BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

VOLUME 36 • 1990

BRIGHAM YOUNG UNIVERSITY
GEOLOGY STUDIES

Volume 36, 1990

CONTENTS

A Publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted by BYU faculty and outside contributors is externally reviewed by at least two qualified persons.

ISSN 0068-1016
5-90 600 44626

Depositional History and Paleogeography of the Early to Late Triassic Ankareh Formation, Spanish Fork Canyon, Utah

RICHARD T. BRANDLEY
Department of Geology, Brigham Young University, Provo, Utah, 84602

Thesis Chairman: J. KEITH RIGBY

ABSTRACT

The Ankareh Formation is a continental red-bed deposit located in north central Utah, southeastern Idaho, and southwestern Wyoming. In Spanish Fork Canyon, Utah, the Ankareh Formation conformably overlies the marine Thaynes Formation and is conformably overlain by the eolian Navajo Sandstone. Deposition of the Ankareh Formation in north central Utah occurred on the eastern shore of the Cordilleran Miogeocline on a broad, gently sloping plain. Sediments are principally arkosic and were derived from the Uncompaghre Uplift situated in west central Colorado. Lowermost Ankareh rocks were deposited on tidal flats. These deposits were then covered by meandering stream deposits that make up the bulk of the formation. Estuarine facies are found at the tidal flat–meandering stream transition. Braided stream deposits indicate an episode of tectonic rejuvenation of the Uncompaghre Uplift in early to mid-Carnian. Eolian facies are found near the contact with the overlying Navajo Sandstone. Rocks of the Ankareh Formation were eventually completely covered by dune sands of the Navajo Sandstone. Paleosols are abundant and range from poorly developed arkosic paleosols to a well-developed profile containing silcrete and ferricrete. In Utah the formation is divided into three members: the lower Mahogany member, the middle Gartra Grit member, and the upper Stanaker member. The Mahogany member is equivalent to upper Moenkopi strata, the Gartra Grit member is equivalent to the Shinarump member of the Chinle Formation, and the Stanaker member is equivalent to the remainder of the Chinle Formation.

SIGNIFICANCE

The Ankareh and Navajo Formations are Triassic-Jurassic continental deposits well exposed in Spanish Fork Canyon, Utah. The formations were studied in order to determine the depositional history of the Ankareh Formation and the paleogeography of north central Utah in Triassic time. The study also yields additional information on sedimentary facies relationships in transitions from fluvial to eolian environments.

LOCATION

The area of study is located in Spanish Fork Canyon, near Diamond Fork, about 30 km southeast of Provo, Utah, in sections 16 and 17, T. 9 S, R. 4 E, on Spanish Fork Peak and Billies Mountain Quadrangles, Utah County, Utah (fig. 1). Three stratigraphic sections totaling 404 units were measured. Measured section 1 contains 211 units. It is exposed in the U.S. 6 roadcut at the southeastern edge of Diamond Fork Valley and extends along the roadcut to the first deep canyon in front of the Navajo Sandstone cuestas. It begins approximately 120 m above the Thaynes/Ankareh contact and encompasses 293.5 m of rock including most of the Mahogany member, all of the Gartra Grit member, and most of the Stanaker member. Measured section 2 is situated in the railroad cut topographically below section 1. It contains 126 units and encompasses 109.8 m of Ankareh rock, all of it in the Mahogany member. Measured section 3 is located along the railroad cut topographically below section 1. It contains 67 units and encompasses 73.2 m of rock including the Stanaker member and basalmost rocks of the Navajo Sandstone. Two other stratigraphic sections were examined, although not measured. The first is located on the west side of Diamond Fork Valley, west of the measured sections, and consists of lowermost Mahogany member

A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, April 1988.

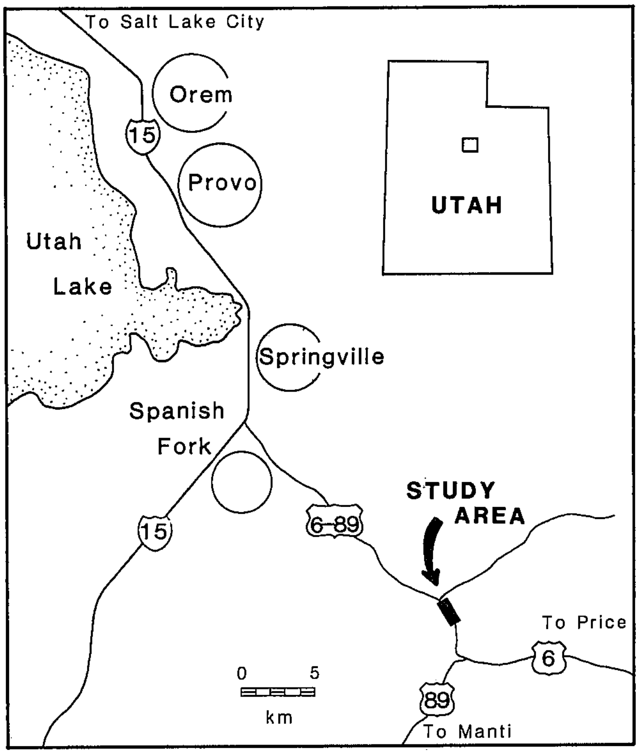

FIGURE 1.—*Index map showing location of the study area.*

rocks extending approximately 100 m upward from the Thaynes/Ankareh contact. The second is a complete section of the Ankareh Formation located at the mouth of Parley's Canyon just east of Salt Lake City, Utah.

PREVIOUS WORK

The Ankareh Formation was originally defined by Boutwell (1907, 1912) in the Park City mining district as the red beds between the Thaynes Formation and the Navajo Sandstone (fig. 2). For some time there was question and debate concerning the formation and its nomenclature. The names Stanaker Formation and Gartra Grit member of the Stanaker Formation were proposed for the upper Ankareh Formation by Thomas and Krueger (1946). However, Kummel (1954) proposed that the name Ankareh Formation be applied to all rocks between the Thaynes Formation and the Navajo Sandstone as Boutwell had originally done. The names Gartra Grit and Stanaker Formation were reduced to member status, thus dividing the Ankareh Formation into the lower Mahogany member, the middle Gartra Grit member, and the upper Stanaker member. Kummel (1954) also studied the Triassic stratigraphy in southeastern Idaho, northeastern Utah, and western and central Wyoming and proposed correlations for many of the Triassic units including the Ankareh Formation. Geologic mapping and stratigraphy near Diamond Fork was done, in part, by Baker (1947, 1972), Rawson (1957), and Young (1976). Three researchers, James (1980), Newman (1974), and Smith (1969), worked on the underlying Thaynes Formation at different locations in north central Utah. James (1980) researched and interpreted paleoenvironments of the section of Thaynes Formation that directly underlies the Ankareh sections studied in this project. No detailed work, however, has been published on the depositional environments of the Ankareh Formation in north central Utah. Preliminary stratigraphic sections were measured by students of the 1987 Brigham Young University summer field course, including Don Barnett, Robert Carman, Mitch Jensen, Victor Salcedo, Jenny Schindler, Marianne Seegmiller, and Li Ming Wu. Their measured sections were utilized as bases for more detailed study during this present research.

METHODS

Stratigraphic sections were measured with a Jacob's staff and Brunton compass. Unit thicknesses were measured to the nearest 0.1 m, and samples were taken of all major lithologies and facies. Paleocurrent directions were determined with a Brunton compass. Where precise current directions were obscure, general trends were noted. Color designations are those of the Geological Society of America rock color chart. The Wentworth-Udden grain-size scale (Lewis 1984) and Folk's (1974) sandstone scheme, modified to include siltstones, were used to classify clastic rocks. Limestone and dolostone classification is according to Dunham (1962). Thin sections were used to determine composition and texture of carbonate and clastic rocks. Clay mineralogy was determined by X-ray diffraction analysis.

TRIASSIC GEOLOGIC SETTING

Early Triassic western North America consisted of the north–south-trending Cordilleran Miogeocline extending from central Utah to central Nevada. The Cordilleran Miogeocline was bounded to the east by remnants of the Colorado Mountains and to the west by the Sonoman Orogenic Belt (Collinson and Hasenmueller 1978). North central Utah was at an approximate latitude of 10° north (Steiner 1983). The area from central Utah to central Nevada was at an elevation close to sea level. East central Utah was also quite low in elevation, considering that most of the Uncompaghre Uplift in Utah had been removed in Late Pennsylvanian and Permian time. The front of the Uncompaghre Uplift, by latest Spathian time (the beginning of Ankareh deposition), had retreated into east central Colorado. The Uncompaghre Uplift of the Colorado Mountains was supplying sediment westward across a gentle, sloping plain bordering the epeiric sea (Blakey 1974, Blakey and Gubitosa 1983, Stewart and

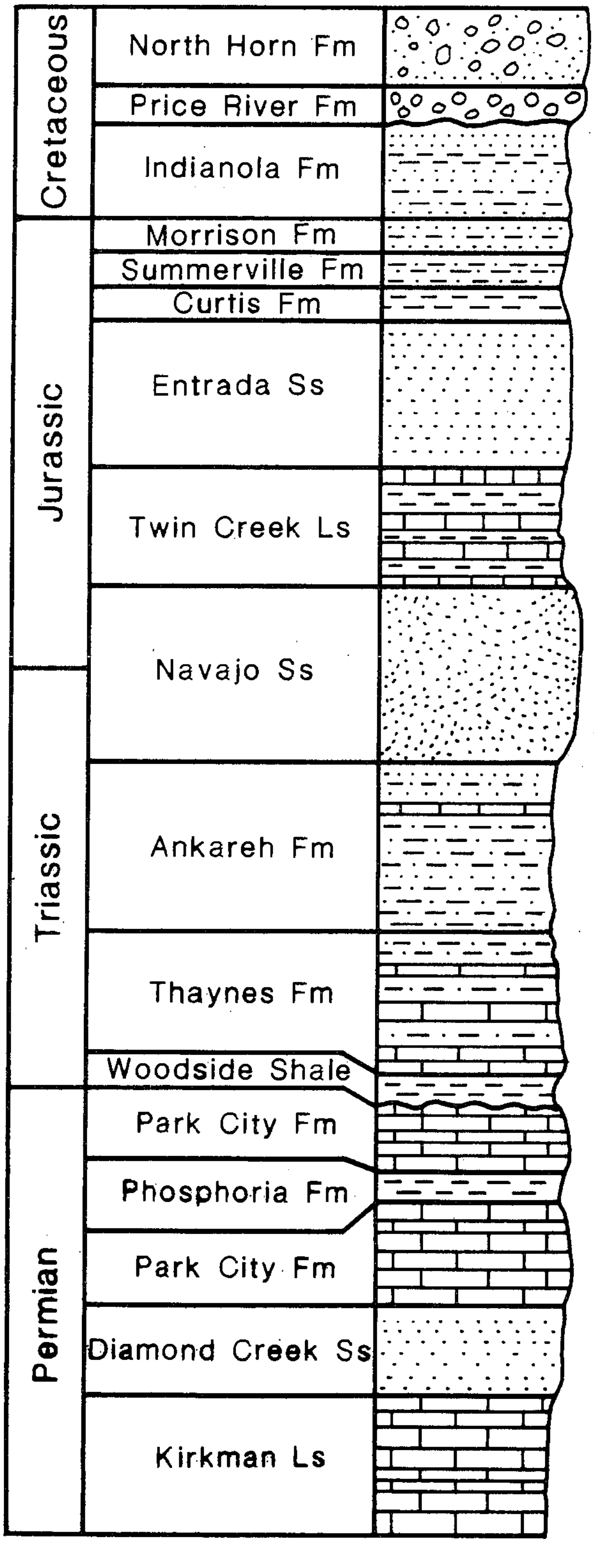

FIGURE 2.—*Stratigraphic column of the Spanish Fork Canyon area showing stratigraphic position of the Ankareh Formation. The Ankareh Formation is underlain by the marine Thaynes Formation and overlain by the eolian Navajo Sandstone. Modified from Hintze (1973).*

