. 1953). Downwarping and deposition in a shallow sea (less than 30 m (100 feet deep)) continued through the end of the Proterozoic. An excellent exposure of Proterozoic - Cambrian strata occurs within Death Valley National Park (Corsetti and Hagadorn 2000).

Paleozoic Era - By the beginning of the Paleozoic, subsidence had developed into a huge, north-northwest trending trough across western North America (the Cordilleran Geosyncline). The Cordilleran Geosyncline persisted through the Paleozoic and into the Mesozoic with several transgressions and regressions of the shallow sea. The region accumulated large volumes of nearshore and offshore marine sediments during this era with up to 7,000 m (23,000 feet) attributed to the Cambrian and Ordovician periods, and over 2,100 m (7,000 feet) in the Silurian and Devonian (Nolan 1943). By the end of the Devonian, uplift resulted in only a few Carboniferous and Permian deposits. The uplift persisted through the Permian into the Mesozoic and eventually assisted in the disappearance of the geosynclinal seas that had covered the region through much of the Paleozoic.

Era	Period	Epoch	Geologic Units: White-Inyo Region	Geologic Units: Death Valley Region
Cenozoic	Quaternary	Holocene	Alluvial fan and lacustrine deposits	
		Pleistocene	Funeral	
	Tertiary	Pliocene	Copper Canyon	
		Miocene	Furnace Creek	
			Artist Drive	
		Eocene	Titus Canyon	
Paleozoic	Permian		Owens Valley	
			Tihvipah	
	Pennsylvanian		Keeler Canyon	
			Rest Spring Shale	
			Lee Flat Limestone	
	Mississippian		Perdido	
			Tin Mountain	
	Devonian	Upper	Lost Burro	
		Middle		
	Silurian		Hidden Valley Dolomite	
	Ordovician		Ely Springs Dolomite	
			Eureka Quartzite	
			Pogonip Group	
	Cambrian	Upper	Nopah	
		Middle	Bonanza King	
			Monola	Carrara
		Lower	Mule Spring	
			Saline Valley	Zabriskie
			Harkless	Wood Canyon
			Poleta	
			Campito	
			Deep Spring	
			Reed	Stirling
Precambrian Proterozoic			Wyman	
				Johnnie

Figure 1. Stratigraphic column for Death Valley National Park.

Mesozoic Era - A series of compressional pulses affected the west coast between mid-Jurassic and Cretaceous time. Initiated by converging tectonic plates, this compression produced uplift of the region and caused folding and faulting of both Proterozoic and Paleozoic strata. This episode of compressional mountain building is known as the Nevadan Orogeny. At the height of the Nevadan Orogeny, the base of the geosynclinal sediments were transformed into molten rock and emplaced as batholiths. These igneous rocks are now unroofed and form the Sierra Nevada batholith and other Mesozoic intrusives throughout the region (Clark 1960).

Cenozoic Era - The early Cenozoic (Paleocene, Eocene and Oligocene epochs) is present only as igneous intrusions and cemented stream gravels. During this time, the region was probably above sea level, exhibited low relief, and was eroded with little deposition. Crustal compression related to the Nevadan Orogeny and associated with the Laramide Orogeny continued to affect the region until the Eocene. By mid-Cenozoic, compressional forces had ceased and by the Miocene, extensional forces began to affect the region, probably caused by the North American continental plate overriding the Gulf of California spreading center. Crustal tension resulted in the basin and range topography created by normal faulting, down-dropped grabens, and uplifted horst block ranges which are elongated north-south, perpendicular to the primary direction of extension. Thick, non-marine basin deposits were formed reminiscent of those being formed today. Associated saline, borate, and shallow lake deposits indicate an arid to semi-arid climate. These conditions have persisted through the late Neogene into Recent geologic time.

PALEONTOLOGY

Death Valley National Park preserves an extensive geologic record ranging from the Proterozoic through the Holocene (Figure 1). Over thirty fossiliferous stratigraphic units have been identified in Death Valley National Park, containing fossil plants, invertebrates, vertebrates and trace fossils. Paleontological resources at the park have been extensively studied for over 100 years and have generated hundreds of scientific publications related to the park's geology and paleontology (refer to review by Nyborg and Santucci 1999). The park museum collection provides a first glimpse into a record of life from the Death Valley area extending back over a billion years. Death Valley fossils occur in museums throughout the United States and include a number of "type" specimens.

The Proterozoic strata of Death Valley National Park are richly fossiliferous containing abundant algal fossils, stromatolites, microfossils, acritarchs, and a few trace fossils. Horodyski (1993) and Hagadorn and Waggoner (2000) have reported on Ediacaran body and trace fossils from localities just outside of the park boundaries. An important Proterozoic metazoan fossil has been reported from within the park's boundary, consisting of small, poorly preserved, mineralized cones referred to as "*Cloudina*" (Langille 1974; Corsetti and Hagadorn 2000). Langille (1974) and Kauffman and Steidtmann (1981) have also reported on undescribed fossils that may possibly be of metazoan origin, but the interpretations have been heavily contested (Hagadorn and Waggoner 2000). Within the deposits of Death Valley National Park, a diverse shelly fauna precedes the first occurrences of trilobites (Signor et al 1987). These pre-trilobite, shelly faunas are inferred to have a worldwide distribution.

Mesoproterozoic and Neoproterozoic formations are associated with either the Death Valley facies or White-Inyo facies (Corsetti and Hagadorn 2000). The Death Valley facies is comprised of nearshore shallow marine and fluvial sediments and the White-Inyo facies represents a more offshore environment (Corsetti and Hagadorn 2000). The Death Valley facies includes the Pahrump Group (Crystal Spring, Beck Spring, and Kingston Peak formations), Noonday Dolomite, Ibex Formation, Johnnie Formation, Stirling Quartzite, and Lower Wood Canyon Formation. Fossils within the Pahrump Group consist of diverse and well-preserved microfossils within cherts, stromatolites, and other algal material (Cloud et al. 1969; Howell 1971; Roberts 1976; Licari 1978; Tucker 1983; Awramik et al. 1994; Pierce et al. 1994; Corsetti et al. 2003). The Noonday Dolomite contains algal, cryptalgal, and clastic dolostone, as well as large domal stromatolites (Wright et al. 1978). No fossils have been reported from the thinly bedded siltstone and limestone Ibex Formation. Various stromatolites have been recorded from the mixed carbonate and siliciclastic sequences of the Johnnie Formation (Cloud et al. 1969; Summa et al. 1991; Awramik et al. 1994; Corsetti and Kaufman 2003). The Stirling Quartzite contains the metazoan shelly fossil, *Cloudina*, and rare occurrences of the trace fossil *Planolites* (Langille 1974; Wertz 1982).

The Neoproterozoic units found within the White-Inyo facies include the Wyman Formation, Reed Dolomite, and Deep Spring Formation. The Wyman Formation is composed of dark-gray phyllite and interbedded limestone and marble layers (Wiggett 1975). Algae and trace fossils have been reported from the Wyman Formation (Langille 1974; Wiggett 1975; Alpert 1976; Nelson 1976; Mount and Signor 1985). The Reed Dolomite consists of white to yellowish-gray dolomite (Stewart 1970). Algae, trace fossils, tubular fossils, and stromatolites have been found within the Reed Dolomite (Noble 1934; Taylor 1966; Nelson 1976; Signor and Mount 1989). The Deep Spring Formation is composed of mixed carbonate and siliclastic deposits (Parsons 1996). Fossils from the Deep Spring Formation include stromatolites, a hyolith, annelids, pre-trilobite shelly assemblage, and significant trace fossils (Alpert 1975, 1976; Signor and Mount 1986; Signor et al. 1987).

