UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Preliminary Report on Mudlumps in Lacustrine Deltas of the Monitor Butte Member of the Upper Triassic Chinle Formation, Southeastern Utah

by

Russell F. Dubiel[1]

Open-File Report 85-27

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1]U.S. Geological Survey, Box 25046, Denver Federal Center, MS 916, Denver, Colorado 80225

1985

CONTENTS

ILLUSTRATIONS

PRELIMINARY REPORT ON MUDLUMPS IN LACUSTRINE DELTAS OF THE MONITOR BUTTE MEMBER OF THE UPPER TRIASSIC CHINLE FORMATION, SOUTHEASTERN UTAH

By Russell F. Dubiel

ABSTRACT

Mudlumps in the Monitor Butte Member of the Upper Triassic Chinle Formation are the product of syndepositional deformation in lacustrine, delta-front, and prodelta deposits. Diapirism in lacustrine and delta deposits caused intraformational folds and faults that were penecontemporaneous with sedimentation.

Deposition of the Shinarump, Monitor Butte, and Moss Back Members of the Chinle Formation in southeastern Utah was in a complex fluvial-lacustrine system, in which fluvial channel systems with abundant wetland floodplain environments flowed generally west into a large lake. Intraformational deformation occurred in lacustrine and deltaic units near the lake margin.

Lacustrine deposits in and near the upper part of Glen Canyon are locally well exposed and are composed of red and purple bentonitic mudstone, which, in places, contain ostracodes, and burrowed, sandy limestone. Prodelta deposits are composed of gray and purple bentonitic mudstone. These lacustrine and prodelta deposits contain high-angle reverse faults, locally vertical beds, and diapiric strata interpreted as mudlumps. Delta-front deposits comprise green, micaceous and carbonaceous, coarsening upward sequences of foreset-bedded siltstone and sandstone that dip as much as 28° and are as much as 24 m thick. Rapid progradation of the delta front over prodelta and lacustrine sediments produced overloading and subsequent deformation by diapirism. The mechanism of formation of the Monitor Butte mudlumps appears to have been similar to that proposed for modern Mississippi River delta mudlumps.

The processes that formed the mudlumps in the vicinity of Glen Canyon may be the same processes that produced the vertical and contorted bedding that is more poorly exposed in the Monitor Butte Member elsewhere on the Colorado Plateau.

INTRODUCTION

Deformational features in modern deltaic deposits are produced by several mechanisms of mass movement including deep-seated clay flowage (Coleman and others, 1974), diapirism (e.g., Morgan and others, 1968), growth faults (Busch, 1975; Walters, 1959; Short and Stauble, 1967; Weber, 1971), and sediment-induced gravity sliding (Chapman, 1973). Mudlumps are diapiric sedimentary structures created by the loading action of rapidly deposited delta-front sands on lower density prodelta deposits, causing the prodelta deposits to be intruded or thrusted upward into and through the delta-front deposits. Mudlump formation, as a result of diapiric deformation on delta fronts, is a well-documented process on the Mississippi River delta and other marine deltas (Morgan and others, 1968; Shepard and others, 1968; Morgan and others, 1963; Morgan, 1961), but only one example of modern lacustrine deltaic diapirism and mudlump formation is known and that is from Pyramid Lake, Nevada (Mifflin, 1967; Mifflin, 1970; Born, 1972). Examples of ancient deltaic deformation due to growth faults (Weimer, 1973; Edwards, 1976; Chisholm, 1977; Brown and others, 1973; Erxleben, 1975; Rider, 1978; Verbeek and Grout, 1983), allochthonous slump blocks (Grout and Verbeek, 1983), and convolution in underlying beds due to overloading of prograding deltaic clastics (Stanley and Surdam, 1978) have been described, but no examples of deltaic mudlumps have been reported from the rock record.

Convoluted and steeply dipping beds of the Monitor Butte Member of the Upper Triassic Chinle Formation have been documented from numerous localities on the Colorado Plateau (fig. 1), including White Canyon and Red Canyon (Stewart and others, 1972a), Capitol Reef (Smith and others, 1963), Circle Cliffs (Davidson, 1967), and Lisbon Valley (Huber, 1980), Utah; Monument Valley (Witkind and Thaden, 1963) and Sonsela Buttes (Byers, 1980), Arizona; and Fort Wingate (Ash, 1978), New Mexico. The beds are commonly underlain and overlain by horizontal Chinle beds, indicating the penecontemporaneous nature of the deformation and the sedimentation. A recent study of depositional environments of the Shinarump, Monitor Butte, and Moss Back Members in the lower part of the Chinle Formation in the Lake Powell area of southeastern Utah has disclosed steeply dipping to overturned Monitor Butte beds adjacent to strata interpreted as Gilbert-type lacustrine deltas (Dubiel, 1983a; 1983b). These deformed strata and possible mechanisms for their formation are documented in this report.

REGIONAL SETTING

Regional stratigraphic correlations of the Chinle and related Triassic formations on the Colorado Plateau (Stewart and others, 1959; 1972a; 1972b) demonstrate that the Chinle Formation unconformably overlies the Lower and Middle(?) Triassic Moenkopi Formation in most places, and locally overlies Paleozoic or Precambrian rocks. The Chinle is composed of six members, in ascending order these are the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock Members (fig. 2). However, not all the members are everywhere present owing to facies variations (Stewart and others, 1972a; Gubitosa, 1981; Dubiel, 1982; 1983a; 1983b) and deposition of some of the members in ancient valleys (Blakey and Gubitosa, 1983; Dubiel,1983b). In the White Canyon-Lake Powell area, only the three lower members of the Chinle Formation were examined in detail.

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

The Shinarump Member is predominantly yellow-orange to gray, very coarse-grained, conglomeratic quartzose sandstone with minor red and gray mudstone. Shinarump sandstones locally have a conglomeratic base, and generally comprise fining-upward sequences from very coarse sand at the base to very fine sand at the top. The beds also possess an upward decrease in the size of trough-crossbeds, and they contain scattered scarce tabular-planar and horizontally laminated sets. Gray, carbonaceous, horizontally laminated clay "plugs" (Stewart and others, 1972a; Dubiel, 1983b) are present in the sequence. Epsilon cross-bedding, suggestive of point bar deposition, is locally present. Thus, these sandstones are interpreted as meandering stream deposits with basal channel lags, abandoned channel fills, and point bars (Reineck and Singh, 1975; Harms and others, 1975).

Red and gray mudstone, horizontally laminated siltstone, and fine-grained sandstone laterally interfinger with and overlie the fluvial sandstones. These fine-grained units are interpreted as overbank and floodplain deposits that accumulated during flood-stage deposition lateral to the main fluvial channel systems.