others 1972). Four transgressive episodes occurred in the miogeocline from Griesbachian through latest Spathian time (Carr and Paull 1983, Haq and others 1987). After the last of these transgressive episodes, widespread deposition of red-bed sediment occurred (Carr and Paull 1983) and resulted in deposition of the Mahogany member of the Ankareh Formation in north central Utah as well as deposition of the upper portions of the Moenkopi Formation in east central and southeastern Utah.

In Middle Triassic the Mesocordilleran High was formed to the west of the Cordilleran Miogeocline, stopping the sea from entering the miogeocline from the west (Blakey and Gubitosa 1983, Dickinson 1981, Stokes 1986). In Late Triassic the Cordilleran volcanic arc developed west and south of the miogeocline and caused an influx of volcanic debris in the sediments. Uplift blocked the northern entrance to the sea and produced a totally nonmarine basin (Blakey and Gubitosa 1983). North central Utah had moved northward to a latitude of approximately 11° north (Steiner 1983). It is in this tectonic setting that the Chinle Formation and the Gartra Grit and Stanaker members of the Ankareh Formation were deposited. The nonmarine basin was eventually inundated by eolian sands of the Navajo Sandstone.

CORRELATIONS

Figure 3 shows correlations and ages of the Ankareh Formation in north central and southeastern Utah. Age determinations are from Carr and Paull (1983), Collinson and Hasenmueller (1978), Imlay (1980), Pipiringos and O'Sullivan (1978), and Steiner (1983). The time scale is from Haq and others (1987). Kummel (1954) proposed that the Mahogany member of the Ankareh Formation was equivalent to the upper Moenkopi Formation in the eastern Uinta Mountains. Kummel also proposed the equivalency of the Gartra Grit member of the Ankareh Formation and the Shinarump member of the Chinle Formation as well as the equivalency of the Stanaker member of the Ankareh Formation and the rest of the Chinle Formation. This present research confirms the correlations made by Kummel.

SEDIMENTARY FACIES

Five major sedimentary facies are interpreted for rocks of the Ankareh Formation in Spanish Fork Canyon. These five facies are (1) meandering stream facies, (2) braided river facies, (3) estuarine facies, (4) supratidal facies, and (5) eolian facies.

Meandering stream environments are interpreted for parts of the Ankareh Formation based on models of meandering stream deposition proposed by Cant (1982), Miall (1984), Scholle and Spearing (1982), Schumm (1972), Turner (1980), Visher (1972), and Walker and Cant (1984).

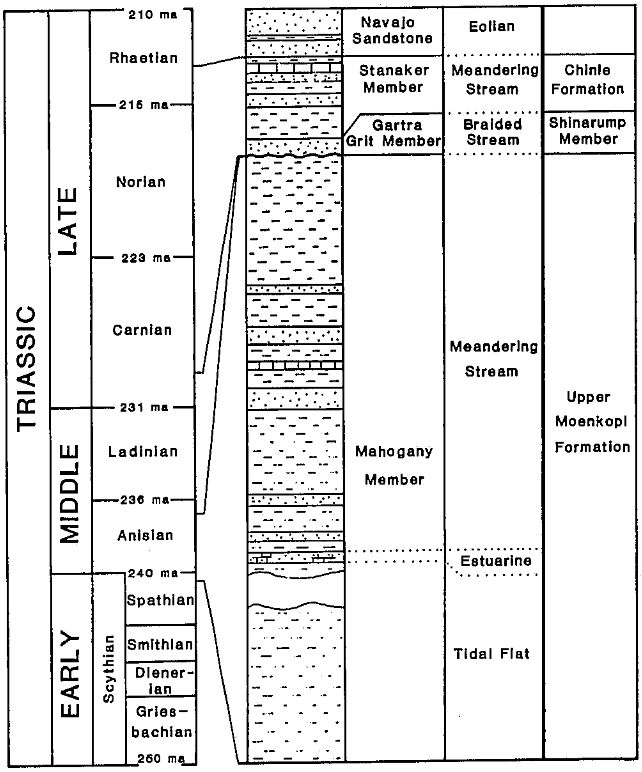

FIGURE 3.—*Generalized stratigraphic section of the Ankareh Formation and basalmost Navajo Sandstone in Spanish Fork Canyon. Ages of deposition are on the left. The two columns to the right of the stratigraphic section show Ankareh Formation members and interpreted environments of deposition for each. The far right column shows correlations with the Chinle and Moenkopi Formations. The Mahogany member, late Spathian to late Anisian, is equivalent to the upper Moenkopi Formation. The Gartra Grit member, early Carnian, is equivalent to the Shinarump member of the Chinle Formation, and the Stanaker member, mid-Carnian to mid-Rhaetian, is equivalent to the Chinle Formation above the Shinarump member.*

Braided stream interpretations are based on a braided stream model developed by Walker and Cant (1984). Eolian interpretations are based on eolian models from Bigarella (1972), Brookfield (1984), and Visher (1972). Tidal flat interpretations are based on models by Miall (1984), Reineck and Singh (1973), and Reinson (1984).

MEANDERING STREAM FACIES

Meandering stream facies are the most abundant in the formation. They consist of vertical accretion deposits that accumulate on floodplains due to overbank deposition, and also lateral accretion and channel-fill deposits (Walker and Cant 1984). Vertical accretion/floodplain deposits generally represent four depositional environments: (1) flood-basin, (2) levee, (3) splay, and (4) backswamp/pond environments. Lateral accretion and channel-fill deposits represent point-bar and stream channel environments.

Flood-Basin Facies

Rocks of the flood-basin facies make up approximately 70% of the measured sections. The facies is characterized by poorly resistant, dark reddish brown to moderate reddish brown mudstones with a blocky weathering habit and weak calcareous cement (fig. 4). Small greenish gray reduced spots are common. Units of this facies have an average thickness of approximately 0.4 m and are generally capped by siltstone. Mudcracks, raindrop impressions, load casts, and convolute laminations occur in these rocks. Small trough cross-beds are also locally found. Many of these flood-basin deposits developed into paleosols and contain root casts and caliche nodules. Mudcracks range in size from less than 2 cm deep and 1 cm wide to 60 cm deep and 5 cm wide at the top. Mudcracks become more abundant near the upper contact with the eolian Navajo Sandstone. Near the Ankareh/Navajo contact, evidence for the presence of evaporite minerals is found. Two thin-bedded mudstone units in measured section 3 show small teepee structures possibly caused by hydration of thin interbeds of anhydrite. Unit 31 of measured section 3, a shallow pond deposit, contains deformed gypsum crystal casts in its basal mudstones. Thin-bedded gypsum was located by Thomas and Krueger (1946) in Ankareh exposures near Lake Fork on the southern flank of the Uinta Mountains northeast of Spanish Fork Canyon.

Levee Facies

Levee facies rocks are characterized by moderately resistant, moderate reddish brown to greenish gray siltstones (fig. 4). The rocks are calcareous and generally have a platy weathering habit made prominent by cross-beds weathered into relief. Small greenish gray reduced spots are common. Units of this facies average approximately 0.3 m thick and are usually overlain by flood-basin mudstones. Small trough cross-beds are found in almost all units of the facies. Small undulatory crested ripple marks occur locally. Flaser cross-beds are poorly developed and rare. Load casts and convolute laminations frequently occur at basal contacts where levee siltstones flooded out over flood-basin mudstones. Root casts and root impressions are locally preserved. Some small vertical and horizontal burrows were observed in thin section.

Splay Facies

Splay facies rocks in the Ankareh Formation are characteristically coarse siltstone to very fine-grained sandstone and are moderately resistant to resistant (figs. 5, 6). They

FIGURE 4.—*Typical flood-basin and levee deposits. Resistant beds are siltstone levee deposits. Nonresistant beds are mudstone flood-basin deposits. Hammer is 32 cm long.*

are generally moderate reddish brown with small greenish gray reduced spots and have sharp non-eroded, lower contacts. The cement is calcareous. Bed thickness ranges from 0.3 m to over 4 m. Most units of this facies contain small-scale trough cross-beds, local large-scale trough cross-beds, and horizontal parallel laminations. Imbricated clay rip-up clasts occur in some units. Many splay deposits contain channel fills and epsilon cross-beds, indicating intrasplay channels several meters wide and up to 2 m deep. Root casts are commonly preserved.

Backswamp/Pond Facies

Rocks of the backswamp/pond facies in the Ankareh Formation range from unfossiliferous silty lime mudstones to silty lime and dolomite wackestones, packstones, and grainstones. Rocks of this facies are typically greenish gray and up to 0.3 m thick (fig. 7). Beds are laterally continuous and were deposited in lakes or marshes a kilometer or more wide. Ostracod carapaces, peloids, silty lime mudstone intraclasts, and gastropod fecal pellets make up the allochems. Basal mudstones are locally bioturbated with horizontal burrows. Small vertical and horizontal burrows were seen in thin section. Trace fossils are poorly preserved and do not fit into the Scoyenia Ichnofacies as redefined by Frey and Pemberton (1984).