During the 1880's, Charles Walcott explored an area north of Waucoba Springs within the Saline Valley Region. He designated a 2,100 meter (6,890 feet) thick section comprising strata of the White-Inyo facies as the Lower Cambrian Waucoban Series (Walcott 1895, 1908). This series includes nine geologic formations and contains some of the oldest known fossils of complex multi-celled organisms, including the oldest occurrences of trilobites (Hunt 1990). Trilobites within this series and other Cambrian deposits in Death Valley National Park record scientifically important depositional settings (Hunt 1990).

The Cambrian deposits found within the Death Valley facies are the Middle and Upper Wood Canyon formations, Zabriskie Quartzite, Carrara Formation, Bonanza King Formation, and Nopah Formation. The Middle and Upper Wood Canyon formations have produced ediacaran, trilobite, echinoderm, brachiopod, and trace fossils (Stewart 1970; Mount 1982; Signor and Savarese 1988; Durham 1993; Horodyski 1993; Hagadorn and Waggoner 2000). The Zabriskie Quartzite contains nearshore and foreshore deposits that include bioturbation and *Skolithos* tubes (Prave and Wright 1986; Prave 1988). The Carrara Formation consists of nine fossiliferous members. These members primarily contain trilobites, although echinoderms, stromatolites, and trace fossils have also been reported (Bates 1965; Palmer and Halley 1979; Awramik et al. 1994). Two members of the Bonanza King Formation are fossiliferous. The Papoose Lake Member contains *Glossopleura* trilobites and the Informal Middle Member contains trilobite “hash beds” and linguloid brachiopod beds (Hall 1971; Hunt 1975). A variety of fossils are found within the Nopah Formation. Stromatolites, sponges, brachiopods, gastropods, trilobites, eocrinoids, conodonts, and additional fossil material have been reported (Hazzard 1937; Denny and Drewes 1965; Hunt and Mabey 1966; Barnes and Christiansen 1967; Hall 1971; Yochelson and Taylor 1974; Hunt 1975; Cooper et al. 1982; Griffin 1987; Stinchcomb and Darrough 1995).

The Cambrian units within the White-Inyo facies consist of the Campito Formation, Poleta Formation, Harkless Formation, Saline Formation, Mule Spring Formation, and Monola Formation. The terrigenous Campito Formation contains the earliest trilobite occurrences, archaeocyathids, helicoplacoid echinoderms, hyolithids, and trace fossils (Nelson 1962, 1976; McKee and Gangloff 1969; Alpert 1975, 1976; Mount 1982; Onken and Signor 1988; Signor and Mount 1989; Mount and Signor 1992; Durham 1993). The Poleta Formation contains bioherms, archaeocyathids, hyolithid beds, eocrinoids, articulate brachiopods, edrioasteroids, helicoplacoids, trilobites, and trace fossils within its three members (Nelson 1962; Nelson and Durham 1966; McKee and Gangloff 1969; Firby and Durham 1974; Gangloff 1975; Rowland 1978, 1979; Mount 1982; Seiple 1984; Onken and Signor 1988; Signor and Mount 1989). The Harkless Formation consists of siltstone, quartzite, and shale (Nelson 1962; Seiple 1984). Large archaeocyathids, brachiopods, trilobites, and trace fossils are found within the Harkless Formation (Nelson 1962; McKee and Gangoff 1969; Seiple 1984; Signor and Mount 1989). Massive quartzite, siltstone, and sand limestone comprise the Saline Valley Formation (Nelson 1962; Seiple 1984). The uppermost member of the Saline Valley Formation contains trilobites in olive-green shale (Firby and Durham 1974; Seiple 1984). The Mule Spring Limestone is a dark blue-gray oncolitic limestone that contains algae and trilobites (Nelson 1962; Palmer and Nelson 1981; Seiple 1984). Lastly, the Monola Formation contains a diverse assemblage of trilobites (Nelson 1976).

The remaining fossiliferous units in Death Valley National Park are all considered part of the Death Valley facies. The Ordovician Pogonip Group is comprised of three carbonate members. The Pogonip Group members have produced fossil assemblages of trilobites, brachiopods, receptaculitids, gastropods, orthoconic and coiled nautiloids, graptolites, echinoderms, and conodonts (Foster 1961; Hall 1971; Miller 1982).

The Ely Springs Dolomite Formation spans in age from the Ordovician to the Silurian. The formation consists of dark gray, cherty dolomite and a light gray dolomite. Silicified rhynchonellid brachiopods, cephalopods, streptelasmid corals, *Halysites*, and conodonts are all found in the lower unit of the Ely Springs Dolomite (Hall 1971; Miller 1982). The Silurian to Devonian Hidden Valley Dolomite Formation contains various corals, articulate brachiopods, crinoid debris, and conodonts within a lower cherty unit (Hazzard 1937, 1954; Hunt 1975; Miller and Hanna 1972; Haug 1981).

The Devonian Lost Burro Formation contains abundant fossil material. Sponge spicules, corals, stromatoporids, brachiopods, microgastropods, crinoid columns, conodonts, and fish remains have been discovered from this formation (Denny and Drewes 1965; Youngquist and Heinrich 1966; Hall 1971; McAllister 1974; Hunt 1975). Fish remains include the placoderm *Dunkleosteus*, a small cladodont, and a cochliodont tooth (Dunkle and Lane 1971). Two genera of rare Devonian fish were discovered in the Lippincott Member of the Lost Burro Formation (Elliott and Ilyes 1993, 1996a, 1996b). These primitive pteraspid (agnathan) fish include the genus *Blieckaspis* and a newly described genus *Panamintaspis* from the Trail Canyon area of the park. These remains shed new light on the early evolution of fish in North America.

The Tin Mountain Limestone and Perdido formations are both fossiliferous Mississippian units exposed within the park. The Tin Mountain Limestone Formation consists of a lower lagoonal or mudflat limestone, above which is a crinoidal limestone that was deposited on an offshore bar or bank (Langenheim and Tischler 1959). Abundant fossils are found within these limestones, including: foraminifera, coelenterates, corals, bryozoans, cephalopods, gastropods, pelecypods, crinoids, brachiopods, trilobites, an annelid worm, and petrified wood (Peck 1950; Langenheim and Tischler 1959; Denny and Drewes 1965; Hall 1971; Hunt 1975). The Perdido Formation is composed of a limestone member and a siltstone member (Hall 1971). Fossils found within the Perdido Formation include foraminifera, coral, cephalopods, and crinoids, as well as a goniatite coquina bed (Tischler 1955; Gordon 1964; McAllister 1970; Hall 1971).

The Lee Flat Limestone and the Rest Spring Shale constitute the Mississippian to Pennsylvanian units exposed within the park. The white to light-gray marble Lee Flat Limestone preserves abundant crinoid columnals (Hall 1971). The siltstone and shale deposits of the Rest Spring Shale Formation contain poorly preserved brachiopods (Hall 1971).

