MINERALOGY AND GEOCHEMISTRY OF UPPER CRETACEOUS CLAY-BEARING STRATA TORREON WASH/JOHNSON TRADING POST AREAS SOUTHEASTERN SAN JUAN BASIN, NEW MEXICO

by

Stanley T. Krukowski

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Geology

New Mexico Institute of Mining and Technolgy

Socorro, New Mexico

January 1983

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

C	chlorite
Cc	calcite
CHS	Cliff House Sandstone
CMbr	Cleary Member
FF	Fruitland Formation
Gyp	gypsum
I	illite
K	kaolinite
lLS	lower Lewis Shale
LS	Lewis Shale
LVT	La Ventana Tongue
M	microcline (potassic feldspar)
M-cc	mixed calcite
MF	Menefee Formation
MS	Mancos Shale
MT	Mulatto Tongue
MX	interstratified clay
Plag	plagioclase (oligoclase)
Q	quartz
S	smectite
ST	Satan Tongue
T	total
uMF	upper Menefee Formation

PLATES AND FIGURES

TABLES

ACKNOWLEDGMENTS

I wish to thank my committee for their guidance and advice. Dr. Marc Bodine, Jr., my principal advisor, was especially helpful for all his suggestions and financial support (under State Mining and Mineral Resource Institute grant No. G5105777). To Dr. George S. Austin of the New Mexico Bureau of Mines and Mineral Resources and Dr. Clay T. Smith of the Geoscience Department, who critically read this thesis, I also wish to express my thanks.

I would like to express my appreciation to David E. Tabet for conducting a field reconnaissance in April, 1980, and Stephen J. Frost for his valuable assistance with some hard-to-find references. I am grateful to Larry Queen, undergraduate field and laboratory assistant, for his company and innovations. Alan Carmichael, my colleague on the project, was also helpful.

Finally, I am grateful and indebted to my wife, Sherry, for her moral support and for her patience in typing the manuscript in its entirety.

ABSTRACT

The Upper Cretaceous rocks of the Torreon Wash/Johnson Trading Post areas, southeastern San Juan Basin, New Mexico resulted from a series of transgressions and regressions. Seventy eight samples were chosen as representative of the clay-bearing Upper Cretaceous sequence, Mulatto Tongue of the Mancos Shale through the Fruitland Formation, and analyzed for clay mineralogy, whole rock mineralogy, and whole rock geochemistry. Whole rock mineralogy and geochemistry show only slight stratigraphic variations. However, the Fruitland Formation shows a relative decrease in quartz and Al_2O_3, and an increase in sodic plagioclase and Na_2O. The principal clay mineral species is smectite. This may suggest a new sediment source in Fruitland times.

Vertical and lateral variations in clay mineralogy in the other shale units were observed. Kaolinite generally was observed increasing from marine to nonmarine facies (Menefee Formation); and, illite, chlorite, and random interstratified illite-smectite increased towards marine depositional sites (Mancos Shale, La Ventana Tongue, and Lewis Shale). Clay mineral assemblages follow the prescribed pattern set forth in the lateral distributions study by Parham (1966).

Lateral variations in clay mineralogy within stratigraphic units can also be ascribed to particle size sorting, e.g. upper Menefee Formation lithologies. Finer-grained humic shales (distal from channel sands) contain less kaolinite and more platy clay minerals (interstratified illite-smectite) than coarser-grained shales and mudstones (proximal to channel sands). This is a result of particle size sorting in the fluvial-paludal depositional environment. Kaolinite in the upper Menefee shales is probably related to provenance, diagenesis or both.

I INTRODUCTION

This report deals with the major clay-bearing units of the Upper Cretaceous sedimentary rocks of the Torreon Wash/Johnson Trading Post area, San Juan Basin, New Mexico. Representative samples were collected and analyzed from the clay-rich units through the entire stratigraphic interval (Table 1). Clay mineralogy and geochemistry are related to the stratigraphy, lithology, and the depositional environments of these strata. In particular, a study of the small-scale lateral variations in clay mineralogy was investigated for upper Menefee member-La Ventana Tongue-Lewis Shale intertonguing by sampling several exposures at sec. 10 and 15, T. 18 N., R. 4 W..

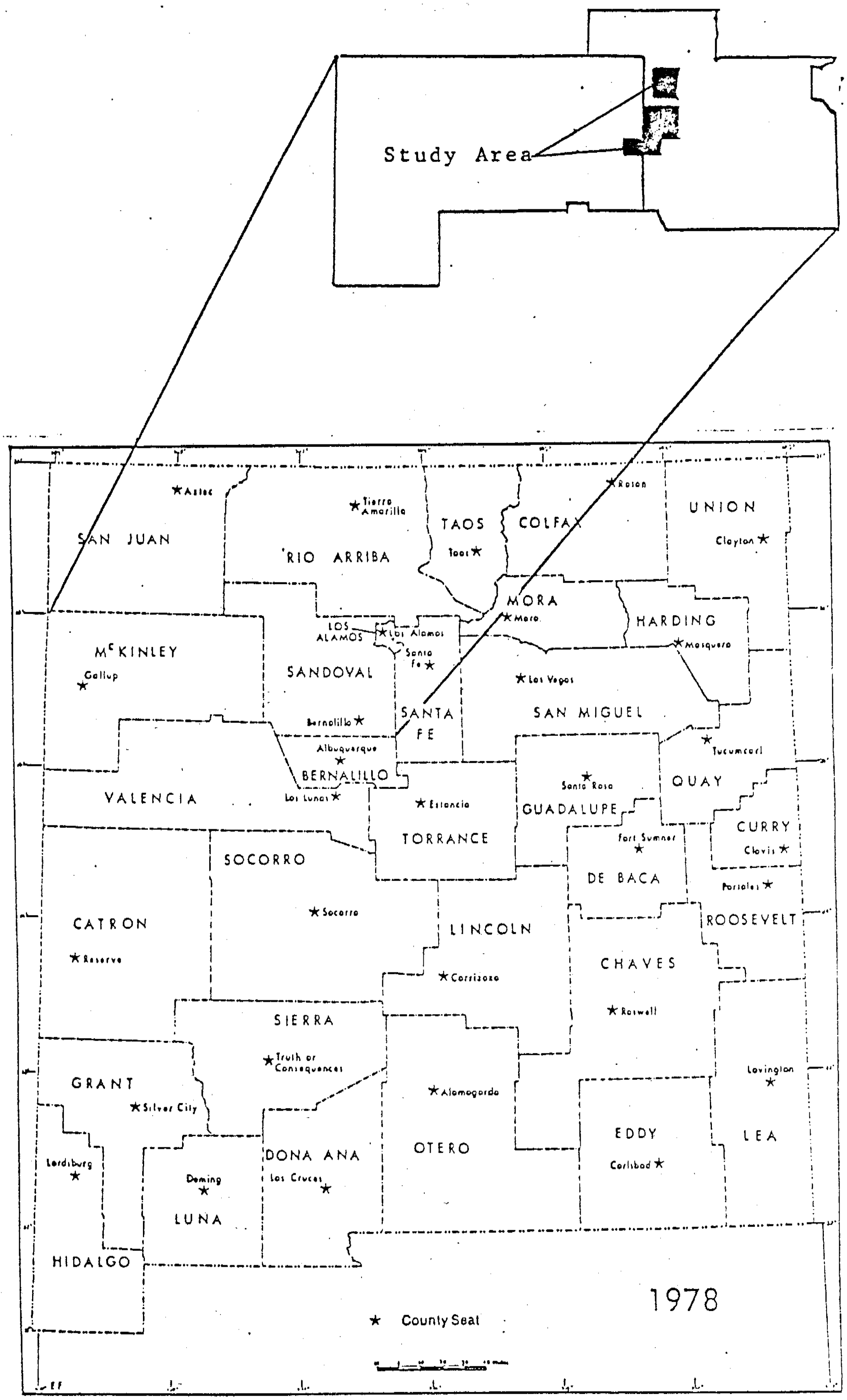
One hundred and seventeen samples were collected from surface outcrops during the field investigations. Seventy eight of these were chosen for study as representative of the stratigraphic interval delineated in Table 1 and for the lateral variations study.

Location and Geography

The study area is located in McKinley County and Sandoval County in northwestern New Mexico (Fig. 1) and covers approximately 200 square miles of the southeast part of the San Juan Basin. All sample localities are situated in sectors mapped previously by Hinds (1966) and Tabet and Frost (1979a).

The topography of the region is expressed as mesas, rolling plains, badlands, and sharp canyons and arroyos. The mesa country is dotted

Figure 1. (Proceeding page). Reference map of study area.


Study Area
SAN JUAN
Aztec
RIO ARRIBA
Tierra Amarilla
TAOS
Taos
COLFAX
Raton
UNION
Clayton
McKINLEY
Gallup
LOS ALAMOS
Los Alamos
SANDOVAL
Bernalillo
Santa Fe
SANTA FE
MORA
Mora
HARDING
Mosquero
SAN MIGUEL
Las Vegas
Tucumcari
QUAY
Albuquerque
BERNALILLO
VALENCIA
Los Lunas
Estancia
TORRANCE
Santa Rosa
GUADALUPE
CURRY
Clovis
Fort Sumner
DE BACA
Portales
ROOSEVELT
SOCORRO
Socorro
CATRON
Reserve
LINCOLN
Carrizozo
CHAVES
Roswell
SIERRA
Truth or Consequences
GRANT
Silver City
Alamogordo
OTERO
Lovington
LEA
EDDY
Carlsbad
Lordsburg
Deming
LUNA
DONA ANA
Las Cruces
HIDALGO
1978
County Seat

with juniper and piñon, and grasslands. The rolling plains are also covered by grasses, but in both cases overgrazing has reduced the vegetation to a very sparse cover. The badlands and arroyos are devoid of vegetation.

Two intermittent tributaries of the Rio Puerco control the drainage in the field area, Torreon Wash flows from north to south and Arroyo Chico drains the area from west to east. The land is semi-arid with 12 to 16 inches of precipitation yearly, mostly as summer thunderstorms. The temperature is controlled by a temperature gradient of 5° F per 1000 ft of elevation; and, the clear skies allow for large temperature differences between day and night.

The land is controlled by the Bureau of Land Management, the Navajo Tribal Council, the U.S. Forest Service, and private citizens. The major occupations of the inhabitants are ranching, farming, and government service, but lumbering, petroleum, coal mining, and tourist industries also employ a substantial number of workers.

The only major town in the vicinity is Cuba with a population of 536 at an elevation of 6910 ft about 15 miles to the northeast. New Mexico Highway 197 and 44 are the major access roads into and through the study area. Other groups also maintain a number of dirt roads and unimproved roads that criss-cross the terrain.

Previous Work

The Mesaverde Formation was first recognized by Holmes in 1877. He divided it into an upper cliff-forming sandstone, a middle coal-bearing shale, and a lower cliff-forming sandstone. Collier (1919) named these units the Cliff House Sandstone, the Menefee Formation, and the Point Lookout Sandstone respectively and also elevated the Mesaverde Formation to group status. Schrader (1906) and Gardner (1909; 1910) traced the Upper Cretaceous coal-bearing rocks of the San Juan Basin and described and classified the coals. These investigations included the Mancos Shale, the Mesaverde Formation, the Lewis Shale, and the Laramie Formation (later renamed the Fruitland Formation in 1916 by Bauer). Sears (1934) named and described the Satan Tongue of the Mancos Shale. Hunt (1936) and Dane (1936) classified coals on public lands in the Mesaverde Group (Gallup Sandstone through the Cliff House Sandstone), Fruitland Formation, and Kirtland Shale, particularly those in the southeastern portion of the San Juan Basin. Subsequent surveys and discussions of the area's coal deposits were done by Shomaker et al. (1971), Fassett and Hinds (1971), Beaumont and Shomaker (1974), and Shomaker and Whyte (1977).

Stratigraphic studies by Sears et al. (1941) and Pike (1947) explain the intertonguing of marine and nonmarine strata, laying the foundation for the concept of transgressions and regressions being caused by the imbalance between sediment influx and the rate of subsidence. Beaumont et al. (1956) revised the nomenclature for the Mesaverde Group in the San Juan Basin, particularly introducing the name Cleary Coal Member for the upper strata of the Gibson Coal Member of the Menefee Formation. Petrography and sedimentology of rocks deposited during the Point Lookout-Menefee-Cliff House regression-transgression cycle were investigated at length by the following: Hollenshead and Pritchard (1961) studied the geometry of Mesaverde sandstones, Sabins (1964) distinguished sandstones of transgressions and regressions, Shomaker et al. (1971), and Fassett and Hinds (1971) recognized the deltaic La Ventana Tongue and associated strata, Shetiwy

(1978) reported paleoenvironments for the Point Lookout Sandstone and associated beds from petrographic and outcrop data, and, Siemers and Wadell (1977), and Siemers (1978) defined and discussed humate deposits in the Menefee Formation in the eastern portion of the basin.

Tabet and Frost (1979a; 1979b) mapped the field study area, and reported on the environmental characteristics of the Menefee Formation coal deposits in the Torreon Wash area for this study. Carmichael (1982) reported on the clay mineralogy of the coal-bearing strata, particularly the upper Mancos Shale, the Menefee Formation (upper coal-bearing member and Cleary Member), and the Fruitland Formation.

Shetiwy (1978) and Mannhard (1976) analyzed mudstones and shales associated with the Point Lookout Sandstone and Cliff House Sandstone respectively. Siemers and Wadell (1977) did some clay analyses of humate-deposit rocks of the Menefee Formation.

Tectonic Framework and Structural Geology

The San Juan Basin, in the southeastern part of the Colorado Plateau physiographic province, is nearly circular, but strongly asymmetrical. The axial trace forms an arc near the northern edge of the basin with a steep northern limb and a gently dipping southern limb (Woodward and Callender, 1977).

The San Juan Basin is bounded on the southeast by the Puerco fault zone, a group of structures of complex origin but partly related to the development of the Rio Grande rift to the east. The basin is bounded on the east by the Nacimiento uplift, a Rocky Mountain-type uplift that is not part of the Colorado Plateau. To the south, west, and north the basin is bounded by uplifts of the Colorado Plateau, specifically, the Zuni uplift, Defiance uplift, and San Juan uplift (Fig. 2).

Structures of the San Juan Basin and adjacent uplifts developed principally during Late Cretaceous and early Tertiary (Laramide) time, whereas epeirogenic uplift of the Colorado Plateau as a whole probably took place later during Tertiary time. Minor doming related to injection of laccoliths and other intrusions occurred after Laramide time and modified some older structures (Woodward and Callender, 1977).

The structure of the Torreon Wash area is a gently northwest-dipping block. The regional strike is northeasterly and dips up to 4-5 degrees to the northwest. A series of northeast-trending normal faults with displacements of only up to a few tens of feet transects the area. The successive step-wise rise of the fault blocks to the east (most prominently displayed in the Point Lookout escarpment) is probably related to the Nacimiento uplift on the San Juan Basin's eastern border (Tabet and Frost, 1979b).

Folding in the area is minor. A small domal structure is located in the southeastern part of T. 18 N., R. 3 W.. Small amounts of folding also occur within 100 ft of some faults as a result of drag along the fault planes (Tabet and Frost, 1979b).

Geologic History/Depositional Setting

During Late Cretaceous time the San Juan Basin was a part of a vast western interior epeirogenic sea (Fig. 3). The San Juan Basin is an Early Tertiary structural basin superposed on the larger Cretaceous depositional basin which allowed the preservation of an almost complete Upper Cretaceous section. It is the site of interplay between the shallow seaway to the northeast and a clastic sediment

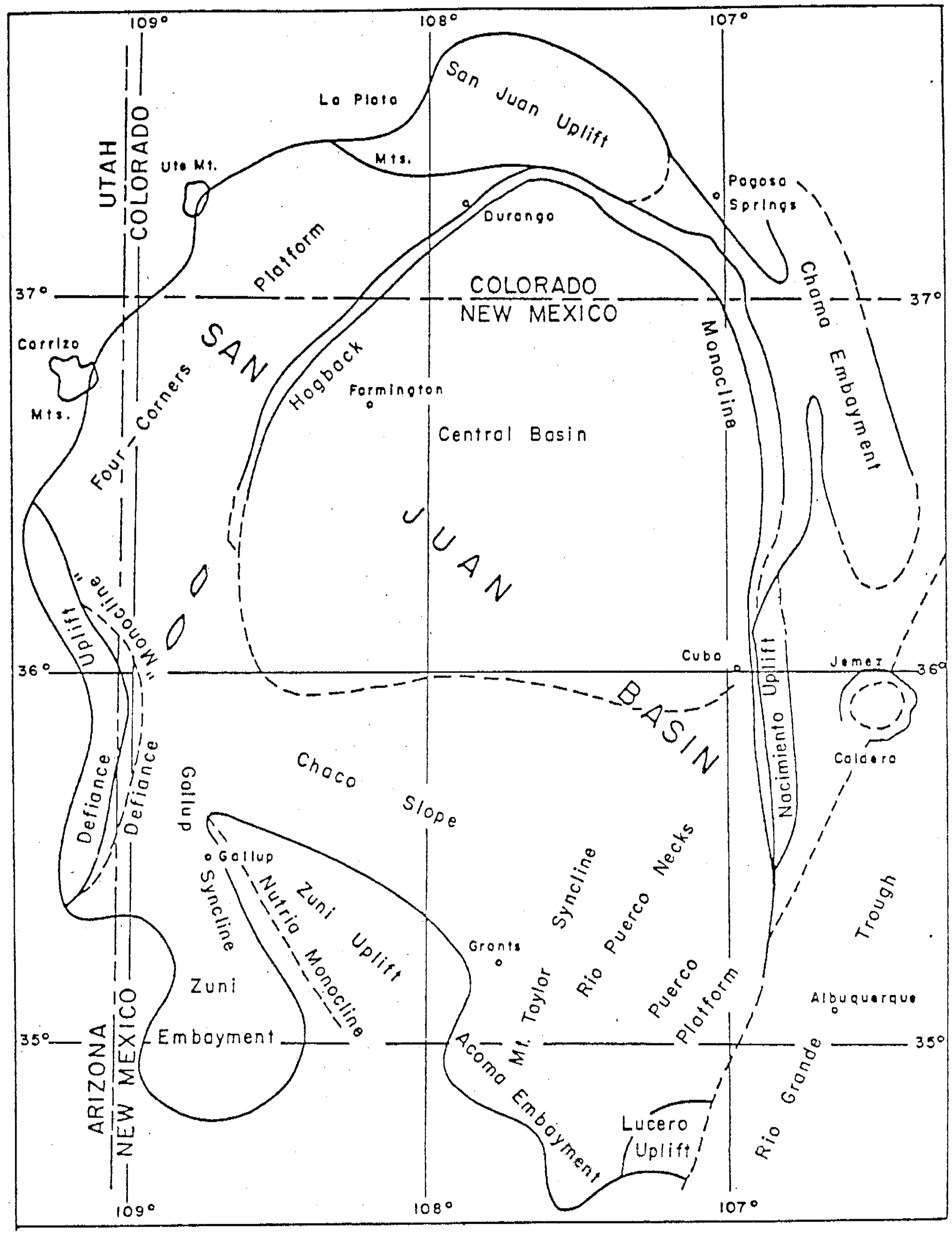


Figure 2 - Structural elements of the San Juan Basin (Shetiwy, 1978).

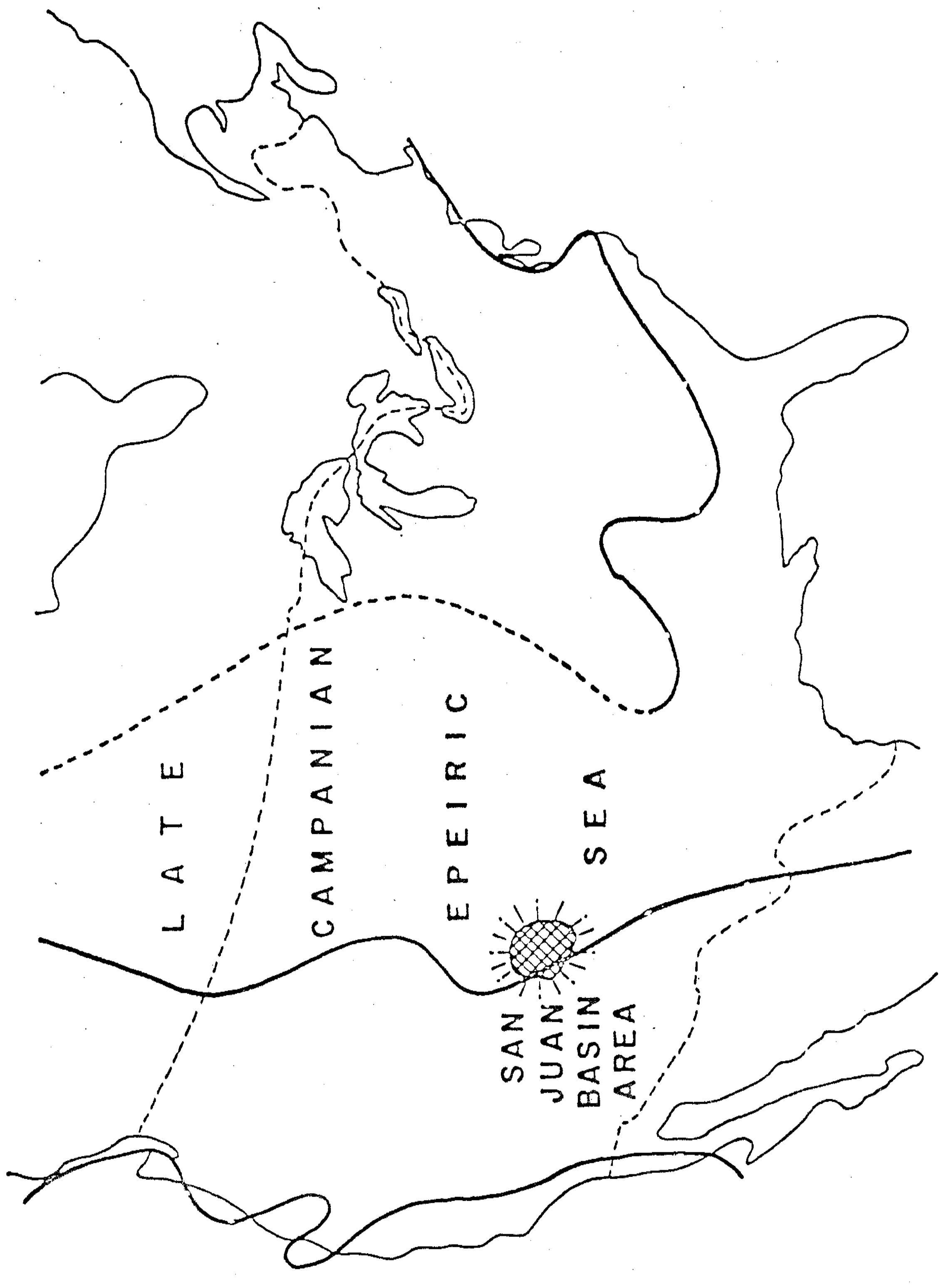


Figure 3 - Configuration of the epicontinental western interior seaway during late Campanian time (Upper Cretaceous) showing the position of the San Juan Basin (Fassett, 1976).

supply from a low-relief area to the southwest.

