AN ABSTRACT OF THE THESIS OF

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Title: CLAY MINERALOGY AND SEDIMENTARY PETROLOGY OF THE CRETACEOUS HUDSPETH FORMATION, MITCHELL, OREGON

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The Cretaceous rocks near Mitchell, Oregon consist of two intertonguing formations. The Gable Creek Formation consists of a series of conglomerate and sandstone beds of fluvial and deltaic origin; the Hudspeth Formation, a thick sequence of marine argillaceous rocks with subordinate sandstones. The Hudspeth Formation includes the following sequence:

(1) Basal Member - a thin sequence of sandstones and conglomerates,

(2) Main Mudstone Member - nearly 3000 feet of argillaceous rocks with thin interbedded sandstones, and

(3) upper units - eleven argillaceous units, ranging in thickness from a few feet to several hundred feet, which intertongue with units of the Gable Creek Formation.

The sandstones interbedded with mudstones of the Hudspeth Formation are fine-grained lithic wackes and lithic arenites which contain numerous rock fragments of volcanic, low-rank metamorphic, and sedimentary origin. Calcite is the dominant cement in the arenites, while wackes contain little or no cement. The sandstones occur as thin lenses, often with scour and fill channels and occasionally graded or showing sole markings. Rare ripple marks and mud cracks indicate that some of the sandstones were deposited in shallow water to subaerial conditions.

The Hudspeth "mudstones" range in grain size from claystones to clayey sandstones, with claystone the dominant type. Statistical analyses indicate that the appearance of claystone and mudstone samples in the field is directly related to the total clay content. Samples which contain a large percentage of clay are usually olive gray in color, break into small, flat chips, and seldom contain sand-sized grains. Samples with smaller amounts of clay have the largest maximum grain size, are usually light olive gray, and break into nearly equi-dimensional blocks which are one inch or more in diameter. Most of the coarse silt and sand grains in the mudstones are quartz, with minor feldspar and lithic fragments. Authigenic minerals include pyrite, silica, and calcite.

The mudstones contain a variety of microstructures. Tiny lenses of coarser material and irregular patches of finer detritus are especially common. Clays and micas in the finer argillaceous rocks usually exhibit aggregate parallel orientation, whereas in coarser mudstones this orientation is lacking.

The clay-size fraction of the mudstones is composed of a complex suite of clay minerals plus quartz and feldspar. The clay suite includes the smectite minerals (beidellite, mixed-layer beidellite-illite, and montmorillonite), vermiculite, illite, kaolinite, and chlorite. In the best-exposed section of the Main Mudstone Member and in the upper units there is a negative correlation between the percent of smectite and vermiculite and the percent of illite. Smectite clays are more abundant toward the top of each section, while illite increases toward the base. Likewise the expandability of beidellite-illite decreases downward in the Main Mudstone Member. Kaolinite is present in all samples, and is slightly more abundant in sandy zones. Chlorite is present as a minor constituent in most samples, however within a few feet of intrusive bodies the proportion of chlorite increases up to four or five times its usual percentage. Montmorillonite occurs only in samples which have been recently weathered.

It is concluded that the Hudspeth Formation accumulated in quiet water in a strongly subsiding marine basin which lay somewhat south of an actively rising source area. Weathering of supracrustal rocks in the source area provided lithic fragments and much clay detritus, including beidellite, vermiculite, illite, kaolinite, and chlorite.

These allogenic clays did not undergo much diagenetic change in the depositional environment, however beidellite-illite and illite formed at the expense of beidellite during deep burial.

Clay Mineralogy and Sedimentary Petrology of the Cretaceous Hudspeth Formation, Mitchell, Oregon

by

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INTRODUCTION

General Statement

The Cretaceous rocks near Mitchell, Oregon consist of two formations, the Gable Creek Formation, a series of conglomerate and sandstone beds of fluvial and deltaic origin, and the Hudspeth Formation, a thick sequence of marine argillaceous rocks with subordinate sandstones. The stratigraphy of the Cretaceous has previously been described in detail, with emphasis on description of the Gable Creek Formation (Wilkinson and Oles, 1968). No detailed work on the sedimentary petrology or clay mineralogy of the argillaceous rocks has been presented.

The purpose of this study is to make a detailed analysis of the clay minerals of the Hudspeth Formation, determining the clay mineral content of the rocks, the distribution of clays, and their relation to other sedimentary parameters. In addition, information obtained from analyses of sandstones interbedded with the argillaceous rocks will be combined with data from the argillaceous rocks, in an attempt to reconstruct the depositional and post-depositional history of the Hudspeth Formation.

Location

The largest Cretaceous outcrop in north central Oregon covers about 70 square miles near the town of Mitchell (Figure 1). This area is accessible by U. S. Highway 26, state highway 207, and numerous ranch roads. In addition, a few small outcrops are scattered throughout the area east of Mitchell (Figure 2).

The Mitchell area has a local relief in excess of 3000 feet. High peaks and ridges are formed by erosion of Tertiary rocks and the Cretaceous Gable Creek conglomerates and sandstones, while the less resistant argillaceous rocks of the Cretaceous Hudspeth Formation are confined to valleys (Figure 3).

The climate of the region is semi-arid, having hot, dry summers with occasional thunderstorms, and cold winters with light rain or snow. Average annual temperature is 50° F, and average annual precipitation is 11.2 inches (Johnsgard, 1963).

The soil, which is thin and poorly developed in this area, is thickest in alluvium near streams or on the weathered argillaceous rocks in some valleys. However, in many places, even the argillaceous rocks crop out with little or no soil cover.

Previous Investigations

Cretaceous fossils from central Oregon were first collected by Thomas Condon, over a century ago. Merriam (1901), described the

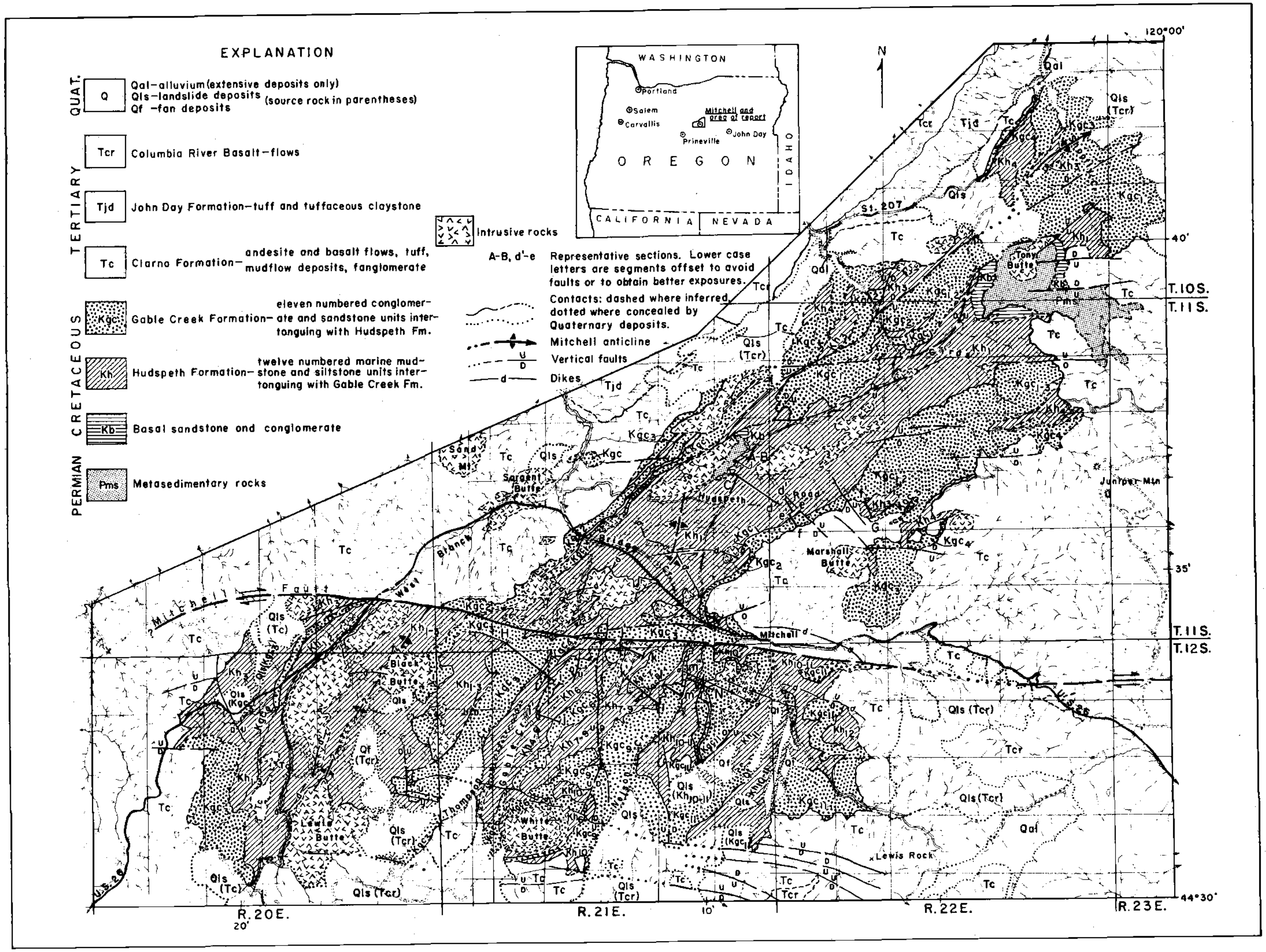

Figure 1. Geologic map of Cretaceous rocks near Mitchell, Oregon (Wilkinson and Oles, 1968).

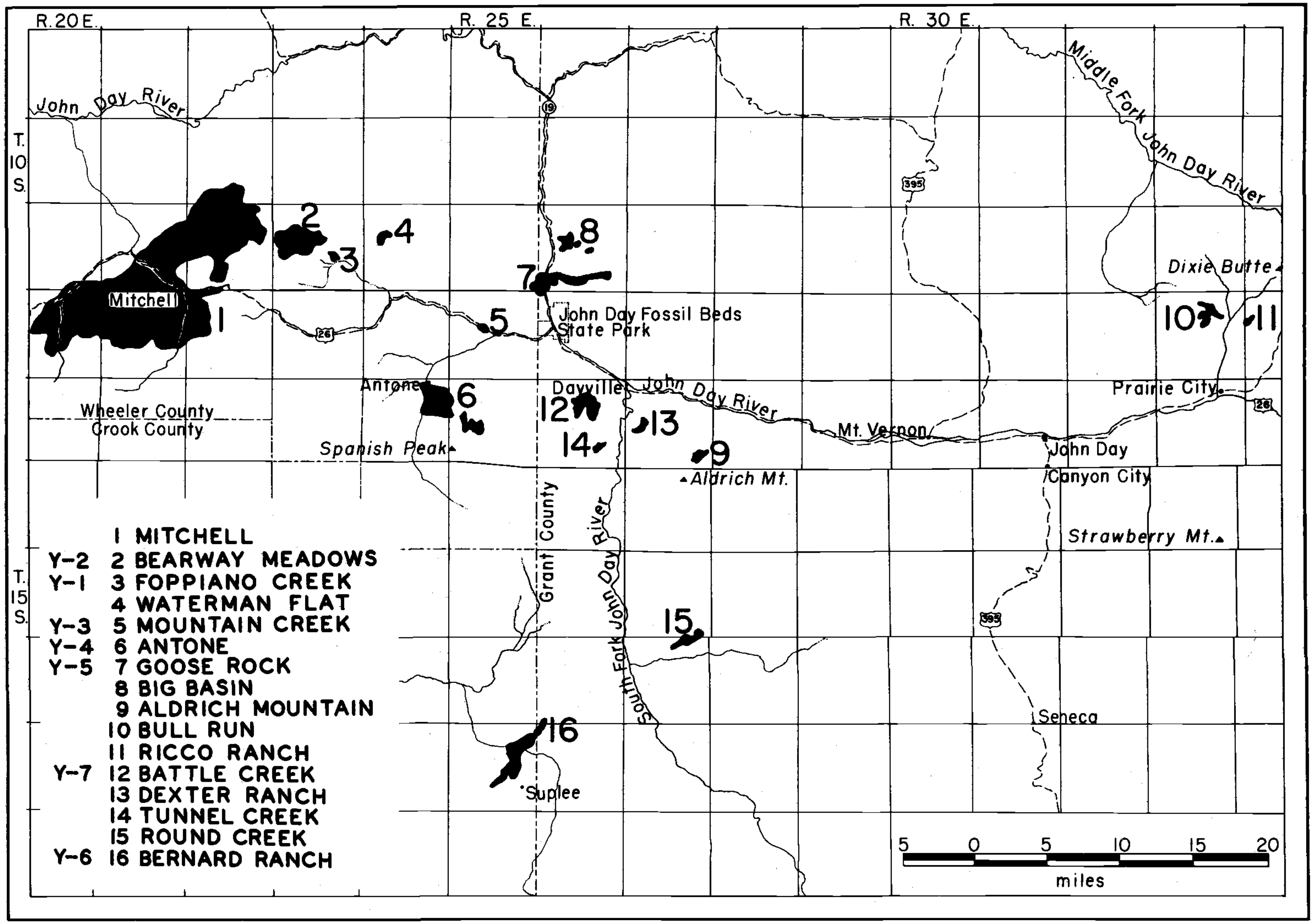

Figure 2. Map of Cretaceous outcrops in central Oregon (Oles, 1973). Locations of samples Y-1 through Y-7 are indicated at lower left.

Figure 3. General view of the Main Mudstone Member of the Hudspeth Formation, looking east from Meyers Canyon The argillaceous unit extends up the lower one-third of the ridge in the background, where it is overlain by conglomerates of the Cretaceous Gable Creek Formation.

geology of the John Day Basin and mentioned the occurrence of marine Cretaceous rocks in central Oregon. Packard (1928, 1929, 1956) and Packard and Jones (1962) described the fauna and age of the Cretaceous rocks. Popenoe, Imlay, and Murphy (1960) sketched the regional correlation of Cretaceous rocks along the Pacific Coast and provided a summary of earlier literature concerning the Cretaceous of Oregon. Several master's theses from Oregon State University have included parts of the Cretaceous sequence in reconnaisance mapping, while McKnight (1964) contributed to knowledge of the Cretaceous stratigraphy. In a more comprehensive study, Wilkinson and Oles (1968) described in detail the stratigraphy and interfingering relationship between the Hudspeth and Gable Creek Formations.

General Geology

Pre-Cretaceous Rocks

The oldest rocks exposed near Mitchell are intensely deformed metasediments of Permian age which are exposed at two localities in the Mitchell quadrangle. The larger outcrop covers two square miles at Tony Butte, in T. 10 S., R. 22 E.; T. 11 S, R. 22 E.; and T. 11 S, R. 23 E., where the major lithic types are phyllites, crystalline limestone, and chert. The smaller and better exposed outcrop is at Meyers Canyon, in sec. 13 and sec. 23, T. 11 S., R. 21 E, where phyllites and subordinate crystalline limestones are present.

Cretaceous Rocks

A 9000 foot section of Cretaceous sedimentary rocks crops out in the south half of the Mitchell quadrangle. Wilkinson and Oles (1968) propose division of these rocks into two intertonguing formations. The partly older Hudspeth Formation is a widespread and thick sequence of marine argillaceous rocks with subordinate sandstones. Intertonguing in intricate pattern with the Hudspeth Formation is the Gable Creek Formation, a series of conglomerates and sandstones, predominantly of fluvial and deltaic origin (Figures 1 and 4). There are 12 tongues of the Hudspeth Formation and 11 of the Gable Creek Formation.

A stratigraphic section would include the following sequence. At the bottom is the Basal Member of the Hudspeth Formation, about 76 feet thick and consisting of thin sandstones and conglomerates. This unit is well-exposed at two localities, near Meyers Canyon and Tony Butte, where it lies with angular unconformity on the Permian metasediments. Directly overlying the Basal Member is the Main Mudstone Member of the Hudspeth Formation which has been described as a thick unit of "mudstone and siltstone." Here mudstone is used as a term for argillaceous rocks with less than 50% silt (Wilkinson and Oles, 1968). Eleven tongues of each formation overlie

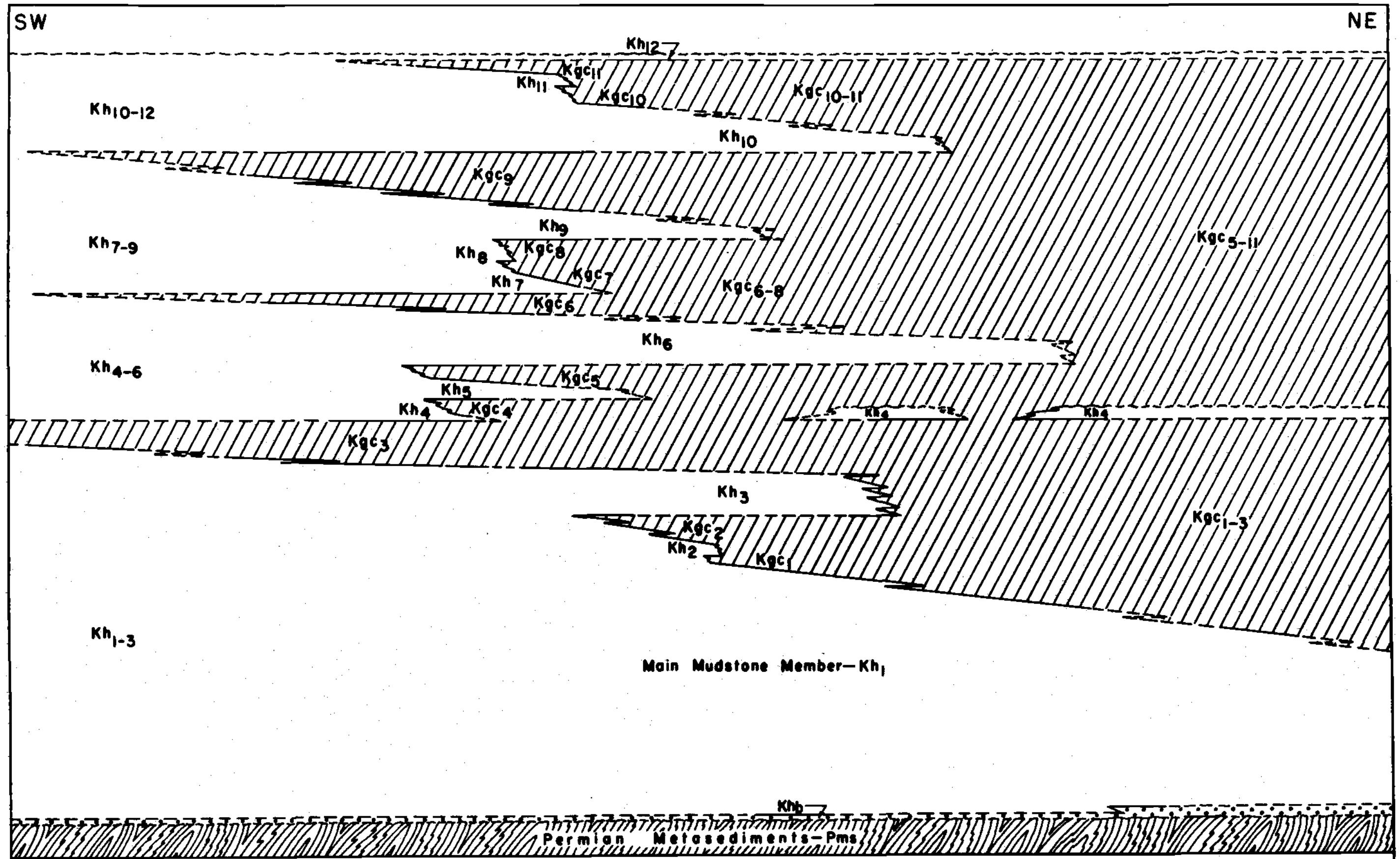

Fig. 2—Schematic Representation of the Intertonguing Hudspeth (Kh) and Gable Creek (Kgc) Formations, Southeast Flank of the Mitchell Anticline, Mitchell Quadrangle, Oregon

Figure 4. Schematic representation of the intertonguing Hudspeth and Gable Creek Formations (Wilkinson and Oles, 1968).

the Main Mudstone Member. Seven tongues of the Gable Creek Formation wedge out southward into the marine facies of the Hudspeth Formation, while the remaining tongues thin markedly to the south and become finer grained. Three tongues of the Hudspeth Formation wedge out northward and most of the other tongues of the formation, including the Main Mudstone Member, appear to thin to the north.

Tertiary Rocks

The Cretaceous rocks are overlain unconformably by Tertiary lava flows and volcanic sedimentary rocks. Numerous dikes, sills, and piston intrusions (plugs) of Tertiary age are present in the Cretaceous rocks. Emplacement of some of these intrusions is controlled by faults while others are randomly oriented. Composition of the piston intrusions is varied and includes andesite, dacite, melabasalt, and leucorhyolite (Oles and Enlows, 1971). Many of the dikes, sills, and irregular intrusions are of andesitic composition similar to flows of the Eocene Clarno Formation. A few large dikes have the same composition as the Miocene Columbia River Basalts. Contact relationships between the intrusions and older Cretaceous rocks exhibit local chill zones at edges of the dikes and sills and slight baked zones in the argillaceous rocks.

Structure

Cretaceous rocks in the Mitchell area are exposed in an eroded asymmetrical anticline with a northeasterly trend. The gently dipping southeast flank provides the best exposures of the Cretaceous sequence.

The anticlinal structure is complicated by numerous faults and intrusions. The Mitchell Fault, a major east-west trending fault, has both right lateral and vertical components of movement. There has been a stratigraphic displacement of approximately 4000 feet and a horizontal displacement of 12,000 feet in the Cretaceous rocks near Mitchell, with the north side upward relative to the south (Wilkinson and Oles, 1968). The upper part of the Cretaceous sequence is exposed only south of the fault; the lower part of the sequence is best exposed north of the fault.

METHODS OF INVESTIGATION

Field Methods

Sampling

Four series of samples were collected in the field. Samples were collected along two measured sections in the Main Mudstone Member of the Hudspeth Formation, along one section in the upper units of the formation, and from scattered outcrops of Cretaceous rocks east and southeast of the Mitchell quadrangle. The section beginning at Meyers Canyon (M-section), SW1/4NE1/4SW1/4 sec. 13, T. 11 S., R. 21 E., and terminating at CSE1/4 sec. 20, T. 11 S., R. 22 E., followed a traverse described by Wilkinson and Oles (1968). The initial point of the Tony Butte section (T-section), which has been measured previously by McKnight (1964), is NE1/4SW1/4NE1/4 sec. 3, T. 11 S., R. 22 E., and the terminal point is NW1/4SW1/4NE1/4 sec. 11, T. 11 S., R. 22 E. The third series of samples (H-section) was collected in the upper units of the Hudspeth Formation which intertongue with the Gable Creek Formation. This section has been measured by Wilkinson and Oles (1968) and extends from NW1/4 SE1/4SW1/4 sec. 32, T. 11 S., R. 21 E. to NE 1/4NE1/4SE1/4 sec. 2, T.12 S., R. 21 E. In addition to rock samples collected in the dissertation area, samples were collected from seven outcrops

(Y-series) of Cretaceous argillaceous rocks east and south of Mitchell (Figure 2) for comparison with the rocks of the Hudspeth Formation.

The M- and T- sections were chosen because the base of the formation is exposed only at these two locations. Despite the fact that these are the most complete sections, approximately one-fifth of the Meyers Canyon section and one-half of the Tony Butte section is covered by soil and vegetation.

To insure random selection, samples were collected along a predetermined grid in the measured sections (Folk, 1965). Approximately one kilogram of rock was collected every ten feet stratigraphically.[1] At each sample location surface debris was removed and the sample was collected from the underlying bedrock. For homogeneity, each sample was taken only from a single layer or stratigraphic unit in the argillaceous rock. In addition, samples were taken from most of the sandstone layers or other "different" rock materials, even if they were not at the ten foot intervals on the grid.

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[1] In the M- and T-sections sample numbers indicate stratigraphic position. For example, T-1120 refers to a sample 1120 feet above the base of the Main Mudstone Member at Tony Butte. Samples H-4 through H-11 indicate representative samples collected in tongues four through eleven of the Hudspeth Formation, while samples Y-1 through Y-7 were collected from outcrops indicated in Figure 2.

Field Descriptions

In the field, samples were classified according to grain size, using claystone, siltstone, sandstone, and conglomerate as size terms after the Wentworth Grade Scale (1922). A rock is designated as a claystone if 50 percent or more by volume consists of clay-sized particles. The term mudstone refers to a fine-grained, non-fissile rock which contains less than 50 percent clay. Field determination of sand grain size was made with a ten power lens and comparison to a sand gauge folder.

Field description of each sample included grain size, color as determined with the aid of the Rock-color Chart published by The Geological Society of America, cement, abundance of fossilized plant fragments, chip size and shape, and size of beds or lenses. Sedimentary structures, concretions, fossils, and slickensides were noted when present.

Petrographic Methods

The petrographic microscope was used to determine (1) composition of sandstones and the coarser argillaceous rocks, (2) the relative proportions of sand, silt, and clay in each sample, and (3) textural relationships. Thin-sections were prepared from 167 rock samples. Of the 70 argillaceous samples studied in detail for this report, 61 were sectioned, however, the remainder were too highly fractured to permit making thin-sections. Modal analyses for composition and size analyses of these 61 thin-sections were made using a point counter. In addition, modal analyses were made for 38 sandstones interbedded with the argillaceous rocks. The remaining thin-sections were mostly of other fine-grained rocks of the Hudspeth Formation which were examined for their textural relationships.

Point counting was done with a mechanical point counter using 300 counts per slide (Krumbein and Pettijohn, 1938; Friedman, 1958) with a spacing of 1.0 millimeters and 0.5 millimeters. When possible, an area of 20 millimeters by 7.5 millimeters on a standard size thin-section was utilized, but many sections were prepared from small rock chips with irregular shape. When a standard section was not possible, the grid was readjusted to 25 by 6 millimeters or some other combination with the same spacing and a total of 300 counts.

Size analysis of the argillaceous rocks was done under high magnification (8X ocular, 50X objective) using a binocular petrographic microscope. Size was estimated visually from a superimposed grid, catagorizing grains as sand (greater than 62.5μ), silt (4 to 62.5μ), or clay (less than 4μ). Size measurements are in terms of the maximum diameter of grains, assuming that the average radius observed is 0.763 of the actual radius of the grains (Krumbein and Pettijohn, 1938). This arbitrary correction factor is only an approximation of the relationship between size in thin-section and actual size of grains. Grain size measured in thin-section is a function of the size and shape of the grain, the orientation of the grain, and/or of the direction in which the section is cut, and of the density of the grains in the section, i. e., packing (Griffiths, 1967). Therefore, the size measurements cannot be interpreted as absolute size measures. It must be stressed that size distribution obtained from the thin-section is a number frequency and not weight percent.

A size analysis of the argillaceous rocks by disaggregating and sieving was not feasible. In wet sedimentation methods size values reflect the method and intensity of disaggregation and dispersion rather than anything inherent in shale (Grim Bradley, and White, 1957; Griffiths, 1967). The mudstones of the Hudspeth Formation are difficult to break down because they are well indurated and held together by clays. Examination with the binocular microscope shows that most larger grains are mudstone fragments rather than individual mineral grains and disaggregation is never complete. Sandstones also do not break down easily because they are cemented with carbonate and clay. Heavy mineral analysis was not performed because of poor disaggregation coupled with a general lack of heavy minerals visible in thin section.

The fine-grained rocks were classified by grain size according to the classification scheme (Figure 5) proposed by Picard (1971).

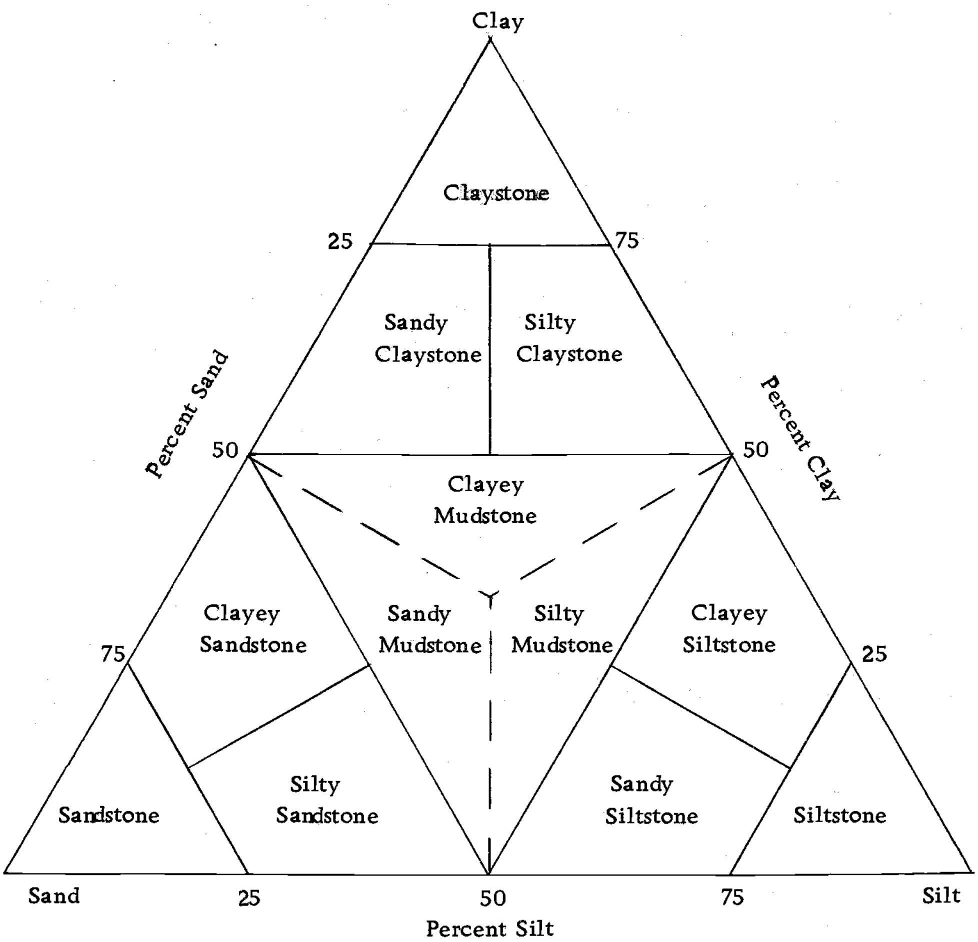


Figure 5. Textural classification of fine-grained rocks (after Picard, 1971).