The Keeler Canyon and Tihvipah formations are both Pennsylvanian to Permian in age. The Keeler Canyon Formation is composed of alternating limestones and marbles preserving fusilinid, bryozoan, brachiopod, and crinoid material (Hall 1971). Gordon (1964) reports cephalopods and fusilinids from the Tihvipah Formation that consists of limestones and chert nodules (McAllister 1952).

The Permian Owens Valley Formation is composed of limestone, siltstone, and shale units (Hall 1971). Reported fossils from the Owen Valley Formation are fusulinids, solitary corals, bryozoans, and gastropods (Hall 1971).

The Eocene Titus Canyon Formation consists of conglomerates, sandstones, calcareous mudstones, algal limestones, and tuffaceous sandstones (Reynolds 1969). Late Eocene (Chadronian) assemblages of fossil mammals have been collected from the Titus Canyon Formation in Death Valley National Park. Fossilized remains of early rodents, carnivores, horses, rhinos, and artiodactyls have been discovered in a red calcareous mudstone unit (Stock and Bode 1935). Miller (1945) reported on the remains of an osteichthyan fish and Stock (1949) reported on turtle scutes, rodent teeth, and a rodent skull from the Titus Canyon Formation. A locality within the Titus Canyon Formation referred to as Titanothere Canyon received its name based upon the discovery of a new species of titanothere, *Protitanops curryi* (Stock and Bode 1935). This specimen represents the first record of a titanothere west of the Rockies. A cast of the *Protitanops* skull is on exhibit at the Furnace Creek Visitor Center (See Stop 3 Titus Canyon).

There are three Neogene units exposed within Death Valley National Park: the Artist Drive, Furnace Creek, and Copper Canyon formations. Diatoms have been reported from the Artist Drive Formation (Cemen et al. 1985; Hardy 1988). The Furnace Creek Formation preserves diatoms, stromatolites, and plant material, including a lateral leaf lobe of *Lyonothamnus mohavensis* (Noble 1934; Axelrod 1940; Pitts 1983; Hardy 1988; Awramik et al. 1994). The Copper Canyon Formation is composed of basalts, alluvial sediments, and lacustrine deposits (Scrivner 1984; Nyborg 2011). The lacustrine deposits have received significant scientific attention due to the preservation of abundant and diverse fossil vertebrate tracks (Curry 1939, 1941; Scrivner 1984; Scrivner and Bottjer 1986; Nyborg 1998; Sarjeant and Reynolds 1999; Nyborg and Santucci 2000; Nyborg 2011).

Fossil vertebrate tracks from the Cenozoic are relatively rare by comparison to Mesozoic vertebrate tracks. Fossil footprints of birds, camels, horses, cats, proboscidians and other vertebrate ichnotaxa are preserved in Pliocene lacustrine deposits within Copper Canyon. The site is so scientifically significant, if it was not protected as part of Death Valley National Park, Copper Canyon would be worthy for consideration as an independent national monument (Nyborg and Santucci 1999) (See Stop 1 Copper Canyon).

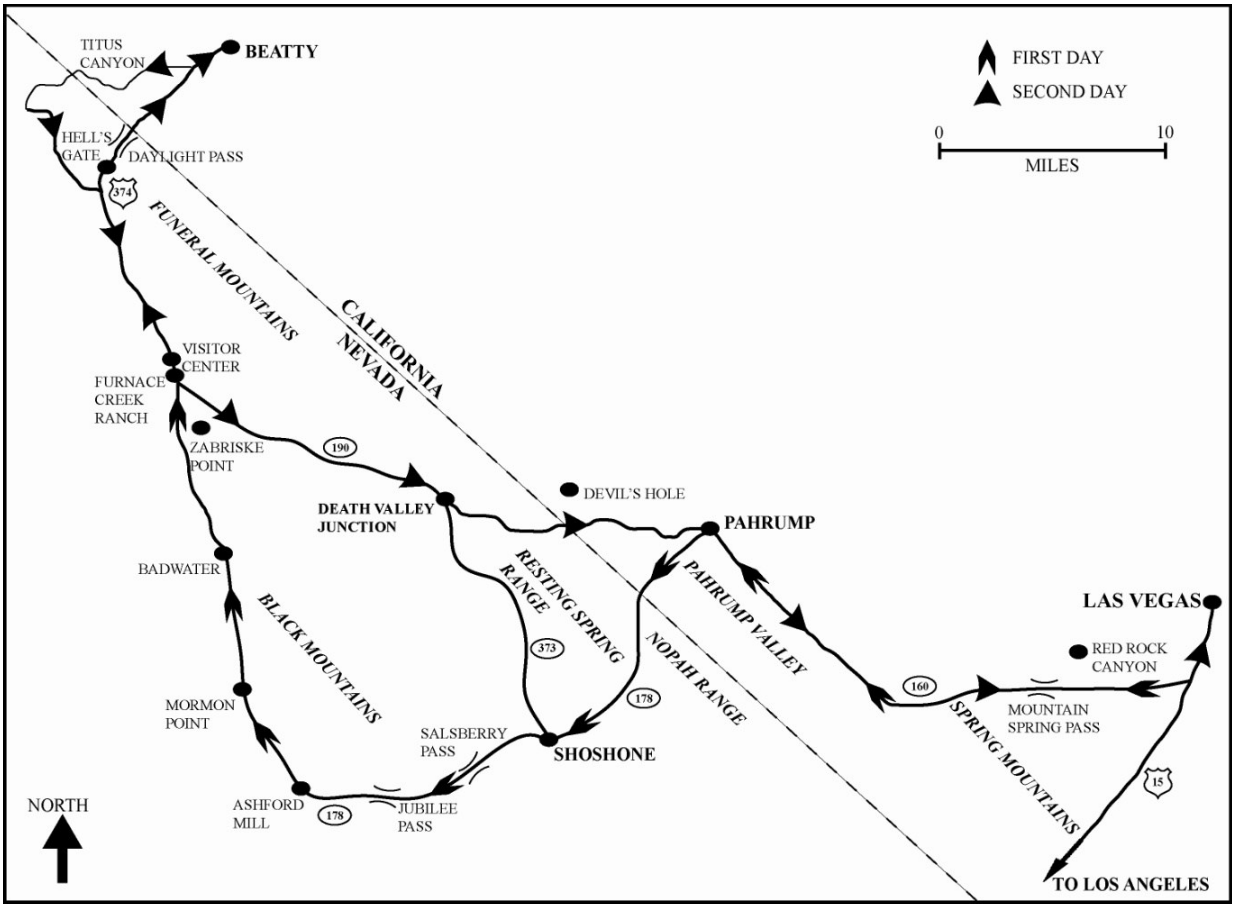


Figure 2. Field trip map showing routes to and from Las Vegas to locations in Death Valley National Park.

Small and large vertebrate fossils from Lake Tecopa, immediately adjacent to Death Valley, provide examples of taxa, habitats, and changes in hydrology and structure from the late Pliocene to late Pleistocene (Reynolds 1987, 1991, 1999, 2001; Woodburne and Whistler 1991). The youngest fossiliferous deposits found within Death Valley National Park are Pleistocene and Holocene lacustrine and alluvial fan deposits. A partial reported proboscidean tusk was discovered within sedimentary deposits of Lake Rogers (Clements 1973).

