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AUTHIGENIC KAOLINITE IN THE BEAR DEN MEMBER (PALEOCENE) OF THE GOLDEN VALLEY FORMATION, IN SOUTHWESTERN NORTH DAKOTA

by
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Bachelor of Science, University of North Dakota, 1975

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

May
1980

...ARY
University of ... Dakota

This thesis submitted by Gordon H. Prichard in partial fulfillment of the requirements for the Degree of Master of Science from the University is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

Lee Clayton

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

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Title AUTHIGENIC KAOLINITE IN THE BEAR DEN MEMBER (PALEOCENE) OF THE GOLDEN VALLEY FORMATION, IN SOUTHWESTERN NORTH DAKOTA

Department Geology

Degree Master of Science

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Signature

Date March 24, 1980

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ABSTRACT

The Golden Valley Formation of North Dakota crops out in isolated remnants over a large area of southwestern North Dakota. The formation has two members, the lower Bear Den Member, which is characterized by kaolin and bright colors and the upper Camels Butte Member, which is characterized by micaceous sand and clay.

Two different theories, either in place weathering or detrital deposition, have developed as to the origin of the kaolinite in the lower member. Early workers suggest that the kaolinite of the member is detrital in origin for the following reasons:

1. No unconformity is present at the top of the Bear Den Member.
2. The unit is too uniform and widespread, and has a stratiform nature that cannot be explained by weathering.
3. Plagioclase, amphibole, pyrite, and siderite are present but would not have been able to withstand weathering.
4. Kaolinite and muscovite show parallel alignment.

This study reviews these ideas and more recent work that suggests that the kaolinite of the Bear Den Member was formed in place by weathering. In addition, analyses made with the scanning electron microscope, microprobe, and X-ray diffractometer give the following evidence that this member has been formed by a weathering process:

1. The mineralogy and mineral profiles are consistent with those of a weathered horizon.

2. Favorable climatic conditions for weathering were present during the Eocene.

3. The topography and thickness relationships of the Bear Den are similar to that of a soil.

4. The kaolinite horizon transgresses Sentinel Butte strata.

5. Scanning electron photomicrographs illustrate a varying degree of crystallinity in the kaolinite.

6. Chemical data show that leaching of the Bear Den sediment has occurred.

7. The Bear Den Member compares favorably with similar units that have been interpreted as weathered horizons.

A review of the evidence for and against the theory of weathering indicates that the kaolinite of the Bear Den Member formed in place by weathering processes.

INTRODUCTION

The Golden Valley Formation is exposed in scattered remnants over a large part of southwestern North Dakota (Figure 1). Most of the formation has been removed by erosion because of its position near the top of the depositional sequence in the Williston Basin. The remaining widely spaced exposures are distributed within an area of 33,670 square kilometres but only cover about 2.5 percent of the land surface, or about 842 square kilometres.

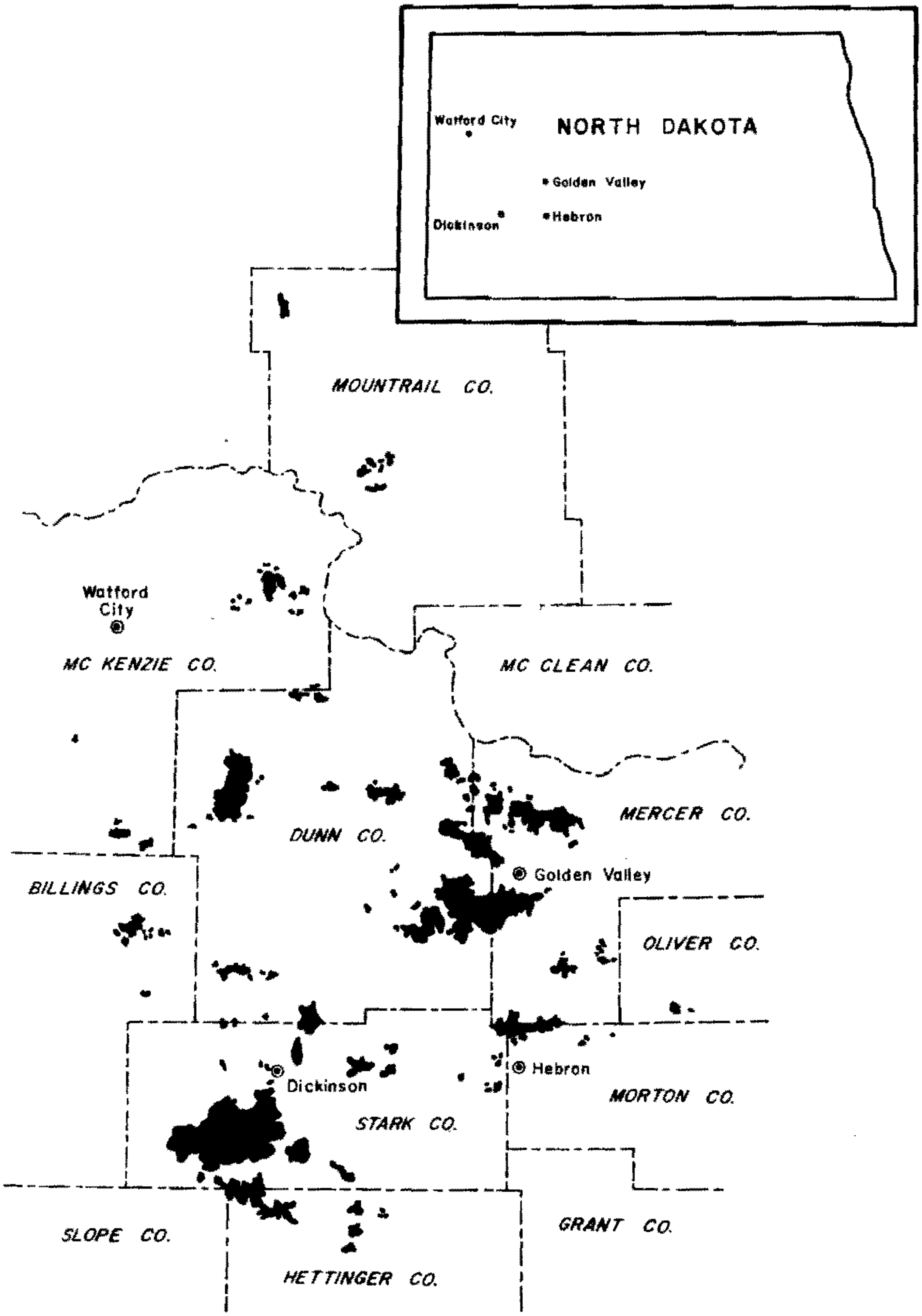
This formation has two members. The lower unit, the Bear Den Member (Hickey 1977), is characterized by kaolinitic clay, silt, and sand and bright colors. These colors have been described by various authors, with most recognizing three zones. These zones are an upper purplish or medium grey zone, a middle bright orange zone, and a lower grey zone. Another characteristic of this unit is the presence of a hard siliceous layer, or silcrete (Wehrfritz 1978), found at the top of the unit in some areas.

The overlying Camels Butte Member (Hickey 1977) is characterized by highly micaceous, cross-bedded sand and laminar silt and clay. The somber gray of this unit, which is similar to the color of the underlying Sentinel Butte Formation is in sharp contrast to that of the Bear Den Member.

Purpose of Study

Conflicting ideas have developed regarding the origin of the Bear Den Member of the Golden Valley Formation. The first workers

Fig. 1. Map showing the distribution of the Golden Valley Formation in western North Dakota.


NORTH DAKOTA
Watford City
Golden Valley
Dickinson
Hebron
MOUNTRAIL CO.
Watford City
MC KENZIE CO.
MC CLEAN CO.
MERCER CO.
DUNN CO.
Golden Valley
BILLINGS CO.
OLIVER CO.
Dickinson
Hebron
MORTON CO.
STARK CO.
SLOPE CO.
GRANT CO.
HETTINGER CO.

(Benson 1952; Freas 1962; Hickey 1966 and 1977) suggested that the kaolin of this member was formed outside of the basin of deposition in a "western highland" area. These workers explained that subsequent uplift and erosion of this western source area caused deposition of the kaolin by either fluvial or lacustrine processes.

More recently Wehrfritz (1978) and Karner, Bjorlie, and Christensen (1978) suggested that the kaolin of the Bear Den Member is not detrital but was formed in place. These authors suggested that the member was the result of deep weathering at the top of the underlying Sentinel Butte or other formations.

The purpose of this study is to evaluate the two opposing theories and to present new information on the origin of the kaolin.

Area of Study

Exposures sampled for this study are located just north of the town of Golden Valley in northwestern Mercer County (Figure 2). The area sampled covers a land surface of about 220 square kilometres. About two-thirds of this area is covered by deposits of the Golden Valley Formation.

This region was chosen for several reasons; a major consideration was the good exposures. Here, the Golden Valley Formation crops out as the highest stratigraphic unit except where a thin covering of glacial debris is present. These outcrops often are bare bluffs rising as high as 80 feet above the surrounding surface (Figures 3 and 4). These excellent exposures permit the accurate description of stratigraphic sections. A second reason this area was chosen was the ease of accessibility to the outcrops as compared to most other areas in

Fig. 2. Map showing the location of the study area in Mercer County, North Dakota.

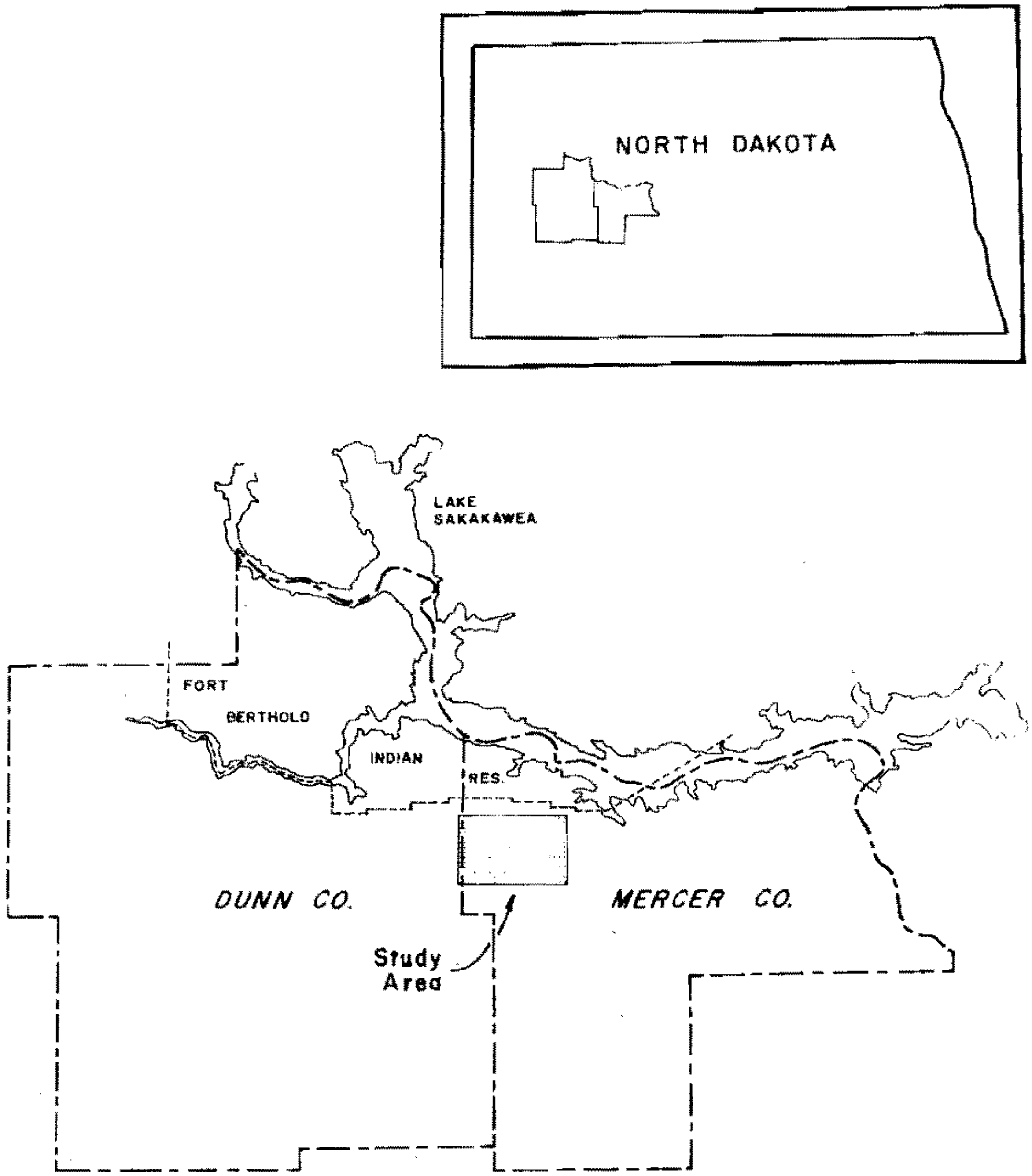

NORTH DAKOTA
LAKE SAKAKAWEA
FORT
BERTHOLD
INDIAN
RES.
DUNN CO.
MERCER CO.
Study Area

Fig. 3. Photograph showing bluffs of outcropping Golden Valley Formation in the southeast quarter of section 11, T.145N., R.90W.

Fig. 4. Photograph of a typical Golden Valley Formation outcrop, northwest quarter, section 2, T.145N., R.90W.

which the Golden Valley Formation occurs. County or township roads are present at most section lines, and ranchers' trails are present on others. As a result, most outcrops are no further than 1 mile from a good trail. A final reason this locality was chosen is the absence of the silcrete layer at the top of the Bear Den Member. This was an important factor as the auger used for this study could not penetrate hard rock.

PREVIOUS WORK

Nomenclature and Age

The Golden Valley Formation was formally named by Benson and Laird (1947, p. 1167).

> The beds that are definitely Eocene have been named the Golden Valley Formation and include those beds bearing the fossil fern Salvina preauriculata. The type exposure of the formation is near the town of Golden Valley for which the formation is named.

In a subsequent work, Benson (1949, p. 1173) gives a more precise definition of this formation.

> The Golden Valley Formation has two members. The distinctive lower member consists of purplish-grey carbonaceous shales interbedded with white sandy kaolinitic clays commonly stained bright yellow orange on outcrop surfaces. The upper member consists largely of fine to coarse grained micaceous sands and silts with small clay lenses.

Previous to this the white kaolinitic clay of the lower member was discussed by several authors. Most of these early discussions were related to the economic value of this clay. As early as 1901, Babcock discussed the "white fire and earthenware clay" found in the Dickinson area. He assigned this clay to the Tertiary age and noted its use at the Dickinson Fire and Pressed Brick Company. Wilder (1902) and Leonard (1904) also discussed this white fire clay, and Leonard included a measured section through the unit.

The first mapping of Tertiary clay in North Dakota was conducted by Babcock and Clapp in 1906. They also discussed the economics, use, and mining of North Dakota clay in great detail. Included in their report were many chemical analyses and physical tests on the fire clay of the Dickinson area, and comparisons were made with several china and fire clays from other parts of the world. Clapp repeated some of this work in a general discussion of the economics of these deposits in 1907.

In 1908, Leonard, although he made no particular reference to what is now known as the Golden Valley Formation, assigned all of the strata between the Fox Hills and the White River Group to the Fort Union Formation. He also divided this strata into an upper "Sentinel Butte coal group" and a lower "Medora coal group" in the area of the Sentinel Butte Coal Field. It was there that "Sentinel Butte" was first used as the name of a rock unit, and it is probable that the present strata of the Golden Valley Formation was included in this group. Later, Leonard (1911) described a unit of light-colored strata that overlies the somber clays of the Sentinel Butte north of Hebron but did not name the unit.

Further subdivisions of the Fort Union strata followed, with Taff (1909) dividing the sediment of the Sheridan Coal Field of Wyoming into three groups, the Ulm, Intermediate, and Tongue River. Correlations by Thom and Dobbin (1924) showed that the "Intermediate coal group" and the "Sentinel Butte coal group" are equivalent. However, they felt that these strata were of Wasatch (Eocene) age.

In 1929 Simpson reassigned the Sentinel Butte to the upper-most Paleocene, but for many years most authors still considered it to be Eocene. For example, Seager (1942, p. 1416) stated:

> The Wasatch Formation of Eocene age is represented by two members. The younger is an unnamed light-colored unit, well exposed north of Hebron, North Dakota. The lower member is the Sentinel Butte, a dark bentonitic unit . . .

This light-colored unit must be the same as that described by Leonard (1911), and it is also the same unit named by Benson and Laird (1947, p. 1167) as shown by the following statement: "The Golden Valley Formation includes the beds formally known as the "unnamed formation" of the Wasatch group. It overlies the Sentinel Butte. . . ." As previously noted, Benson and Laird (1947) picked the boundary between the Paleocene and Eocene at the base of the Golden Valley Formation, so once again the Sentinel Butte was considered upper-most Paleocene.