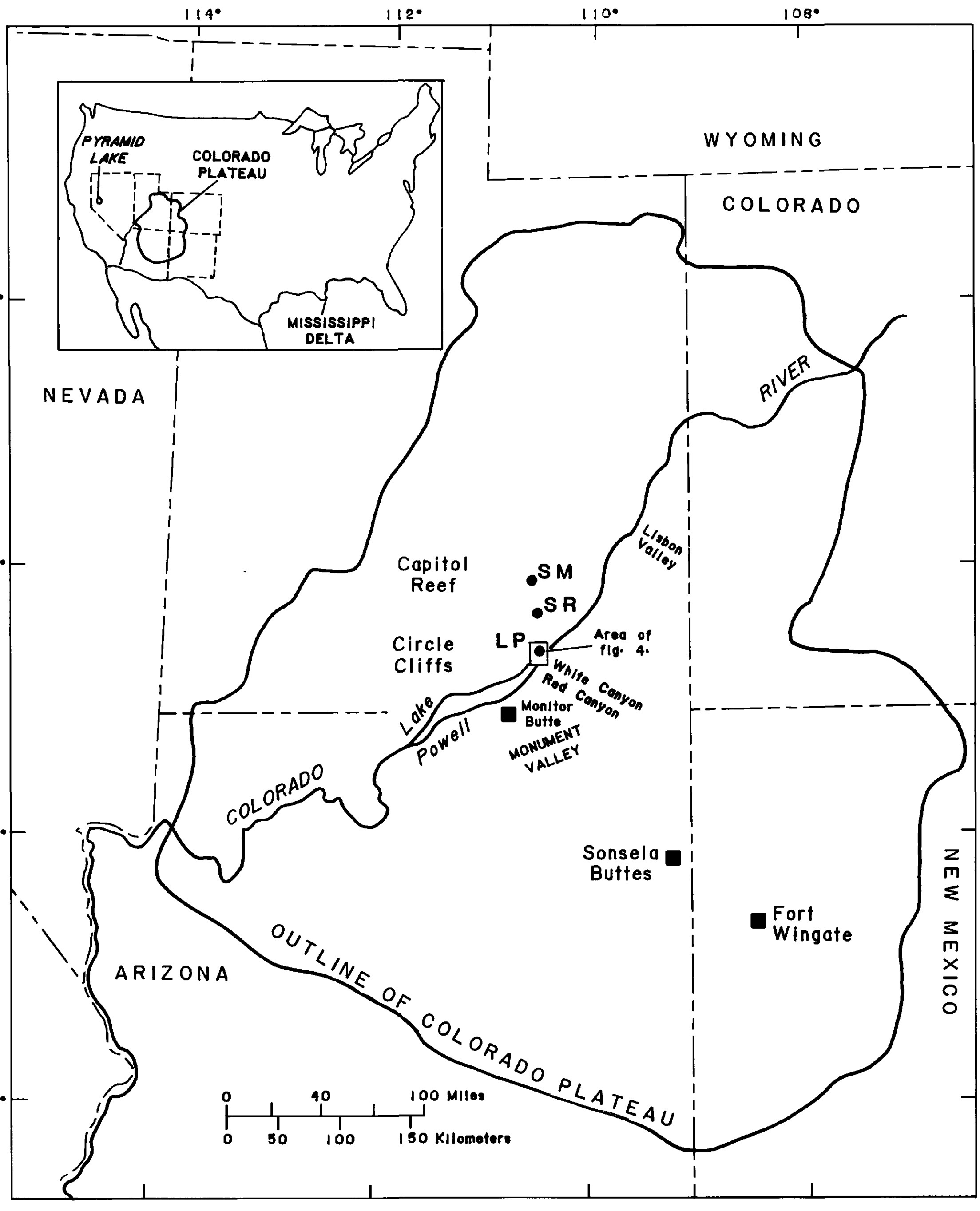

FIGURE 1.--Index map showing the study area and locations discussed in this report. SM (Sam's Mesa), SR (Sun Rust), and LP (Lake Powell) are measured sections referred to in the text.

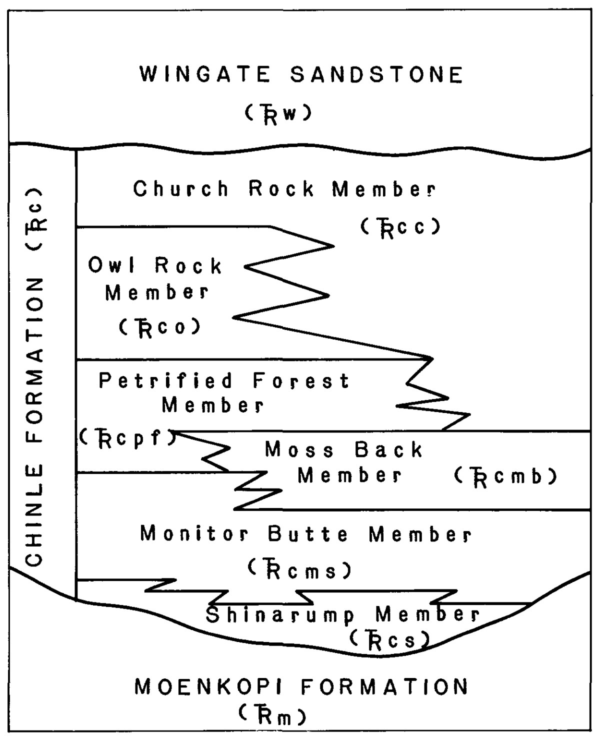

FIGURE 2.--Nomenclature of the Chinle Formation in southeastern Utah (modified from Stewart and others, 1972a).

The Shinarump commonly fills large scours eroded into underlying rocks. Miller (1955) first recognized that the Shinarump in the White Canyon area was deposited in a paleodrainage system eroded into the underlying Moenkopi Formation. Subsequent investigations (Stewart and others, 1972a; Blakey and Gubitosa, 1983; Dubiel, 1983b) have supported this interpretation. The Shinarump Member represents a fluvial system that migrated laterally between the edges of large paleovalleys subsequent to filling of the lower part of these valleys.

The Monitor Butte Member is generally a heterogeneous, fine-grained slope-forming unit. The contact with the underlying Shinarump Member is both gradational and interfingering. In the study area, the Monitor Butte is composed of a variety of lithofacies that were deposited in different depositional environments (Dubiel, 1983b).

Black to gray and brown, horizontally and very thinly laminated mudstone is a common lithology in the Monitor Butte. These rocks contain as much as 20 weight percent organic-carbon (M. R. Stanton, written commun., 1982). In places, the black mudstones fill lenticular depressions scoured into fluvial deposits. More commonly, the black mudstones grade both vertically and laterally into silty, bentonitic, and locally calcareous mudstones or poorly sorted, tan to white- and purple-mottled, burrowed sandstones. Commonly, abundant plant fragments occur in the black mudstone. Conchostracans (R. M. Forester, written commun., 1982) are common in the laminated, organic-rich mudstones, which are rarely interbedded with dark gray to black, calcareous, ostracode-bearing mudstones (R. M. Forester, written commun., 1982). Rarely, thin beds of coal as much as 15 cm thick (Thaden and others, 1964, fig. 10; Dubiel, 1983b) are present in the black mudstones.

The laterally extensive, very thinly laminated beds and the organic-carbon content of the black mudstones indicate deposition in an environment with little or no bioturbation, high organic productivity, and probably anoxic bottom conditions. Modern conchostracans are most common in marginal or ephemeral lacustrine environments. The non-calcified conchostracan carapace is usually not preserved unless the depositional environment has high sediment turbidity (R. M. Forester, written commun., 1982). The conchostracan-bearing black mudstones that fill restricted depressions in fluvial units are interpreted as organic-rich abandoned channel fills. Modern ostracodes, similar to those found in the black, calcareous Monitor Butte beds, prefer an oxygenated, sediment-free, littoral or profundal lacustrine environment (R. M. Forester, written commun., 1982). This combination of factors indicates that the extensive black mudstones containing both conchostracans and ostracodes represent lacustrine-marsh deposits adjacent to a freshwater lake. The interbedding of conchostracan- and ostracode-rich strata in the black mudstones (R. M. Forester, written commun., 1982) suggests that this lake experienced fluctuating water levels (Dubiel, 1984). Johnson and Thordarson (1959), Dubiel (1983a; 1983b), and Blakey and Gubitosa (1983) all recognized the black mudstones east of Jacob's Chair in White Canyon as marsh deposits.

Tan to white- and purple-mottled, silicified, poorly sorted, burrowed and bioturbated sandstones interfinger with and grade laterally into the marsh deposits. The sandstones characteristically contain widely dispersed, very coarse, well-rounded quartz grains and abundant vertical burrows as large as 10 cm in diameter and as much as 1 m long. The lack of primary sedimentary structures and the dispersed nature of the quartz grains are attributed to bioturbation, which, along with the large burrows, is believed to be due to the actions of lungfish (Thomas M. Bown, oral commun., 1983; Dubiel, 1984). The white and purple mottling probably represents a redistribution of iron, which, along with the silicification, is thought to be the result of soil-forming processes that were active at the time of deposition.

