UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# STRATIGRAPHIC AND SEDIMENTOLOGIC STUDIES OF THE UPPER TRIASSIC CHINLE FORMATION, WESTERN COLORADO

by

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## ABSTRACT

The Upper Triassic Chinle Formation is exposed around the Eagle basin, the Aspen sub-basin, and the White River uplift in western Colorado. Ten measured stratigraphic sections of the Chinle Formation depict a series of continental depositional environments, including fluvial, floodplain, lacustrine, and eolian sand sheet environments. Floodplain strata were pedogenically modified and contain plant-root trace fossils, or rhizoliths. The Chinle was deposited to the west and northwest from source areas in the Ancestral Rocky Mountain and the Ancestral Uncompaghre uplfits. In western Colorado, the Late Triassic climate was tropical monsoonal, with alternating wet and dry seasons.

## INTRODUCTION

In western Colorado, the Upper Triassic Chinle Formation is exposed in discontinuous outcrops around the Eagle basin, the Aspen sub-basin, and the White River uplift (Fig. 1). The Chinle Formation is composed of siliciclastic and limestone-pebble conglomerate, fine- to very fine grained sandstone, siltstone, and mudstone that were deposited in a continental setting within fluvial, floodplain, and lacustrine environments. Floodplain strata exhibit evidence of pedogenic modification, and contain several types of vertebrate and invertebrate ichnofossils and plant-root trace fossils, or rhizoliths.

The Uinta-Piceance Basin Project of the Evolution of Sedimentary Basins Program is designed to investigate the depositional and structural history of the Uinta-Piceance Basin (UPB). The present study was initiated to examine Upper Triassic rocks in the UPB. Upper Triassic rocks are exposed in four widely separated areas within the study region encompased by the UPB project: 1) western Colorado in the vicinity of the Eagle basin and the White River uplift, 2) northwestern Colorado and northeastern Utah in the vicinity of Dinosaur National Monument and the Uinta Mountains, 3) west-central Colorado and east-central Utah near the town of Moab, Utah, and 4) central Utah around the San Rafael Swell. This report presents the results of stratigraphic and sedimentologic research during June, 1987 that concentrated on the Chinle Formation around the Eagle basin and the White River uplift in western Colorado. The data are presented as columnar measured stratigraphic sections, and interpretations and conclusions related to depositional environments, paleogeography, and paleoclimatology are summarized.

Few publications have dealt specifically with the Chinle Formation in western Colorado. Stewart and others (1972) provided correlations and interpretations of the Chinle Formation and related Triassic strata throughout the Colorado Plateau, including western Colorado, and also comprehensively summarized previous work. Shropshire (1974) studied the stratigraphy of the Chinle and Jelm Formations of north-central Colorado, including the area of the present study. Outcrops of the Upper Triassic Dolores Formation in southwestern Colorado, which is correlative to the Chinle Formation, were examined by Blodgett (1984, 1988). Dubiel and others (1987c, 1988) described lungfish burrows from the Chinle and Dolores Formations, including localities encompassed by the present study. Several reports have dealt with fossils (Schaeffer, 1967; Elliot, 1983, 1987) and sedimentology and paleoecology of limited Chinle outcrops near Bedrock, in extreme western Colorado.

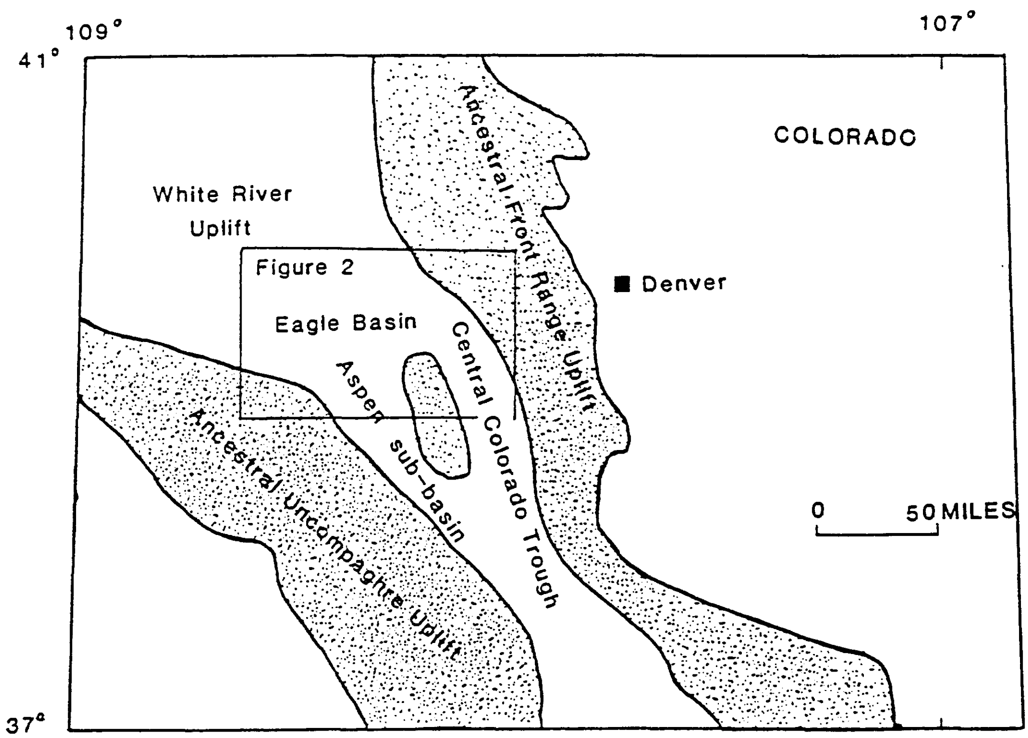


Figure 1. Map showing location of the study area and some geologic features in Colorado (modified from Johnson, 1987).

## STRATIGRAPHY

In the study area of this report, the Upper Triassic Chinle Formation unconformably overlies the Pennsylvanian-Permian Maroon Formation, the Permian Schoolhouse Tongue of the Weber Sandstone, or the Permian and Triassic State Bridge Formation (Stewart and others, 1972; Johnson, 1987). The Chinle Formation crops out within the Eagle basin, the Aspen sub-basin, and around the margins of the White River uplift (Tweto and others, 1978). Continental deposits of the Chinle Formation were shed westward from the ancestral Front Range and north and northeast from the ancestral Uncompaghre uplift into the northwest-trending Central Colorado trough (Stewart and others, 1972; Shropshire, 1974), which had persisted from the early Pennsylvanian and Permian (DeVoto, 1972).

The Pennsylvanian and Permian Maroon Formation forms the base of a thick sequence of red beds in western Colorado. The Maroon Formation is predominantly nonmarine red beds that range in thickness from about 1000 ft to 15,000 ft (Freeman and Bryant, 1977; Johnson, 1987). The nonmarine Schoolhouse Tongue of the Weber Sandstone is currently being renamed and can be considered as the oil-stained, upper portion of the Maroon Formation depositional system (Johnson, 1987; Johnson and others, in press; S.Y. Johnson, oral commun., 1988) The Schoolhouse Tongue ranges in thickness from 0 to about 215 to 230 ft. The Schoolhouse Tongue is overlain by the Permian and Triassic State Bridge Formation. The Fryingpan Member of the Maroon Formation is a yellowish-orange sandstone of eolian origin that locally forms the base of the State Bridge Formation (Freeman, 1971; Johnson, in press). Freeman (1971) also recognized the Sloan Peak Member of the State Bridge Formation, and an informal unit he called the coarse unit of Toner Creek of the State Bridge Formation. The State Bridge Formation ranges from 0 to about 2,400 ft in thickness and is not present at every locality because of erosion and removal beneath the Chinle Formation.

Correlations of the Chinle Formation in Colorado with the Chinle Formation in Arizona, Utah, and New Mexico, and with the Upper Triassic Dolores Formation of southwestern Colorado are uncertain because of large distances between outcrops and the lack of physical or biostratigraphic markers. In the study area, the Chinle Formation unconformably overlies the State Bridge Formation or the Maroon Formation. This study did not find or recognize in the upper part of the State Bridge Formation a unit termed the coarse unit at Toner Creek by Freeman (1971). Within the study area, the Chinle Formation is everywhere unconformably overlain by the Jurassic Entrada Sandstone.