FIELD TRIP OVERVIEW

This field guide provides a brief overview of the geologic history and features that will be observed during a 2-day field trip to Death Valley National Park (Figure 2). This field trip will highlight the vertebrate paleontology of the park with specific stops and discussions related to role of the National Park Service in the management, protection and interpretation of paleontological resources (Santucci et al. 2009). Participants will visit several vertebrate fossil localities, including Titus Canyon and the Copper Canyon Tracksite.

Fossil collecting is not allowed on National Park Service administered lands except under a valid research and collecting permit. All planned field stops are within Death Valley National Park, therefore, no fossil collecting will be permitted on this field trip.

The principle fossil locality that will be visited on this trip will involve some extensive hiking (~6 miles round trip) into a wilderness area. There will be no facilities available in the back country. Participants are encouraged to wear comfortable clothing and sturdy shoes or boots during the field trip. Additionally, each participant should plan to bring at least one gallon of water for the back country hike.

DAY 1

The first day of the Death Valley field trip will begin in Las Vegas, Nevada, and travel through Pahrump, Nevada; Shoshone, California; and ending the day at Furnace Creek in Death Valley National Park (Figure 2). From Las Vegas to Pahrump we will travel south of Red Rock Canyon National Conservation Area, a scenic geologic area managed by the Bureau of Land Management as part of the National Landscape Conservation System. At Mountain Spring Pass gray Cambrian and younger Paleozoic rocks are visible. The route down into the Pahrump Valley takes us through gently to moderately folded sedimentary rocks of late Paleozoic and Mesozoic age. The Pahrump Valley is bounded on the west by the Nopah Range.

From Pahrump to Shoshone we will travel

Figure 3. Aerial view of the town of Shoshone, California, and Pleistocene Lake Tecopa deposits. Lake Tecopa contains vertebrate trace fossils including those identified as artiodactyl, elephant, carnivore, and horse (Hillhouse 1987; Pagnac and Reynolds 2006).

through the Nopah Range. The Nopah Range contains a complete and well-exposed section of Proterozoic and Paleozoic sedimentary rocks (Wright 1973; Corsetti and Hagadorn 2000). The town of Shoshone is within the ancient Lake Tecopa basin.

LAKE TECOPA

Lake Tecopa was a large and long standing Pleistocene lake. Tecopa lake sediments are prominently exposed in the area around Shoshone, California (Figure 3). Pleistocene Lake Tecopa is estimated to have had a maximum size of 137 square km and a depth of up to 122 m (400 feet) (Hillhouse 1978). The upper Tecopa beds contain fossil remains of horses, camels, mammoths, muskrat and other rodents.

At Shoshone we will proceed north one mile and continue on highway 178 into Death Valley National Park. The route into Death Valley passes through the Greenwater Range, Greenwater Valley and the narrow Salsberry and Jubilee passes down into Death Valley. At Ashford Mill the road follows the general trend of the Southern Death Valley and Northern Death Valley fault zones (Machette, 2001). At Mormon Point the Copper Canyon Turtleback is visible to the east. The first and only stop of the day will be hiking into the Copper Canyon Formation.

COPPER CANYON FORMATION

During the Cenozoic, both strike-slip and extensional regimes coexisted in the Death Valley area giving rise to a number of fault-bounded basins.

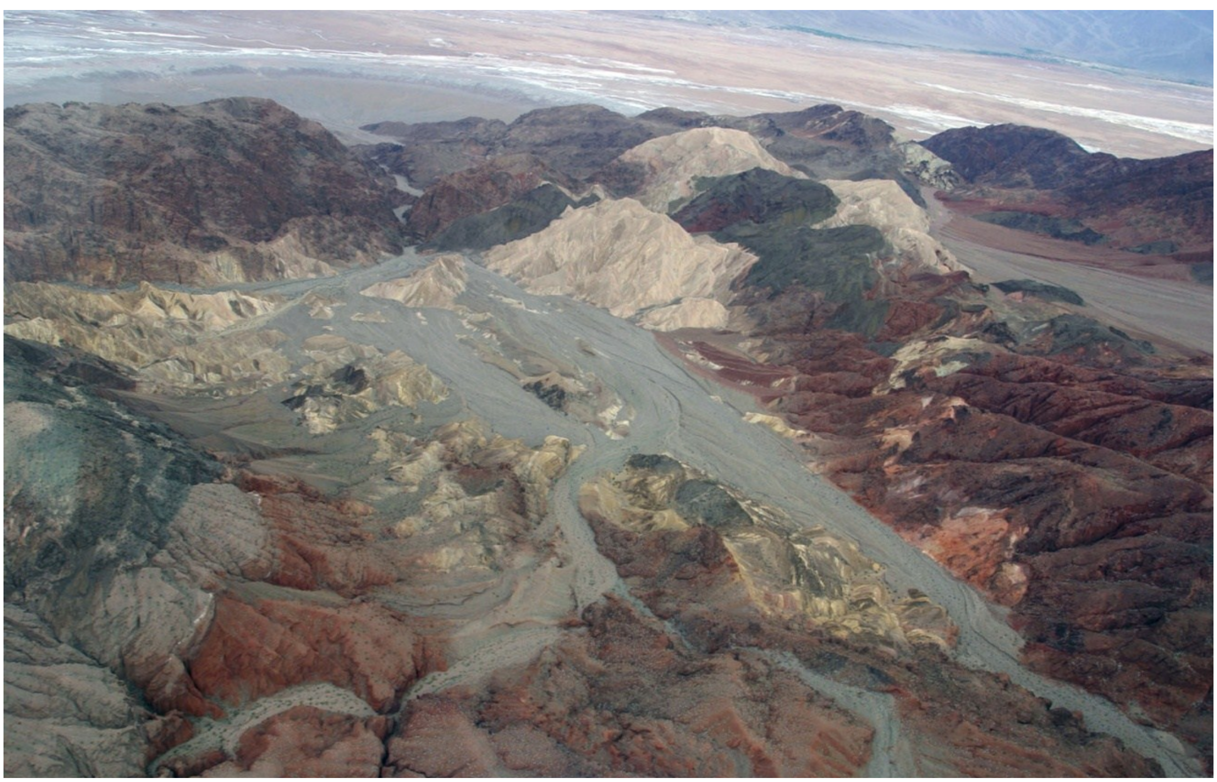
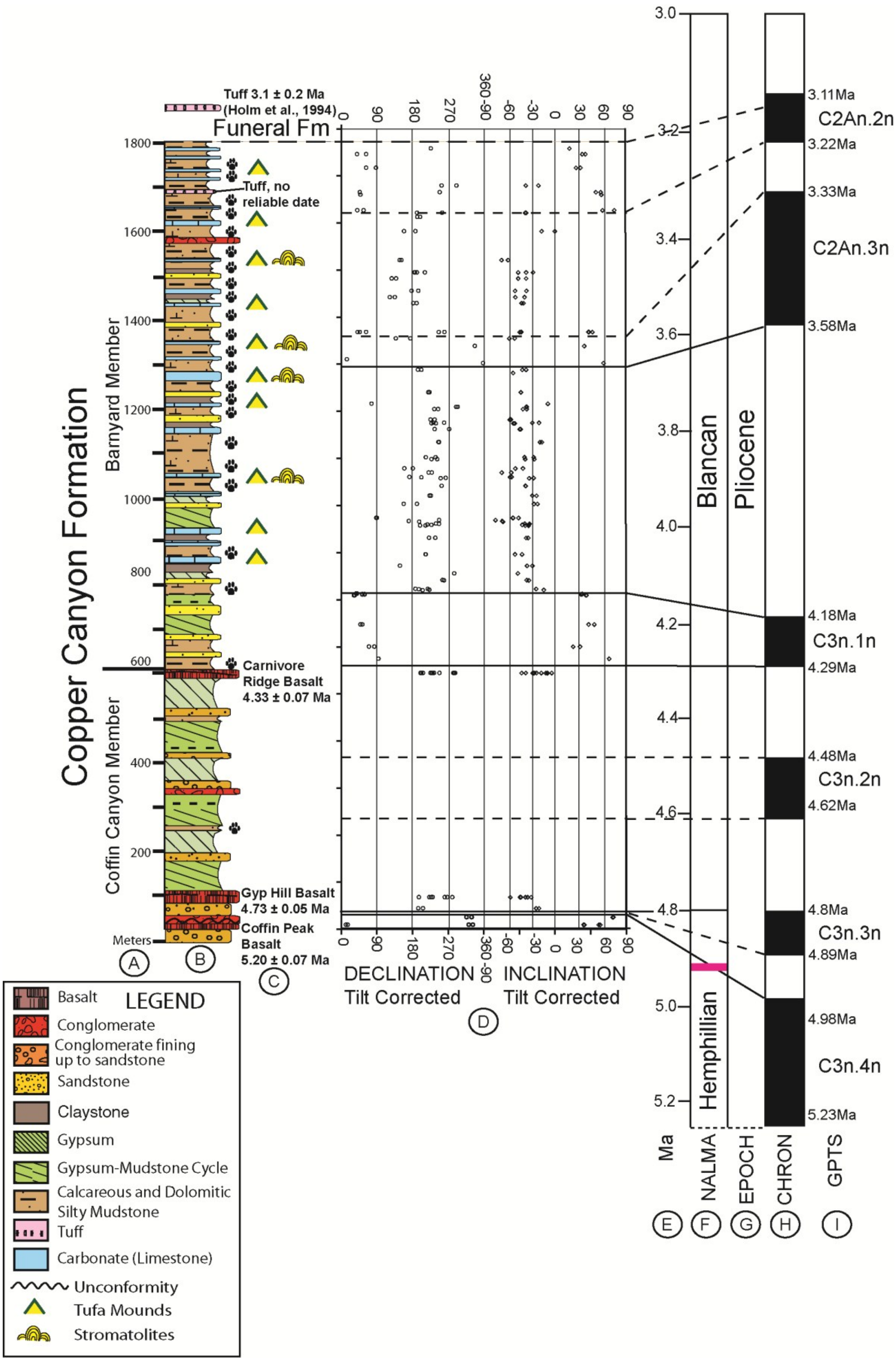


