Clay Minerals of the Morrison(?) Formation of Central Utah

by

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ABSTRACT

Twenty-three mudstone samples, seventeen from the Morrison(?) Formation of central Utah, three from the Morrison Formation and three from the Cedar Mountain Formation of the Colorado Plateau, were collected during the summer of 1983. The whole fraction of each sample was X-rayed to identify the major mineral constituents. All of the samples contained quartz, and most contained calcite. Dolomite, feldspar, and either hematite or goethite were present in small amounts in many. Gypsum was present in a few. Traces of halite and ilmenite were present in one sample each. Oriented mounts of the clay fraction of each sample were X-rayed twice, once after air-drying, and once after solvation in ethylene glycol, to determine the clay mineral constituents. All but one of the samples contained smectite or interstratified smectite-illite as the predominant clay constituent. One sample contained illite as the predominant clay constituent. Kaolinite and discrete illite were present in several samples. The interstratified clays in the mudstones of the Morrison(?) of central Utah and the Morrison of the Colorado Plateau generally contained a higher proportion of smectite than the interstratified clays in the mudstones of the Cedar Mountain. Smectites are frequently bentonite clays, indicating that the clay-sized sediment in the mudstones of the Morrison(?) may have been derived from altered volcanic detritus. The Morrison(?) mudstones studied by Chapman (1981) and Ross (1982) cannot be correlated to the mudstone layers sampled for this study by using the clay mineral constituents in the samples, because the differences in smectite to illite ratios in the interstratified clays occurring in these mudstones may be accounted for by differing stages of alteration of smectite to illite.

INTRODUCTION

The objective of this study is to provide more detailed information on the clay mineral content of the mudstones of the Morrison(?) Formation of central Utah. The results of the clay mineral analysis are used to determine the presence of possible undisturbed or reworked sediment derived from altered volcanic detritus. A comparison is made between the results of this study and the results of previous studies.

STRATIGRAPHY

The Morrison Formation is late Jurassic in age. E. M. Spieker (1946) defined the Morrison(?) Formation of central Utah based on the stratigraphic position and lithology of the unit. The equivalence of the Morrison(?) of central Utah to the Morrison found on the San Rafael Swell and the Colorado Plateau (see Figure 1) has never been proven. A recent study by Steucheli (1984) indicates that the Morrison(?) is actually Cretaceous in age whereas the Morrison of the San Rafael Swell and the Colorado Plateau is late Jurassic in age. Steucheli suggests that the Morrison(?) of central Utah may be equivalent to the upper member of the Cedar Mountain Formation of the Colorado Plateau. This topic is discussed in greater detail in Steucheli's thesis. The stratigraphy of the Morrison(?) of central Utah, the Morrison of the Colorado Plateau, and the Cedar Mountain of the Colorado Plateau will be considered here.

Morrison(?) Formation of Central Utah

The Morrison(?) Formation of central Utah consists of interbedded mudstones, sandstones, and conglomerates. The mudstones vary greatly in color, including red, pink, violet, gray, greenish-gray, and ochre. The sandstones are generally brown, gray, or white. The conglomerates contain quartzite and chert clasts with varying colors and sizes. The colors of the chert clasts include black, brown, and green (Spieker,