For the sandstones and coarse argillaceous rocks composition of framework constituents was plotted on triangular diagrams and the rock was classified according to Gilbert's classification of sandstones (Williams, Turner, and Gilbert, 1955).

Textural relationships were studied at low power. All thin-sections were cut perpendicular to bedding to best illustrate bedding irregularities, parallel extinction, and other textural features.

X-ray Analysis

Clay mineral composition was determined by X-ray diffraction, using two methods of analysis. In the first method, thorough determinative tests were made on several representative samples chosen to represent the main compositional combinations encountered. These samples were tested to determine the identification of all clays present. The second method employed was the routine X-ray analysis, a simplified version of the determinative tests. The procedure included several characterization tests, but the process was simplified by omitting several steps. The main purpose of using a simplified analysis was to have a relatively fast method for preparing numerous samples for X-ray analysis. All samples were treated in the same manner, therefore comparison of composition could be made for numerous samples. Results of the routine X-ray analyses were interpreted semi-quantitatively so information could be treated statistically.

Samples for routine analysis were taken every 80 feet stratigraphically in the M-section, and every 40 feet in the T-section. Closer spacing was necessary in the T-section because part of the unit is poorly exposed or covered and using samples at 80 feet intervals would not provide enough information for statistical analysis.

Routine analysis was also performed on samples from most of the upper units of the Hudspeth Formation, and from outcrops of argillaceous Cretaceous rocks east of the Mitchell area. In thin units or poorly exposed areas, one representative sample was taken for each unit, while for thicker units two or more samples were collected and analyzed and the semi-quantitative results were averaged together.

Sample Preparation for X-ray Analysis

Samples were prepared for routine X-ray analysis in groups of eight (the number of tube holders in the centrifuge). Such grouping assures less introduced variability between samples because all eight samples share the same conditions of preparation. The procedure for analysis followed a scheme (Figure 6) modified from United States Geological Survey methods (Hathaway, 1956; Schultz, 1964). Samples were prepared in the manner described below.

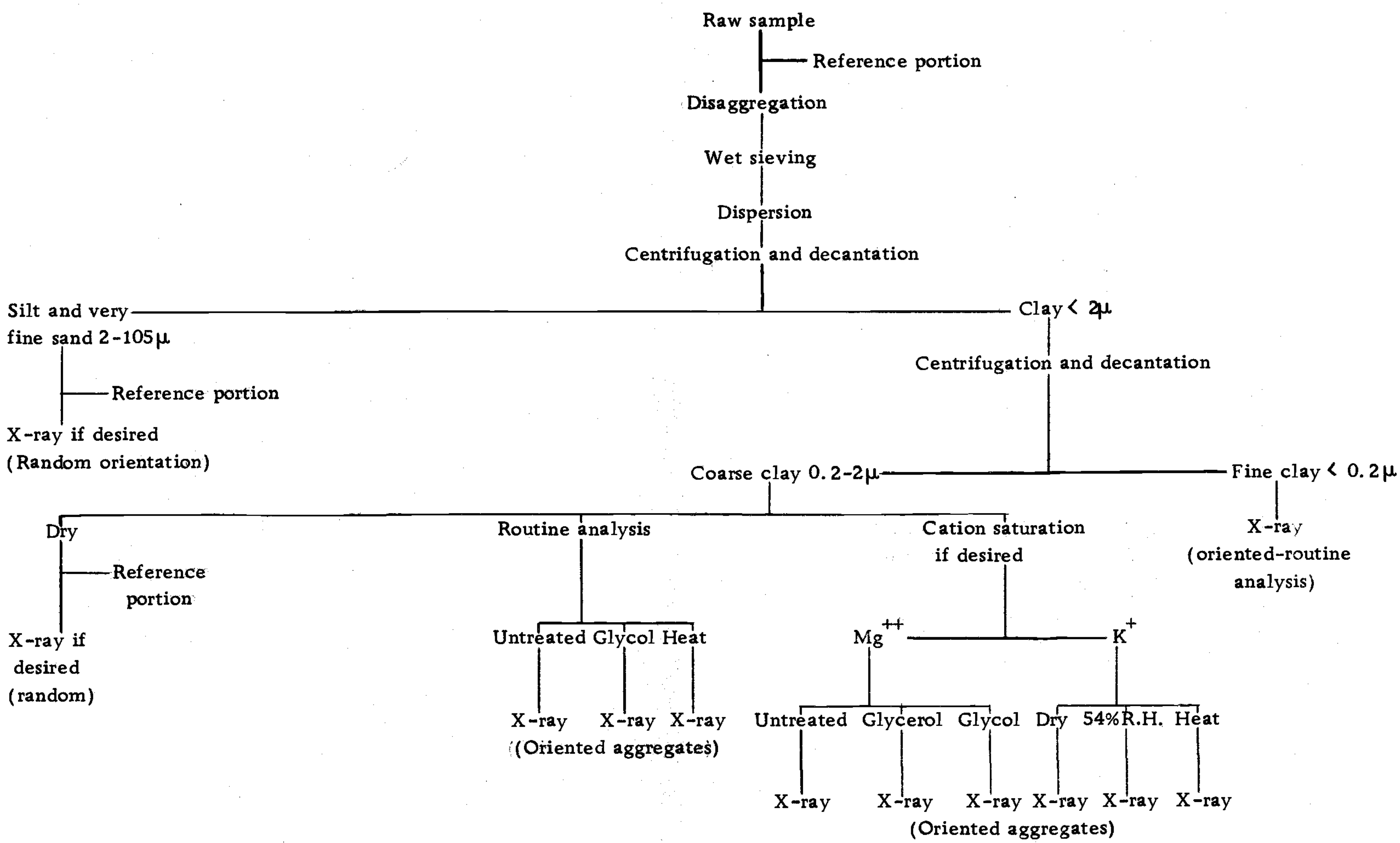


Figure 6. Scheme for X-ray analysis.

Disaggregation. The argillaceous rocks of the Hudspeth Formation are well indurated and difficult to break down for separation of clay minerals. Several disaggregation techniques were tried in a search for an effective method which would least alter the clays chemically or physically. The "gentle" physical methods such as prolonged agitation in water or dilute calgon, ultrasonic cleaners, or gentle rubbing with fingers and rubber pestle have little or no effect. Techniques which require high temperature were avoided because of irreversible changes in the expansive properties of the clays when subjected to high temperature. Grinding to fine sizes was avoided also as such grinding would tend to incorporate broken grains of quartz and other minerals with the clays complicating the X-ray interpretation of the clay size materials. It is also possible that grinding could destroy the crystallinity (Brown, 1961) or alter the expandability of the clays (Jonas and Roberson, 1960). Chemical methods for removal of iron oxide or carbonate cement are also useless because these cements are only minor constituents in the argillaceous samples.

Kerosene is the most effective agent for disaggregating the argillaceous rocks of the Hudspeth Formation. The method used is similar to the one Crowley (1952) used to extract Foraminifera from refractory shales, however, sodium carbonate treatment was omitted and the samples were dried at a lower temperature to preserve the chemical and thermal properties of the clays. Samples were disaggregated using the following procedure. Approximately 100 grams of fresh rock were crushed to pea size particles in a crusher. These particles were dried at 60° C for two hours, then while still hot immersed in kerosene and left several hours or preferably overnight. The kerosene was decanted and distilled water added and allowed to soak several hours or preferably overnight. This procedure caused most samples to partially disintegrate as soon as water was added and even the most stubborn samples were softened enough that sufficient clay was released by crushing with the fingers or a rubber pestle.

Disintegration is seldom complete with this method. Larger fragments of rock which were not broken down were discarded. The kerosene method is most effective when large amounts of expandable clay are present, and is much less effective for samples with little or no expandable clays. Sprinkling sodium bicarbonate directly on wet samples after the kerosene treatment tends to additionally soften the stubborn samples. This also changes the cation state of some clays, requiring calcium or magnesium saturation before X-ray analysis so the X-ray patterns can be readily compared with other samples.

<u>Wet Sieving</u>. The disaggregated rock was wet sieved through a 105 micron (150 mesh/inch) screen. The clay, silt, and fine sand fractions less than 105 microns were recovered from the liquid by centrifuging briefly at high speed, and decanting and discarding the

supernatant liquid. Material that did not pass through the sieve during wet sieving was saved and later examined under the stereoscopic microscope for additional information about the mineral composition. Foraminifera, when present, are also found in this coarse fraction.

Dispersion. The fine fraction was suspended in distilled water or dilute calgon in preparation for size fractionation. Most of the samples studied were easily dispersed in distilled water by adding water to the sediment in a centrifuge tube and stirring with a high speed rotary stirrer. If a sample flocculated in distilled water, calgon diluted to 1 gram per 9 liters was used instead.

Separation of Size Fractions. The less-than-two-micron clay fraction was separated from coarser material by centrifuging the suspended sediment at 750 rpm[2] for five minutes. This settled the silt and fine sand, leaving the two micron or less clay in suspension. The silt and fine sand residue less than 105 microns was retained for possible X-ray analysis or for examination with the stereoscopic microscope.

The less-than-two-micron clay fraction was then further subdivided into coarse and fine clay by centrifuging at 6000 rpm[2] for

[2] The speed required varies, depending on dimensions of the centrifuge and size of sediment to be separated. Speeds can be calculated using the formula given by Hathaway (1956).

seven minutes. This settled the coarse clay, from 0.2 to 2 microns, leaving the fine clay less than 0.2 microns in suspension. The fine clay then could be recovered by centrifuging briefly at high speed.

Routine X-ray Analysis

After size fractionation, duplicate slides of each sample were prepared for routine X-ray analysis. A small portion of clay was removed from a vertical section of the centrifuge tube and smeared evenly on a petrographic slide with a micro-spatula (Theisen and Harward, 1962). This method is preferred, rather than settling the clays out of suspension on a petrographic slide, because it eliminates segregation of the clay minerals by size (Gibbs, 1965). However, care must be taken to ensure a uniform thin layer on all sides because the clay film may crack or peel if too thick, especially if smectite is present.

Four X-ray diffraction traces of the oriented aggregates were run in the following order: (1) dried at room temperature, (2) treated with ethylene glycol, (3) heated at 300° C for one hour, and (4) heated at 550° C for one hour (Schultz, 1964). Traces were run using nickel-filtered copper radiation generated at 35 kilovolts and 20 milliamperes, 1° beam slit, 0.006-inch detector slit, and scanning at 2° per minute.

The advantages of this routine procedure are that it is relatively fast, easy, and fairly reproducible. When several sub-samples from one well-mixed sample are prepared at different times, X-ray patterns are very similar. Proportions of the various clays in these sub-samples agree within five to ten percent calculated by the method outlined below.

A disadvantage of the method is that it may cause difficulty in interpretation of a series of samples with variable cation state. In this study the problem did not arise. Clays of the Hudspeth Formation appear to be naturally saturated with calcium or magnesium and samples give X-ray diffraction patterns that are essentially identical before and after calcium treatment. If cation saturation had been variable in the mudstone sequence, or if sodium bicarbonate had been used during disaggregation, all samples would have required magnesium or calcium saturation as part of the routine procedure so that samples could be easily compared.

Another disadvantage of the simplified routine procedure is the lack of humidity control during X-ray analysis. Peak position of smectites, after collapse by heating, is especially dependent upon humidity and X-ray patterns may indicate incomplete collapse under high humidity conditions.

In addition to X-ray diffraction traces of the oriented clays, several samples were analyzed with random orientation of (1) the whole rock, after grinding to less than 60 microns, (2) silt and very fine sand obtained during size fractionation, and (3) the clay fraction dried after size fractionation.

Characterization Treatments

Several characterization treatments were carried out on representative samples to determine the identification of all clays present in the Hudspeth Formation. Portions of the clay fraction were saturated with magnesium and potassium using 1 N solutions of appropriate chloride salts. The clays were saturated with each cation by washing two or three times with the salt solution, suspending, centrifuging, and decanting the supernatant. Excess salts were removed by two or three washings with distilled water, then slides were prepared for X-ray diffraction analysis by smearing the clay paste on petrographic slides.

Prepared slides were subjected to various solvation, humidity, and heat treatments. Magnesium saturated slides were air dried and then equilibrated at 54 percent relative humidity by suspending in a desicator over a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$ for 24 hours. During X-ray diffraction analysis, air to the goniometer passed through a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$. Magnesium saturated slides were solvated with ethylene glycol by condensation from the vapor (Kunze, 1955). Slides were suspended in a covered container above a small amount of ethylene glycol and held at 65° C for one hour, then left covered 12 hours at room temperature before analysis. Solvation with glycerol was done by condensation of the vapor at 105^{o} C for three hours and equilibrating at room temperature for 12 hours (Brown and Farrow, 1956). Potassium saturated slides were dried at 105^{o} C and analyzed in dry air. Air to the goniometer passed through two columns of $CaSO_4$. Following analysis the potassium slides were rehydrated over a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$ and analyzed at 54 percent relative humidity. Subsequently the potassium slides were heated at 300^{o} C for three hours and analyzed in dry air, then heated at 550^{o} C for three hours and analyzed in dry air.

Identification of clays is based mainly on the approximate (001) spacings (in Å) obtained by characterization treatments (Table 1). In addition to the clays listed, interstratified clay minerals may occur. Regular interstratification is indicated by occurrence of peaks at d-spacings which tend to be the sum of the spacings of two or more interstratified minerals. Random interstratification is indicated by occurrence of peaks at d-spacings intermediate between the spacings of the random components with the magnitude of spacing tending toward that of the component present in the interstratified system in greatest amount. In random interstratification, the (001) series is not an integral sequence (Weaver, 1956).

Differentiating between kaolinite and chlorite presents a problem in the above identification scheme because the basal reflection of

Table 1. Approximate (001) spacings (Å) obtained by characterization treatments.*

	Montmorillonite	Beidellite[1]	Vermiculite	Chlorite	Illite	Kaolinite
Mg-sat'n; 54 % R.H.	14-15	14-15	14-14.5	14	10	7
Mg-sat'n; Eth. Glycol	16-17	16-17	14-14.5[2]	14	10	7
Mg-sat'n; Glycerol	17-18	14-15	14-14.5	14	10	7
K-sat'n; 105° C; Dry Air	10	10	10	14	10	7
K-sat'n; 54 % R.H.	12[3]	12[3]	10	14	10	7
K-sat'n; 300° C; Dry Air	10	10	10	14	10	7
K-sat'n; 550° C; Dry Air	10	10	10	14	10	7

*References: Brown, 1961; Harward, Carstea, and Sayegh, 1969; Warshaw and Roy, 1961.

[1] Tetrahedrally substituted smectite.

[2] Under certain conditions, vermiculite may show expansion to 16.3 Å after Mg-sat'n and Eth. Glycol solvation (Walker, 1958).

[3] Non-integral.

kaolinite coincides with that of chlorite near 7 Å. Several methods have been described for distinguishing between kaolinite and chlorite in X-ray diffraction analysis. The method of Biscaye (1964) includes resolving two peaks at 3.58 Å (kaolinite) and 3.54 Å (chlorite) and is not applicable because the two peaks cannot be resolved in most samples. Also, the 2.38 Å peak of kaolinite and the 4.72 Å peak of chlorite are not detected (Weaver, 1958). The method of Johns, Grim, and Bradley (1954) is also not applicable because experiments show that the 7 Å peak of the Hudspeth clays disappears entirely after heating to 450° C.

The presence of chlorite in the Hudspeth Formation was ascertained by the presence of a 14 Å peak after heating to 550° C. The presence of kaolinite was determined in representative samples by decomposing the chlorite in warm 6 N hydrochloric acid for 16 hours (Schultz, 1964). The 14 Å chlorite peak was not detected in any sample after acid treatment, but a 7 Å peak attributed to kaolinite remained in all samples.

Estimation of Clay Percentages

Some method of quantification is needed for determining trends and comparing one sample to another. To be truly quantitative, X-ray data must be combined with chemical analyses (Alexiades and Jackson, 1965). The clays could not be compared to U. S. Standards for illite, kaolinite, chlorite, and montmorillonite because the standards are quite different in crystallinity and composition from clays of the Hudspeth Formation. Another method of quantification is by extracting "standards" from particular rock samples and analyzing different ratios of these "standards" (Gibbs, 1967). Quantitative estimates of clay percentages can then be obtained by direct comparison to X-ray traces of the "standard" ratios. This extraction technique was not successful for the complex suite of clays in the Hudspeth Formation.

Johns, Grim, and Bradley (1954), Weaver (1958), Biscaye (1965), and others have described several methods for estimating the relative proportions of the different clays in a sample, based on X-ray diffraction data. Most of these methods work best when only two or three clays are present in a sample, but problems arise in interpretation of a complex suite where basal reflections of the various clays may overlap. Smectite, vermiculite, and chlorite all have 14 Å peaks; kaolinite and chlorite both have 7 Å peaks. Therefore, small amounts of these clays may be undetected. In addition, interstratified clays are generally overlooked in these methods.

The calculation procedure used in this report is based on comparison of intensity of the 10 Å reflection before and after heating (Table 2). Illite and the expanding minerals are assumed to reflect X-rays with equal intensity at 10 Å, and the intensity of the 7 Å

Table 2. Procedure for calculation of relative amounts of clay minerals in the Hudspeth Formation (modified after Schultz, 1964).

1. Measurement of areas of the 7 Å, the 10 Å glycol, and the 10 Å 300° C peaks; measurement of heights of the 7 Å and the 14 Å 550° C peaks.

2. Corrected 7 Å peak area $= \frac{7 \text{ Å peak area}}{1.4}$.

3. Kaolinite + chlorite (percent) =

$$\frac{\text{corrected 7 Å peak area}}{\text{corrected 7 Å peak area + 10 Å 300° C peak area}} \times 100.$$

4. Chlorite (percent) =

$$(\text{Kaolinite + chlorite}) \times \frac{\text{14 Å 550° C peak height}}{1.5 \times \text{7 Å peak height}} .$$

5. Kaolinite (percent) = (Kaolinite + chlorite) - chlorite.

6. Illite (percent) =

$$\frac{\text{10 Å glycol peak area}}{\text{corrected 7 Å peak area + 10 Å 300° C peak area}} \times 100.$$

7. Smectite + vermiculite* = 100 - (Kaolinite + chlorite + illite).

*Includes beidellite, montmorillonite, mixed-layer clay, and vermiculite.

reflection is compared to the 10 Å peak for comparison of kaolinite plus chlorite to illite plus the expanding minerals (Schultz, 1960; Schultz, 1964). X-ray traces used for calculation were produced by the routine procedure described earlier. Peak heights and peak areas were measured using the technique of Schultz (1964, Figure 3).

Certain problems arise in using this method of calculating relative percentages. Schultz's calculations for expandable clay are based on presence of montmorillonite and mixed-layer clay. The Hudspeth Formation contains very little pure montmorillonite. Instead it contains beidellite, vermiculite, and mixed-layer clay. In this dissertation, all clays which collapse to 10 Å when heated are included in the percentage of "smectite and vermiculite." The exact relationship between peak sizes of beidellite, vermiculite, montmorillonite, and mixed-layer clay after collapse to 10 Å is not known. Calculations used in this report assume that all reflect X-rays with equal intensity at 10 Å.

Another problem arises in calculations for kaolinite and chlorite. Treatment of several representative samples with hydrochloric acid shows that the correction factor in calculation of percent of chlorite should be closer to 1.0 rather than 1.5. The average decrease in height of the 7 Å peak after acid treatment is about equal to the height of the 14 Å peak after heating to 550° C. The hydrochloric acid method is not infallible and it is possible that some of the kaolinite is also destroyed during acid treatment giving a low value to the chlorite correction factor. Using a correction factor of 1.0 yields negative values of kaolinite in some calculations, therefore the correction factor of 1.5 was used for calculations in this report. This means that values of chlorite may be lower than the true value, while values of kaolinite are correspondingly higher. Where a large proportion of chlorite is present, calculated values appear to be particularly low. Comparison to the illustrations of Grim, Bradley, and White (1957, Figure 2) shows that chlorite is more abundant than kaolinite in an occasional sample, such as M-80, although calculated values do not indicate this.

The semi-quantitative nature of the calculated data must be stressed. Variables affecting attempts at quantification in clay mineral studies include sample treatment, slide preparation, structural and chemical variations between mineral groups and within mineral species, equipment conditions, and the method used to calculate the relative amounts of the different minerals in the sample (Pierce and Siegel, 1969). Thus, results reported in this study can be interpreted semi-quantitatively only. They can be used only to compare one sample to another within this study, and cannot be used to compare percentages directly with those reported in other investigations.

RESULTS

Field Results

Each measured section in this study can be divided into several sub-units. At Meyers Canyon (M-section) the Main Mudstone Member of the Hudspeth Formation consists of seven mudstone and claystone units and one unit of alternating sandstone and mudstone (Figure 7). Minor interbedded sandstones and rare conglomerate occur throughout. Sub-divisions between claystone and mudstone units are often gradational over 50 to 100 feet stratigraphically. Thin sandstone beds usually overlie sharp contacts with the mudstones. Total measured thickness of the section is 2956 feet, of which approximately 600 feet is covered by soil and vegetation. At Tony Butte (T-section) the total measured thickness is 1817 feet, of which approximately 950 feet is covered. Here the Main Mudstone Member consists of five units of mudstone or alternating sandstone and mudstone (Figure 8). Contacts between the various units of the T-section are everywhere covered by soil and vegetation. Changes from one rock type to another are abrupt, but the actual contacts could be sharp, gradational, or faulted. Sandstones are more numerous in the T-section and are often thicker than in the M-section. In the H-section, units of the upper part of the Hudspeth Formation are separated from each other by

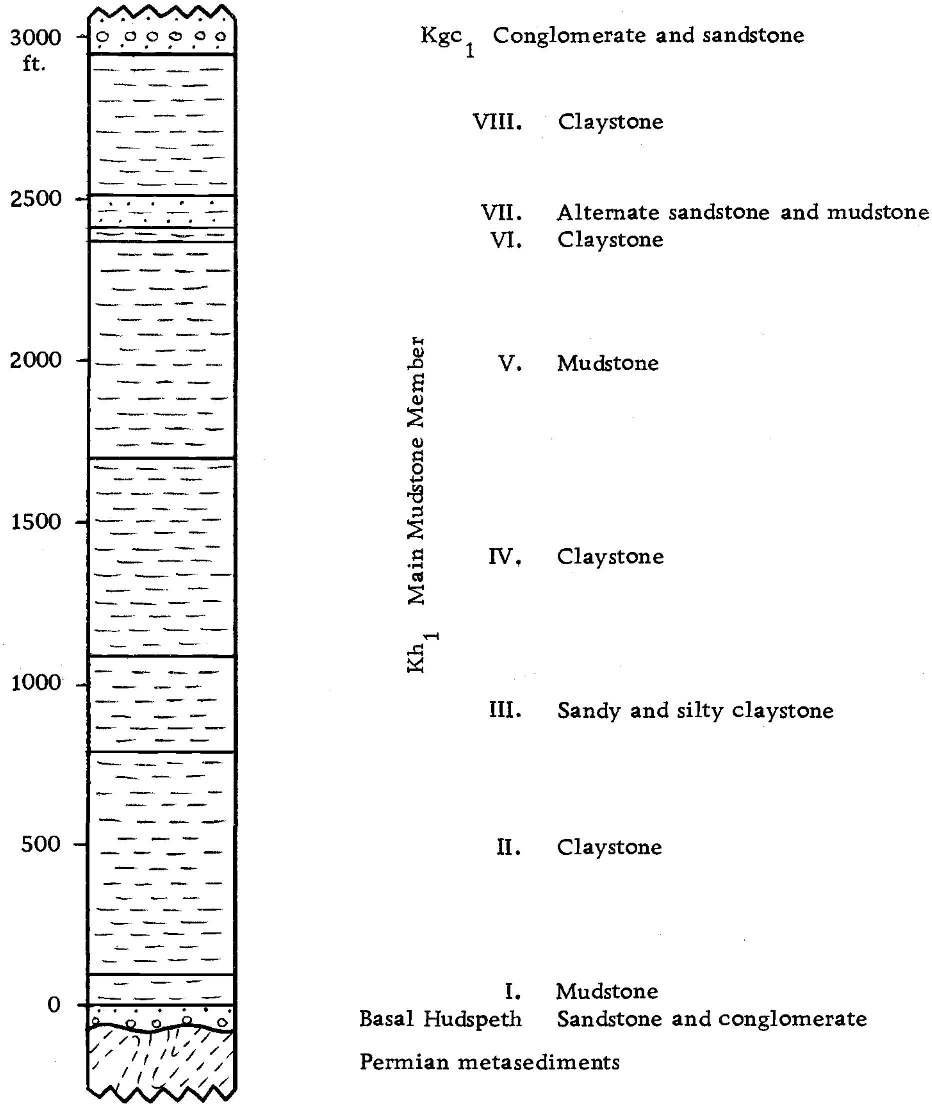


Figure 7. Stratigraphic section of the Main Mudstone Member of the Hudspeth Formation measured near Meyers Canyon.

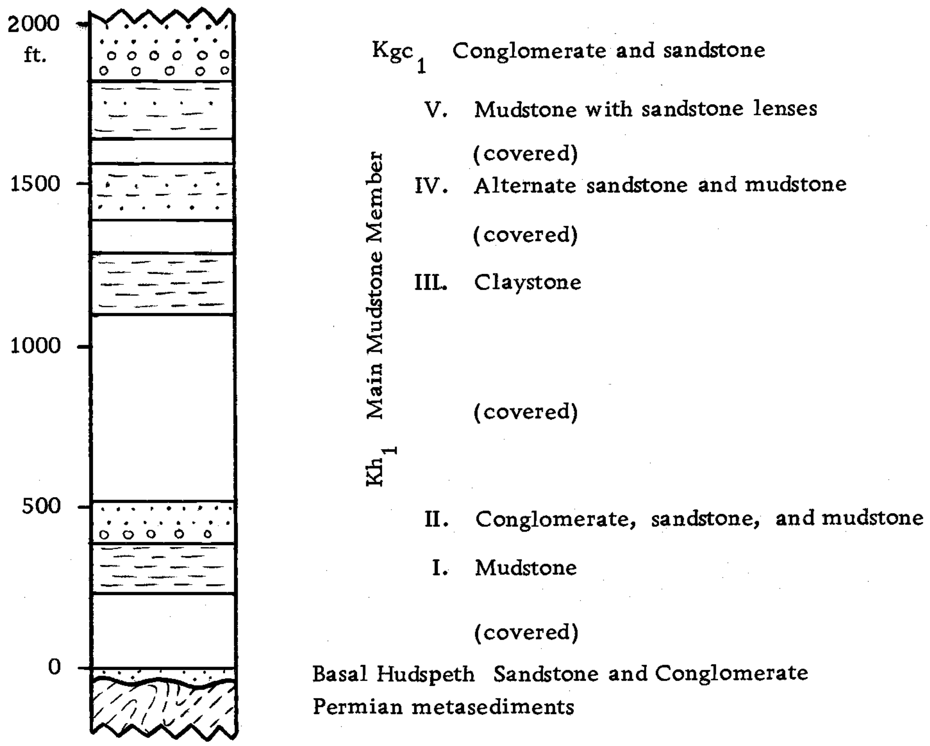


Figure 8. Stratigraphic section of the Main Mudstone Member of the Hudspeth Formation measured near Tony Butte.

interfingering tongues of the Gable Creek Formation. Thickness and lithology of each unit are summarized in Figure 9.

Some faulting exists in each section. This is perhaps minor because strike and dip do not vary much. Although sandstone and conglomerate layers are occasionally offset by small faults (Figure 10), faulting is not conspicuous in mudstones where the bedding is obscure. At five or more localities in the M-section, the rock chips are lenticular in shape, and are slickensided on all faces of the chip, indicating probable shearing in the mudstones. In the T-section, where much of the section is covered, evidence of possible repetition or missing beds is obscured.

General Lithology

The most prominent characteristic of the mudstones is their color, which is commonly olive gray (5 Y 4/1) in claystone and light olive gray (5 Y 5/2) in coarser mudstone. Weathered surfaces of these argillaceous rocks are commonly a moderate brown (5 YR 3/4). Calcareous sandstones are various shades of gray (N3 to N7). Most of the variation in color is attributed to differences in grain size or weathering characteristics. The only other pronounced color change occurs adjacent to intrusions of younger rock where the color changes from light olive gray (5 Y 5/2) several yards from the contact to medium dark gray (N4) a foot or two from the contact.

