PERMIAN-TRIASSIC DEPOSITIONAL SYSTEMS, PALEOGEOGRAPHY, PALEOCLIMATE, AND HYDROCARBON RESOURCES IN CANYONLANDS, UTAH

By

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OBJECTIVES

This four-day field trip examines Pennsylvanian to Jurassic strata in the Paradox Basin on the Colorado Plateau in southeastern Utah. The trip will emphasize four major themes: 1) Permian-Triassic stratigraphy, 2) depositional systems, 3) paleogeography, and 4) paleoclimate (see Dubiel et al., 1996 for recent research on these topics in the Paradox Basin). The trip follows depositional facies in the Permian and Triassic section from proximal continental facies near the ancestral Rocky Mountains in the Uncompahgre Highlands to distal marine settings within the Paradox Basin. We will examine the evolution of these depositional systems from the late Paleozoic to the early Mesozoic, a key period along the west coast of Pangea for paleogeographic and paleoclimatic reconstructions. The trip highlights unconformities and their development by the effects of sea-level change, regional tectonics, and salt diapirism. The trip also integrates depositional sequences of red beds with paleoclimate interpretations and hydrocarbon resources in the Paradox Basin. Rocks examined in detail include the Permian Cutler Group (Halgaito Formation, Cedar Mesa Sandstone, Organ Rock Formation, White Rim Sandstone, and De Chelly Sandstone), the overlying Lower Triassic Moenkopi Formation, and locally the Upper Triassic Chinle Formation. The trip also passes through the underlying Pennsylvanian section and the overlying Jurassic section, including eolianites exposed in and around Canyonlands National Park.

The field guide is organized in several sections. Following these Objectives are the Itinerary of field stops and motels. The Introduction and following text presents a short discussion of material to introduce the major rock units and topics to be presented on the field trip, including illustrations of major points and references. Following that text is a list and description of general field localities that can be viewed from the vehicles on the drive from Denver to Grand Junction. We will not stop at any of these sites, except for Rest Stops on route, but the major geologic features and units can be readily viewed from the vans as we pass through structural features. The last section of text focuses on the individual field stops and optional stops that can be viewed on an excursion through the region. The actual field stops present the major geologic features and concepts to be discussed during the field trip. Some of the stop discussions present detailed accounts of the locality. Other paragraphs briefly describe the geologic setting for the stop and include questions to be answered or concepts to be considered. More stops are included than we might have time to entertain, depending on the particular interests of the group. We will cover the critical stops and include the remaining (optional) stops as time permits.

NOTE: For part of this field trip, while south of the San Juan River, we will be on the Navajo Nation within the Navajo Indian Reservation. This field trip and all geologic studies within the Navajo Nation are done with the cooperation of, and under written permit from, the Navajo Nations Minerals Department located in Window Rock, Arizona. No collecting of geologic or other materials is permitted on this part of the trip. Further information can be obtained from:

Akhtar Zaman, Director; Brad Nesemeier, Geologist
Navajo Nation Minerals Department
P.O. Box 1910
Window Rock, Arizona 86515
(520) 871-6587

NOTE: On other parts of the trip we will be within Glen Canyon National Recreation Area, Canyonlands National Park, and Deadhorse Point State Park in southeastern Utah. No collecting of geologic or other materials is permitted within these state or national parks and recreation areas.

FIELD TRIP ITINERARY

Permian-Triassic Depositional Systems, Paleogeography, Paleoclimate, and Hydrocarbon Resources in Canyonlands, Utah

Thursday, October 24, 1996 , 8:00 a.m. from Denver, CO through Sunday, October 27, 1996.

Leaders: Russell F. Dubiel (U.S. Geological Survey, Denver, CO TEL: 303-236-1540 or 303-499-6451; FAX: 303-236-0459, Jacqueline E. Huntoon (Michigan Technological University, Houghton, MI), John D. Stanesco (Red Rocks Community College, Denver, CO), and Debra Mickelson (University of Colorado, Denver)

Day 0. Wednesday, October 23. Night before Field Trip. Arrive in Denver, Colorado. Stay at Denver Mariott City Center TEL: 303-297-1300).

Day 1. Thursday, October 24, 8 a.m. Meet outside in front of lobby to pack vans
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Opt. Stop	Unaweep Canyon - Jack's Canyon Road; Precambrian/Triassic unconformity
Stop 1.1	Gateway Fan - Cutler Fm. debris flow deposits
Stop 1.2	Gateway, Colo. - Cutler Fm. facies, Triassic rocks
Stop 1.3	Fisher Valley salt anticline overlook (alternate: Paradox Valley salt anticline)
Opt. Stop	Pariott Mesa - Tenderfoot Mbr. of Moenkopi Fm.; gypsum
Opt. Stop	Fisher Valley salt anticline - drive through
Stop 1.4	Fisher Towers - Cutler Fm. interbedded eolian and fluvial facies
Opt. Stop	Professor Valley - Chinle Fm. facies and burrows

Spend night at Best Western, Green Well Motel (801-259-6151) Moab, Utah. **Rooms already booked.**

Day 2. Friday, October 25, 8:00 a.m. Leave Moab.

Opt. Stop	Moab Fault and salt anticline - Pennsylvanian to Jurassic section
Opt. Stop	North Entrance to Canyonlands National Park - Chinle Fm., Organ Rock
Opt. Stop	Glen Canyon Group - Navajo Sandstone eolian structures
Opt. Stop	Deadhorse Point - Geology overview
Stop 2.1	Shafer Trail and Shafer Dome overlook
Stop 2.2	Moenkopi Fm.; Chinle Fm. fluvial point bars
Stop 2.3	Shafer Trail/White Rim Trail - White Rim Sandstone and Hoskinnini Mbr.
Opt. Stop	Potash Road - Chinle Fm. point bars; Organ Rock Formation; Shafer Limestone
Opt. Stop	Indian Creek - Moss Back Mbr., Chinle Fm.
Opt. Stop	Big Spring Canyon - Permian marine-continental interfingering
Opt. Stop	South Entrance, Canyonlands National Park - Newspaper Rk, Glen Canyon Grp.
Stop 2.4	North Wash - Permian/Triassic section; White Rim Sandstone core, Tar Sands
Opt. Stop	Blue Notch Canyon - Chinle Fm.
Stop 2.5	Happy Jack Mine - Chert Cgl. and Hoskinnini Mbr. of Moenkopi Fm.
Opt. Stop	Indian Head Pass - Hoskinnini Mbr. of Moenkopi Fm.
Opt. Stop	White Canyon - Hoskinnini sabkha and fluid escape pipes
Opt. Stop	Hillside Mine - upper Chinle Fm.
Stop 2.6	White Canyon - Permian/Triassic unconformity within red-bed sequence
Opt. Stop	White Canyon Mine - lower Chinle Fm.
Opt. Stop	Moki Dugway - Cedar Mesa Sandstone, Raplee anticline overlook
Stop 2.7	Moki Dugway - Cedar Mesa Sandstone eolianites and regional surfaces
Opt. Stop	Moki Dugway - Halgaito Fm. and Cedar Mesa Sandstone of Cutler Group

Spend night at San Juan Inn (801-683-2220), Mexican Hat, Utah. **Rooms already booked**.

Day 3. Saturday, October 26, 8:00 a.m. Leave Mexican Hat.

Opt. Stop	Gouldings - DeChelly Sandstone pinchout
Stop 3.1	Gouldings Campground - Organ Rock Fm./ DeChelly Sandstone transition
Stop 3.2	Gouldings - DeChelly Sandstone; P-Tr unconformity; Hoskinnini Mbr.
Stop 3.3	Monument Valley - Permian Organ Rock Formation of Cutler Group
Stop 3.4	Monument Pass - Halgaito Formation of Cutler Group, loessites and paleosols
Stop 3.5	Lime Creek Paleosols - Halgaito Formation of Cutler Group
Stop 3.6	Comb Ridge - Cedar Mesa Sandstone of Permian Cutler Group facies change
Opt. Stop	Comb Ridge - Upper Triassic Chinle Fm., Jurassic Glen Canyon Group

Spend night at Four Corners Inn Motel (801-678-3257), Blanding, Utah. **Rooms already booked.**

Day 4. Sunday, October 27, 8:00 a.m. Leave Blanding.

Return to Denver.

We will return you to the Denver Mariott City Center lobby.

INTRODUCTION

The Paradox Basin is a tectonic depression of late Paleozoic age, the boundaries of which are generally defined by the geographic extent of halite deposited within the Paradox Formation during Middle Pennsylvanian time (Fig. 1) (Hite, 1968; Hite et al., 1972; Baars and Stevenson, 1981; Stevenson and Baars, 1987). The Paradox basin was formed in the Middle Pennsylvanian concomitant with structural uplift on the ancestral Uncompahgre Highlands of the ancestral Rocky Mountains. The Paradox Basin continued as a major locus of deposition through and after the Permian and into the latest Triassic. Prior to the formation of the ancestral Rocky Mountains, the region was on the trailing edge of the North American craton and was the site of marine shelf deposition. During uplift of the ancestral Rockies, the basin subsided rapidly, accumulating as much as 9,000 ft of Middle and Upper Pennsylvanian evaporites, shale, and limestone, and about 6,000 ft of Permian marine and continental strata. Following the Permian, the Triassic and Jurassic sections in the Paradox basin were dominated by continental depositional environments, particularly lacustrine, fluvial, and eolian systems.

REGIONAL SETTING

The Paradox Basin is a major northwest-southeast trending structural depression that formed during Middle Pennsylvanian time in association with uplift of the adjacent ancestral Uncompahgre highlands of the ancestral Rocky Mountains in southwestern Colorado. Tectonism created a structural and topographic high adjacent to a deep, asymmetrical subsiding basin. The major locus of subsidence and associated clastic deposition in the Pennsylvanian was on the northeast flank of the basin adjacent to the Uncompahgre Uplift. Evaporites and limestones deposited in the central part of the basin interfinger with coarse clastic material shed from the highland source on the northeast. The clastic rocks are generally restricted to a narrow belt adjacent to the basin-bounding fault on the northeast edge of the basin, forming in part large alluvial fans, although turbidite beds may extend farther into the basin. In the Late Pennsylvanian, coarse clastic systems prograded into the basin and buried the evaporites under a wedge of interbedded carbonate and clastic strata that thin toward the basin center. As clastic sediments accumulated, a density inversion was established, and salt within the evaporite beds rose toward the surface as diapiric domes, anticlines, and walls. The location and orientation of many of the diapiric structures were controlled by preexisting basement faults, lineaments, and structural features (Szabo and Wengerd, 1975; Campbell, 1979; Baars and Stevenson, 1981).

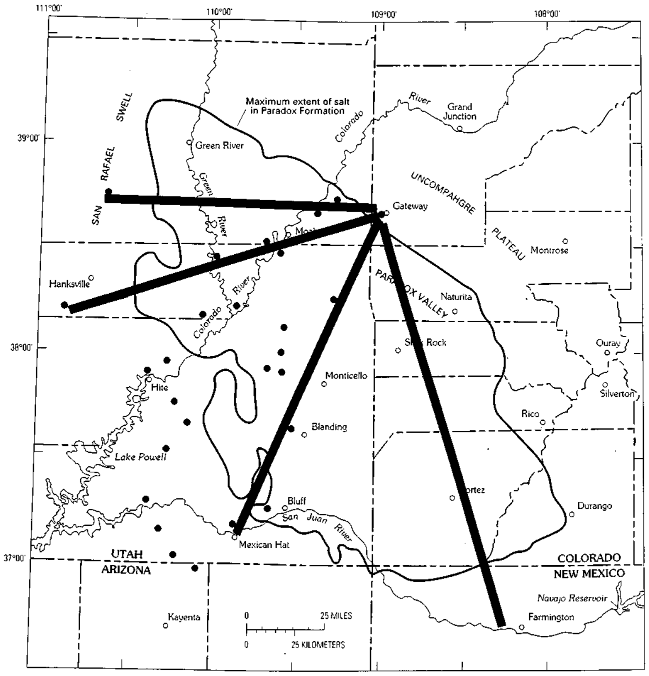

Figure 1. Location map showing outline of the Paradox Basin (solid outline), measured sections of Permian rocks (dots), and lines of cross sections A-D depicted in Figure 3 (from Dubiel et al., 1996).

Clastic sedimentation to the southwest into the Paradox Basin from the southwest flank of the ancestral Uncompahgre Highlands continued into the Permian. Accumulation of clastic material on alluvial fans maintained growth of the salt anticlines. During the Triassic, marginal-marine to continental red beds and minor marine limestones of the Lower and Middle Triassic Moenkopi Formation and variegated to red continental strata of the Upper Triassic Chinle Formation filled the basin (Dubiel, 1994). Local angular unconformities within Permian and Triassic strata attest to continued salt diapirism and movement on the salt anticlines through the Triassic and into the Jurassic (Weir and Puffett, 1981; Goydas, 1989). Adjacent to the Uncompahgre Uplift, angular unconformities between Precambrian, Permian, and Triassic rocks attest to episodic uplift on the faults bounding the Uncompahgre basement block.