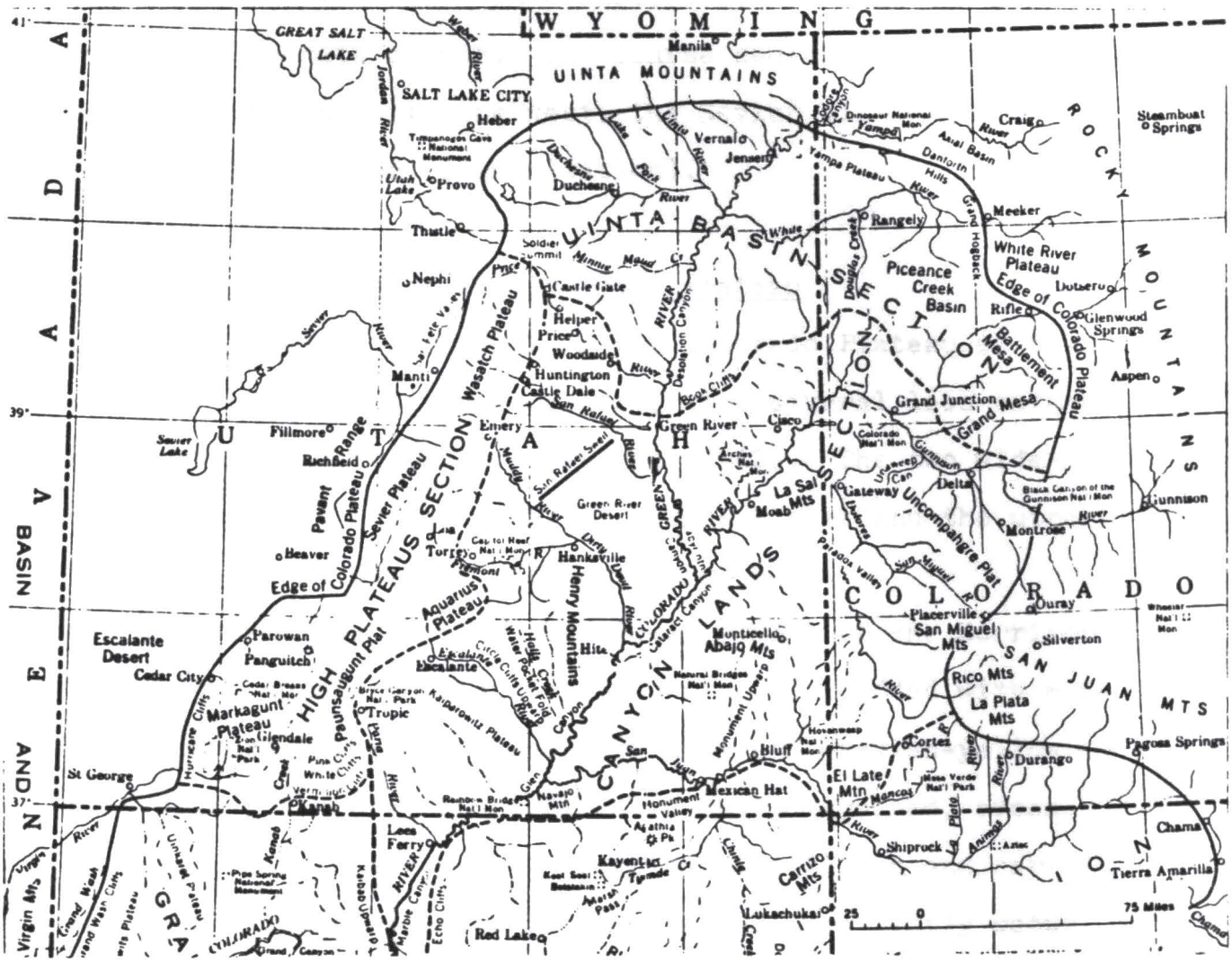

Figure 1. Map of the northern part of the Colorado Plateau, including the San Rafael Swell. The Sanpete Valley is west of the western edge of the Colorado Plateau, near Manti, Utah. (After C. B. Hunt, U. S. Geological Survey Professional Paper 279.)

1946). Some of the conglomerates are "boulder beds" with clasts up to 1.5 meters in diameter. The conglomerates also contain carbonate clasts. The coarse sediment came from a nearby source area to the west, the Sevier highlands (Steucheli, personal communication).

Morrison Formation of the Colorado Plateau

The Morrison Formation of the Colorado Plateau is divided into two widespread members, with several less extensive intertonguing members (Keller, 1962). The two widespread members, the lower or Salt Wash Member and the upper or Brushy Basin Member, are considered here.

The Salt Wash Member, the lower member of the Morrison Formation, consists of sandstone units interbedded with mudstone layers. The sandstones are gray and grayish-yellow to pale orange and off-white, fine- to medium-grained, cross-bedded, and moderately well cemented with silica and carbonates. Stringers of pebbles and granules commonly occur in the sandstones. The mudstones vary in color, ranging from reddish-brown to red, grayish-red, and light greenish-gray. The mudstones contain predominantly quartz and clay minerals, and may be calcareous. The Salt Wash Member ranges in thickness from 200 feet to more than 600 feet, and is a large alluvial fan deposit generated by streams originating in south-central Utah and diverging to the north and east (Keller, 1962).

The Brushy Basin Member, the upper member of the Morrison Formation, is composed of generally non-fissile mudstones interbedded with sandstones. The Brushy Basin also contains conglomeratic sandstone lenses, thin discontinuous limestone beds, polished chert pebbles, and dinosaur bones. Most of the Brushy Basin consists of impure bentonites derived from volcanic ash that was altered in place. The mudstones range in color from red and purplish-red to gray in the northern occurrences, and red and tan to greenish- and bluish-gray in the south. The predominant clay minerals in the mudstones of the Brushy Basin are smectites. The Brushy Basin Member is over 600 feet thick near Vernal, Utah, and thins towards the south. The Brushy Basin was deposited in fluvial and lacustrine environments (Keller, 1962).

Cedar Mountain Formation of the Colorado Plateau

The Cedar Mountain Formation is Cretaceous in age, consists of two members, and lies directly above the Morrison Formation on the Colorado Plateau. The Buckhorn Conglomerate Member, at the base of the formation, allows the formation to be distinguished from the Brushy Basin Member of the Morrison Formation. In regions where the Buckhorn is absent, the Cedar Mountain is not recognized with any certainty because it closely resembles and merges with the Brushy Basin Member of the Morrison Formation. The upper member of the Cedar Mountain has not been named (Peterson et al., 1980).

The Buckhorn Conglomerate Member is gray to brown, and contains pebble-sized clasts of white, gray, and light-brown chert, light-gray quartzite, light-gray limestone, and clear quartz. The conglomerate is cross-stratified and has scour surfaces at the base. The Buckhorn is a fluvial deposit, and probably was a pediment. The source areas for the Buckhorn are to the west and southwest. The Buckhorn has a maximum thickness of 73 feet (Peterson et al., 1980).

The unnamed upper member of the Cedar Mountain Formation consists of mudstones and shales with a few sandstone and conglomerate lenses and beds. The mudstones and shales are pastel shades of greenish-gray, purple, brown, and red; are laminated to thinly bedded; and contain more light-gray limestone nodules and highly polished pebbles than do the mudstones of the Morrison Formation. The sandstones and conglomerates in this member are light-gray to light-brown, and are cross-bedded. The conglomerates in the upper member contain pebbles of the same composition as those in the Buckhorn Conglomerate. The upper member has a maximum thickness of 133 feet, and was deposited in a fluvial environment (Peterson et al., 1980).