Figure 4. Aerial view of the Copper Canyon Formation. The outcrop covers about 13 km^2 with over 60 fossil track localities. Light colored strata represent fluvial-lacustrine deposits of the Copper Canyon Formation. View is looking west with Death Valley in the background.



Tuff 3.1 ± 0.2 Ma (Holm et al., 1994)
Funeral Fm
Copper Canyon Formation
Barnyard Member
Coffin Canyon Member
Tuff, no reliable date
Carnivore Ridge Basalt 4.33 ± 0.07 Ma
Gyp Hill Basalt 4.73 ± 0.05 Ma
Coffin Peak Basalt 5.20 ± 0.07 Ma
Meters
DECLINATION Tilt Corrected
INCLINATION Tilt Corrected
Blancan
Pliocene
Hemphillian
Ma
NALMA
EPOCH
CHRON
GPTS
C2An.2n
C2An.3n
C3n.1n
C3n.2n
C3n.3n
C3n.4n
3.11Ma
3.22Ma
3.33Ma
3.58Ma
4.18Ma
4.29Ma
4.48Ma
4.62Ma
4.8Ma
4.89Ma
4.98Ma
5.23Ma
LEGEND
Basalt
Conglomerate
Conglomerate fining up to sandstone
Sandstone
Claystone
Gypsum
Gypsum-Mudstone Cycle
Calcareous and Dolomitic Silty Mudstone
Tuff
Carbonate (Limestone)
Unconformity
Tufa Mounds
Stromatolites

Figure 5. Simplified lithostratigraphy and magnetostratigraphy of the Copper Canyon Formation deposits. (A), thickness in meters. (B), simplified lithologic column. (C), $^{40}Ar/^{39}Ar$ date locations. (D), tilt-corrected declination and inclination with magnetozone divisions and mean values for each chron. (E), a time scale. (F), stratigraphic zone. (G), epoch. (H), polarity time scale. (I), geomagnetic polarity timescale. Magnetic polarity time scale (GPTS) after Cande and Kent (1995). Global time scale after U.S. Geological Survey Geologic Names Committee (2007). North American Land Mammal age (NALMA) after Woodburne (2004). Data from Nyborg (2011).

One of these basins, exposed within Copper and Coffin Canyons along the northwestern side of the Black Mountains, within Death Valley National Park, California, contains a thick sequence of approximately 1800 m (5905 feet) of conglomerates, basalt flows, and lacustrine deposits (Figures 4, 5). Basalt flows, paleomagnetic analysis, and a tuff bed stratigraphically above the Copper Canyon Formation, constrain the age between ~5 and 3 Ma (Nyborg 2011) (Figure 5). Chronostratigraphy is based on three $^{40}Ar/^{39}Ar$ radiometric dates from interbedded basalt beds and magnetostratigraphy of the upper two-thirds of the 1800 m (5905 feet) sedimentary basin fill deposits. These data give dates of 5.20 Ma for the base of the formation and 3.15 Ma for the top of the formation. Across that time interval 6 normal and 5 reversed magnetozones are identified (chron 3n.4n to 2An.2n) (Nyborg 2011) (Figure 5).

The Copper Canyon Formation depositional history can be roughly divided into three parts: 1) in the early tectonic basin, alluvial fans deposited conglomerates and sandstones into the basin as a low relief, ephermeral, saline lake developed; 2) first lacustrine stage consisting of a hypersaline evaporative lake and water chemistry that favored gypsum deposition; and 3) a later lacustrine stage dominated by a perennial saline lake fed by springs, with mudflat deposits. Interbedded in the lower third of the formation are three basalt flows (Figures 4, 5). Near the top of the formation, carbonate-rich, silty mudstone and limestone beds are replaced with sequences of limestone-mudstone beds (Figure 5). The Copper Canyon Formation can be divided into distinct lithologies, lithofacies, and depositional environments. Animal tracks are mainly confined to the upper two-thirds of the Copper Canyon Formation reflecting animal activity being coincidental with the appearance and distribution of the limestone spring deposits (tufa mounds), suggesting a cause and effect. The Copper Canyon Formation is a distinct formation with diverse local deposits preserving a record of a tectonic basin fill deposit, and a spectacular array of animal tracks. The field trip will travel up section through the Copper Canyon Formation. The lithology, depositional environment, and abundance and distribution of the vertebrate ichnofossils will be the focus of discussions.