The first maps showing distribution of the Golden Valley Formation were produced by Benson (1952) for the Knife River Basin. Several other geologists compiled maps of various parts of this formation, including Mehldahl (1956) who worked in McKenzie County, Johnson and Kunkel (1954), who mapped parts of Oliver and Mercer Counties, and Bergstrom (1956), who mapped parts of Dunn, Mercer, Stark, Hettinger, and McKenzie Counties.

Hickey compiled the first map showing the entire extent of the Golden Valley Formation in 1966. It was also in this work that Hickey assigned informal names to the two members of this formation. The lower kaolinitic sand and shale were named in the following statement (p. 34): "The formal designation "Hebron Member" is here assigned to these strata whose type area include a series of excellent exposures . . . north of the town of Hebron in Morton County . . ." The upper micaceous sand and clay were named as follows (p. 56):

> The name Dickinson member is herein proposed for the unit formerly known as the "upper member of the Golden Valley Formation." The type area for this member lies south and west of the town of Dickinson in Stark County . . . where the best exposures of the unit are found.

In addition to proposing names for the different members, Hickey (1966) reevaluated the flora of the Golden Valley Formation and determined that the Paleocene-Eocene boundary is at the top of the "Hebron Member" and not at its base as previous workers had suggested. This change was based on a close relationship between the flora of the lower Golden Valley and Sentinel Butte Formations. In addition, typical Eocene plants are not found in the lower member, whereas Paleocene mollusks have been found (Hickey 1966).

A final change in terminology occurred in 1977 when Hickey changed his informal names for the two members from "Hebron" and "Dickinson" to "Bear Den" and "Camels Butte."

Two marker beds are often found in the Golden Valley Formation. These are the Alamo Bluff lignite and the Taylor Bed, a hard siliceous layer. In both of Hickey's publications (1966 and 1977), he placed the contact between the two members of this formation at the top of either the Alamo Bluff Bed or the Taylor Bed, which Hickey considered to be lateral equivalents. The position of this contact was questioned by Wehrfritz (1978). By using Hickey's (1966 and 1977) fossil evidence, Wehrfritz placed the contact at the top of the Taylor Bed where it is present, or at the base of the Alamo Bluff lignite. Wehrfritz stated that these two beds are not lateral equivalents but that the Alamo Bluff lignite overlies the Taylor bed. This relationship was previously noted by Hickey (1966, p. 50) in an area west of Taylor in eastern Stark County as he wrote that "the red staining is from the burning of the Alamo Bluff lignite which overlies the Taylor bed. . . ." Wehrfritz's position of the contact is probably correct because an unconformity is present at the base of the Alamo Bluff lignite (Figure 5).

Fig. 5. Photograph showing the disconformable relationship of the Camels Butte and underlying Bear Den Members, Golden Valley Formation. Location of the photograph is near the center of section 16, T.145N., R.89W.

Ideas of Origin

As noted above, conflicting ideas have been developed regarding the origin of the kaolinite in the Bear Den Member of the Golden Valley Formation. As early as 1861 Hayden recognized the fluvial origin of the sediments in this area (Leonard 1912). In 1904, Leonard specifically mentioned the white unit near Dickinson and suggested that only conjecture about its origin is possible. He added that we should not forget that clay may be carried great distances by water.

Benson (1952) was the first author to specifically direct attention to the origin of the lower Golden Valley Formation. He suggested that "the kaolin seems to have been transported as kaolin and deposited as one continuous blanket over southwestern North Dakota" (p. 92). He believed that the kaolin was deposited in a "broad, extremely shallow fresh water lake." He went on, however, and qualified this interpretation with the following statement (p. 93): "Even so, it is still difficult to understand how such a large blanket of relatively pure kaolin could be brought in by streams without having that kaolin mixed with montmorillonite clays or with large amounts of other materials."

In 1954, Benson again stated his idea that the kaolin is a lacustrine deposit, and he indicated that the source of this kaolin was some intensely weathered area to the west. He also noted that the end of the Paleocene was a period of intense and rapid weathering over much of North America.

Freas (1962) looked closely at the mineralogy and texture of the Golden Valley clay. In his study he also concluded that the clay was detrital and was deposited in a lacustrine environment. Before he made this interpretation, however, he stated that (p. 1359) "the stratigraphic variation in clay mineralogy within the clay deposits are consistent with the theory of weathering in place." He then followed this statement with several reasons why this is an unacceptable idea. His reasons included (1) the lack of a recognizable unconformity at the top of this unit, (2) the stratiform nature, widespread distribution, uniformity, and succession of stratigraphic units, (3) the presence of plagioclase, amphibole, pyrite, and siderite, which would not be able to survive severe weathering, and (4) the parallel alignment of kaolinite and muscovite crystals.

Freas had the same reservation as Benson regarding the possibility of the kaolinite being transported into its basin of deposition without being mixed with other minerals. He suggested that this would only be possible if either widespread weathering occurred throughout the source area and the basin of deposition or if the source area of the kaolin was adjacent to the basin of deposition so that the clay need be transported only a very short distance.

He discounted this first idea because Eocene rocks from Wyoming and Montana do not show evidence of widespread weathering. This left the possibility of a source area adjacent to the basin but "unfortunately, a local source cannot be proved since the Eocene rocks in eastern Montana were eroded obscuring the stratigraph relations" (Freas 1962, p. 1366).

Based on Freas' study, Hickey (1966 and 1977) agreed with Benson and Freas that the kaolinite of the Bear Den Member is detrital; however, he disagreed with their idea that the unit is lacustrine. He suggested that the sediment is fluvial and was deposited by "sluggish" streams flowing from the west. His evidence for this idea was found in the sedimentary structures of the unit, including cross-bedding, channel and interchannel facies, and local scouring.

Hickey again disagreed with Freas as he felt that no nearby source was present that could have yielded the amount of sediment thought to have been present in the Bear Den Member before it was eroded to its present extent. Alternatively, Hickey suggested that the sediment was carried a moderate distance by low-gradient streams before being deposited in the Williston Basin. The source area for this sediment possibly having been the Black Hills uplift.

Two recent studies have been completed that suggest that the kaolinite of the Bear Den Member was not transported into its present position but that it was formed in place. Karner, Bjorlie, and Christensen (1978) gave seven major lines of evidence that they felt suggest this. A summary of their reasons follows (p. 158):

1. The tripartite division of the Bear Den is compatible with a soil profile developed on a Sentinel Butte fluvial sequence.

2. The abundance of kaolinite increases upward as does the crystillinity of the kaolinite.

3. Abundant kaolinite and limonite spherules in the orange zone suggest a long period of acid, oxidizing conditions. This may account for all or most of the mineralogical differences from similar Sentinel Butte units.

4. Thin-section studies show kaolinitization of detrital feldspar, mica, and other grains to be incomplete and generally confined to the grain edges.

5. The Alamo Bluff lignite and the silicified Taylor Bed mark the top of the Bear Den Member.

6. Separating the deposition of the Bear Den sediment from the kaolinitization of these sediments facilitates interpretation of the environment of deposition and the source of the kaolinite.

7. Climatic and tectonic conditions in western North America indicate the more or less coincident culmination of a warming trend and a change in tectonics producing an early Eocene lowland in western North Dakota that received little sediment for a relatively long period of time.

In the other study, Wehrfritz (1978), compared the Bear Den Member of the Golden Valley Formation to the "Rhame Bed" of the Slope Formation. In this study she stated that the "Rhame Bed" contains "siliceous rock overlying white to light gray unconsolidated sand, silt, or clay" (p. 27). She applied the name "silcrete" to this siliceous rock and described it as follows (p. 29):

> In hand sample, the grains in the silcrete . . . appear to range from fine sand to silt and are subangular . . . some of the detrital grains show overgrowths or partial overgrowths of "secondary" silica. . . . In this section the grains are surrounded by a matrix of microcrystalline quartz or chert. . . . Fossil plant remains in the silcrete are abundant. Casts of plant branches . . . show insect borings, bark imprints and knots; are curved or straight; are haphazardly arranged in the rock; and are not flattened or otherwise deformed.

The following is Wehrfritz's description of the underlying white to light grazy zone (p. 39):

> The grain size of the white sediment ranges from clay size to very fine sand. . . .
>
> The Rhame Bed generally ranges from white to light gray. The larger grain sizes, fine sand to course silt, are generally white; the smaller grain sizes, silt to clay-size, are

> generally gray. The whitest outcrops commonly have yellowish orange, iron-oxide staining, which forms in bands across the surface. . . . Not all the sediment is white or light gray. Some carbonaceous, medium to dark gray clay-size and silt-size sediment may occur both above and below the whitest sediment.

Wehrfritz interpreted this unit as having been formed by weathering. She based this idea on descriptions of similar units found in other parts of the world. Goudie (1973, p. 17) summarized several of these descriptions:

> [Silcrete is] a predominantly pale gray, extremely indurated, highly siliceous rock with numerous angular quartz clasts distributed in a amorphous or cryptocrystalline matrix . . . even the more massive forms often contain numerous tubular cavities . . . which are formed by root growth.

He went on to state that (p. 18): "Silcretes, like the other main duricrust types, sometimes show a characteristic deep weathering profile development which is a clayey kaolinized pallid zone, sometimes underlain by a ferruginous zone, and then by bedrock."

Finally Wehrfritz compared the "Rhame Bed" to the Bear Den Member, which has the same characteristic silcrete:

> . . . the unit is silicified siltstone composed mainly of silt-sized grains, most of which are quartz, in a microcrystalline silica matrix whose volume does not exceed 25 percent. The rock is massive and light brownish gray when weathered; it breaks into irregular blocks riddled with stem molds (Hickey 1977, p. 23).

The "Rhame Bed" and the Bear Den Member also have the same characteristic underlying unit, which "consists of beds of hard kaolinitic claystone, mudstone, and sandstone that weather white, gray, or orange" (Hickey 1977, p. 17).

From these comparisons, Wehrfritz (1978) concluded that the "Rhame Bed" and the Bear Den Member are similar to the units described by Goudie (1973) and that they both formed by weathering.

Similar Units in This Area

Several other silcrete and weathering profiles near this area have been reported. One of these, described by Ritzma (1965), was thought by Wehrfritz to be equivalent to the "Rhame Bed." It occurs at the base of the Tertiary in the Lewis Formation and Lance Formation in northeastern Wyoming.

Ritzma stated that (p. 137):

> The fossil soil zone makes a conspicuous white, light gray, or bluish-white band at the top of the Lewis. Parts of the zone are very hard and dense and almost porcellaneous. Resistance of the zone to erosion is remarkable, and it frequently is a ridge-forming lithologic unit.

The description of this unit presented by Ritzma clearly indicates that it is a silcrete and deep-weathering profile.

Another similar unit was described by Drury and Knox (1971) in southwestern Wisconsin. It is developed on strata of Cambrian and Ordovician age, but it is thought to have been formed in middle Miocene time. Drury and Knox noted the similarity of this unit with those in Australia (p. 291).

> Duricrusts and deep-weathering profiles are exposed in numerous sections of southwestern Wisconsin. . . . The profiles include pallid zones in their lower parts, with mottled zones next above, and duricrusts at the top, being wholly comparable in their field characteristics and relationships to the profiles and crusts abundantly described from the Southern Hemisphere, notably Australia.

One other deep weathering profile, the Interior Formation, has been described in this area. It crops out in widely scattered areas in western North Dakota, western South Dakota, northwestern Nebraska, and eastern Wyoming. Pettyjohn (1966) dated the period of soil formation as late Eocene and noted that the formation is developed on strata as old as Early Cretaceous and as young as late Eocene.

The Interior Formation differs from the other weathering profiles mentioned as it does not have a silcrete developed at the top of the soil horizon. However, the underlying deep-weathering profile is well developed (Pettyjohn 1966, p. 65).

> The ancient soil under consideration is characterized as a whole by alumina enrichment, moderated to high iron enrichment, red and yellow colors, kaolinization, poor vertical differentiation, and relatively great thickness. These features are those of a pedalfer, particularly of a laterite.

METHODS OF INVESTIGATION

Sample Collection

Samples were collected by three different methods to be used in X-ray and scanning-electron-microscope studies. Most commonly, samples were collected with a truck mounted auger (Figure 6). Three samples were taken from each 5-foot interval. These were described in the field and then combined into one bag to be analyzed in the laboratory. Some 5-foot samples were broken down into smaller intervals at major changes in lithology and bagged separately.

A second set of samples was collected from measured sections. Small hand samples were taken from the exposed face of the section at each major lithologic change. These samples were described and bagged, and their location above the base of the section was determined with a steel tape. Where the thickness of any unit was over 5 feet, samples were combined in one bag at 5-foot intervals.

The base of each measured section lies adjacent to the top of an auger hole. Thus, the number designation of these samples corresponds with the number of the auger hole at the same location.

A third set of samples was obtained from the North Dakota Geological Survey Core Library. These samples were from the United States Geological Survey and North Dakota Geological Survey drilling projects in the area. The samples are from rotary-rig holes and were collected at 5-foot intervals.

Fig. 6. Collecting samples with a truck-mounted auger.

7. The washing was repeated with 150 cubic centimetres of distilled water.

8. The sample was dried overnight at 70°C.

9. The dried sample was reground with mortar and pestle with 1 gram of the resulting powder weighed out for analysis.

10. Approximately 10 drops of ethylene glycol were added to the 1 gram sample to achieve a paste-like consistency.

11. The glycolated sample was placed into a mold, and 1.5 grams of Avicel was added to the top of the mold to form a backing for a pellet.

12. The sample was formed into a pellet under extreme pressure.

13. Pressure on the pellet was held for 15 seconds and then slowly released over a 60 second period.

14. The pellet was mounted in a rotating holder and analyzed using X-ray diffraction techniques.

The machine parameters for each of the X-ray charts produced were held constant and were as follows: tube, CuK_2; Ni; rate meter, 2×10^3 counts per second; scatter slit, 4 micrometres; receiving slit, 6 micrometres; time constant, 1; metres per hour, 1.524. The power settings were 37 kilovolts and 18 milliamps.

The diffractograms produced by this procedure have been reduced in size and are included in appendix B.

The proportion of each of the clay minerals present in each sample was computed using a technique similar to that suggested by Johns, Grim, and Bradley (1954). This method is also similar to that used by Freas (1962) in his study of the Golden Valley Formation.

The method involves computing weighting factors for each clay mineral by preparing 1:1 mixtures of the clay minerals studied. These mixtures are then X rayed. The area under the most intense peak of each of the minerals on the X-ray chart is found. The two areas are set into a ratio. The area under the kaolinite peak was arbitrarily set equal to 1; thus, the other weighting factors are equal to the number that the area of the peak of the mineral must be multiplied by for it to equal 1.

Clay standards of the American Petroleum Institute were used to compute these ratios with two samples being prepared of each of the mixtures. The 1:1 mixtures used were kaolinite: illite; kaolinite: montmorillonite; and illite: chlorite.

The following weighting factors were computed and used in this study:

Kaolinite 1.0

Montmorillonite 0.97

Illite 2.2

Chlorite 0.38

These numbers correspond very well with those computed by Freas (1962). Slight differences are probably attributable to a difference in sample preparation.

After the weighting factors were computed, the area of the most intense peak for each clay mineral in a sample was measured from the diffractogram. This area was multiplied by the weighting factor, and the resulting corrected areas were then set in a ratio to compute the proportion of each clay mineral present relative to the other clay minerals.

Two problems were encountered using this procedure. First, in most samples the 1.1×10^{-9} metre (11Å) illite peak is obscured by a mica peak. In such samples the area of the illite peak was estimated by interpolating the curve of the shoulders of the illite peak into a common point. The arc of the peak transcribed was then used in the calculation to compute the percentage of illite in the sample.

The second problem encountered with this method was the interference between the 7×10^{-10} metre (7Å) kaolinite and chlorite peaks. This occurred in only a few samples where chlorite was very abundant and the acid treatment was not able to remove it completely. When chlorite was encountered in the sample, the two peaks were treated as an addition of two normal statistical curves. This was possible because the two peaks do not overlap completely.

The proportion of the clay minerals found in each sample is listed in appendix C. The area under the most intense peak of each clay mineral and the area under the major feldspar peaks are also included in appendix C.

Scanning-Electron-Microscope Analyses

Photomicrographs of selected samples from the Golden Valley Formation were taken with a scanning electron microscope. These samples were prepared using a technique similar to that of Keller (1976a). The technique consisted of breaking or chipping a sample of the clay such that a small piece with a freshly broken surface was obtained. This small chip was placed with the freshly broken side up on a scanning electron microscope mount without any further processing. The specimen and mount were thinly coated with either gold-paladium or carbon to allow viewing and photographing. Magnifications of 2000 to 5000 were commonly used, which allowed the texture of the samples to be viewed. These photomicrographs are shown in appendix E.

Microprobe Analysis

Chemical analyses were made of two sets of samples using a microprobe in conjunction with the scanning electron microscope. The samples used were first ground in a ball mill for 5 minutes. The resulting powder was pressed into a special mount designed for making chemical analyses with the microprobe. This mount was placed in the scanning electron microscope and each sample was viewed at 100 magnification. This results in analyzing an area of 1 square millimetre. These analyses are presented in appendix D. Any deviation from the above procedures is noted in this appendix.