SAMPLES

Location

Seventeen samples were collected in the Sanpete Valley in central Utah, and six samples were collected from the

San Rafael Swell during the summer of 1983. Samples Jm 1 through Jm 17 were taken from the SW¼ of Section 7, T. 19S., R. 2E., Sterling Quadrangle (see Figure 2). Samples Jm 18, Jm 19, Jm 20, Kcm 21, Kcm 22, and Kcm 23 were collected in Section 8, T. 23S., R. 7E., Mesa Butte Quadrangle, Emery County.

Sample Collection

The samples collected from the Sanpete Valley were taken from two different measured sections. These two sections, measured by Steucheli, are in the lower part of the Morrison(?) Formation of the Sanpete Valley. The base of both sections was taken to be a grayish-white micritic limestone. The beds in these sections strike N. 35°E. and are overturned, dipping about 65°SE. Samples Jm 1 through Jm 12 were taken from section 1, and samples Jm 13 through Jm 17 were taken from section 2 (see Figure 2). Selection of the beds from which the samples were collected was based on variations in the color of the mudstones. The stratigraphic distances, above the base of the sections, from which each sample was collected are summarized in Table 1.

The Morrison samples collected from the San Rafael Swell were not taken from a measured section. The samples are numbered Jm 18 through Jm 20 and they were collected on the basis of color variations of the mudstones. Three samples, Kcm 21 through Kcm 23, were taken from the Cedar Mountain Formation. The samples taken from the Cedar Mountain were

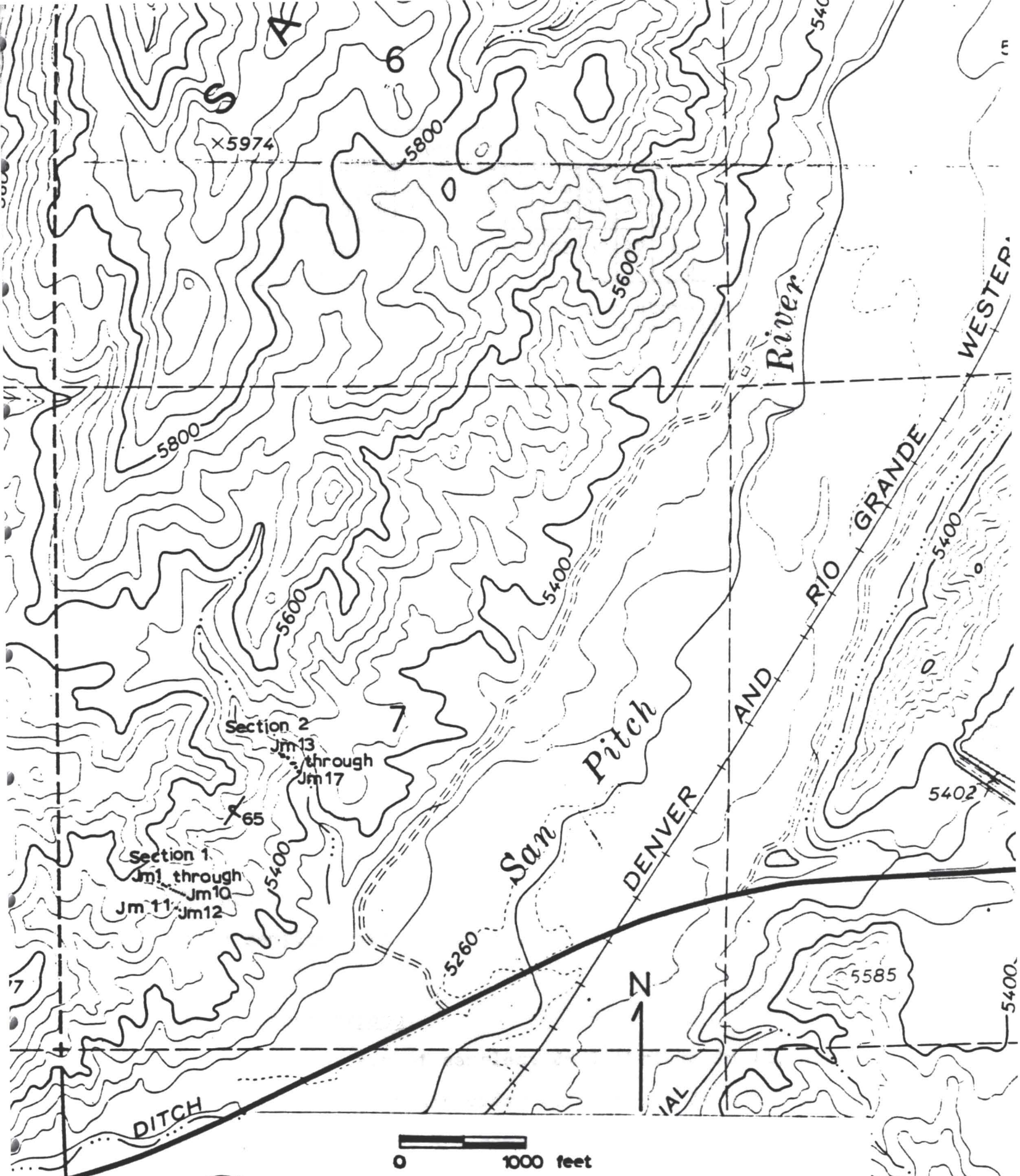

Figure 2. Map of sample collection location in the Sanpete Valley, T. 19S., R. 2E., Sterling Quadrangle, Utah.