Point-Bar Accretion Facies

Rocks of this facies are characterized principally by bed geometry, spatial relationship to channel facies, grain size, and sedimentary structures. Point-bar deposits commonly exhibit typical epsilon cross-beds that visibly thin on both ends. Grain size ranges from coarse siltstone to fine-grained sandstone. The deposits commonly occur lateral to channel fills (figs. 5, 6). Small- and large-scale trough cross-beds, horizontal laminar beds, parting lineations, and clay pebble rip-up clasts are characteristic of Ankareh point-bar accretion facies. Bed thickness ranges from less than 1 m to approximately 7 m, and length of the deposits ranges from less than 1 m up to 30 m. Oscillation ripple marks were found near the top of a point-bar accretion deposit in a mudstone swale filling. Fossils are not found in units of this facies.

Channel-Fill Facies

Channel fills range from moderate reddish brown to moderate yellowish brown or grayish orange pink, mudstone to conglomerate (figs. 5, 6). By far, however, the most abundant grain sizes are mudstone, siltstone, and fine-grained sandstone. Channel fills range in size from less than 1 m wide and 0.2 m deep to approximately 100 m wide and 7 m deep. There are no distinguishable fining upward sequences in the measured sections due to the limited range of grain sizes available to the streams—coarse siltstone to very fine-grained sandstone. Channel lag is very scarce and is limited to granule and pebble-size clay rip-up clasts, which may or may not be imbricated. Unit 202 of measured section 1 is the exception to this, as it contains abundant pebble-sized, clay bank–collapse clasts as channel lag in coarse- to medium-grained sandstones. Small and large trough cross-beds are common. Horizontal parallel laminations and parting lineations also occur in this facies. Channel geometry and scoured bases that commonly exhibit load casts, sole marks, and flute casts are primary evidence for this facies.

Rocks of the channel-fill facies are preserved as a result of either chute or neck cutoff. Chute cutoff channels are characterized by thick waning-current sequences and thin or nonexistent oxbow fillings. Neck cutoff channel fills are characterized by thin waning-flow deposits and thick oxbow fillings (Walker and Cant 1984). Local root impressions and root casts are found in chute cutoff channel-fills. Caliche nodules are locally found in neck cutoff channel fills.

Silicified conifer wood was found in unit 202 of measured section 1 and unit 5 of measured section 3, which are equivalent beds. The preserved wood is dark brown, dense, and usually occurs as elongate slivers with wedge-shaped cross sections. Many such slivers are visible in the outcrop and are generally less than 0.1 m long and 1 cm across. A stick or branch of silicified wood exposed in unit 202 of section 1 is approximately 0.1 m in diameter and 0.3 m long. Siltstone and sandstone deposits of unit 202 in measured section 1 contain two logs of carbonized wood of unknown taxonomy. The carbonized wood is dark brown to black with visible growth rings. Greenish clayey mate-

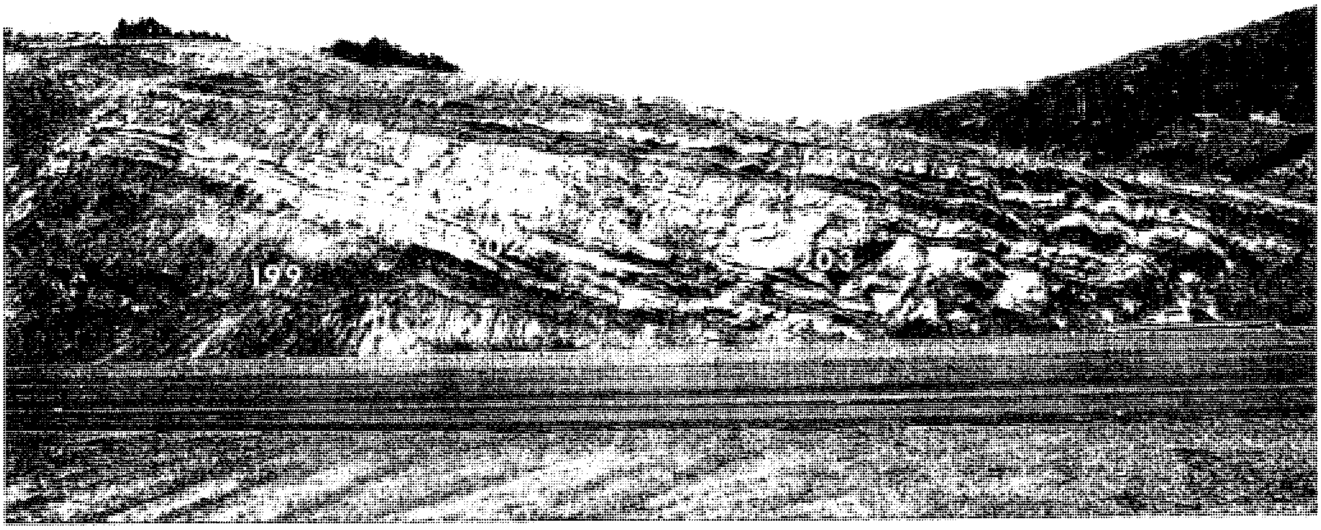

FIGURE 5.—*Photograph of channel-fill, point-bar, splay, levee, and flood-basin deposits in the Stanaker member of measured section 1. Unit 199 is a flood-basin deposit that has developed into a paleosol. Unit 202 consists of chute cutoff channel fills, point-bar accretion surfaces, and levee deposits. Unit 203 is a splay deposit that rests on the channel fills of unit 202.*

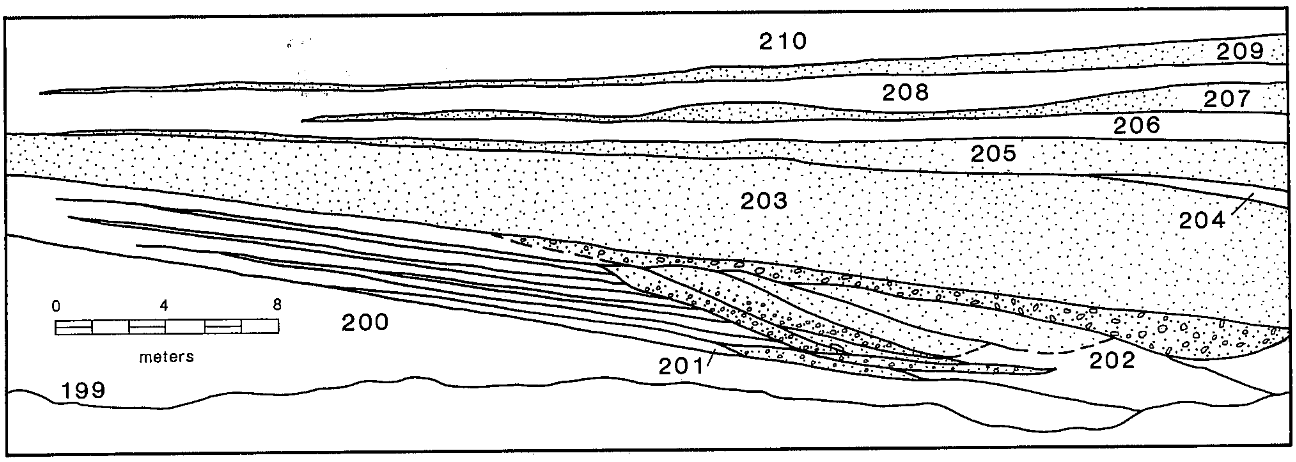

FIGURE 6.—*Diagram of figure 5 showing relationships between channel-fill, point-bar, levee, and splay deposits. In late Triassic the channel of unit 202 covered paleosols of units 199 and 200 and cut laterally to the right into its own levee deposits. The channel fill and levees were then overlain by a series of splay deposits (units 203, 205, 207, and 209) and interbedded flood-basin deposits (units 204, 206, 208, and 210).*

rial coats each log and fills cavities. The logs are up to 0.2 m in diameter and have exposed lengths of up to 0.5 m. Total lengths of the imbedded fragments are unknown.

Bone fragments were found as channel lag in the uppermost conglomeratic channel fill of unit 202 of measured section 1. The bone fragments are common and are up to 3 cm in diameter. Fragments are typically gray to black and have grayish black halos around them. Most fragments have undergone significant abrasion because of stream transport. One lungfish toothplate, approximately 4 cm across and 1 cm thick (fig. 8), was also found as channel lag and identified as such by H. P. Schulze.

Interpretation

Meandering streams that deposited rocks of the Ankareh Formation were generally small with bank-full dimensions ranging from a few meters wide and 1 m deep up to approximately 100 m wide and 7 m deep. The streams flowed northwestward down the regional paleo-

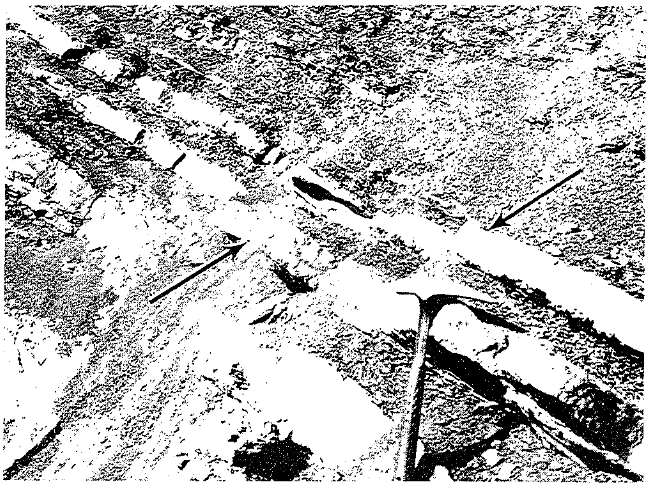

FIGURE 7.—*Typical backswamp/pond deposits (arrows). The limestone beds are generally 10 to 15 cm thick, may be laterally continuous for over a km, and contain ostracods, gastropod fecal pellets, peloids, and local bioturbation. Hammer is 32 cm long.*

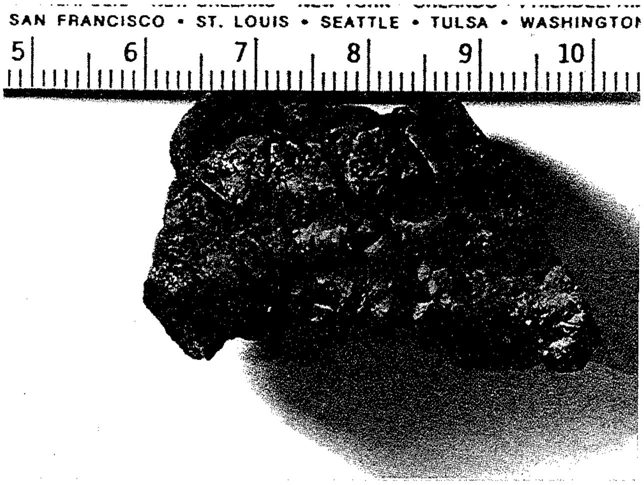

FIGURE 8.—*Photograph of a lungfish toothplate from unit 202 of measured section 1. The view is of the upper surface and shows aligned ridges and grooves parallel to the long axis of the toothplate. Scale is in centimeters.*

slope (fig. 9). Epsilon cross-beds are up to 30 m long and 7 m thick. Some epsilon cross-beds show well-developed swell-and-swale topography on their upper surfaces, with mudstones deposited in the swales. Splay deposits were also small, generally less than 4 m thick. Several splay deposits contain channel fills and epsilon cross-beds, indicating intrasplay channels several meters wide and up to 2 m deep. Levee deposits are generally less than 1 m thick, also indicating relatively small streams. The streams were slow-moving and of low competency, as evidenced by abundant fine-grained sediments and small-scale sedimentary structures, and a distinct lack of coarse sediments and coarse channel lag.