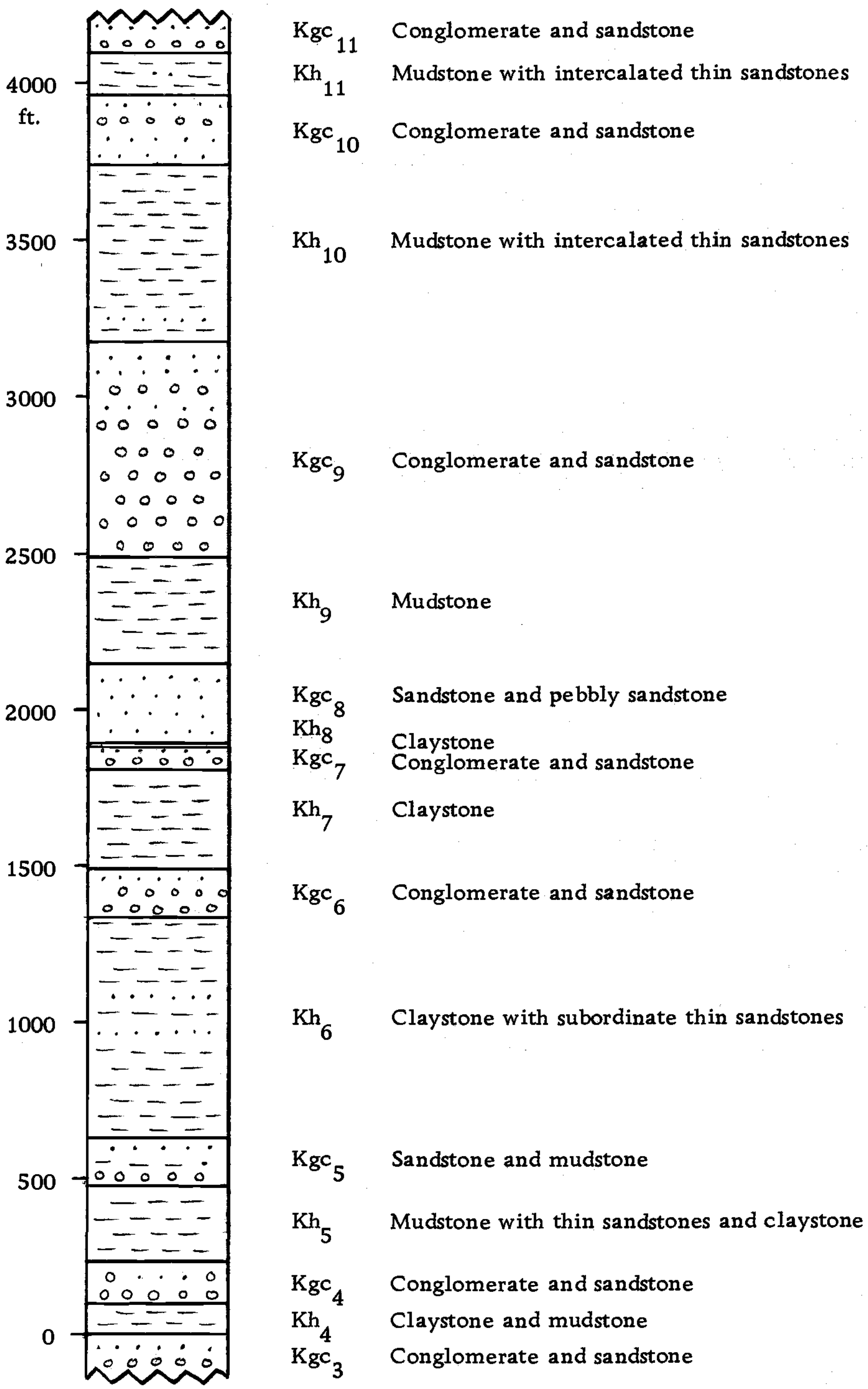


Figure 9. Stratigraphic section of the upper units of the Hudspeth Formation intertonguing with units of the Gable Creek Formation, prepared from the written descriptions presented by Wilkinson and Oles (1968).

Figure 10. Small faults displacing sandstone and conglomerate layers interbedded with mudstone.

Fissility is generally lacking in the Hudspeth mudstones, therefore the term mudstone is used rather than shale (Pettijohn, 1957). The rocks often break with a hackly or subconchoidal fracture, giving angular chips with an equi-dimensional shape. Average dimension of the chips is about one-half inch, but they may be up to two or three inches across. Some chips break out along bedding laminations, yielding flat chips one-quarter to one-half inch thick and one and one-half inches across, but even these samples lack fissility. Although many of the fresh mudstones contain thin laminations caused by differences in color or grain size, the rocks do not split easily along these planes.

Field estimates of grain size in the "mudstones" indicate that many are claystones with at least 50 percent clay. Coarser samples, with less than 50 percent clay, often contain much sand as well as silt, and are mudstones rather than siltstones. A few of the samples collected as "mudstones" are actually friable clayey sandstones.

Many silt and sand grains in the mudstones can be identified in the field with the aid of a ten-power lens. The grains consist mostly of quartz, feldspar, mica and chlorite, with minor rock fragments. Pyrite altering to limonite is visible in some samples. Carbonized plant fragments of silt size or smaller are locally abundant.

Sandstone layers and lenses are interspersed throughout the mudstones, and range in thickness from less than one-quarter inch to about twelve inches, with an average of two to four inches. The sandstones are lithic wackes and lithic arenites. Clastic particles include quartz, feldspar, micas, and rock fragments such as greenstone and phyllite. Metamorphic rock fragments are especially common near the base of the Main Mudstone Member. The sandstone matrix is clay and iron oxide, and the cement is generally calcite. Complete description and modal analyses for rocks analyzed in this study are listed in the appendices.

Concretions are scattered throughout the Hudspeth Formation and are locally abundant (Figure 11). They are conspicuous within the mudstones because of a contrast in color. On a fresh surface

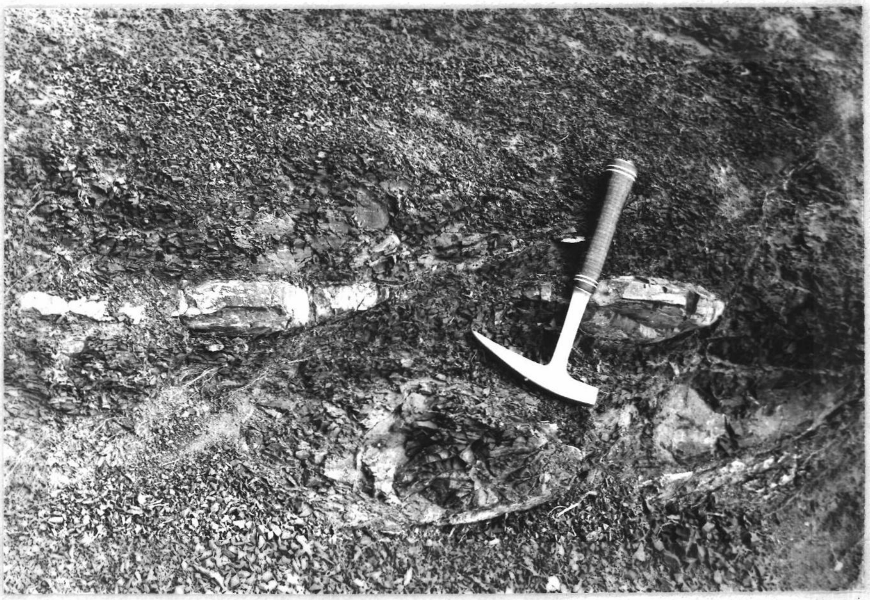


Figure 11. Typical mudstone outcrop showing concretions aligned parallel to the strike and dip.

concretions are medium dark gray (N4) or olive gray (5 Y 4/1), whereas they usually weather to dark yellowish orange (10 YR 6/6) or grayish orange (10 YR 7/4) on the outer surface as included pyrite alters to limonite or hematite. They often exhibit spheroidal weathering and shed streamers of debris down slope. The concretions range in size from one inch spheres to 4' x 3' x 1' ellipsoids; however, they may also occur as eight to ten inch thick bands, parallel to the bedding, and extending many feet along strike. The concretions have finely crystalline calcite cement intermixed with a clay matrix, and a silt composition similar to the surrounding mudstones. Locally septarian concretions have coarsely crystalline calcite filling fractures.

Fossils are common in concretions and may have served as nuclei for their formation. Ammonites are especially common, but generally are poorly preserved or recrystallized. Pelecypods, crabs, and nautiloids have also been described from these concretions (McKnight, 1964).

Paleontology

Megafossils from the Main Mudstone Member of the Hudspeth Formation were identified by Drs. David L. Jones and Earl Packard (1971). They include ammonites and a few pelecypods from the early middle, and late Albian (Appendix A, Part II). No fossils were found in the upper units of the formation. These units and the Cretaceous rocks east and southeast of the Mitchell area are of possible Cenomanian age.

Microfossils are found locally in the fine-grained claystones. These Foraminifera are poorly preserved and often partly replaced by pyrite or chert. Most are planktonic forms of the family Globogerinidae and a few are benthonic forms of the family Lagenidae. These have not been identified specifically, however, they are similar to genera characteristic of the outer shelf and upper slope (100 to 400 meters) (Gary D. Jarman, 1971). Microfossil localities are listed in Appendix A, Part II.

Sedimentary Structures

Sedimentary structures in the Hudspeth Formation have been described by others (Wilkinson and Oles, 1968; McKnight, 1964). A summary of structures noted in the present study is given below.

Thin sheet sands occur with little variation in thickness over many feet, but lensing and pinching beds are much more common. Thinning can be gradual to abrupt. Sandstone layers are often variable in thickness with some layers persisting only a few tens of feet. These features can occur on a large or small scale. In some of the siltier mudstone outcrops, one to two millimeter thick laminations of silt and mud alternate, persisting for several inches, then pinching out, or at places swelling and pinching out several times along the same bedding plane.

Graded bedding is noted in some interbedded sandstone layers, however most layers are not graded. This sparse grading occurs in lenses or channels, usually with coarse sandstone at the base grading upward to finer sandstone and then abruptly to mudstone above. Locally the grading is only partially complete with the top scoured off and another graded bed deposited on top.

Scour-and-fill is common in the thin, lensing sandstones, and occurs on both a large and a small scale. Channels range from several feet wide and several inches deep to a few inches wide and deep. The channels, which commonly are filled with normally graded sandstone, are lens-shaped, flat on top and convex downward.

Sole markings consist mainly of load casts and groove casts (Figure 12) at the bases of sandstones interbedded with the mudstones. Depth ranges from one-quarter inch to three inches.

Ripple marks are rare but occur at places in sandstones interbedded with the mudstones (Figure 13). Both symmetrical and asymmetrical types occur. They are usually small with wavelength less than two inches and amplitude less than one-half inch.

Mud cracks occur at the tops of some sandstones. Contacts between the sandstone and overlying mudstone are sharp, with mud filling the cracks. Areas bounded by these mud cracks are generally less than two inches across and the crack fillings are less than one-quarter inch deep.

Penecontemporaneous deformation (Figure 14) occurs as load casts or as zones of contorted bedding in the sandstones. The latter represent slumping or distortion of hydroplastic beds under the superincumbent load of sediment and they are commonly truncated at the top while dying out below in undisturbed strata.

Large mudstone inclusions are not common within the sandstones of the Hudspeth Formation. However, small mudstone clasts less than one-quarter inch in diameter are locally abundant.

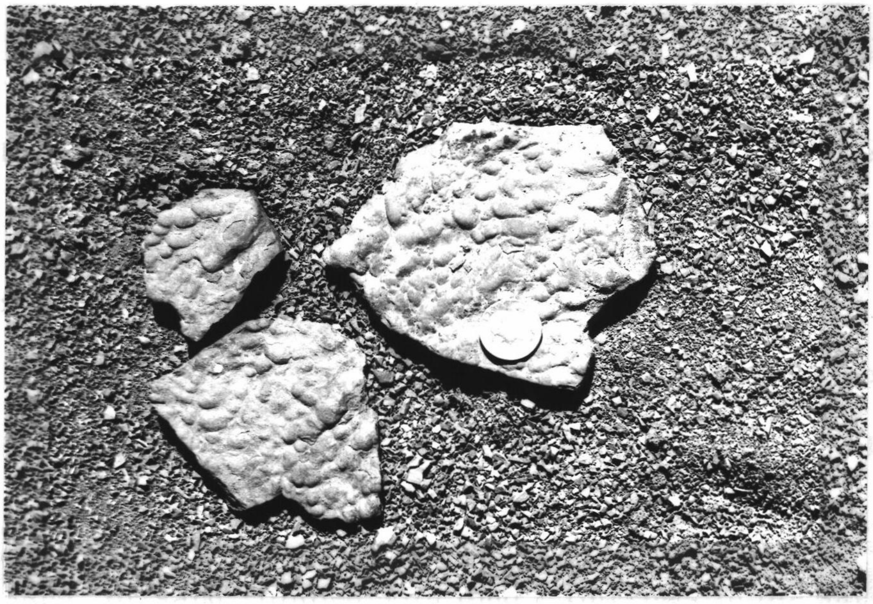


Figure 12. Load casts on underside of sandstone interbedded with mudstone.

Figure 13. Symmetrical ripple marks in sandstone.

Although cross-bedding is uncommon in sandstones interbedded with the mudstones it does occur on a small scale as both planar and trough cross-bedding.

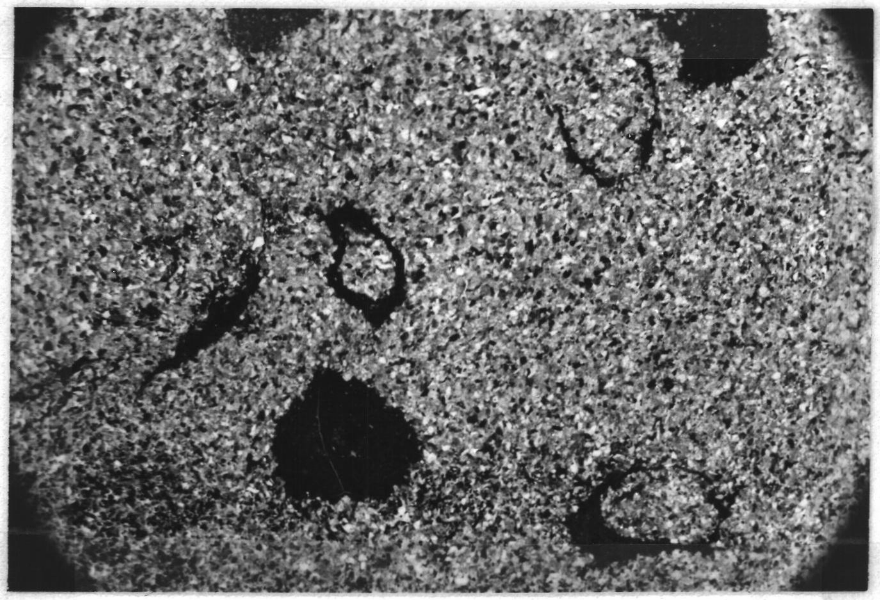
Worm burrows (Figure 15) are locally abundant and commonly found in the sandstone interbeds. They are partly cylindrical, partly sinuous, and up to three inches long. These burrows are filled with mud or sand, or sand rimmed with mud. Burrows in the sandstones do not penetrate the underlying mudstone.

Other than a thinning and increase in sandiness to the north and northeast in the Main Mudstone Member, few indicators of current direction were encountered during field work. Cross-bedding, ripple marks and directional sole markings are not abundant in the Hudspeth Formation. Orientation of foreset strata of cross-beds and asymmetrical ripple marks indicate general current movement was from north to south. Average orientation of directional features is 5° to 10° east of south (Figure 16).

Orientations of linear sole markings are excluded because they are not consistent as directional indicators. They have a range of values from north-south to east-west with no evidence of a preferred orientation.

In previous studies, Wilkinson and Oles (1968) concluded that the transportation direction for the Gable Creek Formation was mainly from north to south. Their interpretation was based on foreset strata,

Figure 14. Penecontemporaneous deformation in sandstone.



1 mm

Figure 15. Burrow fillings in sandstone.

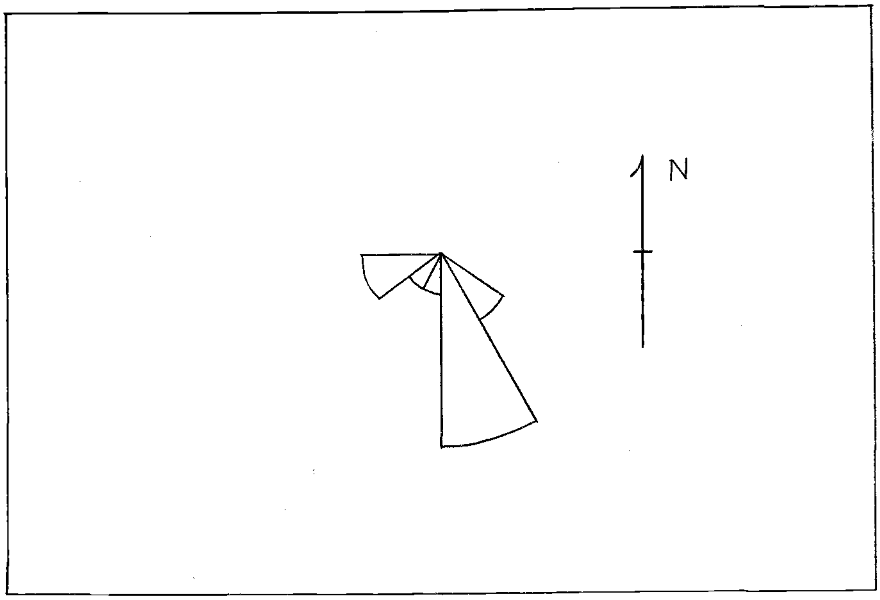


Figure 16. Current rose representing cross-bedding and ripple mark measurements of 11 outcrops.

strike of channels, and geometry of the tongues of the Gable Creek Formation. McKnight (1964) concluded from the orientation of sole markings in the Hudspeth Formation that currents moved from south or southeast toward the north. According to him the average orientation of sole markings is 10^{o} to 15^{o} west of north.

Petrographic Results

Mudstone Textures

Grain size estimates were made by counting 300 points on each slide, classifying grains as sand, silt and clay. Percentages were plotted on a triangular diagram (Figure 17) and the rocks then classified according to the textural classification of fine-grained rocks proposed by Picard (1971). Distribution for "mudstones" of the Hudspeth Formation analyzed for this study includes 49 claystones, nine mudstones, and three sandstones. The percentage of clay ranges from 23 percent to 90 percent, with a concentration of values between 70 and 80 percent. The remainder of the grains are silt and sand sizes. In samples with more than 60 percent clay, most non-clay minerals are silt size. Samples which contain less than 60 percent clay have sub-equal amounts of sand and silt, or more sand than silt.

Maximum particle size as determined by the petrographic microscope ranges from 40 microns in the finest claystones to 500 microns in sandier samples. Samples containing less than 20 percent non-clay material seldom contain grains larger than 65 microns (silt), while samples with more than 40 percent non-clay usually have a maximum grain size greater than 150 microns (fine sand), and often greater than 250 microns (medium sand).

The mudstones exhibit fair to poor sorting according to the terminology of Picard (1971). Those samples with 75 to 90 percent clay are considered to have fair sorting, and those with less than 75 percent have poor sorting.

In some samples, non-clay minerals are disseminated throughout the clay mineral matrix in a heterogeneous assemblage with little

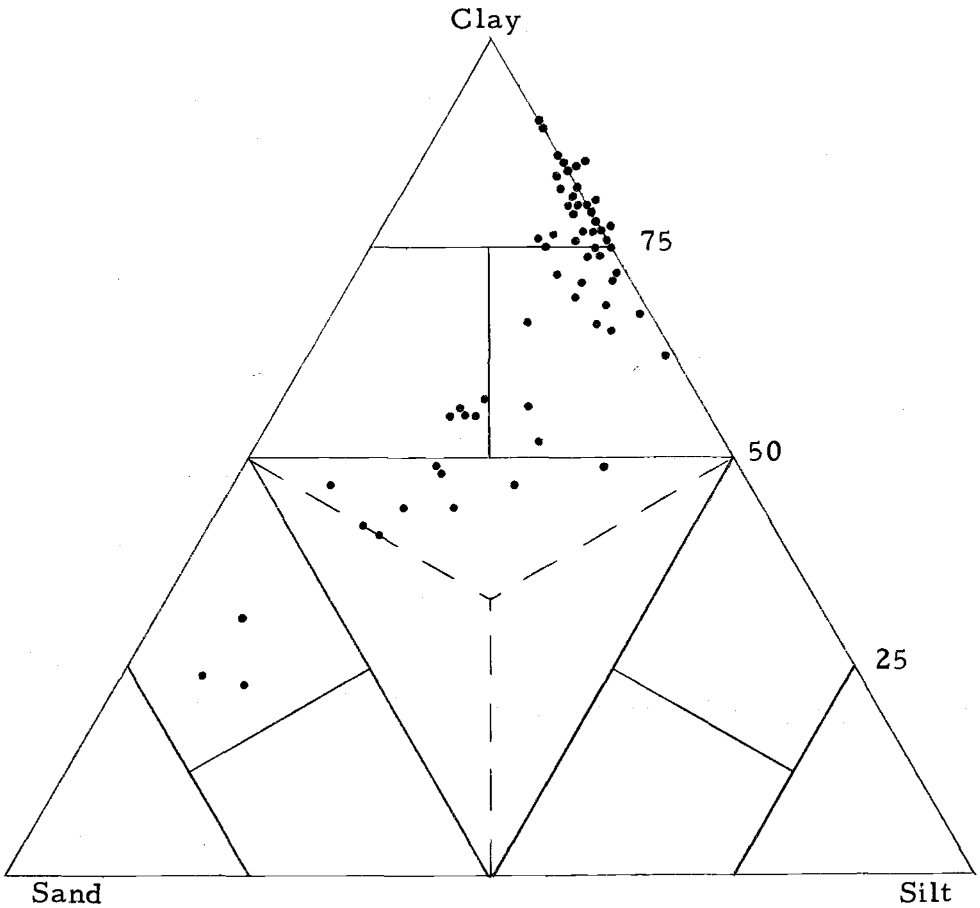


Figure 17. Triangular diagram showing grain size of argillaceous rocks of the Hudspeth Formation. Grain size determined by petrographic microscope. Points outside triangle project to triangle.

tendency to concentrate non-clay and clay minerals in distinct layers. In many samples, non-clay minerals are disseminated throughout as well as occurring as slight concentrations in small lenses or layers. Distinct layering of clay and non-clay minerals exists in a few samples.

The following is a description of microscopic textures common to the argillaceous rocks.

1) Clayey samples (claystone)(Figure 18).

   Clay with disseminated fine silt, including:

   a) small irregular patches of finer material,

   b) discontinuous laminations or lenses where silt is concentrated,

   c) both.

2) Silty samples (silty claystone)(Figure 19).

   Clay with silt scattered throughout, including:

   a) small irregular patches of finer material, not necessarily parallel to bedding.

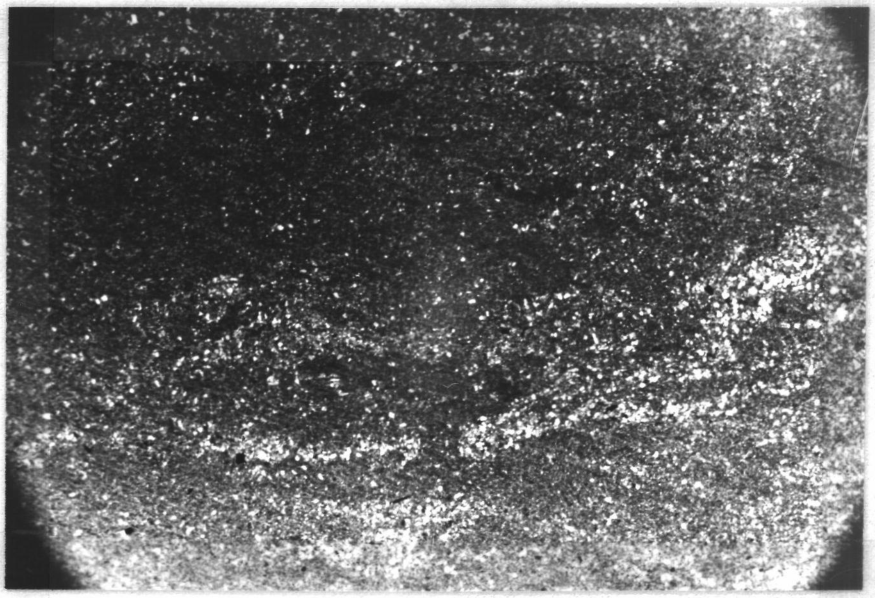
   b) patches or lenses of coarser silt or sand,

   c) rare alternation, in straight bands, of silty mud and either finer or coarser material. Contacts between bands are partly sharp, partly gradational.

3) Sandy samples (sandy claystone, mudstone, or clayey sandstone)(Figure 20).

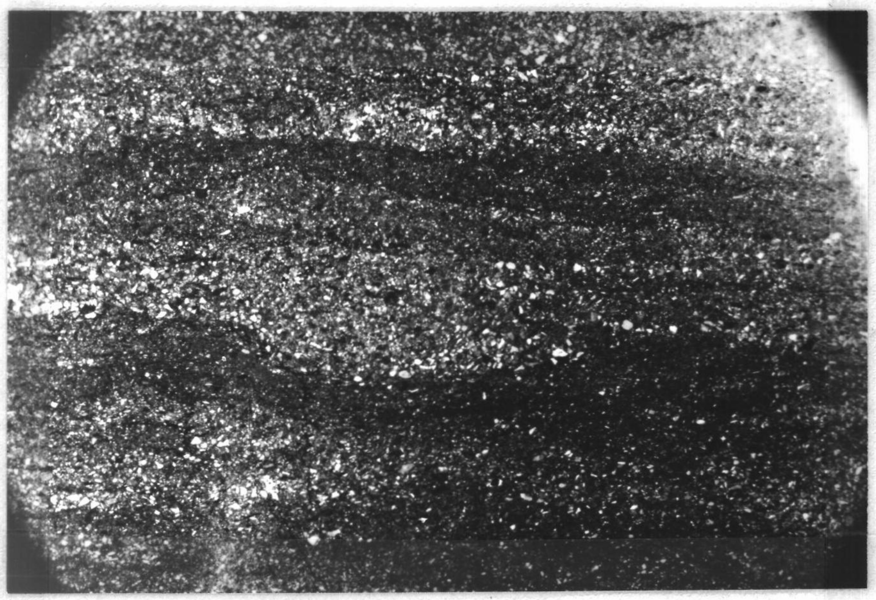
1 mm

Figure 18. Typical claystone texture showing patches of finer material.



1 mm

Figure 19. Typical silty claystone texture showing lenses of coarser material.



1 mm

Figure 20. Texture typical of sandy argillaceous rocks showing alternate bands of fine and coarse material.

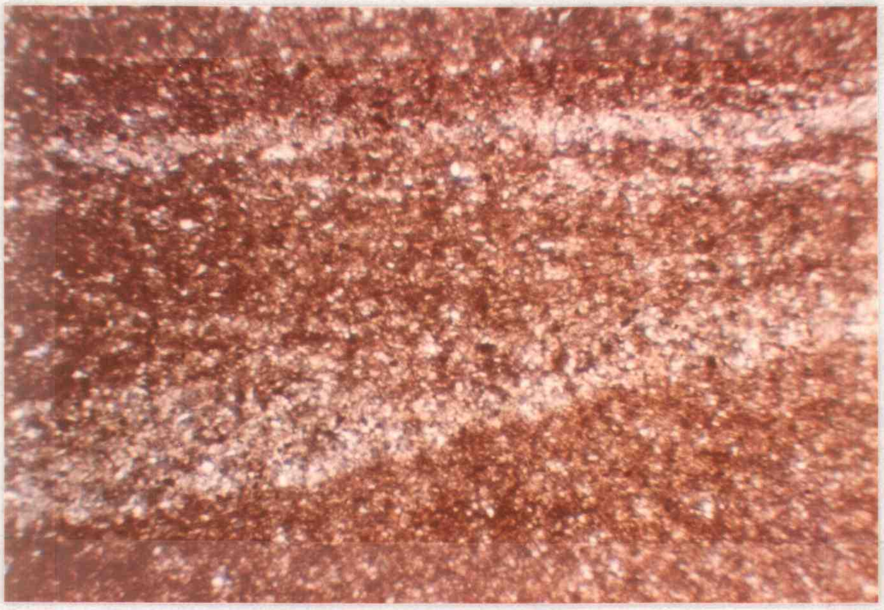
Sand in a matrix of clay and fine silt, including:

a) small irregular patches or lenses of finer material, roughly parallel to bedding, but discontinuous,

b) distinct sandy layers alternating with silty or clayey layers.

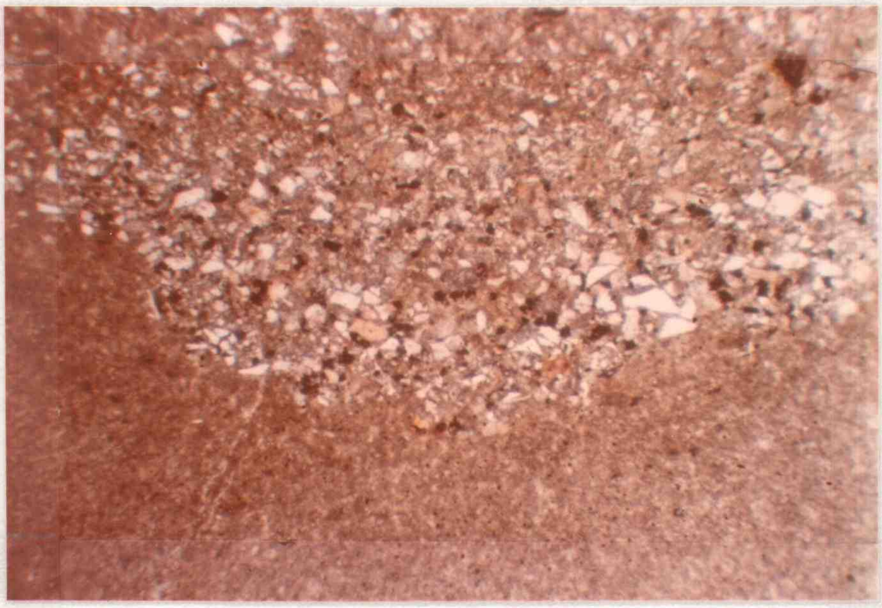
Irregular patches of finer material are usually less than one or two millimeters in size and most appear to be depositional. Some extend along the bedding and pinch out in coarser material. Some exhibit aggregate parallel orientation while others do not. Even the large mud patches could presumably be caused by spurious current deposition although some of the larger patches are probably caused by burrowing organisms. A few sinuous burrows, five to ten millimeters in diameter and slightly flattened, are found parallel to bedding in the mudstones.

Contacts are commonly sharp between sandy and muddy layers. Many layers are straight, or relatively straight, but pinch and swell. Some minute silty and sandy layers in the mudstones, on a small scale, exhibit sedimentary structures similar to those found on a large scale in sandstone outcrops in the field. These include lensing and pinching layers (Figure 21), cross-lamination, scour-and-fill structures, graded bedding (Figure 22), and bedding irregularities (Figure 23).