	Section 1												Section 2				
Sample #	Jm 1	Jm 2	Jm 3	Jm 4	Jm 5	Jm 6	Jm 7	Jm 8	Jm 9	Jm 10	Jm 11	Jm 12	Jm 13	Jm 14	Jm 15	Jm 16	Jm 17
Distance (meters)	90	79	70	66	55	53	48	46	42	37	17	6	139	131	130	128	125

Table 1. Distance of sample collection above the base of the measured sections in the Sanpete Valley.

not collected on the basis of color variations because the mudstones were all light gray at the collection site. The Cedar Mountain samples were collected at approximately equal intervals of about 10 meters. Sample Kcm 21 was taken just above the Buckhorn Conglomerate, which is at the base of the Cedar Mountain Formation.

All of the mudstone samples were collected using the same technique. A hand shovel was used to dig through the regolith until bedrock was reached. In some cases, after digging at least one meter into the regolith, solid bedrock had not been uncovered. In these cases, the least weathered rock fragments available were collected from the bottom of the hole. Using this method, fresh or moderately fresh mudstone samples were collected.

Sample Descriptions

The first set of samples, Jm 1 through Jm 12, was collected in stratigraphic order with sample Jm 1 being stratigraphically youngest and sample Jm 12 being the oldest. The second set of samples, Jm 13 through Jm 17, which is strati-

graphically younger than the first set, was also collected in stratigraphic order, with sample Jm 13 being stratigraphically youngest and Jm 17 being the oldest. The last set of samples, Jm 18 through Jm 20 and Kcm 21 through Kcm 23, taken from the San Rafael Swell, was collected in stratigraphic order with sample Jm 18 being the oldest and sample Kcm 23 being the youngest. Samples Kcm 21 through Kcm 23 were collected from the Cedar Mountain Formation.

Jm 1	Massive, dark red mudstone containing limestone nodules.
Jm 2	Massive, dark red mudstone containing limestone nodules; weathers to pinkish-red; sample is not weathered.
Jm 3	Massive, dark red mudstone containing limestone nodules.
Jm 4	Dark purplish-red, very silty mudstone; abundant limestone nodules.
Jm 5	Massive, reddish-brown mudstone; abundant limestone nodules.
Jm 6	Dark red mudstone containing limestone nodules; fragmented and possibly weathered.
Jm 7	Dark grayish-red mudstone; abundant limestone nodules; fragmented and weathered.
Jm 8	Red-brown mudstone; abundant limestone nodules; fragmented and weathered.
Jm 9	Gray mudstone; weathered.
Jm 10	Gray mudstone; very clayey; contains "gastroliths."
Jm 11	Red-brown mudstone; weathered.
Jm 12	Red-gray, silty mudstone; fragmented.
Jm 13	Massive, dark gray to black mudstone; very clayey; possibly weathered.
Jm 14	Medium gray to greenish, silty mudstone containing limestone; weathered.
Jm 15	Dark gray to lavender and red, silty mudstone; fragmented and possibly weathered.
Jm 16	Light to medium gray and red mudstone; weathered.
Jm 17	Massive, purple-red mudstone; very clayey.
Jm 18	Massive, red and gray, silty mudstone.
Jm 19	Light gray and greenish, silty mudstone.
Jm 20	Massive, light to medium gray, silty mudstone.
Kcm 21	Massive, light green-gray, very silty mudstone.

Kcm 22 Massive, light green-gray, very silty, carbonaceous mudstone, or muddy limestone.

Kcm 23 Massive, light gray-green, very silty, mudstone.

ANALYTICAL PROCEDURE

Whole Fraction Sample Preparation

A 4 to 5 gram quantity of each sample was hand ground to a powder of silt and smaller sized particles with a mortar and pestle. Two types of sample mounts were made with the ground samples. Oriented mounts were made for samples Jm 1 through Jm 9, and powder mounts were made for all twenty-three samples.

The oriented mounts were prepared by placing 0.2 grams of ground sample and about 2 ml of distilled water in a glass vial. The vial was shaken vigorously. An eyedropper was then used to remove the suspension from the glass vial, and to place the suspension on a clean glass slide. Care was taken to ensure that the coarser particles were not left in the vial. The oriented mounts were then allowed to air dry.

Oriented mounts were prepared for only the first nine samples because when these preparations dried, the samples cracked and peeled away from the glass slides. A possible cause of this problem could involve uneven grain size of the ground sample. As the preparations dried, the clay minerals may have formed a thin impermeable layer which settled unevenly on top of the larger and heavier grains in the prepa-

ration. This layer of clay trapped water in the space around the larger grains under the clay layer. As this trapped water evaporated, it caused the clay layer to crack and peel (Tettenhorst, personal communication). A possible solution to this problem is to grind the sample more thoroughly to ensure a more even grain size (Corbatō, personal communication). Another possible solution is to make the preparation using a smaller quantity of ground sample.

Powder mounts were prepared by placing a small quantity of ground sample in an aluminum holder backed by a glass slide. Another glass slide was used to pack the sample into the holder, and to clear away any excess sample. While packing the sample, care was taken to ensure that the surface of the sample was smooth and flush with the top of the aluminum holder.

Clay Fraction Sample Preparation

For the clay fraction preparations, about 4 grams of unground sample was placed in a 600 ml beaker with 300 ml of distilled water. The samples were disaggregated by allowing them to soak in the water. The samples that did not completely disaggregate by soaking were treated by placing them in an ultrasonic tank for 10 to 15 minutes. After the samples were completely disaggregated, they were stirred vigorously. None of the suspensions flocculated.