STRATIGRAPHY

Evaporites and clastic rocks of the Middle and Upper Pennsylvanian Hermosa Group are the oldest sedimentary rocks exposed along the route of the field trip, and include in ascending order, the Pinkerton Trail, Paradox, and Honaker Trial Formations (Fig. 2) (Weir and Puffett, 1981; Baars, 1983; Condon, in press). The Hermosa Group is overlain in the Paradox basin by Permian rocks generally referred to as the Cutler Group (or in earlier papers, locally

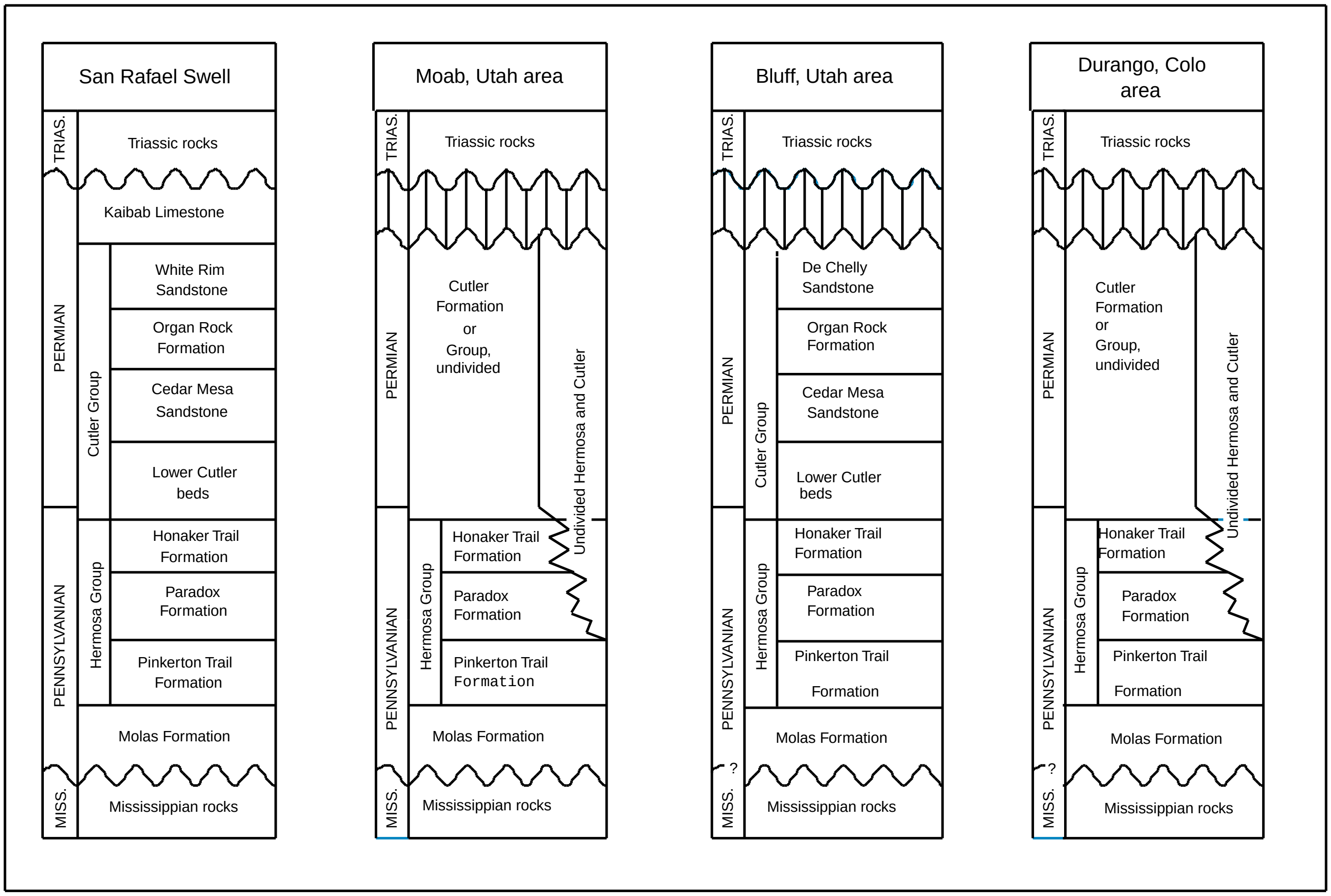

Figure 2. Permian and Pennsylvanian lithostratigraphic nomenclature used in this report (from Dubiel et al., 1996).

as Cutler Formation). The Cutler section (Fig. 3) locally in the distal part of the Paradox Basin contains marine sandstone and limestone, referred to by various authors as Elephant Canyon Formation (Baars, 1962, 1987), part of the marine facies of the Cedar Mesa Sandstone (Campbell and Steele-Mallory, 1979b; Campbell, 1979), Rico Formation (Stanesco and Campbell, 1989), and lower Cutler beds (Loope et al., 1990; Condon, in press). Other subdivisions of the Cutler Group recognized in southeastern Utah are continental rocks that include the Halgaito Formation, Cedar Mesa Sandstone, Organ Rock Formation, De Chelly Sandstone, and White Rim Sandstone (Baars, 1962, 1983; Stanesco and Campbell, 1989). The age of the Cutler Formation is generally thought to be Wolfcampian (Campbell and Steele-Mallory, 1979a, b), although Baars (1962) and McKee et al. (1967) suggested that the upper part of the Cutler may be Leonardian in age. To the west of the Paradox basin, the White Rim Sandstone at the top of the Cutler is cut out to the west by marine rocks of the Permian Kaibab Limestone (Molenaar, 1975; Baars, 1983; Huntoon and Chan, 1987).

The upper contact of the Cutler Group is a regional unconformity (Huntoon et al., 1994; Dubiel et al., 1996, and references therein). Above the unconformity, the Lower and Middle Triassic Moenkopi Formation was deposited in marginal-marine, sabkha, and continental environments (Stewart et al., 1972a; Blakey, 1974; Blakey et al., 1993; Dubiel, 1994). The Moenkopi is composed of red and yellowish-gray siltstone, sandstone, mudstone, and minor limestone. Locally the Moenkopi is composed of siliciclastic- or chert-pebble conglomerate. The terrigenous fraction was derived primarily from the ancestral Uncompahgre Highlands to the northeast, with minor components contributed from the west (Huntoon et al., 1994). The Moenkopi thickens from zero feet near the present Uncompahgre Uplift to several thousand feet in western Utah and eastern Nevada. Continental deposits derived from the east interfinger with a wholly marine section to the west in western Utah and eastern Nevada. Near the Uncompahgre uplift, the Moenkopi consists in ascending order of the Tenderfoot, Ali Baba, Sewemup, and Pariott Members. In Canyonlands, the Moenkopi consists of the Hoskinnini, Black Dragon, Sinbad Limestone, Torrey, and Moody Canyon Members. The upper contact of the Moenkopi is a regional unconformity, with large paleovalleys eroded into the upper Moenkopi probably in late Middle Triassic time in response to lowered sea level (Dubiel, 1994). The Moenkopi is unconformably overlain by the Upper Triassic Chinle Formation.

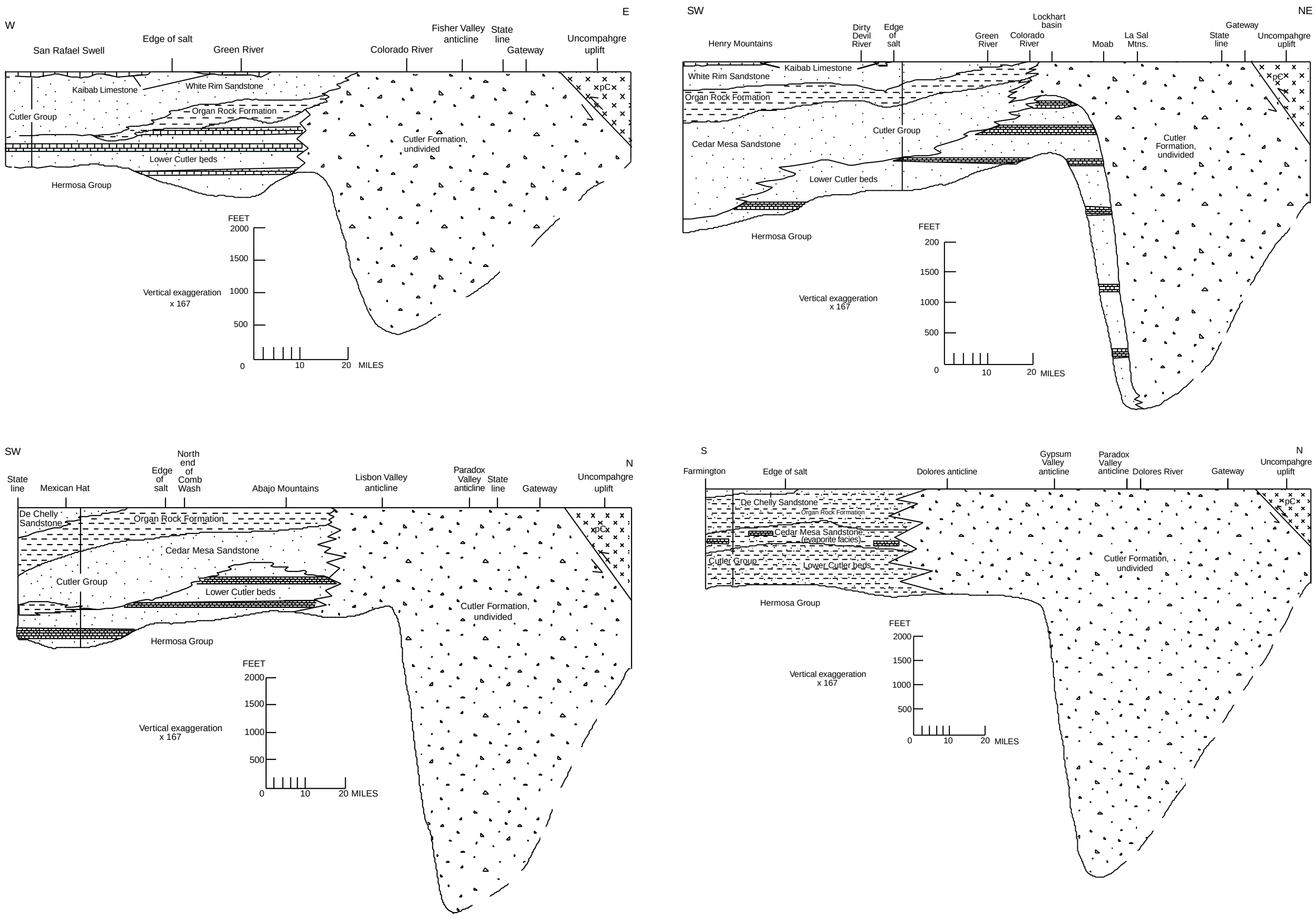

Figure 3. Stratigraphic cross sections of the Paradox Basin's Permian section compiled from isopach maps of each stratigraphic unit constructed from 202 well logs (see Condon, in press, for detailed discussion, distribution of data points, and isopach maps) combined with stratigraphy observed in nearby measured sections (see Fig. 1 for location of sections). Datum is the basal Triassic unconformity. The position and thickness of limestones in the lower Cutler beds is schematic. (Figures from Condon, in press, and from Dubiel et al., 1996)

Through most of its extent on the Colorado Plateau, the Chinle Formation unconformably overlies the Lower and Middle Triassic Moenkopi Formation or equivalent rocks. Locally in the Defiance uplift of northeastern Arizona and in western Colorado, the Chinle overlies Permian strata or older rocks. The Chinle is as much as 500 m thick. Chinle Formation stratigraphy is complex, and the reader is referred to Stewart et al. (1972b) for a comprehensive review of the history of nomenclature of Upper Triassic rocks on the Colorado Plateau. In general, mottled strata and the Shinarump Members lie near or at the base of the Chinle; these are succeeded in turn by the Monitor Butte Member, Moss Back Member, Petrified Forest Member, Owl Rock Member, and Church Rock or Rock Point Members (Stewart et al., 1972b; Blakey and Gubitosa, 1983; Dubiel et al., 1991; Dubiel, 1994).

The Upper Triassic Chinle Formation on the Colorado Plateau was deposited in a continental back-arc basin located about 5-15° north of the paleoequator near the west coast of Pangaea (Dickinson, 1981). A magmatic arc that developed on part of the western edge of the Triassic continent probably provided volcanic ash and clastic sediment to the Chinle depositional basin (Stewart et al., 1972b; Blakey and Gubitosa, 1983). The Chinle depositional basin was centered about the Four Corners region of Colorado, Utah, Arizona, and New Mexico (Blakey and Gubitosa, 1983; Dubiel, 1987a,b, 1989a,b, 1994). Clastic sediment was supplied to the Chinle basin north- and northwestward from the uplifted section adjacent to the magmatic arc, which lay in southern Arizona and northern Mexico, and south-, west-, and northwestward from the ancestral Uncompahgre highlands in southwestern Colorado and the ancestral Front Range highlands in central Colorado (Stewart et al., 1972a; Blakey and Gubitosa, 1983; Dubiel, 1987a, 1989a,b; Dubiel, 1994). The Chinle Formation is unconformably overlain by locally thick eolianites of the Lower Jurassic Wingate Sandstone in the Canyonlands area. The Wingate is overlain by fluvial rocks of the Kayenta Formation and eolianites of the Navajo Sandstone.

PALEOCLIMATE AND PALEOGEOGRAPHY

From the Pennsylvanian to the Jurassic, the Colorado Plateau in the western United States lay near the west coast of Pangea (Fig. 4), a critical location that records in the sedimentary strata the effects of an evolving tropical monsoonal climate. The Colorado Plateau migrated northward from a location about 20° south of the paleoequator in the Pennsylvanian to a position about 30° north of the paleoequator in the Jurassic. The supercontinent Pangaea represented an exceptional phase in Earth's paleogeographic history, a maximum of continental aggregation (Valentine and Moores, 1970) that began in the Carboniferous with the collision of Laurussia and Gondwana and culminated in the Triassic with the addition of Kazakhstan, Siberia, and parts of China and southeastern Asia. In the Triassic, exposed land extended from about 85°N to 90°S (Ziegler et al., 1983). Sea level was low through much of what might be called the "peak" Pangaean interval, the Permian and Triassic (Vail et al., 1977), and the area of exposed land was great (Parrish, 1985). More importantly, with the exception of a small fraction in parts of what is now China and southeast Asia, this exposed land area constituted a single continent. On first principles, it would be expected that the continent would have had an extraordinary effect on global paleoclimate. The continent cut across and therefore disrupted nearly every part of the zonal atmospheric circulation. In addition, the great size of the exposed land, the presence of large landmasses in low mid-latitudes, and the presence of a warm seaway to act as a source of moisture would have maximized summer heating in the circum-Tethyan part of the continent.

The Permian-Triassic interval has long been regarded as unusual, representing a unique and extreme paleoclimatic state, because red beds and evaporites were global in extent (Turner, 1980) and because evaporite depositional regimes covered more area in the Triassic than at any other time (Gordon, 1975). As data on paleoclimatically significant fossils and rocks have gradually been accumulated and put into the context of plate tectonics, the uniqueness of the Permian-Triassic has only been emphasized.