Four or five major transgressions and regressions with as many minor ones occurred (Molenaar, 1977). Figure 4 is a diagrammatic stratigraphic cross-section of Cretaceous and Tertiary rocks of the San Juan Basin from Fassett (1974). During all this time, relative sea level was rising and/or the area was subsiding permitting some 2000 meters (6500 ft) of sedimentary rocks to be deposited. Most deposition took place during regressions (when the shoreline was migrating seaward) and clastic influx from the southwest was in excess, overcoming the rate of susidence (Molenaar, 1977; Sears _et al._, 1941; Shomaker _et al._, 1971).

The regressive wedges consist of composited deltaic and interdeltaic (straight shorelines and thick shoreface or coastal-barrier sands) deposits. These shoreface sands grade to sandy silts and muds as they move seaward into deeper water where lower energy conditions prevailed.

The nonmarine deposits can be divided into a lower delta or coastal-plain facies and an upper delta-plain or alluvial-plain facies. The lower delta or coastal-plain facies consists of paludal carbonaceous shale, coal, lacustrine sandstones, and fluvial or distributary channel sandstones with associated levee and splay deposits (Molenaar, 1977). Where thick sandstones occur due to a still-stand of the shoreline, and, no interference of channel sands, thick deposits of coal developed landward (Fassett, 1977; Molenaar, 1977). On the upper delta or alluvial plain, carbonaceous shales and coal are less common and flood plain or interchannel shales and fluvial-channel sandstones predominate (Molenaar, 1977).

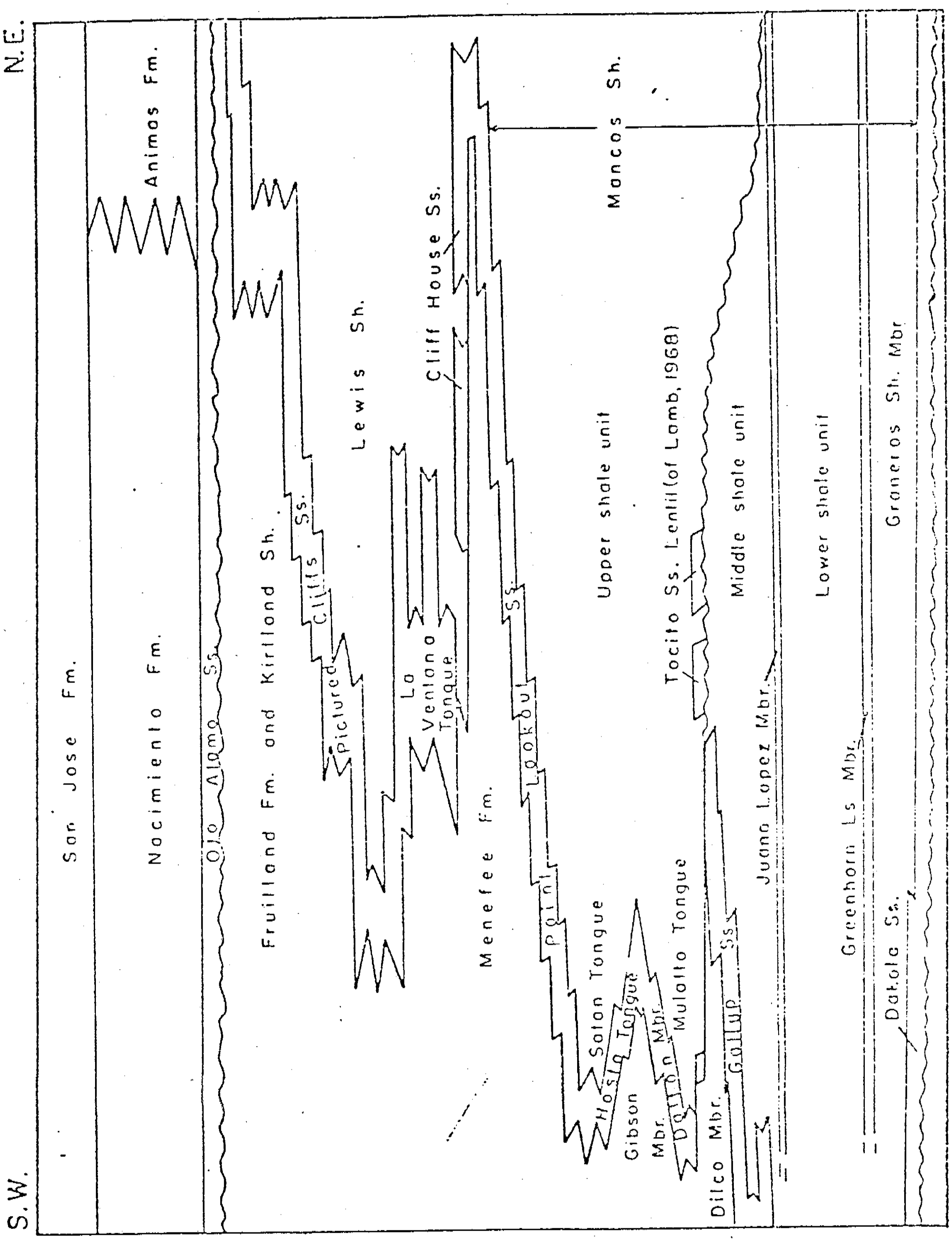


Figure 4 - Diagrammetic stratigraphic cross section of Upper Cretaceous rocks of the San Juan Basin (Fassett, 1974).

The marine deposits represent deposition in offshore quieter waters, to which generally only finer clastics were supplied and could settle out (Shetiwy, 1978).

II CRETACEOUS STRATIGRAPHY

General

Paleocene and Eocene rocks represent the Tertiary sediments of the San Juan Basin. Tertiary rocks were deposited after a hiatus during which time the topmost Cretaceous rocks were upwarped and truncated (Fassett, 1974). Locally the Upper Cretaceous rocks have been intruded and/or overlain by Tertiary volcanics related to the Mount Taylor center to the southwest. (Tabet and Frost, 1979b).

Stratigraphic units of the Upper Cretaceous section contain marine and nonmarine (continental) rocks. Beds are comprised mainly of shales, sandstones, and coals. Lithostratigraphic units include the marine Mancos Shale (Mulatto and Satan Tongues), the Point Lookout Sandstone, the nonmarine Menefee Formation, deltaic and interdeltaic La Ventana Tongue, the transgressive Cliff House Sandstone, the pro-deltaic marine Lewis Shale, the Pictured Cliffs Sandstone, and the Fruitland Formation and Kirtland Shale (Fig. 4). The following discussion is a description of the units that were sampled (Table 1) in ascending order.

Mancos Shale

The Mancos Shale represents the bulk of the marine deposits in the San Juan Basin (Molenaar, 1977). In the Torreon Wash area the Mancos Shale consists of two marine transgressive units, the Mulatto Tongue and the Satan Tongue, separated by the sands of the Hosta Tongue of the Point Lookout Sandstone.

The Mulatto Tongue is the lowermost Upper Cretaceous rocks in

Table 1 - Upper Cretaceous units sampled and analyzed

Unit	Lithology	Depositional Environment
Fruitland Formation	Carbonaceous shale, coal, sandstone	Coastal plain, paludal
Lewis Shale	Fissile olive-gray shale	Offshore marine
Cliff House Sandstone/ La Ventana Tongue	Thin- to thick-bedded sandstones	Transgressive coastal barrier and deltaic
Menefee Formation		
upper Menefee member	Carbonaceous shales, coal	Deltaic and fluvial, paludal
Allison Member	Variegated sandstones and shales	Fluvial and flood plain
Cleary Member	Carbonaceous shales, coal	Deltaic and fluvial, paludal
Mancos Shale		
Satan Tongue	Fissile dark gray silty shale	Offshore marine
Mulatto Tongue	Thin interbedded shale, siltstones, sandstones	Offshore marine

the study area. It is quite sandy and consists of thinly interbedded shale, siltstone, and very fine-grained, ripple-bedded sandstone.

The Hosta Tongue is the basal transgressive sandstone of the Satan transgression in the southern San Juan Basin (Molenaar, 1977). It is a fining-upward sequence representing deepening water (Sabins, 1964). The Satan Tongue represents another transgression. It consists of thinly interbedded, very fine-grained sandstone and fissile, dark gray shale. The contact with the overlying marine Point Lookout Sandstone is an alternating sand-shale transition where the sands gradually thicken upward at the expense of the shales until a massive cliff-forming sandstone exists (Tabet and Frost, 1979b). This aspect of the facies led Shetiwy (1978) to interpret the environment of deposition of the Satan Tongue as offshore marine.

Menefee Formation

The Menefee Formation is approximately 520 meters (1500 ft.) thick in the Torreon Wash area. It consists of interbedded gray to brown claystones, blocky mudstones, and silty shales; brown humic shales (fissile texture); thin coals; thin tubular very fine-grained sandstones and siltstones; and, lenticular medium- to fine-grained channel sandstones. Three members of the Menefee Formation are, in ascending order, the coal-bearing Cleary Member, the sandy Allison Member, and an upper unnamed coal-bearing member. They represent a gradational succession of depositional environments; coastal swamp to a floodplain and back to coastal swamp, respectively. Contacts between members are ill-defined and typically are represented by an increase in sandstones (Allison Member); and, the upper- and lowermost coal-bearing units of the Cleary Member and the upper unnamed member, respectively. Evidence for a fresh water origin of the Menefee Formation are the absence of brackish water macro-invertebrate fossils; presence of channel, levee, and splay sandstones associated with coals; tree-dominated, fresh-water pollen distributions; and, low sulfur coal (Mannhard, 1976 and Tabet and Frost, 1979b).

The Cleary Member has a conformable, transitional contact with the underlying Point Lookout Sandstone. It is about 60 to 90 meters (200 to 300 ft) thick. The lithology consists of finer-grained paludal deposits of silt-clay size with abundant organic debris. Coal beds are found in the lower part. Tabular and lenticular sandstones of the levee and splay, and, channel deposits occur throughout the unit. The amount of sandstone increases upward. Ironstone concretions occur occasionally in the organic-rich shales or mudstones. Organic matter consists of plant impressions and fragments up to the size of small logs (some up to 2.5 meters long) with no preferred orientation of particles implying in situ deposition. The coal is characterized by medium bands of vitrain with bits of amber along horizontal cleats (Tabet and Frost, 1979b).

The Allison Member conformably overlies the Cleary Member. It is about 120 to 170 meters (400 to 500 ft) thick and is composed of channel sandstones and gray and brown claystones, shales, or mudstones with very little or no organic material. The basal Allison Member contains a sequence about 60 meters (200 ft) thick of stacked channel sandstones. No samples were collected from the Allison Member.

The upper member has a gradational lower contact with the Allison Member and it intertongues and is overlain by sandstones of the Cliff House Sandstone, particularly the La Ventana Tongue. Lithology is similar to the Cleary Member except in the upper beds where thicker coals lie inbetween intertongues of the La Ventana Tongue.

La Ventana Tongue/the Cliff House Sandstone

The La Ventana Tongue consists of a sequence of primarily inter-deltaic marine sandstones with some interstratified marine shales. It typically overlies and intertongues with the Menefee Formation in the Torreon Wash area and is 12 meters (40 ft) thick. The quartzose sands of the La Ventana Tongue units are tan to light gray, fine- to very fine-grained, and are moderately well sorted (Tabet and Frost, 1979b). The lower and upper contacts with the upper Menefee Formation are sharp and planar to gently undulating. The basal sandstone, Facies A of Mannhard (1976), incorporates clasts of coal, claystone, mudstone, or shale ranging up to 2.5 cm (1 in) in size, from the underlying Menefee Formation.

Samples for this report came from the lower shoreface of Facies B (Mannhard, 1976). Only the interbedded thin (30 cm) gray marine shales were collected. These shales are light to medium gray, silty, and contain carbon films of plant material, predominantly leafy in nature, with an occasional cleat of carbonized wood.

A deltaic depositional environment for the La Ventana Tongue and Menefee Formation was proposed by Fuchs-Parker (1977). He considers the La Ventana Tongue a fluvial system, whereas Mannhard (1976) describes a deltaic-interdeltaic marine depositional setting.

Lewis Shale

The Lewis Shale represents another significant transgressive period. The contact with the underlying La Ventana Tongue is sharp and planar.

It interfingers with the main Cliff House Sandstone to the northwest. Where it overlies the Menefee Formation shales and mudstones the contact is irregular and difficult to distinguish. This rock unit consists mainly of gray and olive-gray shale and silty shale with common interbeds of siltstone and silty sandstone. Concentrations of fine plant detritus are common and the lowermost shale interbeds contain abundant plant impressions and carbon films. Unoriented sand- and silt-filled deposit feeding burrows (Planolites) are common to abundant but never to the point of destroying bedding features.

The Lewis Shale is noted for its abundant macroinvertebrate fossils. However, no systematic collecting was conducted. The few fossils collected while sampling the unit include the bivalves Ostrea plumosa and Inoceramus vanuxemi, a few unidentified gastropods, and one indeterminable cephalopod.

The lithology of the Lewis Shale suggests deposition in deeper water below wave base. However, the presence of ripple laminated siltstones indicates that wave activity was sufficiently strong to cause some sorting of bottom sediments. The 600 meter (2000 ft) thickness of the Lewis Shale suggests abundant mud supply and high sedimentation rates. The low level of bioturbation also supports this interpretation (Mannhard, 1976).

The Lewis Shale has a conformable and gradational contact with the overlying regressive Pictured Cliffs Sandstone; the shale beds of the Lewis Shale intertonguing with the sandstone beds of the Pictured Cliffs Sandstone (Fassett and Hinds, 1971).

Fruitland Formation

The Fruitland Formation represents nonmarine, lower coastal plain depostion behind the Pictured Cliffs' regressive shoreline (Molenaar, 1977). As the sea retreated coastal swamp, river, flood plain, and lake deposits were laid down shoreward on top of the Pictured Cliffs Sandstone. (Fassett and Hinds, 1971).

The contact with the Pictured Cliffs Sandstone (not exposed in the field study area) is arbitrarily placed at the first coal-bearing unit of the lower Fruitland Formation (Fassett, 1974). The Fruitland Formation is only 30 to 45 meters (100 to 150 ft) thick in the eastern rim of the San Juan Basin due to erosional truncation (Molenaar, 1977). The absence of the Kirtland Shales is similarly explained. The unconformable contact with the overlying Ojo Alamo Sandstone is sharp and planar.

The Fruitland Formation is composed of shale, siltstone, coal, carbonaceous shale, and discrete channel sandstone. Nearly all the rock units of the formation are discontinuous; most individual beds pinching out laterally within a few hundreds of feet. Silicified logs and wood fragments, upright in-place tree stumps, as well as vertebrate bones and coprolites, are relatively common. The subdued topography and badlands development of the Fruitland Formation's outcrop pattern is prized for its scenic tranquility, and hitherto, unaltered beauty.

III PROCEDURES

Field Procedures

Surface outcrop samples were collected from the field study area in April and July, 1980, and in April and July, 1981. The first three field trips were sample-collecting trips with emphasis in April 1980 being placed on reconnaisance of major clay-bearing rock units. July 1980 and April 1981 field trips concentrated on obtaining samples in an area where the La Ventana Tongue of the Cliff House Sandstone intertongues with the upper Menefee member (sec. 10 and 15, T. 18 N., R. 4 W.). It was here in July 1981 that several stratigraphic sections were measured.

Sampling was systematic where possible, but was precluded in places due to lack of lateral and vertical continuity. Representative samples characteristic of the rock stratigraphic unit were, therefore, marked for collection. Fresh rock samples were obtained by removing the weathering rind from the outcrop, and, where necessitated, digging into the exposure to extricate the well-bonded (or consolidated) rock.

Laboratory Procedures

Laboratory preparation began with crushing approximately 110 grams of sample down to particles no larger than 1.5 millimeters in size. A sample splitter was used to separate the crushed sample into homogeneous portions of approximately 55 grams, 41 grams, and 14 grams. The 41-gram split was vialed and placed in reserve in case of any laboratory mishap. The 14-gram portion was ground and sieved to 75 microns (200 mesh Tyler equivalent) for whole rock chemical analysis and x-ray diffraction analysis. Unoriented whole rock smear mounts were made for x-ray diffraction analysis.

The 55 grams of remaining sample was suspended in approximately 400 milliliters of water, vigorously stirred, and subsequently agitated with an ultrasonic probe to completely disaggregate the rock particles. If the particles remained in suspension for 50 minutes after ultrasonic agitation, the sample was considered successfully disaggregated. However, in some samples, matrices of carbonate and sulfate minerals (determined from whole rock x-ray diffraction analysis), or of organic materials, were responsible for settling of the suspended particles within the above-prescribed time interval. When this occurred the sample was boiled in a 0.5 N EDTA (ethylenedinitrilotetraacetic acid) solution at pH 10-12 for four hours to remove the matrix materials (Bodine and Fernalld, 1973). Subsequent centrifugation in the Sorval RC-5 high-speed centrifuge at 8500 revolutions per minute (rpm) for 60 minutes, decanting, and rinsing with distilled water, eliminated the EDTA from the sample.

For most samples two principal clay-size fractions were analyzed: less than 1.0 microns; and less than 0.25 microns. (Samples from the Spring 1980 reconnaisance field trip, prefixed MB-80-, had only the less than 1.0 micron analyzed.) The International SBR centrifuge was utilized to separate the less than 1.0 micron fraction, and the Sorval RC-5 high-speed centrifuge was used to separate the less than 0.25 micron fraction.

Oriented sedimented mounts were made when the samples were finally disaggregated. The suspended clays were sedimented onto three glass slides using a dropping pipet. When allowed to air-dry the suspended particles settled out as a thin clay film of oriented crystallites. The first mount underwent x-ray diffraction analysis untreated. The second oriented mount was saturated with ethylene glycol vapors in a closed container overnight at 60°C. The third mount was heated to 350°C in a muffle furnace four to five hours, and then subsequently heated to 550°C before being x-ray diffracted. Clay minerals were identified by observation of 001 peak shifts and/or destruction as prescribed by Carroll (1970). X-ray diffraction analysis was carried out on the Philips-Norelco x-ray diffractometer with Ni-filtered CuK -radiation at a scanning speed of 2°2θ per minute. Results of the x-ray diffraction clay mineral analysis can be found in Appendix 4.

Chemical analysis was performed on a number of samples for whole rock and 2um clay fraction major element compositions. The technique of Norrish and Hutton (1969) was used in which the samples were fused with lithium borate to form a glass disc. The Rigaku x-ray fluorescence spectrometer linked to a PDP 11/23 computer was utilized to determine the chemical compositions. Results of the analysis, expressed in oxide percents, are found in Appendix 5.

Whole Rock Mineralogy

Whole rock relative mineral abundances (Appendix 3B) was calculated after the method described in Carmichael (1982) and Schultz (1964). Only minerals considered to be major rock-forming constituents were determined. These included quartz, microcline (potassium feldspar), calcite, mixed calcite (substitution by Mg^{+2}, Fe^{+2}, or Mn^{+2}), plagioclase (oligoclase) and gypsum. The value of clay mineral abundances is high due to the fact that consituents other than those listed above were assigned to clay mineral content. This would include such diverse materials as organic matter, amorphous solids, and accessory minerals such as apatite, pyrite, barite, and water-soluble salts. Therefore, clay mineral abundance from this data should be observed only in a relative sense.