1 mm

Figure 21. Detail of sandy lens pinching out in mudstone.



1 mm

Figure 22. Graded bedding associated with minute scour-and-fill channel.

1 mm

Figure 23. Bedding irregularities between mudstone and claystone layers.

Faint laminations visible in the fine-grained samples are caused mainly by aggregate parallel orientation of clay mineral particles. Some of the thin laminations are caused by concentrations of quartz grains in streaks or layers, or organic matter aligned along the bedding planes, although organic matter is usually disseminated throughout. In coarse samples one to two millimeter thick laminations are caused by concentration of non-clay and clay minerals in small lenses or layers. Dark olive-gray bands in rock chips are predominantly clay, while lighter gray bands are composed of silt and sand with a clay matrix.

Aggregate parallel orientation of clay minerals is well-developed in many samples and especially in those with greater than 75 percent clay. These samples exhibit marked parallel extinction under crossed nicols. Samples with less than 50 percent clay show little or no parallel orientation of clays. Deposition of flat-lying clays, plus later compaction, cause this parallel orientation. A large percentage of clay, coupled with aggregate parallel orientation, implies deposition in quiet water where clay particles assumed a flat-lying position as they settled out and were not disturbed by wave action. Where a large percentage of sand and coarse silt is present, water movement was probably more vigorous (Pettijohn, 1957) and clays may not have been parallel when deposited because any large sand grains would have disrupted parallel orientation of the clays. Compaction, if perpendicular to the length of clay particles, tends to increase the parallel orientation of clays where there is a large percentage of clay; however, if much sand and silt is present, compaction may decrease the parallel orientation because it tends to "wrap" clays around the larger grains.

There appears to be a moderate to strong compaction of mudstones in the Hudspeth Formation. Recent clays are deposited with a large percentage of pore space, but as they are buried and compacted the pore space is quickly reduced (Müller, 1967). Very little pore space is evident microscopically in the Hudspeth mudstones. Another evidence of compaction is the bending of mica flakes around adjacent sand grains. Bent mica is not common in the argillaceous rocks because coarser grains are usually separated by clay, but it does occur. Large mica flakes show a tendency toward uniform parallel orientation where parallel to laminations or to the clay orientation. The alignment is not perfect. Some flakes are bent around quartz grains and a few lie at an angle to the laminations.

Most of the quartz, feldspar, and lithic grains of silt and sand size are angular to subangular. Average values for the mudstones of 0.3 for rounding and 0.5 for sphericity are similar to the degree of rounding and sphericity in the sandstones. The only consistently "round" grains are authigenic pyrite and rare authigenic chert. The pyrite, which is now altering to limonite and hematite, occurs as rounded, knobby masses. Some chert has a rounded appearance, but it is more common in flat nodules elongated parallel to the bedding.

Mudstone Mineralogy

Argillaceous rocks of the Hudspeth Formation are composed predominantly of clay, with large amounts of quartz and mica, and lesser amounts of feldspar, organic matter, pyrite and limonite. Accessory calcite, chert, rock fragments, and other minerals occur. Appendix B summarizes the most abundant non-clay minerals.

Although clay minerals, seen as brown or green masses in the thin-sections, are the dominant minerals in most mudstones, they form a complex suite and are better studied by means of X-ray diffraction. Detailed descriptions of the clay minerals are given under the discussion of X-ray analysis results.

Quartz is the most abundant non-clay mineral, and generally is the only other mineral which can be identified microscopically or by X-ray. Quartz comprises at least 40 to 50 percent of the non-clay material present and occurs as silt- and sand-sized grains which are angular to subangular. Few inclusions are visible in even the coarser grains. Embayed grains do occur in more sandy samples, but are rare. There is no evidence of overgrowths on the grains or of a preferred orientation of grains.

Mica in the form of biotite, muscovite and chlorite is common, and most abundant in the finer mudstones where it makes up as much as one-third or more of the non-clay material. Size varies from fine shreds to sand-size flakes. Boundaries between large flakes of mica and small clay particles are distinct. There is no evidence of secondary growth of the large mica flakes and they usually occur in samples containing abundant non-clay minerals. In light of the above evidence, the mica is considered detrital.

Feldspar seldom accounts for more than a few percent of the non-clay minerals. Grains clearly identifiable as feldspar are sand-sized because they are easily confused with quartz when silt-sized. The grains are angular to slightly rounded in thin section and grain mounts. The feldspar is largely sodic plagioclase although sparse grains of calcic plagioclase and orthoclase can be identified. Orthoclase can be distinguished by weathering and optical properties. Some feldspar grains are chemically weathered to clay, but most are fresh. There is no evidence of overgrowths and no indication that the feldspar is authigenic.

Organic material composed of carbonized plant fragments is included as a detrital component. Size ranges from silt-sized to nearly invisible pigmentary matter and depends to some extent on the amount of clay. If much clay is present the organic material occurs as minute fragments whereas samples with a large proportion of silt and sand contain coarser organic material. The organic material is usually disseminated throughout, rather than concentrated in layers.

Abundance ranges from a trace to a few percent in thin sections and averages less than one percent. Total carbon content analysis yielded 0.79 percent carbon in sample M-1730, and 1.45 percent carbon in sample M-2130 on an air-dry basis.

Pyrite usually occurs as "blebs" less than one millimeter in size, rather than as crystals, and makes up less than one percent of the sample. In grain mounts, pyrite is rounded with a bumpy or knobby surface. These tiny round pyrite masses could be called "micro-concretions." Rare macro-concretions up to two inches in diameter are also found. Rounded shapes of the pyrite imply possible authigenic origin, and partial replacement of Foraminifera by pyrite supports this hypothesis. Larger irregular patches of pyrite also occur. Along cleavage and fractures in calcite veins, the pyrite assumes a crystalline form. Small masses of pyrite are usually completely replaced by limonite and hematite, although local examples are found where only the outer surface is altered.

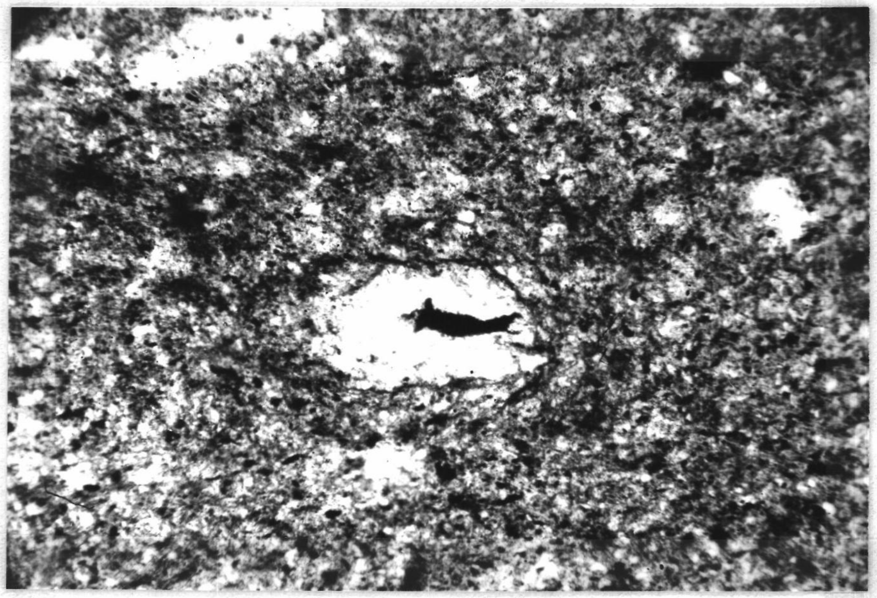
In the field, calcite is found as crack or vein fillings or as cement in concretions. In thin sections, calcite is found in foraminifers and as fracture fillings. Under the stereoscopic microscope calcite appears as tiny slivers or plates representing fracture fillings, or in local concentrations of Foraminifera.

Chert is not commonly found in the mudstones but does exist in a few of the fine-grained claystones where the mode of occurrence indicates an authigenic origin. In a few samples chert replaces the calcite of Foraminifera and in others, it is found as rounded or elongate masses roughly parallel to the bedding. The chert may form around a nucleus of organic matter, although a nucleus is not always visible. Some boundaries between chert and clay matrix are "ragged" and irregular and the clay immediately surrounding the chert is oriented parallel to the chert boundaries (Figure 24).

A few other minerals are present in very minor amounts in the mudstones and include serpentine, hornblende, and ilmenite/leucoxene. Miscellaneous lithic fragments can be identified only in rocks which contain sand and coarse silt. Rock types present in the mudstones include highly altered volcanic and metavolcanic rocks, metamorphic schists and phyllites. Sedimentary mudstone fragments are identified only in the coarsest samples.

Manganese oxide staining, which is visible in thin sections of some of the more weathered samples, develops under conditions of surface weathering. Dendrites appear on the surface and along fractures, but also permeate into the rock one-half inch or more.

Composition of framework grains of sand and coarse silt sizes, where identifiable, were plotted on a compositional triangle similar to that used for sandstones (Figure 25), but only those samples containing more than 30 percent non-clay detritus were plotted. Applying Gilbert's sandstone classification (Williams, Turner, and Gilbert,



1 mm

Figure 24. Authigenic chert showing nucleus and clay rim, plain light.

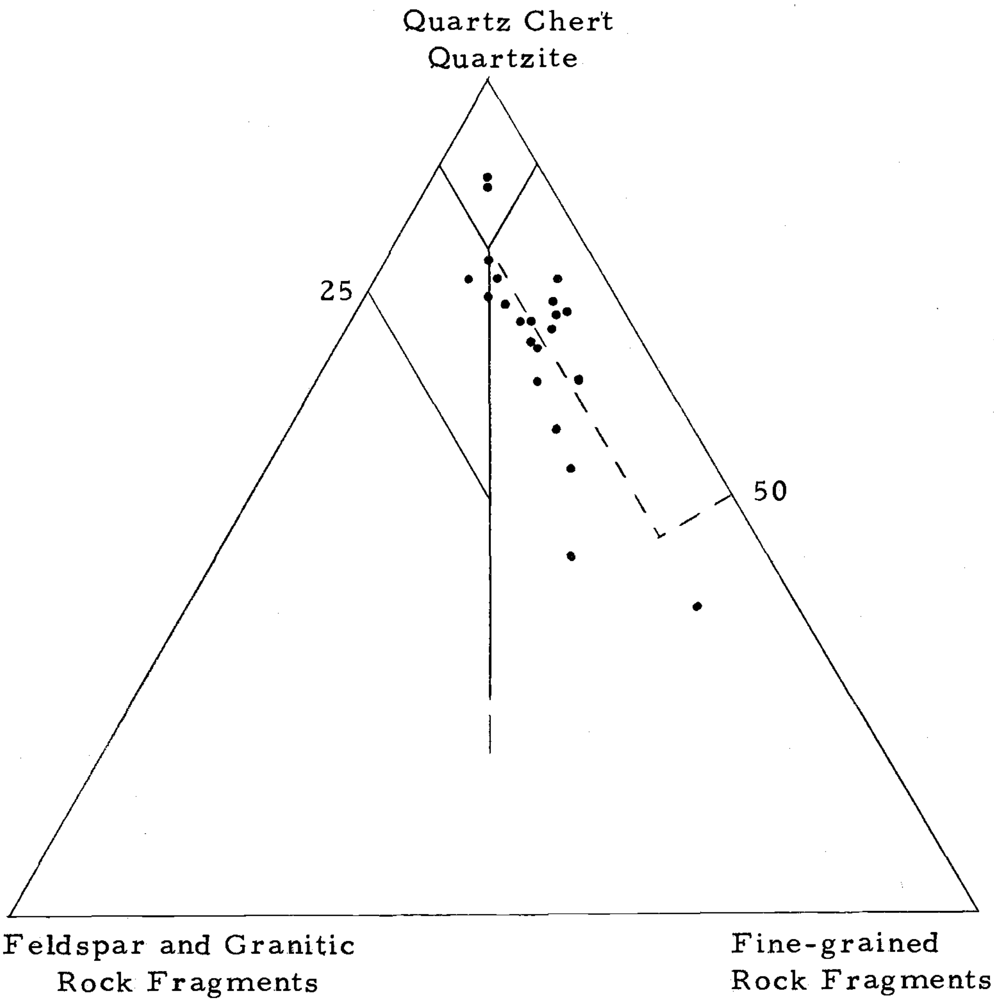


Figure 25. Triangular diagram showing composition of coarse silt and sand grains in argillaceous rocks of the Hudspeth Formation.

1955) to the mudstone composition, most classify as lithic mudstones with a few subfeldspathic lithic mudstones. The low feldspar content may be caused by difficulty in distinguishing unweathered feldspar from quartz in the small grain sizes. As the mudstones become finer-grained, the composition becomes more quartzose with fewer lithic fragments while identifiable non-clay material in the finest samples is nearly all quartz. It is possible that this compositional shift is due to an actual decrease in the proportion of lithic fragments in the finer samples. A more likely explanation is that only the quartz is easily identifiable in the finer sizes. Lithic fragments would blend visually with the clay matrix, or even react chemically to become part of the matrix.

Concretion Texture and Composition

Composition of silt and sand grains in the concretions is essentially the same as in the mudstones with the exception of large amounts of calcite cement in the concretions. The calcite and clay are intimately mixed and cannot be distinguished separately in thin section since calcite occurs as microcrystalline material disseminated throughout the clay matrix. There is no evidence of parallel orientation of clays because the intermixed calcite disrupts the original fabric. Calcite seldom occurs as large single crystals and calcite without admixed clay is found only in foraminifers or as fracture fillings where it occurs as large interlocking crystals. Fractures vary from hair-line width to one-quarter inch. Septarian concretions are occasionally found.

Distribution of coarse detrital material in concretions is similar to the distribution in the surrounding mudstones. Sand, silt, and especially fine silt grains, are disseminated throughout, although some occur as concentrations of coarse material in layers, lenses, or broad bands. Irregular patches of finer material also occur. Silt in concretions is largely, but not exclusively, quartz, just as in the surrounding mudstones.

Distribution of organic matter is similar to that of the surrounding mudstones although preservation of plant fragments is better in the concretions. Organic particles up to 50 microns in diameter are found in most concretions.

Foraminifera are present in some concretions. The calcite of the fossils is more coarsely crystalline than the surrounding clay and calcite matrix. In some samples only "ghosts" or "shadows" of Foraminifera remain where the original material has been recrystallized leaving small round areas of slightly coarser calcite.

A few concretions contain authigenic chert which may have formed around a necleus of organic material. In some instances the chert is later partly replaced by calcite.

Concretions are usually formed around a fossil nucleus such as an ammonite, foraminifer, or plant debris. However at least half of the concretions show no visible evidence of fossils when broken.

Sandstone Textures

Most of the sandstones are poorly sorted or rarely show bimodal sorting. Larger framework grains of relatively uniform size are combined with a matrix of clay and fine silt particles. Hudspeth wackes are all poorly sorted, while some arenites are moderately well sorted, especially when cemented with calcite. Alignment or preferred orientation of grains was not detected.

Most sandstones have low porosity and evidence of slight to marked compaction. Micas that are bent and deformed around other clastic grains indicate compaction. The low porosity is caused by compaction, presence of clay matrix in wackes, and calcite cement in arenites.

Roundness and sphericity were estimated using the method of Krumbein and Sloss (1956). The average value of sphericity is about 0.5 and roundness about 0.3 for the Hudspeth Formation. Grains range from angular to sub-rounded with the majority subangular; a few non-resistant grains are rounded.

In sandstones interbedded with the mudstones, the average grain size is 0.15 millimeters (fine sand). The average maximum grain size in thin-section is 0.25 millimeters (fine to medium sand). Grains larger than 0.5 millimeters are rare in these interbedded sandstones.

Sandstones of the Basal Hudspeth, which are interbedded with conglomerate, have an average grain size of 0.40 millimeters (medium sand) in thin section. The average maximum grain size is 2.10 millimeters (granule).

Sandstone Composition

Framework Constituents. Modal analyses for 38 selected samples are listed in Appendix D. The average composition of framework grains in the sandstones of the Hudspeth Formation is 43 percent quartz, chert, and quartzite; 41 percent fine-grained rock fragments; and 17 percent feldspar.

Angular to subangular grains of quartz are the most abundant detrital component. The majority have moderate undulatory extinction, a few have strong undulatory extinction, and some have little or none. Irregular inclusions and minute regular inclusions are visible in the quartz. Grains are not usually elongate, and show no alignment or preferred orientation.

Many varieties of fine-grained rock fragments occur in the sandstones, including volcanic, meta-volcanic, metamorphic, and sedimentary rocks. It is difficult to differentiate among rock types because they are often greatly altered.

Mafic volcanic and meta-volcanic rock fragments are the most abundant, but are usually greatly altered and difficult to identify. Basalt, andesite, and devitrified glass are the most commonly distinguished volcanic fragments. Many show phenocrysts of plagioclase or "ghosts" of phenocrysts, while others are completely altered to a mixture of chlorite and other minerals. Such highly altered rock fragments are similar in appearance to the matrix of the sandstones and are distinguished only by their round shape or dark outer rims. "Greenstone" fragments are locally abundant and are usually basalt fragments which have been partly altered to serpentine, chlorite, and clay.

Low to medium grade metamorphic rock fragments occur with fine-grained schist and phyllite dominant. Most consist primarily of muscovite, sericite and quartz.

Sedimentary rock fragments are entirely absent in many sandstones, and when present in others appear to be sedimentary rocks reworked from the Hudspeth Formation or possibly older Mesozoic formations. Most fragments are claystones or, less commonly, silty fragments. These argillaceous fragments are very similar in appearance to the argillaceous rocks of the Hudspeth Formation and are similar to the matrix of many of the sandstones, but they appear as discrete rounded grains.

Several varieties of feldspar are present. Plagioclase is more abundant then orthoclase, and microcline is rare. Feldspar is recognized by twinning and/or alteration to clay and mica. Where possible, plagioclase composition was estimated from extinction angles in sections normal to (010). Andesine and oligoclase are the most common. The state of preservation varies in the feldspar, and ranges from clear and unaltered to cloudy and very highly altered. In thin-section, clear, unaltered grains appear side by side with grains which are moderately to intensely altered (Figure 26). Most grains are relatively fresh. In some grains alteration occurs mainly along cleavage fractures while in others alteration has spread throughout the grain with clay and mica the dominant alteration products.

Chert and quartzite, the poly-granular forms of quartz, are present in most of the sandstones with quartzite the more common. The quartzite often has a "dirty" appearance because of inclusions. Undulatory extinction is very common in the coarsely interlocking quartz grains. The chert is very fine-grained and often also has a "dirty" appearance. Chert is difficult to distinguish from meta-volcanic rock fragments which have been silicified. In this report, grains are called chert if they lack phenocrysts or evidence of former phenocrysts.

The micas average two percent of the rock in sandstones, but can account for as much as ten percent. Biotite, muscovite, and chlorite are present. Biotite is the most abundant of the three and muscovite is least common. Chlorite occurs mainly as an alteration product of biotite. Biotite occurs as long, thin flakes, often parallel to bedding and is frequently deformed and bent around other framework grains indicating compaction of the sandstones (Figure 27). Some biotite appears "bleached" and partial or complete alteration to chlorite is common. Other biotite and muscovite appear fresh and unaltered, but are bent due to compaction.

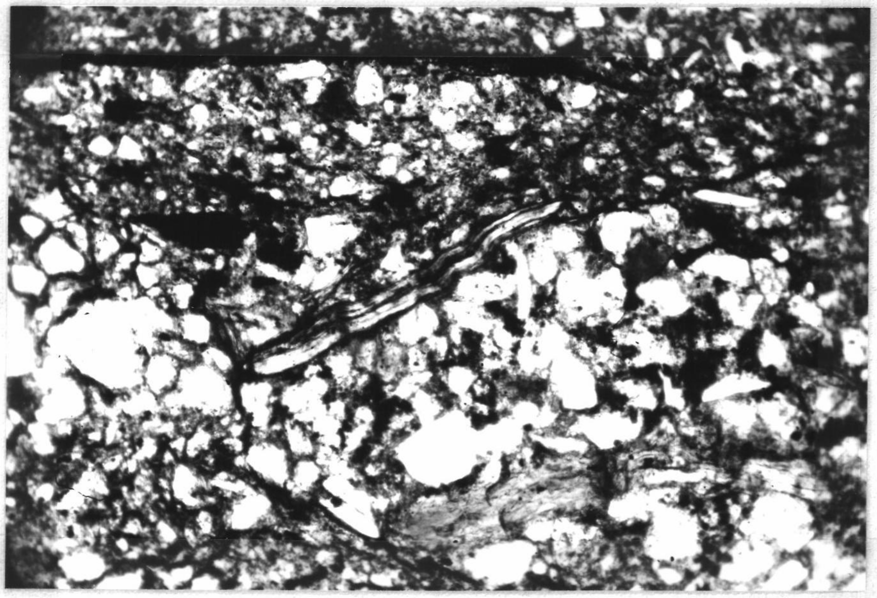
Granitic rock fragments can be identified only in the coarsest sandstones and seldom make up as much as one percent of the rock. They are distinguished from quartzite by the presence of microcline, orthoclase, or sodic plagioclase.

Other minerals occur only in trace amounts. Glauconite and serpentine are rare, but locally present. Opaque minerals including hematite, limonite and leucoxene, are accessory only in the sandstones. These minerals are probably formed by weathering or chemical alteration of iron-bearing minerals originally deposited in the sands.

The composition of framework constituents was plotted on triangular diagrams (Figure 28 and 29) and classified according to the Gilbert classification of sandstones (Williams, Turner, and Gilbert,

1 mm

Figure 26. Adjacent feldspar grains (F), one unaltered, the other moderately altered to clay and mica. Typical wacke texture, plain light.



1 mm

Figure 27. Biotite flakes deformed by compaction between other mineral grains, plain light.

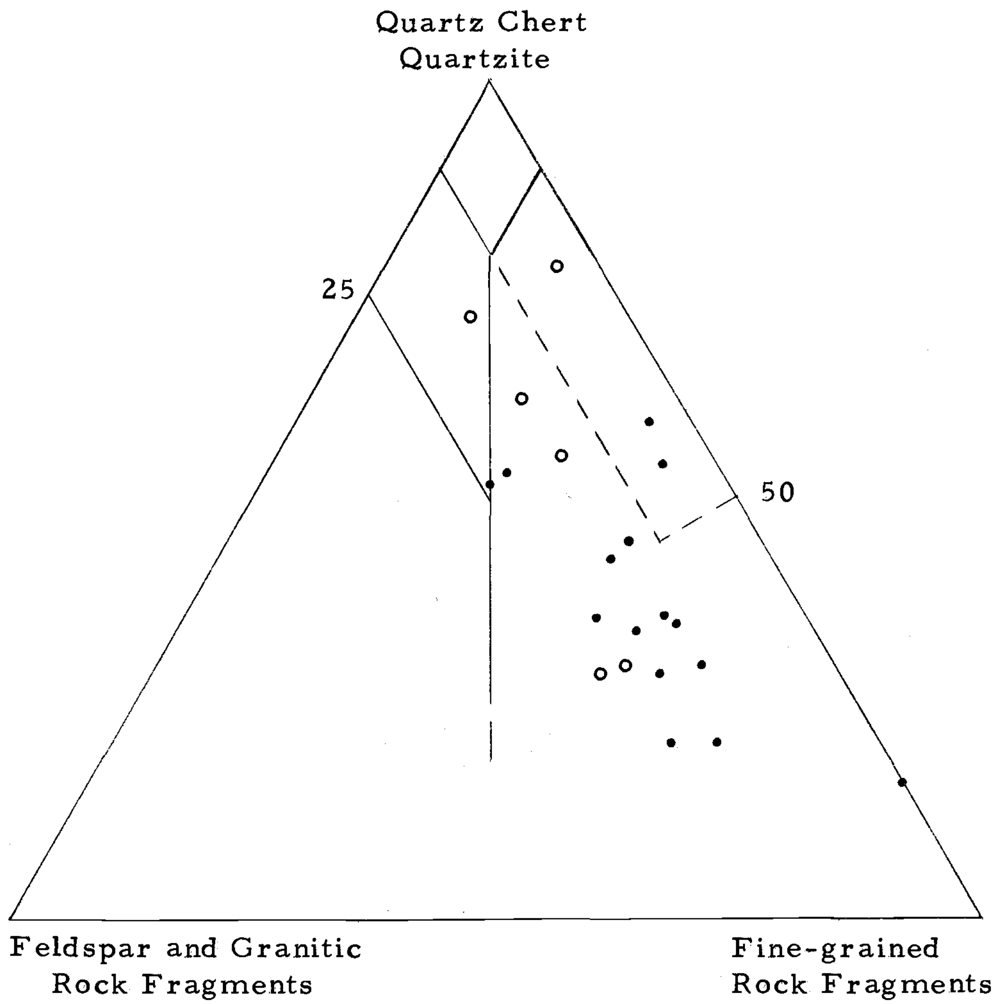


Figure 28. Triangular diagram showing composition of wacke sandstones of the Hudspeth Formation. Dots indicate samples from the Main Mudstone Member. Open circles indicate Basal Hudspeth.

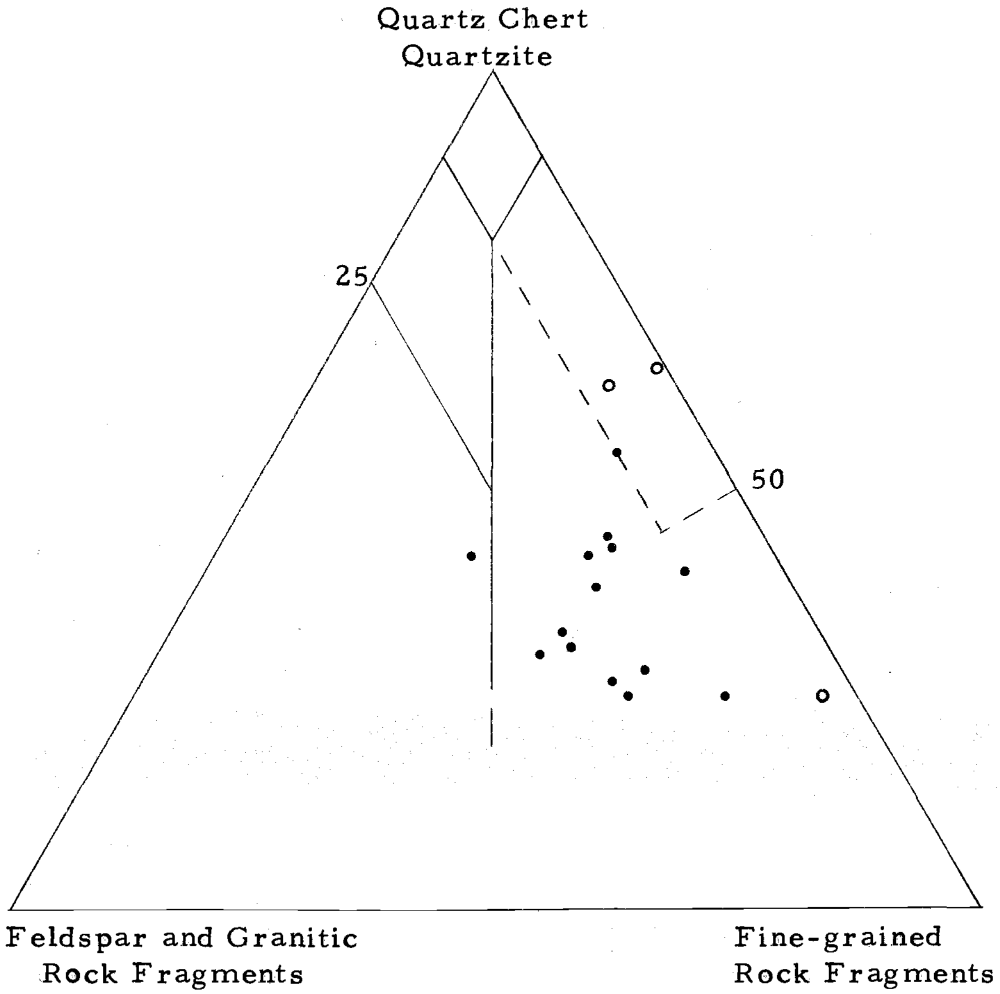


Figure 29. Triangular diagram showing composition of arenite sandstones of the Hudspeth Formation. Dots indicate samples from the Main Mudstone Member. Open circles indicate Basal Hudspeth.

1955). Seventeen are arenites and 21 are wackes. The framework composition of both the arenites and wackes is essentially the same with the only difference resting in the amount of matrix present. Sandstones of the Hudspeth Formation are found mainly in the lithic part of the compositional triangle. There appears to be no significant variation in composition from bottom to top of the stratigraphic sections in the Main Mudstone Member. Sandstones of the Basal Hudspeth, which directly overlies the Permian metasediments, have local concentrations of quartzite and/or phyllite.

Matrix and Cement. The matrix accounts for an average of 12 percent of the rock in sandstones and ranges from none to 36 percent. The matrix consists of a micro-granular aggregate of clay and fine silt composed of mica, quartz, feldspar, and iron oxide. No preferred orientation of clays is evident.

In the Hudspeth wackes the matrix usually occurs without cement or with minor micro-crystalline calcite. In arenites a matrix is present in minor amounts to nine percent. This matrix occurs as a rim around sparry calcite, intimately mixed with micro-crystalline calcite, or between grains where no calcite is present.

Five types of cement are present in sandstones of the Hudspeth Formation, however calcite is the only cement with volumetric significance; it averages 11 percent of the rock and ranges from none to

42 percent. Wackes often have no calcite cement, with most less than three percent cement, and with nearly all less than ten percent. All of the arenites contain calcite cement, with most having more than ten percent. In both wackes and arenites clay plus calcite make up more than ten percent of the rock and porosity is very low. The calcite occurs as spar incorporating several clastic grains or as micro-crystalline calcite occurring with matrix. The micro-crystalline calcite pervades the micro-granular matrix with scattered irregular voids filled with sparry calcite.