In western Colorado, the Chinle Formation has been defined by Poole and Stewart (1964) and by Stewart and others (1972) to consist, in ascending order, of the Gartra Member, the mottled member, and the red siltstone member. Shropshire (1974) divided the Chinle Formation in western Colorado into two informal units, considering the Gartra Member and the mottled member as a single unit referred to as the lower member and the remaining Chinle as the upper member. Stratigraphic studies of this report recognized the Gartra Member, the mottled member, and the red siltstone member of Stewart and others (1972), but the results of the present study also agree with Shropshire's (1974) contention that the mottled member interfingers with and can be included as an integral part of the Gartra Member. Sedimentologic interpretations presented later in this report demonstrate between these three depositional units a gradational and interfingered contact that accounts for the differences in lithology and texture.

The Chinle Formation crops out within the Eagle basin and the Aspen sub-basin and on the margins of the White River uplift in western Colorado (Fig. 1). Complete sections of the Chinle were measured at ten localities within the study area (Fig. 2). The locations of the stratigraphic sections were chosen for geographic distribution and for quality of exposure. Despite the Chinle Formation being a dominantly fine-grained unit that weathers to slopes in many places, adequate cliff-forming exposures permit regional examination and interpretation of the sedimentology of the strata.

## Edwards West

A 308-ft-thick section (Fig. 3) of the Chinle Formation was measured along the Eagle River on State Highway 6 east of the town of Eagle, CO. (Fig. 2). The section is on north-facing slopes on the south side of the Eagle River 1/2 mi (mile) east of the Interstate Highway 70 overpass. Beds of the Chinle strike N32°E and dip 21° N58°W. The Gartra Member of the Chinle unconformably overlies the State Bridge Formation. The Chinle Formation is unconformably overlain by the Entrada Sandstone. Sedimentary structures and bedding are locally covered and poorly exposed where siltstones comprise the section, but even at these points the beds may be traced and observed laterally.

## East Brush Creek

A 1020-ft-thick section of the Chinle Formation (Fig. 4) was measured along East Brush Creek south of Eagle, CO. The section is on south-facing slopes in a natural amphitheatre above an ephemeral stream that intersects the dirt road along East Brush Creek 0.6 mi east of the intersection of the road south from Eagle to Sylvan Lake. Beds of the Chinle Formation strike N60°W and dip 20° N30°E. The Gartra Member of the Chinle Formation rests unconformably on a pale-red, fine-grained sandstone that exhibits large-scale, low-angle trough cross-stratification. This unit appears to be eolian and may be the Sloan Peak Member of the State Bridge Formation of Freeman (1971). The Chinle Formation is unconformably overlain by the Entrada Sandstone. The Chinle at this locality is fairly well exposed in the bottom of the stream channel for the first few hundred feet, and then is very well exposed, although quite steep, in the natural amphitheatre above.

## State Bridge

A 108-ft-thick section of the Chinle Formation (Fig. 5) was measured along the ridgeline about 1/4 mi north of the State Bridge Lodge. The lodge is located just east of the bridge over the Colorado River along the dirt road leading along the Colorado River from State Highway 131 to Kremmling, Colorado. Beds in the Chinle Formation strike N40°E and dip 40° S50°E. The Gartra Member of the Chinle Formation rests unconformably on reddish-brown siltstones and sandstones of the State Bridge Formation. The Chinle Formation is unconformably overlain by the Entrada Sandstone. The Chinle is well exposed, but many siltstone and very fine grained sandstone beds are weathered into smooth slopes and sedimentary structures are difficult to discern.

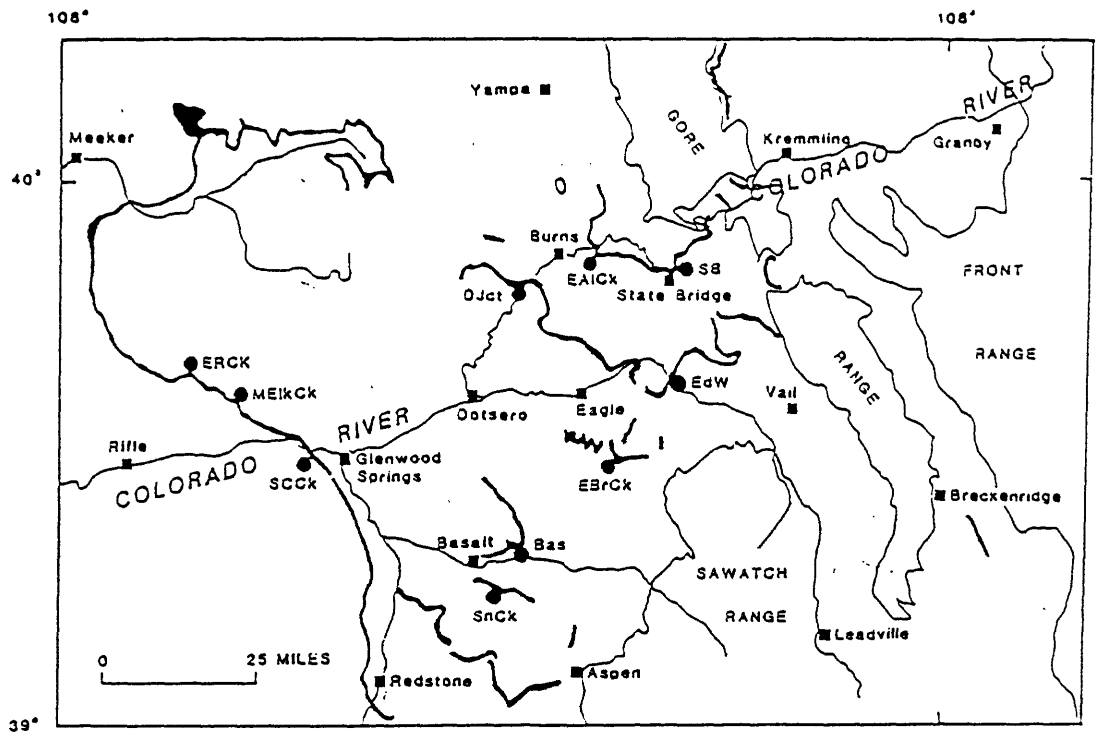


Figure 2. Map of the study area showing location of measured sections outcrops of the Chinle Formation (heavy black lines), and geographic features (modified from Shropshire, 1974). Dots show location of measured sections displayed in figues 3-12; EdW - Edwards West; EBrCk - East Bush Creek; SB - State Bridge; EAlCk - East Alkalai Creek; DJct - Derby Junction; SCCk - South Canyon Creek; SnCk - Snowmass Creek; MElkCk - Main Elk Creek; ERCK - East Rifle Creek; Bas - Basalt.