While the coarse, well-rounded quartz grains in the burrowed units may indicate an original fluvial source for the sediment, the lack of primary sedimentary structures due to extensive bioturbation makes an unequivocal interpretation difficult. The burrowed units interfinger with and grade laterally into lacustrine marsh deposits. Modern African lungfish live in marshes adjacent to fluvial systems (Johnels and Svensson, 1955). This suggests that the Chinle lungfish burrowed into fluvial deposits adjacent to the marshes. The lenticular shape of some burrowed units suggests a fluvial origin, but other units are more tabular with gradational lower contacts into mudstone and sharp upper contacts. It is possible some of the burrowed units were reworked and redistributed in another environment, perhaps levee or beach, subsequent to initial deposition. The burrowed units are overlain by deposits interpreted as lacustrine deltas, suggesting that the burrowed units may have been reworked during an expansion of the lacustrine system.

Portions of the Monitor Butte Member are composed of green to gray and red, bentonitic mudstone and silty mudstone. The gray and green mudstones are micaceous and contain abundant carbonized plant fragments and unidentifiable organic matter. The red mudstones commonly contain calcareous and dolomite-filled nodules that increase in abundance upward and in places coalesce into laterally extensive calcareous masses. These mudstones do not contain organic matter. Locally, the nodule-bearing red mudstones can be traced laterally into sandstone of the Moss Back Member, and are interpreted as overbank strata deposited on floodplains lateral to major fluvial systems. Nodular micritic mudstone that formed as fossil caliche has been described from the "carbonate zone" of the Moss Back Member (Gubitosa, 1981) near Moab, Utah, and from the correlative Dolores Formation (Blodgett, 1980) in Colorado. The carbonate nodules observed in this study formed as a result of similar pedogenic processes, but they may not necessarily imply an arid climate (for example, Blodgett, 1980). Carbonate nodules are present in freshwater swamps in the Atchafalaya Basin, Louisiana (Whelan and Roberts, 1973).

Preservation of carbonaceous material in gray and green mudstones indicates deposition under anoxic conditions that prevented oxidation of the organic matter. Anoxic conditions may have existed on floodplains and in soils with a high water table, in anoxic bottom water of lakes or marshes, or in anoxic sediment and interstitial water of lakes with oxygenated water columns.

Isolated but laterally extensive beds, as much as 2 m thick, and consisting of gray, micritic limestone occur as distinct ledges in predominantly mudstone sections. The association of limestone in a continental sequence with fluvial, deltaic, and marsh deposits implies deposition of the limestone by precipitation in a calcareous lacustrine basin with minimal clastic sediment input.

Another minor component in the Monitor Butte Member is red, fine-grained, thinly bedded, climbing ripple- and symmetrical ripple-laminated sandstone, often containing small, 0.5 cm-diameter burrows. The abundance of small burrows and symmetrical, oscillation ripples in many of these sandstones indicates deposition in an oxygenated, wave washed environment, probably marginal lacustrine.

Much of the remaining Monitor Butte Member is composed of gray to green, micaceous, carbonaceous, and calcareous, interbedded siltstone and fine-grained sandstone in rhythmically bedded coarsening upward sequences. The sequences commonly exhibit large-scale foreset bedding and tilted and convoluted bedding. Bedding planes contain abundant carbonized fragments and whole specimens of Zamites powelli, Phlebopteris smithii (S. R. Ash, written commun., 1981; Ash, 1978; Gottlesfeld, 1972) and other Late Triassic flora. Excellent preservation of carbonaceous, whole-leaf structures of these plants indicates quiet water deposition and rapid burial under anoxic conditions. Rhythmically-bedded, coarsening upward sequences of horizontal beds that can be traced laterally into foreset beds 4.5 to 24 m thick that dip from 15° to 28°, and lateral association with lacustrine and marsh deposits indicates deposition on lacustrine Gilbert-type deltas (Gilbert, 1885). The maximum thickness of the delta foresets, and not considering compaction, indicates that the lake was at least 24 m deep (Dubiel, 1983b).

The Moss Back Member is the youngest member of the Chinle discussed in this report and is composed of brown, medium-grained, conglomeratic sandstone characterized by medium- to small-scale trough cross-beds, overturned cross beds, tabular-planar cross-beds, and horizontal laminations. Abundant tabular-planar cross beds, a general lack of fining-upwards sequences of fine-grained channel fill sediments, a lack of epsilon cross-bedding, and laterally extensive tabular beds suggests deposition by braided streams (Smith, 1970; Rust, 1978; Miall, 1977).

Paleocurrent measurements, distribution of lithofacies from isopach data, lateral and vertical facies variations, and data from previous investigations (Stewart and others, 1972a) were used to interpret the depositional history of the lower Chinle in southeastern Utah (Dubiel, 1983b). Detailed sections showing lithofacies distribution indicate a complex distribution of fluvial, floodplain and lacustrine environments (fig. 3).

Paleocurrent measurements from the Shinarump Member indicate flow to the west and southwest. The sequence of fluvial deposits unconformably overlying the Moenkopi Formation represents a change from degrading streams that cut valleys in the Moenkopi Formation to aggrading fluvial systems that filled the valleys with sediment. In the eastern part of the White Canyon area, the aggrading fluvial valley-fill grades upward into a system of channelized sandstone, lacustrine shales, and lacustrine marsh deposits interspersed with thin coals, small deltas, and crevasse splay deposits. These wetland

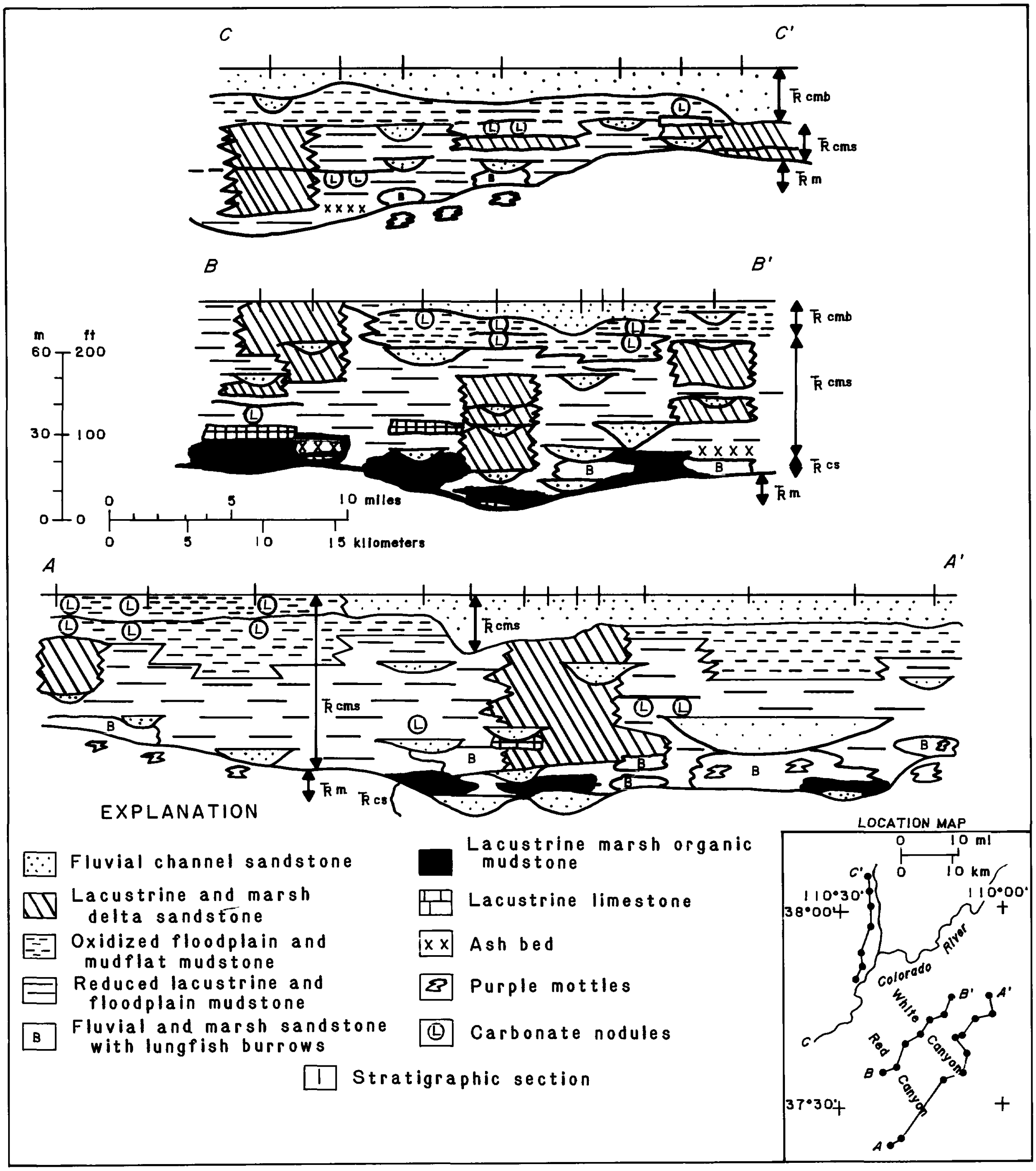

FIGURE 3.--Stratigraphic sections of the lower part of the Chinle Formation showing lithofacies variations and the distribution of depositional environments in the White Canyon area. Locations shown on inset map. Map symbols for stratigraphic units are shown on fig. 2.