Rocks of the formation, particularly in the Mahogany member, show unusually thick vertical accretion sequences of flood-basin mudstones and levee siltstones. The sequences range from less than 1 m to 85.6 m thick. More than one third of the sequences are greater than 10 m thick. Average thickness is 14.42 m. Based on a composite model of meandering stream deposition, Allen (1970) concluded that the average thickness of vertical accretion sequences for meandering stream systems is 3.86 m. Walker and Cant (1984) suggested that vertical accretion deposits greater than 10 m thick may result from stream confinement to meander belts. Thicknesses of vertical accretion sequences in the formation suggest that stream confinement did occur and that in some instances, particularly in the Mahogany member, confinement lasted for a considerable length of time.

The coarse conglomerate and channel fills of unit 202 of measured section 1 suggest a brief period of tectonic activity during deposition of the Stanaker member. Shallow ponds up to a kilometer or more across formed in some of the flood basins. Color of these pond deposits as well as fossil type and the scarcity of fossils indicate that the ponds were poorly oxygenated, stagnant, and unable to support much animal life other than ostracods and small gastropods.

The presence of gypsum in flood-basin rocks near the Ankareh-Navajo contact may indicate that evaporative conditions in an arid climate existed during Late Triassic. Caliche nodules found throughout the deposits suggest that climate conditions were quite arid. The possibility of increasing aridity in Late Triassic is also suggested by the distinct absence of plant fossils and paleosols within approximately 45 m of the Ankareh-Navajo contact. There is no obvious reason for this lack of plant fossils or paleosols in meandering stream rocks other than the increasingly arid conditions that accompanied the encroachment of the desert of the Navajo Sandstone.

BRAIDED RIVER FACIES

Rocks deposited in braided river systems are seen only in unit 192 of measured section 1. This unit is anomalous in both depositional and petrologic character. The sediments are moderately well-sorted, medium- to coarse-grained quartz sand with very sparse quartzite pebbles near the base. The unit fines upward from coarse to medium sand and is capped by siltstone channel fills showing parting lineations. Silica is the dominant cementing agent. The rocks are characterized by lenticular channel fills, up to 1 m deep and 4 m wide, that are stacked into a unit approximately 10 m thick. Large-scale trough cross-beds, up to 1 m high, and small-scale trough cross-beds are both common. Mudstone and siltstone are

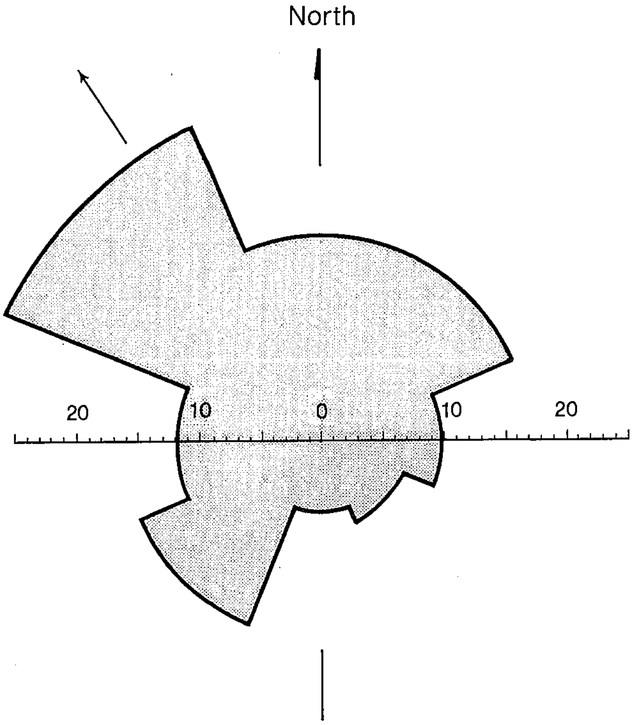

FIGURE 9.—*Rose diagram of paleocurrent directions of the Ankareh Formation. Mean current direction is 327° and is indicated by the arrow. The mean R value is 0.363. N = 117.*

very sparse, and any occurrence is usually in small pockets between sandstone, channel-fill lenses. Current directions are dominantly to the northwest, but southwest, north, southeast, and east current directions are also found.

Interpretation

These rocks were deposited by braided streams that were dominated by channels and had few channel bars or sand flats. The unit is the Gartra Grit member of the Ankareh Formation and is equivalent to the Shinarump member of the Chinle Formation (fig. 3). The Gartra Grit member formed in response to tectonic uplift to the southeast, possibly a reactivation of the Uncompaghre Uplift, the front of which was in west central Colorado. According to Thomas and Krueger (1946), the Gartra Grit is found throughout the Uinta Mountains to the north of Spanish Fork Canyon. Its thickness ranges from 8 m near Hanna, Utah, to 28 m near Jensen, Utah. Near Manila, Utah, on the north flank of the Uinta Mountains, the Gartra Grit is composed of purplish red limestone pebbles set in purplish red coarse-grained sandstone (Thomas and Krueger 1946), indicating a source area different from that of the Gartra Grit member exposed on the south flank of the Uinta Mountains. Baker (1947) examined the Ankareh Formation at Diamond Fork and was unable to distinguish the Gartra Grit member. This is probably because the Gartra Grit member in Spanish Fork Canyon is considerably less resistant, finer grained, and less conglomeratic than at Parley's Canyon near Salt Lake City and at other localities, based on information from Kummel (1954) and Thomas and Krueger (1946). The Gartra Grit in Spanish Fork Canyon is not a ledge former as it is in Parley's Canyon.

ESTUARINE FACIES

A distinct marine influence is seen in three beds in the formation. These beds are located approximately 130 m up from the base of the Mahogany member. Each bed is less than 1 m thick and is composed of light yellow brown calcareous sandstone. Sand grains are well rounded and well sorted. The sand is medium to coarse grained with sparse granules to 2 mm in diameter. Sand grains are quartz, feldspar, and chalcedony and are cemented with displacive calcite cement. Trough cross-beds up to 0.1 m thick and 0.4 m long are found. Current directions are to the northwest. Micrite fecal pellets and rounded echinoderm fragments identified as such by J. K. Rigby and myself are moderately abundant in the unit. These beds are located near the transition of supratidal flats of the lower part of the Mahogany member and meandering stream deposits of the upper part of the Mahogany member. They are interbedded with very fine-grained sandstone channel fills of meandering stream origin. Exposures are limited and geometries cannot be determined precisely.

Interpretation

These beds represent a marine influence in a supratidal environment. They are significantly different from adjacent channel fills in that they show a marine influence in the form of echinoderm fragments. They probably represent estuarine environments that existed during early Triassic when the epeiric sea was still open. Alternatively, they may represent minor marine transgressions or incursions of the sea onto the supratidal flats. The rounded nature of the echinoderm fragments suggests they were transported into the environment of deposition.

SUPRATIDAL FACIES

Rocks of the supratidal facies are characterized by thick sequences of dark reddish brown to dusky red mudstone with sparse thin beds of dark to moderate reddish brown siltstone. Mudstone sequences are up to 30 m thick. The mudstones are very thin bedded, ripple marked, and show small trough cross-beds and local flaser cross-beds. Currents are to the northwest. Siltstone beds are less than

10 cm thick and occur individually, separated by thick mudstones. Small vertical and horizontal burrows are rarely found. This facies is exposed on the western side of Diamond Fork Valley for approximately 100 m above the Thaynes-Ankareh contact.

Interpretation

This facies represents supratidal deposition on a gently dipping tidal plain that bordered the eastern shore of the epeiric sea in the Cordilleran Miogeocline. The rocks show evidence of basinward current movement rather than bidirectional current movement as is sometimes found in tidal flat deposits. The tidal flats were mostly subaerially exposed as indicated by the oxidized color of the rocks. Trace fossils are not abundant, which suggests that the environment was very harsh. Subaqueous dominated tidal flats of the underlying marine Thaynes Formation grade into these subaerially dominated tidal flats of the Mahogany member.

EOLIAN FACIES

Locally, in the upper Stanaker member, eolian deposits occur interbedded with meandering stream floodplain deposits. The eolian facies consists of moderate reddish brown to moderate reddish orange to grayish orange, fine- to medium-grained quartz sandstones. The deposits range from 3.2 m to 4.4 m thick. Large trough cross-beds and wedge planar cross-beds are common. Cross-bed sets are up to 1 m high and 3 m long. Small trough cross-beds indicating eolian ripples are also common. The quartz sand is well sorted, well rounded, and cemented with both silica and calcite. The deposits coarsen upward and contain clay clasts as lag along some laminae. Wind directions were to the south, southeast, and east. All of these deposits occur within 47 m of the basal contact of the Navajo Sandstone.

In addition to these deposits that are distinctly eolian, several units in the formation near the Ankareh/Navajo contact contain evidence for sand being blown into fluvial channels. The channels exhibit distinct basal scouring and load casting and are filled with fine-grained to very fine-grained quartz sand and arkosic mud that occurs as matrix or in thin lenses. Quartz grains are well rounded and appear unimodal. Small trough cross-beds, climbing ripple cross-beds, horizontal laminations, and load casting at basal contacts are common. Current directions are to the southeast. The channel fills are peculiar in that their mineralogy, grain size, sorting, rounding, and current directions are much different than surrounding channel fills and floodplain deposits. Petrologic aspects of these channel fills relate the quartz sands most closely with eolian deposits of the Navajo Sandstone. Local mudcracks near the Ankareh/Navajo contact contain similar fillings composed of arkosic mudstone mixed with well-rounded, unimodal fine-grained quartz sand.