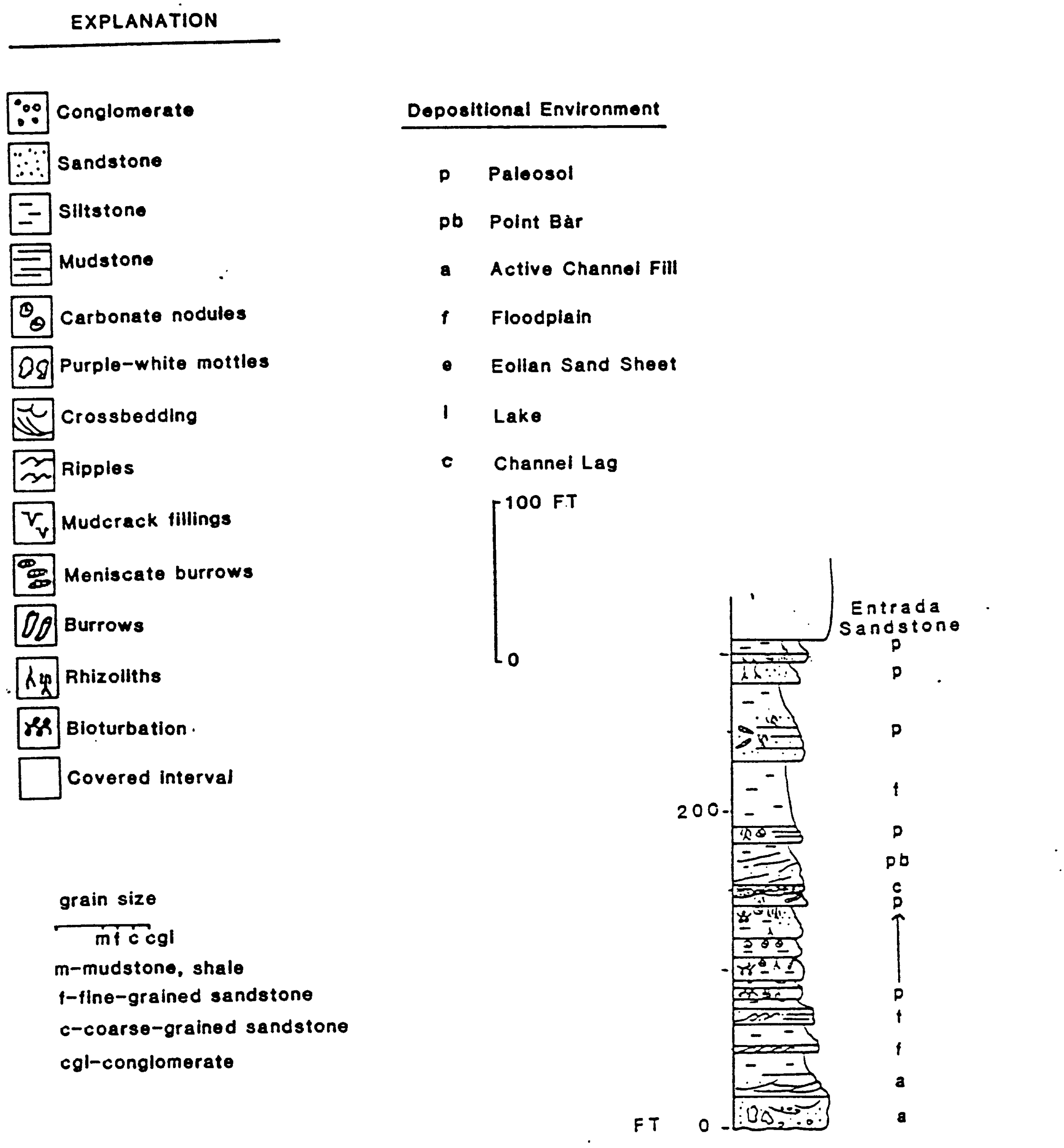


Figure 3. Measured stratigraphic section of the Chinle Formation at Edwards West and explanation of symbols used in figs. 3-12.

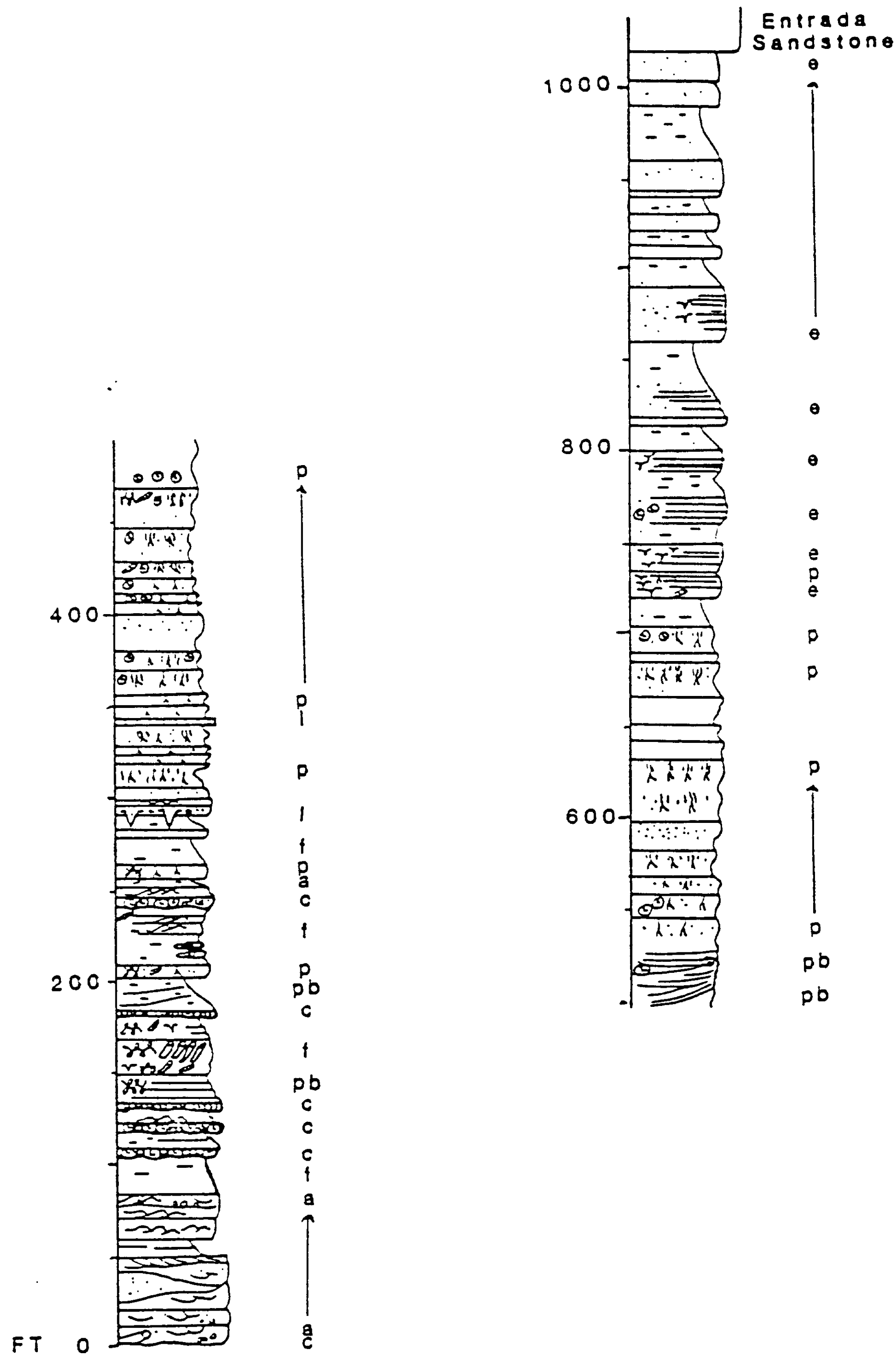


Figure 4. Measured stratigraphic section of the Chinle Formation at East Brush Creek. See fig. 3 for explanation of symbols.

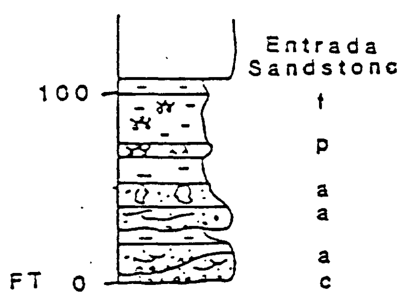


Figure 5. Measured stratigraphic section of the Chinle Formation at State Bridge. See fig. 3 for explanation of synbols.

## East Alkalai Creek

A 306-ft-thick section of the Chinle Formation (Fig. 6) was measured 1/2 mi south of the Colorado River where the road from McCoy to Burns crosses the river. The section is on the west flank of a north-plunging anticline. Beds in the Chinle strike N5$^{o}$E and dip 44$^{o}$ N85$^{o}$W. The Gartra Member of the Chinle Formation unconformably overlies the State Bridge Formation, but the Gartra is lenticular in this area. About 1/4 mi east of the section, the Gartra is not present, and the reddish-brown siltstone member of the Chinle Formation unconformably overlies the State Bridge Formation. The Chinle is unconformably overlain by the Entrada Sandstone.