environments (Smith and Putnam, 1980) represent a vertical gradation from alluvial valley-fill deposits (Shinarump Member) to a low energy, high water table, anastomosed stream (Smith, 1974; Smith and Smith, 1980) and wetland system (Monitor Butte Member) formed in response to subsidence on small synclines active at the time of deposition (Dubiel, 1983b). To the west and northwest, basal fluvial valley-fill deposits and anastomosed fluvial deposits grade laterally into lacustrine basin and lacustrine deltaic deposits. The fluvial and wetland systems aggraded while a thick lacustrine deltaic sequence was deposited farther to the west near measured sections at Sun Rust (SR), Sams Mesa (SM), and Lake Powell (LP), shown on figure 1.

Subsequently, the lacustrine basin was filled with sediment and the Moss Back fluvial system prograded over the area, scouring into the underlying Monitor Butte Member. Sand was deposited as active channel fill of the braided fluvial system and fine-grained sediments were deposited on floodplains lateral to the fluvial system during flood stage.

SYNDEPOSITIONAL DEFORMATION FEATURES

The deformational features in the Chinle Formation that are interpreted as mudlumps are well exposed along the northwest shore of Lake Powell (SE1/4 NE1/4 Sec. 26, T. 34 S., R. 13 E., Garfield County, Utah) (fig. 4). Figure 5 shows several deformed Monitor Butte units that are part of the lacustrine-deltaic sequence. A photomosaic of the outcrop (fig. 5) shows the general facies relationships and the relationship of deformed beds to depositional lithofacies. The Lake Powell (LP) section is on the flank of a paleovalley; thus, no Shinarump Member fluvial deposits are present, and, in this area, the Monitor Butte Member lies directly on the Moenkopi Formation.

Tan, red, and purple, ostracode-bearing, horizontal, medium- to thick-bedded bentonitic mudstone at the base of the Monitor Butte Member unconformably overlies the Moenkopi Formation and is interpreted as bottomset strata deposited in the offshore part of a lacustrine basin. The mudstones extend the entire length of the outcrop.

At the northeast (right) end of the outcrop (fig. 6), the lacustrine basin deposits are overlain by a coarsening-upward sequence more than 24 m thick of green, carbonaceous, micaceous, foreset-bedded muddy siltstone and fine-grained sandstone that dips 28° N. 40° E. An erosion surface truncates the top of the foreset beds and is overlain by horizontal topset beds. This surface becomes conformable with the foreset beds as the overlying topset beds are traced laterally to the right where they dip into foreset beds. The topset beds are composed of about 12 m of horizontally bedded sandstone that grades up into red and purple bentonitic mudstone. The red and purple mudstone encloses a lenticular white sandstone.

This sequence is interpreted as a lacustrine Gilbert-type delta (Gilbert, 1885) overlying lacustrine basin sediments and overlain by fluvial sandstone and oxidized overbank mudstone deposited subaerially on the delta plain. The erosion surface represents a period of lowered lake level, subaerial exposure, and reworking of the top of the delta. The surface can be traced laterally to the southwest (left side of fig. 5) where it truncates other units in the sequence. The horizontal beds that can be traced into foresets represent renewed deltaic deposition following a rise of the lake level. The uppermost

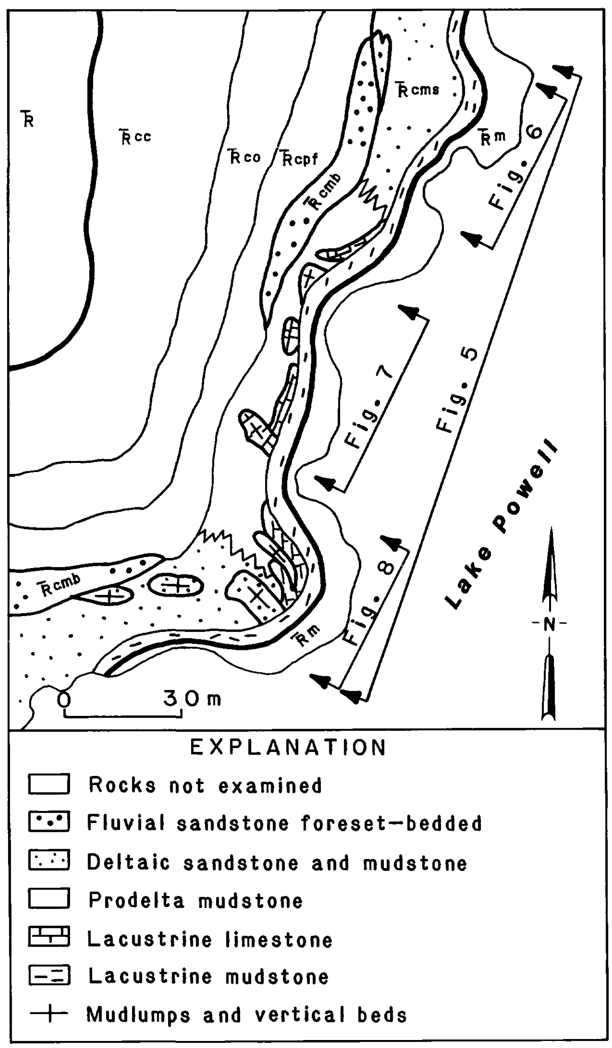

FIGURE 4.--Generalized geologic map of the study area near Lake Powell (location on fig. 1) showing the lithofacies of major units within the lower part of the Chinle Formation, the location of mudlumps, and the location of photos referred to in subsequent figures and the text. Map symbols for stratigraphic units are shown of fig. 2.

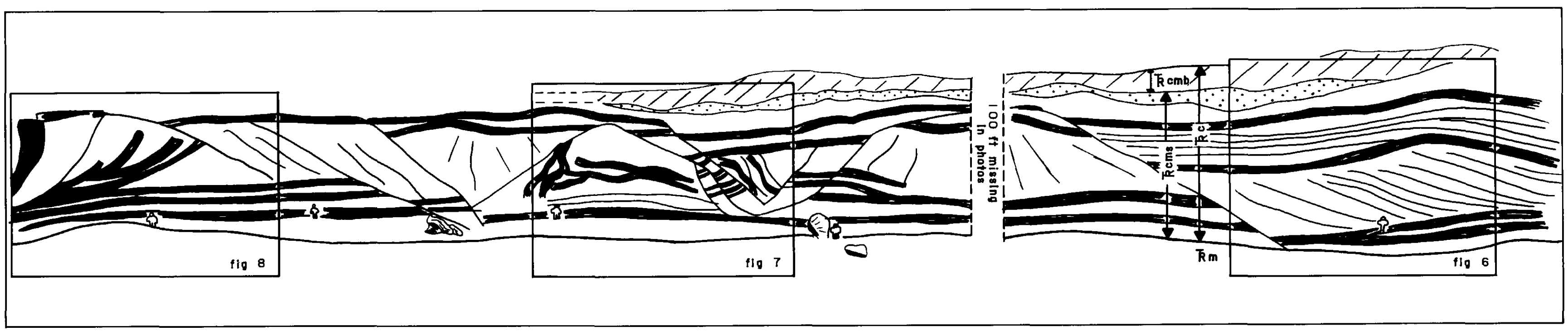

FIGURE 5.--Schematic illustration drawn from photomosaic of the Lake Powell outcrop. Shown are the major beds, deformed structures, and locations of subsequent photographs referred to in the text. Map symbols for stratigraphic units are shown on fig. 2. Geologist is 1.5 m tall. Photographs were taken looking upward approximately 20°.