The climate of Pangea was described by Robinson (1973) as monsoonal,. This interpretation was supported by Parrish et al. (1986), who produced conceptual climate models that demonstrated qualitatively the mechanisms of the Pangean monsoon. As Pangea drifted north prior to and during the Triassic, the exposed land area was distributed

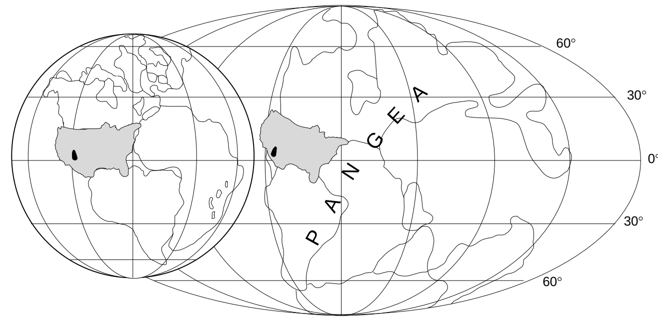

Figure 4. Schematic reconstruction of Pangea showing the approximate Permian location of the Colorado Plateau (dark shading) and the United States (light shading) for reference. Derived from reconstructions by Ziegler et al. (1983) and modified from Dubiel et al. 1993). Round inset: Partial reconstruction of Pangea depicting different orientation and thus rotation of the Colorado Plateau (derived from Bazard and Butler, 1991 and modified from Dubiel et al., 1991).

evenly on either side of the equator (Parrish, 1985). Seasonality would be expected to have been accentuated and the equatorial region and mid-latitude continental interiors to have experienced increased aridity. During the Triassic, the monsoonal circulation probably achieved maximum strength (Parrish and Peterson, 1988; Dubiel *et al*, 1991), and, depending on continental-scale topography, aridity of the continental interior would have been greatest.

Permian Paleoclimate and Paleogeography

In the Permian, the Colorado Plateau was situated on or very near the equator and close to the western margin of Pangea, indicating that temperatures would have been consistently hot in a coastal-lowland setting. Pangea had just come together, and the monsoonal climate that developed in response to consolidation of the supercontinent was just beginning to exert its influence on the western margin of the continent. Moisture that was alternately pulled north and south during opposing seasons into the interior of the continent would have bypassed the Colorado Plateau and the Paradox Basin as they were situated very near the equator. An interpretation of dry climates in the Permian is supported by widespread eolian dune fields, extensive eolian sand sheets, and sabkhas in the Cedar Mesa Sandstone, the De Chelly Sandstone, and the White Rim Sandstone (Fig. 5). However, the seasonal input of moisture is supported by the presence of fine-grained fluvial and floodplain deposits in the Halgaito and Organ Rock Formations that contain abundant rhizoliths and paleosols that contain vertic features, indicating alternating wet and dry seasons. In addition, the paleontologic evidence of freshwater fish and sharks, amphibians, ferns and lycopods indicates abundant moisture, at least along riparian

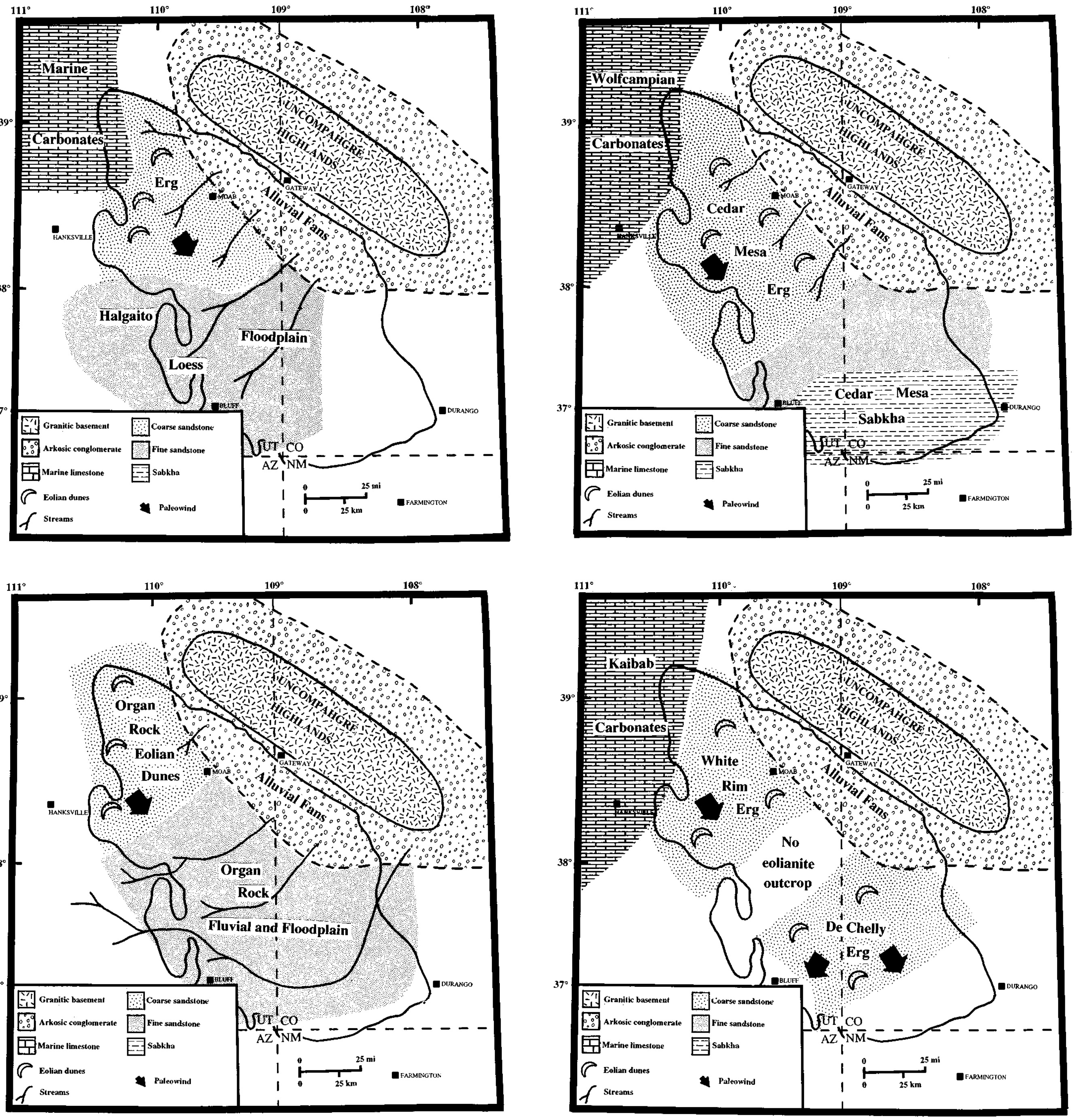

Figure 5. Schematic paleogeographic reconstructions for: A) Early Permian (Wolfcampian) lower Cutler beds and Halgaito time; B) Early Permian (Wolfcampian) Cedar Mesa time; C Early Permian (Leonardian) Organ Rock time; and D) Early Permian (Leonardian to Guadalupian) DeChelly and White Rim time. Note that whereas the De Chelly and White Rim are depicted together on this diagram, regional correlations (see Blakey, 1996) indicate that they are distinct erg systems and that the De Chelly is older than the White Rim. The De Chelly outcrops extend south to Monument Valley and Chinle, AZ, farther than depicted by the pattern in this diagram. (Figures from Dubiel et al., 1996).

environments. The presence of fresh-water fish and sharks also necessitates perennial water bodies, requiring wetter climates, if not on the floodplains themselves, then certainly in the highland source areas. Can this evidence for alternating wet and dry climates be integrated with sea-level fluctuations that also affected depositional systems? Further research is necessary to decipher complex faces variations, but some tentative interpretations are possible.

The Permian Cutler Group represents primarily clastic deposition shed from the Ancestral Uncompahgre highlands southwest into the Paradox Basin. Clastic deposits grade westward into marine units and southward into coastal and marine deposits. Clastics had been shed from the Uncompahgre since the Middle Pennsylvanian (Wengred and Matheny, 1958). Deposition was perhaps continuous from the Hermosa to the Cutler, but due to the lack of temporal control within coarse clastic deposits adjacent to the Uncompahgre, it is difficult to ascertain the age of the lowermost Cutler arkoses. Initiation of Cutler deposition thus possibly began as early as Middle Pennsylvanian in alluvial fans and debris flows adjacent to the highlands.

Eolian units within the Cutler Group (Cedar Mesa Sandstone and the White Rim Sandstone) are interpreted to have been derived from an extrabasinal source, due to their quatrz-rich lithology, which is typical of recycled sedimentary units (Huntoon, 1985). Based on paleocurrent data that indicate northwest winds in the Paradox Basin (Parrish and Peterson, 1988), a likely source for the eolian sand would have been to the north, perhaps the Weber Sandstone of northeastern Utah or other exposed Paleozoic sedimentary rocks. Cessation of eolian deposition after the Cedar Mesa is interpreted to reflect an absence of an appropriate sediment supply for eolian transport. The upward transition from the eolianites of the Cedar Mesa into the Organ Rock, a dominantlyfluvial and floodplain deposit containing abundant evidence of seasonal water, is interpreted to relect a change in climate to more humid conditions. The increase in proportions of locally derived arkosic sediment from the Uncompahgre also reflects a wetter climate and increased mechanical and chemical weathering in the adjacent highlands. A subsequent return to arid conditions is reflected by the transition from the Organ Rock to both the De Chelly and the White Rim erg systems.

In contrast to the climate changes indicated by the Cedar Mesa-Organ Rock-De Chelly-White Rim transition, the limestone units to the west that lie above and beneath this section are more sensitive indicators of relative sea-level changes. Highstands of sea level effectively cut off eolian sediment supply from northern sources due to shoreline transgressions. The presence of loess deposits in the Halgaito attest to aridity at the time of deposition of the lower Cutler beds.

In the Lower Permian (Wolfcampian), the Paradox Basin was situated just north of the equator and was rotated clockwise from its present position. Prevailing winds blew from northeast to southwest (present coordinates) (Parrish and Peterson, 1988). Streams flowed southwest toward the ocean from the Uncompahgre Highland but turned west and north in the vicinity of Monument Valley (Fig. 5). The Halgaito represents deposition on a low-relief plain dominated by fluvial, floodplain, and eolian loess deposition. A large eolian dune field (Cedar Mesa Sandstone) developed downwind of a marine embayment at the northern end of the Paradox Basin. A sabkha existed to the south of the Paradox Basin and may have extended into marine environments south of the San Juan Basin.

The Organ Rock was deposited in fluvial and floodplain settings, probably on a low-relief coastal plain (Fig. 5). To the north and east at this time, eolian and sabkha settings episodically interfingered with fluvial deposition. Organ Rock deposition was dominated by eolian dune deposits to the north and fluvial and alluvial fan deposits to the east.

During the Leonardian, the DeChelly erg developed to the south, and farther south sabkha and marine deposition occurred toward the San Juan Basin. The Uncompahgre continued to shed arkosic clastic debris into the Paradox Basin, and these alluvial fan deposits interfingered with eolian and floodplain ssytems farther out in the basin. The marine Kaibab sea lay to the west, where it interfingered with coastal dune and eolian erg deposits of the White Rim Sandstone. Wind transport in the White Rim was also to the southeast.

While general climatic changes can be inferred from paleontology and depositional systems in the various units, more specific and higher frequency variations still need to be inferred from detailed analysis of the continental facies successions. Whereas general, longer term or lower frequency relative sea-level fluctuations can be deduced from regional correlations and interfingered marine strata in parts of the section, ample opportunity exists for applying sequence analysis within the continental facies.

Triassic Paleoclimate and Paleogeography

The Upper Triassic Chinle Formation was deposited at an exceptional time in Earth's paleogeographic and paleoclimatic history. During the Triassic, the supercontinent Pangaea was at its greatest size, in terms of both aggregated continental crust and exposed land area. Moreover, the exposed land was divided symmetrically about the paleoequator between the northern and southern hemispheres. These conditions were ideal for maximizing monsoonal circulation, as predicted from paleoclimate models. The Chinle was deposited between about 5° to 15° N paleolatitude in the western equatorial region of Pangaea, a key area for documenting the effects of the monsoonal climate. In contrast to the predominance of eolian deposition on the Colorado Plateau in the preceding Permian and subsequent Jurassic Periods (Peterson, 1988), Late Triassic deposition was characterized by a fluvial-deltaic-lacustrine system replete with extensive marshes, bogs, rivers, floodplains, and lakes (Stewart et al., 1972b; Blakey and Gubitosa, 1983; Dubiel, 1987a, 1989b). Blakey and Gubitosa (1983) described perennial fluvio-lacustrine complexes throughout most of Chinle deposition followed by increasingly arid conditions in the upper part of the Chinle. Sedimentological studies of the Chinle in southeastern Utah documented a complex fluvial-lacustrine system and also interpreted Chinle climate as tropical monsoonal, that is, with significant precipitation but punctuated by seasonally dry periods, with an increase in aridity in the upper part of the Chinle (Dubiel, 1987a,b, 1989a). Aquatic habitats indicated by faunal, paleobotanical, and sedimentological evidence point to abundant and perennial water in the depositional system in the Four Corners area. Additionally, trace fossils and floodplain paleosols indicate that sedimentary facies and ground-water tables fluctuated in response to episodic flooding that probably resulted from periodic, and perhaps seasonal, input of moisture. Uppermost Chinle strata consist of lacustrine and marginal-lacustrine mudstones interbedded with minor eolian sand sheets and eolian dunes. Thus, the later Triassic reflects continued precipitation, but was marked by more pronounced and extended dry seasons, terminating in a transition upward into the eolian erg deposits of the Lower Jurassic Wingate Sandstone (Dubiel, 1989a).

FIELD TRIP

During this field trip, we will examine the stratigraphy and sedimentary facies that characterize the Permian, Triassic, and Jurassic systems on the Colorado Plateau. As we examine the sedimentary facies, keep in mind the paleogeographic location of the Colorado Plateau near the western tropical coast of Pangea. By placing the Permian-Triassic-Jurassic of the Colorado Plateau in its Pangean paleogeographic context, one may gain insight into global controls on sea level, depositional systems, and paleoclimate.

As we drive from Denver, CO to the start of the Permian part of the trip in Grand Junction, CO, we pass many interesting geologic features and units. We will describe these briefly with their mileage measured from the Geologic Road Cut along I-70 at the Morrison, CO exit.