## Derby Junction

A 447-ft-thick section of the Chinle Formation (Fig. 7) was measured on the west side of the Colorado River along the dirt road leading from Burns to Dotsero, Colorado. The section is located in a large gulley directly south of the extensive exposure of Chinle Formation in an amphitheatre about 1/2 mi south of Derby Junction. The gully is accessed through a small cliff formed by the Gartra Member of the Chinle Formation and an eolian sandstone at the top of the State Bridge Formation located just west of a small alluvial fan built out to the level of the dirt road. Beds in the Chinle Formation strike due west and dip 5$^{o}$ N. The Gartra Member of the Chinle Formation unconformably overlies a yellowish-orange, fine-to very fine grained sandstone in the State Bridge Formation. This unit is characterized by large-scale, low-angle trough cross-stratification and appears to be an eolian unit, probably the Sloan Peak Member of the State Bridge Formation. The Chinle Formation is unconformably overlain by the Entrada Sandstone.

## South Canyon Creek

A 383-ft-thick section of the Chinle Formation (Fig. 8) was measured on the west side of South Canyon Creek, about 5 mi west of Glenwood Springs, Colorado. The section is located on slopes directly west of South Canyon Creek about 1/2 mi south of the Colorado River. Beds in the Chinle Formation strike N60$^{o}$W and dip 42$^{o}$ S30$^{o}$W. The Gartra Member of the Chinle Formation is thin, and unconformably overlies the State Bridge Formation. The Chinle is unconformably overlain by the Entrada Sandstone.

## Snowmass Creek

A 646-ft-thick section of the Chinle Formation (Fig. 9) was measured on the east side of Snowmass Creek, 5 mi south of Snowmass, Colorado. Beds of the Chinle Formation strike due west and dip 40$^{o}$ S. The section begins on a small knoll on a northwest-trending ridge and continues up the ridge and bare slopes to the Entrada Sandstone. The Gartra Member of the Chinle Formation unconformably overlies dark-reddish-brown, pebbly, arkosic sandstones that appear to be part of the Maroon Formation. The contact was chosen at the base of a 10-ft-thick conglomeratic sandstone containing distinctly larger quartz and gneiss clasts as much as 3.5 in. in diameter, whereas underlying beds contain quartz pebbles and granules less than 1/2 to 1 in. in diameter. The contact is also marked by a subtle color change from dark-reddish-brown strata below to dark-reddish-purple or reddish-gray conglomerate above. The Chinle Formation is unconformably overlain by the Entrada Sandstone.

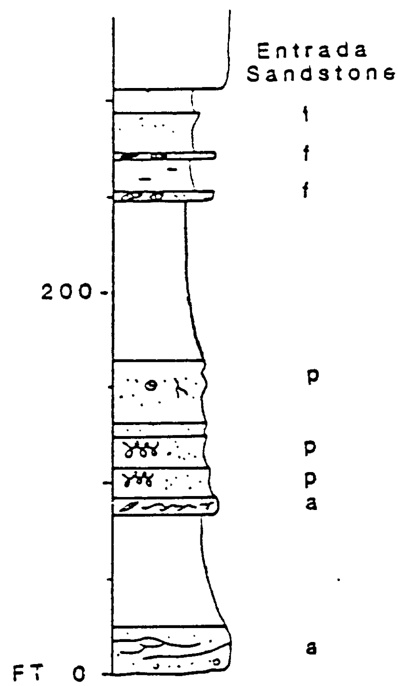


Figure 6. Measured stratigraphic section of the Chinle Formation at East Alkalai Creek. See fig. 3 for explanation of symbols.

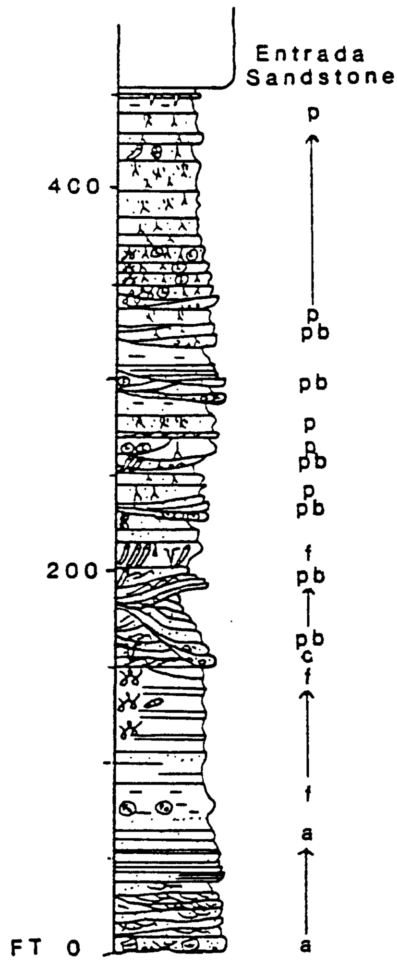


Figure 7. Measured stratigraphic section of the Chinle Formation at Derby Junction. See fig. 3 for explanation of symbols.

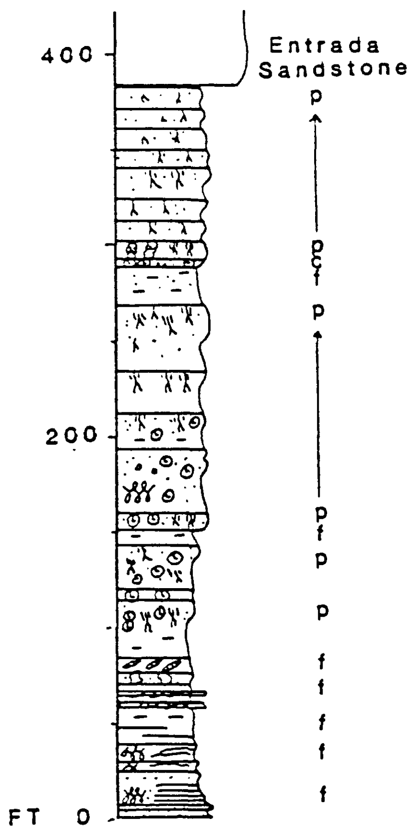


Figure 8. Measured stratigraphic section of the Chinle Formation at South Canyon Creek. See fig. 3 for explanation of symbols.

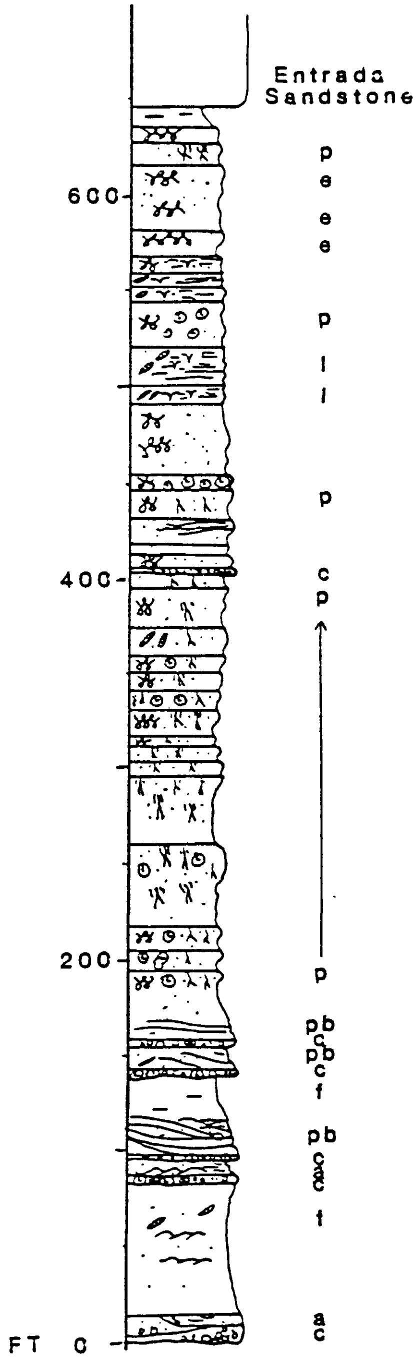


Figure 9. Measured stratigraphic section of the Chinle Formation at Snowmass Creek. See fig.3 for explanation of symbols.