STRATIGRAPHY AND MINERALOGY

Description

The Bear Den Member has been variously described by several authors. As already noted, most authors recognize a three-color zonation. Benson (1952) described these as an upper "purplish gray," a middle "white sandy fire clay mottled and stained yellow orange," and a lower "light purplish gray shaley clay." These colors, which are very common, are not found in every outcrop of the Bear Den Member however, and as noted by Hickey (1977) may be found in reverse order. In the subsurface, the Bear Den Member is usually easily identified from drill cuttings. The cuttings are a very light gray color even when moist, and although the bright orange color is not seen, a zone of mottled, light gray to purplish gray clay is found. (See appendix A for descriptions of measured sections and drill hole data.)

Freas (1962) gave sand, silt, and clay ratios from several samples of the Bear Den Member from the Dickinson area of North Dakota. In his analyses he found that the samples ranged from the extreme of 100 percent clay to 40 percent sand, 40 percent silt, and 20 percent clay. This variability is also found in other areas. Sand was visually estimated to make up 80 to 85 percent of some samples obtained during this study.

The contact between the two members of the Golden Valley Formation is disconformable. It lies at the base of the Alamo Bluff lignite or at the top of the Taylor Bed where it is present. This contact is usually very easily picked in the field because of the abrupt color change from the light gray of the Bear Den. The overlying Camels Butte Member is either a tan sandy unit or a darker yellowish gray to green, silty clay unit. The abruptness of this change may also be noted in the clay mineralogy of the two members. Section GV-36M (Figure 7) shows a sharp contact between the kaolinite-rich clay of the Bear Den Member and the montmorillonite-rich clay of the Camels Butte Member (additional samples are illustrated in appendices B and C). At this locality the two members are separated by only centimetres of lignitic clay that correlate with the Alamo Bluff Lignite.

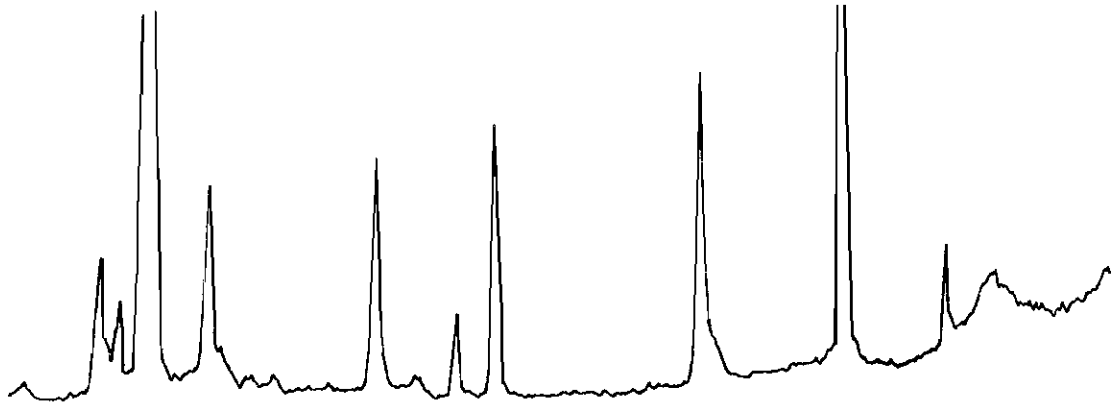
The base of the Bear Den Member is conformable and grades into the underlying Sentinel Butte Formation. This contact is recognized by a change in both color and mineralogy. The contact, as defined by Hickey (1977, p. 18) is "at the base of a cross-laminated, yellowish-gray, kaolinitic siltstone unit. . . . The underlying Fort Union Bed [Sentinel Butte Formation] is a fissle, brownish-gray, nonkaolinitic shale." In this study, the lower contact is also defined as the line at which the kaolinite becomes more abundant than montmorillonite going up section. (See appendix C for Clay mineral percentages).

Mineralogy

Table 1 shows the clay-mineral percentages of the Bear Den Member as determined by Freas (1962) from samples collected in the Dickinson area, and as determined by Hickey (1966 and 1977) from samples collected outside of this area. This table also shows data derived from this study of samples collected in northwestern Mercer and central Dunn Counties.

Fig. 7. Diffractograms and mineral percentages of samples just above and below the Camels Butte, Bear Den contact, section GV-36M.

Base of the Camels Butte Member, sample GV-36M, 29.5-22.5m.
Kaolinite: 7% Montmorillonite: 47% Illite: 35% Chlorite: 11%



Top of the Bear Den Member, sample GV-36M, 22.5-14.5m.
Kaolinite: 82% Montmorillonite: 3% Illite: 15% Chlorite: 0%

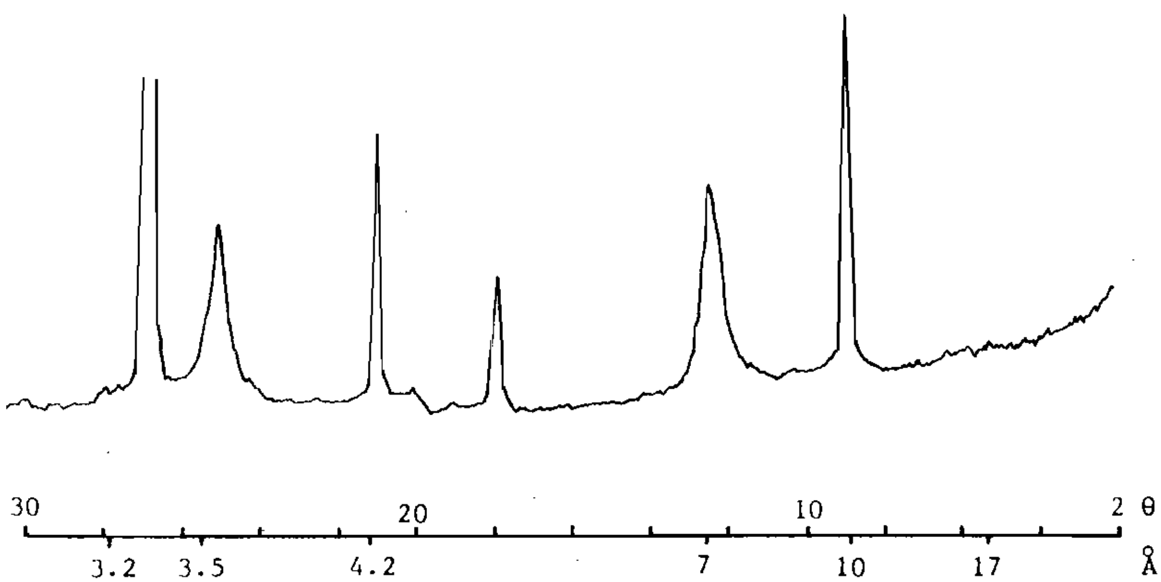


TABLE 1

PERCENTAGES OF CLAY MINERALS IN THE BEAR DEN MEMBER AND ADJACENT UNITS

Unit	Clay Mineral	Freas, 1962	Hickey, 1966	This Study
	Kaolinite	7	12	6
Camels Butte	Montmorillonite	44	46	54
	Illite	35	36	31
	Chlorite	14	6	9
Bear Den Member (Average)[1]	Kaolinite	66	65	66
	Montmorillonite	7	16	18
	Illite	27	18	16
	Chlorite	0	1	0
Carbonaceous Zone	Kaolinite	72	56	74
	Montmorillonite	18	13	22
	Illite	10	28	4
	Chlorite	0	3	0
	Kaolinite	68	84	72
Orange Zone	Montmorillonite	4	Trace	18
	Illite	28	16	10
	Chlorite	0	0	0
	Kaolinite	59	39	69
Gray Zone	Montmorillonite	4	52	15
	Illite	37	9	16
	Chlorite	0	0	0
	Kaolinite	10	17	11
Sentinel Butte Formation	Montmorillonite	7	76	57
	Illite	81	7	29
	Chlorite	2	Trace	3

[1]The mineral percentages of the Bear Den Member (Average) may not be equal to the average of the 3 zones listed below because of an increased number of samples.

This table shows that the clay-mineral composition of the Bear Den Member is consistent throughout its area of occurrence. This is especially evident when the average composition of the unit is compared.

These analyses also demonstrate that montmorillonite generally is dominant in the enclosing units except in the Dickinson area, where the Sentinel Butte Formation has more illite. The data in these tables, however, does not show that the change in the ratio of kaolinite to montmorillonite occurs gradually with depth. This graduational change from kaolinite to montmorillonite can be noted visually in Figure 8. These X-ray charts show a decrease in the 7×10^{-10} metre (7Å) kaolinite peak with a corresponding increase in the 1.8×10^{-9} metre (18Å) montmorillonite peak with depth. The gradual change is also illustrated by the mineral percentages shown in table 2. This agrees with the observations made by Freas (1962), who stated that the amount of kaolinite decreases with depth.

A similar observation may be made from the X-ray charts (Figure 8) and the table showing the area under the clay and major feldspar peaks (table 2). Again the kaolinite peak decreases as the 3.2×10^{-10} metre (3.2Å) feldspar peak increases with depth. (Additional diffractgrams and mineral percentage data are presented in appendices B and C.)

Figure 8 also shows that the kaolinite of the Bear Den Member transgresses lithologies. The first 4 charts in this figure are of samples that are primarily clay. The samples in the next two charts are primarily silt. The remaining charts are diffractograms of the silt and clay present in a sandy horizon. This series of diffractograms shows that the 7×10^{-10} metre (7Å) and 3.57×10^{-10} metre (3.57Å) peaks vary only slightly with the changes in lithology.

The kaolinite in the Bear Den Member is disordered. This is evidenced by the broadness of the 7×10^{-10} metre (7Å) and 3.57 x

Fig. 8. X-ray diffractograms from measured section GV-12M and auger hole GV-12. (Metres x 3.29 = feet).

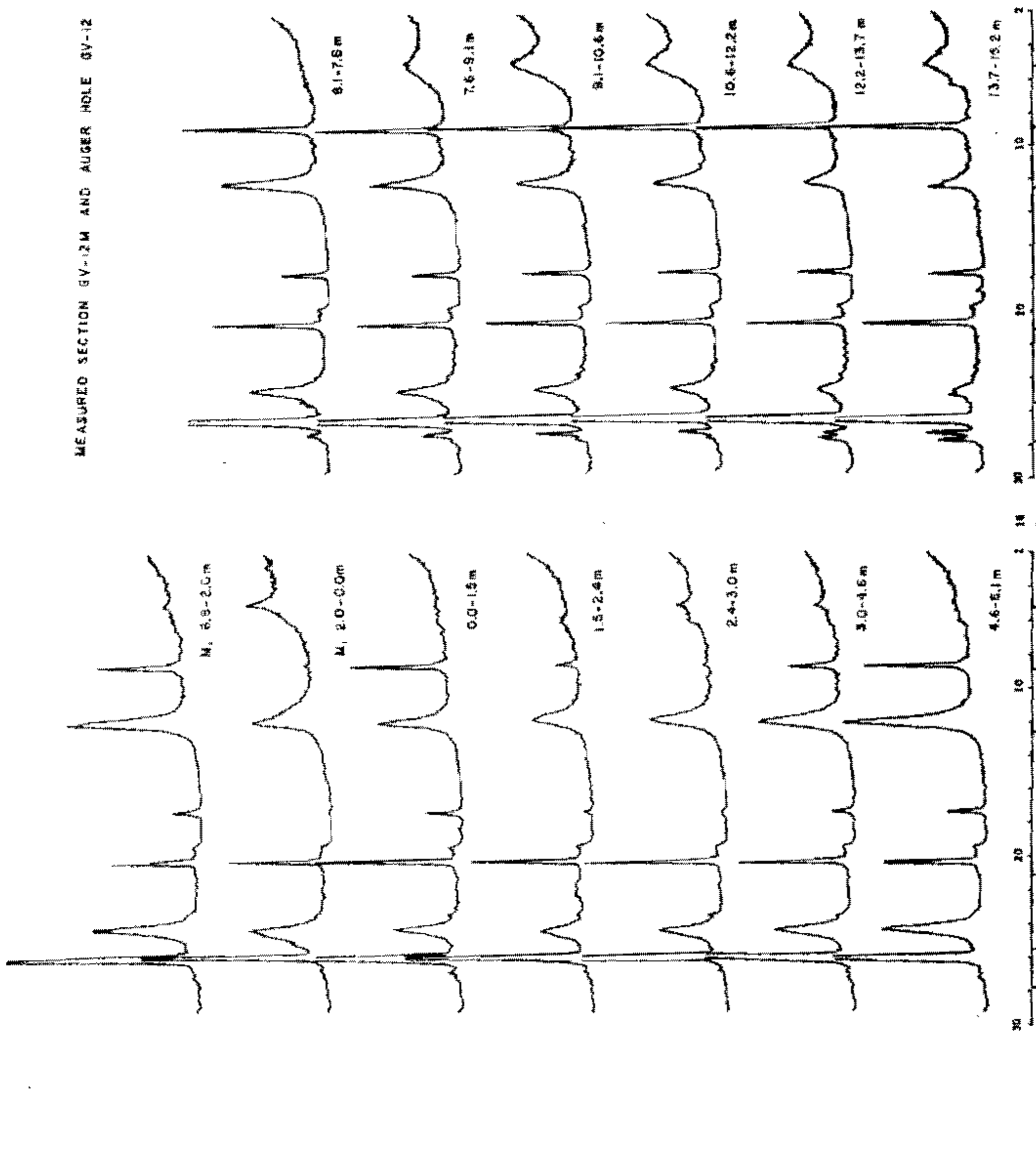

MEASURED SECTION GV-12M AND AUGER HOLE GV-12
M, 6.8-2.0m
M, 2.0-0.0m
0.0-1.5m
1.5-2.4m
2.4-3.0m
3.0-4.6m
4.6-6.1m
6.1-7.6m
7.6-9.1m
9.1-10.6m
10.6-12.2m
12.2-13.7m
13.7-15.2m

TABLE 2

CLAY MINERAL PERCENTAGES AND AREAS UNDER THE MAJOR CLAY AND FELDSPAR PEAKS, MEASURED SECTION GV-12M AND AUGER HOLE GV-12

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} metres				
			K	Mo	I	C	F	K	Mo	I	C
Bear Den Member	22.5-6.5m	6.8-2.0m	68	15	17	0	0.103	7.762	1.716	0.910	0.000
	6.5-0.0m	2.0-0.0m	63	33	4	0	0.303	7.362	3.929	0.200	0.000
	0-5	0.0-1.5	71	9	20	0	0.406	5.542	0.703	0.703	0.000
	5-8	1.5-2.4	75	15	10	0	0.200	4.839	1.007	0.303	0.000
	8-10	2.4-3.0	70	20	10	0	0.103	5.949	1.716	0.406	0.000
	10-15	3.0-4.6	78	13	9	0	0.103	7.562	1.310	0.406	0.000
	15-20	4.6-6.1	74	8	18	0	0.303	9.278	1.007	1.007	0.000
	20-25	6.1-7.6	72	9	19	0	0.703	6.652	0.807	0.807	0.000
	25-30	7.6-9.1	50	35	15	0	1.007	6.052	4.439	0.807	0.000
Sentinel Butte Member	30-35	9.1-10.6	41	49	10	0	1.413	4.536	5.542	0.503	0.000
	35-40	10.6-12.2	39	48	13	0	1.213	4.136	5.245	0.606	0.000
	40-45	12.2-13.7	29	56	15	0	1.413	2.523	5.142	0.606	0.000
	45-50	13.7-15.2	19	57	20	4	2.420	1.523	4.639	0.703	0.703

M = measured section; K = Kaolinite; Mo = Montmorillonite; I = Illite; C = Chlorite.

10^{-10} metre (3.57Å) peaks which would be sharp if the kaolinite were well ordered (Carrol 1970). The broadness of these peaks is also an indication that the crystallinity of the kaolinite is poor. This is in agreement with Freas (1962) who suggested, on the basis of heating samples before X raying, that halloysite may also be present. Scanning electron photomicrographs verify the presence of halloysite, but only in a few samples (Figure 9, appendix E).

Along with the clay minerals, Freas (1962) reported the occurrence of many accessory minerals in the silt and sand of this unit. He indicated that about 50 percent of this size fraction is quartz, which is the predominant nonclay mineral. Freas also indicated that rock fragments constitute about 30 percent and mica about 18 percent of this fraction. The remainder consists of feldspar and numerous opaque and heavy minerals, including siderite, pyrite, leucoxene, anatase, ilmenite, rutile, zircon and tourmaline. He also noted very small amounts of kyanite, staurolite, garnet, zoisite, monazite, sillimanite, tremolite, andalusite, epidote, and siderite. To this list Hickey (1977) added magnetite, and this study, although it did not look at the heavy or opaque minerals, has shown by X-ray diffraction that goethite is also present.