In most samples calcite merely fills interstices between grains, and detrital grains are in contact with each other. However in the four samples with more than 20 percent calcite, grains appear to be "floating" in the calcite cement. The grains appear much less angular, and little or no matrix exists. This texture is the result of two processes. Many grains have reacted and been partially to totally replaced by calcite as evidenced by calcite patches within grains and embayed grain boundaries (Figure 30). Feldspar and rock fragments are especially susceptible. The original texture has also been dilated as calcite penetrated along cleavage fractures in mica books and feldspar laths and forced the minerals apart. Biotite books have been expanded two or three times their original thickness.

Quartz cement is rare. Minor amounts are found only in the Basal Hudspeth as overgrowths on detrital quartz grains.

Ankerite-siderite cement is found mainly in the Basal Hudspeth and especially in the M-section. It is usually micro-crystalline and appears "dirty." Some of this appearance may be attributed to matrix incorporated in the cement, but much of it is caused by alteration of the ankerite-siderite to calcite and hematite or limonite. Where ankerite-siderite lines the voids between grains, sparry calcite in optical continuity with the ankerite-siderite fills the center of the voids (Figure 31).

Chlorite cement is rare. Chlorite occurs as detrital framework grains formed by alteration of biotite, as clay-size detrital matrix, or as an authigenic cement where it forms a fibrous fringe perpendicular to detrital grain boundaries. The fibers meet in interstices between the framework grains, completely filling the void, although the center is occasionally filled with micro-crystalline chlorite or randomly oriented chlorite fibers. Chlorite cement is found only in sandstones with abundant mafic volcanic or meta-volcanic grains. Alteration of these lithic fragments probably provides ions for chlorite development. Much of what appears to be "chlorite cement" is actually small lithic fragments altered to chlorite; however, these altered materials have the form of discrete grains rather than void-fillings.

Iron oxide is a very minor cement. Hematite and limonite are abundant only in thin-sections from the basal Hudspeth where

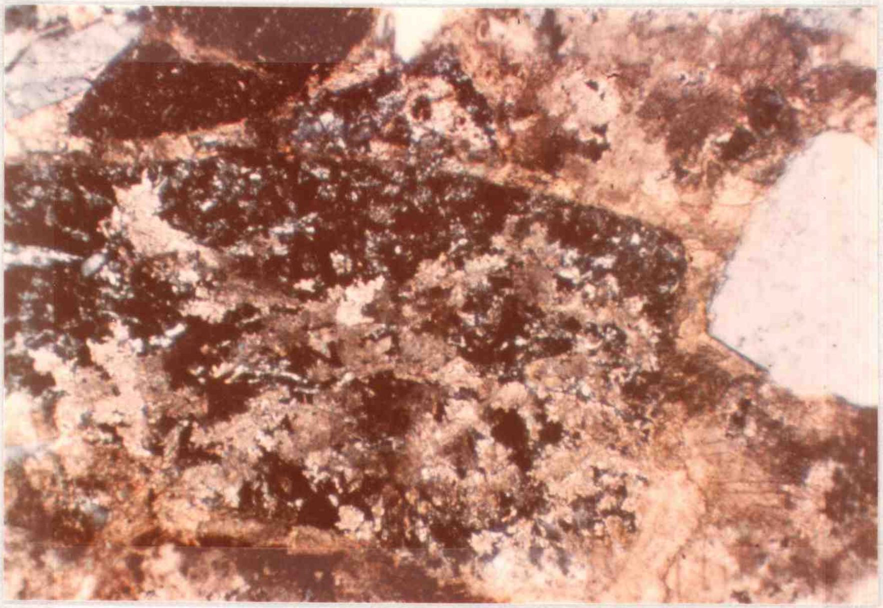


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Figure 30. Large feldspar grain (black) partly replaced by calcite. Typical arenite texture, crossed nicols.

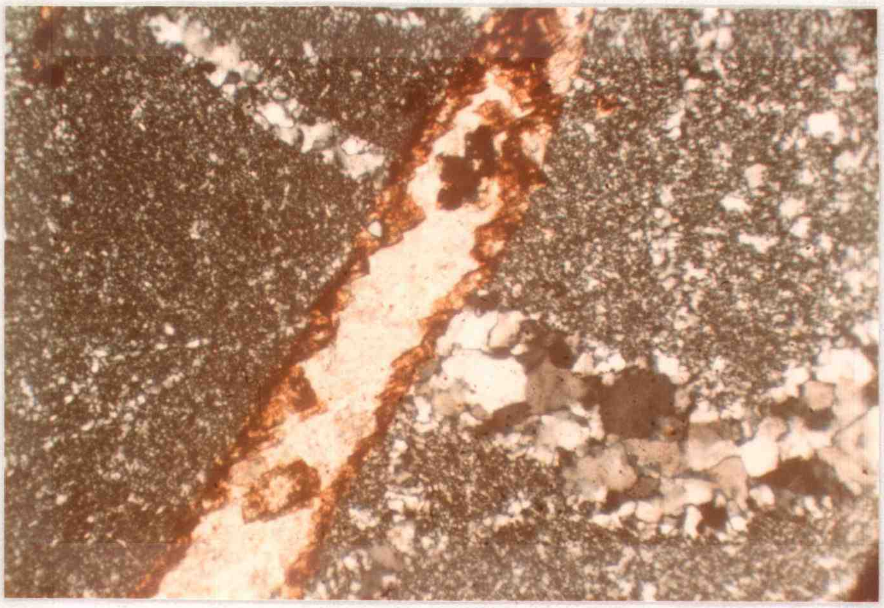

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Figure 31. Calcite cement rimmed with ankerite-siderite crystals, crossed nicols.

ankerite-siderite occurs. They probably developed as a result of alteration of the ankerite-siderite. The iron oxides are disseminated throughout in an indistinguishable mass of clay matrix, micro-crystalline carbonate, and iron oxide.

The paragenesis of cements is difficult to determine because of the patchy distribution. Two cements are seldom found in contact. Quartz overgrowths embayed by calcite indicate the quartz preceded the calcite. Ankerite-siderite developed along grain boundaries while calcite filled the central voids thus indicating it preceded the calcite. Chlorite is a void-filler, however no clear-cut evidence is available concerning the relative time of formation. Iron oxide probably developed last as an alteration product of ankerite-siderite. It is possible that this alteration has taken place during recent weathering after exposure to surface conditions.

Lithification includes all processes that tend to form an indurated rock from loose, unconsolidated sediments. In the sandstones of the Hudspeth Formation, lithification is the result of compaction and/or cementation. Compaction is the main means of lithification in the wackes where little or no cement is present. In the arenites, compaction also played a role in lithification as indicated by bent biotite flakes and fracture of some of the weaker mineral grains which have their edges broken by compaction. Cementation is especially important in arenites. It is probable that the arenites were originally more permeable than wackes, permitting easier migration of solutions. The cement usually fills voids between grains, but calcite does appear to replace matrix material locally.

Little direct evidence exists to explain the origin of the cements. Calcite possibly was derived from solution of calcareous microfossils in nearby mudstones, or from solution of molluscan shells found locally in the near-shore environments of the Basal Hudspeth. Ankerite-siderite could be derived from solution of fossils with addition of ions from alteration of iron-rich lithic fragments. Chlorite developed by recrystallization of matrix, plus ions added from alteration of lithic fragments. Iron oxide as cement is mainly the result of alteration of ankerite-siderite.

Much of the matrix was deposited as detrital clay and silt. The matrix material was probably transported as clay and silt from a source area where the fines developed from weathering of fine-grained rocks, and organic material was incorporated into the detritus prior to deposition. Some of the matrix may have formed in situ from alteration of lithic fragments and feldspar of the framework as suggested by the highly fragmented edges of some framework grains. The central part of these framework grains may be unaltered, but the edges have reacted with the matrix or cement so that grain boundaries are indistinct and the edges appear to be corroded. In some thin-sections, tiny adjacent fragments of feldspar are in optical continuity with a large grain, but are separated from the large grain by matrix and cement.

Conglomerate Textures and Composition

A few conglomerates are interbedded with sandstones of the Basal Hudspeth. They are well-indurated, resistant ledge-formers, with a thickness of three to four feet. About 75 percent of the rock is composed of pebbles, cobbles, and granules with the remainder matrix. Composition of the matrix is a fine sandstone or coarse siltstone that is well-cemented with calcite, or calcite and ankerite-siderite which is weathering to calcite and limonite. The framework clasts range in size from granules to three inch diameter cobbles with the average diameter approximately one-half inch. Most are rounded to sub-rounded, but a few are angular. Slightly elongate pebbles are usually oriented parallel to bedding. Local foresets dip to the southwest.

The pebble composition is variable. Chert and quartzite, volcanic and meta-volcanic rock fragments of silicic and mafic types are most abundant. Rock fragments of granitic and sedimentary origin are minor constituents. In the M-section of the Basal Hudspeth, where conglomerates directly overlie Permian metamorphic rocks, phyllite and other metamorphic rocks are locally abundant and account for 10 to 20 percent of the pebbles. In the T-section, where the basal conglomerate and sandstone facies interfinger with mudstones of the Main Mudstone Member, conglomerates of the upper tongue contain 10 to 20 percent sedimentary rock fragments indistinguishable from rocks of the Main Member. Their presence indicates reworking and incorporation of fragments eroded from the Main Member.

Conglomerates are not common within the Main Mudstone Member. Three units were observed in the measured sections and there are limited outcrops elsewhere. These conglomerate layers are not persistent along strike for more than a few tens of feet and they are not particularly resistant to erosion. They should more appropriately be called pebbly sandstones because the average composition is 25 percent pebbles and 75 percent matrix. The matrix composition is usually mudstone and is commonly impregnated with minor calcite or calcite-limonite cement. Pebble diameter ranges from one-quarter inch to one inch with a few pebbles up to two inches. The composition is less variable than in the Basal Hudspeth. For example, pebble composition in one conglomerate is 80 percent phyllite and metamorphic fragments, while pebbles in another conglomerate are 60 percent sedimentary rock fragments, and the third conglomerate contains 100 percent mudstone clasts. In those containing sedimentary rock fragments, the clasts are very similar in appearance to mudstones and sandstones of the Hudspeth Formation.

X-ray Diffraction Analysis

Composition of the Mineral Suite

While there is a gross uniformity in composition of the clay-size material, slight differences in the relative abundance and occurrence of individual components were observed from one sampling section to another and from one stratigraphic level to another within a section. Crystalline components of the suite include the clay minerals - illite, beidellite, vermiculite, kaolinite, chlorite, montmorillonite, and mixed-layer clay, and the non-clay minerals - quartz and feldspar.

Coarse clay minerals. Identification of the various clays is based on evaluation of changes in relative peak positions and intensities following various diagnostic treatments imposed upon representative samples (Figure 32 through 36). The presence of vermiculite was noted in nearly all samples. It is indicated by a 14 Å peak which does not expand when solvated and collapses to approximately 10 Å when potassium-saturated or heated to 300° C. Vermiculite does not re-expand when a potassium-saturated slide is heated to 105° C and then equilibrated to 54 percent relative humidity. Samples such as M-160 and M-1890 contain large amounts of vermiculite, while Y-3 has little or no vermiculite.

Beidellite is the principle smectite in nearly all samples, and most samples of mudstone contain both beidellite and vermiculite. Beidellite is indicated by a 14 Å peak which expands when solvated with ethylene glycol and does not expand when solvated with glycerol. It re-expands from 10 Å to approximately 12 Å when a potassium-saturated sample is dried at 105° C and is equilibrated at 54 percent relative humidity. X-ray patterns of samples H-7 and Y-3 indicate large amounts of beidellite.

Montmorillonite was detected in a few samples. It is indicated by a relatively intense 14 Å peak which expands with either glycerol or ethylene glycol solvation. Samples M-2840 and Y-3 contain minor amounts of montmorillonite as interpreted from the X-ray pattern after glycerol solvation, while sample M-160 contains no montmorillite.

Mixed-layer clays occur in noticeable quantities only in the lower two-thirds of the M-section. In these samples the 14 Å component does not expand to 17 Å after solvation with ethylene glycol, but undergoes partial expansion to about 15 or 16 Å, or may show a 14 Å peak which is asymmetrical toward 17 Å. Pure beidellite or montmorillonite should expand to approximately 17 Å, while vermiculite and chlorite remain at 14 Å. Montmorillonite, when present, expands to 17 or 18 Å and appears to be pure rather than mixed-layer.

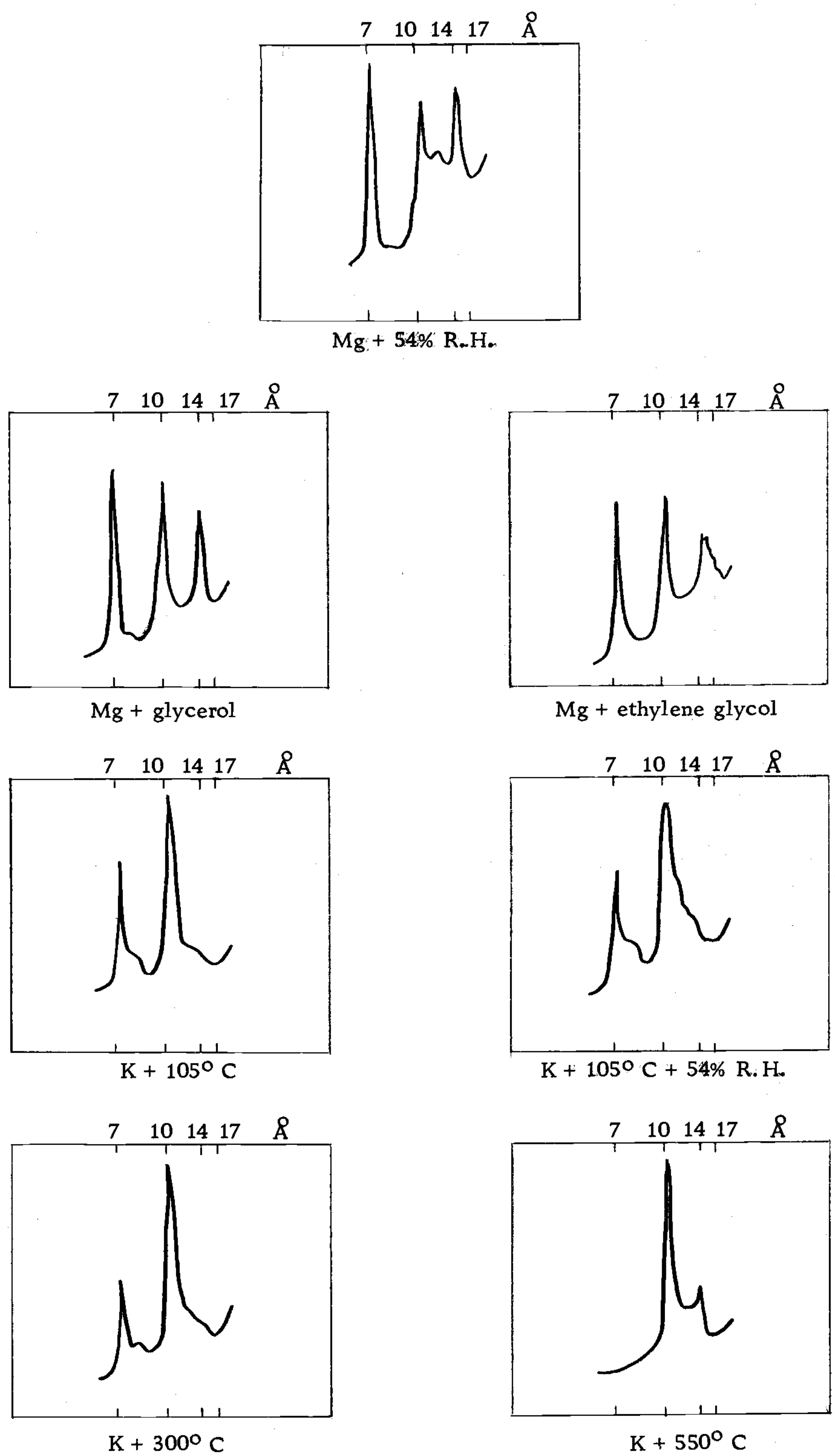

Figure 32. X-ray diffraction patterns for sample M-160. Order of abundance: ILLITE, VERMICULITE, BEIDELLITE, kaolinite, chlorite, mixed-layer clay.

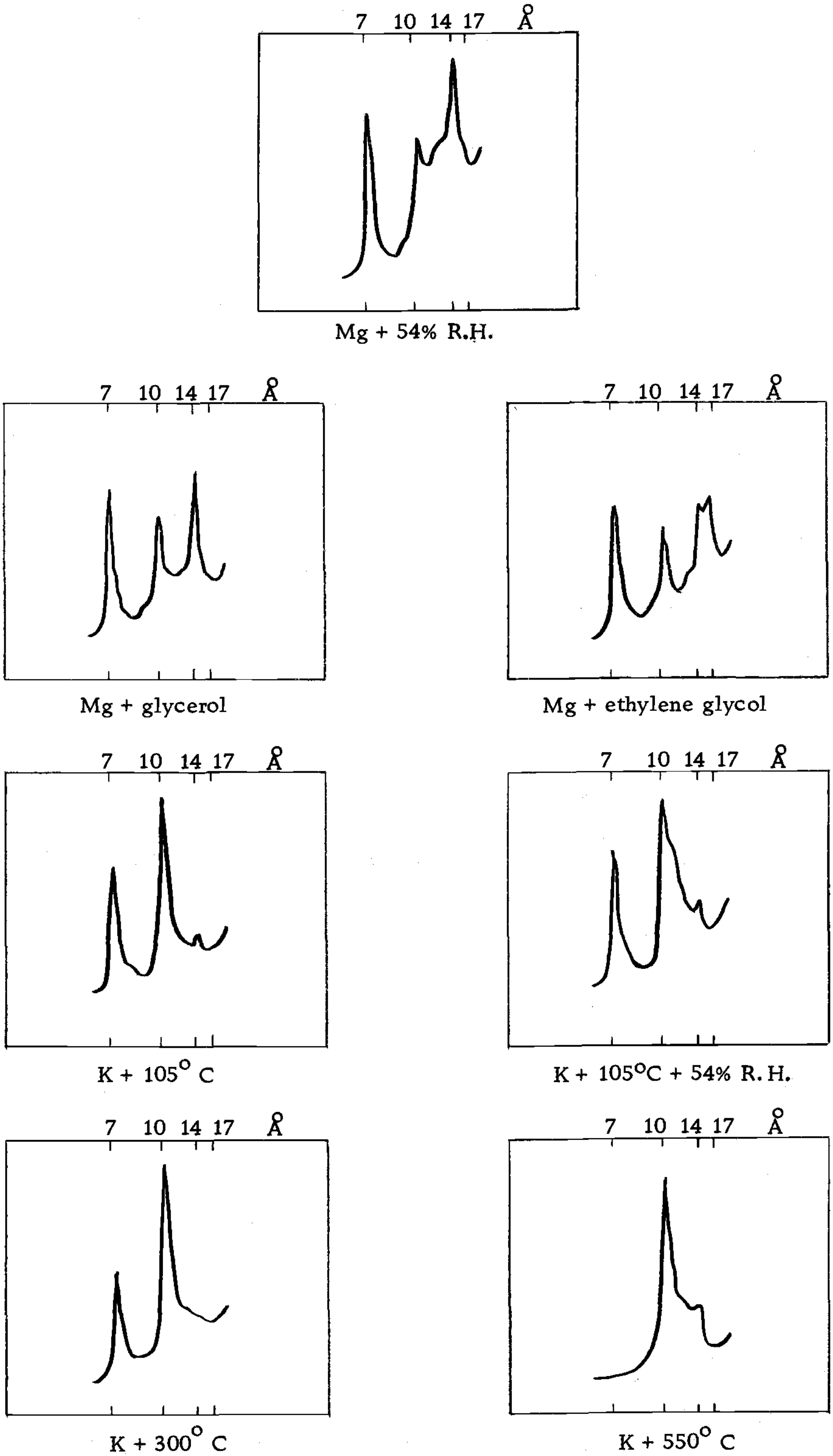

Figure 33. X-ray diffraction patterns for sample M-1890. Order of abundance: ILLITE, BEIDELLITE, VERMICULITE, kaolinite, chlorite, mixed-layer clay.

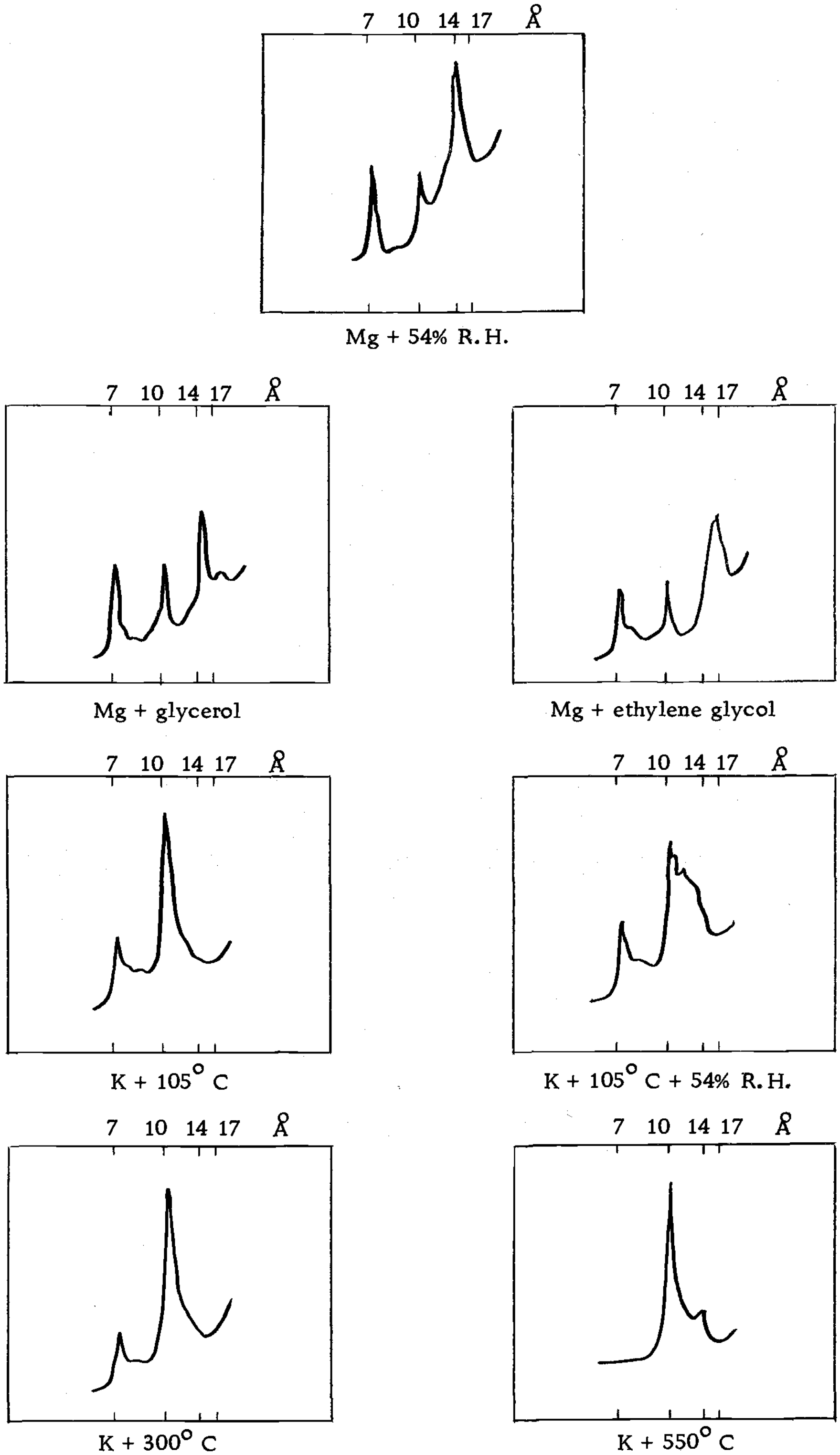

Figure 34. X-ray diffraction patterns for sample M-2840. Order of abundance: BEIDELLITE, ILLITE, vermiculite, kaolinite, montmorillonite, chlorite.

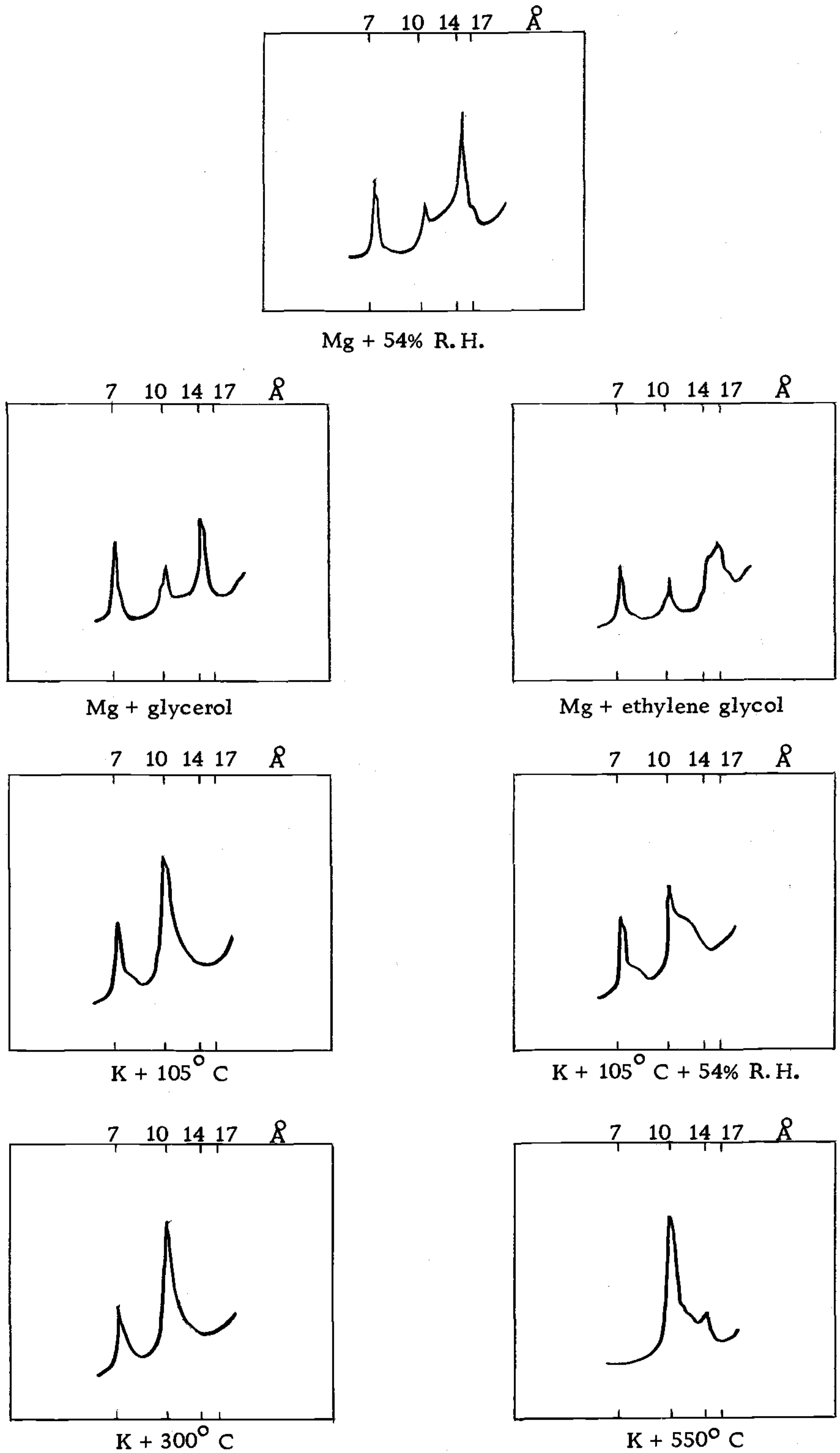

Figure 35. X-ray diffraction patterns for sample H-7. Order of abundance: BEIDELLITE VERMICULITE, illite, kaolinite, chlorite.