## Main Elk Creek

A 322-ft-thick section of the Chinle Formation (Fig. 10) was measured on the west side of Main Elk Creek 6 mi northwest of Newcastle, Colorado. The section is on the west side of Main Elk Creek, about 3 mi upstream from the road to Newcastle. Beds in the Chinle Formation strike N30°W and dip 25° S60°W. The Gartra Member of the Chinle Formation is not well exposed, and is represented by a 1-ft-thick bed of conglomeratic, coarse-grained to granular, black to green quartz sandstone. The Chinle is unconformably overlain by the Entrada Sandstone.

## East Rifle Creek

A 392-ft-thick section of the Chinle Formation (Fig. 11) was measured on the east side of East Rifle Creek about 1 mi south of the State of Colorado campground. The section begins at a drainage canal and continues up a southeast-trending ridge about 500 ft south of an abandoned mine site. Beds of the Chinle Formation strike N80°E and dip 25° S10°E. The Chinle Formation unconformably overlies the Schoolhouse Tongue of the Weber Sandstone and is unconformably overlain by the Entrada Sandstone.

## Basalt

A 608-ft-thick section of the Chinle Formation (Fig 12) was measured in a large natural amphitheatre about 1.5 mi northeast of Basalt, Colorado. Access was gained from the property of Jim Corbett at the end of a dirt road leading from a subdivision just east of Basalt on the north side of the road from Basalt to Ruedi Reservoir. Beds of the Chinle strike N10°E and dip 5° N80°W. The Chinle is exposed in a large natural amphitheatre several hundred feet above the Fryingpan River. The Gartra Member of the Chinle Formation unconformably overlies the State Bridge Formation. The Gartra Member rests on a tan to yellowish-orange, fine-grained quartz sandstone characterized by large-scale, low-angle trough cross-stratification. The unit is interpreted as eolian. The Chinle is overlain by the Entrada Sandstone.

# SEDIMENTOLOGY

The Chinle Formation in western Colorado consists of as much as 1000 ft of predominantly dark-reddish-brown to moderate-reddish-orange (Rock-Color Chart terms, Goddard and others, 1980) fine-grained sandstone, siltstone, and mudstone and lesser amounts of dark-gray to reddish-purple conglomeratic sandstone, sandstone, and limestone-pebble conglomerate. Physical and biogenic sedimentary structures, including rhizoliths (Klappa, 1980) and invertebrate ichnofossils, contribute to designation of lithofacies and the interpretation of Chinle depositional systems.

The Chinle Formation on the Colorado Plateau has been interpreted as the product of deposition in continental fluvial, floodplain, and lacustrine environments (Stewart and others, 1972; Blakey and Gubitosa, 1983; Dubiel, 1983, 1984, 1985, 1987a, 1987b), but no detailed studies have been made on the sedimentology and depositional environments of the Chinle in western Colorado. Previous studies of the Chinle Formation in western Colorado have been concerned with stratigraphy and paleogeography (Shropshire, 1974).

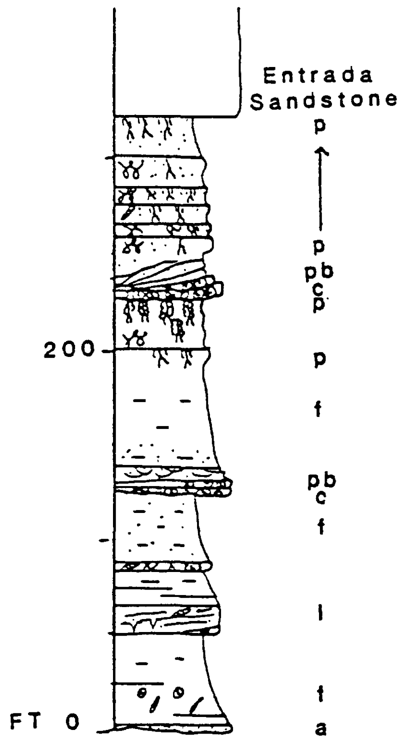


Figure 10. Measured stratigraphic section of the Chinle Formation at Main Elk Creek. See fig.3 for explanation of symbols.

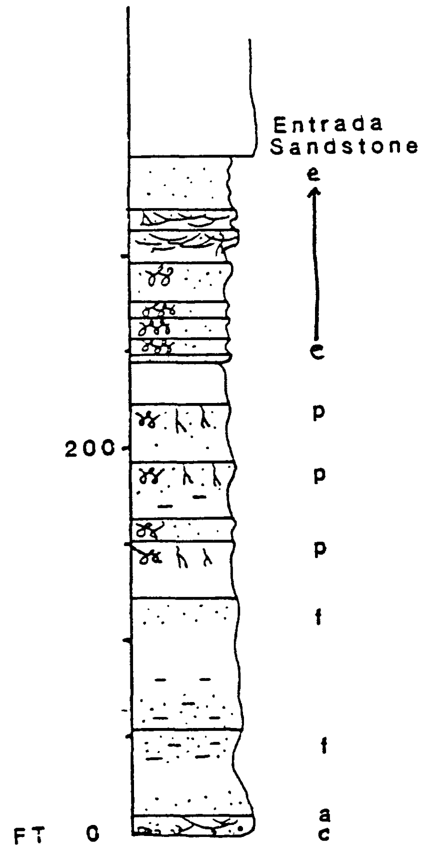


Figure 11. Measured stratigraphic section of the Chinle Formation at East Rifle Creek. See fig. 3 for explanation of symbols.

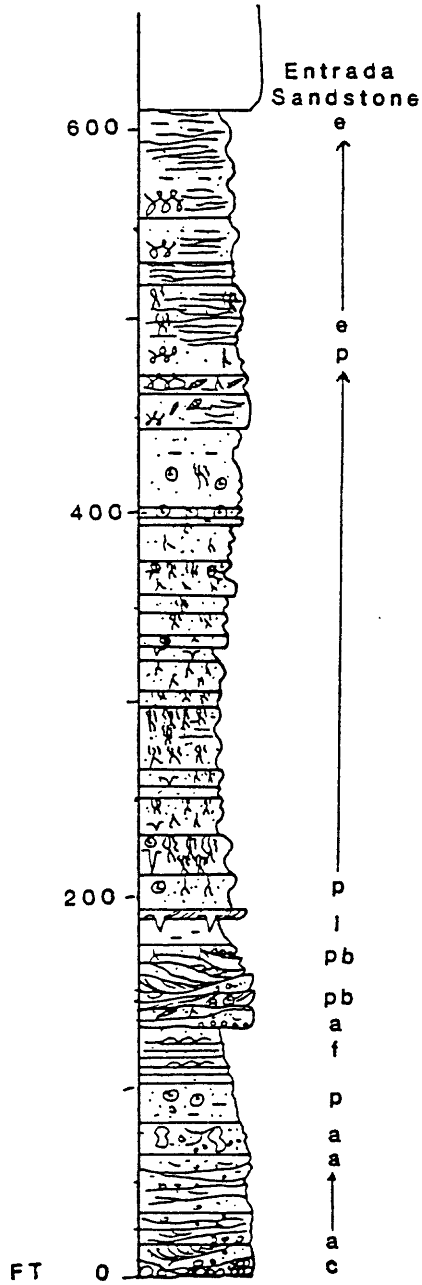


Figure 12. Measured stratigraphic section of the Chinle Formation at Basalt. See fig.3 for explanation of symbols.

This study relates the small-scale depositional environments of the Chinle Formation in western Colorado and to the paleogeography and paleoclimate at the time of deposition within the larger setting of the Eagle basin. Ultimately this study will be integrated with studies of the Chinle Formation and other Triassic strata in outcrops around the Uinta-Piceance basin to decipher the Triassic history of the region.

Stratigraphic sections (Figs. 3-12) were combined with paleocurrent and isopach data from this study and previously published reports (Stewart and others, 1972; Shropshire, 1974) to investigate the lateral and vertical facies relations and facies assemblages to characterize Chinle depositional systems.

Paleosols were recognized in overbank floodplain strata and were incorporated into the depositional synthesis. Rhizoliths (Klappa, 1980) were identified in many of the paleosols. Lungfish burrows (Dubiel and others, 1987, 1988) were recognized in two of the sections at Derby Junction and at East Brush Creek. The lungfish burrows, along with invertebrate ichnofossils, provide additional behavioral and sedimentologic evidence into depositional environments and paleoclimate. Sedimentologic data relevant to the interpretation of Chinle paleogeography and paleoclimate are included in the following discussion.