Chemical Data

The formula for kaolinite, $Al_4(Si_4O_{10})(OH)_8$, indicates that the ideal chemical analysis should be 39.5 percent Al_2O_3, 46.5 percent SiO_2, and 14.0 percent H_2O (Hurlbut 1971). Grim (1968, table 3) listed chemical analyses from several high-grade kaolinite deposits that compare favorably with the ideal analysis. A comparison of Grim's data

TABLE 3

CHEMICAL ANALYSES OF KAOLINITE MINERALS
(Grim 1968)

	Zettlitz, Czechoslovakia	Mexia, Texas	Macon, Georgia	St. Austell, England	Anna, Illinois
SiO_2	46.90	44.81	45.20	46.77	44.59
Al_2O_3	37.40	37.82	37.02	37.79	36.83
Fe_2O_3	0.65	0.92	0.27	0.45	1.14
FeO	...	...	0.06	0.4	...
MgO	0.27	0.35	0.47	0.24	0.39
GO	0.29	0.43	0.52	0.13	1.02
Na_2O	0.44	...	0.36	0.05	0.13
K_2O	0.84	...	0.49	1.49	0.32
TiO_2	0.18	0.37	1.26	...	2.17
H_2O^-	...	1.10	1.55	0.61	...
H_2O^+	12.95	14.27	13.27	12.18	13.63

with the chemical analyses of measured section GV-12M and drill hole GV-12 from this study (table 4) show a large discrepancy. (Additional chemical analyses are in appendix E. The amount of SiO_2 shown in the analyses of GV-12 and GV-12M is consistently 15 to 20 percent higher than that shown in Grim's data. This can be explained by the strong quartz peak that is present in most of the X-ray charts (appendix B). This indicates not only the increase in the amount of SiO_2, but also a relative decrease in the amount of Al_2O_3.

TABLE 4

CHEMICAL ANALYSES FROM MEASURED SECTION GV-12M AND AUGER HOLE GV-12

	Interval Followed by Percent Oxide (metres)									
Oxide	M6.8-2.0	M2.0-0.0	0.0-1.5	2.4-3.0	4.6-6.1	6.1-7.6	7.6-9.1	10.6-12.2	12.2-15.2	16.7-18.2
SiO_2	63.78	63.22	64.71	67.61	65.06	75.06	70.95	70.05	77.75	66.03
Al_2O_3	28.98	31.62	27.68	27.50	20.98	18.86	20.54	19.04	13.65	18.86
Fe_2O_3	2.21	1.95	3.49	1.71	9.92	2.50	4.39	6.21	4.38	8.19
MgO	0.85	0.55	0.70	0.28	0.56	0.42	0.74	1.25	0.80	1.68
CaO	0.04	0.09	0.17	0.12	0.21	0.12	0.12	0.11	0.26	0.15
Na_2O	0.52	0.46	0.18	0.20	0.36	0.17	0.28	0.57	0.46	0.88
K_2O	1.87	0.30	1.39	0.41	0.99	1.63	1.87	2.07	1.80	2.10
TiO_2	1.46	1.32	1.21	1.75	0.85	0.82	0.83	0.64	0.52	0.72
P_2O_5	0.06	0.00	0.09	0.11	0.12	0.18	0.09	0.00	0.00	0.11
MnO	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.10	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_3	0.17	0.43	0.31	0.11	0.88	0.13	0.12	0.00	0.21	1.22

M designates samples from a measured section.

The chemical analyses in table 4 indicate that the percentage of SiO_2 increases with depth. An explanation for this can be found in appendix A where drill-hole data show that samples from GV-12 become increasingly sandy, and hence more quartz rich, with depth.

These chemical analyses also show that the abundance of Mg^{++}, Na^{+}, and K^{+} ions all increase with depth. This may in part be a reflection of the increase in feldspar and mica with depth (appendices B and C). It is probably also a result of the increase in montmorillonite with depth because these ions are commonly present in the interlayer positions within this mineral. However, the chemical analysis of sample GV-12 (2.0 to 0.0 metres) shows that the amount of Mg^{++}, Ca^{++}, Na^{+}, and K^{+} ions is very small, although 38 percent of the clay-mineral fraction is montmorillonite (appendix C). An explanation for this may be found in a study by Weaver and Pollard (1973), who report that montmorillonite prefers cations in the following order: $K^{+}>Na^{+}>H^{+}>Ca^{++}>Mg^{++}$. They go on to say that "the final suite is dependent upon the composition of the water in the environment of deposition; however, it is also dependent upon the original cation suite, time, type of clay, and post depositional leaching. . . ."

Considering the above statements and the X-ray and chemical data, it seems probable that the montmorillonite observed on the X-ray charts has H^{+} as its predominant interlayer cation. This hydrogen montmorillonite must have been formed in an acid-rich environment where most K+, Mg^{++}, Na^{+}, and Ca^{++} cations were removed from the original clay.

Discussion of Mineralogy

Maigniem (1966) outlined the mineralogical characteristics of lateritic soils. He stated that (p. 20) "combined silica is predominately in the form of kaolinite, the characteristic clay of most tropical formations." He noted that this kaolinite is usually only "to some extent crystallized" (p. 23), which is in agreement with Keller (1964), who has observed that kaolinite that has formed through the lateritic alteration of montmorillonite has a disordered crystalline form. Maigniem also stated that silica is usually present as quartz and that iron is present most often as goethite and hematite.

In addition to the above minerals, which are derived through the evolution of laterite, several minerals are found as residual forms. Of these, magnetite and ilmenite are the most common with rutile and anatase also often being present.

The above summary of the mineralogy of a typical lateritic soil compares very favorably with that of the Bear Den Member as discussed above. The primary clay of this unit is kaolinite, and the X-ray data show it to be poorly crystallized. Scanning electron photomicrographs (appendix E) show that although most of the kaolinite is poorly crystallized, the degree of crystallinity varies as the grain size of the unit varies. The highest degree of crystallinity is found in the sandy, more permeable sediments, as would be expected in a soil horizon (De Segonzac 1970).

The stratigraphic variation in the amount of kaolinite found in this unit is also an indication of the probability of it being formed through a weathering process. As previously mentioned, the amount of kaolinite decreases with depth. Freas (1962, p. 1359) stated that these "stratigraphic variations in clay mineralogy within the clay deposit are consistent with the theory of weathering in place."

In addition, the nonvariance in the amount of kaolinite with changing lithologies is also consistent with weathering. In a non-weathered horizon, the kaolinite should not transgress sediments deposited in different environments.

The other minerals found in the Bear Den also compare favorably with Maigniem's summary. The goethite and siderite have been derived through weathering, whereas the ilmenite, magnetite, and other heavy minerals are residual products.

Also present are feldspar minerals that are remnants of incompletely altered parent material. This is indicated in the X-ray data, which shows an increase in the amount of feldspars present with depth. This type of variation is expected in a weathering profile.

A highly leaching, acid-rich environment is indicated by the montmorilllonite clays that are nearly void of Ca^{++}, Na^{+}, K^{+}, and Mg^{++}. This type of environment is necessary for the formation of kaolinite by a weathering process (De Segonzac 1970; Keller 1964).

All of the above mineral characteristics, along with the variations in mineralogy with depth, are evidence that the Bear Den Member gained its present characteristics through a weathering or soil-forming process.

Topography-soil Relationship

Additional evidence that the Bear Den Member was formed as a soil horizon may be found in the relationship between it and its topography. To study this relationship, a structure contour map and an isopach map were made of the study area. These maps were constructed using the drilling data shown in appendix A.

The structure map was contoured on the base of the Bear Den Member because more data points were available here than at its top. The SYMAP computer program (Dougenik and Sheehan 1975) was used to construct the contours in this and in the isopach map. These maps are shown in Plates 3 and 4 respectively. (These maps are in the same area and have the same scale as Plate 1).

In comparing the two maps, a definite relationship can be seen between the topographic highs and lows. The low areas on the structure contour map (Plate 3, light shaded areas) correspond to the thick areas of Bear Den Member on the isopach map (Plate 4, light shaded areas), and the high areas correspond to the thin areas of Bear Den (dark shaded areas).

This relationship is even more obvious on Plates 5 and 6, which show a trend surface of the structure contour and the isopach maps. A trend-surface analysis is a technique of constructing the best-fit geometric surface that corresponds to the data points. The effect of this is to reduce large variations in the contoured surface, allowing trends that are present to be more readily recognized.

Once again it can be seen on these maps that the high areas closely correlate with a thin Bear Den development, whereas the low areas correspond to a thicker unit.

The above relationship of soil to topography is discussed by Birkeland (1974). He attributes this relationship in part to down-slope movement of soil material. Due to this movement, Birkeland (1974, p. 188) stated that "many soil properties correlate well with slope steepness. In particular with increasing steepness the soils are thinner . . ." He indicated that due to down-slope movement of soil materials, the high areas undergo a thinning of the soil profile due to a loss of material, whereas the low areas gain material and become thicker.

A scanning electron photomicrograph (Figure 10, appendix E) shows curved and broken plates of kaolinite. This kaolinite may indicate that some down-slope movement of the clay has occurred because it very closely resembles "ball clay" (Keller 1976b), which is deformed by sediment movement.

Cross-section of the Bear Den

Plate 2 is a cross-section which shows the relationship of the lower member of the Golden Valley Formation to the upper part of the Sentinel Butte Formation. A very widespread sand unit, informally named the "Wolf Creek Sand bed" dominates this cross-section. It can be seen that this unit reflects the regional structure of the area because its base and top follow the structure as indicated by the underlying coal beds. This similarity in regional structure, however, is not found at the base of the Bear Den Member. It does not follow either the "Wolf Creek Sand bed" or the underlying coal beds of the Sentinel Butte Formation. Moreover, the base of the Bear Den dips into and comes out of the top of this sand unit. This same relationship was also noted by Benson (1954, p. 387) who stated that "locally the lower part of the [Golden Valley] formation grades laterally into a white cross-bedded sand with kaolin binder."

The relationship presented above indicates that the Bear Den Member could not have been deposited as a detrital formation with a conformable base because it does not follow regional structure. This is known to be true because the base of the unit penetrates the top of the "Wolf Creek Sand" at some points but not in others. This relationship indicates that the Bear Den Member was formed not from detrital sediment, but by weathering of previously deposited sediments at the top of the Sentinel Butte Formation in this area.

ORIGIN OF THE KAOLINITE

The mineralogic profiles presented in the previous sections of this study indicate that the kaolinite of the Bear Den Member was formed through the weathering of feldspar and montmorillonite.

Keller (1964) indicates that the environment necessary for the formation of kaolinite is highly leaching, well-drained, and acidic. It can be expected that these conditions were met, because the Eocene climate was sub-humid and warm temperate (Epis and Chapin 1975; Hickey 1966 and 1977). This climate could provide an acidic leaching environment resulting from the decay of organic material, and the sediment within and underlying the Bear Den Member could provide good drainage.

Keller (1962) discussed the mechanism of weathering of feldspar. He explained that in an acid-rich environment, feldspar is decomposed by the weakening of the metal-cation bonds between the silica-alumina tretrahedra. The metal cations are replaced by hydrogen ions in this leaching process. During this process Keller (1964, p. 18) noted that "silica is appreciably more soluble below pH 8 than is alumina, and extensive leaching of an aluminum silicate will effect enrichment of alumina."

The above process replaces the metal cations with hydrogen ions and removes excess silica. Both of these are necessary to arrive at the proper chemical formula for kaolinite. This process may also form the silicrete found with the Bear Den Member and other similar units. The excess silica removed by leaching may, upon coming into contact with the proper environment, be deposited as silica cement.

The weathering of montmorillonite has been outlined by Altschuler (1963). In this process the 2:1 clay structure of montmorillonite (tetrahedral layer, octahedral layer, tetrahedral layer) is altered to the 1:1 structure of kaolinite (tetrahedral layer, octahedral layer). This occurs by leaching the interlayer cations of the montmorillonite and then by removing one of the tetrahedral layers of the 2:1 structure. Altschuler did not suggest a mechanism for the removal of tetrahedral layers, but Keller (1958) noted that with an abundance of sodium and potassium ions, which would be expected from the leaching of montmorillonitic clay, silica is stabilized in solution. This enriches the weathered zone in alumina and gives another source for the silica found in silcrete.

The above process is completed when the imbalance of charges created by the removal of a tetrahedral layer is corrected by filling the vacant tetrahedral sites with hydrogen ions.

CONCLUSIONS

Table 5 is a review of the evidence for and against the theory that the Bear Den Member represents a weathered horizon.

Freas (1962), after noting that the mineral profiles of the Bear Den appear to be consistent with that of a weathered profile, presented reasons for concluding that the kaolin is detrital. This study presents evidence that the Bear Den Member represents a weathered horizon.

In addition to the evidence presented (table 5) for the theory that the kaolin of the Bear Den Member was formed in place, explanations are given for the ideas that weathering has not occurred. These explanations are further discussed below.

1. This, and other studies (Wehrfritz 1978; Karner, Bjorlie, and Christensen 1978), have shown that an unconformity is present at the top of the Bear Den Member.

2. The nature and characteristics of the sediments are a result of their fluvial deposition preceding weathering. This type of deposition explains the stratigraphic nature of the sediments. The sediment's widespread distribution is the result of conditions conducive to weathering found throughout the Williston Basin during the formation of the soil horizon in late Paleocene or early Eocene time.

3. Plagioclase and amphibole are not found near the top of this unit and only begin to appear with depth in the less weathered sediment. Pyrite may be present; Keller (1964, p. 18) who stated that "the important effect in the kaolinization process is the

TABLE 5

EVIDENCE FOR AND AGAINST THE THEORY OF IN PLACE WEATHERING OF THE BEAR DEN MEMBER

Evidence against, Freas (1962)	Evidence for, this study
1. No unconformity is present at the top of the Bear Den Member.	1. An unconformity is present at the top of the Bear Den Member.
2. The unit is too uniform and widespread, and has a stratiform nature that cannot be explained by weathering.	2. The Bear Den is not uniform in thickness and cross-cuts stratigraphic units. The distribution of these units is a result of their original fluvial deposition.
3. The plagioclase, amphibole, pyrite, and siderite present should not have been able to withstand weathering.	3. Plagioclase, amphibole, pyrite, and siderite show a gradational increase in abundance toward the base of the member where weathering is less complete.
4. Kaolinite and muscovite show parallel alignment.	4. Kaolinite and muscovite are seldom found with parallel alignment.

Additional Evidence for the Theory of In Place Weathering

1. The mineralogy and the mineral profiles are consistent with those of a weathered horizon.
2. Favorable climatic conditions for weathering were present during the Eocene.
3. The topography and thickness relationships are similar to that of a soil.
4. The kaolinite horizon transgresses Sentinel Butte strata.
5. Scanning electron microphotos show a varying degree of crystallinity in the kaolinite.
6. Chemical data show that leaching of the Bear Den sediments has occurred.
7. The Bear Den Member compares favorably with similar units that have been described as weathered horizons.

removal of Fe from the reacting system, which can also be effected under geologic reducing conditions" where pyrite would be expected to be formed.

4. Kaolinite and muscovite do not always show parallel alignment (Figure 12), but this alignment may be expected to be found because the kaolinite has been derived from clay and feldspar that was deposited by fluvial processes with the muscovite.

The above review demonstrates that the Bear Den Member represents a weathered horizon and that the kaolinite is not detrital but was formed by a weathering process.

APPENDICES

APPENDIX A

DESCRIPTION OF DRILL HOLES AND MEASURED SECTIONS

DESCRIPTIONS OF DRILL HOLES AND MEASURED SECTIONS

This appendix describes the drill holes and measured sections used in this study. Drill holes designated with the prefix GV followed by a number were completed with a truck-mounted auger. Measured sections are designated by the prefix GV followed by a number and the letter M. A final set of samples are from rotary drill holes completed by the United States Geological Survey and the North Dakota Geological Survey. These samples are designated by the prefixes G169, 306-L, or REAP, followed by a number.

Location of the drill holes and measured sections are described by section, township, and range. A series of letters following the section number indicates quarter-quarter-quarter measurements, or 10 acre tracts. Lettering begins in the northeast quarter and goes counterclockwise from A to D. The first letter indicates the quarter (160 acres), the second letter indicates the quarter of a quarter (40 acres), the third letter indicates the quarter-quarter-quarter (10 acres).

Color descriptions of samples in measured sections are from the Munsell Soil Color Chart.

A list of abbreviations used in the descriptions follows.

calc: calcareous
carb: carbonaceous
conc: concretion
dk: dark
FeO: iron oxide
frags: fragments
lg: large
limst: limestone
lt: light
med: medium
sandst: sandstone
siltst: siltstone
sm: small
spl: sample
wx: weathers
xls: crystals

Auger Drill Hole: GV-1
By: Gordon Prichard
Date: 6-13-77

Location: T146N, R90W
Sec. 13, BBB
Elevation: 2165 (660 metres)

Interval		Description of Deposit
Feet	Metres	Glacial Materials
0-3	0.0- 0.9	Clay, silty, brown, topsoil.
3-10	0.9- 3.0	Pebble loam, gray-brown, calc, oxidized.
10-42	3.0-12.8	Pebble loam, olive-brown, calcareous with carb streaks and lignite frags, oxidized.
42-57	12.8-17.4	Pebble loam, gray, lignite frags.
		Sentinel Butte Formation
57-60	17.4-18.5	Sand, med grained, orange-brown, with silt and some clay.