FIGURE 6.--Right (northeast) end of the Lake Powell outcrop (fig. 5). Geologist (arrow) standing near the Moenkopi-Chinle contact. Foreset beds (f) of the lacustrine delta dip to the right at 28° and are overlain by horizontal topset beds (h) that can be traced to the right into foreset beds. Note the two distinct horizontal beds (dhb) for correlation with subsequent photos.

bed of this horizontally bedded topset sequence can likewise be traced to the southwest (left side of fig. 5) into oscillation-ripple laminated sandstone representing nearshore wave-reworking of the delta top prior to deposition of the overlying fluvial and overbank delta-plain deposits. The top of this bed also represents an erosion surface that is the result of minor destruction of the delta top by wave reworking. The two erosion surfaces serve as horizontal marker beds that can be traced the entire length of the outcrop.

In the center portion of the outcrop (fig. 5), tan, red, and purple ostracode-bearing mudstones at the base of the section can be traced directly into the mudstones underlying the previously described deltaic deposits and are similarly interpreted as lacustrine basin deposits. In the center section of the outcrop (fig. 7) however, the lake basin deposits are overlain by thin beds of burrowed, sandy limestone, which inturn are overlain by gray and purple sandy mudstones. The presence of burrows and carbonate indicates an oxygenated water column in the lake at the time of deposition of this unit. This sequence of limestone and gray to purple mudstone adjacent to lacustrine delta deposits is interpreted as prodelta deposits.

In the left (southwest) portion of figure 7, the sandy limestones are deformed, contorted, and vertically faulted into the mudstone part of the section. On the right (northeast) side of figure 7, the sandy limestone sequence is repeated in the section by thrusting along reverse faults. On the extreme right (northeast) side of figure 7, sandy limestones and mudstone are deformed into a small anticline. All of these deformed beds are truncated by the lower of the two erosional surfaces that can be traced directly into the delta sequence at the right (northeast) end of the outcrop (fig. 5).

At the left (southwest) portion of the outcrop (fig. 5) the basal part of the Chinle also consists of tan, red and purple, ostracode-bearing lacustrine mudstone and sandy limestone. Overlying the limestones (fig. 8) are green, micaceous and carbonaceous, thin-bedded sandstone and mudstone interpreted as having been deposited on a delta just off the photo to the southwest. Purple and gray mudstone interpreted as having been deposited as prodelta sediments between the two deltas overlies the green sandstone and mudstone. Most of the southwestern delta has been removed by erosion. The sandy limestones and deltaic beds are displaced along curved high-angle reverse faults and shoved into the gray and purple prodelta mudstones. The faulted beds dip from 32° to vertical and locally are overturned (left side of fig. 8). Despite movement of the beds along the faults, sedimentary structures and burrows remain undisturbed in the displaced beds. The uppermost edges of several of the upward faulted beds can be traced along the outcrop and form subparallel linear ridges. The upturned beds that were shoved the highest into the mudstone are truncated by the lower of the two erosional surfaces that can be traced into the delta foreset beds at the right (northeast) end of the outcrop. The truncation indicates that the deformation took place prior to the second episode of delta progradation represented by the horizontal topset beds that can be traced farther northeast into foreset beds (fig. 6). The deformation also occurred prior to the drop in lake level that resulted in the unconformity at the base of the horizontal topset beds farther northeast. Thus, deformation was essentially contemporaneous with active delta progradation.

FIGURE 7.--Center portion of the Lake Powell outcrop (fig. 5). Geologist (arrow) standing near Moenkopi-Monitor Butte contact. Horizontally-bedded lake bottom sediments (lbs) at base of Chinle Formation are overlain by sandy limestone (sls) beds, which, in turn, are overlain by prodelta mudstones (ms). Note contorted sandy limestones on left side of photo directly above geologist, and repetition of sandy limestones in section by reverse faulting on right side of photo. The two distinct horizontal beds (dhb) can be traced to the right (northeast) into the two beds noted in fig. 6.

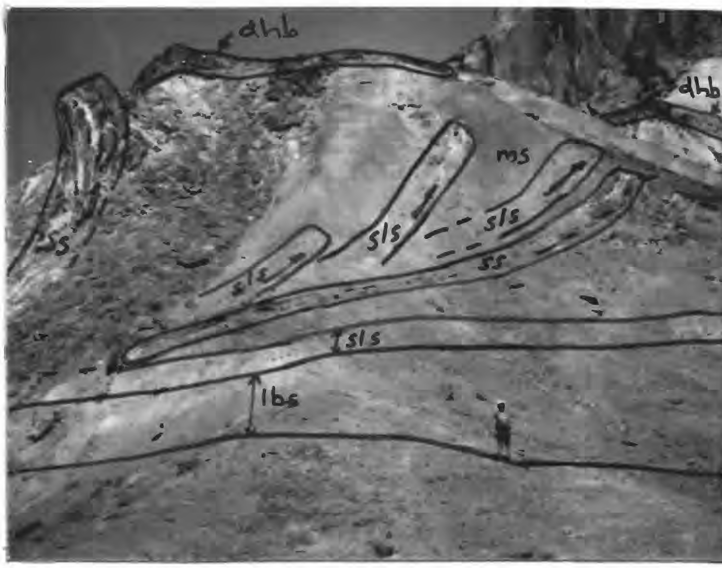

FIGURE 8.--Left (southwest) end of the Lake Powell outcrop. Geologist standing on the Moenkopi-Monitor Butte contact. Horizontally-bedded lake bottom sediments (lbs) are overlain stratigraphically by sandy limestone (sls) and carbonaceous sandstone (ss). Beds of sandy limestone and carbonaceous sandstone have been shoved upward into the overlying prodelta mudstone (ms). The two distinct horizontal beds (dhb), which can be traced to the right the entire length of the outcrop into the delta foresets (fig. 6), are just visible near the top of the exposure.

Although a portion of the southwestern delta has been removed by erosion, enough of the section remains to determine that the lithology and bedding are identical to the previously described delta, which lies just to the northeast. In addition, the two deltaic sequences are bounded by the same underlying lacustrine basin mudstones and overlying distinct horizontal bed and associated erosion surface. Thus, it is felt that sedimentation on the two deltas was essentially contemporaneous and that they may represent lobes of the same lacustrine delta complex.

MODERN ANALOGS AND MODELS

The deformed beds found in the Monitor Butte sediments were compared with mudlumps from two modern deltas, the Mississippi delta (Morgan and others, 1968; Coleman and others, 1974) and the Truckee River delta forming in Pyramid Lake, Nevada (Born, 1972) (fig. 1). Morgan and others (1968) proposed a model for the development of mudlumps by diapiric intrusion in the Mississippi delta system (fig. 9). In their model, coarse-grained, delta-front sediments prograde and differentially load prodelta clays, which intrude as mudlumps along high-angle reverse faults into the overlying units. As progradation of the delta front proceeds, a series of subparallel ridges develops, which may rise above the surface of the lower delta plain as mudlumps or above sea level on the delta front as mudlump islands (Morgan and others, 1968; Coleman and others, 1974). The intrusion of mudlumps along high-angle reverse faults in the model closely resembles the style of deformation of the Monitor Butte beds at the Lake Powell section.

A modern lacustine setting for deltaic mudlumps similar to that seen in the Chinle Formation has been described in the Truckee River delta at Pyramid Lake, Nevada (fig. 1) (Born, 1972). Mudlump islands formed intermittently here as a result of diapiric intrusion that accompanied rapid progradation of the delta (Mifflin, 1967; 1970; Born, 1972). Each case of mudlump formation in the Truckee delta was accompanied by rapid sedimentation caused by heavy runoff in the Truckee River (Mifflin, 1967; Born, 1972, p. 85).