## DEPOSITIONAL ENVIRONMENTS

The lower part of the Chinle Formation in western Colorado fills scours eroded into the underlying rocks. The Chinle unconformably overlies successively older rocks toward the margins of the Eagle basin. The contact is sharp and irregular, with local scours as much as 2 ft deep. The Chinle Formation contains several lithofacies dependent on the particular environment of deposition.

### Active channel deposits

The basal part of the Chinle Formation consists of about 5 to 50 ft of gray to dark-reddish-brown or dark-reddish-purple, multi-storied sandstone, conglomeratic sandstone, and conglomerate containing 4.5-in.-diameter quartz, granite, and gneiss pebbles. Conglomeratic units are medium to thick bedded, exhibiting medium- to large-scale trough and planar crossbeds, or are massive. Sandstone strata are coarse to fine grained, thin to medium bedded, and exhibit planar and trough crossbeds, climbing ripple lamination, or they are horizontally laminated. These units are generally assigned to the Gartra Member. At Derby Junction, the Gartra contains blocks of the underlying eolian sandstone of the State Bridge Formation that are as much as 1.5 ft across, indicating lithification of the underlying strata at the time of Chinle deposition. At East Brush Creek, the Gartra Member contains clasts of silicified wood as much as 2 ft in length. In general, both the size of sedimentary structures and the grain size of the sandstones decrease upward in the Gartra Member.

These sedimentologic features, together with the multi-storied aspect, resemble those described for modern and ancient fluvial sequences (e.g., Allen, 1965; Harms and others, 1975). The massive conglomeratic and planar crossbedded sandstone are interpreted to represent fluvial bedload deposition on in-channel bars (Rust, 1978), whereas the upward transition to finer grained sandstone with horizontal and ripple lamination and trough cross-stratification reflects mixed-load deposition from rapid sedimentation and by megaripples (Jackson, 1978) in more sinuous fluvial systems. It is postulated that as deposition of the basal part of the Chinle proceeded and the remnant topography on underlying rocks was filled, Chinle fluvial systems were able to migrate farther laterally.

The upper part of the Gartra Member is commonly mottled purple and white. This unit is termed the mottled member by Stewart and others (1972), but Shropshire (1974) included the mottled strata in his lower unit of the Chinle Formation along with the Gartra Member. The present study recognizes a gradational contact between the Gartra Member and the mottled strata, and a gradational contact between the mottled strata and the overlying red units of the Chinle Formation. A continuum of bedding, sedimentary structures, and grain size, probably reflects a gradational transition of depositional environments from fluvial systems restricted by confining valley walls cut in the State Bridge Formation to more sinuous fluvial systems not laterally restricted by confining valley walls. Mottled strata herein are included in the Gartra Member and the red upper part of the Chinle Formation is referred to as the red siltstone member (Stewart and others, 1972).

## Lateral Accretion Deposits

Above the Gartra Member and the mottled strata, the Chinle Formation is composed of dark-reddish-brown to reddish-orange, very fine to fine-grained, thin- to thick-bedded sandstone, siltstone, and mudstone of the red siltstone member (Stewart and others, 1972). These red strata are separated into two distinct lithofacies referred to here as lateral accretion deposits and floodplain deposits. The first lithofacies is characterised by dipping beds and the second displays horizontal stratification. The first lithofacies, described in this section, contains sets of large-scale, epsilon cross-stratification (ECS). The ECS sets grade from limestone-pebble conglomerate and quartzose sandstone at the base, through interbedded sandstone, siltstone, and mudstone, to predominantly siltstone and mudstone at the top. Individual beds within the ECS dip as much as $10^{\circ}$ and internally contain small-scale trough and ripple cross-stratification with trough axes that are oblique to the dip of the ECS. The ECS sets are as much as 35 ft thick, and sets are locally superposed. Locally, the ECS units can be traced laterally into the horizontally bedded strata described in the following section as overbank floodplain deposits.

The large-scale epsilon cross stratification is interpreted as lateral accretion stratification (LAS) because the trend of small-scale sedimentary structures within the units is oblique to the dip of the ECS. The interbedded siltstones and sandstones are interpreted as point bar deposits resulting from helical channel flow, whereas the mudstone- and siltstone-dominated upper parts of the LAS are thought to reflect deposition by waning currents in abandoned channels and oxbow lakes in high-sinuosity fluvial systems (Moody-Stuart, 1966; Jackson, 1976). The predominantly fine grain size of the strata indicate a mixed- to suspended-sediment load. The limestone-pebble conglomerate at the base of the LAS sets represent channel lag deposits, and the source of the carbonate clasts was the floodplain calcic paleosols described in the following section.

## Floodplain Deposits and Paleosols

The second lithofacies in the red siltstone member is composed of horizontally stratified, thin- to thick-bedded mudstone, siltstone, and fine-grained sandstone that exhibit varying degrees of carbonate-nodule development and vertical, lavender alteration haloes.

Locally, the flat-bedded strata can be traced laterally into the lateral accretion deposits described in the previous section. Individual beds appear to be very extensive laterally, but substantial cover precludes tracing beds for more than a few hundred yards. Internally, the beds exhibit few physical sedimentary structures, but they do display evidence of pedogenic modification. The beds contain isolated and coalesced carbonate nodules and several types of rhizoliths (Klappa, 1980) and invertebrate trace fossils.

Carbonate nodules are abundant in beds of the red siltstone member. Carbonate occurs as singular and isolated nodules (Stage I, Gile and others, 1966), coalesced nodules (Stage III), and laterally extensive coalesced nodular beds (Stage IV). The fact that similar carbonate nodules occur as clasts in Chinle Formation fluvial deposits in the region indicates nodule formation and induration was penecontemporaneous with sedimentation. The carbonate is interpreted as pedogenic accumulation of carbonate in soil horizons that developed on Chinle floodplains. The interpretation of these units as paleosols is supported by the occurrence of rhizoliths within the beds.

Floodplain strata contain three types of rhizoliths. Root alteration haloes are dark-reddish-purple, vertical and cylindrical mottles around the location of former plant roots. Locally the alteration haloes taper and bifurcate downwards, and grade into finer grained rootlet traces. In places, alteration haloes are peripherally cemented by nodular carbonate stacked vertically along the vertical axes of the haloes. The less-cemented interiors of the haloes weather out, leaving a moldic interior. These structures are rhizotubules (Klappa, 1980). Where the carbonate nodules coalesce and completely encase the root alteration halo, the structures form rhizocretions (Klappa, 1980). The increased carbonate cementation in the rhizocretions indicates that more time was available in distal floodplain paleosol settings to precipitate more carbonate cement (Bown and Kraus, 1987).

Several types of ichnofossils are present in the floodplain strata. Lungfish burrows (Dubiel and others, 1987; 1988) are locally very abundant, but not regionally widespread, in siltstones and fine-grained sandstones at Derby Junction and at East Brush Creek. The burrows appear to be in floodplain deposits, but interpretation is difficult. The medium- to thick-bedded burrow-bearing units exhibit few physical sedimentary structures. The beds are extensively bioturbated, and only the most recent episode of bioturbation is preserved as natural casts. Smaller diameter trace fossils are commonly associated with the rhizoliths. These ichnofossils are sinuous and cylindrical, about 1/4 in. in diameter. The traces are non-branching, but do interpenetrate. Internally, very fine, concave backfills are accentuated by alternating hematite-rich and hematite-poor meniscae. These backfilled trace fossils are interpreted as endichnial burrows belonging to the ichnogenus Muensteria sp., on the basis of meniscate backfill without apparent wall structure or ornamentation, although assignment to that ichnogenus on these criteria was recently questioned by D'Allessandro and Bromley (1987). These trace fossils are interpreted to have been formed as the fodinichnia of sediment-ingesting invertebrates.