Clay Mineralogy

Clay minerals occur in all types of sediments and sedimentary rocks. They are the most abundant minerals in sedimentary rocks perhaps comprising as much as 40 percent of the minerals in these rocks (Weaver and Pollard, 1973). They are fine grained and are built up tetrahedrally (Si, Al, Fe^{3+}) and octahedrally (Al, Fe^{3+}, Fe^{2+}, Mg) coordinated cations to form sheets or chains. Classification is based on combinations of the tetrahedral and octahedral layers. The 1:1 clay mineral type consists of one tetrahedral layer and one octahedral layer. The 2:1 or three-sheet layer lattice is composed of one octahedral sheet sandwiched in between two silica tetrahedral sheets.

Further subdivisions are based on: (1) whether the octahedral sheet contains two cations per half unit cell (dioctahedral) as in gibbsite or three cations per half unit cell (trioctahedral) as in brucite; (2) the amount and type of isomorphous replacement of the cations; and, (3) the manner of stacking of the tetrahedral-octahedral units upon each other (Weaver and Pollard, 1973).

X-ray diffraction was the principal analytical tool in this study. Sedimented glass slide mounts of treated and untreated clay-sized ($\leq$1.0um) particles were analyzed for their clay mineral constituents by identification of 001 peak positions on x-ray diffractograms. The discussion that follows describes those clay minerals found: kaolinite, illite, chlorite, smectite, and random interstratified illite-smectite.

Kaolinite

Kaolinite is a very common mineral; it is present in almost all clay and shale deposits to some extent and often constitutes a major part of the clay fraction (Brindley, 1961). Kaolinite refers to the dioctahetral hydrous aluminum silicates of the 1:1 group of clay minerals. Identification is based on the presence of an approximate 7 Å (001) and 3.6 Å (002) basal reflection in oriented mount. When heated to 550°C the structure collapes to an x-ray amorphous mineral (Carroll, 1970). The kaolinite structure was thus destroyed in all such treated samples.

For the less than 1.0 micron fraction stronger, sharper 7 Å peaks are observed indicating well crystallized kaolinite for carbonaceous shales/mudstones and sandstones. This implies an authigenic (a development in situ during or after deposition) origin for most of the kaolinite in these rocks (Grim, 1968).

Illite

Illite is the most dominant species of clay mineral in argillaceous sedimentary rocks (Grim, 1968). According to Velde (1977) the mineral or group name illite is probably the most passionately debated mineral found in argillaceous sediments. Illite represents the dominantly potassic, dioctahedral, aluminous, mica-like fraction of clay-sized materials. It has a three-sheet or 2:1 layer lattice and represents the polytype (stacking sequence) 1Md (disordered one-layer monoclinic).

Illite is identified by a 10 Å (001) peak that does not shift upon glycolation of the sample. The large ethylene glycol molecules fail to penetrate the illite's interlayers due to its high half cell interlayer charge ($K^+ = 0.7$). Glycolated smectite's (001) reflection will shift to 17 Å, isolating the 10 Å (001) illite peak (Carroll, 1970). "Discrete" illite cannot be resolved from illite-smectite interstratified clays that average greater than 80 percent nonexpandable layers using x-ray diffraction techniques (Hower and Mowatt, 1966; Reynolds and Hower, 1970).

Chlorite

The fundamental unit layer of chlorite consists of a 2:1 layer plus an hydroxide sheet, usually brucite, in which the mica and brucite-like layers alternate, i.e. 2:1:1. The layer thickness is approximately 14 Å; it can range from 13.8 to 14.8 Å (Carroll, 1970; Brindley, 1961). A wide range of ionic substitutions occurs in the tetrahedral and octahedral layers and have been described by Foster (1962). Chlorite is abundant as a clay-sized mineral, but most of it is derived from macroscopic chlorite, i.e. detrital chlorite (Carroll, 1970; Weaver and Pollard, 1973).

Identification of chlorite in oriented mount is determined by an integral series of (001) spacings from 14 Å. However, due to poor crystallinity and/or low concentrations the 14 Å peak is usually low and broad on the diffractograms. The situation is further complicated by kaolinite masking the 002 reflection. By heating the sample to 550°C the kaolinite is destroyed. This was the basis for confirming the presence of chlorite in the samples analyzed.

Smectite

The smectite minerals occur only in extremely small particles so that precise and detailed diffraction data are made up of two silica tetrahedral sheets with a central octahedral sheet (typically dioctahedral) in a 2:1 type of lattice. The outstanding feature of the smectite structure is that water and other polar molecules, such as certain organic molecules, can enter the interlayers causing expansion of the lattice in the c-direction. Table 2 shows the d-spacing in angstroms for expanded smectites with organic molecules in the interlayers. Only Menefee Formation smectites exhibited this phenomenon.

Exchangeable cations occur between the silicate layers, and the c-axis spacing of completely dehydrated smectite depends on the size of the interlayer cation to some extent. Under ordinary conditions a smectite with Na^+ as the exchange cation frequently has one molecular water layer and a c-axis spacing of about 12.5 Å; with Ca^{2+} there are frequently two molecular water layers and a c-axis spacing from about 14.5 to 15.5 Å (Grim, 1968).

Identification of the smectites is accomplished by observation of its characteristic swelling on glycolation from a d-spacing of about 15 Å to one of about 17 to 18 Å (Carroll, 1970). Appendix 7 lists the (001) d-spacing for the untreated oriented mount diffraction traces. Caution must be taken when identifying these peaks as discrete smectite varieties as mentioned above. These strong hard peaks are actually an average value of illite, smectite, and interstratified clay (001) peaks. Given the illite-rich interstratified clay abundances (Appendix 4D and 4E; Appendix 6) only the Fruitland Formation samples of Appendix 7 can be interpreted with confidence. These clays are primarily of the Na^+ - one water molecule layer variety, with samples MB-80-13 and -15 trending towards the Ca^{2+} - two water molecule layer variety.

Table 2 - Smectites with organics in the interlayer position/ Menefee Formation (untreated samples)

Sample	Size Fraction (microns)	d-spacing
MB-80-8	1.0	19.45
-9	1.0	18.76
-17	1.0	16.37
CB-80-5	1.0	17.16
-5	0.25	17.67
-8	1.0	17.67
-8	0.25	17.67
-10	1.0	16.99
-10	0.25	17.78
-12	1.0	16.99
-22	1.0	16.83
-23	1.0	16.37
CB-TN-3	1.0	16.37

Interstratified Clays

Interstratified (mixed-layer) clay minerals are those in which individual crystals are composed of unit cells or basic unit layers of two or more types. The interstratification may be (1) regular; (2) random; or, (3) a segregation within one crystallite into zones of types (1) and (2) (Carroll, 1970). Regular interstratification has a definite periodicity and so is identified by an integral sequence of (001) reflections representing the sum of the constituent layer thicknesses. No regular interstratified clays were detected in the field study area samples.

Random mixed-layer illite-smectite predominates in the study area (Appendices 4D and 4E). Identification of these clays is based on non-integral sequence of (00ℓ) basal reflections; broad, poorly developed (001)/(001) peaks due to combining and averaging of constituent clay layers; and, the formation of 10 Å/8.5 Å, or (001)10/(002)17, peaks when glycolated (Weaver, 1956). Appendices 6A and 6B are a semi-quantitative listing of percent expandable layers of samples from the study area using data from Reynolds and Hower (1970). The dominance of illite (except for Fruitland Formation rocks) is readily observed.

IV RESULTS

Mineralogy

Average whole rock relative mineral abundances are given in Table 3. As with whole rock chemical composition, mineralogy is a function of provenance and diagenetic history (Potter et al., 1980). However, looking at values for calcite and mixed calcite the marine upper Lewis Shale has anomalously higher proportions of these minerals than do other rock units in the study area. One startling fact to note is the low value for quartz in the Fruitland Formation and its high amount of plagioclase compared to the other units. The low value of quartz may possibly be due to selective sampling of more clay-rich rocks in the formation. However, the high amount of plagioclase may have some bearing on geochemistry and its presence is possibly a function of sediment source and transport. Also of note, the Mulatto Tongue of the Mancos Shale is devoid of any gypsum, while the Satan Tongue has the highest average value of all rock formations sampled.

Clay minerals constitute a very large proportion of the whole rock mineralogy of these rocks as observed from data in Appendix 3B and Table 3. The Fruitland Formation is relatively smectite-rich compared to the other formations. The upper Lewis Shale is richest in mixed-layer illite-smectite as are the lower Lewis Shale, the La Ventana Tongue, and the upper Menefee member. The most abundant clay mineral of the Cleary Member is kaolinite. The Satan Tongue and the Mulatto Tongue of the Mancos Shale both contain interstratified layer illite-smectite as the predominant clay type. The Cleary Member is the only rock unit to show no chlorite in the less than 1.0 um fraction. The clay mineral rela-

Table 3 - Average Whole Rock Relative Mineral Abundances

Rock Unit	Q	M	Cc	M-cc	Plag	Gyp	Clay
MT	19	3	--	3	5	---	70
ST	23	4	--	3	5	1	64
CMbr	21	4	--	2	3	1	69
uMF	28	4	--	3	5	---	60
LVT	19	3	--	2	4	1	71
lLS	24	3	2	2	4	---	65
uLS	22	3	4	2	4	---	65
FF	15	5	1	5	9	1	64

tive abundances can easily be observed in the histograms of Figure 5 and in Table 4.

Table 4 also lists the average clay mineral relative abundances for the less than 0.25 um fraction. No data is available for the Satan Tongue of the Mancos Shale. The Fruitland Formation, the La Ventana Tongue, the upper Menefee member, and the Cleary Member show significant decreases in the relative amounts of kaolinite in the less than 0.25 um fraction compared to the less than 1.0 um fraction. Increases in the relative amounts of interstratified layer clay are also observed when comparing the smaller-sized fraction to the 1.0 um splits.

Upon inspection of Appendix 6A, it is noted that the Fruitland Formation mixed-layer illite-smectite is dominated by a high percentage of expandable layers. Samples range from 56 to 100% expandable layers with an average value of 82%. Similar observations are made in Appendix 6B. With few exceptions percent expandable layers for all other rock units averages from 25 to 35%. This means that the dominant clay species comprising the illite-smectite interstratified clays is illite.

Geochemistry

The average whole rock chemical composition of selected samples from the study area arranged by stratigraphic unit are given in Table 5. Oxide percentages for the major elements tend to agree from one unit to the next. However, the Lewis Shale and the Fruitland Formation show a relatively higher percentage of CaO than do the other units. It is generally believed that marine clays contain more calcium than do nonmarine clays (Murray, 1954). However, provenance probably dictates

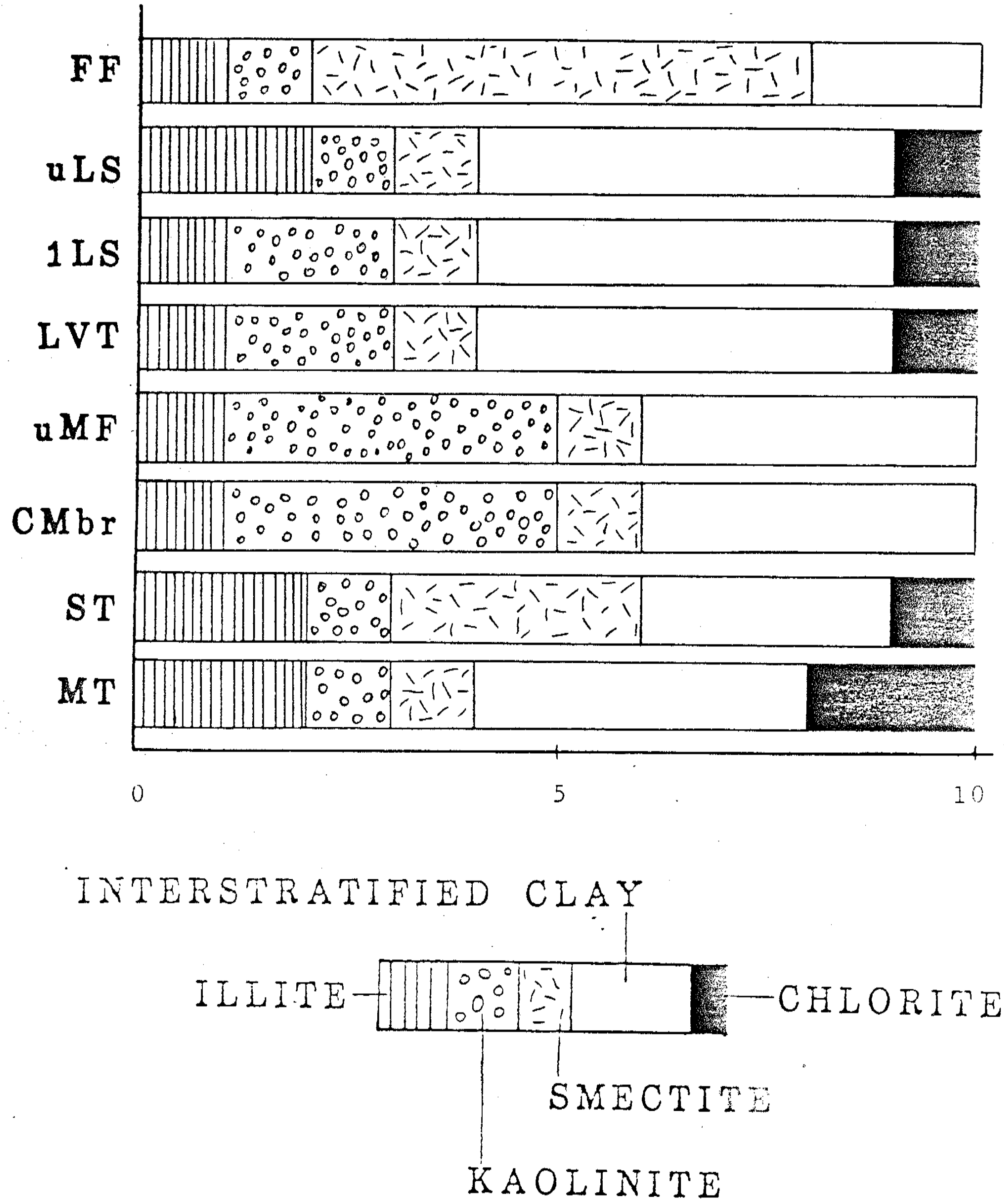


Figure 5 - Histogram of average values for less than 1.0 miron clay mineral relative abundances in parts per 10.

Table 5 - Average Whole Rock Chemical Composition by Stratigraphic Unit

	MS	MF	LVT	LS	FF
SiO_2	63.5	65.9	63.9	65.5	64.1
Al_2O_3	16.3	16.4	17.8	14.1	17.9
Fe_2O_3	5.1	3.4	4.2	3.7	5.0
MgO	2.3	1.5	2.2	1.9	1.8
CaO	0.7	0.4	0.6	1.9	1.1
Na_2O	2.0	1.2	1.2	1.2	2.2
K_2O	2.9	2.8	3.0	2.5	2.3
TiO_2	0.7	0.7	0.8	0.6	0.6
P_2O_5	0.2	0.1	0.1	0.1	0.1
MnO	t	0.1	t	t	t
LOI	6.4	7.6	6.6	9.3	5.0
TOTAL	100.1	100.0	100.4	100.7	100.1

MS - 2 samples
MF - 10 samples
LVT - 6 samples
LS - 5 samples
FF - 4 samples

most of a shale's composition (Potter et al., 1980). Here the offshore marine rocks of the Lewis Shale may attribute the higher level of calcium to environment of deposition, but the coastal plain and paludal deposits of the Fruitland Formation must be explained by provenance.

Table 6 shows average chemical composition of some shales compiled by Blatt et al., 1972 compared to average chemical composition of 29 shales in the Torreon Wash/Johnson Trading Post area. With the exception of increased silica content and a relatively lower value for calcium oxide, the study area shales are not much different from other shale rocks.

Chemical analysis was done for several less than 1.0 um fractions (Table 7). All three samples came from the Fruitland Formation. The assumption that a relatively pure smectite was present comes from the x-ray diffraction data. However, mixed-layer illite-smectite is probably present also. See Appendix 6A. Therefore, recasting will provide an average of more than one clay mineral. A source of error in chemical analysis of montmorillonites (and in other clays) is the presence of amorphous material, particularly silicon and aluminum (Weaver and Pollard, 1973). The presence of other minerals in trace amounts in the less than one micron fraction is also suspect, although the diffraction data do not show it. Appendices 3B and 4D show relative whole rock mineral abundances and clay mineral relative abundances respectively, to illustrate the arguments above.

Only sample MB-80-14-1's recast analysis shows some substitution of aluminum for silicon in the tetrahedral layer. Substitution of magnesium, manganese (only in sample CB-80-71), and possibly ferrous iron for aluminum in the octahedral layer may lead to the small charge

Table 6 - Average Chemical Composition of Pelitic Rocks in Oxide Percents

	A	B	C	D	E	F	G
SiO_2	58.1	58.5	55.4	60.2	56.2	53.4	65.1
Al_2O_3	15.4	17.3	13.8	16.4	15.1	16.6	16.3
Fe_2O_3	4.0	3.0	4.0	4.0	3.4	3.4	4.0
FeO	2.4	4.4	1.7	2.9	2.3	2.8	----
MgO	2.4	2.6	2.7	2.3	2.1	2.4	1.9
CaO	3.1	1.3	6.0	1.4	4.4	5.8	0.9
Na_2O	1.3	1.2	1.8	1.0	1.1	1.1	1.4
K_2O	3.2	3.7	2.7	3.6	2.6	2.7	2.7
TiO_2	0.6	0.8	0.5	0.8	0.8	0.7	0.7
P_2O_5	0.2	0.1	0.2	0.2	0.1	0.2	0.1
MnO	t	0.1	t	t	0.1	0.1	t
LOI	9.0	6.6	11.7	7.7	9.3	9.8	7.3
Misc.	----	1.2	0.1	t	---	---	---
TOTAL	99.7	100.8	100.6	100.5	100.5	100.8	100.4

A - F, compiled from Blatt *et al.*, 1972.
G, 29 samples from Torreon Wash/Johnson Trading Post study area.

Table 7A - Recast Clay Analysis: Sample MB-80-14 (less than 1.0 micron fraction)

Tetrahedral		
Si	= 3.836	
Al	= 0.164	
Total	= 4.000	Charge = -0.164
Octahedral		
Al	= 4.326	
Fe	= 0.864	
Ti	= 0.176	
Mg	= 0.348	
Mn	= -----	
Total	= 5.714	Charge = -0.286
		Total = -0.450
Interlayer		
Ca	= 0.016	
K	= 0.378	
Na	= 0.054	
Total	= 0.448	Charge = 0.448
		Difference = -0.002

Table 7B - Recast Clay Analysis: Sample MB-80-16 (less than 1.0 micron fraction)

Tetrahedral		
Si	= 17.080	
Al	= -----	
Total	= 17.080	Charge = +1.080
Octahedral		
Al	= 3.198	
Fe	= 0.645	
Ti	= 0.084	
Mg	= 0.442	
Mn	= 0.008	
Total	= 4.377	Charge = -1.623
		Total = -0.543
Interlayer		
Ca	= 0.152	
K	= 0.018	
Na	= 0.365	
Total	= 0.535	Charge = +0.535
		Difference = -0.008

Table 7C - Recast Clay Analysis: Sample CB-80-71 (less than 1.0 micron fraction)

Tetrahedral

Si	= 16.212		
Al	= -----		
Total	= 16.212	Charge	= +0.212

Octahedral

Al	= 3.902		
Fe	= 1.076		
Ti	= 0.152		
Mg	= 0.227		
Mn	= 0.002		
Total	= 5.359	Charge	= -0.641
		Total	= -0.429

Interlayers

Ca	= 0.008		
K	= 0.076		
Na	= 0.349		
Total	= 0.433	Charge	= +0.433
		Difference	= +0.004

deficiencies.

Table 8 is a compilation of chemical composition by stratigraphic unit for the less than 1.0 um fraction splits of Appendix 5. High totals were obtained for all major rock units except the Fruitland shales. This may be attributed to a high propensity of the sample to absorb water during the determination of loss on ignition (Kyle, personal communication, 1982). Fruitland Formation clays, however, are anomalously high in silicon, sodium, and calcium, but low in all other components. The high relative amounts of smectite clays may be the cause of these differences. See Appendices 4D and 4E.

No appreciable differences in geochemistry exist between the humic shales and silty shales and mudstones of the upper Menefee Formation nor between the upper and lower Lewis Shale lithologies.

Intertonguing of La Ventana Tongue and upper Menefee Formation

Lithological differences occur in the Lewis Shale and the upper Menefee member where a stratigraphic and lateral variations study was conducted. The major stratigraphic observation is the pinching out of the La Ventana Tongue sandstones and intertonguing with the upper Menefee member (Plates I and II; Figure 6). The lateral discontinuity of strata in the upper Menefee member precludes sampling along a lateral trace. The shales and mudstones have a lateral extent of 15 to 30 meters (50 to 100 ft.).