Geology from Denver to Grand Junction, Colorado

Mile	Geologic Feature
0.0	I-70 Road Cut at Morrison, through Jurassic Morrison Fm and Cretaceous Dakota Sandstone Hogback.
5.5	View of Gore Range, mountains held up by Precambrian granite.
21.2	Gold mines and tailings piles in granitic and gneissic bedrock.
46.0	Eisenhower Tunnel beneath the Continental Divide.
47.5	West side of the Eisenhower Tunnel.
54.5	Remnants of Cretaceous rocks within uplifted granite mountains of the Rocky Mountains.
66.0	Copper Mountain Ski Resort.
69.0	Jacques Mountain Limestone (on left) and Maroon Formation red beds just west of the Gore Fault.
71.2	Vail Pass; entering Eagle Basin between Front Range and the Uncompahgre Plateau.
85.0	Fan deltas in the Minturn Formation.
90.6	Minturn Formation.
91.8	Belden Formation and Eagle Valley Evaporite in the Eagle Basin.
103.7	Triassic through Jurassic section.
104.3	Cretaceous Dakota Sandstone and Mancos Shale.
110.3	Maroon Formation red beds.
131.0	Colorado River.
133.6	Glenwood Canyon, Lower Paleozoic rocks, and Precambrian granite and metamorphic rocks.
170.0	Oil Shale deposits in the Tertiary Green River Formation.
181.3	Tertiary Wasatch Formation fluvial and floodplain strata.
211.8	Gas production from sandstones in the Cretaceous Mesa Verde Formation.
237.4	Grand Junction, CO.

Field Trip Stops

Day 1. Thursday, October, 24, 8 a.m. Meet outside of lobby of Denver Mariott City Center to pack vans.

Route: Head south out of Grand Junction on Hwy. 141 to Whitewater. Turn right (southwest) on Hwy. 141 toward Unaweep Canyon.

Optional Stop - Unaweep Canyon - Jack's Canyon Rd; Precambrian/Triassic unconformity

The Precambrian rocks of the Uncompahgre Plateau were initially uplifted in middle Pennsylvanian time, and they formed the ancestral Uncompahgre Highland of the ancestral Rocky Mountains. The Uncompahgre shed clastic detritus to the west in Permian through Triassic time, and by the Cretaceous, the Highland was completely eroded away. The present-day Uncompahgre Plateau, cored by the same Protoerozoic granite and gneiss, is a Laramide (Late Cretaceous to Early Tertiary) structural feature. The Upper Triassic Chinle Formation here rests unconformably on granite and gneiss. Our first stop is along Jack's Canyon road south of Hwy. 141, where we will drive up through the Precambrian rocks to the contact with the Chinle Formation. We will examine the Precambrian rocks, the nature of the unconformity, and the basal deposits of the Chinle.

What is the composition of the Precambrian rocks? What is the composition of the pebbles in the Chinle? What is the nature of the unconformity and the facies of the basal Chinle strata? What happened to the strata between the Precambrian and the Upper Triassic?

Driving west out of Unaweep Canyon after this stop, we pass up section from the Precambrian rocks through red sandstones and siltstones of the Upper Triassic Chinle Formation and finally through Jurassic and Cretaceous sedimentary rocks.

Route: Continue southwest on Hwy. 141 to southwestern end of Unaweep Canyon. Turn left and proceed up wash at 6 3/10 Road about 1/4 mile.

Stop 1.1 - Gateway Fan; Cutler Group debris flows - Castro Draw at 6 3/10 Road

We have come west far enough to see the Precambrian igneous rocks in the distance to the east. We are close to the fault on the western side of the Uncompahgre Plateau, which is in approximately the same location as the bounding fault on the west side of the ancestral Uncompahgre Uplift. The interpretation for the location of the ancient fault is based in part on the facies present here in the Cutler Formation. We will examine very coarse grained, arkosic boulder conglomerates in the Cutler Formation. The matrix-supported conglomerates, the coarsening upward sequence, and the restricted lateral extent of the deposits suggest that these are debris-flow deposits on an alluvial fan-head trench and attest to the proximity of high topographic relief in the Uncompahgre source area during the Permian. Clast-supported, channel-form conglomerates and sandstones were deposited in streams on the fan surface.

What is the maximum size of the clasts in the Cutler? What is the composition of the clasts? What sedimentary features and bedding are present?

Route: Continue south on Hwy.141 to the town of Gateway, Colo.

Stop 1.2 - Gateway, CO - Cutler Fm. facies, Triassic rocks

From Gateway we can look northwest to Gateway Mesa and observe the Permian Cutler Formation, the Early to Middle Triassic Moenkopi Formation, the Upper Triassic Chinle Formation, and the Lower Jurassic Wingate Sandstone. Units progressively onlap the Uncompahgre uplift to the east. Within the Cutler, purple arkosic fluvial strata are interbedded with thin orange eolian beds, a theme we will see expressed in the next several field stops.

What was the origin of the arkosic fluvial beds and the origin of the orange eolian beds in the Cutler Formation? Why are these beds colored in this manner?

Route: Proceed west up John Brown's Canyon up section through the Cutler, Moenkopi, and Chinle Formations and younger rocks. Continue west on major dirt roads toward the Tertiary laccolithic intrusions of the La Sal Mountains. Stop at major T-intersection for overview of the Fisher Valley salt anticline. (alternate Route: Follow Hwy. 141 south and Hwy. 90 west to town of Bedrock and through Paradox Valley Anticline, if inclement weather conditions dictate.)

Stop 1.3 - Fisher Valley salt anticline overlook

The view from the overlook is to the north and west into the Fisher Valley salt anticline. On the rim are the eolianites of the Lower Jurassic Wingate Sandstone, underlain by the Chinle Formation, the Moenkopi Formation, and the Cutler Formation. Beds dip to the northeast and the southwest away from the central axis of the salt anticline. Within the central part of the structure, white beds of the Pennsylvanian Paradox Formation are intruded upward in the Onion Creek salt diapir. The Fisher Valley salt anticline formed during the Pennsylvanian to Triassic (Goydas, 1989) as beds of halite, gypsum, siltstone and black shale in the underlying Pennsylvanian Paradox Formation were mobilized due to progradation of overlying Pennsylvanian to Permian coarse-grained clastic deposits, which led to development of density instability. This deformation was localized on the southwest flank of the Uncompahgre uplift as the Cutler Formation prograded into the Paradox Basin. The evaporite deposits of the Paradox Formation were deformed in a large region called the Paradox fold and fault belt, with numerous northwest-trending salt anticlines and isolated salt domes deforming overlying strata and influencing the trend of subsequent depositional systems. Interformational and intraformational unconformities within the Permian to Triassic section attest to the complex periods of episodic salt deformation and upward intrusion. Thinning and thickening of strata over the salt structures attest to local salt anticline structural control on depositional systems.

Note the size and orientation of the salt anticlines and their spatial relation to the Uncompahgre Plateau and the ancestral Uncompahgre Highlands.

Route: Proceed west on the dirt road down to the paved road at the head of Castle Valley.

Optional Stop - Pariott Mesa - Tenderfoot Member (Hoskinnini Mbr.) of the Moenkopi Formation

We crossed over the deformed beds in the Moenkopi within the southernmost extent of the Cache Valley salt anticline just north across the Colorado River and are now in the axis of the Castle Valley salt anticline, southwest of our last stop in the Fisher Valley anticline. The upper part of the Cutler Formation here is composed of purple to lavender arkosic fluvial deposits cut out on the top by a regional unconformity. The relationship is angular, probably due to uplift on the salt anticline prior to Moenkopi deposition. Across the valley is an outcrop of white eolian sandstone that is probably an erosional remnant of the Permian White Rim Sandstone, preserved in a salt syncline. The base of the Moenkopi here is the Tenderfoot Member (or Hoskinnini Mbr. of the Canyonlands area), composed of reddish-brown sandstone, siltstone, and white gypsum beds. The Tenderfoot (Hoskinnini) is distinguished in particular by the occurrence of coarse, well-rounded quartz grains and granules. The Tenderfoot grades upward into thin bedded, ripple-laminated sandstones and siltstones of the Ali Baba Member of the Moenkopi.

What is the source of the coarse granules and quartz grains in the Tenderfoot (Hoskinnini)? (HINT: Note the similar source area for the Moenkopi in the ancestral Uncompahgre Highlands and the occurrence of the thick, white eolian sandstone across the valley on top of the Cutler and below the Tenderfoot.)

Route: Continue north on Castle Valley Road. Turn right (north) to Hwy. 128 (Cisco Road) and turn right (northeast) on dirt road to Fisher Valley Salt Anticline and Onion Creek.

Optional Stop - Fisher Valley salt anticline drive through

We drive west through interbedded purple, fluvial arkoses and orange, eolian quartz-rich litharenites of the undifferentiated Cutler Formation toward the core of the Fisher Valley salt anticline along the course of Onion Creek. The Cutler beds are highly contorted and broken by numerous intraformational faults near the central axis of the structure. The evaporites, carbonates, and black shales of the Paradox Formation intrude the Cutler and are themselves highly contorted. No halite remains at the surface in most of the salt anticlines due to dissolution from meteoric weathering, but gypsum is locally abundant.

Route: Proceed west on the dirt road back to Hwy. 128 (Cisco Road) and turn right (northeast), and turn right again on dirt road to Fisher Towers.

Stop 1.4 - Fisher Towers - Cutler Group interbedded eolian and fluvial facies

At the parking lot to Fisher Towers, note the tremendous hoodoos eroded into the undifferentiated Cutler Formation. Take the short trail from the Parking Lot to a small tower. The Cutler Formation at this stop is undifferentiated into the units that are recognized to the west in the Paradox Basin. The Cutler here consists of dominantly arkosic conglomerates and sandstones deposited in fluvial and coarse-grained floodplain settings interbedded with minor eolian sandsheet and dune deposits. Both facies were deposited in a proximal to medial fluvial setting. The fluvial deposits are easily recognized by their purple to lavender color, whereas the eolian deposits are orange. The fluvial strata have eroded bases, abundant crossbedding, and reactivation surfaces, all of which indicate high-energy unidirectional flow conditions. Fine-grained floodplain deposits are present, but make up a minor component of the fluvial system. The eolian strata contain large-scale cross bedding, eolian avalanche strata, and wind ripple lamination indicative of eolian dune sedimentation rather than on sand sheets.

How are these interbedded fluvial and eolian deposits reminiscent of the Cutler fluvial-eolian interbeds at Gateway? How are they different? Why are the fluvial and eolian strata color-coded as purple and orange beds?

Route: Leave Fisher Towers and go back west on Cisco Road.

Optional Stop - Professor Valley - Chinle Formation Facies and Burrows.

A purple-mottled unit typically occurs at the base of the Chinle Formation. The mottled unit is characterized by large, irregular mottles of dark purple, lavender, yellow, and white that reflect varying concentrations of iron-bearing minerals. Ubiquitous in the mottled unit are large cylindrical trace fossils originally interpreted to be the casts of lungfish burrows (Dubiel et al., 1987, 1987c, 1988, 1989a); many are now reinterpreted as decapod (freshwater crayfish) burrows (Hasiotis and Mitchell, 1989, 1993; Hasiotis, Mitchell, and Dubiel, 1993). Both the burrows and the mottled coloration reflect fluctuating water tables within the original depositional setting (Dubiel et al., 1987). The mottling locally extends downward into the Moenkopi at the same stratigraphic level of development in the Chinle and represents a gleyed paleosol formed by fluctuating water tables. The fluctuating water tables produced alternating oxidizing and reducing conditions that resulted in the redistribution of iron and the mottling. Lungfish are believed to have formed their burrows for aestivation in response to seasonal dryness, whereas the crayfish burrowed to keep their living chambers at the bottom of the burrows beneath the water table during seasonally fluctuating water tables. These observations, along with other sedimentologic and paleontologic evidence, suggest that Late Triassic deposystems were affected by seasonal input of precipitation as a direct result of tropical monsoonal climates (Dubiel et al., 1991).

Note the color mottling and the large burrows. What evidence have we seen so far on the trip to suggest climatic fluctuations? Were the processes that produced those rocks and climate variations operating on the same time scale?

Route: Continue west on Hwy. 128 (Cisco Road) to Moab.

Spend night at Best Western Green Well Motel (801-259-6151), Moab, Utah. **Rooms already booked.**

Day 2. Friday, October 25, 8:00 a.m. Leave Moab.

Route: Leave Moab and drive north on Hwy. 191.

Optional Stop - Moab fault and salt anticline

As we proceed north from Moab, we pass through the Moab fault that juxtaposes Pennsylvanian to Permian marine limestones on the left side of the road against Jurassic eolianites on the right. The entire section from the Paleozoic to the Jurassic is exposed on the right-hand cliffs north of the entrance to Arches National Park. At Arches National Park, sandstone arches are developed in the eolianites of the Middle Jurassic Entrada Sandstone.

Turn left (west) on Hwy. 313 toward northern entrance to Canyonlands National Park. Stop on right in small parking lot at exposures of Cutler and Chinle Formation.

Optional Stop - North Entrance Canyonlands NP- Chinle Fm; Moenkopi Fm; Cutler Grp

At this stop we will examine continental deposits of the Upper Triassic Chinle Formation. At the paved parking area, the Cutler contains interbedded fluvial and eolian deposits. Farther west at a dirt pullout and an abandoned uranium mine and tailings pile on the right, the Chinle Formation sits on a thin section of the Moenkopi Formation and the Cutler Formation. At the base of the Chinle lies the quartz-pebble-rich fluvial conglomerates of the basal Shinarump Member that are pervasively color mottled, similar to the deposits we saw along the Colorado River. Locally, large-diameter burrows are present, again implying a deposit that was subjected to fluctuating water tables. Overlying the mottled unit are green sandstones and siltstones of the Kane Springs strata, an informal unit in the Chinle in this area equivalent to the Monitor Butte Member, and thick fluvial sandstones within the upper part of the Chinle. These fluvial sandstones have extremely thick lateral accretion bedding interpreted as point bars in large meandering streams (Dubiel, 1994; Hazel, 1994). Overlying the Chinle are the J-0 unconformity and the Lower Jurassic Wingate Sandstone.

Note the difference in sedimentary facies within the Chinle as compared to the Cutler and Moenkopi Formations. Note the distinctive green color in the lower Chinle and its association with uranium mineralization and mines. This association reflects the high water tables and organic preservation within paleovalleys at the base of the Chinle.

Route: Continue west on Hwy. 313.

Optional Stop - Glen Canyon Group - Navajo Sandstone eolian structures

This stop examines the Lower Jurassic Glen Canyon Group sandstones and in particular the Lower Jurassic Navajo Sandstone, with it's typical eolian sedimentary structures. The Navajo Sandstone represents deposits of the largest eolian erg ever to have developed on Earth. Keep in mind the climate changes that must have been responsible for the development of this tremendous eolian sand sea.

Route: Continue west on Hwy. 313 to Hwy. 279 and proceed to Dead Horse Point State Park.