Auger Drill Hole: GV-2
By: Gordon Prichard
Date: 6-13-77

Location: T146N, R90W
Sec. 13, CCB
Elevation: 2190 (668 metres)

Interval		Description of Deposit
Feet	Metres	
		Bear Den Member
0- 2	0.0- 0.6	Clay, silty, lt gray, kaolinitic.
2-10	0.6- 3.0	Sand, fine grained, silty, lt gray with orange nodules, kaolinitic.
10-25	3.0- 7.6	Sand, fine grained, silty, lt gray-brown with orange nodules, kaolinitic
		Sentinel Butte Formation
25-27	7.6-17.4	Sand, fine grained, silty, lt brown, becomes less silty and more coarse with depth.
27-57	17.4-24.7	Sand, fine grained, lt brown with orange nodules.
57-81	24.7-26.8	Sand, fine grained, brown with lignite frags.
88-93	26.8-28.3	Sand, fine grained, lt brown with orange nodules.
93-94	28.3-28.7	Lignite.
94-98	28.7-29.9	Sand, fine to med grained, dk brown with lignite frags and orange specks.

Auger Drill Hole: GV-3
By: Gordon Prichard
Date: 6-14-77

Location: T146N, R90W
Sec. 15, DDD
Elevation: 2235 (681 metres)

Interval		Description of Deposit
Feet	Metres	Glacial Materials
0- 6	0.0- 1.8	Pebble loam, olive-gray, calc.
6-30	1.8- 9.1	Pebble loam, orange-brown, oxidized.
30-50	9.1-15.2	Pebble loam, gray.
		Sentinel Butte Formation
50-70	15.2-21.3	Sand, fine grained, tan, some mica.

Auger Drill Hole: GV-4
By: Gordon Prichard
Date: 6-15-77

Location: T146N, R90W
Sec. 20, BBC
Elevation: 2120 (646 metres)

Interval		Description of Deposit
Feet	Metres	Sentinel Butte Formation
0-18	0.0-5.5	Sandst, fine grained sand, tan, some

Auger Drill Hole: GV-5
By: Gordon Prichard
Date: 6-15-77

Location: T146N, R90W
Sec. 30, ABB
Elevation: 2100 (640 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 4	0.0- 1.2	Sand, fine grained, silty, dk brown, becomes lighter with depth, topsoil.
		Sentinel Butte Formation
4-27	1.2- 8.2	Sand, fine to med grained, silty, tan.
27-40	8.2-12.2	Sand, fine to med grained, silty, tan, very tight, with carb material and lt blue nodules.

Auger Drill Hole: GV-6
By: Gordon Prichard
Date: 6-16-77

Location: T146N, R90W
Sec. 23, CCC
Elevation: 2250 (686 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0- 1	0.0- 0.3	Silt, clayey, brown, micaceous, soil on bedrock.
1-10	0.3- 3.0	Sand, silty, very fine grained, buff, micaceous, with oxidized nodules.
10-13	3.0- 4.0	Clay, silty, tan to orange, thinly banded.
13-19	4.0- 5.8	Clay, silty, olive-brown, orange on clay partings.
19-23	5.8- 7.0	Clay, silty, dk brown (purple hue), micaceous, with carb material and lignite stringers.
23-29	7.0- 8.8	Sand, very fine grained, silty, tan to buff, very micaceous.
29-35	8.8-10.7	Sand, very fine to fine grained, very micaceous.
35-39	10.7-11.9	Silt, clayey, lt brown to orange, micaceous.
39-45	11.9-13.7	Sand, fine grained, tan, micaceous, with nodules of lt green clay.
45-62	13.7-18.9	Clay, gray-brown with nodules of lt green clay.
		Bear Den Member
62-71	18.9-21.6	Clay, silty, lt gray, kaolinitic.
		Sentinel Butte Formation
71-72	21.6-21.9	Clay, silty, dk gray, carb, some mica, with lignite frags.
72-87	21.9-26.5	Clay, silty, gray with green clay nodules.
87-91	26.5-27.7	Silt, clayey, gray, some mica, with green specks and lignite frags.
91-100	27.7-30.5	Silty and very fine grained sand, gray, some mica.
100-106	30.5-32.3	Sand, fine to med grained, some mica.

Auger Drill Hole: GV-7
By: Gordon Prichard
Date: 6-16-77

Location: T146N, R90W
Sec. 14, CCC
Elevation: 2260 (689 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0- 2	0.0- 0.6	Clay, silty, buff, orange streaks.
2- 4	0.6- 1.2	Clay, silty, tan to orange, with gypsum crystals.
4- 5	1.2- 1.5	Clay, gray-brown, smooth with lignite frags.
5- 6	1.5- 1.8	Clay, dk brown (purple hue), carb, micaceous.
6-20	1.8- 6.1	Silt, clayey, some very fine grained sand, tan, becomes coarser with depth, very micaceous.
20-27	6.1- 8.2	Sand and silt, fine grained, lt brown, micaceous.
27-31	8.2- 9.4	Sand, fine grained, silty, brown, some lignite frags, micaceous.
31-38	9.4-11.6	Sand, fine grained, lt brown, micaceous.
38-42	11.6-12.8	Sand, fine grained, brown, micaceous.
42-47	12.8-14.3	Sand, very fine grained, silty, some clay, tan, micaceous.
		Bear Den Member
47-52	14.3-15.8	Clay, lt gray, smooth, carb, kaolinitic.
		Sentinel Butte Formation
52-66	15.8-20.1	Clay, silty, gray, some mica.
66-95	20.1-29.0	(Poor spl return) Silt with clay, gray, micaceous.

Auger Drill Hole: GV-8
By: Gordon Prichard
Date: 6-17-77

Location: T146N, R90W
Sec. 31, DDA
Elevation: 2055 (626 metres)

Interval		Description of Deposit
Feet	Metres	
		Slope Wash
0-20	0.0- 6.1	Sand, silty, med grained, tan.
		Sentinel Butte Formation
20-32	6.1- 9.8	Sand, silty, fine to med grained, tan.
32-35	9.8-10.7	Sand, silty, fine to med grained, tan to lt brown, with some clay nodules.

Auger Drill Hole: GV-9
By: Gordon Prichard
Date: 6-20-77

Location: T146N, R90W
Sec. 32, DDD
Elevation: 2160 (658 metres)

Interval		Description of Deposit
Feet	Metres	Bear Den Member
0- 1	0.0- 0.3	Sand, silty, fine grained, brown, soil on bedrock.
1- 3	0.3- 0.9	Silt, clayey, lt brown to lt gray, some mica, kaolinitic.
3-10	0.9- 3.0	Silt with some sand, lt gray, mica.
10-18	3.0- 5.5	Sand, some silt and clay, very fine grained, lt brown.
18-22	5.5- 6.7	Sand, some silty and clay, fine to med grained, lt brown.
22-25	6.7- 7.6	Sand, some silt and clay, fine to med grained, lt gray to white.
25-42	7.6-12.8	Sand, fine grained, lt gray-brown, micaceous.
42-55	12.8-16.8	Sand, fine grained, lt brown to tan, some mica.
		Sentinel Butte Formation
55-56	16.8-17.1	Sandst, fine grained, gray-brown.

Auger Drill Hole: GV-10
By: Gordon Prichard
Date: 6-20-77

Location: T145N, R90W
Sec. 4, DDD
Elevation: 2080 (634 metres)

Interval		Description of Deposit
Feet	Metres	Sentinel Butte Formation
0- 2	0.0- 0.6	Sand, silty, fine grained, orange-brown, some mica.
2- 7	0.6- 2.1	Sand, fine to med grained, tan.
7-17	2.1- 5.2	Clay, silty, gray-brown.
17-19	5.2- 5.8	Clay, some silt, gray, thin conc layer at 18'.
19-25	5.8- 7.6	Sand, fine grained, tan to brown.
25-28	7.6- 8.5	Sand, silty, fine grained, tan.
28-37	8.5-11.3	Sand, silty, med grained, orange-brown, some large orange nodules.
27-48	11.3-14.6	Silt, clayey, gray with orange oxidized bands.
48-95	14.6-29.0	Poor spl return. Mostly gray sand with silt and clay; sand is med to fine grained.

Auger Drill Hole: GV-11
By: Gordon Prichard
Date: 6-22-77

Location: T145N, R90W
Sec. 11, CAA
Elevation: 2180 (664 metres)

Interval		Description of Deposit
Feet	Metres	Bear Den Member
0- 5	0.0- 1.5	Silt and very fine grained sand, buff.
5- 8	1.5- 2.4	Silt with some very fine grained sand, very lt gray, some mica, kaolinitic.
		Sentinel Butte Formation
8- 9	2.4- 2.7	Silt and very fine grained sand, orange, mica.
9-12	2.7- 3.7	Silt, clayey, lt gray, some very fine grained sand, mica.
12-14	3.7- 4.3	Silt, clayey, tan, some mica.
14-24	4.3- 7.3	Sand, silty, fine grained, lt gray.
24-26	7.3- 7.9	Sand, silty, fine grained, lt gray-brown.
26-31	7.9- 9.4	Sand, med grained, lt gray to tan, salt and pepper.
31-37	9.4-11.3	Sand, med grained, brown with lignite frags.
37-42	11.3-12.8	Sand, med grained, lt brown with lignite frags.
42-46	12.8-14.0	Sand, med grained, lt gray-brown with lignite frags.
46-47	14.0-14.3	Lignite.
47-53	14.3-16.2	Sand, med grained, brown with some lignite frags.
53-58	16.2-17.7	Sand, med to fine grained, gray-brown, silty.
58-80	17.7-24.4	Sand with silt and clay, med to fine grained, olive-gray, some mica, orange specks.
80-83	24.4-25.3	Silt with clay, some sand, gray, carb stringers.
83-84	25.3-25.6	Lignite.

Measured Section: GV-11M
By: Gordon Prichard
Date: 8-2-77

Location: T145N, R90W
Sec. 11, CAA
Elevation of Base: 2180
(664 metres)

Interval: Feet	Interval: Metres	Description of Deposit
		Camels Butte Member
56.5-71.0	17.2-21.6	Silt, some clay, 2.5Y 7/4 pale yellow, micaceous.
54.0-56.6	16.5-17.2	Clay, silty, 7.5YR 3/2 dk brown with common plant frags and selenite xls. Thin lignite at the top of this unit.
30.0-54.0	9.1-16.5	Silt with some fine grained sand, 5Y 7/2 lt gray, micaceous, some clay, laminated.
28.5-30.0	8.7- 9.1	Silt and clay 10YR 6/2 lt brownish gray, some mica.
26.0-28.5	7.9- 8.7	Clay, silty, 10YR 6/3 pale brown, laminated.
25.5-26.0	7.8- 7.9	Lignite, black, shaley.
		Bean Den Member
22.0-25.5	6.7- 7.8	Clay, silty, 5YR 7/1 lt gray with white specks, massive.
20.0-22.0	6.1- 6.7	Clay, silty, 5YR 8/1 white, mottled by 2.5YR 7/6 yellow staining from wx siderite nodules, laminated.
16.0-20.0	4.9- 6.1	Clay, silty, 5YR 8/1 white, mica, laminated.
5.5-16.0	1.7- 4.9	Clay, silty, 5YR 5/1 gray with white specks, mica, and plant frags.
0.0- 5.5	0.0- 1.7	Clay, silty, 7.5YR 4/2 brown, dk brown with yellow FeO staining, common plant frags, laminated, fissle.

Auger Drill Hole: GV-12
By: Gordon Prichard
Date: 6-22-77

Location: T145N, R90W
Sec. 2, BAC
Elevation: 2180 (664 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 2	0.0- 0.6	Silt and sand, gray brown.
		Bear Den Member
2- 4	0.6- 1.2	Clay, silty, lt gray, kaolinitic with mica.
4- 6	1.2- 1.8	Clay, silty, gray-brown, carb with mica.
6- 8	1.8- 2.4	Clay, silty, dk brown with some smooth black clay, carb.
8-14	2.4- 4.3	Silt, some clay, lt gray to white, some fine grained sand.
14-20	4.3- 6.1	Sand, with silt and clay, fine grained, lt gray, some mica.
20-25	6.1- 7.6	Sand, with silt and clay, fine grained, lt gray to white, some mica.
25-28	7.6- 8.5	Sand, with silt and clay, fine grained, lt gray, some mica.
		Sentinel Butte Formation
28-46	8.5-14.0	Sand, fine to med grained, lt brown to gray, salt and pepper with orange specks.
46-55	14.0-16.8	Sand, med grained, tan, salt and pepper with orange specks.
55-56	16.8-17.1	Lignite.
56-60	17.1-18.3	Sand, med grained, dk brown, lignite stringers.
60-62	18.3-18.9	Sand, med grained, orange-brown, salt and pepper with orange specks.
62-63	18.9-19.2	Sand, fine to med grained, gray, salt and pepper.

Measured Section: GV-12M
By: Gordon Prichard
Date: 8-2-77

Location: T145N, R90W
Sec. 11, CAA
Elevation of Base: 2180
(664 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
48.5-53.0	14.8-16.2	Silt, clayey, 2.5Y 8/4 pale yellow, micaceous, indurated.
48.0-48.5	14.6-14.8	Lignite.
45.5-48.0	13.9-14.6	Clay, silty 5YR 5/3 reddish brown with selenite xls, plant and lignite frags, laminated.
36.5-45.5	11.1-13.9	Silt with very fine sand, 10YR 7/1 lt gray, micaceous with yellow streaks, small scale cross laminations.
34.0-36.5	10.4-11.1	Sand, med grained, 10YR 8/3 very lake brown, micaceous with black specks.
27.0-34.0	8.2-10.4	Sand, fine grained, 10YR 8/2 white, micaceous with black specks.
22.5-27.0	6.9- 8.2	Sand, fine grained with silt, 7.5YR 7/2 pinkish gray, micaceous with lignite frags.
		Bear Den Member
6.5-22.5	2.0- 6.9	Clay with silt, 5YR 8/1 white, massive with yellow staining and siderite nodules.
0.0- 6.5	0.0- 2.0	Clay, some silt, 10YR 4/1 dk gray, massive with white specks.

Auger Drill Hole: GV-13
By: Gordon Prichard
Date: 6-22-77

Location: T145N, R90W
Sec. 5, DDB
Elevation: 2165 (660 metres)

Interval		Description of Deposit
Feet	Metres	
		Slope Wash
0- 3	0.0- 0.9	Silt and clay, orange-brown, mica.
		Bear Den Member
3- 5	0.9- 1.5	Silt with some clay, yellow-orange.
5-29	1.5- 8.8	Clay, silty, very lt gray to white, kaolinitic.
29-33	8.8-10.1	Sand with silt and clay, very fine grained, lt gray.
33-46	10.1-14.0	Sand, little clay, very fine grained, lt gray.
46-51	14.0-15.5	Sand, very fine grained, lt gray-brown.
		Sentinel Butte Formation
51-53	15.5-16.2	Sand, med grained, dk brown, lignite frags.
53-85	16.2-25.9	(Poor spl return). Clay, silty, gray.
85-95	25.9-28.9	(Poor spl return). Sand, fine to med grained, blue-gray, salt and pepper.

Auger Drill Hole: GV-14
By: Gordon Prichard
Date: 6-23-77

Location: T146N, R90W
Sec. 34, CCA
Elevation: 2145 (654 metres)

Interval		Description of Deposit
Feet	Metres	
		Slope Wash
0- 4	0.0- 1.2	Sand and silt, very fine grained, buff to tan with mica.
		Bear Den Member
4-6	1.2- 1.8	Sand, very fine grained, tan with black and orange specks, mica.
6- 7	1.8- 2.1	Sand, fine grained, tan to orange with black and orange specks, mica.
7-23	2.1- 7.0	Clay, silty, lt gray to white with mica, kaolinitic.
23-40	7.0-12.2	Silt with clay and very fine grained sand, lt gray, orange specks and mica.
40-42	12.2-12.8	Silt with very fine grained sand, lt gray to lt blue, micaceous.
		Sentinel Butte Formation
42-48	12.8-14.6	Silt with clay, lt blue-gray, micaceous.
48-60	14.6-18.3	Silt, clayey, blue-gray with mica.
60-61	18.3-18.6	Silt with very fine sand, blue-gray, indurated.
61-70	18.6-21.3	Clay, silty, blue-gray with mica and lignite stringers.