Two general lithologies predominate in the upper Menefee member. Brown humic shales, or humates, occur as thin units (typically about 1 meter thick) that grade or wedge laterally into silty shales and mudstones. Carbonized wood and other plant material is abundant; amber is commonly found in cleats of carbonized wood. Fissility in these beds

Table 8 - Average Decimal Composition of less than 1.0 micron fraction

	MS*	MF	LVT	LS	FF	SA**
SiO_2	51.1	57.0	52.2	53.9	61.5	55.9
Al_2O_3	26.1	22.7	24.9	25.2	17.2	22.8
Fe_2O_3	8.0	6.5	6.8	6.7	5.8	6.6
MnO	t	t	t	t	t	t
TiO_2	0.7	0.7	0.8	0.7	0.5	0.7
CaO	t	0.1	0.1	t	0.4	0.1
K_2O	3.3	3.2	2.9	2.4	1.7	2.3
P_2O_5	t	0.1	0.1	t	t	0.1
MgO	2.5	2.2	2.9	2.4	1.7	2.3
Na_2O	1.9	1.8	0.8	2.0	2.9	1.8
LOI	8.5	7.3	9.1	7.4	5.6	7.4
TOTAL	102.1	101.6	101.3	101.7	96.2	100.5

* represented by only one sample
** average of all less than 1.0 micron fraction samples from study area

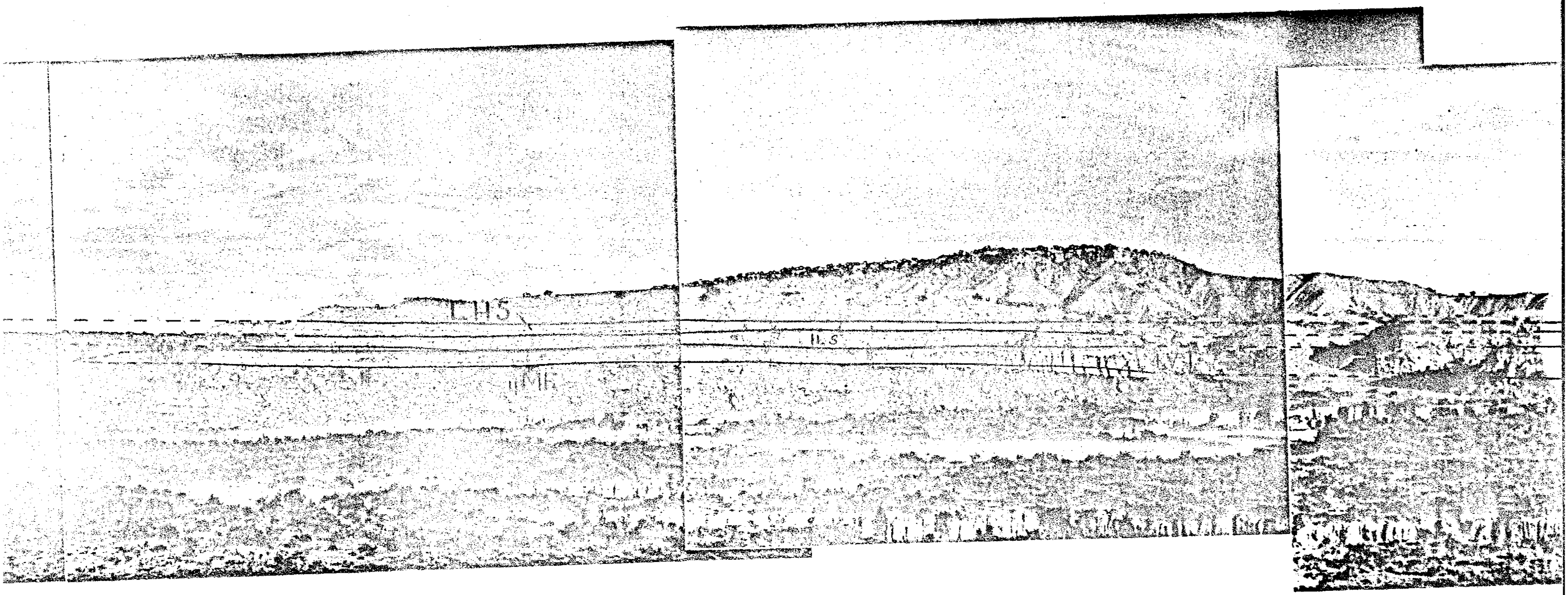
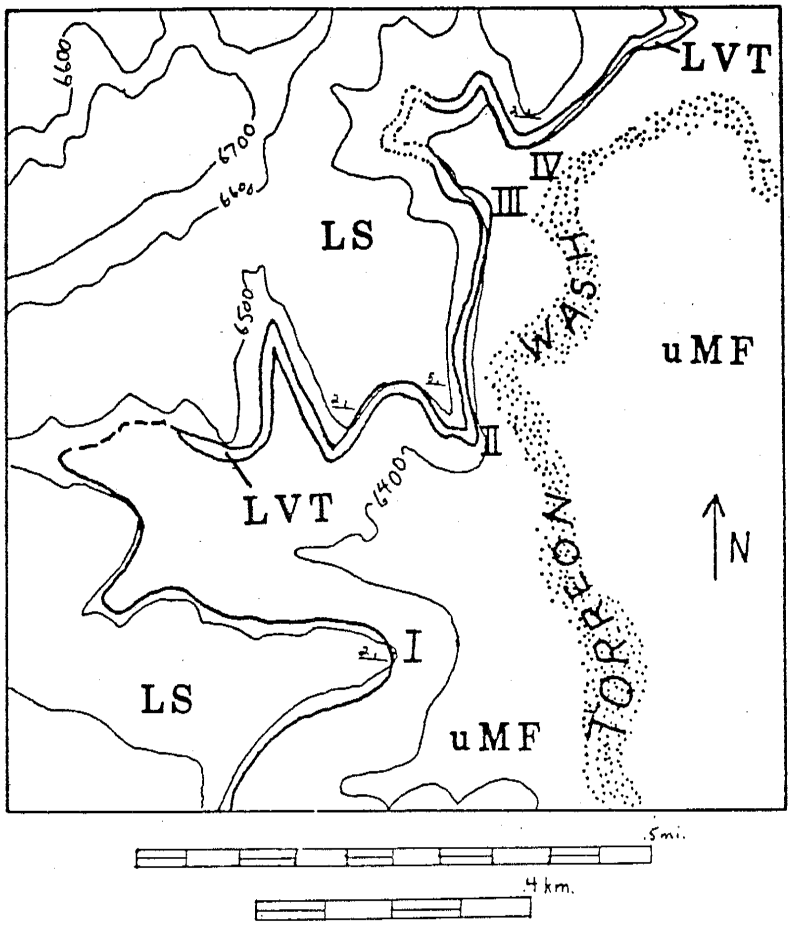


Plate 1. Cross section overlay, La Ventana Tongue pinchout.



LS	Lewis Shale
LVT	La Ventana Tongue
uMF	upper Menefee Formation
(contour symbol)	contour lines
(contact symbol)	formation contacts
I-IV	station locations

Figure 6 - Geologic Map of station locations (revised from Tabet and Frost, 1979a).

is well-developed. The other lithology present is light- to medium-gray silty shales and mudstones. Rocks with a blocky texture are referred to as mudstones and those exhibiting a fissile nature are shales. Plant material is less abundant than in humic shales but may impart a brownish color to these rocks. Slickensided facets of these rocks, particularly the mudstones, is characteristic. These units also laterally grade or wedge into other beds of the upper Menefee Formation. Contacts with underlying and overlying lithologies can be either transitional or abrupt.

Humic shales are represented by samples CB-80-5, -6, -12, -23, -28, and -29. Silty shales and mudstones are illustrated with samples CB-80-4, -7, -11, -22, -24, and -30. See Plate II. Only samples CB-80-11 and CB-80-12 were taken from above the La Ventana Tongue. Underclays and clay-bearing strata otherwise associated with coal beds were not sampled. (For analyses of clay-bearing strata and their relation to coals in the upper Menefee Formation, see Carmichael, 1982).

The lower Lewis Shale is composed of olive-gray to brown shale laminated with silty shale, siltstones, and silty sandstones. These units directly overlie the Menefee Formation or the La Ventana Tongue appropriately. They are laterally continuous as a laminated unit the length of the rock exposure being studied. Locally, concentrations of carbonaceous laminated rock occur (CB-80-1 and -2). As one moves up through the Lewis Shale the laminated nature of bedding begins to give way to thicker units of the above-described lithologies.

Inspection from data in the appendices reveal no perceptible change for lower Lewis Shale lithology with respect to whole rock mineral abundances, clay mineral relative abundances, nor whole rock chemical composition. However, samples CB-80-(1-2) showed a marked increase in kaolinite for both less than 1.0 and 0.25 um fractions as well as a decrease in mixed-layer illite-smectite when compared to other lower Lewis Shale samples. The small change in relative abundance in the 1.0 and 0.25 um splits of CB-80-1 indicate a very fine grain size for the kaolinite. This implies a possible detrital source for both the organic matter and the kaolinite, since the biota and lithologic characteristics of the Lewis Shale is evidence for a marine depositional environment.

Below is a listing of the average values of clay mineral relative abundances for humates and shales/mudstones in the less than 1.0 um fraction.

	Humate	Shale/Mudstone
I	2	1
K	3	4
S	1	1
MX	4	4
T	10	10

The humate samples have relatively more illite than do the shales/ mudstones and less kaolinite. No other significant differences are noted except that a decrease in the relative amount of kaolinite occurs in the 0.25 um fraction for both lithologies.

Whole rock chemical composition and whole rock relative mineral abundances show no significant differences between the humates and the shales and mudstones. However, CB-80-22 and -23 show a relatively high amount of expandable layers in the interstratified illite-smectite clays.

V DISCUSSION

The clay minerals found in shale are a function of provenance (rock type and climate), sedimentary processes (especially transport and sorting), and diagenetic history. The environment of deposition was once thought to exert considerable influence on clay mineralogy through early mineral transformations in the depositional basin. However, once formed, clay minerals resist modification despite later changes of environment (Potter et al., 1980). The clay mineral exists because it is the mineral phase possessing the lowest level of free energy attainable (it may be metastable) in the environment at the time of its genesis (Keller, 1970). Thus clay minerals tend to be indicative of their initial environment of formation. These are the primary-stage minerals of Keller, 1970. If a subsequent environment greatly differs from the initial one, the clay modification may occur (Bowles, 1978; Keller, 1970). These are the N + 1 stage clay minerals of Keller, 1970, and are produced from parent materials of preexisting clay minerals or other layer silicates.

Geochemical parameters responsible for clay mineralogy in geologic environments include temperature, pressure, pH, Eh, concentrations of various metal ions, and concentrations of alumina and silica as ions, polymorphs, complexed soluble compounds and in relation to H^+ and various metal ions (Keller, 1970). Time and temperature are perhaps the most important parameters (Dunoyer de Segonyac, 1970; Keller, 1970; Weaver and Pollard, 1973). Evidence against a significant amount of chemical alteration of clays in the depositional environment is listed in Table 9.

The question of authigenic versus detrital clay mineral particles

Table 9 - Evidence Against Clay Mineral Alteration

Author	Geology/Geography	Evidence
Edzwald and O'Melia, 1975	Pamlico R. Estuary, N.C.	Stability of clay minerals responsible for distribution of clay sediments in estuaries
Gibbs, 1977	Amazon R./Atlantic Ocean	Lateral variations of clay mineral composition determined by physical sorting by grain size
MacKenzie and Garrels, 1966	Gulf of Mexico/E. Pacific Ocean	Clay minerals are in equilibrium in ocean systems and are not altered as allogenic particles
Rhoton and Smeck, 1981	Auglaize R., OH	Stability of illitic soil clays during suspension in fresh water drainage system
Whitehouse and McCarter, 1958	Kaolinite/illite in seawater	No noticeable chemical or mineralogical changes after 5 year storage in sea water

is of paramount importance to this discussion. Potter, et al. (1980) attributes most particles found in shales and mudstones to erosion of preexisting muds, mudstones, and shales. These pelitic rocks constitute 60% of the sedimentary rocks at the earth's surface. However, the ultimate source of clay minerals is the weathering of unstable silicates at the earth's surface. Large amounts of water passing through zones of weathering make it an ideal site for the production of clay minerals in an open system. Climate (particularly the amount of rainfall) and the parent weathering material are the major factors in clay genesis. For example, high relief and rainfall in volcanic terrains add to clay production as it continually exposes new rock to weathering processes. In contrast, low-lying forested hinterlands produce little new clay material because the original clay minerals reside in forest soils for a relatively long time. Detrital clay minerals represented by mudstones and shales may reflect the energies and hydrodynamics of the depositional environment - the medium controlling deposition. The authigenic growth of clay minerals in shales after deposition in a closed system is a more complex and difficult process.

Sharp and well-defined peaks of x-ray diffraction traces at 12.35°2θ indicate well-crystallized kaolinite. The high relative abundances of kaolinite in the Menefee Formation (Table 4) implies an authigenic occurrence. Table 4 shows that, with the exception of the Fruitland Formation clays, only the terrigenous Menefee Formation clays show anomalous distribution for kaolinite. The distribution of other clay varieties in all rock units is relatively the same. Kaolinization of silicate minerals such as the phyllosilicates and the feldspars, is a well known phenomenon in acid, organic-rich environments (Velde, 1977).

Such is the case with the paludal environments of deposition of the Menefee Formation. The presence of kaolinite and its distribution in the Menefee Formation rocks are factors of environment (authigenic growth) and hydrodynamics (sorting). As noted previously, the shales/mudstones of the Menefee Formation contain a larger amount of kaolinite than do the humates. Here kaolinite was formed in the backwater swamps and subsequently eroded by sluggish, low-gradient streams dissecting the Menefee coastal plain. As these waters overflowed their banks, the larger kaolinite crystallites were deposited in sediments relatively close to the main stream channels (shales/mudstones) and the finer-grained kaolinite was carried in suspension into the more distal swamp waters where it settled out later (humates). A decrease in the amount of the 0.25 um fraction of the Menefee Formation samples supports the <u>in situ</u> formation of kaolinite. All rock units from the study area realize this decrease but the Menefee Formation samples experience a 2 parts in 10 decrease. One would expect to find less fine-grained kaolinite if it were authigenic due to the growth of large euhedral crystals in the paludal environment of deposition or in the humic shales themselves.

The decrease in the relative amount of illite in shales/mudstones of the upper Menefee Formation in comparison to the humates may also bear on the above phenomenon. If the presumably more organic-rich humates were considered to be the site for kaolinite manufacture one would also expect to see less illite in the humates. However, this is not the case. If, on the other hand, the amount of illite was controlled by the hydrodynamics of the depositional basin then the higher concentration of illite in the humates could be explained as a phenomenon of sorting just as the above-mentioned finer-grained kaolinite.

Authigenic clays reflect the energies and materials of their genetic reactions. The diagenetic environment is partially influenced by the environment of deposition because those interstitial fluids present originated in the depositional basin. Two major factors during diagenesis of clays are depth of burial (pressure) and temperature. Above 150°C kaolinite begins to deteriorate and begins transformation to illite, in K^+-rich sediments, or chlorite in Mg^{++}-rich sediments (Weaver and Pollard, 1973). Hower et al., 1976, found that at 2000 to 3700 m (6600 to 12000 ft.) depth illite-smectite interstratified clays undergo a conversion from 20 to 80% illite layers. The illite abundance remained constant after 3700 m of depth, but the potassic feldspar decreased to zero.

The large percentage of illite layers in the interstratified clays of the Menefee Formation is comparable to the results of Hower et al., 1976. Some 1200 m (4000 ft.) of consolidated shale rock overlie the Menefee Formation (Fassett, 1974). This would indicate a depth of burial for unconsolidated muds within the range (2000 to 3700 m) proposed by Hower et al., 1976 (MacMillan, personal communication, 1982). However, diagenetic growth of illite most likely would require the partial destruction of kaolinite and the data is contrary to this condition. It is more likely that illite-smectite interstratification is a product of provenance and particle size sorting in the paludal setting.

Appendix 6 shows that most interstratified clays consist of from 25 to 35% expandable layers for all rock units except the Fruitland Formation. Fruitland Formation interstratified clays typically show more than 80% expandable layers. When compared to the Carmichael (1982) data (Appendix 5) there is a major discrepancy. In the Carmichael study

45 to 60% expandable layers is the dominant range. This study and Carmichael (1982) utilized the data from Reynolds and Hower (1970) to compute these results. However, this study analyzed only surface outcrop samples and Carmichael (1982) used a combination of drill core and surface outcrop samples. Upon closer examination of the data in Appendix 5 of the Carmichael (1982) study, his surface outcrop samples show a marked decrease in percentage of expandable layers, coinciding with the figures of this report. Therefore, it is suspected that drilling muds may be responsible for the increased amount of expandable layers or that the low percentage of expandable layers in the surface outcrops is a result of some undefined weathering process.

Inspection of Table 4 reveals rocks considered offshore marine (MT, ST, LVT, lLS, uLS) have a lesser amount of kaolinite than do the fluvial-deltaic-paludal sediments (CMbr, uMF) with the exception of the Fruitland Formation. Small relative increases of illite and chlorite also exist for the offshore marine rocks but decrease for the terrigenous units (including the Fruitland Formation). This sort of clay mineral distribution appears to fit the model reported by Parham, 1966. Clay minerals in fresh river waters flocculate when they encounter marine (saline) waters and settle differentially according to their mineralogy in decreasing order: kaolinite and chlorite, illite, and smectite as shown in Figure 7 (Bowles, 1978; Parham, 1966). Intermediate kaolinite values for the La Ventana Tongue (Mannhard, 1976; Fuchs-Parker, 1977) and the lower Lewis Shale fit Parham's scheme because these units represent paleoenvironments existing near shore. Parham's model uses detrital clay as an indicator of environment of deposition and does not see clays as heavily dependent upon the environment of deposition in regards to their genesis.

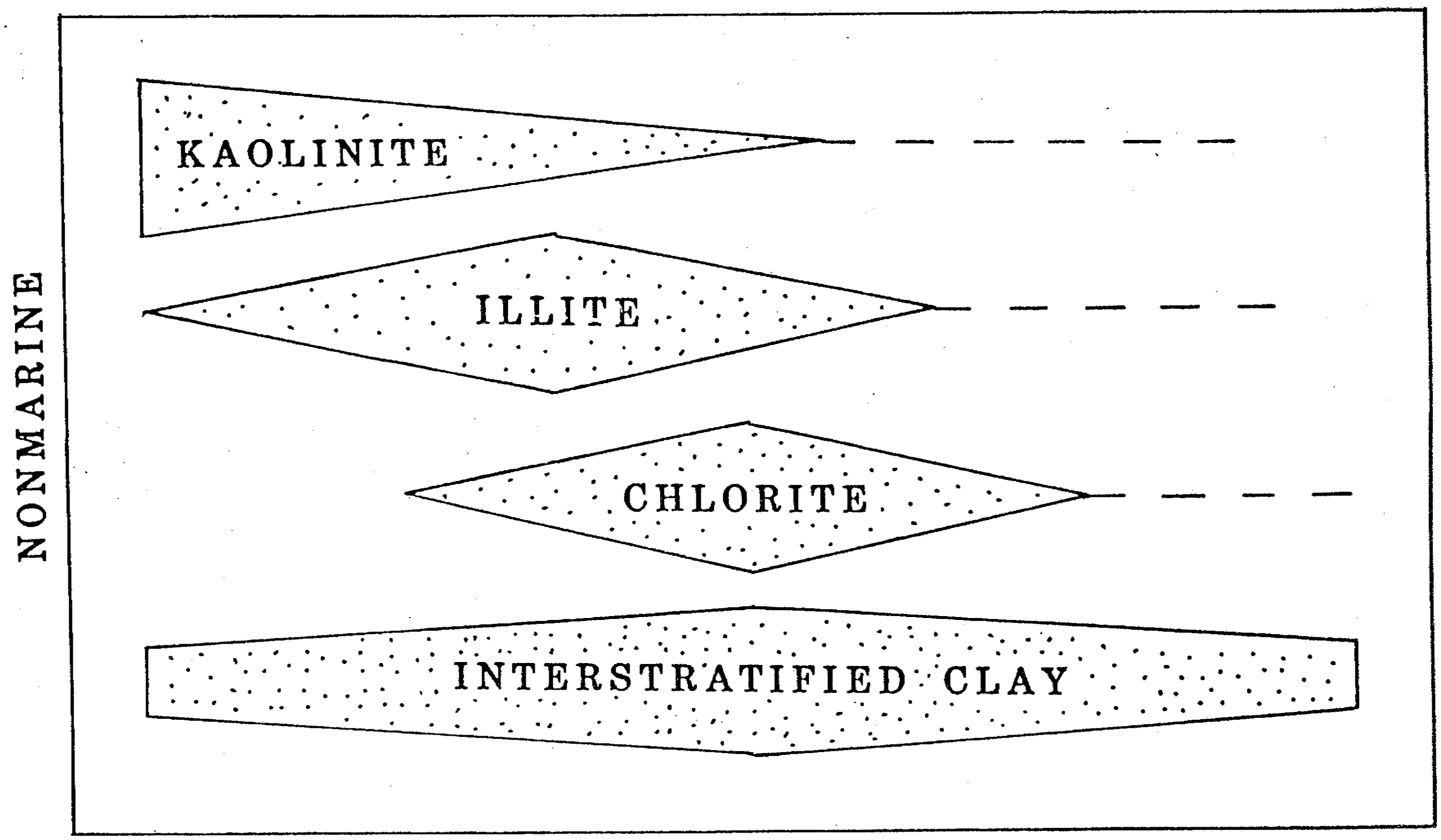


Figure 7 - Generalized lateral variations in clay-mineral assemblages. (Modified from Parham, 1966; and, Russell, 1979).