Optional Stop - Dead Horse Point

The view from Dead Horse Point provides a spectacular summary of the stratigraphy and structural setting for the field trip. Looking east we can see the Tertiary laccolithic intrusions of the La Sal Mountains and to the south the Abajo Mountains. Farther west are the Henry Mountains, where G.K. Gilbert first observed and described the processes operating to form these laccoliths and associated igneous intrusions. The broad curved skyline in the right distance is the crest of the Monument upwarp, a Laramide structural uplift that is in part responsible for the present structure and erosional features. It is also a feature that was probably active during deposition of many of the Permian to Triassic rocks that we are examining. Below the overlook, the Colorado River has eroded through Shafer Dome, a prominent salt anticline. The inner Canyon along the Colorado River is cut into the Permian Elephant Canyon Formation (which equals the lower Cutler beds, and the Rico of earlier geologists), which is marked at the top by a distinct gray, grassy covered ledge of the Shafer Limestone. Overlying the Shafer Limestone are the Permian to Triassic rocks. The distinctive white ledge is the White Rim Sandstone, a marker for placing yourself in the stratigraphic sequence. We are standing on the Lower Jurassic Kayenta Formation, underlain by the Wingate Sandstone and the Chinle Formation. From this view one can also see the salt anticlines in the Paradox Fold and Fault belt, and the distillation ponds that produce potash and other salts from solution mining activities 2,500 ft in the subsurface from the Pennsylvanian Paradox Formation. We will also drive past hydrocarbon production from horizontal drilling in the Cane Creek Shale interval of the Paradox Formation.

Exit the park and head north and east back to Hwy 191. Continue on Hwy 191 to the entrance of Canyonlands National Park and turn left at the Shafer Trail turnoff.

Stop 2.1 - Shafer Trail - Shafer Dome salt anticline overlook

From this overlook one can see the structure of the salt anticlines and the general stratigraphy of the region. The prominent structure in the middle ground is the Shafer Dome salt anticline.

Continue down the Shafer Trail.

Stop 2.2 - Moenkopi Fm.; Chinle Fm. fluvial point bars

We pass down section from the Jurassic eolianites into the Chinle Formation. About half way down the Shafer Trail stop at exposures of the Chinle Formation. Note the lateral accretion stratification in the point bar deposits of the fluvial sandstone. How large was the fluvial system that deposited these units? What was the climate like that must have supported these fluvial systems? Farther down we pass into the reddish-brown slope-forming units of the Lower Triassic Moenkopi Fm., in ascending order, Hoskinnini, Black Dragon, Sinbad Limestone, Torrey, and Moody Canyon Members.

Continue down the Shafer Trail into Shafer Canyon and the intersection of the Shafer Trail with the White Rim Trail.

Stop 2.3 - Shafer Trail - White Rim Trail intersection; White Rim SS and Hoskinnini

The White Rim Sandstone is the youngest Permian unit exposed in the region. It is composed of subrounded to well-rounded dominantly very-fine to fine-grained quartz arenite sandstone that was primarily deposited in an eolian environment (erg margin; Chan, 1989). Common characteristics of the White Rim include large-scale, high-angle cross-stratification, and, at a smaller scale, grainfall and grainflow laminae and translatent strata (Huntoon, 1985). Well-rounded coarse to very coarse quartz grains are present throughout the formation, particularly in horizontally laminated facies that are interpreted as interdune deposits. Near the top of the formation, however, the coarse to very coarse quartz grains become common. The quartz grains in the formation are interpreted to be derived from a series of preexisting eolian formations that are present to the north and east of Canyonlands, and that become progressively older away from Canyonlands (Poole, 1962). In contrast to the underlying Permian Organ Rock Formation and the overlying basal part of the Triassic Moenkopi Formation, the source of the White Rim Sandstone is located to the northeast of the depocenter, and transport of material into the White Rim depocenter was most effective during periods of low relative sea level. During most of the Permian, the paleoshoreline was oriented approximately NE-SW with marine conditions dominant to the west.

In addition to the coarse to very coarse quartz grains, the upper portion of the formation also contains well-rounded coarse to very coarse chert grains. These chert grains were probably derived from the Kaibab Limestone (a lateral partial time equivalent of the White Rim Sandstone that is present to the west of the Canyonlands region in central and western Utah). These grains are interpreted to have been transported to the White Rim depocenter by onshore winds, blowing from west to east. To the west of Canyonlands, the Kaibab Limestone overlies the White Rim in a transgressive relationship. Relative sea level must have been rising near the end of deposition of the White Rim Sandstone for this relationship to have been produced. At Shafer Trail, there is no evidence of this Permian transgression, but in the Elaterite Basin (just to the west of the confluence of the Green and Colorado Rivers), a marine reworked veneer is present at the top of the White Rim Sandstone.

The marine reworked veneer of the White Rim Sandstone is overlain by the Permian-Triassic (TR-1) unconformity and the Hoskinnini Member of the Moenkopi Formation in the Elaterite Basin. The Hoskinnini is similar to the marine reworked veneer, but it contains abundant variable sized chert clasts, along with scattered well rounded coarse to very coarse quartz grains (similar to the Tenderfoot Member).. Megapolygons, large-scale soft sediment deformation features and large-scale wavy bedding are commonly observed in the Hoskinnini. The Hoskinnini is present at Shafer Trail, where it is appears as the white or red highly deformed unit between the White Rim Sandstone and the Moenkopi Formation. At the Shafer Trail, the Hoskinnini fills paleotopographic relief at the top of the White Rim Sandstone. In the Elaterite Basin, paleotopographic relief is present because the upper surface of the eolian portion of the unit was reworked during the marine transgression that produced the veneer (Huntoon and Chan, 1987). Along the White Rim Trail, however, paleotopographic relief at the top of the White Rim Sandstone has been interpreted as a series of paleo-yardangs (Tewes and Loope, 1991).

Above the Hoskinnini are the thin bedded sandstones and siltstones of the Black Dragon Member of the Moenkopi Formation, correlative to the Ali Baba Member that we saw in Castle Valley. The Hoskinnini is equivalent to the Tenderfoot Member in that area. The Black Dragon is similarly interpreted as marginal-marine mudflat, probably tidal flat, deposits.

Proceed left at intersection and east on the Potash Road.

Optional Stop - Potash Road - Chinle Fm. Point bars, Organ Rock, Shafer Limestone

We will make several short stops along this part of the drive out of the northern part of Canyonlands National Park. As we proceed, we pass down into undivided Cutler arkosic fluvial sandstones interbedded with eolianites. The Shafer limestone is a marine bed deposited by a marine transgression from the west into Cutler continental facies on the east. The mines extract potash from the Pennsylvanian Paradox Formation. The Chinle Fm. east of the Potash mines contains both sheet and ribbon fluvial sandstones. The fluvial style was controlled by the growth of salt anticlines during deposition. Note the lateral accretion bedding in point bar deposits of the Chinle.

Return along Potash road to the intersection of the White Rim Trail and the Shafer Trail. Turn right on the Shafer Trail and head back to Moab.

Route: From Moab, drive south on Hwy. 191 to the southern entrance to Canyonlands National Park, driving west on the Indian Creek Road (Hwy. 211).

Optional Stop - Indian Creek - Moss Back Mbr., Chinle Fm.

Along Indian Creek, the Organ Rock is overlain by the Moenkopi Formation, and the White Rim Sandstone is not present at this locality east of the Colorado River. The Moenkopi Formation is unconformably overlain by the Moss Back Member of the Chinle Formation. Locally, small pods of the mottled unit of the basal Chinle are present, and they host uranium mines. The Moss Back Member is a fluvial sandstone, dominated by large cut and fills, black chert and carbonate pebble conglomerate, and siliciclastic sandstone.

What produced the sheet sandstone nature of the Moss Back? What is the source of the carbonate pebbles in the Moss Back? What style of fluvial deposition is this - braided or meandering? Does the style imply anything about paleoclimate? Note the Chinle rock colors.

Continue west to the Big Spring Canyon Trailhead.

Optional Stop - Big Spring Canyon: Permian marine-continental interfingering

Along Indian Creek, the Cedar Mesa Sandstone is overlain by the Organ Rock Formation. We will drive to the parking area at the end of the road. At this stop we will take a short hike to examine interbedded continental and marine strata in lower Cutler beds (Elephant Canyon Formation). This stop illustrates the proximity of the marine environment to the continental Cutler facies we have examined so far. The interbedded strata at this stop expose fluctuating shoreline conditions during lower Cutler deposition.

Note the fossiliferous marine carbonates interbedded with tidal and eolian arkosic sandstones. Note the gradual change upward in the section to dominantly continental erg deposition in the overlying Cedar Mesa Sandstone.

Return driving east on Indian Creek road.

Optional Stop - South Entrance Canyonlands Ntl Pk - Newspaper Rk, Glen Canyon Grp.

Along Indian Creek, we will make several short stops to examine the Lower Jurassic Glen Canyon Group (Lower Jurassic Wingate Sandstone, Kayenta Formation, and Navajo Sandstone) and Anasazi petroglyphs at Newspaper Rock, and if lowered creek level permits, reptile footprints in the Chinle Formation.

Route: Return on 211 east to Hwy. 191. Turn right and head south on Hwy. 191 through Blanding. Turn right (west) on Hwy. 95 towards Lake Powell and past Hite, Utah. Head over the Colorado River and Dirty Devil Bridges around Lake Powell and up the hill to road cut outcrops of the Permian section.

Stop 2.4 - North Wash - Permian to Triassic; White Rim Sandstone, Core, Tar Sands

On the way up North Wash, we will examine most of the rocks in the Permian and Triassic section as short stops. The Cedar Mesa Sandstone at the base of the Cutler Group is exposed around the shores of Lake Powell. The Cedar Mesa here represents eolian dune deposits in the center of the erg. Note the three-dimensional views of avalanche-produced dune strata and wind-ripple laminae in large transverse and barchanoid dunes. Also exposed are pedogenic features, invertebrate bioturbation, and rhizolith development on stabilization surfaces in the erg, probably due to higher than normal ground water levels. What might have caused the stabilization surfaces and the higher ground water tables?

Our next short stop is in the Organ Rock Formation of the Cutler Group. At this stop we are in the distal fluvial facies interbedded with eolian dunes deposits that are recognizable by the laterally extensive, planar orange beds. The dark brown beds in the Organ Rock include probable sheet-wash deposits in broad, shallow, mud-filled channels. There is a noticeable lack of carbonate nodules as clasts in the channels, especially compared to the Organ Rock channels at Monument Pass. Note the laterally continuous eolian strata within the Organ Rock. If time permits we will make a short stop to examine the distinctive salmon-colored eolianite within the Organ Rock, referred to informally on these field trips as “Elvis”.

Overlying the Organ Rock is the White Rim Sandstone of the Cutler Group. The youngest Permian unit present at any of the sites visited on this field trip is the White Rim Sandstone (and perhaps the De Chelly Sandstone). This formation in probably Leonardian in age, but it does not contain any fossils that would permit precise dating. The unit was primarily deposited in an eolian environment, and is characterized by the presence of large-scale, high-angle cross-stratification and ripple translatent strata (Huntoon, 1985; Huntoon and Chan, 1987). It consists of fine to very fine grained quartzarenitic sandstone, but well-rounded coarse to very coarse grains are common in the upper 1-2 meters of the formation (where the upper part of the formation has not been removed by late Permian or earliest Triassic erosion). First-, second-, and third-order bounding surfaces are all present in the eolian White Rim Sandstone, which, in this area, has been interpreted as an erg margin deposit (Chan, 1989).

At North Wash, the TR-1 unconformity separates the Permian White Rim Sandstone from the Triassic chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation. Although the chert-pebble conglomerate present at North Wash cannot be traced directly into the type locality of the Black Dragon Member of the Moenkopi Formation, correlation between the units is supported by their similarity in lithology, sedimentary structures and stratigraphic position (Ochs, 1988; Ochs and

Chan, 1990). At North Wash, the matrix-supported chert-pebble conglomerate is arranged in a series of stacked channels. The conglomerate within the channels is characterized by the presence of planar-tabular and trough cross-stratification, and pebble imbrication. The lower part of the conglomerate contains channels that lack internal stratification and contain randomly oriented clasts. Lensoid sandstone bodies containing trough cross-stratification are locally capped by mudcracked sandy siltstones.

Clasts within the conglomerate range from 2 mm to 13 cm in size, and are composed of chert, weathered chert, red shale rip-up clasts, sandstone rip-up clasts, and dolomitic rip-up clasts. The matrix of the conglomerate is composed of very-fine to very-coarse grained sandstone. Chert within the conglomerate is probably derived from the Kaibab Limestone (a lateral time equivalent of the eolian White Rim Sandstone that was deposited in a shallow marine shelf environment present to the west of the Canyonlands region during the Permian) (Ochs, 1988; Ochs and Chan, 1990). Sandy material within the conglomerate is interpreted to have been derived from the White Rim Sandstone. The extensive scouring of the top of the White Rim Sandstone apparent at North Wash supports this interpretation.

This conglomerate is interpreted as a braided stream deposit at North Wash (Ochs, 1988; Ochs and Chan, 1990), and paleocurrents measured throughout the area indicate a dominantly east to southeastward transport direction (Huntoon and Baker 1992a,b). Paleocurrent and provenance information obtained from the chert-pebble conglomerate are significant because they indicate that the regional paleoslope dipped to the south or southeast during deposition of the unit. This contrasts with the westward dipping regional paleoslope that controlled sedimentation in the area during the Permian. Huntoon and Baker (1992a,b) suggest that these data indicate that the southern part of the Emery Uplift was active during deposition of the chert-pebble conglomerate.

To the east of North Wash, in the vicinity of the Happy Jack Mine (Stop 3.2), the TR-1 unconformity overlies the Permian Organ Rock Formation. Although the eastern limit of the White Rim Sandstone has been previously described as a pinch-out (Baars, 1962; Baars and Seager, 1970), aerial viewing of cliff faces along White Canyon suggests that its upper surface is actually truncated by the basal Triassic erosional surface (Dubiel et al., 1993; Dolson, J., pers. comm.). This relationship adds support to the hypothesis that southern Utah was affected by a localized tectonic disturbance during the latest Permian or earliest Triassic.