Twenty-six ichnotaxa associated with felids, camelids, equids, proboscideans and birds have been documented from at least 60 localities (Curry 1939, 1941; Scrivner and Bottjer 1986; Nyborg 1998; Santucci and Nyborg 1999b; Nyborg and Santucci 1999, 2000) (Figures 6-8). The approximately 1800 m (5905 feet) deposits span the upper Hemphillian and lower Blancan North American Land Mammal Ages (NALMA) (Lindsay et al. 2002; Woodburne

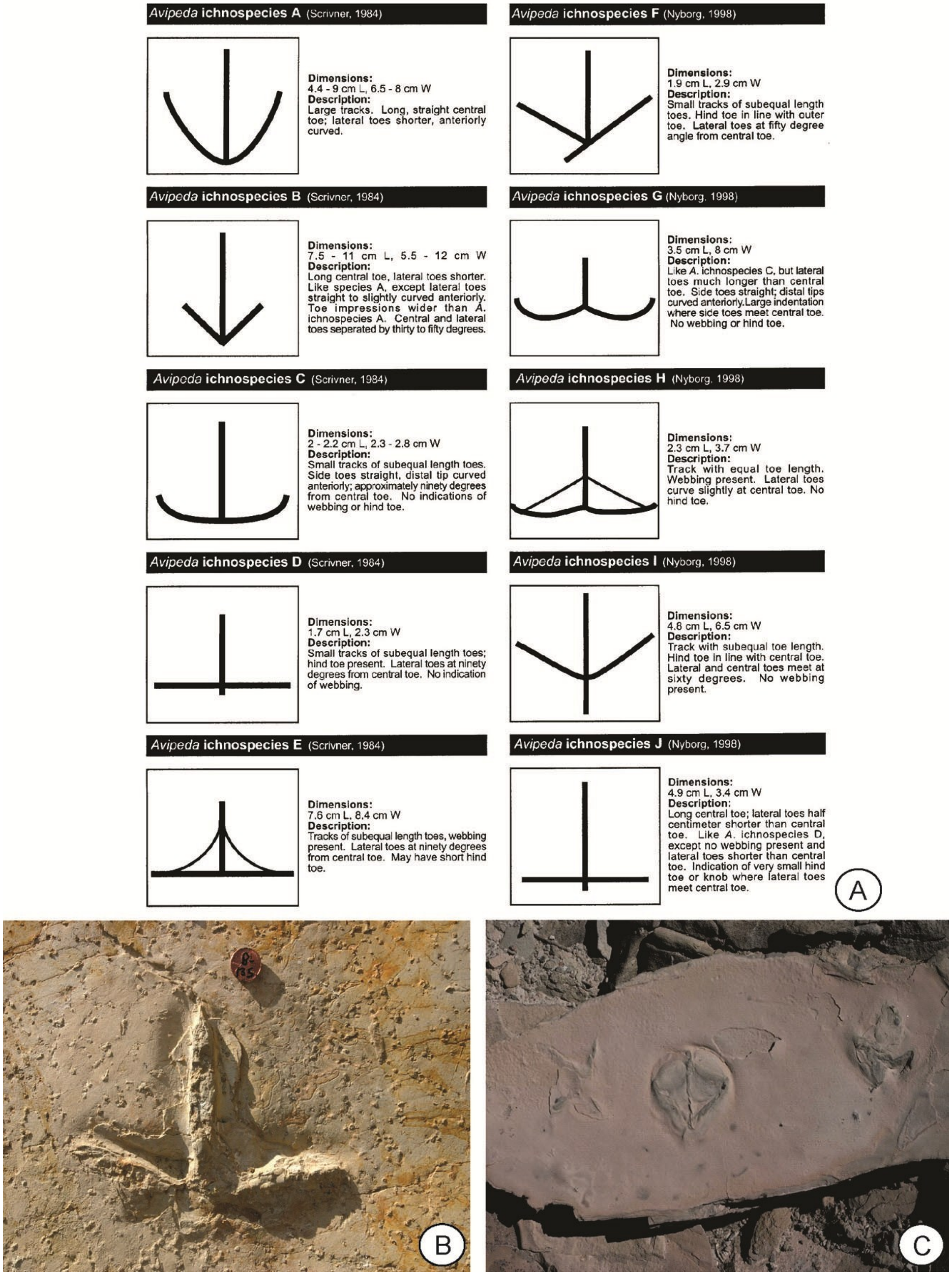


Figure 6. Bird (Avipeda) ichnospecies from the Copper Canyon Formation. (A), line drawings of the representative bird (Avipeda) inchnospecies adapted from Scrivner (1984) and Nyborg (1998) classification. (B), large bird track corresponding to ichnopsecies I; note the bioturbation; penny for scale. (C), several ichnospecies of bird tracks on bedform of talus material; no scale, tracks are similar in size to B.