The mudlump islands that formed in Pyramid Lake contained steeply dipping to locally vertical beds, but primary sedimentary structures within these beds were generally undisturbed (Born, 1972). Although the syndepositional deformation appears similar to Mississippi delta mudlumps, Born (1972) proposed a different mechanism for the formation of Pyramid Lake diapirs based on their circular geometry, observed delta-front slumping, and more rapid rate of formation than Mississippi mudlumps. A schematic illustration (fig. 10) of Born's (1972) model shows that slumping, induced either by earthquakes or by sediment overload (Born, 1972), causes liquefaction of confined sand bodies in the prodelta sediments. The resulting over-pressurized sand mass then deforms and domes the sediments upward.

The Pyramid Lake mudlumps result in steeply dipping beds, but they are accompanied by doming and normal faulting whereas deformation in the Monitor Butte strata appears to be the result of reverse faulting that is more like the stlye of deformation present in the Mississippi mudlumps.

Growth faults are common on rapidly prograding deltas (Busch, 1975; Walters, 1975; Short and Stauble, 1967; Weber, 1971) and have been recognized in ancient deltaic deposits (e.g., Weimer, 1973; Edwards, 1976; Rider, 1978),

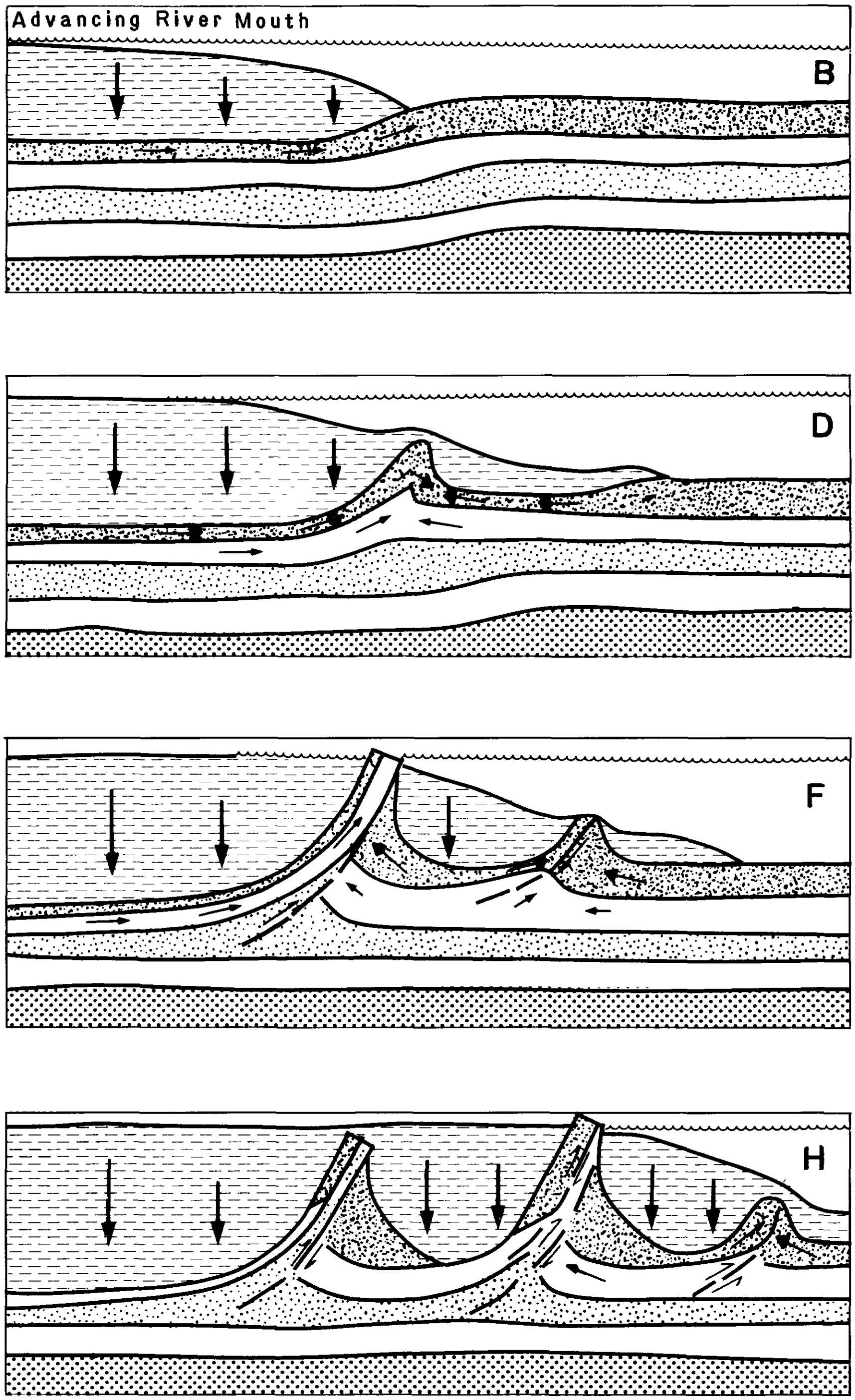

FIGURE 9.--Schematic illustration showing progressive stages in the development of mudlumps in the Mississippi delta system (modified from Morgan and others, 1968).

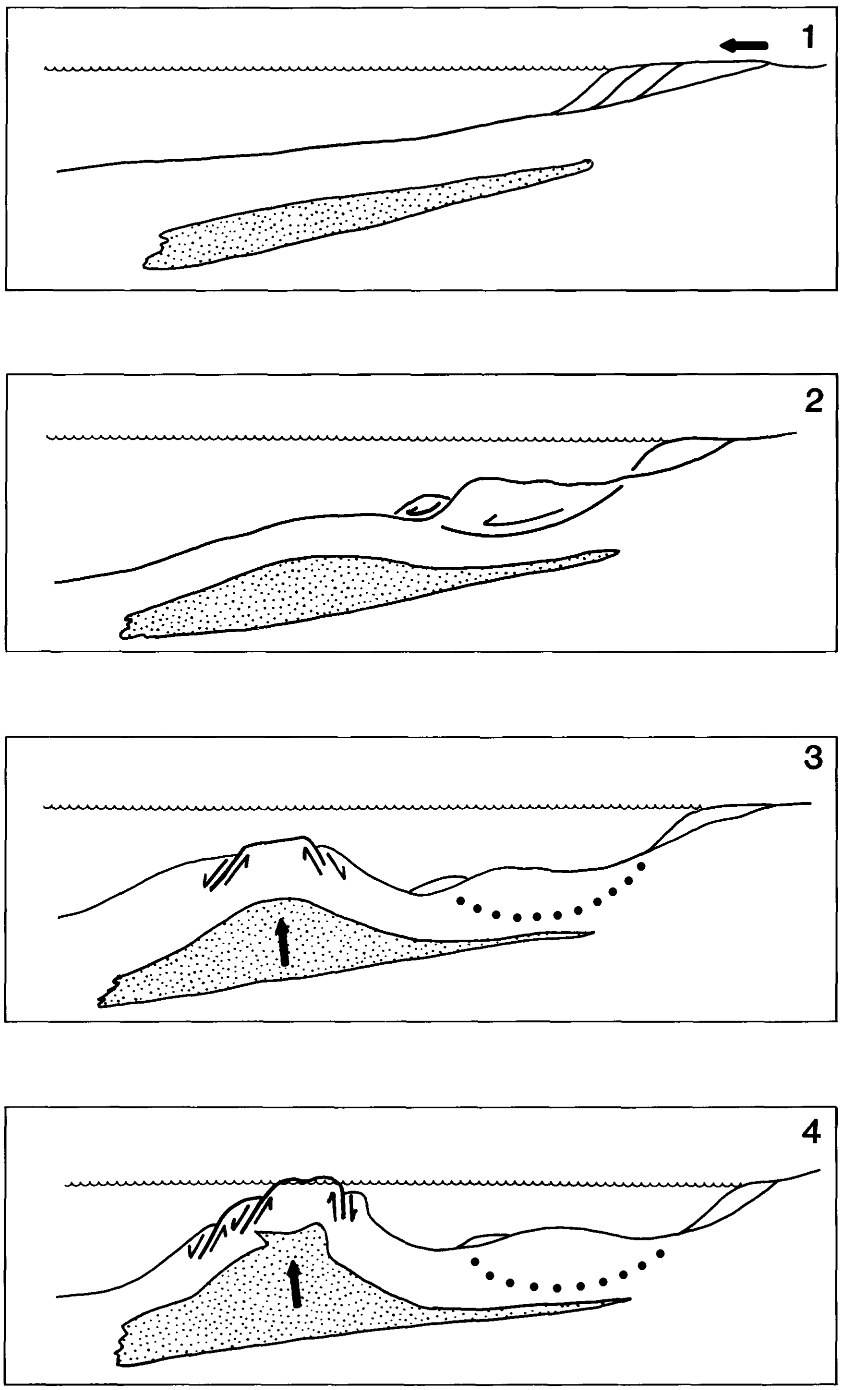

FIGURE 10.--Schematic illustration showing progressive stages in the development of mudlumps at Pyramid Lake, Nevada (modified from Born, 1972).