Measured Section: GV-14M
By: Gordon Prichard
Date: 8-3-77

Location: T146N, R90W
Sec. 34, CCA
Elevation of Base: 2145
(654 metres)

Interval Feet	Interval Metres	Description of Deposit
		Camels Butte Member
46.5-50.0	14.2-15.2	Clay, silty, 10YR 7/1, lt gray with orange specks, laminated.
43.5-46.5	13.3-14.2	Clay, some silt, 2.5Y 5/2 grayish brown, micaceous with lignite frags, laminated.
42.0-43.5	12.8-13.3	Silt, clayey, 7.5YR 4/4 dk brown, very micaceous, with selenite xls and plant frags, laminated, fissle.
39.0-42.0	11.9-12.8	Sand, fine grained with silt, 5Y 7/3 pale yellow, micaceous, with lignite frags, and small scale cross laminations.
37.5-39.0	11.4-11.9	Clay, silty, 5Y 6/3 pale olive, micaceous with orange streaks and plant frags, laminated.
34.5-37.5	10.5-11.4	Sand, fine grained with silt, 10YR 8/2 white, micaceous with black specks and orange staining. Thin black carb clay at the top of this unit.
21.5-34.5	6.6-10.5	Clay, silty, 2.5Y 7/4 pale yellow, with mica, laminated.
21.0-21.5	6.4- 6.6	Lignite, black.
		Bear Den Member
18.0-21.0	5.5- 6.4	Clay, silty, 10YR 7/1 lt gray with carb streaks, massive.
7.0-18.0	2.1- 5.5	Clay, some silt, 2.5YR 4/0 dk gray with lignite frags and white specks, massive.
0.0- 7.0	0.0- 2.1	Silt, clayey with some very fine grained sand, 10YR 7/1 lt gray with orange staining, massive.

Auger Drill Hole: GV-15
By: Gordon Prichard
Date: 6-23-77

Location: T146N, R90W
Sec. 21, BCA
Elevation: 2220 (677 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 3	0.0- 0.9	Silt and clay, with sand, gray brown.
		Bear Den Member
3- 7	0.9- 2.1	Clay, silty, dk brown to purple, lignitic, brittle.
7-13	2.1- 4.0	Clay, silty, lt gray, kaolinitic.
13-18	4.0- 5.5	Silty with very fine grained sand, buff, micaceous with orange specks.
18-25	5.5- 7.6	Silt, clayey, lt gray, micaceous with lignite frags and orange specks.
		Sentinel Butte Formation
25-28	7.6- 8.5	Sand, fine to med grained, tan, some mica with orange specks and lignite frags.
28-37	8.5-11.3	Sand, fine to med grained, gray brown, some mica, salt and pepper.
37-42	11.3-12.8	Sand, fine to med grained, tan to gray, some mica, salt and pepper with lignite frags.
42-50	12.8-15.2	Clay, silty, dk gray, micaceous with lignite frags.
50-51	15.2-15.5	Clay, dk gray to black, smooth, carb with lignite.
51-56	15.5-17.1	Clay, silty, gray, very micaceous.
56-60	17.1-18.3	Sand, fine to med grained, olive brown.

Measured Section: GV-15M
By: Gordon Prichard
Date: 8-3-77

Location: T146N, R90W
Sec. 21, BCA
Elevation of Base: 2220
(677 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
63.0-70.0	19.2-21.3	Clay, silty, 5Y 7/2 lt gray with mica and plant frags, laminated.
62.0-63.0	18.9-19.2	Silt, with clay, 5YR 4/3 reddish brown, micaceous with selenite xls, laminated.
61.0-62.0	18.6-18.9	Clay, 7.5YR 2/0 black, very carb, laminated.
49.0-61.0	14.9-18.6	Sand, fine to med grained, 10YR 7/1, lt gray, micaceous with indurated layers, small scale cross laminations.
45.0-49.0	13.7-14.9	Silt with some clay, 2.5Y 7/2 lt gray, some fine grained sand, micaceous with orange staining, laminated.
24.5-45.0	7.5-13.7	Clay, silty, banded 10YR 8/1 white with 10YR 8/3 very pale brown, some mica, laminated. Unit has a thin conc layer at 26' and a thin carb clay layer at the top.
24.0-24.5	7.3- 7.5	Lignitic shale, black, fissle.
		Bear Den Member
0.0-24.0	0.0- 7.3	Clay, silty, 5YR 4/1 dk gray, some lignite specks, massive. Unit is banded gray and dk gray with some orange streaks.

Auger Drill Hole: GV-16
By: Gordon Prichard
Date: 6-23-77

Location: T146N, R90W
Sec. 21, CCB
Elevation: 2245 (684 metres)

Interval		Description of Deposit
Feet	Metres	
		Slope Wash
0- 4	0.0- 1.2	Sand, very fine grained with silt, tan, micaceous.
		Bear Den Member
4-11	1.2- 3.4	Clay, silty, gray to purple.
11-32	3.4- 9.8	Clay, gray to lt gray to purple, smooth, becomes silty and lighter with depth.
		Sentinel Butte Formation
32-40	9.8-12.2	Sand, very fine grained, tan, micaceous with orange specks and lignite stringers.
40-44	12.2-13.4	Sand, very fine grained, with silt, lt gray-brown, micaceous, lignite stringers.
44-50	13.4-15.2	Sand, fine grained, gray-brown, micaceous, salt and pepper with lignite stringers.

Auger Drill Hole: GV-17
By: Gordon Prichard
Date: 7-7-77

Location: T145N, R90W
Sec. 12, AAD
Elevation: 2145 (654 metres)

Interval		Description of Deposit
Feet	Metres	Sentinel Butte Formation
0- 6	0.0- 1.8	Sand, fine grained, silty, lt brown, micaceous with orange and black specks.
6- 9	1.8- 2.7	Sand, fine grained, silty, tan, micaceous, with orange and black specks.
9-14	2.7- 4.3	Sand, fine grained, silty, lt brown, micaceous, with orange and black specks.
14-17	4.3- 5.2	Sand, fine to med grained, lt gray-brown, some silt with mica and black specks.
17-21	5.2- 6.4	Sand, fine to med grained, tan to orange, some silt, little mica, with black specks.
21-29	6.4- 8.8	Sand, fine to med grained, tan, some mica, with black specks.
29-31	8.8- 9.4	Sand, very fine grained, with silt ald clay, lt gray mottled with orange streaks, micaceous, with black specks.
31-34	9.4-10.4	Silt, with clay, lt gray, some carb streaks, micaceous.
34-36	10.4-11.0	Silt, with some sand and clay, tan to orange, micaceous.
36-39	11.0-11.9	Silt, some sand, dk brown, micaceous, very carb with lignite stringers.
39-45	11.9-13.7	Silt, tan, micaceous, lignite specks.
45-50	13.7-15.2	Silt, sandy, tan to orange, micaceous with black specks.
50-54	15.2-16.5	Silt, tan, micaceous, black specks.
54-62	16.5-18.9	Silt, sandy with some clay, olive-brown, some mica and black specks. Thin lignite stringer at about 58'.
62-70	18.9-21.3	Silt and clay, some sand, blue-gray, micaceous, with lignite stringers.

Auger Drill Hole: GV-18
By: Gordon Prichard
Date: 7-8-77

Location: T146N, R90W
Sec. 36, ADA
Elevation: 2310 (704 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0-14	0.0- 4.3	Clay, buff, smooth with plant frags and orange streaks.
14-15	4.3- 4.6	Clay, black with orange staining, lignitic.
15-19	4.6- 5.8	Clay, some silt, lt gray-brown.
19-20	5.8- 6.1	Clay, black, very carb to lignitic, selenite xls.
20-25	6.1- 7.6	Silt, some clay, brown, micaceous with lignite frags.
25-32	7.6- 9.8	Sand, very fine grained, with silt, tan, very micaceous.
32-34	9.8-10.4	Clay, silty, dk gray-brown, carb with mica.
34-42	10.4-12.8	Silt, some clay, med to lt blue-gray, very micaceous with carb streaks.
42-50	12.8-15.2	Clay, silty, med to lt blue-gray with mica and lignite frags.
50-60	15.2-18.3	Clay, silty, gray, micaceous with lignite frags.
60-64	18.3-19.5	Silt, with clay, med to dk green, micaceous.
64-80	19.5-24.4	Clay, silty, greenish gray, micaceous.
80-81	24.4-24.7	Clay, dk gray, carb.
81-85	24.7-25.9	Clay, silty, gray, micaceous with a thin lignite at about 82'.
85-92	25.9-28.0	Clay, silty, lt green, micaceous, very tough.

Auger Drill Hole: GV-19
By: Gordon Prichard
Date: 7-12-77

Location: T145N, R89W
Sec. 4, CCC
Elevation: 2275 (693 metres)

Interval		Description of Deposit
Feet	Metres	Topsoil
0- 3	0.0- 0.9	Silt with very fine grained sand, brown, micaceous.
		Camels Butte Member
3- 6	0.9- 1.8	Silt with some very fine grained sand, lt brown, micaceous with black specks.
6-10	1.8- 3.0	Silt with some very fine grained sand, buff, with mica and black specks.
10-17	3.0- 5.2	Fine grained sand with silt, buff, micaceous with black and orange specks.
17-19	5.2- 5.8	Fine grained sand with silt, orange, micaceous.
19-20	5.8- 6.1	Clay with silt, dk brown to black, lignitic.
		Bear Den Member
20-26	6.1- 7.9	Clay, lt gray to lt blue, smooth with orange streaks.
		Sentinel Butte Formation
26-37	7.9-11.3	Silt, buff to tan, some mica, becomes sandy with depth.
37-44	11.3-13.4	Silt with clay, gray, some mica with light streaks.
44-47	13.4-14.3	Clay, dk brown to black, lignitic.
47-52	14.3-15.8	Clay, silty, med to dk gray, micaceous.
52-70	15.8-21.3	Clay, some silt, gray with orange specks and mica.
70-72	21.3-21.9	Clay, dk brown to black, very carb.
72-73	21.9-22.3	Clay, gray, smooth with mica.
73-75	22.3-22.9	Clay, lt green, smooth with black streaks.
75-85	22.9-25.9	Clay, with silt, gray, some mica.

Auger Drill Hole: GV-20
By: Gordon Prichard
Date: 7-12-77

Location: T145N, R89W
Sec. 15, DDD
Elevation: 2125 (648 metres)

Interval		Description of Deposit
Feet	Metres	Sentinel Butte Formation
0- 3	0.0- 0.9	Sand, fine to med grained, tan, salt and pepper.
3- 5	0.9- 1.5	Sand, fine to med grained, orange-brown, oxidized, salt and pepper.
5-23	1.5- 7.0	Sand, med grained, tan to orange, with orange specks, salt and pepper.
23-24	7.0- 7.3	Sandstone, med grained, brown to orange, poorly indurated.
24-25	7.3- 7.6	Silt, some clay, tan to orange with orange banding.
25-28	7.6- 8.5	Sand, med grained, tan, some mica.
28-35	8.5-10.7	Sand, fine grained, with silt and some clay, brown, very carb, some mica.
35-42	10.7-12.8	Sand, fine grained with some silt, tan, some mica.
42-56	12.8-17.1	Clay, silty, gray with mica.
56-57	17.1-17.4	Lignite.
57-67	17.4-20.4	Clay, silty, gray with some dark carb streaks and lignite frags.
67-68	20.4-20.7	Lignite.
68-75	20.7-22.9	Clay, silty, gray, some mica.

Auger Drill Hole: GV-21
By: Gordon Prichard
Date: 7-13-77

Elevation: T145N, R89W
Sec. 20, BBB
Elevation: 2170 (661 metres)

Interval		Description of Deposit
Feet	Metres	Bear Den Member
0- 6	0.0- 1.8	Clay, silty, lt gray to white with yellow streaks, some mica.
6-11	1.8- 3.4	Silt with some clay and very fine grained sand, lt gray with orange streaks and mica.
11-16	3.4- 4.9	Sand, fine grained, lt gray to white with orange specks, micaceous.
16-23	4.9- 7.0	Sand, fine to med grained, lt gray, salt and pepper with mica.
23-25	7.0- 7.6	Sand, fine to med grained, lt gray-brown, salt and pepper with lignite frags and mica.
25-26	7.6- 7.9	Lignite.
26-27	7.9- 8.2	Sand, fine to med grained, lt gray-brown, salt and pepper with lignite frags and mica.
		Sentinel Butte Formation
27-34	8.2-10.4	Sand, fine to med grained, tan, salt and pepper with some mica.
34-36	10.4-11.0	Sand, med grained, brown, some mica and lignite frags.
36-40	11.0-12.2	Sand, med grained with some silt balls, lt gray-brown, sand is 80-85% quartz, little mica.
40-41	12.2-12.5	Clay, silty, lt blue-gray to lt brown with orange oxidized streaks, micaceous.
41-42	12.5-12.8	Clay, silty, lt blue-green micaceous.
42-50	12.8-15.2	Silt with clay, gray, micaceous, thin conc at 49'.

Auger Drill Hole: GV-22
By: Gordon Prichard
Date: 7-13-77

Elevation: T145N, R89W
Sec. 16, BDA
Elevation: 2200 (671 metres)

Interval		Description of Deposit
Feet	Metres	Bear Den Member
0-11	0.0- 3.4	Clay, silty, lt gray to white, kaolinitic.
11-13	3.4- 4.0	Sand, very fine grained with silty, lt gray with black specks, micaceous.
13-21	4.0- 6.4	Sand, very fine grained, silty, buff, salt and pepper, micaceous.
21-23	6.4- 7.0	Sand, very fine grained, silty, lt gray, salt and pepper, micaceous.
23-25	7.0- 7.6	Sand, very fine grained, silty, lt gray-brown, salt and pepper, micaceous.
25-28	7.6- 8.5	Sand, very fine to fine grained, lt gray-brown, salt and pepper with lignite frags.
		Sentinel Butte Formation
28-37	8.5-11.3	Sand, fine to med grained, tan to lt brown, salt and pepper with lignite frags.
37-38	11.3-11.6	Sand, fine to med grained, tan, salt and pepper.
38-47	11.6-14.3	Sand, fine grained, silty, lt gray-brown, with orange streaks and black specks, some mica.
47-70	14.3-21.3	Sand, fine to med grained, some silt, lt brown to lt olive-brown, black specks, some mica.

Measured Section: GV-22M
By: Gordon Prichard
Date: 8-4-77

Location: T145N, R89W
Sec. 9, CDC
Elevation of Base: 2200
(671 metres)

Interval		Description of Deposit
Feet	Metres	
		Glacial Materials
49.5-56.0	15.1-17.1	Pebble loam, 5Y 6/3 olive-gray, with orange nodules and lignite frags.
		Camels Butte Member
36.5-49.5	11.1-15.1	Silt with some clay, 5Y 7/2 lt gray, micaceous with lignite streaks, laminated. A layer of petrified wood is at the top of this unit.
27.5-36.5	8.4-11.1	Clay, silty, 5Y 8/3 pale yellow, micaceous, laminated.
26.5-27.5	8.1- 8.4	Lignite.
25.5-26.5	7.8- 8.1	Clay, silty, 5YR 4/3 reddish brown, micaceous with plant frags and selenite, laminated with some small scale cross laminations in the silty streaks.
19.0-25.5	5.8- 7.8	Clay, silty, 5Y 6/2 lt olive-gray with orange streaks on bedding, micaceous, laminated.
12.0-19.0	3.7- 5.8	Clay, little silt, 5Y 5/2 olive-gray with some lt and dk streaks, some selenite xls, laminated.
11.0-12.0	3.4- 3.7	Clay, 7.5 YR 4/0 dk gray, lignitic, laminar, fissle, brittle.
		Bear Den Member
0.0-11.0	0.0- 3.4	Clay, silty, 10YR 8/1 white, some orange staining, massive.

Auger Drill Hole: GV-23
By: Gordon Prichard
Date: 7-13-77

Location: T145N, R89W
Sec. 8, BCC
Elevation: 2170 (661 metres)

Interval		Description of Deposit
Feet	Metres	
		Glacial Materials
0- 5	0.0- 1.5	Pebble loam, buff to tan with orange nodules and lignite frags.
		Bear Den Member
5- 8	1.5- 2.4	Sand, fine grained with silt, lt gray to tan with orange oxidized streaks, micaceous.
8-22	2.4- 6.7	Silt with clay and very fine sand, lt gray with orange oxidized streaks, micaceous.
22-28	6.7- 8.5	Sand, fine grained, lt gray with orange specks, micaceous.
28-31	8.5- 9.4	Sand, fine grained, lt gray-brown with orange specks, micaceous.
		Sentinel Butte Formation
31-35	9.4-10.7	Sand, fine to med grained, tan, with orange specks, micaceous.
35-36	10.7-11.0	Sand, fine to med grained, tan to orange, micaceous.
36-42	11.0-12.8	Sand, fine to med grained, lt gray-brown, micaceous.
42-46	12.8-14.0	Sand, med grained, brown with lignite frags.
46-50	14.0-15.2	Sand, med grained, tan to orange.
50-53	15.2-16.2	Sand, fine grained with silt, gray-brown.
53-58	16.2-17.7	Sand, fine grained, silty, lt brown with mica.
58-60	17.7-18.3	Sand, fine grained, silty, tan with mica.
60-62	18.3-18.9	Sand, fine grained, silty, lt brown, some mica.
62-65	18.9-19.8	Sand, fine grained and silt, tan, some mica.
65-70	19.8-21.3	Sand, med grained, silty, lt brown with some mica and lignite frags.