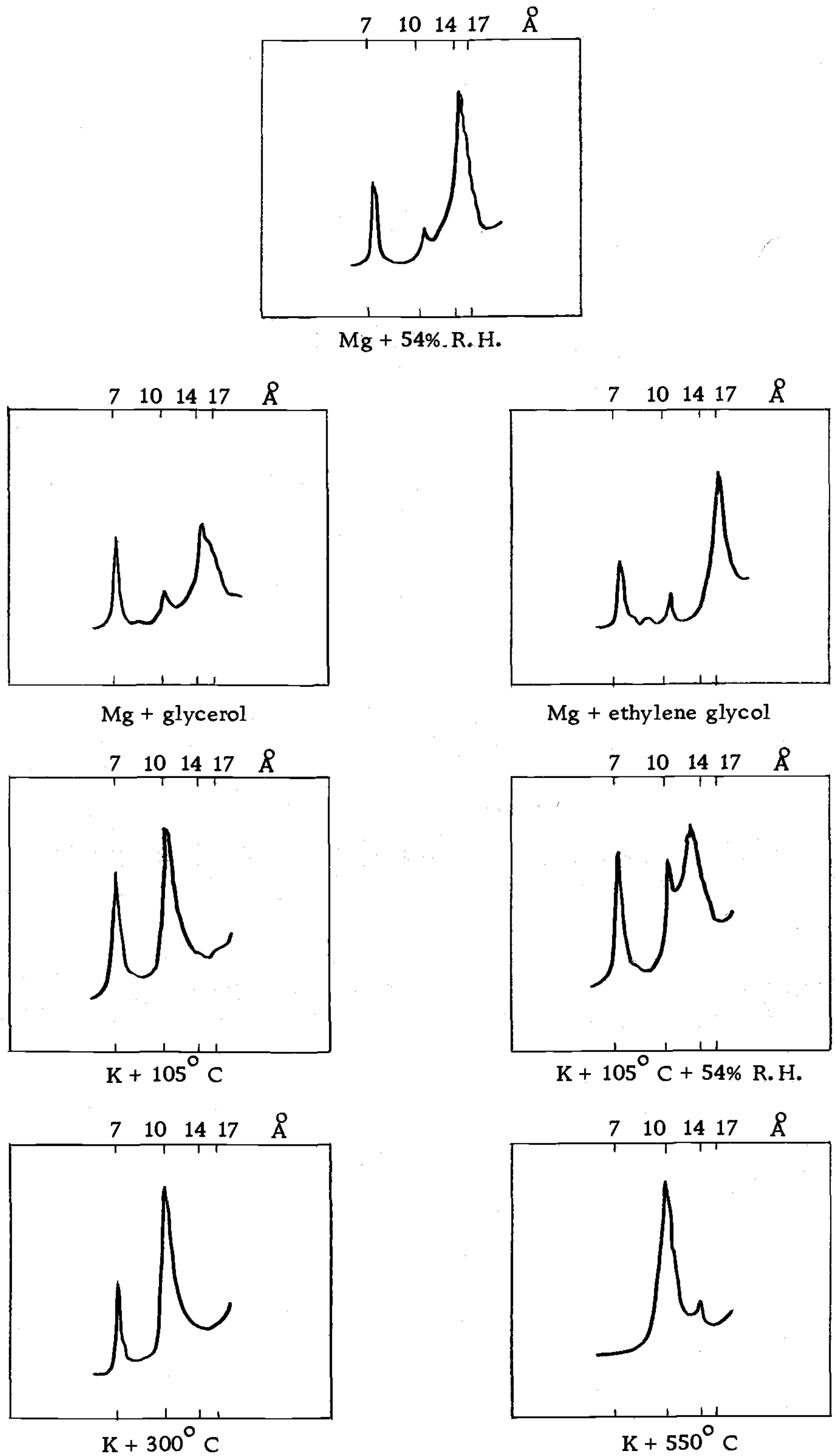

Figure 36. X-ray diffraction patterns for sample Y-3. Order of abundance: BEIDELLITE, montmorillonite, illite, vermiculite, kaolinite, chlorite.

The incomplete expansion after ethylene glycol solvation could be explained by mixed-layer combinations such as beidellite-illite, beidellite-chlorite, or beidellite-vermiculite.

Samples which are characterized by incomplete expansion often display a broad diffraction maximum between 10 and 14 Å on X-ray patterns before solvation (Figure 32). This high does not constitute a sharp peak. Although the position of the maximum is dependent upon humidity conditions at the time of X-raying, the maximum persists even when the magnesium-saturated sample has been desiccated and X-rayed in dry air. The position of the maximum between 10 and 14 Å indicates that beidellite-illite probably accounts for much of the mixed-layer clay.

No discrete peaks occur in the 25 to 30 Å range on X-ray diffraction patterns. The mixed-layer clay is therefore randomly interstratified rather than having an orderly internal arrangement of the two components (Hower, 1967).

An intergrowth of beidellite-vermiculite might also contribute to the incomplete expansion with ethylene glycol solvation, however, there is no concrete evidence of this combination in the Hudspeth Formation. In the lower part of the M-section the 14 Å component collapses readily to 10 Å with potassium-saturation and drying at 105° C. However it does not show a distinct 12 Å peak on re-hydration after heating to 105° C, but only a broadening and asymmetry of the 10 Å peak. This could indicate the presence of beidellite-vermiculite, or alternatively could be interpreted to mean that beidellite is present in insufficient quantities to create a separate peak.

It is possible that some mixed-layer beidellite-chlorite also exists in the Hudspeth Formation in small quantities. Its occurrence would be indicated primarily by the observation that certain of the 14 Å components resist collapse to a 10 Å spacing on potassium-saturation and heating to 300° C.

Illite, or micaceous material, as indicated by a stable 10 Å reflection regardless of pre-treatment, occurs persistently in all samples. In sample M-160, illite is a dominant mineral, while in Y-3 it is minor. The 10 Å component is considered to be illite rather than well-crystallized mica. The lack of sharpness of the 10 Å peak, as expressed by its area: height ratio, suggests a poorly crystallized illitic type of clay mineral (Schultz, 1964). Biotite and muscovite may also contribute to the 10 Å peak.

Chlorite is minor in nearly all samples. It is indicated by the persistance of a 14 Å diffraction maximum of varying intensity following heating to 550° C. Sample M-160 contains minor chlorite.

Kaolinite is present in nearly all samples, and is usually more abundant than chlorite. Shape of the 7 Å peak indicates that it is intermediate to poorly crystallized (Schultz, 1960). Kaolinite is indicated by a 7 Å peak regardless of saturating cation, humidity, or solvation. The presence of kaolinite is difficult to determine by X-ray diffraction if chlorite is also present because the first order reflection of kaolinite and the second order reflection of chlorite coincide at 7 Å. Upon heating to 550° C, the 7 Å peak is destroyed for both of these minerals in the Hudspeth Formation. The presence of kaolinite in the Hudspeth mudstones is verified by two methods. After treatment with hydrochloric acid (Schultz, 1964), the 14 Å is entirely absent when heated to 550° C. Therefore chlorite is probably entirely removed. A 7 Å peak of varying intensity remains after treatment and is attributed to kaolinite.

In a few samples two separate peaks can be resolved by slow scan across 3.52 Å (chlorite) and 3.58 Å (kaolinite). The kaolinite peak has higher intensity than the chlorite peak in nearly all of these samples. Comparison with illustrations of Grim, Bradley, and White (1957, Figure 2), suggests that the amount of kaolinite is equal to or greater than the amount of chlorite.

Fine clay minerals. The clay suite of the fine clays less than 0.2 microns is similar to that of coarse clays, except that the peaks are broader and less sharp (Figure 37) and there is a greater proportion of smectite and mixed-layer clay in the fine fraction. The smectites and mixed-layer clays are apparently of finer grain sizes than

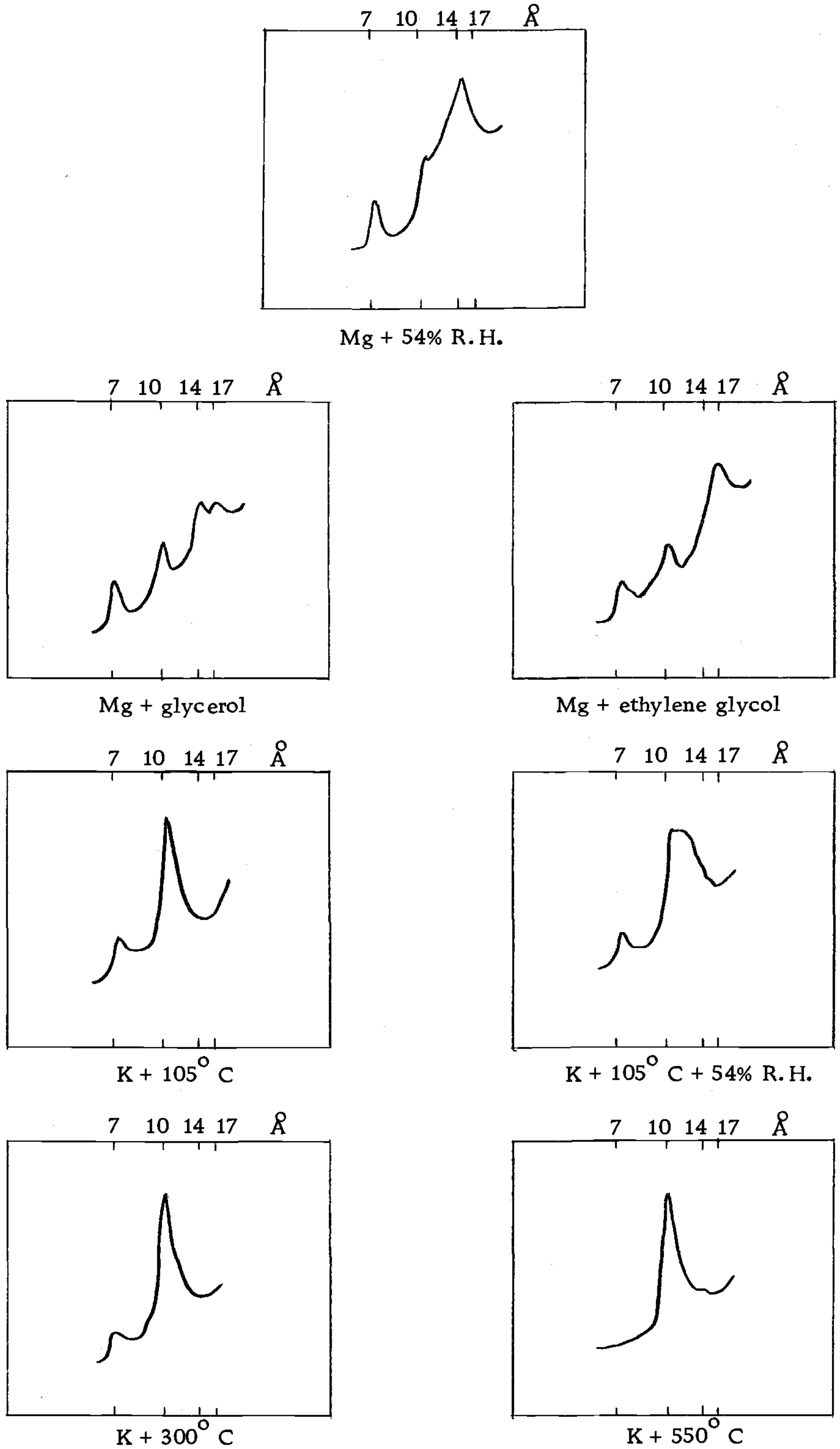

Figure 37. X-ray diffraction patterns for fine clays, sample M-2840. Order of abundance: BEIDELLITE, ILLITE, vermiculite, montmorillonite, kaolinite, chlorite, mixed-layer clay.

the other clays. Other authors (Gibbs, 1965; Grim, 1953) have noted that smectites, such as montmorillonite, occur as extremely fine-grained particles.

Silt and sand fraction. The whole rock method of Schultz (1964), in which the entire rock is ground to fine size and then X-rayed with random orientation, gives poor results for the Hudspeth mudstones because of the small amount of silt and sand present in the total rock. Other than a low, broad maximum near 5 Å which represents clay, the only significant peaks are the major reflections of quartz at 3.34 Å and 4.26 Å. X-ray diffraction patterns of the silt and fine sand fraction are more definitive, although these X-ray patterns may have high background scatter caused by silt - and sand-sized fragments of mudstone which did not completely disaggregate in the routine procedure. Quartz is the dominant mineral in all samples, and all quartz peaks are marked by strong reflections. There is some feldspar with a major peak between 3.18 and 3.20 Å and occasional calcite with peaks at 3.03 Å and 2.28 Å. X-ray patterns show no evidence of pyrite, serpentine, or other minerals that occur in small amounts.

Distribution of Clays in the Stratigraphic Sections

Semi-quantitative interpretation of the relative amounts of each clay in the samples analyzed (Appendix C) is based on interpretation of untreated samples as described earlier. Values are intended to denote the significance of each clay relative to other components of the sample and have no quantitative implication for comparison with other studies of clay minerals. They only provide a means by which to compare differences within a section and from one section to another within this study.

M-section. Figures 32, 33, and 34 illustrate X-ray diffraction patterns of samples from the base, middle and top of the M-section. Illite is common throughout the section and the relative abundance decreases upward. It is the dominant clay at the bottom of the section as well as an important constituent at the top.

Beidellite and vermiculite are common throughout the M-section and together account for most of the 14 Å peak in X-ray patterns. The total amount of smectite and vermiculite increases upward in the section, however the proportion of vermiculite in the sample decreases slightly toward the top of the section and the proportion of beidellite increases significantly.

Kaolinite is present throughout the section and the relative abundance remains fairly constant. Chlorite is present throughout and is usually minor but may locally be abundant. Near the bottom and in mid-section, chlorite increases slightly because of nearby Tertiary intrusions. Although the intrusive bodies are about one-quarter mile away, small amounts of chlorite have developed as a response to the increase in temperature. Such chlorite development is better shown in samples taken closer to intrusive contacts as discussed later.

Montmorillonite is not common in the M-section. The few samples which contain minor amounts of montmorillonite are found near the top of the section.

The dominant mixed-layer clay in the M-section is beidellite-illite. Peak expansion after solvation with ethylene glycol varies (from 15 Å at the base of the section to 17 Å at the top) indicating a gradual change in the relative proportions of beidellite and illite. In the lower third of the M-section, the 14 Å component assumes a 15 to 15.5 Å peak position after solvation; in the middle third the peak position is 15.5 to 16 Å; while peak position in the upper third is 16 to 17 Å. In the lower two-thirds of the section, a diffraction maximum is often visible between 10 Å and 14 Å for magnesium treated slides, strengthening the hypothesis that beidellite-illite interstratification causes the shift in peak position.

Weaver (1956) shows the following table of peak positions for randomly interstratified mixed-layer clays composed of expandable 17 Å and non-expandable 10 Å components. Weaver assumes a 17 Å value for the maximum expansion of smectites. Using this assumption, all of the "beidellite" in the Hudspeth Formation is actually interstratified beidellite-illite with an average of 80 percent beidellite and 20

Percent Expanded Layers	10/17 Å peak position	
	Calculated (Å)	Measured (Å)
50	15.4	15.4
60	16.2	16.0
70	16.5	16.4
80	16.7	16.7

percent illite for the top third of the M-section and for the T- and H-sections. If it is assumed that "beidellite" includes material which expands to 16.7 Å after solvation with ethylene glycol (Harward, Carstea, and Sayegh, 1969), then mixed-layer beidellite-illite would only be important in the lower two-thirds of the M-section. In this report, the term "beidellite" is used in the latter sense, while the term "mixed-layer clay" is reserved for interstratified clay which expands to 16 Å or less with solvation.

All of the mixed-layer clays are randomly interstratified. This is expected if beidellite-illite is similar to montmorillonite in interstratification. According to Reynolds and Hower (1970) virtually all illite-montmorillonite with expandabilities of 40 to 100 percent are randomly interstratified.

T-section. In the T-section of the Main Mudstone Member, the distribution pattern shows basically the same clay mineral suite throughout with no significant change in composition from bottom to top of the section, and little or no correlation with changes that occur in the M-section. All samples contain nearly the same proportion of clay types. Clay minerals present include in order of decreasing abundance: beidellite and vermiculite, illite, kaolinite, chlorite, minor montmorillonite locally, and little or no mixed-layer clay. The only significant shift in composition is a slight increase in kaolinite and decrease in chlorite toward the bottom of the section where sandier units are concentrated.

H-section. The H-section in the upper units of the Hudspeth Formation, contains the same clay suite as the T-section. Illite shows a slight, but significant, decrease from bottom to top in the section and chlorite increases slightly. The smectite and vermiculite content increases slightly upward, but the increase is not statistically significant.

Summary. The distribution of clays in the Hudspeth Formation is as follows:

1) The proportion of smectite and vermiculite increases from bottom to top in each section.
2) Chlorite increases from bottom to top in each section except the M-section, in which the proportion of chlorite remains fairly constant.

3) Kaolinite decreases in abundance from bottom to top in each section.

4) Illite decreases in abundance significantly in two of the sections, but increases slightly from bottom to top in the T-section.

Y-series. In the younger Cretaceous rocks east of Mitchell (Y-series), the dominant clay is beidellite. Montmorillonite is usually present with minor illite, kaolinite, and/or chlorite, however little or no vermiculite or mixed-layer clay is present. In two samples montmorillonite is the dominant clay mineral and in another, kaolinite and beidellite are the most abundant components. The remaining samples are similar in composition to mudstones from the T- and H-sections, but contain somewhat more smectite.

Effect of Tertiary Intrusions on Mudstones

The Cretaceous rocks are cut by numerous Tertiary andesite and basalt intrusives. This igneous activity has had at least two visible effects on the Cretaceous mudstones. As the material forced its way to the surface, it locally disturbed the bedding so that strikes and dips of beds immediately surrounding intrusions are often different from the prevailing attitude. The high temperature of the igneous bodies created thermal effects in the adjacent older rocks affecting the clay mineralogy of the mudstones. Instead of the typical olive gray color (5 Y 4/1), mudstones near an intrusive body take on a characteristic medium dark gray color (N 4).

Several samples were analyzed to determine what mineralogical change is responsible for the color change in mudstones adjacent to intrusions. The total amount of clay is fairly constant when comparing gray and olive-gray samples from the same vicinity. X-ray analysis of bulk samples indicates that quartz, minor feldspar, and several clay minerals are present. Most of the mineralogic difference is in the relative proportions of clays within the total clay component. Mudstones near the dike and sill located in NW1/4NE1/4 sec. 35, T. 11 S., R. 21 E., illustrate this compositional change. X-ray diffraction patterns of a typical olive-gray sample from this area (Figure 38) indicate illite, smectite and vermiculite, and also some kaolinite and chlorite. The X-ray patterns from a typical medium dark gray sample (Figure 39) show the same peaks and clay minerals, but the relative proportions differ. The 7 Å peak of the untreated slide and the 14 Å peak of the slide heated to 550° C are much more pronounced, indicating that chlorite has increased relative to the other clays.

Near an intrusive body, the chlorite content is much greater than the normal chlorite content of the mudstones. The gray sample (Figure 39) which was collected two or three inches from the dike contact, contains 25 to 30 percent chlorite, while the olive-gray

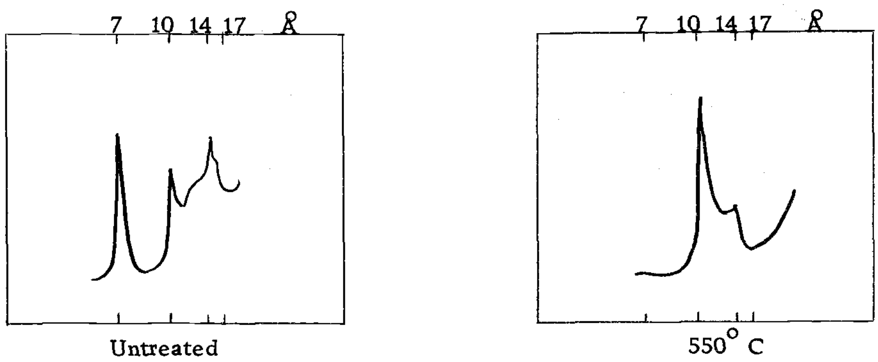

Figure 38. X-ray diffraction patterns for a typical olive-gray sample, twenty feet from dike contact.

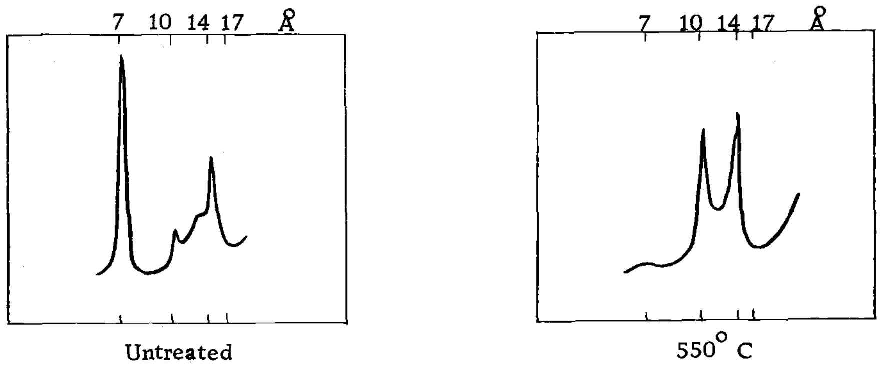

Figure 39. X-ray diffraction patterns for a medium dark gray sample, three inches from dike contact.

sample (Figure 38) collected 20 feet from the contact contains 5 to 10 percent chlorite, which is typical of mudstones in this area. An intermediate sample, also medium dark gray, collected three to four feet from the contact has 20 to 25 percent chlorite.

The width of the zone of thermal effect varies with the size of the intrusive body. At a two foot thick basalt dike, the medium dark gray color is noted for a few inches on either side. Samples taken within these few inches contain about 15 percent chlorite, while a few feet away the effect diminishes rapidly to a typical 5 percent chlorite. Near a large andesite sill approximately 380 feet thick, a 10 percent increase in chlorite is detected 30 to 40 feet from the contact.

Statistical Analysis

Chi-square Test for Homogeneity

The chi-square test for homogeneity was applied to each measured stratigraphic section. The M-section of the Main Mudstone Member was divided into eight sub-units on the basis of grain size and depth (Figure 7). Samples were taken at 80 foot intervals throughout the section and anayzed for the presence of the four clay types (1) smectite and vermiculite, (2) illite, (3) kaolinite and (4) chlorite. From the analyses of the samples in each sub-unit an average value of percent of each clay was calculated (Table 1, Appendix E).

The hypothesis tested is that the relative proportions of the four clay types are the same irrespective of depth. Selecting a level of significance $\alpha = .10$ (Koch and Link, 1970), the critical region is $\chi^2_{21} > \chi^2_{21;90} = 29.62$. The statistic used is

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

where: o = observed value

e = expected value.

If the hypothesis of homogeneity is true, the equation has an approximate chi-square distribution with (r-1)(c-1) degrees of freedom, where r = number of rows and c = number of columns. In this analysis there are 21 degrees of freedom.

Computation of the chi-square statistic yields a value of 41.14 for the M-section. Since $\chi^2_{21;90} = 29.62$ and $\chi^2_{21;99} = 38.93$, the hypothesis of homogeneity is rejected at a level smaller than 0.01 (1%). The conclusion is that the relative proportions of the four clays change with depth in the M-section.

The chi-square test for homogeneity was applied in similar manner to the T-section of the Main Mudstone Member and to the H-section in the upper Hudspeth units. The T-section was divided into five sub-units based on outcrop pattern and lithology (Figure 8) and samples were taken at 40 foot intervals. From analyses of the samples in each sub-unit, an average percentage value of each clay was calculated (Table 3, Appendix E). Computation of the chi-square statistic yields a value of 9.03, with 12 degrees of freedom. Since $\chi^2_{12;90} = 18.55$, the hypothesis of homogeneity is accepted and it is concluded that the relative proportions of the four clays do not change with depth.

The H-section was divided into eight natural sub-units (Figure 9) separated from one another by tongues of Gable Creek conglomerate and sandstone. Average percentage values of each clay were calculated for representative samples taken in each sub-unit (Table 5, Appendix E). Computation of the chi-square statistic yields a value of 40.38, with 21 degrees of freedom. Since $\chi^2_{21;99} = 38.93$, the hypothesis of homogeneity is rejected at a level smaller than 0.01 (1%). It is concluded that the relative proportions of the four clays does change with depth.

Correlation Coefficient and t-test

Correlation coefficient and t-distribution analyses were used to determine if changes in the percent of each clay type are related to changes in stratigraphic position in the sections. For each sub-unit, computational values used are the average value of depth and average percentage value of each clay as listed in Appendix E.

Examining first the smectite and vermiculite in the M-section the hypothesis that the percent of smectite and vermiculite clay is independent of depth of the sample is tested. The level of significance $\alpha = .10$ was selected. The critical region is $t_6 < t_{6;.10} = -1.440$, $t_6 > t_{6;.90} = 1.440$. The statistic used is

$$t_{n-2} = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

where: r = correlation coefficient

n = number of pairs.

This random variable has a t-distribution with $n - 2 = 6$ degrees of freedom.

The computed value of the correlation coefficient is .8593, and the value of t is 4.11. Since $t_{6;.90} = 1.440$ and $t_{6;.99} = 3.143$, the hypothesis of independence is rejected at a level smaller than 0.01, and the conclusion is that there is a relationship between the percent of smectite and vermiculite clay and the sample depth.

Testing the hypothesis that the percent of illite in the M-section is independent of depth, it is calculated that:

$$r = -0.9258$$

$$t = -6.01$$

The hypothesis of independence is rejected at a level smaller than 0.01 and it is concluded that there is a relationship between the percent of illite and the sample depth.

Testing the hypothesis that the percent of kaolinite is independent of depth, it is calculated that:

$$r = -0.4261$$

$$t = -1.15.$$

The hypothesis of independence is accepted at a level smaller than 0.10 and it is concluded that there is no relationship between the percent of kaolinite and the sample depth.

Testing the hypothesis that the percent of chlorite is independent of depth, it is calculated that:

$$r = .0558$$

$$t = 0.14$$

The hypothesis of independence is accepted and it is concluded that there is no relationship between the percent of chlorite and the sample depth.

The same method was used in comparing the percent of each clay to the average stratigraphic position in the T-section. Testing the hypothesis of independence, the following values of the t statistic were calculated:

smectite and vermiculite	$t_3 = 0.44$
illite	$t_3 = 0.99$
kaolinite	$t_3 = -1.99$
chlorite	$t_3 = 2.25.$

Since the critical region is $t_3 < t_{3;.10} = -1.638$, $t_3 > t_{3;.90} = 1.638$, the hypothesis of independence is accepted at a level smaller than 0.10 for smectite and vermiculite and for illite, and it is concluded that there is no relationship between the percent of each clay type and the sample depth. However, the hypothesis of independence for kaolinite and chlorite is rejected and it is concluded that there is a relationship between percent clay and sample depth for these two clay types.

The following values of the t statistic were calculated for the H-section:

smectite and vermiculite	$t_6 = 1.01$
illite	$t_6 = -2.48$
kaolinite	$t_6 = -0.73$
chlorite	$t_6 = 2.84$

Since the critical region is $t_6 < t_{6;.10} = 1.440$, $t_6 > t_{6;.90} = 1.440$, the hypothesis of independence is accepted for smectite and vermiculite and for kaolinite, but the hypothesis of independence is rejected for illite and chlorite. It is concluded there is no relationship between the percent of smectite and vermiculite and the sample depth, or between kaolinite and the sample depth; but there is a relationship between illite and the sample depth, and between chlorite and the sample depth.

Regression Lines

The relationship between each clay type and the stratigraphic position of the sample is summarized by the regression line for each clay type (Figures 40, 41, and 42). A and B values for the regression

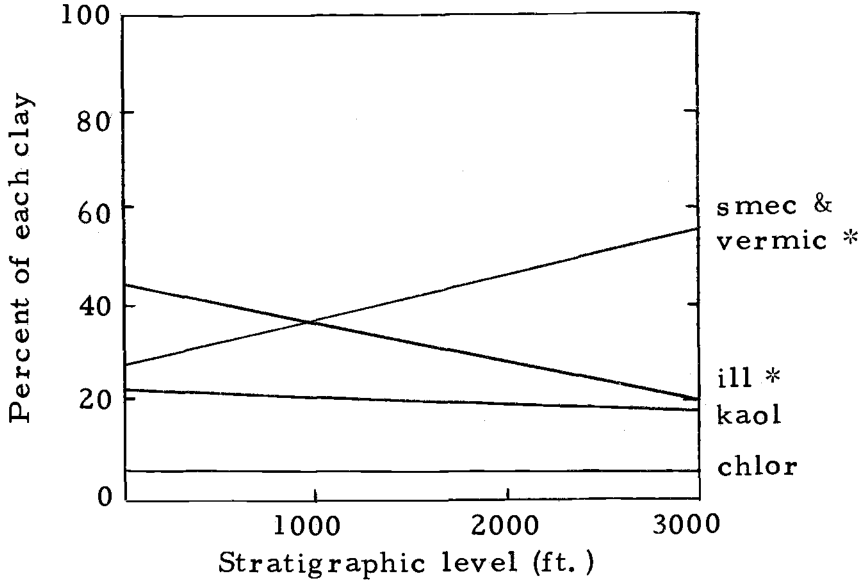

Figure 40. Regression lines showing relationship between percent of each clay type and stratigraphic position above the base of the M-section. (*) indicates statistically significant at a level smaller than .10.

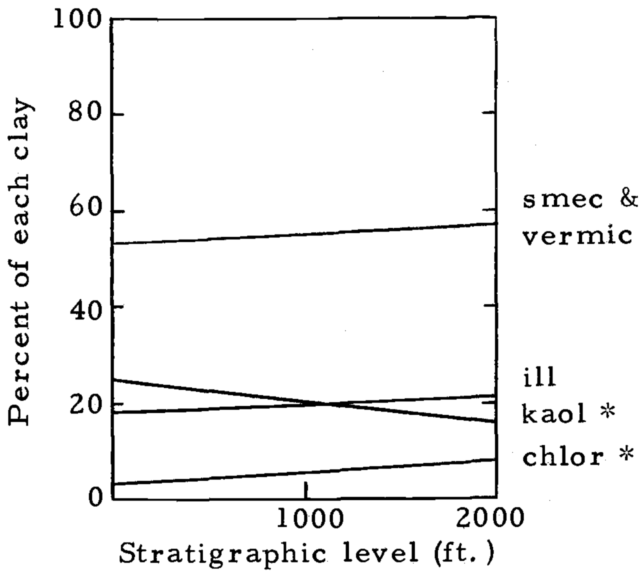

Figure 41. Regression lines showing relationship between percent of each clay type and stratigraphic position above the base of the T-section. (*) indicates statistically significant at a level smaller than .10.