The relative clay mineral abundance of the lower Lewis Shale as depicted in Station II of Plate II shows dramatically how the clay mineralogy can be used as an indicator of environment of deposition. This example represents as near an ideal approximation to the sequential deposition of clay minerals as portrayed in the schematic sketch of Figure 7. The transgressive lower Lewis Shale represents deposits of increasingly deeper water as one progresses up the section. This deepening of marine waters, and hence a further distance from shore, is accompanied by a progressive decrease in kaolinite; a progressive increase in interstratified clays; and, the appearance of chlorite towards the top of the section.

The clay mineralogy of the Fruitland Formation is markedly different from that of the Menefee Formation despite the similarities in depositional environments. The Fruitland Formation has a relatively greater amount of smectite and lesser amounts of kaolinite. Also, the mixed-layer illite-smectite of the Fruitland Formation is dominated by a high percentage of expandable layers, generally greater than 50% with an average value of 82%. Physical variables in sedimentary processes such as provenance, greater distance of transport, lower stream gradients, and more humid climate may be responsible. The distribution of the smaller smectite particles in the Fruitland shales is easily explained by the factors mentioned above. Lower stream gradients allow only the smallest particles to be transported and carried in suspension due to low amounts of energy available for transport. Secondly, the humid climate would allow more smectites to be manufactured from parent materials such as feldspars and other phyllosilicates. The influence of provenance on the amount of smectite found is not so easily ascribed.

The relatively larger amounts of sodic plagioclase along with a decrease in quartz and Al_2O_3 (shown in Table 3 and 7) in these shales could imply a new sediment source. Formation of clays via chemical weathering of sodic rocks (and consequently alumina-poor rocks) favors smectites (Velde, 1973) and also explains the lower values for illite and kaolinite in Fruitland shales.

The change in the nature of source rocks can be explained by one of two occurrences. The occurrence of thinly bedded (up to 3 cm thick) claystones occupying the troughs of cross-bedded channel sandstones and depressions in the surrounding shales implies volcanic ash that was later weathered in situ to smectite-rich clays. However, no volcanic activity is reported during Fruitland times in the San Juan Basin. The second explanation is the erosion of the hinterlands supplying sediments to the shales stratigraphically below the Fruitland Formation, particularly the Mancos Shale, the Menefee Formation, and the Lewis Shale. The result of this erosion was the exposure of a new rock type which supplied new sediments to the depositional basin during Fruitland time.

VI SUMMARY AND CONCLUSIONS

The Upper Cretaceous rocks of southeastern San Juan Basin are representative of a series of major transgressions and regressions. Regressive (terrigenous) clay-bearing strata are typically kaolinite-rich (Menefee Formation) or smectite-rich (Fruitland Formation). Transgressive (marine) strata generally contain interstratified illite-smectite clays as the dominant clay constituent. Those deposited near shore (La Ventana Tongue and lower Lewis Shale) contain relatively more kaolinite than illite, and the reverse for farther offshore deposits (Mancos Shale and upper Lewis Shale). This is in agreement with the Parham (1966) model of lateral clay minerals distributions by depositional environments for detrital clays.

Abundance of mixed-layer illite-smectite clays in units below the Fruitland Formation are attributed to either provenance, depth of burial (diagenesis), or both. Upper Menefee lithologies owe their clay mineral distribution to diagenesis in the form of authigenic kaolinite synthesized in the high acid, organic-rich environment of back water swamps. Provenance and particle size sorting in the upper Menefee Formation are evidenced by illite abundance distally from channel sandstones along with coarse-grained kaolinite in silty shales/mudstones proximal to main stream channel deposits.

The low percentage of expandable layers in illite-smectite interstratified clays could be a product of depth of burial as described by Hower et al., 1976. It is more likely that the interstratified clays in the rocks analyzed are a product of provenance and particle size sorting. If they resulted from a diagenetic effect, the kaolinite in the Menefee shales in particular would not be well-developed crystals as the data indicates and illite would be formed at the expense of kaolinite.

The increase in smectites in the Fruitland Formation and an increase in the amount of plagioclase along with a decrease in Al_2O_3 content may indicate a change in the source rocks. The new source rock may either be volcanic in nature or freshly exposed quartz-deficient and sodic-rich lithologies. Lower stream gradients and increased distance to the depositional site are also likely explanations for the nature of the Fruitland shales.

Clay mineral analysis alone cannot determine the change in provenance for any stratigraphic unit. The whole rock mineralogy and whole rock major element geochemical analysis need to be supplemented with new data.

Appendix 1 - Sample Locations

Rock Unit	Samples	Quadrangle	Township and Range
MT	CB-81-(11-13)	Guadalupe	NW1/4, SE1/4, sec 13, T16N, R4W
ST	MB-80-(19-21)	Arroyo Empedrado	NE1/4, SE1/4, sec 3, " "
CMbr	MB-80-(17-18)	" "	SE1/4, NE1/4, sec 34, T17N, R4W
	CB-80-(48-49)	" "	" " " " "
uMF	MB-80-(8-9)	Tinian	SW1/4, SW1/4, sec 16, T18N, "
	CB-80-4	"	NW1/4, NW1/4, sec 15, " "
	-(5-12)	T/WS*	NE1/4, NW1/4, " " "
	-(22-25)	"	SW1/4, SW1/4, sec 10, " "
	-(28-30)	Wolf Stand	NE1/4, " " " "
	CB-81-(1-3)	" "	SE1/4, NE1/4, sec 15, " "
	-(6-8)	" "	NE1/4, " " " "
LVT	CB-80-13	T/WS	" NW1/4, " " "
	-(31-33)	Wolf Stand	" SW1/4, sec 10, " "
	CB-81-(4-5)	" "	SE1/4, NE1/4, sec 15, " "
	-(9-10)	" "	NW1/4, SE1/4, sec 10, " "
	CB-TN-3	" "	SE1/4, SE1/4, " " "
lLS	MB-80-10	Tinian	NW1/4, NE1/4, sec 18, " "
	-11	Wolf Stand	SE1/4, SW1/4, sec 8, " R3W
	CB-80-(1-3)	Tinian	NW1/4, NW1/4, sec 15, " R4W
	-(14-21)	T/WS	NE1/4, NW1/4, " " "
	-(26-27)	"	SW1/4, SW1/4, sec 10, " "
	-(34-36)	Wolf Stand	NE1/4, SW1/4, " " "
	CB-TN-2	" "	SW1/4, SW1/4, sec 11, " "
uLS	MB-80-5	Tinian	" NE1/4, sec 30, T19N, "
	-(6-7)	"	SE1/4, SE1/4, sec 28, " "
	-12	PATP**	NE1/4, " sec 7, " R6W
	CB-80-(37-40)	Tinian	NW1/4, SW1/4, sec 10, T18N, R4W
	-55	"	" " sec 17, " "
FF	MB-80-(2-4)	JTP***	" NE1/4, sec 11, T19N, "
	-(13-16)	Star Lake	SW1/4, SW1/4, sec 8, T20N, R6W
	CB-80-61	JTP	NE1/4, NE1/4, sec 5, T19N, R3W
	-71	"	" " " " "

Appendix 1 - Sample Locations (con't)

*T/WS - Tinian/Wolf Stand
**PATP - Pueblo Alto Trading Post
***JTP - Johnson Trading Post

MT - Mulatto Tongue
ST - Satan Tongue
CMbr- Cleary Mbr.
uMF - upper Menefee Fm.
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Fm.

Appendix 2 - Sample Weight Loss during Laboratory Preparation

Sample	Sample wt.(g)	+1.0u wt.(g)	-1.0u wt.(g)	wt. loss(-)/ gain(+), (g)	% wt. loss(-)/ gain(+)
CB-80-1	98.1	79.8	4.3	14.0-	14.3-
-2	51.8	39.0	12.2	0.6-	1.2-
-3	60.4	34.1	19.2	7.1-	11.8-
-4	49.1	35.7	8.9	4.5+	9.2+
-5	52.2	29.0	16.4	6.8-	13.0-
-6	51.5	17.6	12.3	21.6-	41.9-
-7	57.3	51.8	5.0	0.5-	0.9-
-8	68.2	32.6	19.9	15.7-	23.0-
-9	58.2	47.1	16.2	5.1+	8.8+
-10	56.4	34.8	16.7	4.9-	8.7-
-11	52.3	36.4	10.5	5.4-	10.3-
-12	62.9	47.9	10.5	4.5-	7.2-
-13	58.3	44.5	9.7	4.1-	7.0-
-14	66.9	45.1	13.1	8.7-	13.0-
-15	58.7	44.0	8.9	5.8-	9.9-
-16	57.9	36.1	15.5	6.3-	10.9-
-17	57.3	42.2	10.6	4.5-	7.9-
-18	57.8	32.7	18.1	7.0-	12.1-
-19	62.8	40.2	17.2	5.4-	8.6-
-20	54.6	25.5	21.6	7.5-	13.7-
-21	54.3	32.1	16.0	6.2-	11.4-
-22	76.6	46.2	14.9	15.5-	20.2-
-23	65.5	47.0	14.7	3.8-	5.8-
-24	53.0	40.7	9.5	2.8-	5.3-
-26	60.9	36.9	18.0	6.0-	9.9-
-27	58.0	38.7	18.5	0.8-	1.4-
-28	60.2	32.2	19.0	8.9-	14.8-
-29	63.4	53.8	9.8	0.2+	0.3+
-30	57.1	45.4	5.3	6.5-	11.4-
-31	58.1	47.9	10.2	----	----
-32	63.1	37.9	19.5	5.7-	9.0-
-33	62.4	43.8	13.3	5.3-	8.5-
-34	63.1	50.0	8.9	4.2-	6.7-

Appendix 2 - Sample Weight Loss during Laboratory Preparation (con't)

Sample	Sample wt.(g)	+1.0u wt.(g)	-1.0u wt.(g)	wt. loss(-)/ gain(+), (g)	% wt. loss(-)/ gain(+)
CB-80-35	57.8	37.5	15.8	4.7-	7.8-
-36	51.8	40.9	5.8	5.1-	9.9-
-37	58.5	47.0	7.0	4.5-	7.7-
-38	51.5	33.0	13.4	5.1-	9.9-
-39	52.7	33.3	14.3	5.1-	9.7-
-40	52.7	38.2	10.6	3.9-	7.4-
-48	59.8	53.8	6.8	0.8+	1.3+
-49	48.8	40.6	8.0	0.2-	0.4-
-55	58.8	44.2	12.6	2.0-	3.4-
-61	62.7	45.3	13.8	3.6-	5.7-
-71	58.7	17.9	39.9	0.9-	1.5-

wt. = weight
g = grams
+1.0u wt. = greater than one micron weight
-1.0u wt. = less than one micron weight

Appendix 3A - Data for Whole Rock Relative Mineral Abundance counts per second (cps)

Sample	Q	M	Cc	M-cc	Plag	Gyp
MB-80-2	3400	350	---	200	550	---
-3	4395	465	170	200	600	---
-4	----	---	---	---	---	---
-5	3185	355	655	---	270	---
-6	3015	235	565	---	274	---
-7	3342	218	763	180	344	---
-8	3749	232	---	110	215	---
-9	4489	220	---	---	220	---
-10	3459	272	272	136	310	---
-11	3197	246	273	164	279	---
-12	3544	256	436	136	316	125
-13	1096	252	---	239	618	---
-14	2796	728	---	250	572	---
-15	1922	343	---	158	805	120
-16	2572	337	171	155	1310	781
-17	3471	236	---	---	---	184
-18	3732	483	---	155	327	158
-19	4432	248	---	---	387	259
-20	2776	300	---	156	417	---
-21	4495	296	---	161	430	270
CB-80-1	7065	489	---	111	434	84
-2	----	---	---	---	---	---
-3	3134	210	284	85	240	98
-4	4597	288	---	163	435	---
-5	4476	346	---	126	258	---
-6	3611	222	---	193	294	---
-7	5180	328	---	272	328	218
-8	3972	278	---	---	333	110
-9	3380	170	---	---	240	---
-10	3889	193	---	126	342	---
-11	4578	188	322	161	376	---
-12	8191	318	---	106	530	---
-13	5991	187	144	107	321	---
-14	5376	269	284	---	333	---
-15	4342	242	511	124	350	---
-16	4400	354	310	125	408	---
-17	2817	164	273	82	164	---
-18	3224	180	245	---	191	---
-19	3319	257	235	109	344	---
-20	2063	194	170	103	307	85
-21	4694	230	---	---	430	108
-22	5010	332	107	160	535	---
-23	5010	338	---	187	445	---
-24	7098	402	---	177	604	---
-25	4029	280	---	161	447	---
-26	3683	188	279	160	322	161
-27	3492	215	91	127	394	111
-28	4079	270	---	200	370	---

Appendix 3A - Data for Whole Rock Relative Mineral Abundance - counts per second (cps) (con't)

Sample	Q	M	Cc	M-cc	Plag	Gyp
CB-80-29	3801	269	---	123	359	---
-30	3403	215	---	160	392	---
-31	4392	445	---	133	402	---
-32	3780	247	---	123	323	---
-33	3935	304	108	145	362	108
-34	4603	247	---	123	482	---
-35	3990	523	214	164	288	---
-36	6800	214	---	91	240	---
-37	5268	284	290	123	311	---
-38	3642	196	308	103	438	---
-39	3608	242	---	103	257	150
-40	5077	272	190	102	375	---
-48	3747	241	77	138	442	---
-49	3391	256	---	87	359	---
-55	3556	247	---	77	309	---
-61	2731	309	---	144	453	---
-71	637	139	---	112	847	---
CB-81-1	3585	303	---	109	338	---
-2	6546	227	---	100	650	357
-3	3188	181	---	91	295	---
-4	2035	177	---	104	358	---
-5	2267	290	---	103	562	482
-6	4353	414	---	103	266	---
-7	5734	164	---	---	108	54
-8	5926	214	---	---	225	---
-9	2466	241	64	125	428	---
-9C	133	---	---	---	---	---
-10	2570	181	---	---	230	---
-11	4023	253	---	134	455	---
-12	2538	238	---	109	290	---
-13	3281	229	52	109	474	---
CB-TN-2	5543	456	---	---	508	---
-3	5116	405	---	172	587	---

Q - quartz
M - microcline
Cc - calcite
M-cc- mixed calcite
Plag- plagioclase
Gyp - gypsum

Appendix 3B - Whole Rock Relative Mineral Abundances - parts per 100

Sample	Q	M	Cc	M-cc	Plag	Gyp	Clay
MB-80-2	20	4	-	5	7	-	64
-3	26	6	2	5	7	-	54
-4	--	-	-	-	-	-	---
-5	19	4	8	-	3	-	66
-6	18	3	7	-	3	-	69
-7	20	3	9	4	4	-	60
-8	22	3	-	3	3	-	69
-9	26	3	-	-	3	-	68
-10	20	3	3	3	4	-	67
-11	19	3	3	4	3	-	68
-12	21	3	5	3	4	1	63
-13	7	3	-	6	7	-	77
-14	17	9	-	6	7	-	61
-15	11	4	-	4	10	1	70
-16	15	4	2	4	15	6	54
-17	20	3	-	-	-	1	76
-18	22	6	-	4	4	1	63
-19	26	3	-	-	5	2	64
-20	16	4	-	4	5	-	71
-21	26	4	-	4	5	2	59
CB-80-1	42	6	-	3	5	1	43
-2	-	-	-	-	-	-	--
-3	18	3	3	2	3	1	70
-4	27	3	-	4	5	-	61
-5	26	4	-	3	3	-	64
-6	21	3	-	5	4	-	67
-7	31	4	-	6	4	2	53
-8	23	3	-	-	4	1	69
-9	20	2	-	-	3	-	75
-10	23	2	-	3	4	-	68
-11	27	2	4	4	4	-	59
-12	49	4	-	3	6	-	38
-13	35	2	2	3	4	-	54
-14	32	3	3	-	4	-	58
-15	26	3	6	3	4	-	58
-16	26	4	4	3	5	-	58
-17	17	2	3	2	2	-	74
-18	19	2	3	-	2	-	74
-19	20	3	3	3	4	-	67
-20	12	2	2	2	4	1	77
-21	28	3	-	-	5	1	63
-22	30	4	1	4	6	-	55
-23	30	4	-	4	5	-	57
-24	42	5	-	4	7	-	42
-25	24	3	-	4	5	-	64
-26	22	2	3	4	4	1	64
-27	21	3	1	3	5	1	66
-28	24	3	-	5	4	-	64

Appendix 3B - Whole Rock Relative Mineral Abundances - parts per 100 (con't)

Sample	Q	M	Cc	M-cc	Plag	Gyp	Clay
CB-80-29	22	3	-	3	4	-	68
-30	20	3	-	4	5	-	68
-31	26	5	-	3	5	-	61
-32	22	3	-	3	4	-	68
-33	23	4	1	3	4	1	65
-34	27	3	-	3	6	-	61
-35	24	6	3	4	3	-	60
-36	40	3	-	2	3	-	52
-37	31	3	3	3	4	-	56
-38	21	2	4	2	5	-	66
-39	21	3	-	2	3	1	70
-40	30	3	2	2	4	-	59
-48	22	3	1	3	5	-	66
-49	20	3	-	2	4	-	71
-55	21	3	-	2	4	-	70
-61	16	4	-	3	5	-	75
-71	4	2	-	3	10	-	81
CB-81-1	21	4	-	3	4	-	68
-2	39	3	-	2	8	3	45
-3	19	2	-	2	4	-	73
-4	12	2	-	3	4	-	79
-5	13	3	-	2	7	4	71
-6	26	5	-	2	3	-	64
-7	34	2	-	-	1	-	63
-8	35	3	-	-	3	-	59
-9	15	3	1	3	5	-	73
-9C	1	-	-	-	-	-	99
-10	15	2	-	-	3	-	80
-11	24	3	-	3	5	-	65
-12	15	3	-	3	3	-	76
-13	19	3	1	3	6	-	68
CB-TN-2	33	5	-	-	6	-	56
-3	30	1	-	4	7	-	58

Q - quartz
M - microcline
Cc - calcite
M-cc - mixed calcite
Plag - plagioclase
Gyp - gypsum

Appendix 4A - Method for Semi-Quantitative Clay Mineral Analysis

This study uses a slightly modified method of semi-quantitative analysis of clay minerals currently in use at the New Mexico Bureau of Mines and Mineral Resources.

The following peak heights (peak intensities) were taken above background:

1. The initial untreated run:

   K(1) at 7 Å, 12.4 degrees two-theta
   K(2) at 3.6 Å, 24.9 degrees two-theta
   I(2) at 5 Å, 17.8 degrees two-theta
   C(3) at 4.6 to 4.8 Å, 18.4 to 18.9 degrees two-theta
   C(4) at 3.5 Å, 25.1 degrees two-theta;

2. The ethylene glycol run:

   S(1) at 17 Å, 5.2 degrees two-theta
   I(1G) at 10 Å, 8.8 degrees two-theta;

3. The 350 degree Celsius heated run:

   I(1H) at 10 Å, 8.8 degrees two-theta.

The following is the method of calculation with answers given in parts in 10:

Illite(I) = (I(1G)/T) x 10

Smectite(S) = ((S(1)/4)/T) x 10

Chlorite(C) = (C(3)/I(2)) x (I(1G)/T) x T

Interstratified clays(MX) = ((I(1H) - (I(1G) + (S(1)/4))/T) x 10

Kaolinite(K) = (K(1)/T) x 10, or if chlorite is present:

Kaolinite(K) = (K(2)/2C(4)) x (C(3)/I(2)) x (I(1G)/T) x 10

I(1H) is equal to the counts for illite, smectite, and interstratified clays, T is equal to the "total counts" and is calculated thusly:

T = I(1H) + K(1), or if chlorite is present:

T = [I(1H)] + [(C(3))(I(1G))/I(2)] + [(K(2))(C(3))(I(1G))/(2C(4)(I(2))].