A 5 micron and less size fraction was desired for preparation of oriented mounts of the clay fraction. Stokes' law

(Jackson, 1956) was used to calculate the settling time required to obtain a minus 5 micron fraction.

$$t = \frac{18nh}{g(S_p - S_1)D^2}$$

where,

t = time of fall (seconds)
n = viscosity of the fluid (poises)
h = depth of fall (cm)
g = gravitational constant (980 cm/sec^2)
S_p = specific gravity of the particle (gm/cm^3)
S_1 = specific gravity of the fluid (gm/cm^3)
D = spherical diameter of the particle (cm)

The following values were assigned in the calculation of the required settling time for a particle with a 5 micron diameter:

n = 0.01 poises
S_p = 2.65 gm/cm^3
S_1 = 1.00 gm/cm^3
h = 2.00 cm

The required settling time determined from this calculation was 14.8 minutes. This result was rounded off to 15 minutes because only an approximation was needed. After stirring, each sample was allowed to settle for 15 minutes, at which time 5 ml of the suspensions were pipetted from a depth of 2 cm. Roughly equal amounts of the 5 ml portions of each suspension were placed on two clean glass slides and allowed to air dry. One slide of each sample was stored as a reserve; the other slide was X-rayed and then glycolated. The slides were glycolated by exposing them to ethylene glycol in

a closed container at room temperature for at least 48 to 72 hours. After the slides were saturated with ethylene glycol, they were X-rayed again.

While the clay fraction slides were drying, the clays on some of the slides flocculated, but not enough to render the slides useless. The slides that underwent flocculation of the clays still had relatively smooth surfaces. Flocculation appeared to be most intense on the slides for samples Jm 3, Jm 4, Jm 6, Jm 7, Jm 10, Jm 11, and Jm 12.

The clay fraction slide of sample Jm 9 bubbled and peeled during glycolation. A new slide was prepared using the same procedure as before, but with only 2 grams of unground rock placed in 300 ml of distilled water. The new slide was allowed to air dry, X-rayed, and then glycolated. It did not bubble and peel during glycolation, and was X-rayed again.

X-Ray Diffraction Technique

The whole fraction preparations were X-rayed using a Philips XRG 3100 generator equipped with a scintillation detector, a graphite monochromator, a theta-compensating slit, a pulse height analyzer, and copper radiation. The following settings were used:

goniometer speed:	2° 2θ/min.
chart speed:	1"/min.
voltage:	35 kV
amperage:	15 mA
time constant:	0.5 sec.
range:	500 counts/sec.

Both the oriented mount and the powder mount of the whole fraction of sample Jm 1 were X-rayed. The oriented mount of sample Jm 1 was the smoothest and least fractured of all of the oriented mounts made. The X-ray patterns of the oriented mount and the powder mount showed no significant differences. Only the powder mounts of the whole fractions of the remaining samples were X-rayed.

The oriented mounts of the clay fractions of the samples were X-rayed on the Philips XRG 3100 generator equipped with a geiger detector, copper radiation, and a nickel filter. The clay fraction slide of each sample was X-rayed twice, once before and once after glycolation. In general, the following settings were used:

goniometer speed:	1° 2θ/min.
chart speed:	0.5"/min.
voltage:	35 kV
amperage:	15 mA
time constant:	1 sec.
range:	400 counts/sec.

The high intensity of the peaks at about 7° 2θ on the patterns of the non-glycolated slides, and the peaks at about 5° 2θ on the patterns of the glycolated slides of many of the samples caused the peaks to go off the chart. The slides producing these high intensity peaks were X-rayed again between the observed diffraction angles of 2° 2θ and 12° 2θ at lower amperage and voltage settings, and occaisionally higher range settings. Table 2 summarizes the settings used on the oriented mounts before and after glycolation between the diffraction angles 2° 2θ and 12° 2θ. Although the settings

Sample #	Voltage (kV)	Amperage (mA)	Range (counts/sec.)	Settings (adjusted or normal)
Jm 1	35	10	400	adjusted
Jm 2	25	10	400	adjusted
Jm 3	35	15	400	normal
Jm 4	35	15	400	normal
Jm 5	35	10	400	adjusted
Jm 6	25	10	400	adjusted
Jm 7	35	10	400	adjusted
Jm 8	30	10	400	adjusted
Jm 9	35	10	400	adjusted
Jm 10	25	10	800	adjusted
Jm 11	25	10	400	adjusted
Jm 12	35	15	400	normal
Jm 13	35	10	400	adjusted
Jm 14	35	10	400	adjusted
Jm 15	25	10	400	adjusted
Jm 16	25	10	800	adjusted
Jm 17	25	10	800	adjusted
Jm 18	25	10	400	adjusted
Jm 19	25	10	800	adjusted
Jm 20	25	10	800	adjusted
Kcm 21	35	15	400	normal
Kcm 22	35	15	400	normal
Kcm 23	35	15	400	normal

Table 2. Adjusted X-ray instrument settings for clay fraction oriented mounts; observed diffraction angles 2° 2θ to 12° 2θ.

varied from sample to sample for this range of diffraction angles, the settings were held constant for both the non-glycolated and glycolated patterns for each specific sample.

X-RAY ANALYSIS

Interplanar spacings were derived from the observed diffraction angles of the peaks recorded on the strip charts using Bragg's law:

$$\lambda = (2d)\sin\theta$$

where

λ = wavelength of the radiation (1.54184 Å)
d = interplanar distance (Å)
θ = angle of reflection (degrees).

The interplanar spacings (d-spacings) were used to identify the mineral constituents of the samples.