Locally, the floodplain deposits are in direct contact with lateral accretion deposits, having been cut out by lateral migration of the point bar system. The floodplain strata form the cut bank of the outside bend of the point bar deposits. At localities such as Derby Junction, the floodplain deposits exhibit abundant, superposed sand-filled desiccation cracks. The abundance and superimposed nature of the mudcracks indicate many episodes, possibly seasonal episodes, of channel overbank flooding and subsequent desiccation.

On the basis of fine grain size, lateral continuity, trace fossils, rhizoliths, and lateral association with fluvial channel and point bar deposits, these flat lying strata are interpreted as floodplain deposits (e.g., Leeder, 1982). Carbonate nodules occur as clasts in many Chinle fluvial channel sandstones in the area, attesting to their early formation and induration in the floodplain strata as pedogenic carbonate in paleosol profiles (Hubert, 1978; Wright, 1982).

## Lacustrine Deposits

At Derby Junction, East Brush Creek, and Main Elk Creek, planar-bedded units in the red siltstone member are distinct from the floodplain paleosols. These units are composed of horizontally stratified, laminated to very thin bedded, medium-brown, mudcracked, clayey siltstone. Each unit is about 10 ft thick, and contains abundant, small, horizontal and vertical meniscate backfilled trace fossils. Fine grain size, tabular and laterally extensive thin beds, abundant bioturbation, and lack of rhizoliths suggest a floodplain lacustrine origin for these units (e.g., Fouch and Dean, 1982).

## Sand Sheet Deposits

At most sections measured for this study, the Entrada Sandstone rests unconformably on the Chinle Formation, and it is difficult to determine how much, if any, of the Chinle Formation may have been eroded. At East Brush Creek, Basalt, and Snowmass Creek, the three thickest sections of Chinle measured for this study, the upper part of the red siltstone member comprises a lithofacies not encountered elsewhere in this study. This lithofacies consists of reddish-orange to light-orange-brown, thin- to thick-bedded, horizontally laminated to low-angle crossbedded, fine-grained quartz sandstone and red-brown siltstone. The thin laminations are highlighted by very thin clay drapes that are mudcraked and contain small, meniscate backfilled trace fossils. This lithofacies does not contain the abundant rhizoliths characteristic of the floodplain deposits, but rather is characterized by small ichnofossils and in many places by a bioturbated texture.

The horizontal laminations in a fine-grained sandstone with very thin mudstone drapes and the thick, laterally extensive tabular bedding suggest that these units are eolian sand sheet deposits (Kocurek and Nielson, 1986). Similar eolian sand sheet deposits have been described for the Dolores Formation in southwestern Colorado (Blodgett, 1984, 1988), a probable lateral equivalent to the Chinle in western Colorado. The fact that only the three thickest measured sections of the Chinle, and especially the thickest section at East Brush Creek, contain this lithofacies implies that some part of this lithofacies and an unknown part of the Chinle Formation at each of the other sections has been removed by erosion prior to deposition of the Entrada Sandstone. The upsection change from floodplain deposits to inferred eolian environments at the top of the thickest Chinle sections also implies that Late Triassic paleoclimate was becoming drier at the close of Chinle deposition, an interpretation suggested by Blakey and Gubitosa (1983) and Dubiel (1987a, 1987b).

## DEPOSITIONAL SYSTEMS AND PALEOGEOGRAPHY

The reddish-brown, siltstones, sandstones, and mudstones of the Chinle Formation in western Colorado were deposited in a succession of channel, floodplain, lacustrine, and eolian sand sheet environments. The abundance of large-scale, lateral accretion cross-stratification and laterally extensive fine-grained strata indicates that at least some Chinle fluvial systems were high-sinuosity meandering streams with mixed- to suspended loads. The deposits at the base of the Chinle are coarser grained than those above, exhibit more numerous cut-and-fill features, and lack lateral accretion features. These units represent fluvial deposition in less sinuous fluvial systems, and may have been restricted in their lateral migration by the enclosing paleotopography carved in underlying units.

Chinle floodplains were characterized by petrocalcic soil horizons, rhizotubules and rhizocretions, and floodplain lakes. The uppermost part of the Chinle Formation, where exposed, displays laterally extensive fine-grained burrowed sandstones deposited as eolian sand sheets.

The direction of transport of clastic material for the Chinle depositional systems in western Colorado was northward from the ancestral Uncompaghre uplift and westward from the ancestral Front Range uplift (Stewart and others, 1972; Shropshire, 1974). Paleostream directions determined from direction of decrease in pebble clast size and trend of trough crossbed axes in fluvial rocks indicate that in general paleoflow was to the northwest in the vicinity of the Eagle basin (Stewart and others, 1972; Shropshire, 1974).

The Chinle Formation depositional systems are similar to those described for the Upper Triassic Dolores Formation in southwestern Colorado (Blodgett, 1984; 1988) and the occurrence of high-sinuosity fluvial and eolian sand sheet depositional systems in each formation indicates that at least some part of the formations are equivalent.

## PALEOCLIMATE

Several aspects of the sedimentology can be used to infer the paleoclimate at the time of Chinle deposition. Paleomagnetic reconstructions place this part of the Colorado Plateau within the tropics during the Late Triassic (Van der Voo and French, 1974; Van der Voo and others, 1976). It is reasonable to assume that temperatures were warm to hot the entire year. The fluvial, floodplain, and lacustrine depositional facies indicate that water was abundant in the depositional system at least until the final stages of Chinle eolian sand sheet deposition. The fine grained nature of many of the floodplain and point bar deposits and the abundant lateral accretion deposits indicate high-sinuosity streams with abundant suspended sediment load. However, the accumulation of pedogenic calcic horizons in fine-grained floodplain strata and the abundant desiccation cracks in floodplain deposits in a tropical setting suggest that the moisture input was seasonal (Buringh, 1968; Mohr and others, 1972; Young, 1976). Thus the region of deposition can be described as having had a tropical monsoonal climate. The advent of eolian sand sheet deposition at the top of the Chinle indicates that the climate became drier at the close of Chinle deposition.

## SUMMARY

Stratigraphic sections of the Upper Triassic Chinle Formation were measured at ten localities in the Eagle basin, the Aspen sub-basin, and around the White River uplift in western Colorado. Sedimentologic studies of these measured sections includes examination of physical and biogenic sedimentary structures and paleosols to characterize lithofacies, facies assemblages, and depositional environments. The studies are incorporated into an interpretation of the depositional environments, paleogeography, and paleoclimate that existed during the Late Triassic in this part of the Uinta-Piceance basin.

The Chinle Formation consists of fluvial, floodplain, lacustrine, and eolian sand sheet environments. The Gartra Member at the base of the Chinle consists of bedload, low-sinuosity fluvial deposits that filled the remnant topography on the underlying rocks. Depositional environments of the mottled member of the Chinle Formation are considered to be transitional between the depositional systems of the Gartra Member and those of the overlying red siltstone member.

The red siltstone member comprises several lithofacies. Large-scale lateral accretion bedding interpreted as point bar deposits of a high-sinuosity fluvial system are adjacent to flat-bedded overbank and floodplain strata. These floodplain units display several degrees of development of rhizoliths and pedogenic calcic horizons. Lungfish burrows and invertebrate ichnofossils are locally abundant. Locally, fine-grained lacustrine strata are interbedded with floodplain deposits. The uppermost parts of the Chinle at three localities contain eolian sand sheet strata characterized by horizontal laminations and very finely laminated clay drapes.

The Chinle was deposited to the west of source areas in the ancestral Front Range and to the north and northwest of the ancestral Uncompaghre uplift. Fluvial systems flowed generally northwestward in the vicinity of the Eagle basin. Floodplain deposits were pedogenically modified and contain several examples of calcic horizons and rhizoliths. Depositional environments, trace fossils, paleosols, and paleomagnetic evidence indicate that the Late Triassic climate was tropical monsoonal with alternating wet and dry seasons.

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## REFERENCES


Allen, J.R.L., 1965, A review of the origin and characteristics of Recent alluvial sediemnts: Sedimentology, v. 5, p. 89-191.