Beginning with the basal unit of the Navajo Sandstone, deposition is dominantly eolian with some fluvial interludes. These eolian deposits consist of moderate yellowish brown to grayish orange pink fine-grained, well-rounded, quartz sand with 2 m high tabular-planar and wedge-planar cross-beds. Second-order bounding surfaces near the lower Navajo contact contain small hematite pseudomorphs of pyrite. Fluvial interludes in the eolian deposition are abrupt and short-lived and consist of poorly sorted mudstone and siltstone to coarse-grained sandstone with abundant, small, trough cross-beds and pale green to dark reddish brown, granule to pebble-sized rip-up clasts. Bases of these fluvial interludes show scouring and currents to the northwest. Above this zone of mixed eolian-fluvial deposition is the Navajo Sandstone, which, at this locality, consists of moderate reddish brown to grayish orange pink quartz sand. The sand is fine grained, well sorted, well rounded, and slightly calcareous. Large wedge-planar and trough cross-beds are abundant.

Interpretation

The Stanaker member records a transition from meandering stream deposition to eolian deposition of the Navajo Sandstone. This transitional record consists of (1) mixed eolian and meandering stream deposition, (2) eolian deposition with fluvial interludes, and (3) eolian deposition of the Navajo Sandstone. Mixed eolian and meandering stream deposition probably represents a period when winds swept dune sands across the meandering stream environment. Locally, sand dunes were formed on floodplain deposits. These dunes eventually subsided and were overlain by later floodplain sediments. In some instances the wind blew sand into fluvial channels, either after the channels were abandoned or while they contained water. As winds swept sand across the desiccated floodplains, the winds also picked up fluvial sediments by deflation and deposited the mixture of arkosic fluvial sediments and quartz-rich eolian sediments in desiccation cracks. As the body of the desert moved closer, the influx of sand became so great that meandering stream processes were slowed and eventually stopped, and large eolian sand sheets covered meandering stream deposits of the Stanaker member. During this period of time, some intermittent streams still managed to flow across the desert and rework the eolian sands, mixing them with arkosic mudstone. The water table was initially high, and the dunes record their subsidence below the water table in the form of pyrite crystals that were later oxidized to hematite. After a period of time the intermittent streams ceased to flow, and eolian processes created the inland sand sea of the Navajo Sandstone. The encroachment of sands of the Navajo Sandstone over meandering stream deposits of the Stanaker member probably indicate a changing climate—one that was becoming increasingly arid. Increasing aridity is also indicated by a lack of plant fossils and paleosols and by the presence of gypsum as discussed above.

PETROLOGY

CLASTIC ROCKS

Twenty-seven rock units were analyzed to determine composition and texture. Samples were chosen to represent each of the different facies dominated by terrigenous clastic sediments: nine samples from the channel-fill and point-bar facies, eight from the levee facies, six from the flood-basin facies, and four from the splay facies. Thin sections and insoluble residues were prepared by standard procedures and used in the petrologic analyses. Point counts on individual thin sections ranged from approximately 150 to over 350, but were generally between 300 and 350. Counts of mudstone and fine- to medium-grained siltstone were low (less than 250), and thus produced only approximate analyses. Roundness and sorting were determined by visual comparison to standard charts. Maximum and minimum grain sizes were determined by averaging 20 grains for each limit in thin section.

Figure 10 is a trinary diagram of quartz, feldspar, and lithic fragments. Each of the twenty-seven thin sections studied were plotted on the diagram according to their compositions. Twenty-one of the twenty-seven samples have the same approximate arkosic mineralogy. This natural grouping of similar compositions is labeled Field A on figure 10. Based on these sampled units, as well as field observations of units not sampled, more than 85% of the rocks of the Ankareh Formation are arkosic. The remainder of the sampled rocks are sublitharenite to subarkose (Field B of fig. 10) and feldspathic litharenite to lithic arkose (Field C of fig. 10). The following is a detailed description of each of these compositional fields and their relationships to the various facies.

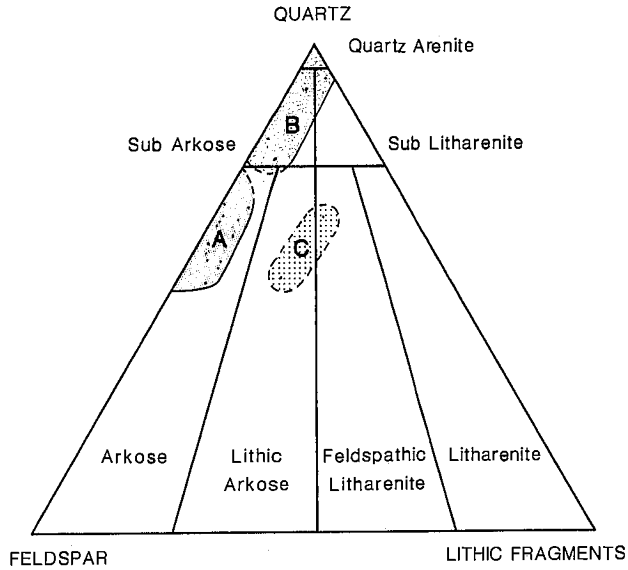

FIGURE 10.—*Classification of clastic rocks modified from Folk (1974). Twenty-seven samples representing the various sedimentary facies were plotted on this diagram. Of these 27 samples, 21 are arkosic and have the same approximate mineralogy, designated A on the diagram. Field A, therefore, represents the dominant mineralogy of Ankareh rocks. Fields B and C reflect variations from the dominant arkosic mineralogy.*

Field A

All sampled rocks of the flood-basin facies, all of the splay facies, 76% of the levee facies rocks, and 44% of the channel-fill and point-bar facies rocks have arkosic compositions and plot in Field A on figure 10. Because this field represents the composition of samples from various facies, it contains a range of grain sizes from mudstone to very fine-grained sandstone. These arkosic sediments contain clean, generally monocrystalline quartz and both plagioclase and alkali feldspar including minor microcline and perthite. Quartz constitutes up to 74% of the grains, and feldspars compose up to 50% of the grains. Feldspar grain surfaces tend to be altered. Chert fragments, clay grains, and fine sedimentary rock fragments constitute the lithic fragments and compose less than 10% of the grains. Chlorite, epidote, biotite, muscovite, and Fe-Ti oxides occur in varying amounts but usually make up less than 5% of the grains. Tourmaline and zircon grains were consistently found throughout the samples, but usually constitute less than 1% of the grains. Calcite and hematite are the cementing agents. The rocks have generally undergone only slight compaction. Most grain contacts are point or concavo/convex. Some grains have solution embayments indicating that diagenetic fluids moved through the sediments. Mica flakes are generally broken and bent by quartz grains, indicating a principally detrital origin for the mica.

Field B

The second compositional field consists of medium-grained to very fine-grained subarkose to sublitharenites. Thirty-three percent of the channel-fill and point-bar facies as well as 12% of the levee facies rocks are subarkose to sublitharenite and plot in Field B on figure 10. Although these sediments have similar compositions and thus plot together, there are no common genetic factors involved in their formation. Some were deposited in sandy braided stream environments, others in mixed eolian/fluvial environments, and still others in estuarine environments. Sediments from each environment will be discussed individually.

Those sediments deposited in braided stream environments (the Gartra Grit member) show evidence of slight metamorphism due to compaction. They are well-sorted, medium-grained quartz sandstones. Grains are angular to subangular. The rock is 90% quartz, has 6% alkali and plagioclase feldspar including microcline, and 4% lithic fragments that are mostly chert and fine-grained sedimentary rocks. Scarce metamorphic rock fragments were also found. Sparse quartzite pebbles are found near the base of the unit. There is less than 1% each of chlorite, biotite, muscovite, and epidote grains. Quartz grains are generally monocrystalline, but some polycrystalline strained quartz is found. Optically continuous euhedral quartz overgrowths cement the grains.

Sediments deposited in mixed fluvial/eolian environments are the least quartz rich in this field. These rocks are poorly sorted with quartz grains ranging from silt size to medium-grained sand size. Quartz constitutes approximately 80% of the grains, with alkali and plagioclase feldspar making up 19% of the grains. Lithic fragments are composed of fine-grained sedimentary rock and kaolin clay and make up 4% of the grains. Muscovite, biotite, chlorite, Fe/Ti oxides, tourmaline, and epidote make up less than 1% each of the grains. In one sample, cementation occurred in three episodes. Initially silica was introduced and cemented the rocks. Later, the silica cement was partially replaced with siderite/dolomite, which was then partially replaced with calcite. The dolomite/siderite rhombs appear zoned from iron-poor centers to iron-rich rims. These subarkosic Field B sediments could feasibly grade from arkosic Field A sediments at one extreme to quartz arenite eolian sediments at the other extreme. Based on field observations, Field B sediments of this origin become more abundant near the Ankareh/Navajo contact, reflecting increased interaction with quartz-rich sediments of the Navajo Sandstone. They result from abandoned fluvial channels being filled with eolian sands or from flowing streams having sand blown into them. Field observations describing these deposits are found in the eolian facies section of this paper.

Sediments of mixed marine/fluvial origin are moderately sorted, fine-grained calcareous sandstone. Grains are subrounded to well rounded. Clean, monocrystalline quartz makes up 93% of the grains. Alkali and plagioclase feldspar including perthite make up 2% of the grains, and chert, chalcedony, fine sedimentary rock, and illite compose 5% of the grains. Biotite, Fe/Ti oxides, chlorite, and tourmaline make up less than 1% each of the grains. The rock contains 38% displacive calcite cement by weight. Rounded echinoderm fragments are moderately abundant. Micrite fecal pellets are also found. The unit was probably deposited in an estuarine environment as discussed above.

Field C

Rocks that group in Field C of figure 10 range from very fine-grained feldspathic litharenite to medium-grained lithic arkose. These sediments occur in units 50–53 of section 1 and units 34–36 of section 2, which are stratigraphically equivalent beds. These beds are channel-fill and point-bar sheet sandstones up to 12.4 m thick with very little interbedded floodplain material. The only other observed field C sediments in the formation occur in units 202 of section 1 and unit 5 in section 3, which are equivalent beds. These beds are also channel-fill and point-bar deposits up to 2.7 m thick. Quartz grains in both these rocks are generally monocrystalline, but some polycrystalline grains were found. Both plagioclase and alkali feldspars occur, including microcline and perthite. Feldspar constitutes 16% to 30% of the grains. Lithic fragments are generally clay grains, chert, and fine-grained sedimentary rock and make up less than 20% of the grains. Biotite, partially to completely altered to chlorite, makes up 14% of the grains in the feldspathic litharenite and less than 1% in the lithic arkose. Epidote, muscovite, unaltered biotite, Fe/Ti oxides, tourmaline, and zircon are also found and compose less than 5% of the grains. Both hematite and calcite cements occur.