A schematic diagram (Fig. 6) shows the inferred position of the Emery Uplift during deposition of the chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation. Reconnaissance field study indicates that basal Triassic units are absent from the Circle Cliffs region (within the hypothetical position of the uplift). Orientation of streams draining the uplift are based on

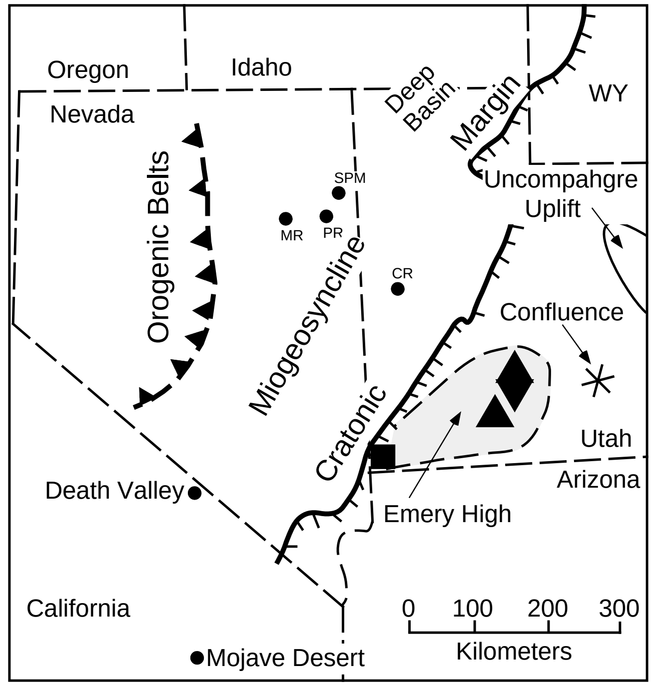

Figure 6. Schematic diagram depicting the local tectonic positive area responsible for shedding clastic material at the base of the Moenkopi Formation to the east in the vicinity of North Wash and White Canyon in southeastern Utah (see Huntoon et al., 1994 for detailed discussion).

paleocurrent data (Ochs, 1988; Ochs and Chan, 1990; Huntoon and Baker, 1992a,b) obtained from the fluvial chert-pebble conglomerate. The evaporite basin in the figure indicates the site of deposition of the Hoskinnini Member, a lateral equivalent of the chert-pebble conglomerate.

Proceed to overlook area at the top of the hill along North Wash.

<u>CORE at Lunch time - White Rim Tar Sands</u>

Heavy hydrocarbons are commonly present within the White Rim Sandstone at several locations in southeastern Utah. The Tar-Sand Triangle area (located just west of the confluence of the Green and Colorado Rivers) contains an estimated 13 x 10^9 bbl of oil (Dana et al., 1984; Kerns, 1984). This is the largest tar-sand deposit in the United States, but much of the oil in place is degraded. The Tar-Sand Triangle is characterized by a feature that is common to many large tar-sand deposits: an unconformity appears to have influenced hydrocarbon migration and entrapment within the formation. Events associated with the generation and burial of the Permian-Triassic or TR-1 unconformity in southeastern Utah resulted in conditions favorable for accumulation of large amounts of hydrocarbons within the White Rim Sandstone. Along most of White Canyon, a fluvial chert-pebble conglomerate (the basal chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation) overlies the TR-1 unconformity. At such locations, the position of the unconformity is easily identified because of the presence of an obvious scoured surface at the base of the chert-pebble conglomerate, and the abrupt change in lithology across the unconformity. In the eastern part of White Canyon, and to the north of White Canyon, however, the fluvial chert-pebble conglomerate is absent, and it is difficult to identify the position of the unconformity. Careful examination of outcrops or analysis of core is necessary to accurately identify the different units that are juxtaposed on each side of the unconformity. For example, the Altex Oil #1 Government core contains the TR-1 unconformity, but its position is not obvious. Huntoon et al. (1994) place the TR-1 unconformity at a depth of 1488 ft. Porosity measurements, and capillary pressure and permeability data indicate an abrupt decrease in pore throat sizes at this boundary (Dolson, J., pers. comm.). Thin section studies (Hansley, P., pers. comm.) indicate that above about 1488 ft. in the Altex core, pyrite is a relatively common cement. Below 1488 ft. nonferroan calcite, ferroan calcite and dolomite cements are dominant. The amount of oil staining apparent in the core changes radically across the 1488 ft. boundary, probably reflecting the differing diagenetic histories of the Permian and Lower Triassic strata. From 1488 ft. to about 1511 ft. the Altex core penetrated the Permian marine veneer of the White Rim Sandstone. This unit is not present at any of the sites visited on this field trip, but it is described in detail by Huntoon and Chan (1987). The lithologic similarity between the marine veneer of the White Rim Sandstone and the Hoskinnini Member that is apparent in the Altex core makes it difficult to locate the boundary between the two units in outcrop (Huntoon et al., 1994). Laboratory analysis of samples is probably necessary to precisely determine the position of the TR-1 unconformity when it separates these two units. Note that the Permian marine veneer of the White Rim Sandstone is, however, heavily saturated with hydrocarbons.

Route: Return down North Wash and east on Hwy. 95 to the Blue Notch Pass Road.

Optional Stop - Blue Notch Canyon - Chinle Fm.

At Blue Notch we can observe the Petrified Forest, Owl Rock, and Church Rock Members in the upper part of the Chinle Formation, and the change upward to the Lower Jurassic Wingate Sandstone. The Owl Rock was deposited in a large lacustrine system, and the Church Rock in lacustrine playas and mudflats, with minor eolian dune development. We suspect that a major climate change evolved at the close of Triassic deposition to allow the Wingate erg to develop. What might have caused this climate change from the wet depositional systems in the Chinle?

Route: Continue east on Hwy. 95 to Happy Jack Mine Road. Proceed up the dirt road on the right to the Permian-Triassic unconformity.

Stop 2.5 - Happy Jack Mine - Chert Cgl. and Hoskinnini Mbr. of Moenkopi Fm.

Relationship between the chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation and the Hoskinnini Member of the Moenkopi: Along the Happy Jack Mine Road and at Indian Head Pass (Optional Stop), the lateral transition from the basal chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation to the Hoskinnini can be observed. To the west of the intersection of the Happy Jack Mine Road and Utah Highway 95, the Black Dragon chert-pebble conglomerate unconformably overlies the Organ Rock Formation and underlies the Torrey Member of the Moenkopi Formation. To the east of the Happy Jack Mine Road - Hwy. 95 intersection, the Hoskinnini occupies the same stratigraphic position. The basal contact of the Hoskinnini truncates the Organ Rock all along the Happy Jack Mine Road; the amount of truncation increases to the east. In contrast, the upper contact of the Hoskinnini is typically gradational, and it parallels bedding in Lower Triassic units throughout the area. Increasing truncation of the Organ Rock results in a rapid eastward thickening of the Hoskinnini. The unconformity at the base of the Hoskinnini is interpreted to be the Permian-Triassic (TR-1) unconformity because paleomagnetic data (Helsley, 1969; Helsley and Steiner, 1974; Helsley, C., pers. comm.) collected along the road to the Bears Ears (near the entrance to Natural Bridges National Monument) places the Hoskinnini within the Triassic System. The Organ Rock Formation is Permian in age. As described earlier, the TR-1 unconformity is also interpreted to lie beneath the Black Dragon chert-pebble conglomerate (Stewart et al, 1972a,b; Blakey, 1974; Ochs, 1988; Ochs and Chan, 1990; Dubiel et al., 1992; Huntoon and Baker, 1992a,b; Huntoon et al., 1994), suggesting that the Hoskinnini and the Black Dragon chert-pebble conglomerate are approximately the same age. Lithologic similarities support the interpretation that the two units are lateral equivalents. For example, both contain chert pebbles and coarse to very coarse well-rounded quartz grains, despite their differing depositional environments. At Happy Jack Mine and Indian Head Pass, it is easy to demonstrate that the Hoskinnini and the Black Dragon chert-pebble conglomerate are lateral equivalents, because one can walk through the transition from one unit to the other. The Hoskinnini is dominantly a siliclastic sabkha deposit (Dubiel et al., 1992) that contains a variety of facies. Near Happy Jack Mine, the Hoskinnini begins with an erosional surface that is overlain by relatively massive chert-pebble conglomerate displaying poorly developed upward-fining. The upper portion of this lower facies often contains megapolygons, which are interpreted to result from the expansive growth of evaporitic minerals (primarily gypsum) and perhaps to dewatering and disruption of strata. The lower facies is overlain by contorted beds that are possibly burrowed, and also contain large dish structures and/or megapolygons (Dubiel et al., 1992). The seemingly paradoxical occurrence of both megapolygons and dish structures can be reconciled if the Hoskinnini is viewed as the product of deposition in a shallow restricted basin that underwent periodic wetting and drying cycles. The uppermost Hoskinnini is a fluvial chert-pebble conglomerate that is identical to the basal chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation. The transition between the Black Dragon chert-pebble conglomerate and the Hoskinnini, and the pronounced eastward thickening of the Hoskinnini are also observable at Indian Head Pass. The easternmost parts of the Black Dragon chert-pebble conglomerate are interpreted as meandering stream deposits because well-developed flood-plain features (mudcracked, even-bedded siltstones to very fine-grained sandstones), and lateral accretion sets within channels are apparent along south-facing cliffs at Indian Head Pass. Presence of chert-pebbles throughout the Hoskinnini, particularly near its upper and lower contacts, indicates that chert was supplied to the Hoskinnini throughout its deposition. The channels that are now filled with Black Dragon chert-pebble conglomerate are interpreted to have been the feeder channels that supplied sediment to the Hoskinnini depositional basin. In addition to its dominant facies, the Hoskinnini also contains large fluid escape features that are interpreted to be the result of isolated springs emitting fluid to the surface from the lower levels of the member while the upper part was being deposited (Dubiel et al., 1992). The giant pipes and slumps observed along the north-facing cliffs of White Canyon, and on the north side of Indian Head pass are interpreted to reflect the activity of these springs. The Hoskinnini's white color at Happy Jack Mine and at Indian Head Pass is interpreted to result from migration of hydrocarbons through the member (Dubiel et al., 1992; Huntoon et al., 1994). A black film of hydrocarbons can be observed on freshly broken samples of several of the facies within the Hoskinnini Member near its western edge. Bleaching decreases to the east in the Hoskinnini. Near its western edge the entire formation is white, then, moving to the east, bleaching is confined to isolated layers. Farther to the east, bleaching is limited to beds within only the top one-half of the formation, and finally the entire formation is red. This observed decrease in bleaching to the east suggests that hydrocarbons migrated into the formation from the west. Because the Black Dragon chert-pebble conglomerate is also bleached, and it commonly contains hydrocarbons, it is interpreted to be the migration conduit. Sequence stratigraphic interpretation of the Lower Triassic rocks in White Canyon place deposition of the Hoskinnini and the Black Dragon chert-pebble conglomerate within a transgressive systems tract (Huntoon et al., 1994). A generally high or rising water table is assumed necessary for deposition of the Hoskinnini sabkha (Dubiel et al., 1992, 1993;). Transgressive systems tract deposition is also suggested by the presence of an erosional boundary at the base of the Hoskinnini (low-stand surface of erosion), the overall upward-fining of the Hoskinnini beneath its uppermost fluvial facies, and the interpreted heightened activity of springs during deposition of the upper portion of the Hoskinnini. The fluvial chert-pebble conglomerate facies at the top of the Hoskinnini initially appears to represent highstand deposition because of its progradational character.

Note the schematic cross-sections across the study area (Fig. 7). a) Northwest to southeast cross-section across the study area. Permian units shown are: the Kaibab Limestone=Pk, the White Rim Sandstone=Pwr, the Organ Rock Formation=Por and the Cutler Formation undifferentiated=Pc. The Triassic units shown are the Moenkopi Formation (Torrey Member=TRmt, Sinbad Member=TRms, Black Dragon Member=TRmbd, chert-pebble conglomerate facies of the Black Dragon Member=TRmbd(cpcgl)), the unnamed chert pebble conglomerate (TRucpcgl) and the Hoskinnini Member (TRh). The TR-1 unconformity is shown and is interpreted as a lowstand surface of erosion (LSE). Portions of the Triassic section are interpreted as transgressive systems tract deposits (TST) and highstand systems tract deposits (HST). (Modified from Huntoon et al., 1994).

Optional Stop - Indian Head Pass - Hoskinnini Mbr. of Moenkopi Fm.

If time permits we may travel to Indian Head Pass to observe the Hoskinnini Member of the Moenkopi Formation. At this location the lateral facies change from the chert-pebble conglomerate facies of the Black Dragon Member of the Moenkopi Formation (present to the west) and the Hoskinnini Member (present to the east) can be observed. The description of the stop at Happy Jack Mine Road applies to this optional stop as well.

Route: Travel east on Hwy. 95 to the fluid escape pipes in the Hoskinnini.

Optional Stop - White Canyon - Hoskinnini sabkha and fluid Escape pipes

We will examine the fluid escape structures in the Hoskinnini (Dubiel et al., 1992). If time permits, we will hike up to the pipes. The Hoskinnini here contains large, cylindrical pipes interpreted as fluid escape structures. Note the facies of the Hoskinnini that contains the pipes. What observations suggest these are fluid escape features? What processes resulted in their formation? Why are there pipes in this red and white interbedded facies of the Hoskinnini?