Blakey, R.C., and Gubitosa, R., 1983, Late Triassic paleogeography and depositional history of the Chinle Formation, southeastern Utah and northeastern Arizona, in Reynolds, R.M., and Dolly, E.D., eds., Mesozoic paleogeography of the west-central United States: Rocky Mountain Section, Soc. Econ. Paleontologists and Mineralogists, Denver, p. 57-86.

Blodgett, R.H., 1984, Nonmarine depositional systems and paleosol development in the Upper Triassic Dolores Formation, southwestern Colorado, in Brew, D.C., ed., Field Trip Guidebook, 37th Annual Meeting, Rocky Mountain Section, Geological Society of America, Durango, p. 46-61.

Blodgett, R.H., 1988, Calcareous paleosols in the Upper Triassic Dolores Formation, southwest Colorado, in Reinhardt, J., and Sigleo, W.R., eds., Paleosols and weathering through geologic time: Geologic Society of America Special Paper 216, p. 103-122.

Bown, T.M., and Kraus, M.J., 1987, Integration of channel and floodplain suites in aggrading alluvial systems: Developmental sequence and lateral relations of lower Eocene alluvial paleosols, Willwood Formation, Bighorn Basin, Wyoming: Journal of Sedimentary Petrology, v. 57, p. 587-601.

Buringh, P, 1968, Introduction to the study of tropical and subtropical soils: Wageningen, The Netherlands, Centre for Agricultural Publishing and Documentation, Agricultural University of Wageningen, 118 p.

D'Alessandro, A.D., and Bromley, R.G., 1987, Meniscate trace fossils and the Muensteria-Taenidium problem: Paleontology, v. 30, pt. 4, p. 743-763.

DeVoto, R.H., 1972, Pennsylvanian and Permian striatigraphy and tectonism in central Colorado: Quarterly of the Colorado School of Mines, v. 67, p. 139-185.

Dubiel, R.F., 1983, Sedimentology of the lower part of the Upper Triassic Chinle Formation, southeastern Utah: U.S. Geological Survey Open-File Report 83-459, 48 p.

Dubiel, R.F., 1984, Evidence for wet paleoenvironments, Upper Triassic Chinle Formation, Utah: Geological Society of America, Rocky Mountain Section, 37th Annual Meeting, Abstracts with Program, v. 16, p. 220.

Dubiel, R.F., 1985, Preliminary report on mudlumps in lacustrine deltas of the Monitor Butte Member of the Upper Triassic Chinle Formation, southeastern Utah: U.S. Geological Survey Open-File Report 85-27, 29 p.

Dubiel, R.F., 1987a, Sedimentology and new fossil occurrences in the Chinle Formation, southeastern Utah, in Campbell, J.C., ed., The geology of Cataract Canyon and vicinity: Four Corners Geological Society, 1987 Field Conference Guidebook, p. 99-107.

Dubiel, R.F., 1987b, Sedimentology of the Upper Triassic Chinle Formation, southeastern Utah: Ph.D. Thesis, Univ. of Colorado at Boulder, 132 p.

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

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

Elliott, D.K., 1983, New material of Chinlea sorenseni from the Chinle Formation, Dolores River, Colorado (abs.): Symposium on Southwestern Geology and Paleontology, Flagstaff, Museum of Northern Arizona, p.4.

Elliott, D.K., 1987, A new specimen of Chinlea sorenseni from the Chinle Formation, Dolores River, Colorado, 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. 47-52.

Freeman, V.L., 1971, Stratigraphy of the State Bridge Formation in the Woody Creek quadrangle, Pitkin and Eagle Counties, Colorado: U.S. Geological Survey Bulletin 1324-F, p. F1-F17.

Freeman, V.L., and Bryant, Bruce, 1977, Red bed formations in the Aspen area, in Veal, H.K., ed., Exploration frontiers of the central and southern Rocky Mountains: Rcoky Mountain Association of Geologists, Denver, p. 181-189.

Fouch, T.D., and Dean, W.E., 1982, Lacustrine and associated clastic environments, in Scholle, P.A., and Spearing, D., eds., Sandstone depositional environments: AAPG Memoir 31, p. 87-114.

Gile, L.H., Peterson, F.F., and Grossman, R.S., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Goddard, E.N., Trask, P.D., DeFord, R.K., Rove, O.N., Singewald, J.T., and Overbeck, R.M., 1980, Rock Color Chart: Geological Society of America, Boulder, Colorado.

Harms, J.C., Southard, J.B., Spearing, D.R., and Walker, R.G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists, Short Course Notes no. 2, 161 p.

Hubert, J.F., 1978, Paleosol caliche in the New Haven Arkose, Newark Group, Connecticut: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 24, p. 151-168.

Jackson, R.G., 1976, Depositional model of point bars in the lower Wabash River: Journal of Sedimentary Petrology, v. 46, p. 579-594.

Jackson, R.G., 1978, Preliminary evaluation of lithofacies models for meandering alluvial streams, in Miall, A.D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 543-562.

Johnson, S.Y., 1987, Stratigraphic and sedimentologic studies of Late Paleozoic strata in the Eagle basin and northern Aspen sub-basin, northwest Colorado: U.S. Geological Survey Open-File Report 87-286, 82 p.

Johnson, S.Y., in press, The Fryingpan Member of the Maroon Formation (Middle Pennsylvanian to Upper Permian), an ancient basin margin dune field in the Aspen sub-basin of northwestern Colorado: U.S. Geological Survey Bulletin 1787, 26 p.

Johnson, S.Y., Schenk, C.J., Anders, D.A., and Tuttle, M.L., in press, Sedimentology and petroleum occurrence, Schoolhouse Tongue of the Weber Sandstone (Lower Permian), northwest Colorado: Geological Society of America Bulletin.

Klappa, C.F., 1980, Rhizoliths in terrestrial carbonates: classification, recognition, genesis and significance: Sedimentology, v. 27. p. 613-629.

Kocurek, G., and Nielson, J., 1986, Conditions favorable for the genesis of warm-climate aeolian sand sheets: Sedimentology, v. 33, 795-816.

Leeder, M.R., 1982, Sedimentology, process and product: London, George Allen and Unwin, 344 p.

Mohr, E.C.J., Van Baren, F.A., and Van Schuylenborgh, J., 1972, Tropical Soils: The Hague, Netherlands, Mouton-Ichtiar Baru-Van Hoeve, 480 p.

Moody-Stuart, M., 1966, High- and low-sinuosity stream deposits, with examples from the Devonian of Spitzbergen: Journal of Sedimentary Petrology, v. 36, p. 1102-1117.

Poole, F.G., and Stewart, J.H., 1964, Chinle Formation and Glen Canyon sandstone in northeastern Utah and northwestern Colorado: U.S. Geological Survey Professional Paper 501-D, p. D30-D39.

Rust, B.R., 1978, Depositional model for braided alluvium, in Miall, A.D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 605-625.

Schaeffer, Bobb, 1967, Late Triassic fishes from the western United States: Bulletin of the American Museum of Natural History, v. 135, article 6, p. 285-342.

Shropshire, K.L., 1974, The Chinle and Jelm Formations (Triassic) of north-central Colorado: Ph.D. thesis, University of Colorado at Boulder, 229 p.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Upper Triassic Chinle Formation and related strata on the Colorado Plateau region, with a section on Sedimentary Petrology, by Cadigan, R.A.: U.S. Geological Survey Professional Paper 690, 336 p.

Tweto, Ogden, Moench, R.H., and Reed, J.C., Jr, 1978, Geologic map of the Leadville $1^{o}x2^{o}$ quadrangle, northeastern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-999, scale 1:250,000.

Van der Voo, R., and French, R.B., 1974, Apparent polar wandering for the Atkantic bordering continents: Late Carboniferous to Eocene: Earth Science Reviews, v. 10, p. 94-119.

Van der Voo, R. Mauk, F.J., and French, R.B., 1976, Permian-Triassic continental configurations and the origin of the Gulf of Mexico: Geology, v. 4, p. 177-180.

Wright, V.P., 1982, Calcrete paleosols from the lower Carboniferous Llanelly Fomation, South Wales: Sedimentary Geology, v. 240, p. 671-675.

Young, A., 1976, Tropical soils and soil survey: Cambridge University Press, 468 p.