The feldspathic litharenite sheet sandstones of units 50–53 of measured section 1 contain sparse, rounded, medium to fine quartz grains as well as rare silt size, rounded echinoderm (?) fragments. The major compositional difference between Fields A and C is the increase in lithic fragments in Field C rocks. These fragments are principally detrital clay grains and may have been incorporated in the stream systems as they cut into floodplain deposits of the Ankareh Formation itself or of the upstream-lying Moenkopi Formation. Thickness, lateral extent, coarser grain size, and channel origin of units with this mineralogy suggest that minor uplift caused streams to downcut into previously deposited sedimentary material, thus incorporating clasts of fine-grained sedimentary rock and clay.

RELATIONSHIP TO MOENKOPI SEDIMENTS

Cadigan (1971) studied the petrology of the laterally equivalent upper Moenkopi Formation in the Colorado Plateau region. The petrology of the two formations is quite similar except that Mahogany member rocks lack lithic fragments such as quartzite, granite, felsite, and volcanic tuff as are found in Moenkopi sediments. Mahogany member sediments also tend to be finer grained with a higher portion of mudstone than Moenkopi sediments. Graywacke, marine limestones, and quartz arenites are nonexistent in the Mahogany member of the Ankareh Formation. These variations in the petrology of Mahogany member sediments as compared to Moenkopi sediments suggest that Mahogany member sediments are more distal to the Uncompaghre Highland of southwestern Colorado than are upper Moenkopi sediments.

CARBONATE ROCKS

Carbonate rocks in the Ankareh Formation represent backswamp/pond environments that formed on floodplains of meandering streams. The rocks range from greenish gray, silty lime mudstones to silty, pelletal, intraclast, and ostracodal lime and dolomite wackestones, packstones, and grainstones. Peloids and pellets range from 1.4 mm to 3 mm in diameter. Some units contain ostracod carapaces generally less than 0.4 mm long. Micro cross-laminations and small trace fossils are locally present. Silt content ranges from 20% to 30%. Locally the rocks have been dolomitized and have lost most of their primary structure.

PALEOSOLS

Paleosols are found in flood-basin, levee, splay, and neck cutoff channel-fill facies. They are characterized principally by root casts, root impressions, caliche nodules, and color changes. Detectable microscopic soil textures, greenish gray mottling, disruption of bedding, and lack of sedimentary structures and bedding are also characteristic of the more developed paleosols.

FEATURES

Root Casts

Root casts are of two types: (1) casts of subvertical taproots, and (2) casts of subhorizontal runner and rhizome systems. Subvertical taproot casts are most abundant and are generally less than 4 cm in diameter and 0.7 m long. They commonly exhibit only minor branching of smaller rootlets from the main taproot. Casts of local tuber-shaped taproots, however, show horizontal runners up to 4 cm in diameter extending laterally outward from the main taproot.

The second type of root cast consists of well-preserved casts of subhorizontally growing runner and rhizome root systems. Unit 98 of section 1, for example, contains casts of runners approximately 5 cm in diameter and traceable for 30 cm, although they are probably much longer. These runners terminate in rhizomes that have casts of small roots, approximately 1 cm in diameter, that penetrate downward. There is a cast of a thin stem as well, less than 1 cm in diameter, that grew upward from the rhizome. Unit 89 of section 2 also contains well-preserved casts of a runner and rhizome system, complete with a stem approximately 0.1 m in diameter. The stem has a raised ridge with buds from which roots or leaves possibly grew. The exposed horizontal root system is approximately 2 m long (fig. 11). Root casts are commonly found in rocks of the flood-basin and splay facies.

Root Impressions

Root impressions are of three types: (1) shallow branching roots; (2) long subvertical taproots; and (3) inverted, cone-shaped bulbs. Shallow, branching root systems consist of a main, subvertical root with a dense network of smaller, branching roots (fig. 12). Lateral penetration of the roots is almost as great as their vertical penetration. These root impressions have a maximum preserved length of approximately 0.6 m and a maximum diameter of approximately 2 cm. Preservation is good enough to allow distinction of rootlets less than 1.0 mm in diameter. The second type of root impressions are those of taproots that range from 0.6 m to 2.0 m long and taper downward from a preserved maximum diameter of 3 cm. They consist essentially of a main taproot with only a few smaller branching roots. The taproots are also well preserved, and rootlets less than 1 mm in diameter are preserved on some root impressions. The third type of root impressions are of plant bulbs (?) (fig. 13) that have an inverted triangular or cone shape and are generally less than 5 cm across at their widest. A taproot, up to 1 cm in diameter and several tens of centimeters long, extends downward from the lower point of the triangle. The top of the bulb has thin spikes that arch upward and outward from the bulb at

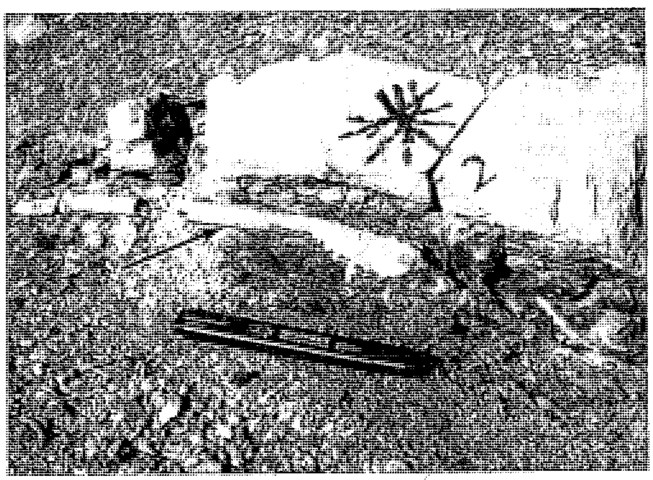

FIGURE 11.—*Cast of a horizontal root system (arrow) in flood-basin mudstones. The top of the photograph is up. A rhizome is situated between two runners. The rhizome shows casts of small roots that grew downward from the body of the rhizome. Pen is approximately 15 cm long.*

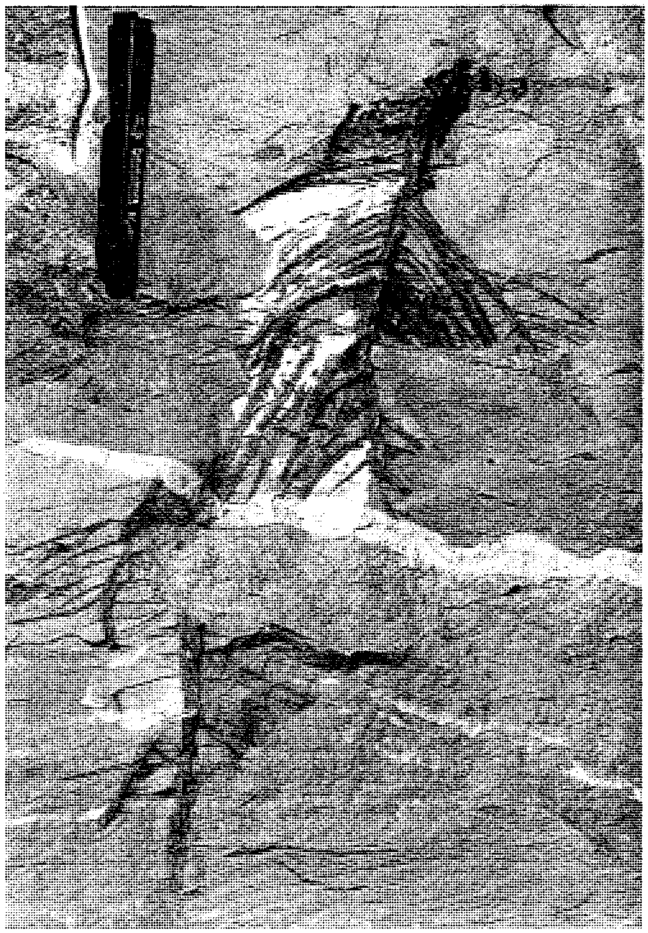

FIGURE 12.—*Impression of a shallow, branching root system in a siltstone splay deposit. Rootlets as small as 1 mm are preserved. The top of the photograph is up. Pen is approximately 15 cm long.*

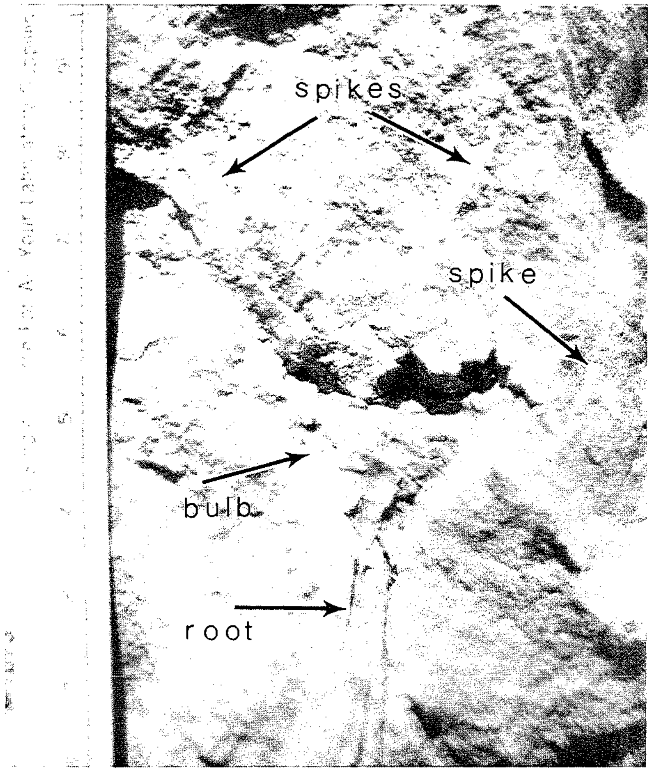

FIGURE 13.—*Impression of a plant bulb (?) showing a small taproot that grew downward and thin spikes or leaves that arched upward and outward from the bulb. The body of the bulb has an inverted triangular shape. Scale is in centimeters.*

raised points of attachment. Each bulb now shows two to four preserved spikes. Root impressions are found most commonly in splay, levee, and channel-fill facies.

Caliche Nodules

Caliche nodules are pedogenic features that reflect arid climatic conditions with periodic episodes of precipitation. Caliche nodules in the Ankareh Formation are generally subspherical and less than 10 cm in diameter. They occur in three distinct patterns: (1) densely scattered throughout a bed, (2) arranged in obscure, subvertical columns, or (3) arranged in shallow clumps. Root casts and impressions are frequently found with the nodules. The caliche nodules are generally mottled greenish gray and moderate reddish brown and locally show drab halos that penetrate into/through the nodules. Varied arrangements of the nodules combined with the presence of drab halos suggest that plants may have had an influence on their formation. The plants could draw water from the soil into their roots, leaving behind the calcium carbonate, which would then be cemented into caliche nodules. This process may be reflected in the arrangements and patterns of the caliche nodules: taproots may have caused subvertical arrangements of the nodules, and dense, shallow networks of small rootlets may have caused shallow, clumped arrangements. Caliche nodules are found only in rocks of the flood-basin facies.