but they do not account for the type of deformation seen in the Chinle. Growth faults are synsedimentary faults that form in deltaic areas due to rapid sedimentation, differential compaction, and an overpressured, undercompacted shale mass (Bruce, 1973). They have a concave-upward profile that flattens with depth, passing basinward into bedding plane faults. These are normal faults with the downthrown side on the basinward side of the delta. Also, a thickened sandstone succession is commonly found on the downthrown side of the fault. These characteristics contrast with the high-angle, reverse faults and lack of thickening of distal sandstone strata in the Lake Powell section.

Vertical to overturned bedding has been reported from deltaic deposits of the Eocene Uinta Formation by Verbeek and Grout (1983) and Grout and Verbeek (1983) and is interpreted by these authors to be the result of delta-front slumping. The deformation ranges from slight dip-slip movement to detachment of large blocks. This subaqueous prodelta slumping of coherent sediment blocks resulted in the high-angle intersection of slip surfaces with bedding and contortion by overloading of underlying sediments (Verbeek and Grout, 1983, fig. 18). The normal or dip-slip faulting associated with these slump blocks and the deformation of underlying sediments by overloading of the allochthonous block makes this an unlikely interpretation for the Lake Powell section.

The presence of high-angle reverse faults, which deformed deltaic beds upwards into subparallel ridges, suggests that the Mississippi delta mudlump model (Morgan and others, 1968) is the closest analogue for the type of deformation seen in the Monitor Butte Member of the Chinle Formation.

CONCLUSIONS

Deformation of the Monitor Butte Member at the Lake Powell section appears to have been the result of syndepositional mudlump formation on lacustgrine deltas. Overloading of prodelta and basinal lacustrine deposits by prograding delta-front sediments resulted in intrusion along high-angle reverse faults of prodelta and other lacustrine deposits into overlying sediments. The intruded sediments form a series of subparallel linear ridges within deltaic and interdeltaic deposits. The Monitor Butte deformation features closely resemble those described for mudlumps in the Mississippi delta system (Morgan and others, 1968) and a similar mechanism of formation is here proposed.

The Mississippi delta system is building out into a relatively deep basin containing marine water and has an essentially stable base level. Fluvial gradients are low, sediment influx is high, and the high-constructive, elongate delta system has low offshore slopes. Monitor Butte deltas, in contrast, are part of a freshwater system that prograded into a relatively shallow lacustrine basin with a fluctuating base level and comparatively steep offshore slopes. Presumably, fluvial gradients were low and sediment influx was high. Monitor Butte deltas exhibit the classic topset, foreset, and bottom set bedding well described nearly a century ago by Gilbert (1885). Delta-front deposits of the Monitor Butte delta system are expressed as large-scale foreset beds that dip up to 28°, whereas Mississippi delta-front sediments are deposited at slopes generally less than 1°. Additionally, sand and silt-sized material in foreset beds of Monitor Butte deltaic strata suggests deposition of bed load material, whereas finer-grained Mississippi delta-front sediments were deposited as suspended load. Despite these morphologic and lithologic differences, mudlump structures in the Monitor Butte and Mississippi deltas are quite similar and suggest a similar mechanism of formation by rapid sedimentation and overloading.

Contorted Monitor Butte strata elsewhere on the Colorado Plateau that are lithologically, sedimentologically, and structurally similar to those exposed at the Lake Powell outcrop may be inferred to have a similar origin. For example, green, carbonaceous and micaceous, thinly bedded siltstone and sandstone in the Monitor Butte Member generally imply deposition under anoxic conditions, as evidenced by their high organic content and reduced sediment color. Where Monitor Butte strata of this particular lithology exhibit vertical and contorted beds, and especially where they are overlain by horizontal Chinle beds, one should consider the possiblility of deltaic mudlumps in the interpretation of syndepositional sedimentary features.

ACKNOWLEDGMENTS

I would like to express my gratitude to Robert H. Weimer, Colorado School of Mines, for introducing me to a study of deltaic systems, and, in particular, to mudlumps. Sidney R. Ash, Weber State College, provided identifications of Triassic flora and informative discussions on the Chinle Formation. The organic-carbon analyses were performed by Mark R. Stanton of the U.S. Geological Survey. Richard M. Forester, U.S. Geological Survey, identified the microfossils found in this study and provided insight into their paleoenvironmental interpretation. Thomas M. Bown, U.S. Geological Survey, assisted with the identification of the lungfish burrows. Each of these persons has contributed to my understanding of Chinle depositional systems. I would like to thank Mark J. Larson, Charles G. Patterson, Paul G. Milde, and Carl Harris of the U.S. Geological Survey both for assistance in the field and for fruitful discussions at the outcrop. Thanks also are expressed to Romeo M. Flores, Ronald C. Johnson, Omer B. Raup, and Fred Peterson of the U.S. Geological Survey for critical reviews of early drafts of this manuscript and for helpful suggestions for its improvement.

REFERENCES CITED

Ash, S. R., 1978, ed., Geology, paleontology and paleoecology of a Late Triassic lake, western New Mexico: Brigham Young University Geology Studies, v. 25, part 2, 100 p.

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

Blodgett, R. H., 1980, Triassic paleocaliche in red beds of Dolores Formation, southwestern Colorado: American Association of Petroleum Geologists Bulletin, v. 45, p. 678.

Born, S. M., 1972, Late Quaternary history, deltaic sedimentation, and mudlump formation at Pyramid Lake, Nevada: Center for Water Resources Research, Desert Research Institute, University of Nevada System, 97 p.

Brown, L. F., Jr., Cleaves, A. W., II, and Erxleben, A. W., 1973, Pennsylvanian depositional systems in north-central Texas: a guide for interpreting terrigenous clastic facies in a cratonic basin: Bureau of Economic Geology, Austin, Texas, Guidebook no. 14, 122 p.

Bruce, C. H., 1973, Pressured shale and related deformation: mechanism for development of regional contemporaneous faults: American Association of Petroleum Geologists Bulletin, v. 57, no. 5, p. 878-886.

Busch, D. A., 1975, Influence of growth faulting on sedimentation and prospect evaluation: American Association of Petroleum Geologists Bulletin, v. 59, p. 217-230.

Byers, V. P., 1980, Geologic map of tne Sonsela Buttes quadrangle, Apache County, Arizona and McKinley County, New Mexico: U.S. Geological Survey Open-File Report 80-788.

Chapman, R. E., 1973, Petroleum geology: a concise study: Elsevier, Amsterdam, 304 p.

Chisholm, I. C., 1977, Growth faulting and sandstone deposition in the Namurian of the Stanton syncline, Derbyshire: Proceedings of the Yorkshire Geologic Society, v. 41, p. 305-323.

Coleman, J. M., Suhayda, J. N., Whelan, T., and Wright, L. D., 1974, Mass movement of Mississippi River delta sediments, in Shirley, J. W., ed., Transactions of the Gulf Coast Association of Geological Societies, v. 24, p. 49-68.

Davidson, E. S., 1967, Geology of the Circle Cliffs area, Garfield and Kane Counties, Utah: U.S. Geological Survey Bull. 1229, 140 p.