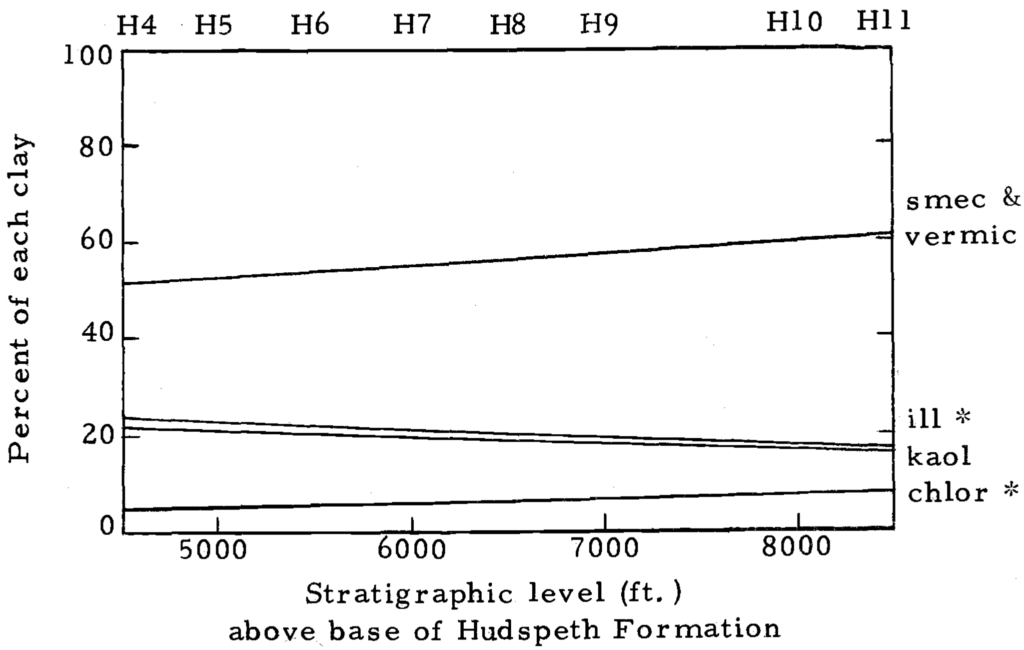

Figure 42. Regression lines showing relationship between percent of each clay type and stratigraphic position in the H-section. (*) indicates statistically significant at a level smaller than .10.

lines (Appendix E) were calculated from the values of the average percent clay and average stratigraphic position for each sub-unit. Only those regression lines marked with an asterisk (*) show variation which is statistically significant at a level smaller than 0.10.

Chi-square Test for Independence

Additional chi-square tests were conducted using data concerning some textures and structures of the claystones and mudstones (Appendix E, Tables 7 through 15). Briefly summarizing the results, analyses show that there is a relationship in the following:

1) Degree of parallel orientation of clay particles compared to total clay content in the sample. -- The hypothesis of independence is rejected at a level smaller than 0.005. Those samples which exhibit good parallel extinction of clay and mica particles are those which contain the largest percentage of clay, while samples with less than 50 percent clay usually show little or no parallel orientation of clays.

2) Sphericity of sample chips collected in the field compared to total clay content. -- The hypothesis of independence is rejected at a level smaller than 0.005. Samples containing large amounts of clay usually break in flat chips with low sphericity values, whereas samples containing less clay and more silt and sand grains tend to break in nearly equidimensional chips with high sphericity values.

3) Maximum chip size compared to total clay content. -- The hypothesis of independence is rejected at a level smaller than 0.005. Samples which break in small chips with a maximum size less than one inch tend to contain large amounts of clay, while those breaking in blocks of two inches or more have a large percentage of sand and silt with less clay.

4) Maximum grain size in sample compared to percent non-clay materials. -- The hypothesis of independence is

rejected at a level smaller than 0.005. Samples containing large amounts of silt and sand, especially more than 30 or 40 percent, have the largest maximum grain size.

5) Percent kaolinite compared to total clay content. -- The hypothesis of independence is rejected at a level smaller than 0.10. Sandy and silty mudstone samples contain a larger proportion of kaolinite than samples composed predominantly of clay.

6) Color compared to total clay content. -- The hypothesis of independence is rejected at a level smaller than 0.10. Olive gray (5Y 4/1) is the most common color of claystone, while coarser mudstones are usually light olive gray (5Y 5/2).

Analyses show that there is no relationship in the following:

1) Percent quartz in silt and sand fraction compared to total percent non-clay minerals. -- The hypothesis of independence is accepted at a level smaller than 0.10. There appears to be a slight increase in the apparent percent quartz in the finer-grained samples, but the shift in composition is not statistically significant.

2) Clay type compared to maximum chip size. -- The hypothesis of homogeneity is accepted. There is no relationship

between the proportions of the four clay types and the maximum chip size.

3) Clay type compared to total clay content. -- The hypothesis of homogeneity is accepted. There is no relationship between the proportions of the four clay types and the total clay content of the samples.

DISCUSSION

Mineralogy of Source Rocks

Basal Hudspeth

Sandstone and conglomerate composition indicates a supracrustal origin with some erosion of crystalline basement rock. Pettijohn (1957) indicates that the ratio of feldspar to lithic grains suggests a supracrustal source if lithic fragments outnumber feldspar grains. In sandstones of the Basal Hudspeth, the feldspar to lithic ratio averages 0.45 thus indicating a supracrustal origin.

Many quartz grains contain both regular and irregular inclusions and have undergone moderate strain as indicated by undulose extinction. This extinction implies that much of the quartz is from metamorphic sources according to Pettijohn's (1957) interpretation, however Blatt and Christie (1963) conclude that the presence of undulatory extinction is of very limited usefulness in determining provenance of sediments.

Average composition of lithic fragments in sandstones and conglomerates indicates the following rock types in the Basal Hudspeth:

Sandstones	Conglomerates at base of unit	Conglomerate tongue 400 ft. above base
38% Quartzite	31% Chert	58% Volcanic
23% Metamorphic	26% Metamorphic	16% Sedimentary
21% Volcanic	25% Quartzite	12% Chert
10% Chert	16% Volcanic	5% Granitic
6% Sedimentary	1% Granitic	4% Quartzite
2% Granitic	- Sedimentary	4% Metamorphic

These data indicate a dominant supracrustal origin with the main sources being: (1) low-rank metamorphic - mainly quartzite, chert, phyllite and schist with minor "greenstone"; (2) volcanic - mainly basalt with some devitrified glass, andesite and rhyolite; (3) reworked sedimentary rocks - mainly mudstone (sandstone and calcareous concretions may be present in conglomerates); and (4) plutonic - granitic rock fragments.

The composition of the conglomerates tends to reflect the composition of underlying rocks. Where they directly overlie low-rank metasediments of Permian age, the conglomerates have a high content of quartzite, unstable metamorphic rock fragments, and chert. Near Tony Butte, where a tongue of Basal Hudspeth conglomerate interfingers with mudstone and is underlain with mudstone, the metamorphic content is lower with proportionately higher amounts of volcanic and sedimentary material. Sandstone composition shows no consistent variation from bottom to top in the Basal Hudspeth.

Hudspeth Mudstones and Interbedded Sandstones

Sandstones interbedded with mudstones of the Main Mudstone Member have a predominantly supracrustal origin. The feldspar to lithic ratios and quartz types are similar to sandstones of the Basal Hudspeth, and the average composition of lithic fragments is:

39% Volcanic
22% Sedimentary
17% Metamorphic
16% Quartzite
5% Chert
2% Granitic

Compared with sandstones of the Basal Hudspeth, sandstones of the Main Mudstone Member contain somewhat more reworked mudstone and fragments of basalt, devitrified glass, and andesite, and less low-rank metamorphic material. A possible explanation is that Permian basement rocks became less accessible to erosion as they were covered with Cretaceous sediments in the basin of deposition. As new highlands were raised, a greater variety of material became available and the low-rank metamorphic source may have been further "diluted" by reworking of Cretaceous sedimentary and possible volcanic material.

Composition of the sand and silt fraction in the argillaceous rocks reflects the same parent material as in the coarser samples. The feldspar to lithic ratio in the coarser mudstones is similar to the ratio in the sandstones, although lithic fragments and feldspar make up a small percentage of the total rock. Specific rock types are difficult to distinguish because of the small grain size.

Clay composition of a sedimentary rock may or may not reflect the parent rock. The final clay composition of a sediment depends on many factors, including parent rock composition, climate, topography, vegetation, and time involved in the weathering process (Grim, 1953). Composition of the parent rock is especially important in the initial stages of weathering where the most important aspect is the content of alkalies and alkali earths.

All of the minerals in the clay suite of the Hudspeth Formation could readily have formed from weathering of rocks in the source area. It is assumed that the argillaceous rocks and sandstones derived their materials from the same source, since silt and sand grains of the coarser mudstones have the same composition as framework grains in the sandstones. The most abundant unstable grains of the sandstones, such as fine-grained lithic fragments, feldspar, and mica, suggest a source that could supply large amounts of clay under certain conditions of weathering. Chlorite, kaolinite, and illite are commonly derived from the alteration of metamorphic and/or sedimentary rocks (Weaver, 1958b). Kaolinite is especially important as an alteration product from feldspar, while chlorite is often produced from the weathering of ferromagnesian minerals (Milner, 1962). Clay vermiculite usually develops from alteration of biotite (Foster, 1961), muscovite, or chlorite. Much of the expanded clay reported in the literature is derived from volcanic material, chlorite, or hornblende (Weaver, 1958c). Smectite and mixed-layer clay may come from weathering of volcanic ash and tuff, basaltic rocks, and calcic feldspar in an alkaline environment, or from the alteration of older sedimentary rocks. The presence of beidellite may be attributed to weathering of feldspar and ferromagnesian minerals (Milner, 1962). In addition to alteration of minerals and unstable fine-grained rocks, some clay may be inherited directly from older argillaceous rocks (van Houten, 1953).

Most of the clay minerals in the Hudspeth Formation are considered to have a detrital origin, with the type of source rocks having more influence than soil environment or depositional environment. Soils in the source area probably had neither a highly alkaline nor acid environment with a modest amount of rainfall. Such environments have the broadest frequency distribution of clay minerals (Barshad, 1965). Beidellite, vermiculite, and kaolinite probably resulted from weathering of fine-grained rocks and minerals in such an environment, as did most of the illite and chlorite present in the Hudspeth Formation. It is proposed that these minerals were deposited rapidly, with little subsequent change in the diagenetic environment.

Probable Transport Direction

Limited data from cross bedding and ripple marks indicate that sediment was transported from the north. Wilkinson and Oles (1968) also concluded that the source of the Hudspeth and Gable Creek Formations was to the north and northeast. As pointed out by Wilkinson and Oles (1968), the area north and northeast of the Hudspeth outcrops is now buried under Tertiary volcanic material, but limited outcrops of pre-Cretaceous rock occur within the Mitchell quadrangle and also farther to the east. Pre-Cretaceous outcrops presently exposed in these areas include quartz, chert, phyllite, limestone, quartzite, conglomerate, schist, greenstone, granodiorite and tonalite (Taubeneck, 1959), deeply weathered granitic and metamorphic rocks. No exposures of pre-Cretaceous acid volcanic rocks have been reported.

Maturity

Sandstones of the Hudspeth Formation are immature in texture and composition. Using the ratio of quartz and chert to feldspar and lithic fragments as an index of maturity, sandstones of the Hudspeth Formation have an average value of 0.75. Comparison to a 1.2

average for graywacke and a 2.3 average for lithic sandstones (Pettijohn, 1957) suggests that the sandstones of the Hudspeth Formation are very immature in composition because highly feldspathic or lithic sandstones are more immature than quartzose sandstones.

Using Folk's (1951) classification, nearly all of the sandstones of the Hudspeth Formation are texturally immature. Most contain more than five percent clay and the sand grains are not well sorted or rounded. A few would classify as submature, with less than five percent clay. According to Dott's (1964) modification of Folk's textural classification, all of the wackes (containing more than ten percent matrix) are very immature texturally. Over two-thirds of the arenites of the Hudspeth Formation are moderately immature (five to ten percent matrix); the remainder are submature (less than five percent matrix). There is a complete gradation in the Hudspeth Formation from claystone and mudstone with predominant matrix, through wacke sandstone, to arenite sandstone with little or no matrix.

Tectonics, Relief, and Climate

Relief and climate have a major effect on the composition and maturity of a sedimentary deposit. The immaturity of the Hudspeth sandstones indicates a low total input of energy. Either the weathering processes acted for only a short time before deposition, or the intensity of weathering was low, or both effects were combined (Pettijohn, 1957).

The length of time that weathering and erosional processes operate is determined by the relief of the area. Immature sediments, such as the Hudspeth Formation, imply short duration of the weathering processes. An area of fairly high relief where soil formation lags behind sediment removal would permit much incompletely weathered material to enter streams and be transported to the depositional site. Feldspar and other mineral grains in the Hudspeth sandstones are usually sub-angular and not more than sub-rounded; therefore the source was relatively close, and transport distance was not great.

The intensity of weathering is determined by the climate. The immaturity of the Hudspeth sandstones suggests a low intensity of weathering, possibly in a rigorous, cold or arid climate; however, the abundance of silt- and clay-site material and the amount of weathered feldspar and lithic fragments suggests more advanced chemical decay in a climate that was at least moderately warm and moist. The presence of numerous carbonized wood fragments also indicates a mild climate.

Feldspar grains in the Hudspeth sandstones show a wide range in degree of alteration. All stages of alteration exist within any one sample with no apparent compositional control. The partial replacement of feldspar by calcite is post-depositional, but most of the alteration to clay and mica is probably pre-depositional. The presence of fresh and weathered feldspar together suggest a relatively humid climate with high relief where streams can cut through a weathered mantle to erode fresh bedrock (Pettijohn, 1957).

Active tectonism would be required to create this relatively high relief. Tectonic instability of the region during Cretaceous time is also implied by the alternating tongues of coarse-grained Gable Creek Formation and fine-grained Hudspeth Formation.

Basin of Deposition

Summary of Events

The Cretaceous rocks of the Hudspeth and Gable Creek Formation accumulated in a strongly subsiding basin which lay near an actively rising source area. Wilkinson and Oles (1968) proposed that a major river draining from the source region poured quantities of clastic sediments into a large, shallow marine embayment. The mudstones of the Hudspeth Formation were deposited in this marine environment, while the coarse sandstones and conglomerates of the Gable Creek Formation are considered to be of fluvial-deltaic origin. Wilkinson and Oles attributed the intertonguing relationship of these two formations to the interaction of three mechanisms - episodic downwarping of the basin of deposition, intermittent uplift of the source area, and presence of a large river delta with periodic reorientation of the major distributary channel.

Deposition of the Hudspeth Formation

The Basal Hudspeth represents a marine transgression of the Cretaceous sea over eroded Permian metasediments. Sandstones of the Basal Hudspeth contain marine pelecypods and moderately large fragments of fossilized plant debris, suggesting that the sandstones and conglomerates of this basal unit were probably deposited in a high energy upper neritic or littoral marine environment.

The mudstones of the Hudspeth Formation represent rapid deposition of fine-grained detritus. Thousands of feet of mudstones associated with thick conglomerate and sandstone deposits suggest that an abundance of clastic material was brought into the sedimentary basin over a relatively short interval of geologic time.

The sediments of the Hudspeth Formation were deposited mainly in quiet water with intermittent periods of more vigorous current action, and after deposition the sediments remained undisturbed. Krumbein and Sloss (1956) postulate that widespread shales were deposited by slow circulating currents with bottom currents being feeble or absent. Evidence of wave action or benthonic activity is generally lacking in the Hudspeth Formation. Survival of benthonic organisms may have been inhibited by the rapid influx of sediment. Thin laminations, such as those commonly present in the argillaceous rocks of the Hudspeth Formation, are preserved only in the absence of bottom turbulence. The "reducing" minerals, such as sedimentary pyrite, also form where no turbulence or aeration is present, regardless of water depth. Occasional variability in current action is marked by irregular coarse laminations which taper out, or by larger and coarser sandstone beds which are somewhat uneven in thickness.

Most fossils are planktonic forms which give no indication of water depth. A quiet-water environment with an absence of carbonate sediments and a predominance of shales may indicate comparatively deep water (Pettijohn, 1957), however no direct evidence of water depth was found. In recent sediments, carbonates dissolve at depths below approximately 6000 meters, but an absence of carbonate fossils does not necessarily imply solution at abyssal depths. In the Hudspeth Formation some of the carbonate of microfossils has been replaced by pyrite and silica, however the carbonate solution probably was in response to a slightly acid diagenetic environment rather than solution at great depth.

Sandstones interbedded with the mudstones locally contain mud cracks and short wavelength oscillation ripple marks in association with a benthonic fauna, suggesting that the depositional environment was shallow marine to subaerial. Depth of associated mudstones was most likely neritic or upper bathyal.

Diagenetic Environment

Most diagenetic changes take place at the water-sediment interface or immediately below this interface in the stage of shallow burial. Chemical parameters of this environment can often be deduced from the resulting mineralogical changes in the rocks. No evidence is found in the Hudspeth Formation of abnormal salinity or temperature in the depositional environment.

The oxidation-reduction potential (Eh) was apparently low. A normal benthonic fauna occurs locally in sandy zones, but most of the fossils in mudstones are floating forms such as ammonites and planktonic Foraminifera. The presence of pyrite in concretions, and locally in mudstones, and considerable limonite as an alteration product of pyrite in mudstones, suggests a reducing environment. The zone containing iron sulfide and iron carbonate is a reducing zone according to the subdivisions of Teodorovich (Chilingar, 1955). Authigenic silica, pyrite, and organic matter existing together in mudstones indicate a low Eh (-0.2 to -0.3) and intermediate pH (7.0 to 7.8) using the classification of non-clastic sediments proposed by Krumbein and Garrels (1952). Isolated mudstones contain both authigenic silica and calcareous Foraminifera, therefore it can be assumed that the environment at the time silica formed was probably near the pH = 7.8 "limestone fence" of Krumbein and Garrels, otherwise all of the calcareous microfossils would have dissolved in the acid environment. Foraminifera are often partly replaced by authigenic pyrite or silica. A few sandstones contain siderite cement or glauconite grains. Both of these minerals suggest intermediate Eh (0.0 to -0.2) and pH (7.0 to 7.8) (Krumbein and Garrels, 1952).

It is proposed that the calcite cement of concretions and sandstones developed later than the authigenic pyrite and silica. Although authigenic silica and calcite do not commonly occur together in the same mudstone sample, a few concretions contain both. The silica occurs in discontinuous bands parallel to bedding in the surrounding mudstones. Calcite surrounds the silica, and in a few samples appears to be replacing the silica, giving a ragged, embayed appearance to the silica. Development of silica therefore preceded calcite. Calcite cement in sandstones also developed later than siderite. Euhedral ankerite-siderite crystals line interstices, with irregular calcite filling in the remaining voids.

Both pyrite and calcite concretions may have formed during shallow burial at depths less than 500 meters (Muller, 1967). After formation of pyrite and silica in an environment of intermediate pH, the diagenetic environment then apparently became more alkaline with a pH greater than 7.8 and calcite formed as cement in sandstone and concretions. This calcite cement was probably derived largely from solution of calcareous fossils. Calcite cement tends to be concentrated in the arenites, with most wackes containing little or no cement. Considering the complete gradation in amount of matrix, from mudstones, through wackes, to arenites, it is probable that arenites were more permeable than wackes when deposited because much of the matrix material was winnowed out. The greater permeability would permit fluids to circulate and deposit calcite cement more easily in the arenites. In concretions, calcite was deposited around a nucleus, such as an ammonite shell, where a local environment suitable for formation of calcite prevailed.

Composition of clays present in mudstones of the Hudspeth Formation is not a reliable indicator of depositional environment. According to Weaver (1958a) no particular clay is restricted to a particular environment, and any clay type can occur in any of the major depositional environments. Glass (1958) points out that rapid deposition favors allogenic clays. Weaver (1958a) agrees that most clays are allogenic, and only slightly modified in their depositional environment. He states that the most common process acting on clay minerals in a marine environment is the secondary process of cation absorption, while the basic clay mineral lattice is inherited from the source materials. Grim (1958) concludes that the main change in clay composition during transition from a fresh water to a marine environment would be the regeneration of degraded illite and chlorite by absorption of potassium and magnesium from the saline water. He believes that montmorillonite might also take potassium and magnesium ions in exchange for calcium, but would not change beyond the stage of mixed-layer structures of expandable and non-expandable material.

The one variation in proportion of clay in the Hudspeth Formation that may be caused by environmental influence is the distribution of kaolinite. There is a slightly higher percentage of kaolinite in sandy samples than in finer-grained samples. Weaver (1961) drew the same conclusion regarding Late Cretaceous rocks of the Washakie Basin, Wyoming, where he found the kaolinite content greater in sandstones than in adjacent shales. In his study, kaolinite increased from marine to continental environments, and was especially dominant in fluvial and near-shore deposits. This clay distribution is mainly caused by preferential flocculation, current sorting, and source floods, although some later diagenesis may also occur (Weaver, 1957). At least two slight concentrations of kaolinite occur in the Main Mudstone Member. One is in the sandy mudstones associated with near-shore and fluvial sandstones and conglomerates of the upper tongue of Basal Hudspeth at Tony Butte (T-360 to T-520). The other is in mudstones which contain abundant sand and silt grains (M-1970 to M-2130). This zone yields a few pelecypods, and interbedded sandstones contain oscillation ripple marks, indicating a possible near-shore environment.

Post-depositional Changes

Mudstones

Part of the authigenic development of pyrite, silica, and calcite may be post-depositional, occurring somewhat below the water-sediment interface. However, in this discussion, "post-depositional" refers to later changes, including some "diagenetic" effects which occurred after considerable burial.

Development of mixed-layer beidellite-illite in the lower part of the Main Mudstone Member near Meyers Canyon probably resulted from burial after deposition. In the M-section, the amount of smectite (beidellite) decreases downward in the section, while illite and mixed-layer beidellite-illite increase. Several authors have noted a similar change in clays with depth of burial. Weaver (1960) noted that glycolated peak expansion in smectites changes from 17 Å at 8,000 feet depth, to 14 to 17 Å at 8,000 to 12,000 feet, and 12 to 14 Å below 12,000 feet. Burst (1959) recorded that at depths of 3,000 to 14,000 feet, montmorillonite lattices are commonly interstratified with illite components in Gulf Coast Eocene rocks, and no unmixed montmorillonite occurs below 10,000 feet. In another study of Tertiary rocks of the Gulf of Mexico, Powers (1959) found smectite dominant, with minor illite, chlorite, and mixed-layer clay, in sediments less than 5,000 feet deep. With increased depth, illite increased slightly while the amount of mixed-layer illite-smectite increased greatly. Perry and Hower (1970) reported that the composition of mixed-layer clay changed from 80 percent expanded clay to 20 percent expanded clay with increased depth in Gulf Coast sediments. Discrete illite occurs as a detrital component in the sediments they studied and they concluded that the detrital illite seems to break down with increased depth, supplying potassium for interlayer fixation in mixed-layer illite-montmorillonite.

If clays of the Hudspeth Formation react in a manner similar to those described above, maximum depth of burial of the formation was probably 10,000 to 12,000 feet. In the lower two-thirds of the Main Mudstone Member at Meyers Canyon (M-section), the proportion of expandable clay in the mixed-layer clay decreases to approximately 50 percent near the base of the unit. However development of mixed-layer beidellite-illite is minor in the top one-third of the Main Mudstone Member and in the upper units (H-section) of the formation. Mudstones near the base of the Main Mudstone Member at Tony Butte (T-section) also contain little or no mixed-layer clay, and the distribution of clays is relatively homogeneous from top to bottom in the section. The rocks at the base of the T-section can be correlated with those at the base of the M-section on the basis of early Albian fossils. Although the rocks are the same age, they apparently have undergone different post-depositional histories. The T-section probably was not buried as deeply as the M-section. Perhaps, being closer to the source area, this region was subjected to episodic subaerial erosion during Cretaceous time and did not accumulate as great a sediment load as the Meyers Canyon area. An alternative explanation is that the base of the M-section underwent greater compression than the T-section at the time the "Mitchell anticline" was formed.

Another post-depositional change in the mudstones is the development of chlorite near Tertiary intrusions. Some mineralization and development of calcite also occurs at contacts between mudstones and intrusions. The proportion of chlorite increases from 5 or 10 percent in the majority of mudstones to 20 or 30 percent or more in mudstones adjacent to intrusive bodies. The development of chlorite is attributed to "baking" or incipient contact metamorphism in the mudstones. Temperature in the mudstones probably did not rise above a few hundred degrees Celsius because the 14 Å peak of beidellite is still present in most of the mudstones effected, whereas smectites collapse to 10 to 12 Å at temperatures above 150° C.

A more recent process affecting the mudstones is the weathering currently in progress. The mudstones are presently exposed to an oxidizing environment in a semi-arid climate. Mineralogic results of this weathering include the alteration of pyrite to limonite and hematite and the development of montmorillonite. This clay mineral is uncommon in the Hudspeth Formation, and when present accounts for only a small percentage of the clay fraction. It occurs only in weathered samples, and is most abundant in the most weathered samples. The present regime is ideal for the formation of montmorillonite; a semi-arid climate combined with an easily weathered, somewhat basic parent rock, should encourage the development of montomorillonite (Barshad, 1965).

Sandstones

Post-depositional changes in mineralogy also occurred in sandstones of the Hudspeth Formation. The exact stage at which cementation took place is conjectural because the process may be partly diagenetic and partly post-depositional after considerable depth of burial. Another change which may have taken place during or after deposition is chemical reaction between fine-grained lithic fragments and matrix of the sandstones. It is likely that the proportion of matrix material in sandstones actually increased slightly after deposition by alteration of lithic fragments to clays similar to those already present in the matrix. Indistinct boundaries and vague outlines make some rock fragments nearly indistinguishable from matrix.

As sandstones underwent deep burial, the compaction caused mica flakes to bend and deform as they were squeezed between more equi-dimensional grains. Bent mica flakes and calcite cement often occur together in the same sample suggesting that the micas may have been deformed before the sediment was rigidly held together by cement.

Many of the sandstones have a yellowish brown weathered rind invading a half inch or more. The color is caused by oxidation of iron minerals, such as pyrite and siderite, to limonite and hematite. In addition lithic grains tend to alter to clay in the present weathering environment.

Summary

The Hudspeth Formation accumulated in a strongly subsiding sedimentary basin which lay somewhat south of an actively rising source area. Deposition took place in quiet water in neritic or upper bathyal depths, interspersed with rare periods of shallow neritic or littoral deposition. The formation interfingers with fluvial-deltaic deposits of the Gable Creek Formation which were deposited simultaneously with the Hudspeth Formation.

A variety of supracrustal rocks were exposed in the source area. Sandstones contain numerous lithic fragments derived from volcanic, metamorphic, and sedimentary strata. Weathering of these rocks also provided abundant clay material for accumulation of mudstones and matrix in the sandstones.

Clays derived from weathering of the source rocks include beidellite, vermiculite, kaolinite, and most of the illite and chlorite. These allogenic clays did not undergo much diagenetic change in the depositional environment, however mixed-layer beidellite-illite and illite formed at the expense of beidellite during deep burial. The slight increase in beidellite upward in the formation, with proportional decrease in most of the other clays, is probably caused partly by the effect of burial and partly by a change in source rock availability. Montmorillonite and non-detrital chlorite are later additions. Chlorite content increases in mudstones adjacent to Tertiary intrusions, while montmorillonite is confined to mudstones which have been recently weathered.

Mineralogical changes in the diagenetic environment include formation of pyrite and silica in mudstones, calcite in concretions, and ankerite-siderite and calcite cement in sandstones. Pyrite, silica, and ankerite-siderite formed first in an environment with low to intermediate oxidation-reduction potential and intermediate acidity-alkalinity. The calcite formed somewhat later in a more alkaline diagenetic environment.

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APPENDICES

APPENDIX A

Summary of Field Data for Selected Samples
Part I

Sample Number	Color[1]	Sorting[2]	Lamination[3]	Chip[4] Size	Chip[5] Shape	Bedding Characteristics	Miscellaneous
M-15	5 Y 4/1	P	Grain size	M	Irreg.	Homogeneous	--
M-80	5 Y 4/2	P	--	L	Equi-D	Local sandy lenses to 6" thick	--
M-160	5 Y 4/1	F	--	S	Flat	Local sandy lenses to 1" thick	Slickensides
M-480	5 Y 4/1	F	--	S	Flat	Homogeneous	Slickensides
M-560	5 Y 4/2	F	--	S	Flat	"	Slickensides
M-640	5 Y 4/2	F	Clay	M	Flat	"	--
M-720	5 Y 4/2	F	Clay	M	Flat	"	--
M-790	5 Y 4/2	P	Clay	L	Flat	"	--
M-870	5 Y 5/2	F	Clay	M	Equi-D	"	--
M-950	5 Y 5/2	P	--	L	Equi-D	"	--
M-1030	5 Y 5/2	F	Clay	M	Irreg.	"	--
M-1110	5 Y 4/1	F	Clay	S	Flat	"	Efflorescent[6]
M-1190	5 Y 4/1	P	--	S	Flat	"	Slickensides, Efflorescent
M-1270	5 Y 4/1	F	Clay	S	Flat	"	--
M-1650	5 Y 4/2	P	Clay	M	Irreg.	"	--
M-1730	5 Y 4/2	F	Clay	M	Equi-D	"	--
M-1810	5 Y 4/2	P	Clay	S	Flat	"	Slickensides
M-1890	5 Y 5/2	P	--	L	Equi-D	"	--
M-1970	5 Y 5/2	P	--	L	Equi-D	"	--
M-2050	5 Y 5/2	P	--	L	Equi-D	"	--
M-2130	5 Y 5/2	P	--	L	Equi-D	"	--
M-2290	5 Y 5/2	P	--	M	Irreg.	Local sandy lenses to 4" thick	--
M-2360	5 Y 4/1	F	--	L	Flat	Homogeneous	Slickensides, Efflorescent
M-2410	5 Y 4/1	P	--	M	Flat	"	Slickensides, Efflorescent

Appendix A1. Continued.