Mineralogy

Mineralogy of the paleosols is varied, ranging from arkosic sediments essentially undisturbed by soil-forming processes to siliceous and ferruginous paleosols. Soil textures found in each are also varied, but developed paleosols may show cutans, pedotubules, voids, and nodules, in the terminology of Brewer (1964). By far, the most abundant paleosols are those formed in calcareous arkosic flood-basin, levee, and splay sediments, showing low to moderate degrees of soil development.

The most interesting paleosol profile is found in units 163 through 175 of section 1 (figs. 14, 15). The lowest paleosol in the profile is a calcareous paleosol; it is not shown on the figures. It is overlain by a series of silicified flood-basin deposits that become increasingly more silicic

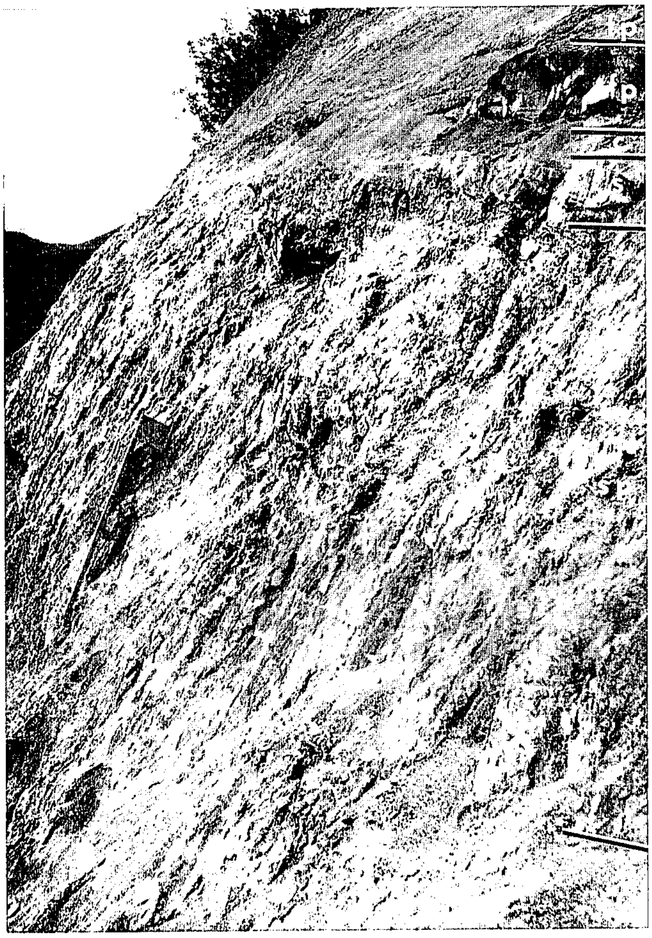

FIGURE 14.—*Photograph of a paleosol profile that contains porcelanite (p), a siliceous paleosol (sp), silcrete (s), a siliceous clay (c), and ferruginous paleosols (fp) or ferricrete. This profile is found in the upper Mahogany member of measured section 1.*

stratigraphically upward. Capping these silicified flood-basin mudstones is a siliceous paleosol that contains a very dense network of silicified root casts (?) up to 2 m long and 0.3 m in diameter. The rock is composed of more than 90% quartz grains and microcrystalline quartz cement. Kaolin clays compose the remaining portion of the rock and occur in the form of argillans and nodules. Voids and pedotubules are also found. The internal structure of the root casts is not preserved, and their mineralogy is the same as the siliceous matrix. Directly above this siliceous unit is a light gray siliceous rock with lenses of grayish pink to moderate yellowish brown chert up to 0.6 m across. The rock is composed of more than 95% silica with kaolin clay found as argillans and is interpreted to be a silcrete (fig. 16). It is overlain by a thin clay bed and two ferruginous paleosols. The ferruginous paleosols or ferricretes are approximately 0.7 m thick and are dusky red. They are composed of fine-grained monocrystalline quartz (31%) and iron oxide ooids/pisolites (17%) sup-

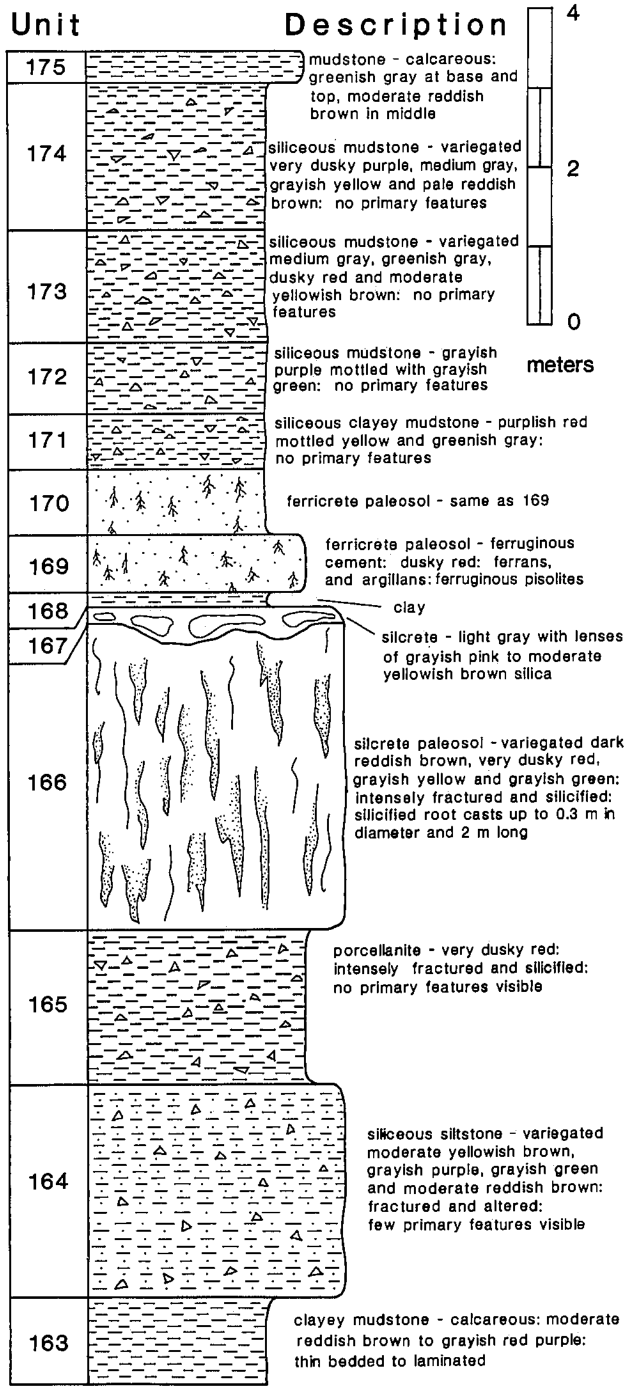

FIGURE 15.—*Diagram of figure 14 showing detailed relationships of the silcrete paleosol profile (units 163 through 175 of measured section 1). Silica content is indicated by small triangles. Unit 166 is a well-developed siliceous paleosol with root casts (?) up to 0.3 m in diameter and preserved for up to 2 m. Unit 167 is the silcrete. Units 169 and 170 are ferruginous paleosols or ferricretes and show evidence of a high degree of soil development.*

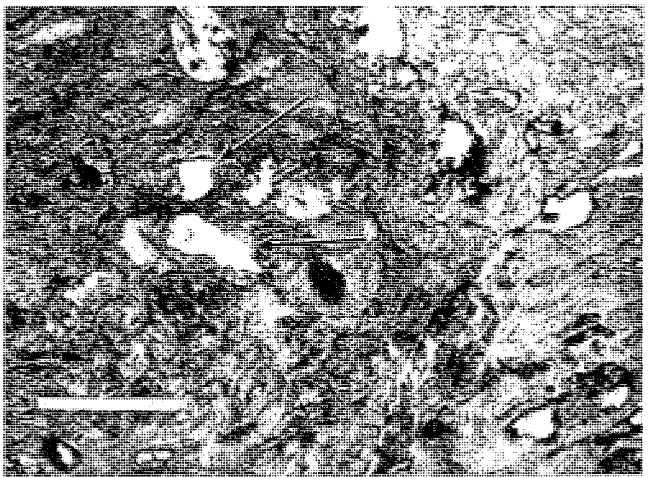

FIGURE 16.—*Photomicrograph of silcrete, unit 167 of measured section 1. The silcrete is composed of quartz grains (arrows) in a microcrystalline to cryptocrystalline quartz matrix. The left two-thirds of the photograph shows light gray microcrystalline silica with quartz grains. The right one-third of the photograph shows banded cryptocrystalline quartz. Bar is 1 mm long. Plain light.*

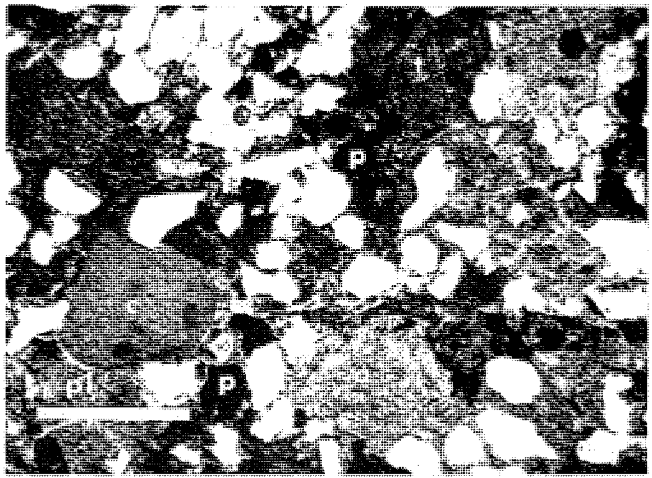

FIGURE 17.—*Photomicrograph of a ferruginous paleosol, unit 169 of measured section 1. Shows an argillan (a), ferruginous ooids and pisolites (p), a cutan of undetermined composition (c), soil plasma (pl), and a possible pedotubule (t). White grains are quartz. Bar is 1 mm long. Plain light.*

ported in soil matrix. Cutans, pedotubules, and nodules occur and are composed principally of kaolin clays and iron oxides (fig. 17). Silicification then decreases upward to normal calcareous flood-basin deposits. This sequence of paleosols was not found during examination of Ankareh exposures in Parley's Canyon, nor was it mentioned in other works dealing with the Ankareh Formation (Kummel 1954, Thomas and Krueger 1946).