Appendix 4B - Peak Intensity Data for Relative Clay Mineral Abundances: less than 1.0 micron fraction - parts per 100

Sample	T	I(1H)	I(1G)	I(2)	K(1)	K(2)	S(1)	C(3)	C(4)
MB-80-2	57.2	43.0	6.0	----	14.2	----	67.1	----	----
-3	70.3	52.8	10.8	----	17.5	----	85.2	----	----
-4	30.2	17.9	9.4	----	12.3	----	20.0	----	----
-5	56.4	51.0	15.6	----	5.4	----	69.0	----	----
-6	53.7	42.5	22.8	----	11.2	----	94.0	----	----
-7	81.8	68.8	21.0	----	13.0	----	65.0	----	----
-8	59.3	34.5	6.8	----	24.8	----	36.2	----	----
-9	110.0	63.3	12.4	----	46.7	----	67.6	----	----
-10	85.1	65.7	15.5	----	19.4	----	57.6	----	----
-11	65.4	54.5	12.0	12.4	26.0	22.0	53.0	6.0	12.5
-12	91.6	69.6	12.7	----	22.0	----	75.9	----	----
-13	----	----	----	----	----	----	55.2	----	----
-14	----	----	----	----	----	----	67.0	----	----
-15	59.0	53.0	24.0	----	6.0	----	120.0	----	----
-16	----	----	----	----	----	----	57.1	----	----
-17	89.4	29.2	9.0	----	60.2	----	29.1	----	----
-18	124.0	81.8	14.0	----	42.2	----	216.0	----	----
-19	79.9	71.1	17.3	12.5	78.8	64.2	71.6	10.2	53.4
-20	60.3	46.0	11.8	----	14.3	----	43.1	----	----
-21	62.2	46.4	12.2	7.1	33.8	32.0	42.6	5.6	24.5
CB-80-1	118.2	19.2	6.5	----	99.0	----	7.3	----	----
-2	109.9	61.7	15.5	----	48.2	----	6.7	----	----
-3	53.1	45.0	8.0	5.3	17.5	16.2	39.7	4.0	10.6
-4	179.2	77.2	16.6	----	102.0	----	51.2	----	----
-5	91.3	58.6	9.1	----	32.7	----	44.8	----	----
-6	115.8	84.8	20.2	----	31.0	----	69.7	----	----
-7	131.4	68.8	15.0	----	62.6	----	45.2	----	----
-8	72.8	46.8	8.8	----	26.0	----	37.0	----	----
-9	132.8	84.0	16.0	10.4	48.8	43.0	78.4	7.0	20.0
-10	67.0	45.2	7.2	4.0	21.8	17.9	37.3	2.3	10.4
-11	77.8	48.2	8.2	4.8	29.6	25.1	41.8	4.0	15.1
-12	136.7	82.4	12.8	----	54.3	----	107.6	----	----
-13	115.8	74.9	18.4	11.6	84.5	86.6	81.0	8.6	46.6

Appendix 4B - Peak Intensity Data for Relative Clay Mineral Abundances: less than 1.0 micron fraction - parts per 100 (con't)

Sample	T	I(1H)	I(1G)	I(2)	K(1)	K(2)	S(1)	C(3)	C(4)
CB-80-14	95.8	71.0	14.8	8.0	62.2	64.0	69.5	5.6	29.5
-15	107.4	84.7	13.2	11.2	77.4	77.4	87.6	4.0	17.5
-16	58.6	48.4	8.8	6.7	23.6	25.0	47.7	4.3	17.5
-17	57.2	44.9	8.9	7.4	41.0	48.2	40.9	5.0	22.9
-18	117.3	86.1	17.4	9.8	44.0	45.4	86.4	5.2	33.0
-19	91.9	76.2	14.1	9.0	42.0	41.0	73.8	5.0	20.0
-20	118.2	89.0	19.4	13.9	57.9	61.3	81.0	10.0	33.3
-21	77.7	60.2	58.2	10.5	68.0	73.0	58.4	7.0	49.0
-22	72.1	50.0	9.7	----	22.1	----	45.3	----	----
-23	135.7	81.2	17.4	----	54.5	----	97.0	----	----
-24	146.7	84.3	14.8	----	62.4	----	99.2	----	----
-25	76.5	52.1	14.0	----	24.4	----	50.8	----	----
-26	93.3	78.3	11.9	8.8	36.0	35.4	82.9	6.0	20.8
-27	83.0	71.2	13.1	27.4	37.8	51.8	41.6	13.6	31.8
-28	66.9	49.2	8.0	----	17.7	----	46.9	----	----
-29	78.7	57.9	13.0	----	20.8	----	62.7	----	----
-30	109.2	74.2	13.1	----	35.0	----	58.2	----	----
-31	100.2	72.2	11.3	----	28.0	----	55.5	----	----
-32	112.5	85.8	14.3	----	26.7	----	78.2	----	----
-33	109.4	87.2	13.0	10.4	39.6	43.1	82.5	9.0	22.1
-34	98.4	73.3	13.7	8.2	72.5	62.9	64.4	8.0	35.9
-35	61.5	50.0	8.8	5.3	24.5	23.3	48.6	4.0	15.8
-36	100.4	71.6	21.1	14.2	72.5	86.5	65.5	10.2	48.0
-37	114.0	89.0	16.4	10.4	75.8	64.3	70.6	8.8	40.3
-38	57.5	48.7	7.2	5.5	20.0	20.6	48.2	3.8	13.5
-39	70.6	56.4	12.7	8.2	21.9	21.9	44.3	5.6	16.9
-40	111.0	91.8	17.3	12.8	44.5	43.5	78.2	8.5	32.5
-48	98.4	81.4	15.6	12.2	23.6	28.4	119.4	6.6	14.0
-49	131.1	71.0	14.4	----	60.1	----	70.8	----	----
-55	66.3	58.0	8.3	14.8	29.7	37.0	40.4	9.0	29.0
-61	102.3	90.2	12.8	8.4	9.6	12.0	128.0	5.4	13.4
-71	61.4	----	----	----	----	----	58.6	----	----
CB-81-1	127.6	78.4	14.0	----	49.2	----	70.6	----	----

Appendix 4B - Peak Intensity Data for Relative Clay Mineral Abundances: less than 1.0 micron fraction - parts per 100 (con't)

Sample	T	I(1H)	I(1G)	I(2)	K(1)	K(2)	S(1)	C(3)	C(4)
CB-81-2	----	----	----	----	----	----	----	----	----
-3	70.4	52.2	14.0	----	18.2	----	52.6	----	----
-4	79.2	54.4	17.7	17.7	55.6	56.4	36.5	9.5	17.5
-5	36.3	28.3	10.3	6.2	32.0	40.5	30.4	2.4	9.5
-6	95.0	72.0	14.6	----	23.0	----	62.6	----	----
-7	----	----	----	----	----	----	----	----	----
-8	37.0	9.0	3.3	----	28.0	----	3.0	----	----
-9	82.9	60.0	20.1	21.0	44.4	46.0	40.8	10.0	16.5
-9C	19.6	11.0	2.6	----	8.6	----	6.3	----	----
-10	127.7	90.3	34.0	32.7	80.0	78.4	55.6	15.0	28.0
-11	88.0	67.5	15.0	14.8	42.0	36.8	76.4	11.8	25.8
-12	71.6	52.0	15.4	16.2	33.9	38.1	52.8	11.7	25.1
-13	69.3	54.1	14.8	15.0	20.7	22.8	65.9	6.3	8.4
CB-TN-2	64.0	55.8	8.2	4.2	24.8	19.3	54.4	2.4	12.8
-3	116.4	87.6	13.6	14.8	28.8	30.4	63.5	----	----

T - total counts
I(1H) - first-order illite peak on heated run
I(1G) - first-order illite peak on glycolated run
I(2) - second-order illite peak on untreated run
K(1) - first-order peak on untreated run
K(2) - second-order peak on untreated run
S(1) - first-order smectite peak on glycolated run
C(3) - third-order chlorite peak on untreated run
C(4) - fourth-order chlorite peak on untreated run

Appendix 4C - Peak Intensity Data for Relative Clay Mineral Abundances: less than 0.25 micron fraction - parts per 100

Sample	T	I(1H)	I(1G)	I(2)	K(1)	K(2)	S(1)	C(3)	C(4)
CB-80-1	113.2	41.6	26.5	----	71.6	----	33.5	----	----
-2	125.9	88.5	14.1	----	37.4	----	58.0	----	----
-3	67.4	55.0	10.1	7.0	12.4	15.8	55.1	4.5	12.3
-4	113.8	65.7	16.2	----	48.1	----	52.0	----	----
-5	84.2	62.2	12.3	----	22.0	----	55.0	----	----
-6	110.7	65.7	16.0	----	45.0	----	50.6	----	----
-7	66.6	45.8	6.7	----	20.8	----	37.4	----	----
-8	85.7	67.7	10.0	----	18.0	----	69.5	----	----
-9	82.8	67.6	9.2	----	15.2	----	59.2	----	----
-10	60.6	50.5	7.8	5.4	10.1	13.3	61.2	3.5	10.0
-11	90.2	71.0	9.5	6.8	19.2	22.0	69.1	4.3	15.0
-12	99.5	81.8	11.4	----	17.7	----	110.4	----	----
-13	138.8	88.0	20.2	----	50.8	----	84.0	----	----
-14	115.0	84.5	11.6	8.8	30.5	30.1	79.6	5.0	21.8
-15	98.6	68.4	9.9	8.0	30.2	26.8	66.1	5.3	21.7
-16	65.2	53.6	8.8	----	11.6	----	47.0	----	----
-17	87.8	74.2	12.0	8.5	25.0	23.5	59.6	5.0	19.1
-18	83.1	74.0	9.9	10.5	15.7	22.6	78.6	5.6	21.0
-19	99.3	86.7	12.5	10.9	16.4	23.9	78.3	7.8	22.4
-20	87.2	71.6	15.7	10.4	17.8	26.4	59.4	6.4	18.6
-21	75.9	58.6	18.6	15.0	49.7	72.3	73.6	9.0	66.3
-22	66.5	54.5	8.6	----	12.0	----	55.5	----	----
-23	84.6	68.2	12.7	----	16.4	----	73.6	----	----
-24	85.6	68.6	10.2	----	17.0	----	80.7	----	----
-25	116.8	95.6	20.2	----	21.2	----	88.0	----	----
-26	86.4	75.4	12.5	10.7	16.3	20.6	85.5	6.0	18.3
-27	122.4	103.2	19.2	----	19.4	----	77.2	----	----
-28	78.0	68.9	10.2	----	9.1	----	41.1	----	----
-29	113.6	98.2	18.4	----	15.4	----	80.2	----	----
-30	72.1	57.0	10.4	----	15.1	----	40.2	----	----
-31	61.9	52.2	9.6	----	9.7	----	42.7	----	----
-32	90.6	80.7	12.1	----	9.9	----	80.8	----	----
-33	65.6	111.0	18.0	11.9	18.8	17.2	83.6	8.6	15.7
-34	69.5	57.6	10.5	6.6	29.4	24.8	61.3	4.5	18.8

Appendix 4C - Peak Intensity Data for Relative Clay Mineral Abundances: less than 0.25 micron fraction - parts per 100 (con't)

Sample	T	I(1H)	I(1G)	I(2)	K(1)	K(2)	S(1)	C(3)	C(4)
CB-80-36	91.2	70.0	18.7	10.5	36.9	36.5	54.8	7.5	31.0
-37	109.2	75.7	12.0	7.8	33.5	29.0	78.2	4.0	12.0
-38	97.1	78.2	13.8	7.2	17.6	17.7	70.2	6.2	15.0
-39	132.2	105.4	24.2	----	26.8	----	81.2	----	----
-40	107.2	92.5	12.7	10.0	23.6	25.6	81.8	7.3	21.6
-48	88.8	82.0	15.6	9.6	6.8	10.6	99.0	----	----
-49	113.0	83.3	10.5	----	29.7	----	73.7	----	----
-55	106.2	88.0	14.7	24.3	23.0	34.8	62.2	17.8	25.3
-61	68.4	54.5	14.6	6.0	2.6	4.4	82.3	4.2	6.0
-71	----	----	----	----	----	----	88.0	----	----
CB-81-1	58.2	47.0	15.0	----	11.2	----	46.2	----	----
-2	----	----	----	----	----	----	----	----	----
-3	80.7	72.0	17.9	----	8.7	----	70.6	----	----
-4	116.0	93.6	31.8	22.3	12.4	12.8	75.2	3.0	12.0
-5	98.2	73.6	27.4	15.4	6.0	14.6	77.8	8.0	10.0
-6	58.4	51.4	8.7	----	7.0	----	46.4	----	----
-7	----	----	----	----	----	----	----	----	----
-8	14.4	9.2	4.2	----	5.2	----	3.0	----	----
-9	108.8	85.8	28.0	18.8	9.1	12.0	63.8	10.0	11.0
-9C	20.1	15.7	7.0	3.5	2.6	3.0	----	1.5	3.2
-10	88.3	67.5	23.2	12.1	10.4	6.8	43.7	6.7	5.5
-11	45.2	31.0	11.0	3.8	5.8	4.1	30.0	3.6	4.0
-12	71.0	52.0	17.3	8.8	12.1	9.8	43.8	6.0	8.0
-13	86.1	65.6	20.0	11.7	8.0	9.1	74.0	6.3	8.4
CB-TN-2	51.8	43.0	6.3	4.3	8.8	10.4	53.8	2.5	9.9
-3	61.7	55.7	10.3	----	6.0	----	51.4	----	----

T - total counts
I(1H) - first-order illite peak on heated run
I(1G) - first-order illite peak on glycolated run
I(2) - second-order illite peak on untreated run

Appendix 4C - Peak Intensity Data for Relative Clay Mineral Abundances: less than 0.25 micron fraction - parts per 100 (con't)

K(1) - first-order peak on untreated run
K(2) - second-order peak on untreated run
S(1) - first-order smectite peak on glycolated run
C(3) - third-order chlorite peak on untreated run
C(4) - fourth-order chlorite peak on untreated run

Appendix 4D - Clay Mineral Relative Abundances: less than 1.0 micron fraction - parts per 10

Rock Unit	Sample	I	K	S	MX	C
MT	CB-81-11	2	1	1	5	1
	-12	2	1	1	4	2
	-13	2	1	2	4	1
ST	MB-80-19	2	1	6	T*	1
	-20	2	2	1	5	-
	-21	2	1	1	5	1
CMbr	MB-80-17	1	7	T	2	-
	-18	1	4	1	4	-
	CB-80-48	2	1	3	3	1
	-49	1	5	1	3	-
uMF	MB-80-8	1	4	1	4	-
	-9	1	4	1	4	-
	CB-80-4	1	6	T	3	-
	-5	1	4	T	5	-
	-6	2	3	T	1	-
	-7	1	5	1	3	-
	-8	1	4	1	4	-
	-9	1	4	1	4	T
	-10	1	3	1	5	T
	-11	1	4	1	4	T
	-12	1	4	2	3	-
	-22	1	3	1	5	-
	-23	1	4	1	4	-
	-24	1	4	1	4	-
	-25	2	3	1	4	-
	-28	1	3	T	6	-
	-29	2	2	1	5	-
	-30	1	3	1	5	-
	CB-81-1	1	4	1	4	-
	-2	-	-	-	-	-
	-3	2	4	1	4	-
	-6	2	2	1	5	-
	-7	-	10	-	-	-
	-8	1	8	T	1	-
LVT	CB-80-13	2	1	T	5	2
	-31	1	3	1	5	-
	-32	1	3	1	5	-
	-33	1	1	1	6	1
	CB-81-4	2	2	1	4	1
	-5	2	1	1	5	1
	-9	2	2	1	4	1
	-9C	2	4	T	4	-
	-10	3	2	T	4	1
	CB-TN-3	1	2	1	6	T

Appendix 4D - Clay Mineral Relative Abundances: less than 1.0 micron fraction - parts per 10 (con't)

Rock Unit	Sample	I	K	S	MX	C
lLS	MB-80-10	2	2	1	5	-
	-11	2	1	2	4	1
	CB-80-1	1	8	T	1	-
	-2	1	5	T	4	-
	-3	1	1	1	6	1
	-14	2	1	1	5	1
	-15	1	1	1	6	1
	-16	1	1	1	6	1
	-17	1	1	1	6	1
	-18	1	2	1	5	1
	-19	1	1	1	6	1
	-20	2	1	T	6	1
	-21	2	1	T	6	1
	-26	1	1	1	6	1
	-27	1	1	T	7	1
	-34	2	1	1	5	1
	-35	1	1	1	6	1
	-36	2	1	-	5	2
	CB-TN-2	1	2	2	5	T
uLS	MB-80-5	3	1	1	5	-
	-6	4	2	2	2	-
	-7	3	2	1	4	-
	-12	1	2	1	6	-
	CB-80-37	1	1	1	6	1
	-38	1	1	1	6	1
	-39	2	1	T	6	1
	-40	2	1	T	6	1
	-55	1	T	1	7	1
FF	MB-80-2	1	2	4	3	-
	-3	2	2	3	3	-
	-4	3	4	-	3	-
	-13	-	-	10	-	-
	-14	T	T	10	T	-
	-15	-	1	9	-	-
	-16	-	-	10	-	-
	CB-80-61	1	T	3	5	1
	-71	-	-	10	-	-
AVE		1.4	2.4	1.5	4.1	.4
Std. dev.		.7	2.2	2.6	1.9	.7

I - illite
K - kaolinite
S - smectite
MX - interstratified clays
C - chlorite

Appendix 4D - Clay Mineral Abundances: less than 1.0 micron fraction - parts per 10 (con't)

MT - Mulatto Tongue
ST - Satan Tongue
CMbr - Cleary Member
uMF - upper Menefee Formation
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Formation

* Trace

Appendix 4E - Clay Mineral Relative Abundances: less than 0.25 micron fraction - parts per 10

Rock Unit	Sample	I	K	S	MX	C
MT	CB-81-11	2	1	2	3	2
	-12	2	1	1	4	2
	-13	2	1	2	4	1
CMbr	CB-80-48	2	1	3	4	T*
	-49	1	3	1	5	-
uMF	CB-80-4	2	4	T	4	-
	-5	1	3	1	5	-
	-6	2	4	T	4	-
	-7	1	3	1	5	-
	-8	1	2	1	6	-
	-9	1	2	1	6	-
	-10	1	2	1	6	T
	-11	1	2	1	6	T
	-12	1	2	3	4	-
	-22	1	2	1	6	-
	-23	1	2	1	6	-
	-24	1	2	1	6	-
	-25	2	2	1	5	-
	-28	1	1	1	7	-
	-29	2	1	1	6	-
	-30	1	2	1	6	-
	CB-81-1	3	2	1	4	-
	-2	-	-	-	-	-
	-3	2	1	1	6	-
	-6	2	1	1	6	-
	-7	-	-	-	-	-
	-8	3	4	T	3	-
LVT	CB-80-13	1	4	T	5	-
	-31	1	2	1	6	-
	-32	1	1	1	7	-
	-33	1	1	1	6	1
	CB-81-4	3	1	1	5	T
	-5	3	1	1	4	1
	-9	3	1	1	4	1
	-9C	3	1	-	4	2
	-10	3	1	1	4	1
	CB-TN-3	2	1	1	6	-
lLS	CB-80-1	3	6	T	1	-
	-2	1	3	T	6	-
	-3	2	2	1	5	T
	-14	1	3	1	5	T
	-15	1	3	1	5	T
	-16	1	2	1	6	-
	-17	1	1	1	6	1
	-18	1	T	1	7	1

Appendix 4E - Clay Mineral Relative Abundances: less than 0.25 micron fraction - parts per 10 (con't)

Rock Unit	Sample	I	K	S	MX	C
lLS	CB-80-19	1	T*	1	7	1
	-20	2	1	T	6	1
	-21	2	1	1	5	1
	-26	1	1	1	6	1
	-27	2	2	T	6	-
	-34	1	1	1	6	1
	-35	1	2	1	6	-
	-36	2	1	-	6	1
	CB-TN-2	1	2	2	5	T
uLS	CB-80-37	1	3	1	5	T
	-38	1	1	1	6	1
	-39	2	2	T	6	-
	-40	1	T	1	7	1
	-55	1	1	1	6	1
FF	CB-80-61	2	1	5	1	1
	-71	-	-	10	-	-
AVE		1.5	1.7	1.1	4.9	0.4
Std. dev.		.8	1.1	1.4	1.7	0.6

I - illite
K - kaolinite
S - smectite
MX - interstratified clays
C - chlorite

MT - Mulatto Tongue
ST - Satan Tongue
CMbr - Cleary Member
uMF - upper Menefee Formation
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Formation

* Trace

Appendix 5 - Whole Rock Major Element Chemical Composition-Weight Percents of Oxide Consituents

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	TiO_2	CaO	K_2O	P_2O_5	MgO	Na_2O	LOI	TOTAL
MB-80-5	58.7	14.9	4.60	0.047	0.632	5.45	2.59	0.140	2.08	1.07	8.97	99.1
-5-1*	53.0	23.8	7.64	0.010	0.642	0.048	3.46	0.039	2.42	1.97	7.32	100
-14-1*	59.7	21.2	5.93	0.014	0.902	0.086	0.672	0.043	1.81	3.04	6.09	99.5
-16-1*	64.3	17.5	7.56	0.021	0.787	0.071	0.969	0.024	1.21	2.82	4.97	100
-21	62.1	16.8	5.16	0.018	0.604	0.702	2.63	0.123	1.92	1.83	7.21	99.1
-21-1*	51.1	26.1	7.98	0.014	0.717	0.025	3.26	0.042	2.48	1.88	8.47	102
CB-80-1	77.0	11.0	1.80	0.005	0.397	0.111	2.11	0.010	0.459	0.962	9.39	103
-4	68.2	15.7	1.78	0.006	0.733	0.056	2.63	0.079	1.08	1.12	8.02	99.4
-5	65.3	16.1	2.15	0.008	0.727	0.168	2.51	0.028	0.978	0.735	10.8	99.5
-5	65.3	16.2	2.15	0.003	0.714	0.183	2.51	0.027	0.957	0.885	10.8	99.7
-11	65.3	15.2	2.96	0.036	0.688	2.35	2.64	0.126	2.06	1.37	6.74	99.5
-11-1*	54.4	25.6	5.65	0.014	0.767	0.037	3.45	0.030	2.35	1.80	7.65	102
-13	67.6	14.9	3.28	0.032	0.637	1.66	2.39	0.147	2.06	1.18	6.19	100
-13-1*	52.0	25.9	7.31	0.021	0.728	0.048	3.52	0.035	2.54	1.42	8.27	102
-19	62.7	16.8	4.69	0.045	0.704	1.65	2.84	0.130	2.14	1.08	6.90	100
-19-1*	52.6	24.7	8.15	0.025	0.698	0.046	3.48	0.052	2.39	1.90	7.65	102
-22	68.9	15.3	1.92	0.009	0.698	0.145	2.73	0.005	1.49	1.25	7.11	99.6
-23	68.9	15.3	3.14	0.025	0.649	0.143	2.75	0.110	1.68	1.39	5.80	99.9
-23-1*	69.1	15.4	3.13	0.025	0.641	0.158	2.74	0.119	1.64	1.43	5.80	100
-26	62.9	17.3	3.82	0.032	0.695	1.95	2.77	0.099	2.06	0.879	7.72	100
-26-1*	54.6	25.4	5.86	0.019	0.691	0.042	3.27	0.040	2.31	2.25	7.46	102
-28	64.7	17.6	2.45	0.008	0.729	0.056	2.84	0.046	1.58	0.990	8.58	99.6
-28-1*	56.8	25.3	4.03	0.012	0.819	0.015	3.72	0.046	1.99	1.91	7.78	102
-29	65.2	16.5	4.26	0.011	0.729	0.191	2.94	0.066	1.21	1.09	7.74	99.9
-30	64.9	17.1	5.23	0.043	0.713	0.189	2.77	0.110	1.63	1.13	6.24	100
-31	67.1	16.7	2.42	0.008	0.761	0.074	2.81	0.064	1.59	0.975	6.41	98.9
-31-1*	53.0	25.0	4.45	0.007	0.815	0.088	3.42	0.126	3.00	0.461	10.1	101
-34	69.8	14.2	3.54	0.027	0.594	1.134	2.40	0.132	2.10	1.52	5.56	101
-35-1*	54.5	25.5	6.01	0.011	0.694	0.031	3.48	0.026	2.54	1.94	7.17	102
-49	63.5	16.8	8.12	0.005	0.726	0.137	2.82	0.064	1.53	1.89	5.42	101
-49-1*	51.8	23.4	11.9	0.014	0.584	0.105	2.67	0.054	2.53	1.64	7.78	102
-54	72.9	9.77	3.27	0.024	0.380	2.041	1.94	0.111	2.48	1.07	5.66	99.6
-54-1*	50.4	24.9	9.38	0.040	0.652	0.110	3.30	0.038	2.73	1.51	8.25	101