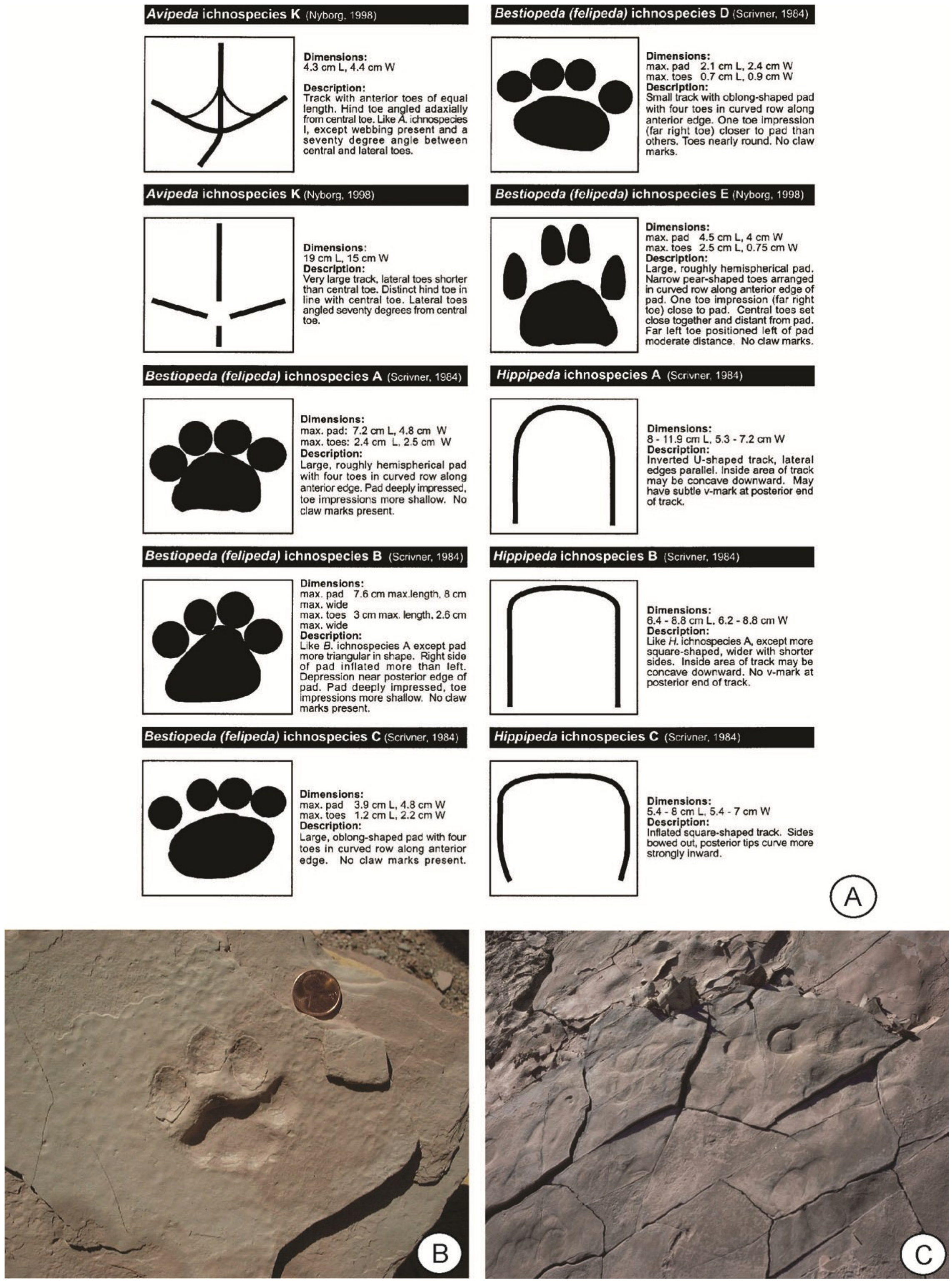


Figure 7. Cat (Felipeda) and horse (Hippipeda) ichnospecies from the Copper Canyon Formation. (A), line drawings of the representative cat (Felipeda) and horse (Hippipeda) ichnospecies adapted from Scrivner (1984) and Nyborg (1998) classification. (B), cat track corresponding to ichnopsecies A; penny for scale. (C), trackway of horse tracks representing several individuals corresponding to ichnopsecies A; no scale because bedform was overhanging outcrop.

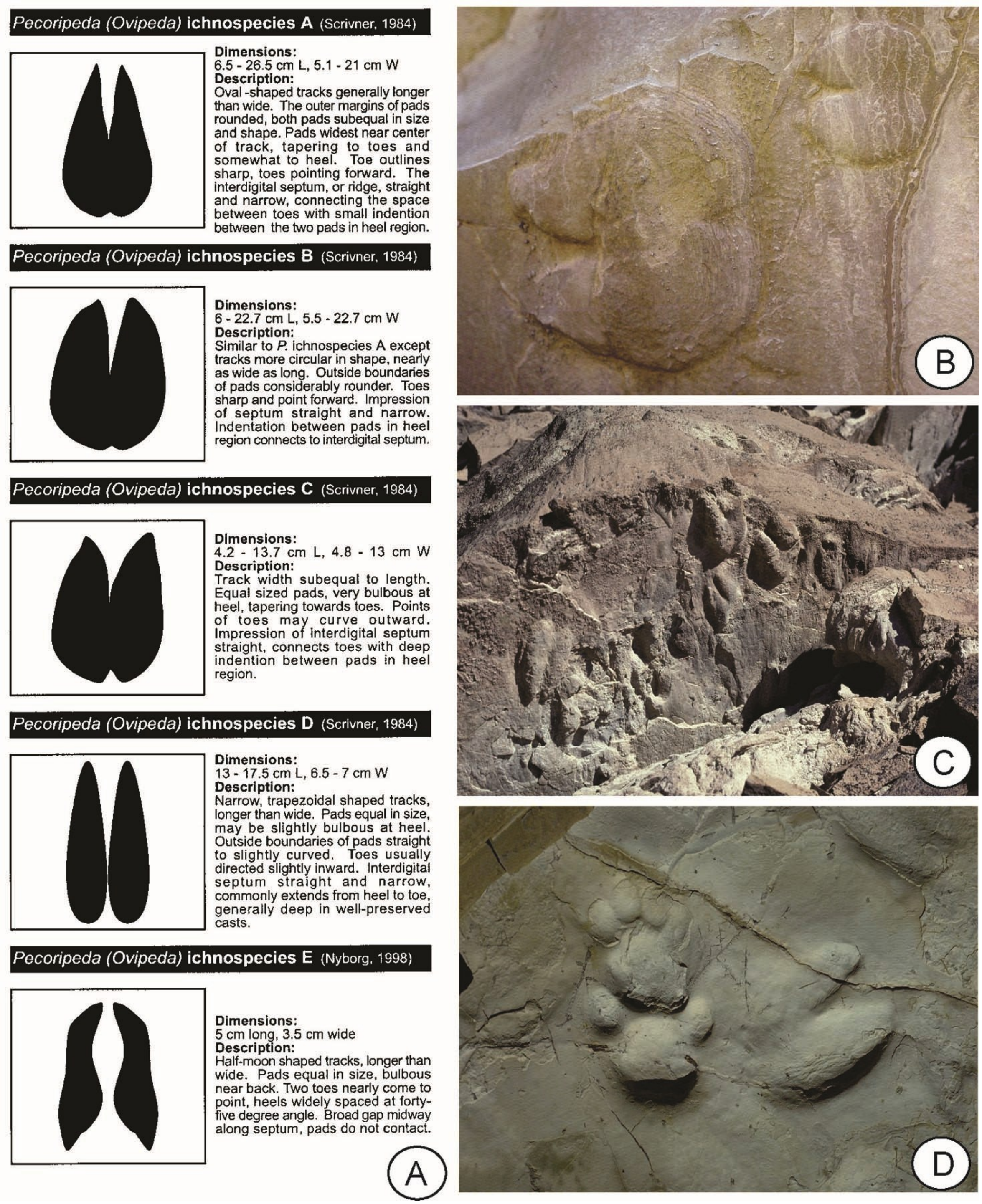


Figure 8. Camel (Ovipeda) ichnospecies from the Copper Canyon Formation. (A), line drawings of the representative camel (Ovipeda) ichnospecies adapted from Scrivner (1984) and Nyborg (1998) classification. (B), two camel tracks representing an adult and juvenile animals corresponding to ichnospecies B. (C), a number of camel tracks deeply casted into the sediments representing several ichnospecies. (D), large single camel track and two cat tracks on bedform. There are no scales for B-D because bedform was overhanging outcrop.

Figure 9. National Park Ranger/Geologist Donald Curry (right) and Ranger Doudna plane table mapping in the Black Mountains during the 1930's. Photo courtesy of Donald Curry (deceased).

2004) with the higher abundance of vertebrate tracks within the Blancan.

Donald Curry, was the first naturalist (geologist) to work for Death Valley Monument during the 1930's (Santucci and Nyborg 1999a) (Figure 9). Curry is credited with the discovery of the titanothore skull in the Titus Canyon Formation. Curry was also the first to publish on the vertebrate trace fossils from the Copper Canyon Formation, noting the numerous mammal and bird tracks (Curry 1939, 1941). Curry also coined the term "turtlebacks" for the convex-upward detachment surfaces that take on the appearance of a turtles shell. Three turtlebacks are found along the Black Mountains in Death Valley National Park (Curry 1954).

BADWATER

Badwater is a closed basin (endorheic basin) representing the lowest point of elevation in North America at -86 m (-282 feet) below sea level (Figure 10). Badwater consists of a small spring-fed pool of water heavily saturated with dissolved salts. Hexagonal patterns of salt crust form tee-pee structures related to expanding crystallization of the salt at Badwater. It is interesting to note that Mount Whitney, the highest point of elevation in the contiguous lower forty-eight states, is only 84.5 miles (136 km) to the west of Badwater.