INTERPRETATIONS

Paleosols in the Ankareh Formation are of three types. The first type is recognized only by the presence of plant fossils. Soil-forming processes in these paleosols did not have enough time to form distinct soil horizons and textures before the land surface was buried by fluvial deposits. These paleosols formed principally in levee and splay deposits and locally in flood-basin deposits. The abundance of these paleosols suggests that climatic conditions were favorable for plant growth.

The second type of paleosol formed principally in flood basins. This type is recognized by the presence of caliche nodules, root casts, and root impressions, and also by the presence of faint horizons, distinct color changes, and faint microscopic soil textures. Soil-forming processes were active for somewhat longer time periods and resulted in soils that were more developed than the first type. These paleosols are quite common throughout the formation and suggest that the climate was arid but favorable for plant growth.

The third type of paleosol includes the siliceous and ferruginous paleosols of the upper Mahogany member. These paleosols are very different from the preceding two types in that they are well developed and provide strong evidence for wet and warm climatic conditions. Today, much silcrete is found in areas that presently have arid to semiarid climates, as for example the Great Basin of Australia. These silcretes, however, are relict from former warm, humid climatic conditions (Dury and Habermann [1978], Langford-Smith [1978]). Research suggests that silcrete forms either in warm stagnant water or in lower portions of soil profiles in tropical to subtropical climates (Langford-Smith [1978], Wopfner [1978]). Ferruginous paleosols are also thought to require warm, wet conditions for their development as they are preliminary soils in the development of iron laterite soil profiles (Langford-Smith and Watts 1978). Wopfner (1978) has documented periods of formation of some Australian silcretes to be anywhere from an approximate few millions of years to 34 million years. It is generally believed that a long residence time for silica in pore spaces is necessary for formation of silcrete (Summerfield 1983).

The silcrete, siliceous, and ferruginous paleosols of the Mahogany member occur in the thickest vertical accretion sequence in the formation. Streams were probably confined for long periods of time, allowing the formation of silcrete in adjacent flood-basin deposits. Caliche nodules are found in paleosols directly below the sequence and in paleosols above the sequence, indicating arid, evaporative climates. Although the silcrete and associated paleosols probably represent a significant portion of Ankareh time, they are local in nature, being restricted to the area near Diamond Fork, and not present in Ankareh exposures at Parley's Canyon or in other localities (based on data from Kümmel [1954] and Thomas and Krueger

[1946]). I believe the siliceous paleosols and silcrete of the Ankareh Formation formed in isolated, warm, stagnant flood-basin water in an arid, warm climate.

Brewer (1964), Retallack (1981, 1983), and the USDA Soil Survey Staff (1951, 1984) discuss the identification and interpretation of paleosols and soils. Silcrete, ferruginous soils, and their relationships and interpretations are discussed by Hutton and others (1978), Langford-Smith (1978), Langford-Smith and Watts (1978), Summerfield (1983), vanDijk and Beckman (1978), and Wopfner (1978).

Plants of the Ankareh Formation were of several types including: (1) small herbaceous plants with tuberose roots; (2) small shrublike plants with long subvertical taproots; (3) plants that grew in dense, shallowly rooted clumps; and (4) larger treelike plants with taproots up to 0.3 m in diameter. Due to the absence of stem and leaf remains in the formation, taxonomy of the plants is unknown, although one poorly preserved stem fragment appears as though it belongs to a group of primitive plants called horsetails. Remains of horsetail plants are common in the laterally equivalent Chinle Formation to the south (Ash 1987).

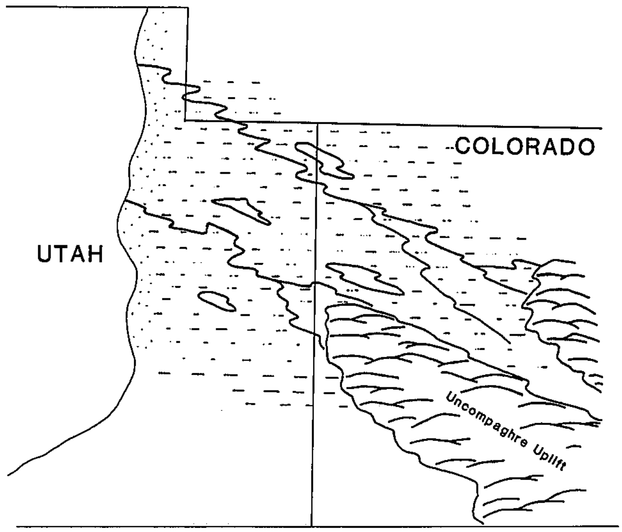

FIGURE 18.—*Early Triassic paleogeography (late Spathian to late Anisian) resulting in deposition of the Mahogany member of the Ankareh Formation. The Uncompaghre Uplift was the source area for meandering streams that carried sediments northwestward across a broad, gentle plain (dashed lines) bordering the epeiric sea. An area of tidal flat deposition (dotted area) occurred immediately adjacent to the sea.*

PALEOGEOGRAPHY

EARLY TRIASSIC

In Early Triassic the area from eastern Utah to central Utah was a gently sloping plain of low relief and low elevation with a regional paleoslope to the northwest. The last transgressive episode into the Cordilleran Miogeocline had occurred in late Spathian time and resulted in deposition of open marine and tidal flat rocks of the Thaynes Formation. It is in this setting in late Spathian to mid-Anisian time that the Mahogany member of the Ankareh Formation was deposited (fig. 18). Subaerially dominated tidal flats of the Mahogany member were deposited next to the epeiric sea on a broad, gently sloping tidal plain. Landward of the tidal flats were small meandering streams carrying sediments across east central Utah from the Uncompaghre Uplift. These streams deposited the bulk of the Mahogany member of the Ankareh Formation. Tectonic activity was minimal from latest Spathian to mid-Anisian time, exposing no new source rocks nor significantly altering paleoslope or stream courses. North central Utah was at a latitude of 10°. The climate was warm and probably semiarid and resulted in the growth of plants on flood-basin, levee, and splay deposits.

LATE TRIASSIC

After a period of erosion that lasted from mid-Anisian to early Carnian time, deposition began again in north central Utah. Resurgent uplift of the Uncompaghre Uplift to the southeast in early Carnian time resulted in braided stream deposition of the Gartra Grit member of the Ankareh Formation. Braided streams formed a sand sheet that extended from the Spanish Fork Canyon area northward to at least the northern flank of the Uinta Mountains (fig. 19). After uplift ceased, post orogenic meandering streams began to flow northwestward across the broad floodplain, depositing the Stanaker member of the Ankareh Formation (fig. 20). Meandering stream deposition continued on the broad, gently sloping floodplain through mid-Norian. A small, short-lived tectonic pulse occurred during this time interval. North central Utah was at a latitude of approximately 11° north. In mid-Norian the climate became increasingly arid, and an inland desert moved down from the north and northwest. Eventually, eolian dunes of the Navajo Sandstone completely inundated meandering streams of the Stanaker member of the Ankareh Formation.

ACKNOWLEDGEMENTS

J. Keith Rigby was thesis chairman. James L. Baer and Willis H. Brimhall were thesis committee members. J. K. Rigby, Jr., of Notre Dame University, and Hans-Peter Schulze, University of Kansas, aided in vertebrate and plant identification, and William D. Tidwell, Brigham Young University, aided in fossil wood identification. Financial assistance was provided by the American Association of Petroleum Geologists Grants in Aid program,

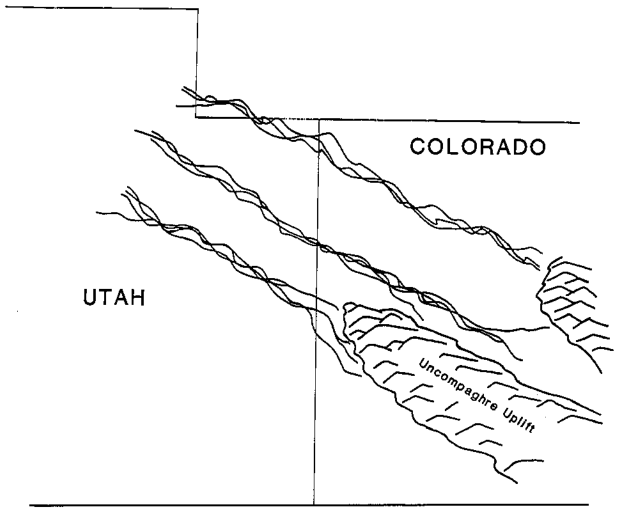

FIGURE 19.—*Late Triassic paleogeography (early to mid-Carnian) resulting in deposition of the Gartra Grit member of the Ankareh Formation. The front of the Uncompaghre Uplift had receded to the east. Rejuvenation of the Uplift resulted in rapid erosion of the source area, high sediment load, and braided stream deposition on the broad, gentle plain.*

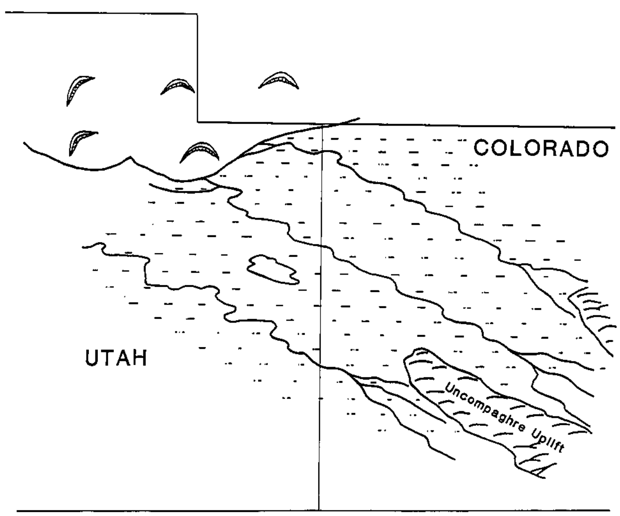

FIGURE 20.—*Late Triassic paleogeography (mid-Carnian and mid-Rhaetian) resulting in deposition of the Stanaker member of the Ankareh Formation. The front of the Uncompaghre Uplift had receded farther into Colorado. Post-orogenic meandering streams carried sediments across the broad plain to a nonmarine basin. The sand sea of the Navajo Sandstone (depicted in the upper part of the diagram) began moving into the area from the north and northwest and by late Norian/early Rhaetian had covered meandering streams of the Stanaker member. This diagram is of late Norian/early Rhaetian paleogeography.*

by the Associated Students of Brigham Young University Research Fund, and by a grant from the Brigham Young University Geology Department, based on a gift from Floyd Peterson of Salt Lake City, Utah.

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