Appendix 5 - Whole Rock Major Element Chemical Composition-Weight Percents of Oxide Constituents (con't)

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	TiO_2	CaO	K_2O	P_2O_5	MgO	Na_2O	LOI	TOTAL
CB-80-55	62.8	17.1	4.89	0.020	0.659	0.851	2.55	0.098	2.29	1.49	7.32	100
-56	66.3	16.7	5.25	0.016	0.665	0.505	2.83	0.036	1.55	1.97	4.94	101
-61	65.7	16.7	5.14	0.028	0.668	0.606	3.08	0.151	1.71	1.91	5.21	101
-71	60.5	22.3	3.85	0.033	0.405	1.90	0.319	0.266	1.85	3.39	5.78	101
-71-1*	60.5	12.8	4.03	0.034	0.377	1.00	0.157	0.050	2.11	2.68	5.64	99.3
CB-81-3	64.2	18.1	2.33	0.013	0.705	0.076	3.00	0.046	1.73	1.14	9.94	101
-3	64.3	18.2	2.34	0.008	0.699	0.078	3.01	0.049	1.70	1.13	9.94	101
-4	60.5	19.8	4.24	0.017	0.859	0.262	3.19	0.090	2.48	1.06	7.44	99.9
-5	22.6	7.47	52.5	0.467	0.308	0.535	1.05	0.109	2.16	0.568	12.8	101
-5	22.6	7.48	52.3	0.460	0.301	0.552	1.05	0.106	2.17	0.654	12.8	100
-9	59.0	20.9	4.57	0.020	0.896	0.481	3.61	0.130	2.95	1.65	6.59	101
-9C	11.3	3.82	68.0	0.960	0.170	0.224	0.597	0.187	2.11	0.698	12.9	101
-9C-1*	17.5	9.16	57.5	0.756	0.269	0.039	1.61	0.145	1.63	1.07	12.5	102
-10	59.8	17.6	7.91	0.031	0.739	0.510	3.13	0.115	2.60	1.23	7.33	101
-10-1*	51.4	23.7	8.64	0.030	0.864	0.296	3.95	0.084	3.24	0.396	8.80	101
-11	64.8	15.8	4.93	0.033	0.786	0.662	3.21	0.221	2.66	2.11	5.53	101
CB-TN-2	59.0	13.7	4.06	0.020	0.601	0.878	2.45	0.132	2.50	1.24	15.7	100
-3	69.4	16.5	2.83	0.007	0.882	0.360	2.77	0.021	1.37	1.20	5.74	101

* less than 1.0 micron fraction

Appendix 6A - Percent Expandable Layers for Random Interstratified Clays: less than 1.0 micron fraction

Rock Unit	Sample	2-theta	d-spacing	% expandable layers
MT	CB-81-11	9.04	9.78	24
	-12	9.07	9.74	26
	-13	9.33	9.48	36
ST	MB-80-19	9.00	9.83	23
	-20	8.98	9.85	23
	-21	8.94	9.89	21
CMbr	MB-80-17	8.80	10.05	70
	-18	9.00	9.83	23
	CB-80-48	9.51	9.30	43
	-49	8.95	9.88	21
uMF	MB-80-8	9.30	9.51	35
	-9	9.00	9.82	56
	CB-80-4	8.94	9.89	21
	-5	8.93	9.90	20
	-6	8.95	9.88	21
	-7	9.14	9.68	28
	-8	8.80	10.05	10-
	-9	8.90	9.94	20
	-10	8.94	9.89	21
	-11	8.91	9.92	18
	-12	10.03	8.82	68
	-22	8.96	9.87	21
	-23	8.97	9.86	22
	-24	8.95	9.88	21
	-25	9.00	9.83	23
	-28	8.92	9.91	19
	-29	9.00	9.83	23
	-30	9.08	9.74	26
	CB-81-1	9.37	9.44	37
	-3	9.00	9.83	23
	-6	9.18	9.63	30
	-8	8.72	10.14	10-
LVT	CB-80-13	8.98	9.85	23
	-31	9.23	9.58	33
	-32	9.00	9.83	23
	-33	8.98	9.85	23
	CB-81-4	9.07	9.74	26
	-9	9.00	9.83	23
	-10	8.95	9.88	21
	CB-TN-3	9.40	9.41	38
lLS	MB-80-10	9.11	9.71	52
	-11	8.90	9.94	20
	CB-80-1	8.88	9.97	62
	-2	8.87	9.97	62

Appendix 6A - Percent Expandable Layers for Random Interstratified Clays: less than 1.0 micron fraction (con't)

Rock Unit	Sample	2-theta	d-spacing	% expandable layers
lLS	CB-80-3	8.90	9.94	20
	-14	8.90	9.94	20
	-15	8.97	9.86	22
	-16	8.77	10.08	10-
	-17	8.94	9.89	21
	-18	8.89	9.95	17
	-19	8.88	9.97	62
	-20	9.00	9.83	23
	-21	9.94	9.89	21
	-26	8.94	9.89	21
	-27	8.97	9.86	22
	-34	8.90	9.94	20
	-35	8.90	9.94	20
	-36	8.90	9.94	20
	CB-TN-2	8.98	9.85	43
uLS	MB-80-5	9.08	9.74	25
	-6	9.10	9.72	53
	-7	8.93	9.90	60
	-12	8.95	9.88	23
	CB-80-37	9.07	9.75	25
	-38	8.91	9.92	20
	-39	9.00	9.83	23
	-40	9.04	9.78	24
	-55	8.94	9.89	21
FF	MB-80-2	10.20	8.67	85
	-3	10.30	8.60	90+
	-4	9.00	9.82	56
	-13	10.40	8.51	90+
	-14	10.29	8.60	75
	-15	10.34	8.56	90+
	-16	10.40	8.51	70
	CB-80-61	10.14	8.72	80
	-71	10.42	8.49	100

MT - Mulatto Tongue
ST - Satan Tongue
CMbr - Cleary Member
uMF - upper Menefee Formation
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Formation

Appendix 6B - Percent Expandable Layers for Random Interstratified Clays: less than 0.25 micron fraction

Rock Unit	Sample	2-theta	d-spacing	% expandable layers
MT	CB-81-11	8.93	9.90	20
	-12	9.14	9.68	28
	-13	9.33	9.48	36
CMbr	CB-80-48	9.62	9.19	47
	-49	8.91	9.92	20
uMF	CB-80-4	9.12	9.70	27
	-5	8.97	9.86	22
	-6	8.90	9.94	18
	-7	9.07	9.75	25
	-8	8.90	9.94	18
	-9	9.28	9.53	34
	-10	9.15	9.67	28
	-11	9.07	9.75	25
	-12	9.80	9.03	55
	-22	9.22	9.59	90+
	-23	9.89	8.94	58
	-24	9.20	9.61	30
	-25	9.20	9.61	30
	-28	9.20	9.61	30
	-29	9.18	9.63	30
	-30	9.25	9.56	33
	CB-81-1	9.26	9.55	33
	-3	9.14	9.68	28
	-6	9.40	9.41	38
LVT	CB-80-13	9.03	9.79	24
	-31	9.31	9.50	35
	-32	9.20	9.61	30
	-33	9.17	9.64	30
	CB-81-4	9.37	9.44	37
	-5	9.20	9.61	30
	-9	9.19	9.62	30
	-10	9.04	9.78	24
	CB-TN-3	9.57	9.24	45
lLS	CB-80-1	8.75	10.11	10-
	-2	8.94	9.89	20
	-3	9.00	9.83	25
	-14	9.22	9.59	90+
	-15	9.07	9.75	25
	-16	9.27	9.54	34
	-17	9.06	9.76	25
	-18	9.06	9.76	25
	-19	9.13	9.69	27
	-20	9.04	9.78	24
	-21	8.95	9.88	21

Appendix 6B - Percent Expandable Layers for Random Interstratified Clays: less than 0.25 micron fraction (con't)

Rock Unit	Sample	2-theta	d-spacing	% expandable layers
lLS	CB-80-26	9.04	9.78	24
	-27	9.28	9.53	34
	-34	8.96	9.87	21
	-35	9.14	9.68	28
	-36	8.91	9.92	20
	CB-TN-2	9.30	9.51	34
uLS	CB-80-37	9.14	9.68	28
	-38	9.20	9.61	30
	-39	9.12	9.70	27
	-40	9.03	9.79	24
	-55	9.29	9.52	34
FF	CB-80-61	10.17	8.70	78
	-71	10.36	8.54	90+

MT - Mulatto Tongue
CMbr - Cleary Member
uMF - upper Menefee Formation
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Formation

Appendix 7A - (001) D-spacing for Smectite-Interstratified Clay - Illite Reflections: less than 1.0 micron fraction

Rock Unit	Sample	D-spacing(Å)
MT	CB-81-11	13.70
	-12	13.31
	-13	13.39
ST	MB-80-19	11.43
	-20	11.45
	-21	11.54
CMbr	MB-80-17	11.21
	-18	11.95
	CB-80-48	11.69
	-49	11.63
uMF	MB-80-8	12.28
	-9	13.00
	CB-80-4	11.16
	-5	11.39
	-6	11.33
	-7	12.56
	-8	11.62
	-9	11.51
	-10	11.60
	-11	11.71
	-12	11.76
	-22	11.48
	-23	11.63
	-24	11.60
	-25	12.94
	-28	11.28
	-29	12.28
	-30	13.06
	CB-81-1	12.92
	-2	-----
	-3	11.42
	-6	12.45
	-7	-----
	-8	-----
LVT	CB-80-13	11.33
	-31	12.79
	-32	11.69
	-33	11.63
	CB-81-4	12.63
	-5	11.28
	-9	12.21
	-9C	-----
	-10	13.08
	CB-TN-3	12.77

Appendix 7A - (001) D-spacing for Smectite-Interstratified Clay-Illite Reflections: less than 1.0 micron fraction (con't)

Rock Unit	Sample	D-spacing(Å)
lLS	MB-80-10	11.62
	-11	13.10
	CB-80-1	10.55
	-2	11.24
	-3	11.71
	-14	11.68
	-15	11.63
	-16	11.36
	-17	11.53
	-18	11.51
	-19	11.50
	-20	11.09
	-21	11.32
	-26	13.15
	-27	12.63
	-34	11.63
	-35	11.57
	-36	11.05
	CB-TN-2	12.08
uLS	MB-80-5	11.53
	-6	11.63
	-7	11.42
	-12	11.66
	CB-80-37	11.57
	-38	11.59
	-39	11.31
	-40	11.48
	-55	12.11
FF	MB-80-2	12.52
	-3	12.28
	-4	12.48
	-13	13.35
	-14	12.29
	-15	14.10
	-16	12.63
	CB-80-61	12.16
	-71	12.72

MT - Mulatto Tongue
ST - Satan Tongue
CMbr - Cleary Member
uMF - upper Menefee Formation
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Formation

Appendix 7B - (001) D-spacing for Smectite-Interstratified Clay-Illite Reflections: less than 0.25 micron fraction

Rock Unit	Sample	D-spacing(Å)
MT	CB-81-11	11.89
	-12	12.23
	-13	12.42
CMbr	CB-80-48	11.69
	-49	11.38
uMF	CB-80-4	11.09
	-5	11.38
	-6	11.33
	-7	12.57
	-8	11.39
	-9	11.69
	-10	11.72
	-11	11.76
	-12	11.71
	-22	11.47
	-23	11.51
	-24	11.69
	-25	12.45
	-28	11.05
	-29	12.28
	-30	12.63
	CB-81-1	12.63
	-2	-----
	-3	11.42
	-6	12.31
	-7	-----
	-8	-----
LVT	CB-80-13	11.25
	-31	12.29
	-32	11.51
	-33	11.47
	CB-81-4	12.18
	-5	11.12
	-9	12.04
	-9C	-----
	-10	11.79
	CB-TN-3	12.35
lLS	CB-80-1	10.78
	-2	11.32
	-3	11.71
	-14	11.68
	-15	11.63
	-16	11.42
	-17	11.41

Appendix 7B - (001) D-spacing for Smectite-Interstratified Clay-Illite Reflections: less than 0.25 micron fraction (con't)

Rock Unit	Sample	D-spacing(Å)
lLS	CB-80-18	11.63
	-19	11.50
	-20	11.18
	-21	10.95
	-26	11.53
	-27	12.28
	-34	11.54
	-35	11.42
	-36	11.11
	CB-TN-2	11.80
uLS	CB-80-37	11.42
	-38	11.48
	-39	11.22
	-40	11.39
	-55	11.72
FF	CB-80-61	11.76
	-71	12.52

MT - Mulatto Tongue
CM - Cleary Member
uMF - upper Menefee Formation
LVT - La Ventana Tongue
lLS - lower Lewis Shale
uLS - upper Lewis Shale
FF - Fruitland Formation

BIBLIOGRAPHY

Austin, G. S. and R. K. Leininger, 1976, The effects of heat-treating sedimented mixed-layer illite-smectite as related to quantitative clay mineral determinations: J. Sed. Pet., v. 46, p. 206-215.

Baltz, E. H., S. R. Ash, and R. Y. Anderson, 1966, History of nomenclature and stratigraphy of rocks adjacent to the Cretaceous-Tertiary boundary western San Juan Basin, New Mexico: USGS Prof. Paper 524-D, 23 p.

Bauer, C. M., 1916, Stratigraphy of a part of the Chaco River Valley: USGS Prof. Paper 98, 274 p.

Beaumont, E. C., C. H. Dane, and J. D. Sears, 1956, Revised nomenclature of Mesaverde Group in San Juan Basin: AAPG Bull., v. 40, p. 2149-2162.

______________, and J. W. Shomaker, 1974, Upper Cretaceous coal in the Cuba-La Ventana-Torreon area, eastern San Juan Basin, New Mexico: in C. T. Siemers (ed.), New Mexico Geol. Soc. Guidebook, 25th Field Conf., Ghost Ranch. p. 329-345.

Blatt, H., G. Middleton, and R. Murray, 1972, Origin of sedimentary rocks. Prentice-Hall, Englewood Cliffs, N. J. 634 p.

Bodine, M. W., Jr., 1979, Geochemistry and mineralogy of shales in coal-bearing strata: a potential exploration tool. Grant Proposal, N. M. Inst. of Mining and Tech. 14 p.

______________, and T. H. Fernalld, 1973, EDTA dissolution of gypsum, anhydrite, and Ca-Mg carbonates: J. Sed. Pet., v. 43, p. 1152-1156.

Bowles, F. A., 1978, Clay as a sediment: in R. W. Fairbridge and J. Bourgeois (eds.), Encyclopedia of sedimentology. Dowden, Hutchinson, and Ross, Stroudsburg, Pa. p. 139-148.

Brown, G. (ed.), 1972, The x-ray identification and crystal structures of clay minerals. Mineralogical Society, London, 544 p.

Brown, L. F., Jr., S. W. Bailey, L. M. Cline, and J. S. Lister, 1977, Clay mineralogy in relation to deltaic sedimentation patterns of Desmoinesian cyclothems in Iowa-Missouri: Clay and Clay Minerals, v. 25, p. 171-188.

Brownlow, A. H., 1979, Geochemistry. Prentice-Hall, Englewood Cliffs, N. J. 498 p.

Bureau of Business and Economic Research, 1980, New Mexico statistical abstracts: 1979-80. University of N. M., Albuquerque, N. M. 225 p.

Carmichael, A. B., 1982, Mineralogy and geochemistry of Upper Cretaceous clay mineral assemblages from the Star Lake-Torreon coal field, San

Juan Basin, New Mexico. M. S. Thesis, N. M. Inst. of Mining and Tech. 87 p.

Carroll, D., 1962, The clay minerals: in H. B. Milner (ed.), Sedimentary petrography, v. 2, p. 288-371.

__________, 1970, Clay minerals: a guide to their x-ray identification: GSA Spec. Paper 126, 80 p.

Collier, A. J., 1919, Coal south of Mancos, Montezuma County, Colorado: USGS Bull. 691, 296 p.

Dane, C. H., 1936, The La Ventana-Chacra Mesa coal field: USGS Bull. 860-C, p. 81-161.

Dunoyer de Sergonzac, G., 1970, The transformation of clay minerals during diagenesis and low-grade metamorphism: a review: Sedimentology, v. 15, p. 281-346.

______________________, 1978, Clay diagenesis: in R. W. Fairbridge and J. Bourgeois (eds.), Encyclopedia of sedimentology. Dowden, Hutchinson and Ross, Stroudsburg, Pa. p. 149-152.

Edzwald, J. K. and C. E. O'Melia, 1975, Clay distributions in Recent estuarine sediments: Clay and Clay Minerals, v. 23, p. 39-44.

Fassett, J. E., 1974, Cretaceous and Tertiary rocks of the eastern San Juan Basin, New Mexico and Colorado: in C. T. Siemers (ed.), New Mexico Geol. Soc. Guidebook, 25th Field Conf., Ghost Ranch, p. 225-230.

_____________, 1976, Stratigraphy of the coals of the San Juan Basin: Symposium on the Geol. of Rocky Mountain Coal, p. 61-71.

_____________, and J. S. Hinds, 1971, Geology and fuel resources of the Fruitland Formation and Kirtland Shale of the San Juan Basin, New Mexico and Colorado: USGS Prof. Paper 676, 76 p.

Foster, M. D., 1962, Interpretation of the composition and a classification of the chlorites: USGS Prof. Paper 414-A, 33 p.

Fuchs-Parker, J. W., 1977, Alibi for a Mesaverde misfit: the La Ventana Formation Cretaceous delta, New Mexico: in J. E. Fassett (ed.), New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 199-206.

Gardner, J. H., 1909, The coal fields between Gallina and Raton Springs, New Mexico: in Coal Fields of Colorado, New Mexico, Utah, Oregon, and Arizona: USGS Bull. 341-C, p. 335-351.

_____________, 1910, The coal field between San Mateo and Cuba, New Mexico: in Coal Fields in Colorado and New Mexico: USGS Bull. 381-C, p. 461-473.

Gibbs, R. J., 1965, Error due to segregation in quantitative clay mineral x-ray diffraction mounting techniques: Am. Min., v. 50, p. 741-751.

__________, 1968, Clay mineral mounting techniques for x-ray diffraction analysis: a discussion: J. Sed. Pet., v. 38, p. 242-244.

__________, 1977, Clay mineral segregation in the marine environment: J. Sed. Pet., v. 47, p. 237-243.

Glover, E. D., 1961, Method of solution of calcareous materials using the complexing agent, EDTA: J. Sed. Pet., v. 31, p. 622-626.

Grim, R. E., 1968, Clay mineralogy (2nd ed.). McGraw-Hill, N. Y. 596 p.

Heling, D., 1978, Diagenesis of illite in argillaceous sediments of the Rhinegraben: Clay Minerals, v. 13, p. 211-219.

Heller-Kallai, L. and Z. H. Kalman, 1972, Some naturally occurring illite-smectite interstratifications: Clays and Clay Minerals, v. 20, p. 165-168.

Hollenshead, C. T. and R. L. Pritchard, 1961, Geometry of producing Mesaverde sandstones, San Juan Basin: in J. A. Peterson and J. C. Osmond (eds.), Geometry of sandstone bodies: AAPG Symposium, p. 98-118.

Holmes, W. H., 1877, Geologic report on the San Juan District, Colorado: U. S. Geol. and Geog. Surv., Terr. 9th Ann. Rept., for 1875, 35 p.

Hower, J., 1967, Order of mixed-layering in illite/montmorillonites: in S. W. Bailey (ed.), Clays and clay minerals: proceedings of the fifteenth conference. Pergamon Press, N. Y., p. 63-74.

__________ and T. C. Mowatt, 1966, The mineralogy of illites and mixed-layer illite/montmorillonites: Am. Min., v. 51, p. 825-854.