Figure 10. Aerial view of an alluvial fan at Badwater in Death Valley National Park.

The road from Badwater to Furnace Creek Ranch passes multicolored Cenozoic sedimentary rocks of the Artist Drive, Furnace Creek, and Funeral formations. The Badwater Turtleback is visible from the Badwater area of the park. The final route of the day will proceed to Furnace Creek.

FURNACE CREEK

The Furnace Creek area of Death Valley National Park is considered a desert oasis. Furnace Creek is situated on top of a remarkably symmetrical alluvial fan. Although Death Valley average less than 3 inches of rainfall annually, Furnace Creek is one of those rare spots in the arid desert where spring water emerges to support one of the most biologically diverse environments in the Mojave Desert. The availability of water also has attracted human settlement. Furnace Creek is the location of Death Valley National Park Headquarters, Visitor Center and the famous Furnace Creek Hotel and Ranch.

DAY 2

The second day route will include a stop at an unammed unit that contains fossil vertebrate tracks. The field trip will then proceed to the town of Beatty to access the drive through Titus Canyon. The route back to Las Vegas will again pass through Furnace Creek and then travel a different route by way of Death Valley Junction to Pahrump, Nevada.

The first stop on day 2 will involve a short hike to unnamed deposits at the foot of the Funeral Mountains that preserve mammal and bird tracks. Since this locality has not been mapped or dated, comparison of the tracks with the Copper Canyon Formation tracks will be discussed. After this stop we will continue along highway 190 to the town of Beatty, Nevada. At Hell's Gate, Corkscrew Peak is visible within the Grapevine Mountains. Corkscrew Peak lies within the axis of a large recumbent fold, hence the name.

On route to Beatty, Nevada, the field trip will travel over Daylight Pass, elevation 1,315 m (4317 feet). The old road that leads north to the ghost town named Rhyolite is visible. The type locality for the Titus Canyon Formation is a few miles to the west of Daylight Pass and the field trip will proceed through the canyon on the Titus Canyon Road.

TITUS CANYON

Titus Canyon Road is a one-way 43 km (27 mile) road which heads west across the Amargosa Valley and climbs into the Grapevine Mountains. At

Figure 11. Photo of Titus Canyon Road; road follows outcrop of the Titus Canyon Formation. It was during the building of this portion of the road that the titanothere skull and other bones were discovered.

White Pass it enters upper Titanothere Canyon. The Titus Canyon Formation is exposed between upper Titanothere Canyon and Red Pass (Figure 11). Red Pass at an elevation of 1600 m (5250 feet) divides the Titanothere and Titus canyons. From there the road descends past the remnants of the ghost town Leadfield into Titus Canyon. Just below Leadfield, the road enters the main fork of Titus Canyon into the Titus Canyon Narrows. Twisty slot canyons, composed mainly of (Eocene? Oligocene, Miocene?) limestones, tower above the road.

The Titus Canyon Formation consists of conglomerates, sandstones, calcareous mudstones, algal limestones, and tuffaceous sandstones (Reynolds 1969). Reynolds (1969) recognized four major sedimentary units in the Titus Canyon Formation: 1) a sedimentary breccia unit (alluvial fan deposits) that usually forms the base of the formation; 2) a brown conglomerate unit restricted to the west fork of Titus Canyon and the area of most of the fossil vertebrates were collected; 3) a variegated unit consisting of conglomerates, sandstones, siltstone, mudstone, and marl (algal limestone beds) and; 4) a green conglomerate unit (alluvial fan/fluvial and a small amount of lacustrine deposits).

During blasting operations for the construction of the Titus Canyon Road, Don Curry discovered the remains of a titanothere skull (Stock 1936). A cast of the titanothere (*Protitanops*) skull was on display at the Furnace Creek Visitor Center in Death Valley National Park for many years (Figure 12). The reference section, and where many of the other fossils have been discovered from the formation, is along the east side of Titus Canyon and is too difficult to include within the time-span of this field trip.

In addition to *Protitanops,*the remains of *Mesohippus, Colodon, Teletaceras, Protoreodon, Pambromylus,* and *Leptomeryx* have been reported from the Titus Canyon Formation (Stock and Bode 1935; Stock 1949). *Fundulus* and *Cyprinodon* osteichthyan fish, a number of turtle scutes, rodent teeth and skull have also been found been dicsovered (Stock 1949; Miller 1945). The exact age of the Titus Canyon Formation is questionable because the stratigraphy and structure of the formation are complex (Prothero pers. comm.). The presence of *Mesohippus* and *Colodon* suggest earliest Chadronian however the presence of *Teletaceras* suggests Duchesnean (Prothero 2005).

Once out of the Titus Canyon Road the field trip will proceed back to the Furnace

Figure 12. Titanothere skull on display in the old Furnace Creek Visitor Center, Death Valley National Park. Photo courtesy of Lloyd T. Bradbury.

Figure 13. Photo from Zabriske Point showing lacustrine deposits of the Furnace Creek Formation in the foreground and the Panamint Mountains in the background.

Creek Visitor Center. After the visitor center we will continue via the Furnace Creek Wash to Zabriske Point and leave Death Valley National Park through Death Valley Junction.

ZABRISKIE POINT

Zabriskie Point is a scenic erosional landscape in the Amargosa Range in Death Valley National Park (Figure 13). The location was named after Christian Zabriskie, general manager of the Pacific Coast Borax Company during the early 1900s. This company used the twenty-mule teams to transport borax mined from locations in Death Valley. The borate minerals were concentrated in ancient lakes including Lake Manly and Furnace Creek Lake. One of the primary sources of borate minerals is the Furnace Creek Formation, which is prominently exposed at Zabriskie Point. The Furnace Creek Formation preserves scarce mammal and bird tracks.

DEVONIAN FISH AT TRAIL CANYON

Devonian deposits are not common in Death Valley, however a small fossiliferous exposure occurs in the Trail Canyon area of the park. Two genera of rare Devonian fish were discovered at Trail Canyon from the Lippincott Member of the Lost Burro Formation (Elliott and Ilyes, 1993, 1996a, 1996b). These primitive pteraspid (agnathan) fish include the genus *Blieckaspis* and a newly described genus *Panamintaspis*. Additional work in the area may reveal additional specimens.

At Death Valley Junction the fieldtrip will travel another route into Pahrump that passes by Ash Meadows and Devils Hole.

DEVILS HOLE

Devils Hole is a 40 acre detached unit of Death Valley National Park east of the Amargosa Range and Funeral Mountains within the boundaries of Ash Meadow National Wildlife Refuge. The area administered by the National Park Service contains a geothermal, aquifer-fed pool within a limestone cavern in the Amargosa Desert. Devils Hole branches into deep caverns at least 91 m (300 feet) below the surface.

Devils Hole is the home for the only naturally occurring population of the endangered Devils Hole Pupfish (*Cyprinodon diabolis*) (Figure 14). The pupfish thrive in the warm desert spring waters feeding on algae and diatoms. The Devils Hole pupfish is considered an annual species, with the historic population fluctuating between 100-200 in winter and 300-500 in late summer.

Figure 14. The Devils Hole pupfish (*Cyprinodon diabolis*), which was listed as an endangered species in 1967. This iridescent blue inch-long fish's only natural habitat is in the 93 degree waters of Devils Hole, Nevada, which is a detached unit of Death Valley National Park.

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