Whole Fraction

The peaks recorded on the strip charts produced by X-raying the powder mounts revealed the whole fraction mineral composition of the samples. Quartz, which was detected in every sample, was the predominant mineral in every sample except Kcm 22. Calcite was the predominant mineral in sample Kcm 22. Commonly occurring minerals, other than quartz, include calcite, clay minerals, and traces of feldspar. Dolomite, hematite or goethite, gypsum, halite, and ilmenite each were observed in at least one sample. A summary of the mineral constituents detected in the samples during this analysis is presented in Table 3.

Sample #	Minerals											
	Quartz	Calcite	Dolomite	Feldspar	Hematite or Goethite	Gypsum	Halite	Ilmenite	Smectite	Illite	Mixed-layer (I-S)	Kaolinite
Jm 1	X	X	X	t	t				X			t?
Jm 2	X	X	X		t				X			
Jm 3	X			t?							X	
Jm 4	X										X	
Jm 5	X	X			t?				X			
Jm 6	X	X		X	X				X			
Jm 7	X	X			X	X				?	X	
Jm 8	X	X				X				?	X	
Jm 9	X	X									X	
Jm 10	X						t?				X	
Jm 11	X	X	X		?				X			
Jm 12	X			t	t					X	X	
Jm 13	X	X	X	t		t				X	X	X
Jm 14	X	X	X	t		X				X	X	X
Jm 15	X			t?						?	X	X
Jm 16	X			t?						t?	X	t
Jm 17	X	X			X?				X			
Jm 18	X	X			X					t	X	
Jm 19	X	t		X					X			
Jm 20	X			X					X			
Kcm 21	X			t?						?	X	
Kcm 22	X	X	t?					t?			X	
Kcm 23	X			X							X	

Table 3. Major mineral constituents as determined by X-ray diffraction.

Note: t - trace of mineral present
? - mineral is possibly, but not definitely present

Clay Fraction

The clay fraction, consisting of the minus 5 micron fraction, was separated from the coarse fraction by sedimentation in water. By obtaining a clay fraction, and preparing oriented mounts of this fraction, the basal clay mineral peaks were intensified on the X-ray diffraction patterns. The clay mineral constituents were identified from the X-ray diffraction patterns produced after air-drying, and after glycolation in a closed container containing liquid glycol at room temperature for 48 to 72 hours.

Upon glycolation, smectite absorbs the ethylene glycol and expands in the direction of the c-axis. The (001) interplanar spacing of smectite expands from about 13Å to about 17Å when glycolated. The identification of smectite in the samples was based on this property. Most of the samples did not show ideal interplanar spacings for smectite due to random interstratification of smectite and illite.

Mixed-layer illite-smectite clays produce broader, less distinct peaks than those produced by pure smectite. The smectite in these mixed-layer clays also expands from about 13Å to 17Å when glycolated. The X-ray diffraction patterns produced by the glycolated samples were used to determine the percentage of 17Å layers (smectite) to 10Å layers (illite). Peak intensities at 17Å (5.2° 2θ) and 10Å (8.8° 2θ) and the diffraction profiles were used to determine the percentages of smectite and illite in the mixed-layer clays. As the proportion of illite increases, the intensity of the 17Å peak

decreases, and the intensity of the 10Å peak increases (Reynolds and Hower, 1970).

Illite does not expand when glycolated, consequently, the peaks produced by illite do not shift when the sample is saturated with ethylene glycol. Identification of illite was based on a (001) interplanar spacing of 10Å (peak at 8.8° 2θ), and other diagnostic interplanar spacings at higher angles. Although most of the illite in the samples was found to be interstratified with smectite, several samples contained discrete illite which was identified by sharp, distinct peaks, rather than broad peaks produced by the interstratification.

Kaolinite also does not expand when glycolated, consequently, the peaks produced by kaolinite do not shift when the sample is saturated with ethylene glycol. Kaolinite was identified by a sharp peak produced by an interplanar spacing of about 7Å (12.4° 2θ).

RESULTS

Distribution of Clay Minerals

The clay mineral constituents of each sample are summarized in Table 4. Smectite-illite mixed-layer clays occur in most of the samples, but eight samples contain pure smectite without any interstratified illite. Table 5 summarizes the ratios of 17Å (smectite) to 10Å (illite) in the mixed-layer clays. These ratios were determined by comparing the

Sample #	Clay Minerals			
	Smectite	Illite	Kaolinite	Interstratified
Jm 1	X		trace?	
Jm 2	X			
Jm 3				X
Jm 4				X
Jm 5	X			
Jm 6	X			
Jm 7		?		X
Jm 8		?		X
Jm 9				X
Jm 10				X
Jm 11	X			
Jm 12		X		X
Jm 13		X	X	X
Jm 14		X	X	X
Jm 15		?	X	X
Jm 16		trace?	trace	X
Jm 17	X			
Jm 18		trace		X
Jm 19	X			
Jm 20	X			
Kcm 21		?		X
Kcm 22				X
Kcm 23				X

Table 4. Clay mineral constituents as determined by X-ray diffraction.

Note: ? - mineral is possibly, but not definitely present.