__________, E. V. Eslinger, M. E. Hower, and E. A. Perry, 1976, Mechanism of burial metamorphism of argillaceous sediment: 1. Mineralogical and chemical evidence: GSA Bull., v. 87, p. 725-737.

Hunt, C. B., 1936, The Mount Taylor coal field: USGS Bull. 860-B, p. 31-80.

Johns, W. D. and R. E. Grim, 1954, Quantitative estimations of clay minerals by diffraction methods: J. Sed. Pet., v. 24, p. 242-251.

Keller, W. D., 1970, Environmental aspects of clay minerals: J. Sed. Pet., v. 40, p. 788-854.

Kelly, V. C., 1957, Tectonics of the San Juan Basin and surrounding areas: in Geology of southwestern San Juan Basin, New Mexico Geol. Soc. Guidebook, 2nd Field Conf., Four Corners, p. 44-52.

Keroher, G. C. and others, 1967, Lexicon of geologic names of the United States 1936-1960: USGS Bull. 1200 in 3 volumes, 4341 p.

Kinter, E. B. and S. Diamond, 1956, A new method for preparation and treatment of oriented-aggregate specimens of soil clays for x-ray diffraction analysis: Soil Science, v. 81, p. 111-120.

van Langveld, A. D., S. J. van der Gaast, and D. Eisma, 1977, A comparison of the effectiveness of eight methods for the removal of organic matter from clay: Clay and Clay Minerals, v.26, p. 361-364.

Mannhard, G. W., 1976, Stratigraphy, sedimentology, and paleoenvironments of the La Ventana Tongue (Cliff House Sandstone) and adjacent formations of the Measverde Group (Upper Cretaceous), southeastern San Juan Basin, New Mexico. Ph. D. Thesis, Univ. of N. M. 182 p.

Millot, G., 1978, Clay-genesis: in R. W. Fairbridge and J. Bourgeois (eds.), Encyclopedia of sedimentology. Dowden, Hutchinson and Ross, Stroudsburg, Pa. p. 152-156.

Mills, J. G. and M. A. Zwarich, 1972, Recognition of interstratified clays: Clays and Clay Minerals, v. 20, p. 169-174.

Molenaar, C. M., 1974, Correlation of the Gallup Sandstone and associated formations, Upper Cretaceous, eastern San Juan and Acoma Basins, New Mexico: in C. T. Siemers (ed.), New Mexico Geol. Soc. Guidebook, 25th Field Conf., Ghost Ranch, p. 251-258.

________________, 1977, Stratigraphy and depositional history of Upper Cretaceous rocks of the San Juan Basin area, New Mexico and Colorado, with a note on economic resources: in J. E. Fassett (ed.), New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 159-166.

Murray, H. H., 1954, Genesis of clay minerals in some Pennsylvanian shales of Indiana and Illinois: Clays and Clay Minerals, v. p. 49-67.

Norrish, K. and J. T. Hutton, 1969, An accurate x-ray spectrographic method for the analysis of a wide range of geological samples: Geochim. Cosmo. Acta, v. 33, p. 431-453.

Parham, W. E., 1966, Lateral variations of clay mineral assemblages in modern and ancient sediments: in A. V. Carozzi (ed.), Sedimentary Rocks: concept and history. Dowden, Hutchinson and Ross, N. Y. p. 174-184.

Pettijohn, F. J., 1975, Sedimentary Rocks. Harper and Row, N. Y. 628 p.

Picard, M. D., 1971, Classification of fine-grained sedimentary rocks: J. Sed. Pet., v. 41, p. 179-195.

Pike, W. S., Jr., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: GSA Mem. 24, 103 p.

Potter, P. E., J. B. Maynard, and W. A. Pryor, 1980, Sedimentology of shale: study guide and reference source. Springer-Verlag, N. Y. 306 p.

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

Rhoton, F. E. and N. E. Smeck, 1981, Equilibration of clays in natural and simulated bottom-sediment environments: Clays and Clay Minerals, v. 29, p. 17-22.

Russell, J. A., 1979, Refractory clay resources of the Burro Canyon(?) Formation-Dakota Sandstone, north-central New Mexico: M. S. Thesis, N. M. Inst. of Mining and Tech. 111 p.

Russell, K. L., 1970, Geochemistry and halmyrolysis of clay minerals, Rio Ameca, Mexico: Geochim, Cosmo. Acta, v. 34, p. 893-907.

Sabins, F. F., Jr., 1964, Symmetry, stratigraphy and petrography of cyclic Cretaceous deposits in the San Juan Basin: AAPG Bull., v.48, p. 292-316.

Schrader, F. C., 1906, The Durango-Gallup coal field of Colorado and New Mexico: USGS Bull. 285-F, p. 241-258.

Schultz, L. G., 1964, Quantitative interpretation of mineralogical composition from x-ray and chemical data for the Pierre Shale: USGS Prof. Paper 391-C, 31 p.

Sears, J. D., 1934, The coal field from Gallup eastward toward Mount Taylor: USGS Bull. 860, p. 1-29.

____________, C. B. Hunt, and T. A. Hendricks, 1941, Transgressive and regressive Cretaceous deposits in southern San Juan Basin, New Mexico: USGS Prof. Paper 193, p. 101-121.

Shaw, D. M., 1956, Geochemistry of pelitic rocks. Part III: Major elements and general geochemistry: GSA Bull., v.67, p. 919-934.

Shetiwy, M. M., 1978, Sedimentologic and stratigraphic analysis of the Point Lookout Sandstone, southeast San Juan Basin, New Mexico. Ph. D. Thesis, N. M. Inst. of Mining and Tech. 262 p.

Shomaker, J. W., E. C. Beaumont, and F. E. Kottlowski, 1971, Shippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado: New Mexico Bur. of Mines and Min. Res., Circ. 25, 189 p.

______________ and M. R. Whyte, 1977, Geologic appraisal of deep coals, San Juan Basin, New Mexico: New Mexico Bur. of Mines and Min. Res., Circ. 155, 39 p.

Siemers, C. T., 1978, Generation of a simplified working depositional model for repetitive coal-bearing sequence using field data: an example from the Upper Cretaceous Menefee Formation (Mesaverde Group), northwestern New Mexico: *in* H. E. Hodgson (ed.), Proceedings of the second symposium on the geology of Rocky Mountain coal. Colo. Geol. Surv., Resource Series 4, p. 1-22.

__________ and J. S. Wadell, 1977, Humate deposits of the Menefee Formation (Upper Cretaceous), Northwestern New Mexico: *in* J. E. Fassett (ed.), New Mexico Geol. Soc. Guidebook Supplement, 28th Field Conf., San Juan Basin III, p. 1-21.

Singer, A., 1979/80, The paleoclimatic interpretation of clay minerals in soils and weathering profiles: Earth Science Reviews, v. 15, p. 303-326.

Sudo, T., 1979, Studies of clays in sediments - a review: *in* M. M. Mortland and V. C. Farmer (eds.), International Clay Conference 1978. Elsevier, N. Y. p. 241-249.

Tabet, D. E. and S. J. Frost, 1979a. Coal geology of Torreon Wash area, southeast San Juan Basin, New Mexico: New Mexico Bur. of Mines and Min. Res., Geol. Map 49.

______________________, 1979b, Environmental characteristics of Menefee coals in the Torreon Wash area, New Mexico: New Mexico Bur. of Mines and Min. Res., Open File Report 102, 134 p.

Till, R., 1974, Statistical methods for the earth scientist: an introduction. John Wiley and Sons, N. Y. 154 p.

Velde, B., 1977, Clays and clay minerals in natural and synthetic systems. Elsevier, N. Y. 218 p.

Weaver, C. E., 1956, The distribution and identification of mixed-layer clays in sedimentary rocks: Am. Min., v. 41, p. 202-221.

__________, 1967, Potassium, illite and the ocean: Geochim. Cosmo. Acta, v. 31, p. 2181-2196.

__________, 1978, Clay sedimentation facies: *in* R. W. Fairbridge and J. Bourgeois (eds.), Encyclopedia of sedimentology. Dowden, Hutchinson, and Ross, Stroudsburg, Pa. p. 159-164.

__________ and L. D. Pollard, 1973, The chemistry of clay minerals. Elsevier, N. Y. 213 p.

Weimer, R. J., 1976, Stratigraphy and tectonics of western coals: Symposium on the Geol. of Rocky Mountain Coal, p. 9-27.

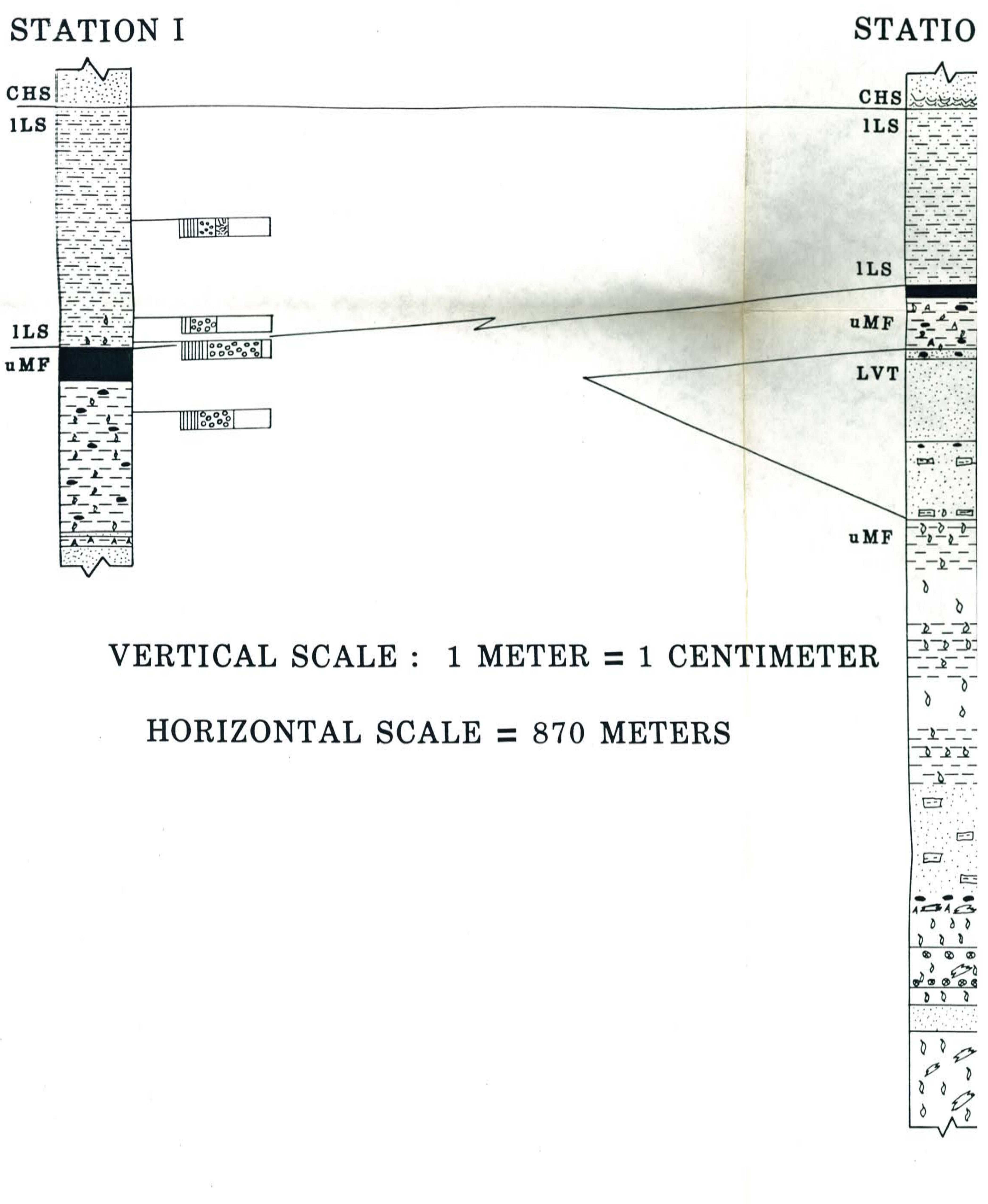
Whyte, M. R. and J. W. Shomaker, 1977, A geological appraisal of the deep coals of the Menefee Formation of the San Juan Basin, New Mexico: *in* J. E. Fassett (ed.), New Mexico Geol. Soc. Guidebook Supplement, 28th Field Conf., San Juan Basin III, p. 41-48.

Williams, J. L. and P. E. McAllister (eds.), 1979, New Mexico in maps.

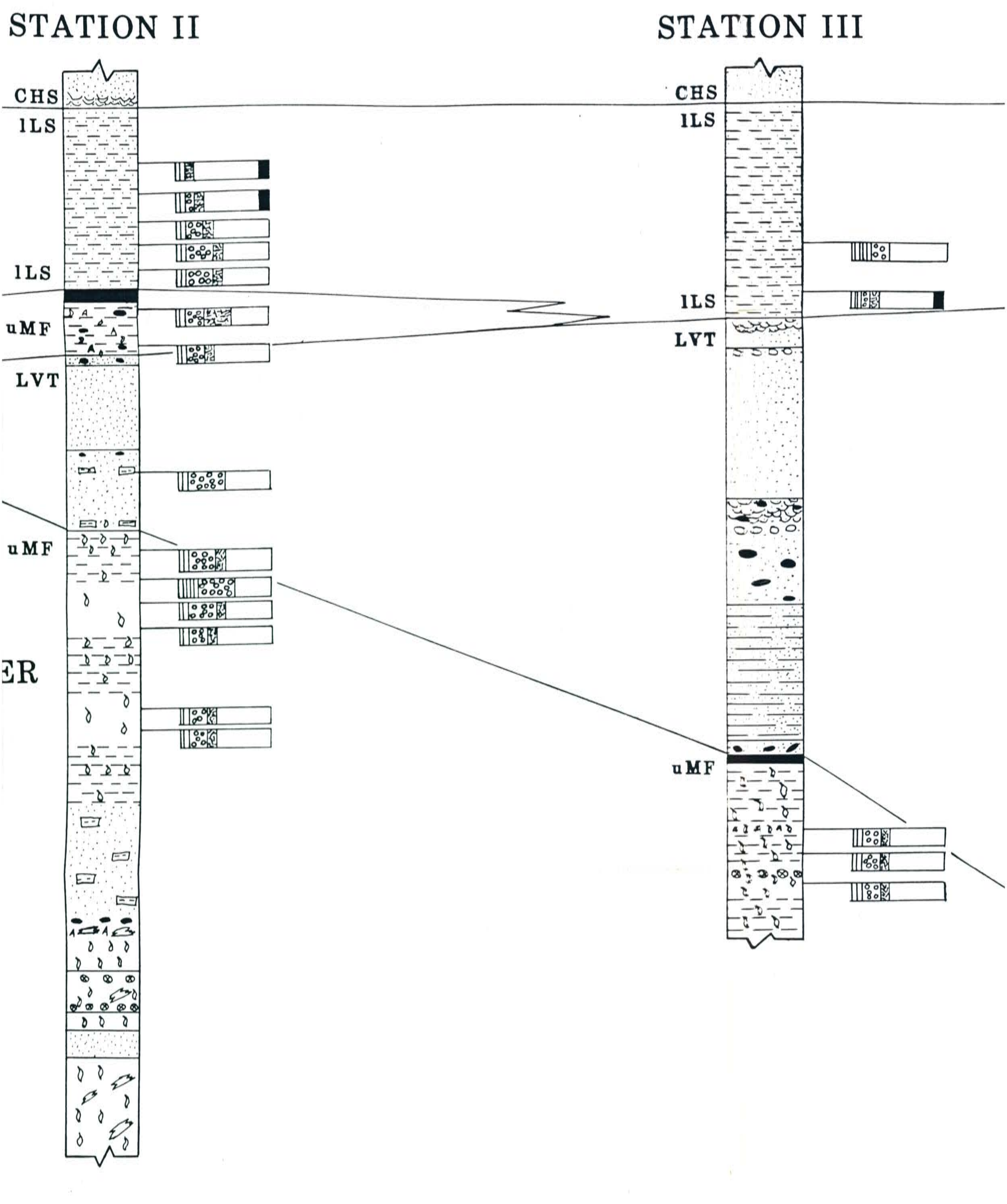
Univ. of N. M., Albuquerque, N. M. 176 p.

Woodward, L. A. and J. F. Callender, 1977, Tectonic framework of the San Juan Basin: in J. E. Fassett (ed.), New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 209-212.

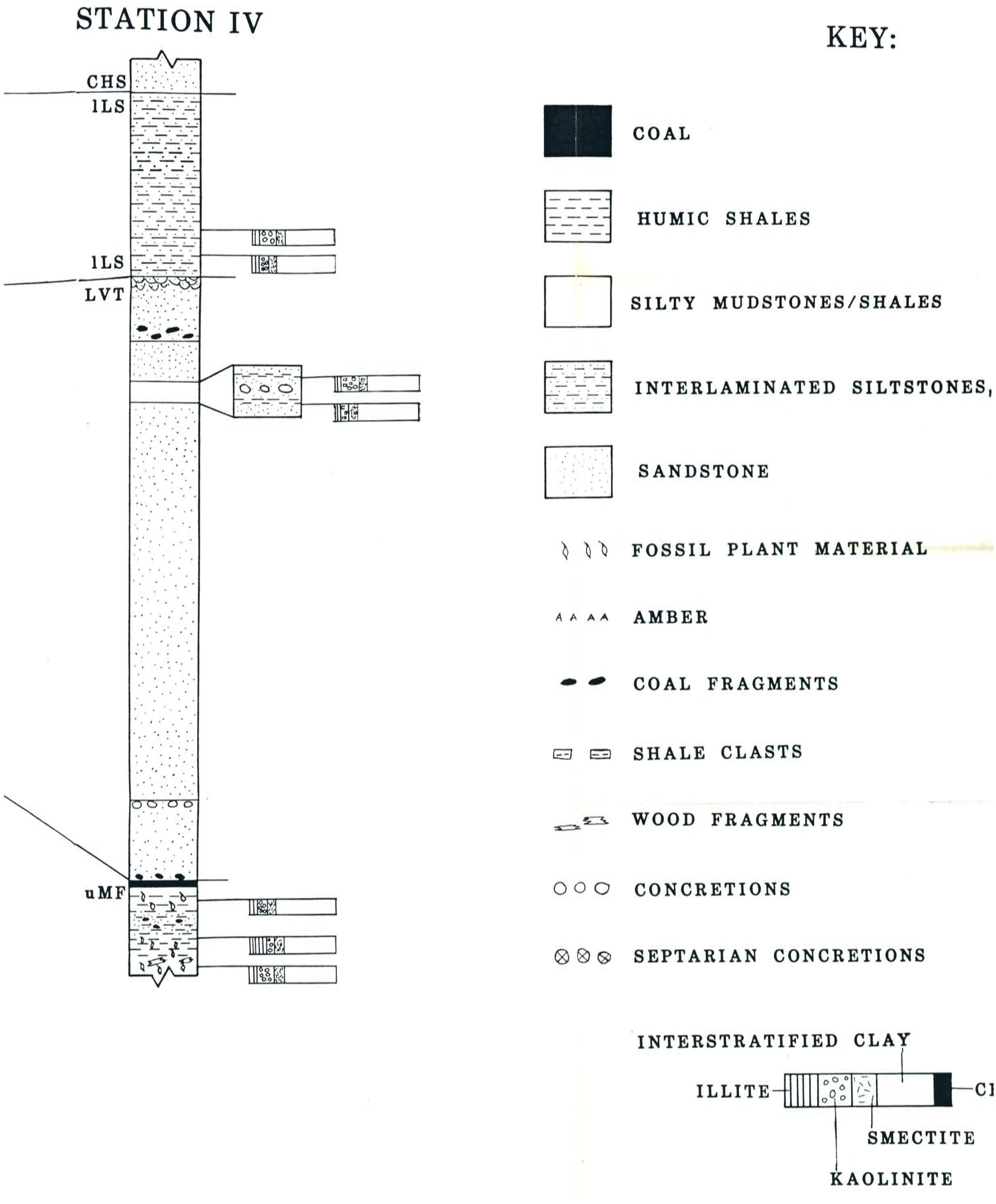
PLATE II: STRATIGRAPHY AND CLAY MINERALOGY: I



OGY: LA VENTANA TONGUE/UPPER MENEFEE FORMATIO



'ION INTERTONGUE, TORREON WASH, NEW MEXICO



H, NEW MEXICO

KEY:

COAL

HUMIC SHALES

SILTY MUDSTONES/SHALES

INTERLAMINATED SILTSTONES, SHALES, SANDSTONES

SANDSTONE

FOSSIL PLANT MATERIAL

AMBER

COAL FRAGMENTS

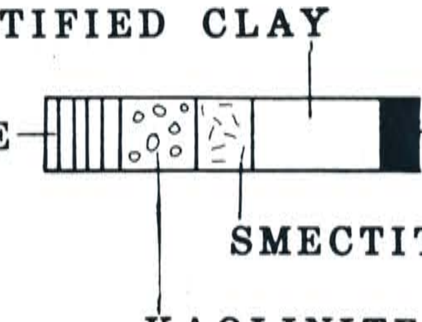
SHALE CLASTS

WOOD FRAGMENTS

CONCRETIONS

SEPTARIAN CONCRETIONS

INTERSTRATIFIED CLAY

ILLITE  CHLORITE

SMECTITE

KAOLINITE

STANLEY T. KRUKOWSKI, 1982