Sample Number	Color[1]	Sorting[2]	Lamination[3]	Chip Size[4]	Chip Shape[5]	Bedding Characteristics	Miscellaneous
M-2440	5 Y 4/1	P	Clay	M	Equi-D	Alternate sand- and mudstone, average 2" thick	Efflorescent
M-2480	N4	P	Grain size	M	Equi-D	Alternate sand- and mudstone, average 4" thick	--
M-2520	5 Y 4/1	P	--	M	Equi-D	Subordinate sandy lenses to 4" thick	--
M-2600	5 Y 4/2	P	Clay	L	Equi-D	Homogeneous	--
M-2680	5 Y 4/1	F	--	M	Irreg.	"	Efflorescent
M-2760	5 Y 4/1	F	Grain size	M	Equi-D	"	--
M-2840	5 Y 5/2	F	Grain size	S	Irreg.	Subordinate sandy lenses to 6" thick	--
M-2920	5 Y 5/2	F	Grain size	S	Flat	Homogeneous	--
T-240	5 Y 4/2	P	--	M	Equi-D	"	--
T-280	5 Y 4/1	P	--	M	Irreg.	"	--
T-320	5 Y 4/1	F	--	S	Irreg.	"	--
T-360	5 Y 5/2	P	--	L	Equi-D	"	--
T-480	5 Y 5/2	F	--	M	Equi-D	Alternate sand- and mudstone, to 1' thick	--
T-520	5 Y 6/4	P	--	M	Flat	Alternate sand- and mudstone, to 2' thick	--
T-1080	5 Y 5/2	F	Clay	S	Irreg.	Homogeneous	--
T-1120	5 Y 5/2	F	Clay	L	Irreg.	"	--
T-1160	5 Y 4/1	F	--	M	Flat	"	--
T-1200	5 Y 4/1	F	Grain size	S	Irreg.	"	--
T-1240	5 Y 4/2	F	Grain size	S	Flat	"	--
T-1280	5 Y 5/1	F	Grain size	M	Flat	Local sandy layers to 6" thick	--
T-1400	5 Y 5/1	P	Grain size	M	Flat	Numerous sandy layers to 6" thick	--
T-1440	5 Y 5/2	P	Grain size	L	Equi-D	Numerous sandy lenses to 6" thick	--

Appendix A1. Continued.

Sample Number	Color[1]	Sorting[2]	Lamination[3]	Chip Size[4]	Chip Shape[5]	Bedding Characteristics	Miscellaneous
T-1480	5 Y 5/2	P	Clay	L	Equi-D	Numerous sandy lenses to 4" thick	--
T-1520	5 Y 4/2	P	Grain size	L	Flat	Few sandy lenses to 1" thick	--
T-1640	5 Y 4/2	F	Clay, Grain size	M	Flat	Homogeneous	--
T-1680	5 Y 5/2	F	Clay, Grain size	M	Irreg.	Local sandy lenses to 2" thick	Slickensides
T-1720	5 Y 5/2	F	--	M	Flat	Subordinate sandy lenses to 2" thick	--
T-1760	5 Y 4/2	P	Clay	M	Irreg.	Numerous sandy lenses to 6" thick	--
T-1800	5 Y 4/1	P	--	S	Irreg.	Numerous sandy lenses to 1" thick	--
H-4	5 Y 4/1	P	Clay, Grain size	L	Flat	Homogeneous	--
H-5	5 Y 5/2	F	Grain size	M	Flat	Subordinate sandy lenses to 2" thick	--
H-6	5 Y 4/2	F	Clay	M	Flat	Subordinate sandy lenses to 1' thick	--
H-7	5 Y 4/2	F	Clay	M	Flat	Homogeneous	--
H-8	5 Y 4/2	F	--	M	Irreg.	"	--
H-9	5 Y 4/1	P	Clay	M	Irreg.	Local sandy lenses to 3" thick	--
H-10	5 Y 4/1	F	Clay	M	Flat	Intercalated sandstone to 1" thick	--
H-11	5 Y 4/1	P	Clay, Grain size	M	Irreg.	Intercalated sandstones to 6" thick	--
Y-1	5 Y 5/1	P	Clay	L	Flat	--	--
Y-2	5 Y 4/1	F	--	M	Flat	--	--
Y-3	5 Y 4/2	P	--	M	Flat	--	--
Y-4	5 Y 5/2	P	--	M	Irreg.	--	--
Y-5	N4	F	Clay	L	Irreg.	--	Efflorescent
Y-6	5 Y 5/2	P	--	M	Irreg.	--	--
Y-7	10 Y 5/2	F	Clay	L	Flat	--	--

Appendix A1. Continued.

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[1] 5 Y 4/1 = olive gray; 5 Y 5/2 = light olive gray; 5 Y 4/2 = intermediate between 5 Y 4/1 and 5 Y 5/2.

[2] P = poor sorting; F = fair sorting.

[3] Clay = faint lamination due to parallel orientation of clay minerals.
Grain size = lamination due to concentration of silt or sand in thin beds or lenses.

[4] S = small, average maximum size < 1".
M = medium, average maximum size = 1" to 2".
L = large, average maximum size > 2".

[5] Flat - average sphericity < 6.
Irregular - average sphericity = 6.
Equi-dimensional - average sphericity > 6, by Zingg's classification (Krumbein and Sloss, 1956).

[6] Surface coated with powdery calcium carbonate

Identification of Megafossils from the Hudspeth Formation (Identification by Jones and Packard, 1971)

Part II

Location and sample number	Identification and age
SE1/4NE1/4SW 1/4 sec. 13, T. 11 S., R. 21 E. (Mb-54)	Aucellina sp. (Lower Albian)
SW1/4SE1/4SW1/4 sec. 13, T. 11 S., R. 21 E. (M-25)	Leconteites lecontei (Anderson) (Lower Albian)
SW1/4SE1/4SW1/4 sec. 13, T. 11 S., R. 21 E. (M-55)	Leconteites lecontei (Lower Albian)
NW1/4NW1/4NE1/4 sec. 24, T. 11 S., R. 21 E. (M-1010)	Cleoniceras (?) frag. (Middle Albian ?)
SW1/4SW1/4NW1/4 sec. 19, T. 11 S., R. 22 E. (M-1970)	Desmoceras (Pseudouhligella) sp. (Upper Albian)
SW1/4SE1/4NW1/4 sec. 19, T. 11 S., R. 22 E. (M-2125)	Desmoceras (Pseudouhligella) sp. (Upper Albian)
SW1/4SE1/4NW1/4 sec. 19, T. 11 S., R. 22 E. (M-2145)	Desmoceras (Pseudouhligella) sp. (Upper Albian)
SW1/4SE1/4NW1/4 sec. 19, T. 11 S., R. 22 E. (M-2182)	Desmoceras sp. (Upper Albian)
NW1/4SW1/4NW1/4 sec. 2, T. 11 S., R. 22 E. (T-375)	Leconteites lecontei (Lower Albian)
SW1/4SW1/4SE1/4 sec. 26, T. 11 S., R. 21 E.	Desmoceras (Pseudouhligella) sp. (Upper Albian)
SW1/4NE1/4 sec. 3, T. 11 S., R. 22 E.	Leconteites lecontei (Anderson) (Lower Albian)
"	Douvilleiceras sp. of D. mammillatum (Lower Albian)
"	Phylloceras sp.
"	Pholadomya sp.
"	Nanonavis sp.
(?)	Oxytropidoceras sp. (Middle Albian)

Microfossil Localities

Appendix AII. Continued.

Sample Number	Location
M-510	SE1/4SE1/4SW1/4 sec. 13, T. 11 S., R. 21 E.
M-1680	SE1/4NE1/4NE1/4 sec. 24, T. 11 S., R. 21 E.
M-2360	NW1/4NE1/4SW1/4 sec. 19, T. 11 S., R. 22 E.
M-2680	SW1/4NE1/4SW1/4 sec. 19, T. 11 S., R. 22 E.
M-2760	SW1/4NE1/4SW1/4 sec. 19, T. 11 S., R. 22 E.
T-280	NW1/4SW1/4NW1/4 sec. 2, T. 11 S., R. 22 E.
T-480	SW1/4SW1/4NW1/4 sec. 2, T. 11 S., R. 22 E.
T-1120	SW1/4NE1/4SW1/4 sec. 2, T. 11 S., R. 22 E.
T-1240	NE1/4SE1/4SW1/4 sec. 2, T. 11 S., R. 22 E.
T-1520	CNW1/4 sec. 11, T. 11 S., R. 22 E.
T-1640	NW1/4SE1/4NW1/4 sec. 11, T. 11 S., R. 22 E.

APPENDIX B

Summary of Data Obtained from Thin-Section Studies of Mudstones

Part I. Grain size and texture

Sample Number	Classification	Clay Minerals: Abundance (%)	Clay Minerals: Orientation[2]	Non-clay Minerals[1]: Maximum size (μ)	Non-clay Minerals[1]: Occurrence[3]	Organic Matter: Abundance[4]	Organic Matter: Maximum size (μ)	Texture[5]
M-15	Silty claystone	56	pr	240	D	C	150	P
M-80	Clayey mudstone	40	r	200	D	C	125	P
M-560	Claystone	80	P	65	D, L	T	60	B
M-640	Claystone	77	P	85	D, L	C	60	P, S
M-720	Claystone	86	P	60	D	C	30	P
M-790	Silty claystone	71	pr	130	D	C	100	P
M-870	Claystone	75	pr	175	D, L	T	125	P, S
M-950	Sandy claystone	57	pr	200	D, L	C	150	B
M-1030	Claystone	76	pr	125	D	T	80	P
M-1110	Claystone	77	p, r	60	D, L	C	50	P, S
M-1190	Silty claystone	65	r	100	D, L	T	100	B, S
M-1270	Claystone	83	P	110	D	C	60	P
M-1650	Silty claystone	71	P	115	D	C	40	P
M-1730	Silty claystone	67	P	90	D	C	60	P
M-1810	Claystone	80	pr	125	D	T	100	P
M-1890	Clayey mudstone	44	r	250	D	-	-	P
M-1970	Clayey mudstone	48	pr	270	D	C	150	P

Appendix BI. Continued.

Sample Number	Classification	Clay Minerals		Non-clay Minerals[1]		Organic Matter		
		Abundance (%)	Orientation[2]	Maximum size (μ)	Occurrence[3]	Abundance[4]	Maximum size (μ)	Texture[5]
M-2050	Clayey mudstone	41	r	160	D	C	150	P
M-2130	Clayey mudstone	42	r	200	D	C	250	P
M-2290	Silty claystone	66	pr	135	D	A	100	P
M-2360	Claystone	80	pr	125	D	T	50	P
M-2440	Silty claystone	52	pr	185	D	C	150	P
M-2520	Silty claystone	72	P	300	D, L	T	250	P, S
M-2600	Silty claystone	66	r, pr	300	D, L	C	80	B, P, S
M-2680	Claystone	79	P	40	D	C	50	P
M-2760	Claystone	84	P	80	D	A	20	P
M-2840	Claystone	81	P	40	D	T	50	P
M-2920	Claystone	77	pr	165	D, L	T	60	P, S
T-240	Clayey mudstone	49	r	115	D	C	250	P
T-280	Silty claystone	69	pr	120	D, L	T	80	S, O
T-320	Claystone	76	r	165	D, L	T	100	B, P
T-360	Clayey sandstone	31	r	250	D	-	-	P
T-480	Claystone	80	r	125	D	T	80	P
T-520	Clayey mudstone	47	r	185	D	C	200	P
T-1080	Claystone	78	P	110	D, L	C	60	S
T-1120	Claystone	83	P	80	D, L	C	30	S
T-1160	Claystone	89	P	60	D, L	C	40	S

Appendix BI. Continued.

Sample Number	Classification	Clay Minerals		Non-clay Minerals[1]		Organic Matter		
		Abundance (%)	Orientation[2]	Maximum size (μ)	Occurrence[3]	Abundance[4]	Maximum size (μ)	Texture[5]
T-1200	Claystone	84	P	40	D	T	40	P
T-1240	Claystone	84	P	60	D	C	30	P
T-1280	Claystone	75	P	85	D	C	60	P
T-1400	Silty claystone	74	r	80	D, L	T	80	B, P, S
T-1440	Clayey sandstone	24	r	200	D, L	-	-	B, S
T-1480	Sandy claystone	55	r	150	D, L	-	-	B, P, S
T-1520	Silty claystone	72	P	65	D, L	C	60	P, S
T-1640	Claystone	82	P	65	D.	C	40	P
T-1680	Claystone	77	P	80	D, L	C	30	P, S
T-1720	Claystone	77	P	80	D, L	C	40	B
T-1760	Clayey sandstone	23	r	170	D, L	-	-	S
T-1800	Sandy claystone	51	r	180	D	-	-	P
H-4	Silty claystone	71	pr	90	D, L	T	80	P, S
H-5	Claystone	76	P	140	D, L	A	60	B
H-6	Claystone	75	P	40	D	C	40	P
H-7	Claystone	85	P	65	D, L	C	30	S
H-8	Claystone	79	pr	90	D, L	C	80	B
H-9	Silty claystone	67	pr	160	D, L	C	80	P, S
H-11	Clayey mudstone	44	r	250	D, L	-	-	B
Y-1	Silty claystone	62	P	65	D	C	100	B

Appendix BI. Continued.

Sample Number	Classification	Clay Minerals		Non-clay Minerals[1]		Organic Matter		Texture[5]
		Abundance (%)	Orientation[2]	Maximum size (μ)	Occurrence[3]	Abundance[4]	Maximum size (μ)	
Y-2	Claystone	90	P	65	D	C	30	P
Y-3	Sandy claystone	54	r	500	D, L	T	180	B
Y-4	Clayey mudstone	49	r	170	D	C	60	P
Y-6	Sandy claystone	55	r	115	D	C	200	P

[1] Minerals present in very small amounts are not considered.

[2] p indicates parallel orientation; r random orientation; pr partial parallel orientation.

[3] D = disseminated; L = concentrated in streaks or lenses.

[4] A = abundant; C = common; T = trace.

[5] P = irregular patches of finer material.
S = lenses of sand or silt.
B = alternate bands or streaks of coarse and fine.
O = lenses of organic matter.

APPENDIX B

Part II. Composition of non-clay minerals

	Quartz	Polyquartz[7]	Feldspar	Lithic	Mica	Opaque	Chert[7]	Carbonate
M-15	17	4	2	7	4	-	-	-
M-80	17	7	6	11	3	-	-	16
M-560	8	-	-	-	9	-	T	-
M-640	6	-	2	-	8	2	-	-
M-720	4	-	-	-	2	1	-	-
M-790	15	-	-	-	9	1	-	-
M-870	10	-	-	3	7	1	-	-
M-950	20	4	4	3	7	-	-	-
M-1030	14	-	-	-	6	-	-	-
M-1110	11	-	-	-	6	1	T	-
M-1190	14	-	1	4	10	2	-	-
M-1270	6	-	-	-	4	2	-	3
M-1650	18	-	-	-	1	-	T	-
M-1730	8	-	1	1	9	2	-	-
M-1810	10	-	1	-	7	1	-	-
M-1890	31	8	6	7	4	1	-	-
M-1970	21	3	3	7	8	-	-	-
M-2050	26	3	4	9	5	-	-	-
M-2130	23	9	4	9	7	1	-	-
M-2290	14	1	1	1	9	-	-	-
M-2360	9	-	-	-	6	2	-	-
M-2440	19	2	4	8	10	-	-	1
M-2520	10	-	1	1	5	-	-	-
M-2600	11	1	1	3	3	2	-	-
M-2680	7	-	1	-	11	-	-	-
M-2760	2	-	-	-	6	-	-	-
M-2840	6	-	-	-	9	-	T	-
M-2920	12	-	-	-	4	-	-	-

Appendix BII. Continued.

	Quartz	Polyquartz[7]	Feldspar	Lithic	Mica	Opaque	Chert[7]	Carbonate
T-240	17	6	2	7	5	-	-	-
T-280	13	3	3	1	8	-	-	-
T-320	10	1	-	3	5	1	-	-
T-360	19	13	9	19	4	1	-	-
T-480	10	-	-	-	6	-	-	-
T-520	25	1	4	8	9	-	-	-
T-1080	6	-	4	-	8	1	-	-
T-1120	4	-	-	-	7	-	-	-
T-1160	5	-	-	-	4	-	T	-
T-1200	8	-	-	-	4	2	-	-
T-1240	8	-	-	-	6	-	T	-
T-1280	6	-	2	-	10	2	-	-
T-1400	12	1	-	1	4	-	-	-
T-1440	23	3	7	38	1	1	-	-
T-1480	20	3	3	10	4	-	-	-
T-1520	7	-	3	-	12	1	-	-
T-1640	5	-	-	-	7	-	T	-
T-1680	7	-	1	-	6	-	-	-
T-1720	8	-	2	-	9	2	-	-
T-1760	23	5	13	24	6	2	-	-
T-1800	15	5	3	4	7	-	-	12
H-4	7	-	-	-	8	1	-	10
H-5	7	-	-	-	5	-	-	-
H-6	10	-	1	-	8	1	-	-
H-7	4	-	1	-	4	1	-	-
H-8	11	-	-	-	8	-	-	-
H-9	14	-	1	1	8	2	-	5
H-11	29	2	2	8	7	-	-	-
Y-1	11	1	1	1	12	3	-	1
Y-2	1	-	2	-	2	-	-	-

Appendix BII. Continued.

	Quartz	Polyquartz[7]	Feldspar	Lithic	Mica	Opaque	Chert[7]	Carbonate
Y-3	14	1	3	8	3	-	-	2
Y-4	25	3	2	3	10	-	-	-
Y-6	15	1	2	2	5	-	-	-

[7] "Polyquartz" includes detrital chert and quartzite fragments. "Chert" indicates authigenic silica.

APPENDIX C

Results of X-ray diffraction analyses. Semi-quantitative estimates of clay percentages are calculated using the procedure of Schultz (1964)

Sample Number	Smectite and Vermiculite[1]	Illite	Kaolinite	Chlorite
M-15	21	49	22	8
M-80	12	53	25	10
M-160	29	41	22	8
M-480	42	36	16	6
M-560	41	35	19	5
M-640	38	40	19	3
M-720	41	40	16	3
M-790	45	28	23	4
M-870	45	33	17	5
M-950	42	35	19	4
M-1030	47	29	19	5
M-1110	31	34	28	7
M-1190	41	28	23	8
M-1270	36	36	21	7
M-1650	38	32	24	6
M-1730	36	39	20	5
M-1810	35	39	21	5
M-1890	52	23	19	6
M-1970	54	19	23	4
M-2050	42	24	27	7
M-2130	31	39	25	5
M-2290	41	31	22	6
M-2360	51	23	21	5
M-2410	47	29	18	6
M-2440	51	22	18	9
M-2480	56	20	16	8
M-2520	50	30	15	5
M-2600	62	18	16	4
M-2680	47	24	19	10
M-2760	56	22	16	6
M-2840	57	23	15	5
M-2920	51	25	18	6

Appendix C. Continued.

Sample Number	Smectite and Vermiculite[1]	Illite	Kaolinite	Chlorite
T-240	51	25	20	4
T-280	55	20	20	5
T-320	57	19	21	3
T-360	53	16	26	5
T-480	49	19	27	5
T-520	58	15	25	2
T-1080	64	19	14	3
T-1120	52	25	15	8
T-1160	57	20	16	7
T-1200	45	24	20	11
T-1240	51	22	21	6
T-1280	54	23	17	6
T-1400	54	18	21	7
T-1440	65	17	14	4
T-1480	69	16	12	3
T-1520	55	20	18	7
T-1640	57	22	16	5
T-1680	51	25	19	5
T-1720	48	23	21	8
T-1760	50	23	20	7
T-1800	54	19	18	9
H-4	41	26	28	5
H-5	65	20	11	4
H-6	48	24	22	6
H-7	66	18	10	6
H-8	55	18	23	4
H-9	55	16	22	7
H-10	52	18	23	7
H-11	67	18	7	8
Y-1	67	7	22	4
Y-2	69	15	12	4
Y-3	68	16	11	5
Y-4	52	9	36	3
Y-5	61	18	20	1
Y-6	82	9	8	11
Y-7	67	24	7	4

[1] Includes vermiculite, beidellite, montmorillonite, and mixed layer clays.

APPENDIX D

Modal analyses of sandstone samples

Sample[1]	Mb-4	Mb-16	Mb-21	Mb-25	Mb-34	Mb-38	Mb-50	Mb-75	M-14	M-41	M-87	M-1070	M-1935	M-2162	M-2300	M-2415	M-2469	M-2474	M-2930
Cement	10	-	1	12	42	5	14	11	38	42	6	4	3	19	11	12	18	12	15
Matrix	8	21	17	7	15	13	15	18	30	9	36	9	7	10	8	10	6	11	3
Grains	82	78	82	80	43	83	71	71	32	49	58	86	90	71	81	76	76	76	82
Quartz	-	7	6	-	26	1	16	23	1	10	25	16	30	27	24	12	16	17	27
Quartzite	29	12	18	42	4	55	19	15	3	9	6	9	7	3	5	8	2	4	6
Chert	21	4	1	7	1	9	4	5	1	-	1	3	2	-	-	1	1	-	1
Feldspar	3	18	17	1	7	-	11	11	-	5	2	21	14	11	15	10	17	12	15
Granitic Rx.	3	1	-	-	-	3	-	-	-	-	-	1	-	-	-	2	-	1	-
Fine-grained Rx.	25	37	40	27	5	15	21	15	27	24	20	35	35	28	32	43	34	39	31
Volcanic[2]	2	23	26	4	5	3	9	2	4	7	7	23	21	20	19	23	22	32	24
Metamorphic	23	7	9	23	-	12	12	4	23	7	5	8	11	6	11	10	5	5	5
Sedimentary	-	6	5	-	-	-	-	9	-	10	8	4	3	2	2	10	7	2	2
Mica	-	-	-	-	-	-	-	1	-	1	4	2	2	2	5	2	3	3	2
Opaque	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2	1	-
Others	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-

Appendix D. Continued.

Sample[1]	Tb-1	T-420	T-490	T-500	T-520	T-1104	T-1110	T-1163	T-1460	T-1471	T-1490	T-1500	T-1505	T-1534	T-1540	T-1546	T-1550	T-1639	T-1759
Cement	32	-	-	26	11	-	-	17	3	-	-	1	12	2	5	3	2	14	17
Matrix	-	15	20	3	8	14	18	1	12	16	12	18	9	15	8	9	18	8	-
Grains	69	82	79	68	76	86	82	81	85	83	88	81	79	83	84	88	80	78	83
Quartz	4	28	19	15	14	27	23	31	14	20	25	19	20	12	23	12	20	12	24
Quartzite	10	13	16	3	10	14	3	12	3	3	7	5	1	2	11	6	4	7	5
Chert	3	4	5	3	-	2	-	-	-	1	4	3	-	2	2	4	3	-	6
Feldspar	1	16	18	15	19	4	15	8	16	9	10	10	15	12	23	19	14	10	12
Granitic Rx.	1	3	1	3	5	-	-	-	1	1	-	-	-	-	3	1	-	-	1
Fine-grained Rx.	49	21	19	29	32	32	31	29	47	46	34	40	39	49	23	45	38	47	33
Volcanic[2]	21	15	7	22	27	14	14	18	22	28	10	30	22	20	10	19	18	16	29
Metamorphic	18	4	8	6	5	9	8	9	7	5	15	7	6	18	10	12	13	15	3
Sedimentary	10	2	4	1	-	9	9	2	18	13	9	3	11	11	3	14	7	16	1
Mica	-	-	2	3	1	5	9	1	3	1	8	4	2	5	2	2	-	2	1
Opaque	-	-	-	-	-	2	1	-	-	1	-	-	2	1	-	-	1	-	-
Others	1	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	1

[1] Samples labeled Mb or Tb are from the Basal Hudspeth.

[2] "Volcanic" rock fragments include volcanic and meta-volcanic fragments.

APPENDIX E

Statistical Analyses

Table 1. Average clay content in the Meyers Canyon Stratigraphic Section, Main Member, Hudspeth Formation.

Depth (ft. above base)	Clay Type			
	Smectite and Vermiculite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)
2720	54	24	16	6
2460	54	21	17	8
2360	46	28	20	6
2010	45	26	24	6
1420	38	34	22	6
870	44	32	20	4
600	40	38	18	4
80	21	48	23	9

Chi-square = 41. 15 NDF = 21

Since $\chi^2_{21;90} = 29.62$, $\chi^2_{21;95} = 32.67$, reject the hypothesis of homogeneity.

Table 2. Relationship between depth and percent of each clay type in the Meyers Canyon Section.

X	Y	Linear Regression Line $Y = A + BX$ A	B	Correlation Coefficient	t-distribution
Depth (ft. above base)	% Smectite and Vermiculite	28.20	0.009	0.86	4.11 *
Depth	% Illite	44.35	-0.008	-0.93	-6.01 *
Depth	% Kaolinite	21.98	-0.001	-0.43	-1.15
Depth	% Chlorite	5.97	0.0001	0.06	0.14

* Statistically significant at a level smaller than .10 (10% level of significance).

Percentage points of the t-distribution (Li, 1957; Guenther, 1965).

Degrees of Freedom	20%	10%	5%	1%	.5%
6	0.906	1.440	1.943	3.143	3.707

Table 3. Average clay content in the Tony Butte Stratigraphic Section, Main Member, Hudspeth Formation.

Depth (ft. above base)	Clay Type			
	Smectite and Vermiculite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)
1720	52	23	19	7
1460	61	18	16	5
1180	54	22	17	7
500	53	17	26	3
300	54	20	22	4

Chi-square = 9.03 NDF = 12

Since $\chi^2_{12;90} = 18.55$, accept the hypothesis of homogeneity.

Table 4. Relationship between depth and percent of each clay type in the Tony Butte Section.

X	Y	Linear Regression Line Y = A + B X		Correlation Coefficient	t-distribution
		A	B		
Depth (ft. above base)	% Smectite and Vermiculite	53.32	0.001	0.25	0.44
Depth	% Illite	17.86	0.002	0.50	0.99
Depth	% Kaolinite	25.17	-0.005	-0.75	-1.99 *
Depth	% Chlorite	2.81	0.002	0.79	2.25 *

* Statistically significant at a level smaller than .10 (10% level of significance).

Percentage points of the t-distribution (Li, 1957; Guenther, 1965).

Degrees of Freedom	20%	10%	5%	1%	.5%
3	0.978	1.638	2.353	4.541	5.841

Table 5. Average clay content in the Hudspeth Interfingering Units, Stratigraphic Section.

Depth (ft. above base)	Clay Type: Smectite and Vermiculite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)
8500	67	18	7	8
8000	52	18	23	7
7000	55	16	22	7
6500	55	18	23	4
6000	66	18	10	6
5500	48	24	22	6
5000	65	20	11	4
4500	41	26	28	5

Chi-square = 40. 38 NDF = 21

Since $\chi^2_{21;90} = 29.62$, $\chi^2_{21;95} = 32.67$, reject the hypothesis of homogeneity.

Table 6. Relationship between depth and percent of each clay type in the Hudspeth Interfingering Units.

X	Y	Linear Regression Line Y = A + B X: A	B	Correlation Coefficient	t-distribution
Depth (ft. above base)	% Smectite and Vermiculite	39.99	0.003	0.38	1.01
Depth	% Illite	30.89	-0.002	-0.71	-2.48 *
Depth	% Kaolinite	28.24	-0.002	-0.29	-0.73
Depth	% Chlorite	0.88	0.001	0.76	2.84 *

* Statistically significant at a level smaller than .10 (10% level of significance).

Percentage points of the t-distribution (Li, 1957; Guenther, 1965).

Degrees of Freedom	20%	10%	5%	1%	.5%
6	0.906	1.440	1.943	3.143	3.707

Table 7. Relationship between total clay content and degree of parallel orientation of clays and micas.

Percent clay	Orientation of clays		
	random	partial parallel	parallel
< 60	15	4	0
60-75	3	6	7
>75	2	5	19

Chi-square = 33.55 NDF = 4
Since $\chi^2_{4;90} = 7.78$, $\chi^2_{4;95} = 9.49$, reject the hypothesis of independence

Table 8. Relationship between total clay content and sphericity of sample chips.

Percent clay	Sphericity of chips		
	Flat	Irregular	Equi-dimensional
< 60	2	6	11
60-75	8	4	4
>75	15	9	2

Chi-square = 16.68 NDF = 4
Since $\chi^2_{4;90} = 7.78$, $\chi^2_{4;95} = 9.49$, reject the hypothesis of independence

Table 9. Relationship between total clay content and average maximum chip size.

Percent clay	Average maximum chip size		
	Small (< 1")	Medium (1"-2")	Large (>2")
< 60	1	9	9
60-75	1	10	5
>75	10	14	2

Chi-square = 15.30 NDF = 4
Since $\chi^2_{4;90} = 7.78$, $\chi^2_{4;95} = 9.49$, reject the hypothesis of independence

Table 10. Relationship between total clay content and maximum grain size.

Percent clay	Maximum grain size			
	< 65μ	70-120μ	125-190μ	>200μ
< 60	0	2	7	10
60-75	3	7	4	2
> 75	11	8	7	0

Chi-square = 28.85 NDF = 6

Since $\chi^2_{6;90} = 10.64$, $\chi^2_{6;95} = 12.59$, reject the hypothesis of independence

Table 11. Relationship between total clay content and percent kaolinite.

Percent clay	Percent kaolinite		
	< 18	18-21	>21
< 60	5	6	8
60-75	4	4	8
>75	10	13	3

Chi-square = 8.47 NDF = 4

Since $\chi^2_{4;90} = 7.78$, reject the hypothesis of independence

Table 12. Relationship between total clay content and color of sample chips.

Percent clay	Color		
	Olive gray	Intermediate	Light olive gray
< 60	4	4	10
60-75	5	9	2
>75	9	8	9

Chi-square = 8.08 NDF = 4

Since $\chi^2_{4;90} = 7.78$, reject the hypothesis of independence

Table 13. Relationship between percent non-clay and percent quartz in silt and sand fraction of coarse-grained mudstones.

Percent non-clay	Percent quartz in framework		
	< 70	70-75	>75
< 40	0	3	4
40-50	3	2	2
>50	6	3	3

Chi-square = 5.27 NDF = 4

Since $\chi^2_{4;90} = 7.78$, accept the hypothesis of independence.

Table 14. Relationship between average maximum chip size and clay type.

Maximum chip size	Percent of each clay type			
	Smectite	Illite	Kaolinite	Chlorite
Small	36	36	22	6
Medium	47	29	19	6
Large	42	32	21	6

Chi-square = 2.60 NDF = 6

Since $\chi^2_{6;90} = 10.64$, accept the hypothesis of homogeneity.

Table 15. Relationship between total clay content and clay type.

Percent clay	Percent of each clay type			
	Smectite	Illite	Kaolinite	Chlorite
< 60	48	26	20	6
60-75	48	26	20	6
>75	50	26	18	6

Chi-square = 0.19 NDF = 6

Since $\chi^2_{6;90} = 10.64$, accept the hypothesis of homogeneity.