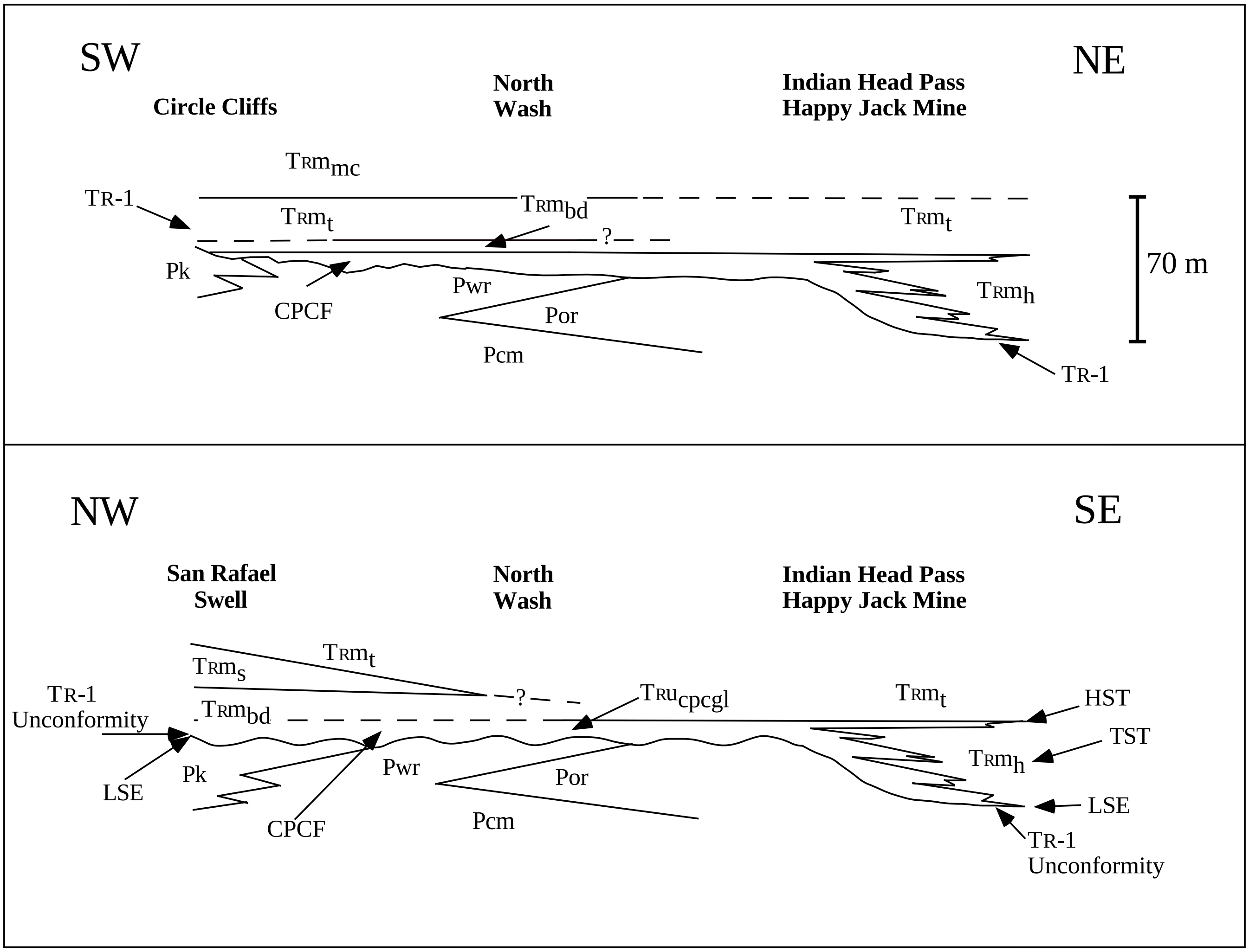

Figure 7. Regional schematic cross section along White Canyon showing relationships at the Permian-Triassic unconformity (from Huntoon et al., 1994)

Route: Travel east along White Canyon on Hwy 95 and past the Fry Canyon Store. Stop and head up the dirt road leading to the Hillside Mine.

<u>Optional Stop - Hillside Mine - upper Chinle Fm.</u>

The Shinarump Member of the Chinle Formation hosts uranium at this locality. The Monitor Butte Member here is overlain by thick fluvial sandstones of the Moss Back Member, the unit we observed at the base of the Chinle along Indian Creek in Canyonlands. Here in White Canyon, the Chinle fills a large valley eroded into the underlying Moenkopi, and several members have filled the paleovalley prior to deposition of the Moss Back. The Moss Back is overlain by the Petrified Forest Member. Note the change in fluvial style between the different fluvial systems. What might have caused the change in fluvial systems?

Return to the Fry Canyon Store, head east on Hwy 95 and turn south at White Canyon Mine Road.

<u>Stop 2.6 - White Canyon Mine - Permian/Triassic unconformity</u>

On the way up to the White Canyon Mine, note that there is no White Rim Sandstone present, and that the Moenkopi Formation lies directly on the Organ Rock Member of the Cutler Formation. How can you recognize the Permian/Triassic unconformity within this red-bed sequence? Is there a difference in bedding or lithology across the contact? The contact is picked by the appearance of coarse quartz grains in the Hoskinnini that were derived from underlying eolian strata.

<u>Optional Stop - White Canyon Mine - lower Chinle Fm.</u>

In the Chinle Formation, we will examine fluvial sandstones and conglomerates of the Shinarump Member at the base of the section that host uranium mineralization. Black shales and green sandstones and siltstones of the overlying Monitor Butte Member aided in localizing the uranium deposits. The Monitor Butte Member contains abundant plant fossils that indicate wet conditions and high water tables to preserve organic material. The fluvial and floodplain deposits of the Chinle, and in particular their colors contrast markedly with the red beds in the underlying Moenkopi Formation. What factors were responsible for the change in depositional regime and in the colors of the rocks?

Route: Proceed back down to Hwy 95 and head east on Hwy. 95 and then south on Hwy. 261 toward Mexican Hat. Next stop is at the top of the Moki Dugway, pullout on the right.

Optional Stop - Moki Dugway - Cedar Mesa Sandstone; Raplee anticline overlook

The view from the top of the Moki Dugway shows large-scale tectonic and stratigraphic relations. The large tectonic structure in the distance is the Raplee Anticline, which brings to the surface Pennsylvanian and lower Permian strata. At the top of the Moki Dugway the Cedar Mesa Sandstone is exposed. This stop prompts discussion of the conspicuous horizontal bounding surfaces separating eolian strata near the downwind margin of the Cedar Mesa erg. Note the fore-erg sand sheet and dune deposits. Mudcracks and bioturbation are present in the strata along the bounding surfaces. Contrast the erg margin deposits here with the erg center of the Cedar Mesa deposits that we will see next at Lake Powell.

Stop 2.7 - Moki Dugway - Cedar Mesa Sandstone eolianites and regional surfaces

In the middle of the Moki Dugway, one can see regionally extensive, essentially flat surfaces within the Cedar Mesa Sandstone. Interdune deposits are locally associated with the surfaces. What mechanisms formed these regional surfaces?

Proceed to the bottom of the Moki Dugway.

Optional Stop - Moki Dugway - Halgaito Member of Cutler Group

This stop is at the base of the road cut up through the Cedar Mesa Sandstone. The Halgaito Member of the Cutler is exposed here as medium-bedded sandstones and shales. The units represent loessites and floodplain deposits with paleosols similar to those seen in the Halgaito at Lime Creek (Murphy, 1987). The paleosols contain carbonate nodules and locally abundant root trace fossils.

Route: Continue south on Hwy. 261 to Hwy. 163. Turn south on Hwy. 163 toward Mexican Hat.

Spend night at San Juan Inn (801-683-2220), Mexican Hat, Utah. **Rooms already booked**.

Day 3. Saturday, October 26, 8:00 a.m. Leave Mexican Hat.

Route: Continue west on Hwy. 163, turn right to Gouldings Trading Post and left up the “Gap” to Gouldings KOA.

Optional Stop - Gouldings - De Chelly Sandstone pinchout

If time allows, we will drive north of Gouldings to observe the “pinch out” of the DeChelly. The DeChelly is actually “cut out” below the Hoskinnini by erosion at the Permian-Triassic unconformity. This relation parallels that of the eolian White Rim Sandstone, which we saw yesterday on the west side of the Monument upwarp. The relations indicate that the Monument upwarp was tectonically active and controlled erosion and/or eustatic sea level adjacent to the uplift that affected development of the Permian-Triassic unconformity.

Stop 3.1 - Gouldings Campground- Organ Rock/De Chelly Sandstone transition

We will examine the transition from the upper part of the Organ Rock fluvial and eolian deposition to the eolian erg deposits of the DeChelly Sandstone along a well established foot trail behind the campground that heads past the school. The Organ Rock here contains sandstones and shales with rain drop imprints and adhesion ripple marks. What is the environment of deposition? Note the transition upward toward the DeChelly Sandstone with its steep cliffs. The upper part of the Organ Rock contains thicker and more abundant eolian sand sheet and small dune deposits. The De Chelly Sandstone contains abundant large-scale cross bedding, ripple translatent strata, and avalanche deposits that are characteristic of eolian deposition. The De Chelly represents an eolian deposit on the eastern flank of the Monument Upwarp. Both the De Chelly and the White Rim are eolian units are cut out on opposite flanks of the Monument Upwarp as a result of being eroded below the Permian-Triassic unconformity.

Stop 3.2 - Gouldings - De Chelly Sandstone; P-Tr unconformity; Hoskinnini Mbr.

Hike a short distance around the foot trail, through the notch, past the school, and into a natural amphitheater that exposes the upper part and upper contact of the De Chelly Sandstone. Hike up through the De Chelly, noting the eolian sedimentary structures and the grain size. Where is the upper contact of the De Chelly Sandstone? On what criteria do you base this contact? The overlying unit is the Hoskinnini Member of the Lower Triassic Moenkopi Formation. What sedimentary structures and grain size are in the Hoskinnini? What is the source of the coarse sans grains? The unconformity is a flat surface that probably represents erosion to water table or sea level (Dubiel et al., 1993).

Route: Retrace route back to Monument Pass.

Stop 3.3 - Monument Valley - Permian Organ Rock Formation of Cutler Group.

This is a moving stop. Note the world-famous monuments made famous in cigarette and car commercials and John Wayne western movies. The mesas in Monument Valley are composed of Organ Rock, DeChelly Sandstone, in places thin Moenkopi Formation, and they are capped by the Shinarump Member of the Chinle Formation The Moenkopi Formation present here is very thin or absent below the Shinarump Member of the Chinle, implying structural uplift and erosion or nondeposition on the Monument upwarp prior to Chinle deposition.

Continue east and stop at Monument Pass.

Stop 3.4 - Monument Pass - Permian Organ Rock Formation of Cutler Group.

This section exposes the Organ Rock Formation, which here overlies the evaporite facies of the Cedar Mesa Sandstone. The Organ Rock also has an upward transition to eolian erg deposits of the DeChelly Sandstone. We will start at the base of the Organ Rock and examine the contact with the underlying Cedar Mesa, along with the basal fluvial and floodplain strata within the Organ Rock. Note the stacked fluvial channel sandstones of moderately sinuous streams with lateral accretion surfaces and the lateral gradation into levee and floodplain deposits. Floodplain deposits contain rhizoliths and pedogenic carbonate nodules. There is a gradual transition to eolian deposition near the top of the Organ Rock Shale (Dubiel et al., 1993).

What do the facies and paleosols imply about climate during Organ Rock deposition?

Route: Continue east on Hwy. 163 to exposures of the Halgaito Formation Loess deposits.

Stop 3.5 - Lime Creek Paleosols - Halgaito Formation of the Cutler Group

At this stop we will examine exposures of the Halgaito , the unit below the Cedar Mesa Sandstone in the Cutler. The Halgaito is composed of red siltstones that are interpreted as loess deposited downwind of coastal dunes in the lower Cutler Formation (Murphy, 1987). Note the paleosols characterized by rhizoliths and pedogenic carbonate nodules. Possible adhesion structures and desiccation cracks were formed in damp loess strata. What does these facies imply about the Permian depositional system and climate? How do they compare to the climatic implications of the Cedar Mesa Sandstone?

Continue northeast on Hwy. 163, toward Blanding.

Stop 3.6 - Comb Ridge - Cedar Mesa facies change

This stop reveals a very abrupt facies change from eolian strata in the erg of the Cedar Mesa Sandstone exposed to the north at the Moki Dugway cliffs into sabkha deposits here. We examined the eolian facies yesterday. Note here the interbedded sandstone, gypsum, limestone, and shale. There may have been structural control of the sabkha facies along the margin of the Monument Upwarp. We will discuss coastal versus inland sabkha interpretations.

Proceed east on Hwy 163.

Optional Stop - Comb Ridge - Upper Triassic Chinle Fm.; Glen Canyon Group

Comb Ridge is a north-trending monocline, probably formed by draping of rocks over a reactivated basement fault. The strike valley is eroded in sandstones and shales of the Upper Triassic Chinle Formation. The upper unit in the Chinle, the Owl Rock Member, contains lacustrine beds, and the overlying Church Rock Member contains an eolian deposit similar in lithology and structures to the overlying erg deposits of the Lower Jurassic Wingate Sandstone. The Wingate is overlain by the Kayenta Formation and the Navajo Sandstone. Below the Chinle is the Moenkopi Formation and the Permian section.

Continue east on Hwy. 163 to Bluff, Utah and then head north on Hwy. 191 to Blanding, Utah.

Spend night at Four Corners Inn Motel (801-678-3257), Blanding, Utah. **Rooms already booked.**

Day 4: Sunday, October 27, 8:00 a.m. Leave Blanding.

Proceed north out of Blanding on Hwy 191. At Hwy. 128 head east on the Cisco Road. At I-70 junction head east and return to Denver.

REFERENCES

Baars, D.L., 1962, Permian System of the Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 46, p. 149-218.

Baars, D.L., 1983, The geology in and near Canyonlands and Arches National Parks, Utah, *in* Gurgel, K.D., ed., Geologic excursions in Stratigraphy and Tectonics: From southeastern Idaho to the Southern Inyo Mountains, California, via Canyonlands and Arches National Parks, Utah: Utah Geological and Mineral Survey Special Studies 60, GSA Rocky Mountain and Cordilleran Sections Meeting Fieldtrip Guidebook Part II, p. 75-92.

Baars, D.L., 1987, The Elephant Canyon Formation revisited, *in* Campbell, J.A., ed., Geology of Cataract Canyon and vicinity: Four Corners

Geological Society Field Conference, 10th, Guidebook, p. 81-90.

Baars, D.L., and Seager, W.R., 1970, Stratigraphic control of petroleum in White Rim Sandstone (Permian) in and near Canyonlands National Park, Utah: American Association of Petroleum Geologists Bulletin, v. 54, p. 709-718.

Baars, D.L., and Stevenson, G.M., 1981, Tectonic evolution of the Paradox Basin, Utah and Colorado, *in* Wiegand, D.L., ed., 1981, Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference Guidebook, p. 23-31.

Bazard, D.R., and R.F., Butler 1991, Paleomagnetism of the Chinle and Kayenta Formations, New Mexico and Arizona: Journal of Geophysical Research, v. 96, p. 9847-9871.

Blakey, R.C., 1974, Stratigraphic and depositional analysis of the Moenkopi Formation, southeastern Utah: Utah Geological and Mineral Survey Bulletin 194, p. 1-85.

Blakey, R.C., 1996, Permian eolian deposits, sequences, and sequence boundaries, Colorado Plateau, *in* Longman, M.W., and Sonnenfeld, M.D., eds., Paleozoic Systems of the Rocky Mountain Region, Rocky Mountain Section-SEPM (Society for Sedimentary Geology), p.405-426.

Blakey, R. C. and Gubitosa, Richard, 1983, Late Triassic paleogeography and depositional history of the Chinle Formation, southern Utah and northern Arizona, *in* Reynolds, M.W., and Dolly, E.D., Mesozoic Paleogeography of West Central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Paleogeography Symposium 2, p. 57-76.