Dubiel, R. F., 1982, Measured sections of the Shinarump, Monitor Butte, and Moss Back Members of the Chinle Formation (Upper Triassic) in the White Canyon and Red Canyon area, southeastern Utah: U.S. Geological Survey Open-File Report 82-729, 37 p.

Dubiel, R. F., 1983a, Stratigraphic sections of the Shinarump, Monitor Butte, and Moss Back Members of the Upper Triassic Chinle Formation in the northern part of the White Canyon, Red Canyon, and Blue Notch Canyon area, southeastern Utah: U.S. Geological Survey Open-File Report 83-188, 44 p.

Dubiel, R. F., 1983b, Sedimentology of the lower part of the Upper Triassic Chinle Formation and its relationship to uranium deposits, White Canyon area, southeastern Utah: U.S. Geological Survey Open-File Report 83-459, 60 p.

Dubiel, R. F., 1984, Evidence for wet paleoenvironments, Upper Triassic Chinle Formation, Utah: Geologic Society of America, Abstracts with Programs, v. 16, p. 220.

Edwards, M. B., 1976, Growth faults in Upper Triassic deltaic sediments, Svalbard: American Association of Petroleum Geologists Bulletin, v. 60, no. 3, p. 341-355.

Erxleben, A. W., 1975, Depositional systems in Canyon Group (Pennsylvanian System) north-central Texas: Report Investigations of the Bureau of Economic Geology, Austin, Texas: v. 82, 75 p.

Gilbert, G. K., 1885, The topographic features of lake shores: Fifth Annual Report, U.S. Geological Survey, p. 69-123.

Gottlesfeld, A. S., 1972, Paleoecology of the lower part of the Chinle Formation in the Petrified Forest, in Breed, C. S., and Breed, W. J., eds., Investigations in the Triassic Chinle Formation: Museum of Northern Arizona Bulletin, no. 47, p. 59-73.

Grout, M. A., and Verbeek, E. R., 1983, Field studies of joints--insufficiences and solutions, with examples from the Piceance Creek basin, Colorado, in, Gary, J. H., ed., Proceedings, 16th Oil Shale Symposium Golden, Colorado: Colorado School of Mines Press, 13 p.

Gubitosa, Richard, 1981, Depositional systems of the Moss Back Member, Chinle Formation (Upper Triassic), Canyonlands, Utah: Master's Thesis, Northern Arizona University, 98 p.

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

Huber, G. C., 1980, Stratigraphy and uranium deposits, Lisbon Valley District, San Juan County, Utah: Quarterly of the Colorado School of Mines, v. 75, no. 2, 45 p.

Johnels, A. G., and Svensson, S. O., 1955, On the biology of *Protopterus annectens* (Owen); Arkiv for Zoologi, Band 7, p. 131-164.

Johnson, H. S., Jr. and Thordarson, W., 1959, The Elk Ridge-White Canyon channel system, San Juan County, Utah: Its effect on uranium distribution: Economic Geology, v. 54, p. 119-129.

Miall, A. D., 1977, A review of the braided-river depositional environment: Earth Science Review, v. 13, p. 1-62.

Mifflin, M. D., 1967, Formation of mudlumps at Pyramid Lake, Nevada (Abs.): Program, 1967 Annual Meetings, Geological Socierty of America, New Orleans, Louisiana, p. 148A-149A.

Mifflin, M. D., 1970, Mudlumps and suggested genesis in Pyramid Lake, Nevada: Symposium on hydrology of deltas, Proceedings at Bucharest, Rumania Meeting, 1969; International Association of Science and Hydrology, no. 90, p. 75-88.

Miller, L. J., 1952, Uranium ore deposits of the Happy Jack Deposit, White Canyon, San Juan county, Utah: Economic Geology, v. 50, p. 159-169.

Morgan, J. P., 1961, Mudlumps at the mouths of the Mississippi River, *in*, Genesis and paleontology of the Mississippi River mudlumps: Louisiana Department of Conservation Geologic Bulletin, v. 35, 116 p.

Morgan, J. P., Coleman, J. P., and Gagliano, S. M., 1963, Mudlumps at the mouth of South Pass, Mississippi River; sedimentology, paleontology, structure, origin, and relation to deltaic processes: Louisiana State University Coastal Studies Series, v. 10, 190 p.

Morgan, J. P., Coleman, J. M., and Gagliano, S. M., 1968, Mudlumps: diapiric structures in Mississippi delta sediments: American Association of Petroleum Geologists Bulletin, no. 8, p. 145-161.

Reineck, H. E., and Singh, I. B., 1975, Depositional sedimentary environments: Springer-Verlag, New York, 439 p.

Rider, M. H., 1978, Growth faults in Carboniferous of Western Ireland: American Association of Petroleum Geologists Bulletin, v. 62, p. 2191-2213.

Rust, B. R., 1978, Depositional models for braided alluvium, *in* Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir, no. 5, p. 605-625.

Shepard, F. P., Dill, R. F., and Heezen, B. C., 1968, Diapiric intrusions in foreset slope sediments off Magdalena delta, Columbia: American Association of Petroleum Geologists Bulletin, v. 52, p. 2197-2207.

Short, K. C., and Stauble, A. J., 1967, Outline of the geology of the Niger delta: American Association of Petroleum Geologists Bulletin, v. 51, p. 761-779.

Smith, D. G., 1974, Aggradation of the Alexandra-North Saskatchewan River, Banff Park, Alberta, in Marisawa, M., ed., Fluvial geomorphology: Binghampton, State Univewrsity of New York, Publications in Geomorphology, p. 201-219.

Smith, D. G., 1976, Effect of vegetation on lateral migration of anastomosed channels of a glacial meltwater river: Geological Society of America Bulletin, v. 87, p. 857-860.

Smith, D. G., and Putnam, P. E., 1980, Anastomosed river deposits: modern and ancient examples in Alberta, Canada: Canadian Journal of Earth Science, v. 17, p. 1396-1406.

Smith, D. G., and Smith, N. D., 1980, Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta: Journal of Sedimentary Petrology, v. 50, p. 157-164.

Smith, J. F., Jr., Huff, L. C., Hinrich, E. N., and Luedke, R. G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geological Survey Professional Paper 363, 102 p.

Smith, N. D., 1970, The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians: Geological Society of America Bulletin, v. 81, p. 2293-3014.

Stewart, J. H., Williams, G. A., Albee, H. F., and Raup, O. B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geological Survey Bulletin 1046-Q, p. 487-576.

Stewart, J. H., Poole, F. G., and Wilson, R. F., 1972a, 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.

Stewart, J. H., Poole, F. G., and Wilson, R. F., 1972b, 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.

Thaden, R. E., Trites, A. F., Jr., and Finnel, T. L., 1964, Geology and ore deposits of the White Canyon area, San Juan and Garfield counties, Utah: U.S. Geological Survey Bull. 1125, 166 p.

Verbeek, E. R., and Grout, M. A., 1983, Fracture history of the northern Piceance Creek basin, northwestern Colorado, in Gary, J. H., ed., Proceedings, 16th Oil Shale Symposium, Golden, Colorado: Colorado School of Mines Press, 19 p.

Walters, J. E., 1959, Effects of structural movement on sedimentation in the Pheasant-Francitas area, Matogorda and Jackson counties, Texas: Texas Gulf Coast, Association Geol. Socs., v. 9, p. 51-58.

Weber, K. J., 1971, Sedimentological aspects of oil fields of the Niger delta: Geologie en Mijnbouw, v. 50, p. 559-576.

Weimer, R. J., 1973, A guide to uppermost Cretaceous stratigraphy, central Front Range, Colorado; deltaic sedimentation, growth faulting and early Laramide crustal movement: The Mountain Geologist, v. 10, no. 3, p. 53-97.

Whelan, T., III, and Roberts, H. H., 1973, Carbon isotope composition of diagenetic carbonate nodules from freshwater swamp sediments: Journal of Sedimentary Petrology, v. 43, p. 54-58.

Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona: U.S. Geological Survey Bulletin 1103, 171 p.