Auger Drill Hole: GV-24
By: Gordon Prichard
Date: 7-14-77

Location: T145N, R89W
Sec. 6, DAD
Elevation: 2195 (669 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0- 5	0 - 1.5	Clay, silty, olive brown, some mica.
5- 6	1.5- 1.8	Clay, silty, tan to orange with orange streaks, micaceous.
6-12	1.8- 3.7	Clay, silty, lt gray-brown with orange streaks, micaceous with plant frags.
12-13	3.7- 4.0	Lignite.
13-14	4.0- 4.3	Clay, blue-gray with orange streaks, smooth.
14-17	4.3- 5.2	Silt, clayey, tan, micaceous with plant frags.
17-22	5.2- 6.7	Clay, silty, olive gray, micaceous with orange specks.
22-23	6.7- 7.0	Lignite.
23-25	7.0- 7.6	Clay, silty, blue-green with carb streaks.
25-26	7.6- 7.9	Clay, silty, lt blue-gray with carb streaks.
26-38	7.9-11.6	Clay, silty, gray, micaceous.
38-40	11.6-12.2	Clay, silty, dk gray to black, highly carb with lignite frags.
		Bear Den Member
40-45	12.2-13.7	Clay, silty, gray to lt gray (becomes lighter with depth), some mica.
45-50	13.7-15.2	Clay, silty, lt gray, greasy, kaolinitic.
50-58	15.2-17.7	Silt, clayey, lt gray, greasy, kaolinitic.
58-65	17.7-19.8	Silty and clay, some very fine grained sand, lt gray, kaolinitic with some mica.
65-70	19.8-21.3	Silt and clay, some very fine grained sand, lt to med gray, some mica.

Auger Drill Hole: GV-24, cont.

		Sentinel Butte Formation
70-75	21.3-22.9	Silt and clay, some very fine grained sand, gray, some mica.
75-82	22.9-25.0	Silty and very fine grained sand, med to lt gray, micaceous.
82-85	25.0-25.9	Silt, clayey with some very fine grained sand, gray, micaceous.
85-90	25.9-27.4	Sand, fine to med grained, salt and pepper, micaceous.

Auger Drill Hole: GV-25
By: Gordon Prichard
Date: 7-14-77

Location: T146N, R89W
Sec. 32, AAB
Elevation: 2245 (684 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0-10	0 - 3.4	Silt and clay, buff to tan, very micaceous.
10-15	3.4- 4.6	Clay, grey-brown, micaceous with plant frags.
15-17	4.6- 5.2	Clay, black, smooty, very carbonaceous with lignite frags.
17-23	5.2- 7.0	Clay, lt grey-green, smooth with plant frags and some mica.
23-24	7.0- 7.3	Lignite.
24-27	7.3- 8.2	Clay, dk grey, smooth, carbonaceous with lignite frags.
27-29	8.2- 8.8	Lignite.
29-44	8.8-13.4	Clay, silty, lt grey, micaceous.
44-45	13.4-13.7	Lignite.
45-50	13.7-15.2	Clay, silty, lt to med grey, with some mica.
50-57	15.2-17.4	Clay, silty, grey with lt grey streaks, micaceous.
57-60	17.4-18.3	Clay, silty, grey-green, micaceous.
60-75	18.3-22.9	Clay, silty, grey with brown carbonaceous streaks, micaceous.

Auger Drill Hole: GV-26
By: Gordon Prichard
Date: 7-14-77

Location: T145, R89W
Sec. 4, BBB
Elevation: 2260 (689 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 3	0.0- 0.9	Clay, silty, dk brown to black.
		Glacial Materials
3-23	0.9- 7.0	Pebble loam, olive with orange nodules and many large to small lignite chunks. Large carbonate are very numerous.
23-24	7.0- 7.3	Gravel with orange silt and clay.
24-40	7.3-12.2	Pebble loam, grey, unoxidized with only a few pebbles and little lignite.

Auger Drill Hole: GV-27
By: Gordon Prichard
Date: 7-14-77

Location: T145N, R89W
Sec. 10, BBC
Elevation: 2230 (680 metres)

Interval		Description of Deposit
Feet	Metres	
		Slope Wash
0- 6	0.0- 1.8	Sand, fine to med grained, tan to brown.
		Glacial Materials
6-11	1.8- 3.4	Pebble loam, olive with orange nodules and white calc streaks, some lignite frags.
11-25	3.4- 7.6	Pebble loam, grey unoxidized with lignite frags.
		Bear Den Member
25-75	7.6-22.9	Clay, silty, lt to med grey, micaceous.
75-85	22.9-25.9	Silt with some clay and very fine grained sand, grey, micaceous.
85-90	25.9-27.4	Sand, fine grained, grey, salt and pepper.

Auger Drill Hole: GV-28
By: Gordon Prichard
Date: 7-15-77

Location: T146N, R90W
Sec. 36, BBD
Elevation: 2265 (690 metres)

Interval		Description of Deposit
Feet	Metres	Glacial Materials
0- 5	0.0- 1.5	Pebble loam, lt brown with orange nodules, some lignite frags and mica.
		Camels Butte Member
5-17	1.5- 5.2	Sand, fine grained with silt, tan with orange specks and lignite frags, micaceous.
17-22	5.2- 6.7	Sand, fine grained with silt, buff, micaceous.
22-26	6.7- 7.9	Clay, silty, dk brown, carb with lignite frags.
26-27	7.9- 8.2	Lignite.
27-31	8.2- 9.4	Clay, silty, lt blue-grey, micaceous.
31-38	9.4-11.6	Clay, very silty, buff to tan with orange streaks and some mica.
38-45	11.6-13.7	Clay, silty, lt to med grey, some mica.
45-48	13.7-14.6	Clay, some silt, grey, micaceous.
48-51	14.6-15.5	Clay, silty, grey with plant and lignite frags, some mica.
51-52	15.5-15.8	Lignite.
52-70	15.8-21.3	Clay, silty, grey with dk grey mottling, micaceous.
70-72	21.3-21.9	Sand, fine grained, grey, micaceous.
72-75	21.9-22.9	Sand, very fine grained, silty, lt brown, micaceous.
75-78	22.9-23.8	Silt, clayey, lt to med brown, micaceous.
78-82	23.8-25.5	Clay, becomes silty with depth, grey, micaceous.
82-85	25.5-25.9	Clay, silty, med to lt grey, greasey (kaolinitic), some mica.

Auger Drill Hole: GV-29
By: Gordon Prichard
Date: 7-19 77

Location: T146N, R90W
Sec. 33, ABD
Elevation: 2200 (671 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 3	0.0- 0.9	Clay and silt, some very fine grained sand, grey-brown, some mica.
		Bear Den Member
3-11	0.9- 3.4	Silt and clay, tan to orange, greasy, kaolinitic with some mica.
11-23	3.4- 7.0	Sand, very fine grained with silt, lt grey with orange and black specks.
23-26	7.0- 7.9	Sand, very fine grained with silt, lt grey to tan with orange and black specks.
26-43	7.9-13.1	Sand, very fine grained, silty, lt grey to tan with black specks.
43-56	13.1-17.1	Sand, very fine grained, silty, lt grey-brown, salt and pepper.
		Sentinel Butte Formation
56-64	17.1-19.5	Sand, very fine grained, silty, lt brown, salt and pepper.
64-67	19.5-20.4	Sand, very fine grained, silty, olive grey with black specks.

Measured Section: GV-29M
By: Gordon Prichard
Date: 8-3-88

Location: T146N, R90W
Sec. 33, ABD
Elevation of Base: 2200
(671 metres)

Interval Feet	Interval Metres	Description of Deposit
		Camels Butte Member
44.5-47.0	13.6-14.3	Sandst, 10YR 6/6 brownish yellow, poorly indurated, micaceous with lg scale cross laminations.
38.5-44.5	11.7-13.6	Clay, silty, 2.5Y 7/2 lt gray, micaceous, laminated.
38.0-38.5	11.6-11.7	Lignite.
		Bear Den Member
33.0-38.0	10.1-11.6	Clay, silty, 10YR 8/1 white with carb streaks and lignite frags, micaceous.
16.0-33.0	4.9-10.1	Clay, silty, banded 10YR 6/8 brownish yellow and 5YR 8/1 white with black specks and some yellow staining, laminated.
4.0-16.0	1.2- 4.9	Clay, silty, 5YR 8/1 white with some carb streaks, massive.
0.0- 4.0	0.0- 1.2	Clay, silty, 5YR 5/1 gray with some carb streaks, wx 5YR 6/1 gray, massive.

Auger Drill Hole: GV-30
By: Gordon Prichard
Date: 7-19-77

Location: T146N, R90W
Sec. 34, AAD
Elevation: 2140 (652 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 2	0.0- 0.6	Clay with sand and silt, dk brown.
2-17	0.6- 5.2	Sand, fine grained, silty, brown, some small pebbles.
		Glacial Materials
17-24	5.2- 7.3	Pebble loam, olive with orange nodules and lignite frags.
		Sentinel Butte Formation
24-31	7.3- 9.4	Silt, with very fine grained sand, lt blue-grey, micaceous.
31-40	9.4-12.2	Silt and very fine grained sand, tan to orange with orange streaks and black specks, micaceous.
40-52	12.2-15.8	Sand, very fine grained, silty, lt blue with black specks, micaceous.
52-53	15.8-16.2	Lignite.
53-65	16.2-19.8	Sand, very fine grained, lt blue with black specks, micaceous.

Auger Drill Hole: GV-31
By: Gordon Prichard
Date: 7-19-77

Location: T145N, R90W
Sec. 2, ADD
Elevation: 2250 (686 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 2	0.0- 0.6	Silt and fine grained sand, brown, micaceous.
2- 8	0.6- 2.4	Silt and clay, tan, calc streaks.
		Camels Butte Member
8-10	2.4- 3.0	Silt, clayey, tan to orange, calc streaks.
10-11	3.0- 3.3	Silt, clayey, orange, micaceous.
11-12	3.3- 3.6	Silt, dk brown, very carb with lignite frags.
12-20	3.6- 6.1	Silt, some very fine grained sand, buff to tan with orange and reddish streaks, micaceous.
20-27	6.1- 8.2	Clay, silty, tan to brown with orange streaks.
27-32	8.2- 9.8	Clay, grey, smooth with carb streaks.
32-33	9.8-10.1	Lignite.
33-41	10.1-12.5	Sand, very fine grained, silty, blue-grey, micaceous.

Auger Drill Hole: GV-32
By: Gordon Prichard
Date: 7-20-77

Location: T146N, R90N
Sec. 32, BBB
Elevation: 2245 (684 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0- 9	0.0- 2.7	Silt, some clay, tan with orange FeO specks, micaceous.
9-15	2.7- 4.6	Silt with very fine grained sand, buff, micaceous.
15-23	4.6- 7.0	Sand, fine to very fine grained, silty, buff with black specks, micaceous.
23-25	7.0- 7.6	Clay, silty, tan to orange, micaceous.
25-32	7.6- 9.7	Clay, silty, grey, some micaceous.
32-33	9.7-10.1	Lignite.
33-42	10.1-12.8	Silt with very fine grained sand, grey, micaceous.
42-45	12.8-13.7	Clay, silty, grey, micaceous.
45-55	13.7-16.8	Sand, very fine to fine grained, lt grey-brown, micaceous.
55-57	16.8-17.1	Sand, very fine grained, silty, grey-brown, micaceous.
57-60	17.1-18.3	Clay, silty, med to dk grey, micaceous, lignite frags.
60-68	18.3-20.7	Silt with clay, grey, micaceous with lignite frags.
		Bear Den Member
68-70	20.7-21.3	Clay, silty, lt blue-grey (dries white), greasey, kaolinitic.
70-73	21.3-22.3	Clay, silty, lt grey to green-grey (dries white), mottled, some mica.
73-80	22.3-24.4	Clay, silty, variegated, mostly lt grey with some purple, green, and blue, dries white. Fracture surfaces have white nodules.
80-84	24.4-25.6	Silt with clay, lt grey, micaceous.
84-95	25.6-29.0	Sand, very fine grained, silty, lt blue-grey, some mica.

Auger Drill Hole: GV-33
By: Gordon Prichard
Date: 8-9-77

Location: T145N, R88W
Sec. 5, CBA
Elevation: 2180 (664 metres)

Interval		Description of Deposit
Feet	Metres	Bear Den Member
0-10	0.0- 3.0	Clay, silty, lt grey with dk carb streaks, micaceous.
10-12	3.0- 3.7	Clay, silty, lt grey with carb streaks, micaceous.
12-16	3.7- 4.9	Clay, silty, grey with carb streaks, micaceous.
16-18	4.9- 5.5	Clay, silty, very dk grey, carbon with lignite frags.
18-20	5.5- 6.1	Sand, very fine grained, silty, lt grey-brown, micaceous.
		Sentinel Butte Formation
20-22	6.1- 6.7	Sand, fine grained, brown, micaceous.
22-26	6.7- 7.9	Sand, fine to med grained, brown with lignite frags, micaceous.
26-27	7.9- 8.2	Sand, med grained, pale yellow with lignite frags, micaceuus. Lignite frags are coated with jarosite.
27-30	8.2- 9.1	Sand, med grained, brown with lignite frags, micaceous.
30-32	9.1- 9.8	Sand, med grained, dk brown, carb with lignite frags and mica.
32-40	9.8-12.2	Sand, fine grained, silty, lt grey, micaceous.

Measured Section: GV-33M
By: Gordon Prichard
Date: 8-9-77

Location: T145 N, R88W
Sec. 5, CBA
Elevation of base: 2180
(664 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
41.0-49.0	12.5-14.9	Clay, some silt, 5Y 6/2 lt olive gray with plant frags, micaceous. A siltst is found at the top of this unit.
37.0-41.0	11.3-12.5	Clay, silty, 2.5Y 7/4 pale yellow, micaceous, laminated.
28.5-37.0	8.7-11.3	Clay, silty, 10YR 7/8 yellow with lignite frags, micaceous, laminated. Thin siltst conc are found in this unit.
		Bear Den Member
27.5-28.5	8.4- 8.7	Clay, silty, 10YR 7/1 lt gray with lignite frags, micaceous.
24.5-27.5	7.5- 8.4	Clay, 10YR 5/1 gray (purple hue) smooth, greasy.
21.5-24.5	6.6- 7.5	Clay, 10YR 6/1 gray, smooth, greasey with white specks.
20.5-21.5	6.2- 6.6	Clay, silty, 2.5Y 7/8 yellow with dk mottling, micaceous, fractured.
19.0-20.5	5.8- 6.2	Clay, 7.5YR 4/0 dk grey, smooth, greasey, laminated with lignite frags.
10.5-19.0	3.2- 5.8	Clay, silty, 7.5YR 5/2 brown with plant frags and lignite stringers at base, shaley, micaceous.
0.0-10.5	0.0- 3.2	Clay, silty, 10YR 7/1 lt grey with orange FeO specks and streaks, micaceous, massive.

Auger Drill Hole: GV-36
By: Gordon Prichard
Date: 8-11-77

Location: T146N, R92W
Sec. 20, DAA
Elevation: 2340 (714 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0- 5	0.0- 1.5	Clay with silt and very fine grained sand, buff with orange FeO specks, micaceous.
		Bear Den Member
5- 6	1.5- 1.8	Clay, silty, dk brown, carb with lignite frags, micaceous.
6-15	1.8- 4.6	Clay, silty, med to lt gray with some lignite frags, micaceous.
15-16	4.6- 4.9	Silt, clayey, lt gray to white with orange streaks, micaceous.
16-18	4.9- 5.6	Clay, silty, gray with dk carb streaks, micaceous.
18-22	5.6- 6.7	Clay, very silty, dk gray to brown, lignite frags, micaceous.
22-26	6.7- 7.9	Silt, clayey, lt gray-brown with yellow streaks, micaceous.
26-30	7.9- 9.1	Sand, fine to very fine grained, lt gray-brown, salt and pepper, micaceous.
30-36	9.1-11.0	Sand, fine grained, buff with lignite frags, micaceous.
36-45	11.0-13.7	Sand, fine grained, lt brown with lignite frags, micaceous.
45-52	13.7-15.8	Sand, med grained, grey-brown with lignite frags, micaceous.

Measured Section: GV-36M
By: Gordon Prichard
Date: 8-11-77

Location: T146N, R92W
Sec. 20, DAA
Elevation of Base: 2340
(713 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
29.5-35.0	9.0-10.7	Sand, very fine grained, silty, 5Y 6/3 pale olive, very micaceous, small scale cross laminations.
23.0-29.5	7.0- 9.0	Silt with clay, 5YR 7/3 pale yellow with orange streaks, micaceous, laminated.
22.5-23.0	6.9- 7.0	Lignite.
		Bear Den Member
14.5-22.5	4.4- 6.9	Clay, very silty, 5YR 6/2 pinkish gray with orange FeO specks, some lignite frags, micaceous.
9.5-14.5	2.9- 4.4	Clay, silty, 5YR 7/1 lt gray with orange banding and orange siltst, micaceous, fractured
4.5- 9.5	1.4- 2.9	Clay, silty, 5YR 5/1 gray, micaceous, massive.
0.0	0.0- 1.4	Clay, silty, 5YR 7/1 lt gray with carb streaks, micaceous, massive.