Sample #	17Å	10Å		Sample #	17Å	10Å
Jm 1	1.0	0		Jm 13	0.7	0.3
Jm 2	1.0	0		Jm 14	0.7	0.3
Jm 3	0.6	0.4		Jm 15	0.8	0.2
Jm 4	0.5	0.5		Jm 16	0.9	0.1
Jm 5	1.0	0		Jm 17	1.0	0
Jm 6	1.0	0		Jm 18	0.9	0.1
Jm 7	0.7	0.3		Jm 19	1.0	0
Jm 8	0.8	0.2		Jm 20	1.0	0
Jm 9	0.6	0.4		Kcm 21	0.5	0.5
Jm 10	0.75	0.25		Kcm 22	0.5	0.5
Jm 11	1.0	0		Kcm 23	0.4	0.6
Jm 12	0.4	0.6				

Table 5. Proportions of 17Å (smectite) and 10Å (illite) in the randomly interstratified clays determined by comparison with the overall fit of the diffraction profiles with similar profiles in Reynolds and Hower (1970).

overall fit of each diffraction profile with similar profiles given by Reynolds and Hower (1970). Samples Jm 10, and Jm 16 contain interstratified smectite-illite with very high intensity (001) peaks. Samples Jm 17, Jm 19, and Jm 20 contain pure smectite with very high intensity (001) peaks. A small amount of discrete illite occurs in samples Jm 12, Jm 13, Jm 14, and Jm 18, and probably occurs in samples Jm 7, Jm 8, Jm 15, Jm 16, and Kcm 21. Kaolinite occurs in several samples and is probably a weathering product derived from feldspars, and other clays and silicates.

The most intense peak occurring on the X-ray pattern for the air-dried oriented mount of the clay fraction of sample Jm 12 was at an interplanar spacing of 10.5Å (8.4° 2θ). The presence of palygorskite was considered to be the reason for this peak. Glycolation caused this peak to broaden and diminish in intensity, but did not cause the position of the peak to shift. Another air-dried oriented mount of this sample was heated to 200°C for about 24 hours, and then X-rayed. The 10.5Å peak did not shift, but appeared to be slightly diminished in intensity compared to the peak on the X-ray pattern for the original unheated, air-dried oriented mount. After heating at 200°C for 24 hours, the peak was still more intense than it was after glycolation. The air-dried mount was then heated to 400°C for 30 minutes. Heating at 400°C for 30 minutes would destroy the structure of palygorskite and its 10.5Å interplanar spacing, consequently, the peak should not appear on the X-ray pattern. Instead of being destroyed, the 10.5Å interplanar spacing collapsed and the peak appeared at an interplanar spacing of 10.0Å (8.8° 2θ) with a slightly diminished intensity. An interplanar spacing of 10Å is the standard (001) interplanar spacing for illite.

The (001) interplanar spacing of the illite in sample Jm 12 was expanded to 10.5Å with interlayer water. Heating the sample at 200°C for 24 hours did not dehydrate the illite. Heating the sample at 400°C for 30 minutes dehydrated the illite and collapsed its basal interplanar spacing to the standard 10Å.

Smectites are frequently bentonite clays, indicating that the clay-sized sediment in these mudstone samples may have been derived from volcanic ash deposits that were either reworked or altered in place. Smectite or interstratified smectite-illite are the predominant clay minerals in all except one, sample Jm 12, of the mudstone samples collected from both the lower part of the Morrison(?) Formation in the Sanpete Valley and the upper part of the Morrison Formation on the San Rafael Swell. The upper or Brushy Basin Member of the Morrison Formation of the Colorado Plateau is composed predominantly of impure bentonites altered in place from volcanic ash (Keller, 1962).

The upper member of the Cedar Mountain Formation is difficult to distinguish from, and merges with the underlying upper or Brushy Basin Member of the Morrison Formation in areas where the lower or Buckhorn Conglomerate Member of the Cedar Mountain is absent (Peterson et al., 1980). The mudstone samples from the Cedar Mountain collected for this analysis were taken from a location on the San Rafael Swell where the Buckhorn is present. These mudstone samples, Kcm 21 through Kcm 23, do not contain pure smectite, but contain interstratified smectite-illite clays. These mixed-layer clays could have been formed by the alteration of pure smectite to illite, and therefore could have resulted from the alteration of volcanic ash. A larger and more complete set of samples from the upper member of the Cedar Mountain Formation might have included mudstones containing pure

smectite as the predominant clay constituent instead of interstratified smectite-illite clays.

Comparison with Previous Studies

Chapman (1981) analyzed 8 mudstone samples from the Morrison(?) Formation of central Utah. Seven of the samples were collected from the same location as the Morrison(?) samples collected for this study: Section 7, T. 19S., R. 2E., Sterling Quadrangle. One sample analyzed by Chapman was collected in Salina Canyon, Section 33, T. 21S., R. 1E., Salina Quadrangle, which is about 20 miles south of the collection location in the Sterling Quadrangle.

Most of the Morrison(?) mudstone samples analyzed in this study contain interstratified smectite-illite, whereas most of the samples analyzed by Chapman contain pure smectite without interstratification. Since the illite in the interstratified clays may have been derived from the alteration of smectite, Chapman's samples may have been less altered than the samples used in this study.

Feldspar and kaolinite are present in a larger proportion of Chapman's Morrison(?) samples. Occurrences of feldspar, kaolinite, and smectite without interstratification in a larger proportion of Chapman's samples may indicate that these mudstones contain a higher percentage of sediment derived from volcanic detritus than the mudstones analyzed in this study. Chapman's samples were probably not collected from the same mudstone layers as the samples for this study,

and therefore could have been collected from mudstone layers containing a higher percentage of sediment derived from altered volcanic detritus.

Ross (1982) also analyzed 8 mudstone samples from the Morrison(?) Formation of central Utah. Five of the samples were collected from the Gunnison Plateau, on the road from Wales to Levan, in Sections 11 and 12, T. 15S., R. 1E., Nephi Quadrangle. This location is about 25 miles north of the collection location of the samples analyzed in this study (Section 7, T. 19S., R. 2E., Sterling Quadrangle). Two samples were collected in Section 27 and one was collected in Section 32, T. 18S., R. 2E., Sterling Quadrangle. These sites are in the Sanpete Valley and about 3 miles north of the collection location of the samples analyzed in this study.