Blakey, R.C., Basham, E.L., and Cook, M.J., 1993, Early and Middle Triassic paleogeography, Colorado Plateau and vicinity, *in* Morales, M., ed., Triassic Symposium, Museum of Northern Arizona Bulletin, p. 13-26.

Campbell, J.A., 1979, Lower Permian depositional system, northern Uncompahgre basin, *in* Baars, D.L., ed., Permianland: Four Corners Geological Society Field Conference, 9th, Guidebook, p. 13-21.

Campbell, J.A., 1980, Lower Permian depositional systems and Wolfcampian paleogeography, Uncompahgre basin, eastern Utah and southwestern Colorado, *in* Fouch, T.D., and Magathan, E.R., eds., Paleozoic paleogeography of west-central United States: Rocky Mountain Section, Society of Economic Mineralogists and Paleontologists, Rocky Mountain Paleogeography Symposium 1, p. 327-340.

Campbell, J.A., and Steele-Mallory, B.A., 1979a, Uranium in the Cutler Formation, Lisbon Valley, Utah, *in* Baars, D.L., ed., Permianland: Four Corners Geological Society Field Conference, 9th, Guidebook, p. 23-32.

Campbell, J.A., and Steele-Mallory, B.A., 1979b, Depositional environments of the uranium-bearing Cutler Formation, Lisbon Valley, Utah: U.S. Geological Survey Open-File Report 79-994, 39 p.

Chan, M.A., 1989, Erg margin of the Permian White Rim Sandstone, SE Utah: Sedimentology, v. 36, n. 2, p. 235-250.

Condon, S.M., in press, Geology of the Pennsylvanian and Permian Cutler Group and Permian Kaibab Limestone in the Paradox Basin, southeastern Utah and southwestern Colorado: U.S. Geological Survey Bulletin, 60 p.

Dana, G.F., Oliver, R.L., and Elliott, J.R., 1984, Geology and resources of the tar sand triangle, southeastern Utah: Laramie, WY, United States Department of Energy, 50 p.

Dickinson, W.R., 1981, Plate tectonic evolution of the southern Cordillera, *in* Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 113-135.

Dubiel, R.F., 1987a, Sedimentology of the Upper Triassic Chinle Formation, southeastern Utah: Ph.D. Dissertation, University of Colorado at Boulder, 132 p.

Dubiel, R. F., 1987b, Sedimentology and new fossil occurrences of the Upper Triassic Chinle Formation, southeastern Utah, *in* Campbell, J.A., ed., Geology of Cataract Canyon and vicinity: Four Corners Geological Society, Tenth Field Conference Guidebook, p. 99-107.

Dubiel, R.F., 1987c, Sedimentology of the Upper Triassic Chinle Formation, southeastern Utah - Paleoclimatic implications, *in* Morales, M., and Elliott, D.K., eds., Triassic continental deposits of the American Southwest: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 35-45.

Dubiel, R.F., 1989a, Sedimentology and revised nomenclature of the Upper Triassic Chinle Formation and the Lower Jurassic Wingate Sandstone, northwestern New Mexico and northeastern Arizona, *in* Anderson, O.J., Lucas, S.G., Love, D.W., and Cather, S. M., eds., Southeastern Colorado Plateau: New Mexico Geological Society, 40th Field Conference Guidebook, p. 213-223.

Dubiel, R.F., 1989b, Depositional and climatic setting of the Upper Triassic Chinle Formation, Colorado Plateau, *in* Lucas, S.G., and Hunt, A.P., eds., Dawn of the age of dinosaurs in the American Southwest: New Mexico Museum of Natural History, 1989 Spring Field Conference Guidebook, p. 171-187.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the Western Interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section - SEPM, p. 133-168.

Dubiel, R. F. , R.H. Blodgett, and T.M. Bown, 1987, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau: Journal of Sedimentary Petrology, v. 57, p. 512-521.

Dubiel, R. F. , R.H. Blodgett, and T.M. Bown, 1988, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau: Comments on the recognition criteria of fossil lungfish burrows: Reply: Journal of Sedimentary Petrology, v. 58, p. 367-369.

Dubiel, R. F., Blodgett, R. H., and Bown, T. M., 1989, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau: New evidence suggests origin by a burrowing decapod crustacean: Reply: Journal of Sedimentary Petrology, v. 59, p. 876-878.

Dubiel, R.F., Huntoon, J.E., Condon, S.M., and Stanesco, J.D., 1996, Permian deposystems, paleogeography, and paleoclimate of the Paradox Basin and vicinity, *in* Longman, M.W., and Sonnenfeld, M.D., eds., Paleozoic Systems of the Rocky Mountain Region, Rocky Mountain Section-SEPM (Society for Sedimentary Geology), p.427-444.

Dubiel, R.F., Stanesco, J.D., and Brown, J.B., 1993. Permian-Triassic stratigraphy, unconformities, and depositional facies in the Paradox Basin: U.S. Geological Survey Circular, Paradox Basin Symposium, 2 p.

Dubiel, R.F., Stanesco, J.D., and Huntoon, J.E., 1992, Clastic sabkha facies and paleogroundwater flow in the Hoskinnini Member of the Moenkopi Formation (Triassic, Paradox Basin) - Implications for hydrocarbon emplacement: SEPM - Rocky Mountain Section Newsletter, v. 17, no. 8, p. 2.

Dubiel, R.F., Parrish, J.T., Parrish, J.M., and Good, S.C., 1991, The Pangaean megamonsoon - Evidence from the Upper Triassic Chinle Formation, Colorado Plateau: Palaios, v. 6, p. 347-370.

Gordon, W.A., 1975, Distribution by latitude of Phanerozoic evaporite deposits: Journal of geology, v. 83, p. 671-684.

Goydas, M.J., 1989, Stratigraphy, structure, and holokinetic history of Fisher Valley quadrangle, Grand County, Utah: Manhattan, Kansas State University, M. S. Thesis, 190 p.

Hasiotis, S.T., and Mitchell, C.E., 1989, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau: New evidence suggests origin by a burrowing decapod crustacean: Discussion: Journal of Sedimentary Petrology, v. 59, p. 871-875.

Hasiotis, S.T., Mitchell, C.E., and Dubiel, R.F., 1993, Application of burrow morphologic interpretations: Permian and Holocene lungfish burrow morphologies and their comparison to Upper Triassic Chinle Formation burrow localities in western Colorado: Ichnos - An International Journal for Plant and Animal Traces, v. 2, p. 315-333.

Hazel, J.E., Jr., 1994, Sedimentary response to intrabasinal salt tectonism in the Upper Triassic Chinle Formation, Paradox Basin, Utah: U.S. Geological Survey Bulletin 2000-4, 34 p.

Helsley, C.E., 1969, Magnetic reversal stratigraphy of the Lower Triassic Moenkopi Formation of western Colorado: Geological Society of America Bulletin, v. 80, p. 2431-2450.

Helsley, C.E., and Steiner, M.B., 1974, Paleomagnetism of the Lower Triassic Moenkopi Formation: Geological Society of America Bulletin, v. 85, p. 457-464.

Hintze, L.F., 1988, Geologic history of Utah: Brigham Young University Geology Studies, Special Publication 7, 202 p.

Hite, R.J., 1968, Salt deposits of the Paradox Basin, southeast Utah and southwest Colorado, in Saline deposits: GSA Special Paper 88, p. 319-330.

Hite, R.J., Cater, F.., and Liming, J.A., 1972, Pennsylvanian rocks and salt anticlines, Paradox Basin, Utah, *in* Mallory, W.W., ed., Geologic atlas of the Rocky Mountain region: Denver, Rocky Mountain Association of Geologists, p. 133-138.

Huntoon, J.E., 1985, Deposition environments and paleotopographic relief of the White Rim Sandstone (Permian) in the Elaterite basin, Canyonlands National Park and Glen Canyon National Recreation Area: Salt Lake City, unpublished M.S. thesis, University of Utah, 143 p.

Huntoon, J.E., and Baker, S.P., 1992a, Stratigraphic relations among Lower Triassic (?) units: South-central Utah (abs.): Presented at the 1992 Society of Economic Paleontologists and Mineralogists Mesozoic of the Western Interior Theme Meeting, Ft. Collins, CO.

Huntoon, J.E., and Baker, S.P., 1992b, Stratigraphic relations among Lower Triassic units in south-central Utah: Evidence of tectonic activity at the Permian-Triassic boundary (abs.): Presented at the Workshop on the Pennsylvanian and Permian Sediments of the Paradox Basin, U.S.G.S. Core Repository, Denver, CO.

Huntoon, J.E., and Chan, M.A., 1987, Marine origin of paleotopographic relief on the eolian White Rim Sandstone (Permian), Elaterite Basin, Utah: American Associaton of Petroleum Geologists Bulletin, v 71, p. 1035-1045.

Huntoon, J.E., Dolson, J. and Henry, B., 1994, Seals and migration pathways in paleogeomorphologically trapped petroleum occurrences: Permian White Rim Sandstone, Tar Sand Triangle Area, southeastern Utah, in J.C. Dolson, M. Hendricks, K. Shanley, and B. Wescott, eds., Unconformity related hydrocarbon accumulation and exploitation in clastic and carbonate settings: Rocky Mountain Association of Geologists 1993 Field Conference Guidebook, p. 99-118.

Huntoon, J.E., Dubiel, R.F., and Stanesco, J.D., 1994, Tectonic influence on the development of the Permian-Triassic unconformity and basal Triassic strata, Paradox Basin, southeastern Utah, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic Systems of the Rocky Mountain Region, USA: Rocky Mountain Section - SEPM, p. 109-130.

Kerns, R., 1984, Utah tar sands: Utah Geological and Mineral Survey Notes, v. 17, p. 1-9.

Loope, D.B., Sanderson, G.A., and Verville, G.J., 1990, Abandonment of the name “Elephant Canyon Formation” in southeastern Utah - Physical and temporal implications: The Mountain Geologist, v. 27, p. 119-130.

McKee, E.D., Oriel, S.S., et al., 1967, Paleotectonic investigations of the Permian System in the United States: U.S. Geological Survey Professional Paper 515, 271 p.

Molenaar, C.M., 1975, Stratigraphic correlation chart for Canyonlands country, *in* Fasset, J.E., and Wengred, S.A., eds., Canyonlands Country: Four Corners Geological Society, Eighth Field Conference Guidebook, p. 4.

Murphy, K., 1987, Eolian origin of Late Paleozoic red siltstones, Mexican Hat, Utah: unpublished M.S. Thesis, University of Nebraska, Lincoln, Nebraska, 128 p.

Ochs, S., 1988, Stratigraphy, depositional environments, and petrology of the lowermost Moenkopi Formation, southeastern Utah: Salt Lake City, unpublished M.S. thesis, University of Utah, 202 p.

Ochs, S., and Chan, M.A., 1990, Petrology, sedimentology and stratigraphic implications of Black Dragon Member of the Triassic Moenkopi Formation, San Rafael Swell, Utah: The Mountain Geologist, v. 27, p. 1-18.

Parrish, J.T., 1985, Latitudinal distribution of land and shelf and absorbed radiation during the Phanerozoic: U.S. Geological Survey, Open-File Report 85-31, 21 p.

Parrish, J.M., J.T. Parrish, and A.M. Ziegler, 1986, Permian-Triassic paleogeography and paleoclimatology and implications for therapsid distributions, *in* N.H. Hotton, III, P.D. MacLean, J.J. Roth, and E.C. Roth, The biology and ecology of mammal-like reptiles. Smithsonian Press, Washington, D. C., p. 109-132.

Parrish, J.T., and Fred Peterson, 1988, Wind directions predicted from global circulation models and wind directions determined from eolian sandstones of the western United States-a comparison: Sedimentary Geology, v. 56, p. 261-282.

Peterson, Fred, 1988, Pennsylvanian to Jurassic eolian transportation systems in the western United States: Sedimentary Geology, v. 56, p. 207-260.

Poole, F.G., 1962, Wind directions in Late Paleozoic to Middle Mesozoic time on the Colorado Plateau: U.S. Geological Survey Professional Paper 450-D p. 147-151.

Robinson, P.L., 1973, Paleoclimatology and continental drift, *in* D.H. Tarling and S.K. Runcorn, eds., Implications of continental drift to the earth sciences, I.: London, Academic Press, p. 449-476.

Stanesco, J.D., and Campbell, J.A., 1989, Eolian and noneolian facies of the Lower Permian Cedar Mesa Sandstone Member of the Cutler Formation, Southeastern Utah: U.S. Geological Survey Bulletin 1808-F, 13 p.

Stevenson, G.M., and Baars, D.L., 1987, The Paradox - A pull-apart basin of Pennsylvanian age, *in* Campbell, J.A., ed., Cataract Canyon and vicinity: Four Corners Geological Society, 10th Field Conference Guidebook, p. 31-50.

Stewart, J.H., Poole, F.G., and Wilson, R.W., 1972a, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, 195 p.

Stewart, J.H., Poole, F.G., and Wilson, R.W., 1972b, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

Szabo, Ernest, and Wengerd, S.A., 1975, Stratigraphy and tectogenesis of the Paradox basin, *in* Fassett, J.E., ed., Canyonlands Country: Four Corners Geological Society Field Conference, 8th, Guidebook, p. 193-210.

Tewes, D.W. and Loope, D.B., 1991, Paleo-yardangs: wind-scoured desert landforms at a Permian unconformity: Sedimentology, v. 39, p. 251-261.

Turner, P., 1980, Continental red beds: Developments in Sedimentology 29, Amsterdam, Elsevier, 562 p.

Vail, P.R., Mitchum, R.M., Jr., and Thompson, S., III., 1977, Global cycles of relative sea level change: Seismic stratigraphy—applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 26, p. 83-97.

Valentine, J.W., and Moores, E.M., 1970, Plate-tectonic regulation of faunal diversity and sea level: a model: Nature, v. 228, p. 657-659.

Wengred, S.A., and M.L. Matheny, , 1958, Pennsylvanian system of the Four Corners region, Colorado and Utah: AAPG Bulletin, v. 38, p. 2157-2199.

Wier, G.W., and Puffett, W.P., 1981, Incomplete manuscript on the stratigraphy, structural geology, and uranium-vanadium and copper deposits of the Lisbon Valley area, Utah and Colorado: U.S. Geological Survey Open-File Report 81-39, 296 p.

Ziegler, A.M., Scotese, C.R., and Barrett, S.F., 1983, Mesozoic and Cenozoic paleogeographic maps, *in* Brosche, P., and Sundermann, J., eds., Tidal friction and the earth’s rotation, II.: Berlin, Springer-Verlag, p. 240-252.

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