Two of the three mudstone samples from the Sanpete Valley that were analyzed by Ross are similar to the Morrison(?) samples from the Sanpete Valley that were analyzed in this study. One of these similar samples analyzed by Ross contains only quartz and smectite. The other sample contains quartz, feldspar, calcite, smectite, kaolinite, and discrete illite. The sample from the Sanpete Valley that is different from the samples analyzed in this study contains quartz, calcite, dolomite, illite, kaolinite, and does not contain any smectite.

The clay mineral constituents of the five samples collected from the Nephi Quadrangle that were analyzed by Ross

are different than the constituents of most of the mudstone samples collected in the Sanpete Valley that were analyzed in both Ross' study and this study. These five samples contain kaolinite and discrete illite. Only one sample from the Sanpete Valley, analyzed by Ross, contains kaolinite and discrete illite without any smectite. Four of these samples from the Nephi Quadrangle contain mixed-layer illite-smectite clays. The interstratified clay in only one of these four samples contains a higher percentage of smectite than illite (60 percent 17Å, 40 percent 10Å). The interstratified clays in the other three samples range from 40 percent to 50 percent 17Å (smectite) and 50 percent to 60 percent 10Å (illite). Only samples Jm 12 and Kcm 23 in this study contain mixed-layer clays with higher percentages of illite than smectite. Two of the samples from the Cedar Mountain Formation, Kcm 21 and Kcm 22, and one sample from the Morrison(?) Formation, Jm 4, analyzed in this study contain mixed-layer clays with equal percentages of smectite and illite.

CONCLUSIONS

The predominant clay constituents of the Morrison(?) Formation of central Utah are smectite and interstratified smectite-illite. The abundance of these clays suggests that the clay-sized sediment in the mudstones of the Morrison(?) was derived from volcanic ash that was either altered in place or reworked. The X-ray patterns from the clay-fraction

analysis of samples Jm 10, Jm 16, and Jm 17 from the Morrison(?) in the Sanpete Valley, and samples Jm 19, and Jm 20 from the Morrison on the San Rafael Swell showed very intense (001) peaks at 17Å (5.2° 2θ). These intense (001) peaks indicate that the clay-sized sediment in the mudstone layers from which these samples were taken contains a high percentage of material derived from volcanic detritus.

The Morrison(?) mudstone layers studied by Chapman (1981) and Ross (1982) cannot be effectively correlated to the mudstone layers sampled for this study by using the mineral constituents identified in the mudstone samples. The differences in smectite to illite ratios in the interstratified clays occurring in these mudstones may be accounted for by differing stages of alteration of smectite to illite.

The Morrison(?) Formation of central Utah is similar in mineral composition to the Morrison Formation of the Colorado Plateau. The equivalence of these two units is not necessarily proven by their similar compositions. Age determinations presented by Steucheli (1984) indicate that the Morrison(?) of central Utah is actually Cretaceous rather than Jurassic in age, and may be equivalent to the Cedar Mountain Formation of the Colorado Plateau. Alternatively, the Morrison(?) Formation of central Utah may represent a completely different formation than either the Morrison or Cedar Mountain Formations of the Colorado Plateau.

SUGGESTIONS FOR FURTHER RESEARCH

A more thorough and systematic analysis of the clays in the Morrison(?) Formation of central Utah in the Sanpete Valley might allow the correlation of mudstone layers from different locations. A better sampling of the clays in the Morrison(?) might be obtained by measuring more sections and taking samples from continuous trenches perpendicular to the strike of the beds in these sections. Drill cores could also provide a better sampling of the clays in the Morrison(?) Formation of central Utah.

A thorough analysis of the clays in the Cedar Mountain Formation of the Colorado Plateau could be used to compare with the clays in the Morrison(?) Formation of central Utah. The comparison of these two units could help determine whether or not the Morrison(?) Formation of central Utah is equivalent to the Cedar Mountain Formation of the Colorado Plateau.

REFERENCES

Chapman, D. D., 1981, Clay minerals of the Jurassic, Arapien, Twist Gulch, and Morrison Formations of central Utah [B.S. senior thesis]: Columbus, The Ohio State University, 18 p.

Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geological Survey Professional Paper 279, 99 p.

Jackson, M. L., 1956, Soil Chemical Analysis--Advanced Course: Madison, Department of Soils, University of Wisconsin, p. 110.

Keller, W. D., 1952, Clay minerals in the Morrison Formation of the Colorado Plateau: U.S. Geological Survey Bulletin 1150, 90 p.

Peterson, F., Ryder, R. T., Law, B. E., 1980, Stratigraphy, sedimentology, and regional relationships of the Cretaceous System in the Henry Mountains region, Utah, in Picard, M. D., (ed.), Utah Geological Association Henry Mountains Symposium, p. 151-170.

Reynolds, R. C. and Hower, J., 1970, The nature of interlayering in mixed-layer illite-montmorillonites: Clays and Clay Minerals, v. 18, p. 25-36.

Ross, D. K., 1982, X-ray analysis of the clay minerals of the Morrison(?), Twist Gulch and Arapien Formations of central Utah [B.S. senior thesis]: Columbus, The Ohio State University, 16p.

Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, p. 117-161.

Steucheli, P., 1984, The sedimentology, depositional setting, and age of the Morrison(?) Formation of central Utah [M.S. thesis]: Columbus, The Ohio State University.