Drill Hole: G169-36
Date: 8-5-75

Location: T146N, R91W
Sec. 30, CCC
Elevation: 2240 (683 metres)

Interval		Description of Deposit
Feet	Metres	Glacial Materials
0-30	0.0- 9.1	Pebble loam, yellow brown.
30-33	9.1-10.1	Gvl.
		Sentinel Butte Formation
33-40	10.0-12.2	Sand, very fine grained, silty.
40-75	12.2-22.8	Sand, fine grained, yellow-brown.
75-77	22.8-23.4	Sandst.
77-83	23.4-25.2	Sand, fine grained, bluish gray.
83-84	25.2-25.5	Clay, med gray.
84-86	25.5-26.1	Lignite.
86-89	26.1-27.1	Silt, clayey.
89-91	27.1-27.7	Lignite.
91-92	27.7-28.0	Shale, carb.
92-103	28.0-31.3	Clay, silty, med gray.
103-106	31.3-32.2	Silt.
106-110	32.2-33.4	Sand, very fine grained, silty.
110-117	33.4-35.6	Lignite.
117-118	35.6-35.9	Clay, silty, med gray.
118-126	35.9-38.3	Clay, med gray.
126-129	38.3-39.2	Lignite.
129-135	39.2-41.0	Clay, silty, gray.
135-137	41.0-41.6	Clay, carb.
137-139	41.6-42.3	Lignite.
139-144	42.3-43.8	Clay, silty, med gray.
144-148	43.8-45.0	Lignite.
148-149	45.0-45.3	Clay.
149-151	45.3-45.9	Clay, carb.
151-165	45.9-50.2	Sand, very fine grained, silty.
165-173	50.2-52.6	Clay, silty, greenish gray.
173-175	52.6-53.2	Lignite.
175-177	53.2-53.8	Clay, brown-gray.
177-185	53.8-56.2	Silt, greenish gray.
185-188	56.2-57.2	Clay, silty, med to lt gray.
188-192	57.2-58.4	Clay, brown-gray, carb.
192-195	58.4-59.3	Clay, brown-gray.
195-199	59.3-60.5	Silt, sandy.

Drill Hole: G169-37
Date: 8-7-75

Location: T146N, R92W
Sec. 20, ACA
Elevation: 2320 (707 metres)

Interval		Description of Deposit
Feet	Metres	Camels Butte Member
0-12	0.0- 3.6	Clay, silty, lt brown-gray.
		Bear Den Member
12-28	3.6- 8.5	Sand, very fine grained, lt brown-gray to lt gray.
		Sentinel Butte Formation
28-97	8.5-29.5	Sand, very fine grained, yellow-brown.
97-99	29.5-30.1	Lignite.
99-102	30.1-31.0	Sandst.
102-113	31.0-34.4	Sand, fine to med grained.
113-114	34.4-34.7	Lignite.
114-140	34.7-42.6	Clay, silty, med gray.
140-149	42.6-45.3	Lignite.
149-157	45.3-47.7	Clay, silty, lt brown-gray.
157-162	47.7-49.2	Silt, sandy, lt brown-gray.
162-176	49.2-53.5	Clay, silty, lt brown-gray.
176-181	53.5-55.0	Lignite.
181-188	55.0-57.2	Sand, very fine grained, silty.
188-190	57.2-57.8	Lignite.
190-194	57.8-59.0	Clay, silty, brown-gray.
194-198	59.0-60.2	Sand, very fine grained, silty.
198-202	60.2-61.4	Sandst.
202-205	61.4-62.3	Sand, very fine grained.
205-208	62.3-63.2	Lignite.
208-210	63.2-63.8	Clay, silty, brown-gray.
210-227	63.8-69.0	Silt.
227-230	69.0-69.9	Clay, silty.
230-242	69.9-73.6	Sand, very fine grained, silty.
242-250	73.6-76.0	Silt, clayey, green-gray.
250-253	76.0-76.9	Sandst.
253-259	76.9-78.7	Silt, clayey.
259-263	78.7-80.0	Clay, green-gray.
263-268	80.0-81.5	Silt, clayey.
268-273	81.5-83.0	Silt, gray.
273-275	83.0-83.6	Lignite.
275-276	83.6-83.9	Clay.
276-284	83.9-86.3	Sand, very fine grained, silty.

Drill Hole: G-169-47
Date: 8-19-75

Location: T145N, R90W
Sec. 24, AAA
Elevation: 2100 (640 metres)

Interval		Description of Depsoit
Feet	Metres	Sentinel Butte Formation
0- 2	0.0- 0.6	Sand, brownish gray.
2- 3	0.6- 0.9	Lignite.
3- 5	0.9- 1.5	Sand, brownish gray.
5- 7	1.5- 2.1	Sandst.
7-40	2.1-12.2	Sand, brown, oxidized.
40-47	12.2-14.3	Sandst, blue-gray.
47-53	14.3-16.1	Sand, brown.
53-54	16.1-16.4	Lignite.
54-56	16.4-17.0	Sand, brown.
56-57	17.0-17.3	Lignite.
57-62	17.3-18.8	Sand, brown.
62-64	18.8-19.5	Lignite.
64-66	19.5-20.1	Clay, green-gray.
66-68	20.1-20.7	Silt, green-gray.
68-70	20.7-21.3	Clay, green-gray.
70-74	21.3-22.5	Silt, sandy, green-gray.
74-78	22.5-23.7	Clay, silty, green-gray.
78-80	23.7-24.3	Lignite.
80-85	24.3-25.8	Clay, silty, green-gray.
85-91	25.8-27.7	Silt, sandy, green-gray.
91-96	27.7-29.2	Silt, clayey, green-gray.
96-100	29.2-30.4	Silt, sandy, gray-green.
100-102	30.4-31.0	Clay, silty, green-gray.
102-104	31.0-31.6	Clay.
104-107	31.6-32.5	Sandst.
107-108	32.5-32.8	Clay, gray.
108-111	32.8-33.7	Clay, silty, gray.
111-122	33.7-37.1	Sand, gray.
122-126	37.1-38.3	Lignite.
126-132	38.3-40.1	Clay, silty, green-gray.
132-137	40.1-41.6	Lignite.
137-139	41.6-42.3	Clay, green-gray.
139-144	42.3-43.8	Clay, silty, green-gray.
144-152	43.8-46.2	Lignite.
152-157	46.2-47.7	Clay, green-gray.
157-163	47.7-49.6	Clay, silty, green-gray.
163-181	49.6-55.0	Silt, gray.
181-202	55.0-61.4	Sand, very fine grained, silty, gray, conc at 200'.
202-212	61.4-64.4	Sand, fine grained, blue-gray.
212-215	64.4-65.4	Lignite.
215-217	65.4-66.0	Clay.
217-220	66.0-66.9	Lignite.
220-229	66.9-69.9	Clay, silty, green-gray.

Drill Hole: G169-48
Date: 8-21-75

Location: T146N, R89W
Sec. 30, CCD
Elevation: 2240 (681 metres)

Interval Feet	Interval Metres	Description of Deposit
		Glacial Materials
0-30	0.0- 9.1	Pebble loam, sandy, brown to drk gray.
		Camels Butte Member
30-40	9.1-12.2	Clay, sandy, brown.
40-45	12.2-13.7	Clay, gray, lignite frags.
45-46	13.7-14.0	Clay, silty, gray.
46-48	14.0-14.6	Lignite.
48-50	14.6-15.2	Clay, silty, gray.
50-60	15.2-18.2	Clay, gray to black.
		Bear Den Member
60-65	18.2-19.8	Clay, silty, green-gray.
65-70	19.8-21.3	Clay, silty, green-gray to white.
70-75	21.3-22.8	Clay, white.
75-80	22.8-24.3	Clay, white to gray, lignite frags.
		Sentinel Butte Formation
80-85	24.3-25.8	Clay-gray.
85-90	25.8-27.4	Clay, silty with sand, gray.
90-95	27.4-28.9	Clay, sandy, gray.
95-105	28.9-31.9	Clay, some sandst, friable, grey.

Drill Hole: 306-L24
Date: 8-12-76

Location: T145N, R90W
Sec. 4, AAA
Elevation: 2120 (646 metres)

Interval		Description of Deposit
Feet	Metres	Slope Wash
0-10	0.0- 3.0	Silt, sandy, tan.
		Bear Den Member
10-14	3.0- 4.3	Sand, very fine grained, silty, lt gray with orange streaks.
14-18	4.3- 5.5	Clay, silty, lt gray.
		Sentinel Butte Formation
18-20	5.5- 6.1	Sand, very fine grained, silty, dk gray.
20-21	6.1- 6.4	Lignite.
21-27	6.4- 8.2	Sand, very fine grained, silty, dk gray.
27-30	8.2- 9.1	Clay, dk gray.
30-42	9.1-12.8	Clay, silty, dk gray.
42-44	12.8-13.4	Sandst, gray.
44-47	13.4-14.3	Sand, very fine grained, gray.
47-49	14.3-14.9	Silt, clayey, gray.
49-50	14.9-15.2	Lignite.
50-74	15.2-22.5	Sand, very fine grained, gray.
74-76	22.5-23.1	Sandst, gray.
76-93	23.1-28.3	Sand, very fine grained, gray.
93-98	28.3-29.8	Clay, silty, gray.
98-100	29.8-30.4	Silt, gray.
100-102	30.4-31.0	Clay, silty, gray.
102-109	31.0-33.1	Sand, very fine grained, silty, gray.
109-111	33.1-33.7	Clay, gray.
111-115	33.7-35.0	Lignite.
115-116	35.0-35.3	Clay, gray.
116-128	35.3-38.9	Sand, very fine grained, silty, gray.
128-132	38.9-40.1	Clay, silty, gray.
132-135	40.1-41.0	Sand, very fine grained, silty, gray.
135-138	41.0-42.0	Limest, gray.
138-140	42.0-42.6	Clay, gray.
140-152	42.6-46.2	Sand, very fine grained, silty, gray.
152-154	46.2-46.8	Lignite.
154-162	46.8-49.2	Silt, clayey, gray.
162-172	49.2-52.3	Sand, very fine grained, silty, gray.
172-175	52.3-53.2	Lignite.
175-176	53.2-53.5	Clay, gray.
176-185	53.5-56.2	Silt, gray.

Drill Hole: 306-L24, cont.

185-187	56.2-56.8	Clay, gray.
187-191	56.8-58.1	Lignite.
191-192	58.1-58.4	Clay, gray.
192-197	58.4-59.9	Lignite.
197-202	59.9-61.4	Clay, silty, gray.
202-204	61.4-62.0	Lignite.
204-207	62.0-62.9	Clay, gray.
207-213	62.9-64.8	Sand, very fine grained, silty, gray.
213-224	64.8-68.1	Clay, silty, gray-green.
224-233	68.1-70.8	Sand, very fine grained, silty, gray.
233-240	70.8-73.0	Silt, gray.
240-243	73.0-73.9	Clay, silty, gray.
243-246	73.9-74.8	Lignite.
246-255	74.8-77.5	Clay, silty, gray.

Drill Hole: 306-L25
Date: 8-11-76

Location: T146N, R91W
Sec. 22, DDD
Elevation: 2190 (666 metres)

Interval		Description of Deposit
Feet	Metres	Sentinel Butte Formation
0-16	0.0- 4.9	Silt, tan with traces of orange, topsoil.
16-19	4.9- 5.8	Sandst.
19-24	5.8- 7.3	Sand, very fine grained, silty, tan with orange streaks.
24-28	7.3- 8.5	Lignite.
28-32	8.5- 9.7	Clay, silty, gray-tan.
32-35	9.7-10.6	Sand, very fine grained, gray-tan with carb streaks.
35-38	10.6-11.6	Sandst, lt gray.
38-52	11.6-15.8	Sand, very fine grained, gray-tan, traces of orange.
52-56	15.8-17.0	Sandst, lt gray.
56-61	17.0-18.5	Sand, very fine grained, tan with traces of orange.
61-63	18.5-19.2	Lignite. (Poor sam le return below 61', lost circulation.)
63-77	19.2-23.4	Sand.
77-79	23.4-24.0	Sand, carb.
79-88	24.0-26.8	Sand.
88-91	26.8-27.7	Clay, silty, carb.
91-98	27.7-29.8	Sand, very fine grained.
98-100	29.8-30.4	Clay.
100-101	30.4-30.7	Lignite.
101-103	30.7-31.3	Sand.
103-109	31.3-33.1	Silt, clayey.
109-118	33.1-35.9	Sand, very fine grained, silty.
118-124	35.9-37.7	Clay, silty.
124-142	37.7-43.2	Sand, very fine grained, silty.
142-146	43.2-44.4	Clay, silty.
146-151	44.4-45.9	Lignite.
151-155	45.9-47.1	Clay.
155-159	47.1-48.3	Lignite.
159-172	48.3-52.3	Silt, clayey.
172-176	52.3-53.5	Clay.
176-196	53.5-59.6	Sand, very fine grained.
196-200	59.6-60.8	Sand, very fine grained, silty.
200-203	60.8-61.7	Silt, clayey.
203-206	61.7-62.6	Clay, carb.
206-212	62.6-64.4	Sand, very fine grained.
212-221	64.4-67.2	Sand, silty.

Drill Hole: 306-L25, cont.

221-226	67.2-68.7	Silt, claye.
226-230	68.7-69.9	Sandst.
230-234	69.9-71.1	Silt.
235-238	71.1-72.4	Sand, very fine grained, silty.
238-240	72.4-73.0	Lignite.
240-242	73.0-73.6	Clay, carb.
242-244	73.6-74.2	Sand, very fine grained, silty.
244-245	74.2-74.5	Sandst.
245-249	74.5-75.7	Sand, very fine grained, silty.
249-251	75.7-76.3	Silt, clayey.
251-264	76.3-80.3	Silt.
264-267	80.3-81.2	Lignite.
267-275	81.2-83.6	Silt.
275-277	83.6-84.2	Clay, carb.
277-285	84.2-86.6	Silt, clayey.
285-290	86.6-88.2	Sand, very fine grained.
290-294	88.2-89.4	Silt, clayey.
294-299	89.4-90.9	Lignite.
299-302	90.9-91.8	Clay.
302-304	91.8-92.4	Lignite.
304-307	92.4-93.3	Clay, silty.
307-310	93.3-94.2	Lignite.
310-316	94.2-96.1	Clay, silty.
316-320	96.1-97.3	Sand, very fine grained, silty.
320-321	97.3-97.6	Lignite.
321-322	97.6-97.9	Clay.
322-324	97.9-98.5	Lignite.
324-330	98.5-100.3	Clay, silty.

Drill Hole: 306-L29
Date: 9-8-76

Location: T145N, R88W
Sec. 8, DDD
Elevation: 2205 (670 metres)

Interval		Description of Deposit
Feet	Metres	Glacial Materials
0-20	0.0- 6.1	Pebble loam, tan.
20-65	6.1-19.8	Pebble loam, gray.
		Sentinel Butte Formation
65-68	19.8-20.7	Silt, clayey, tan to orange.
68-100	20.7-30.4	Sand, very fine grained, tan to orange with ironest conc.
100-132	30.4-40.1	Sand, very fine grained, blue-green with black specks.
132-140	40.1-42.6	Sandst, very fine grained, blue-green, calc cement.
140-146	42.6-44.4	Sand.
146-148	44.4-45.0	Clay, silty, green.
148-152	45.0-46.2	Sand.
152-154	46.2-46.8	Clay, silty, green.
154-164	46.8-49.9	Sand, very fine grained, blue-green.
164-167	49.9-50.8	Lignite.
167-177	50.8-53.8	Silt, clayey, gray.
177-181	53.8-55.0	Clay, carb.
181-191	55.0-58.1	Silt, clayey, gray.
191-194	58.1-59.0	Lignite.
194-206	59.0-62.6	Silt, clayey, gray.
206-210	62.6-63.8	Sandst, gray, calc cement.
210-221	63.8-67.2	Sand, very fine grained, silty, gray.
221-236	67.2-71.7	Clay, silty, gray.
236-239	71.7-72.7	Lignite.
239-246	72.7-74.8	Clay, silty, gray.
246-250	74.8-76.0	Clay, carb, silty.
250-262	76.0-79.6	Lignite.
262-268	79.6-81.5	Sand, very fine grained, silty, lt green-gray.
268-270	81.5-82.1	Clay, silty, carb.
270-280	82.1-85.1	Silt, sandy, gray.
280-290	85.1-88.2	Lignite.
290-292	88.2-88.8	Clay, dk gray.
292-296	88.8-90.0	Clay, silty, dk gray.
296-302	90.0-91.8	Silt, clayey, green.

Drill Hole: REAP-6
Date: 9-9-76

Location: T146N, R89W
Sec. 36, DDD
Elevation: 2270 (690 metres)

Interval		Description of Deposit
Feet	Metres	Topsoil
0- 2	0.0- 0.6	Silt, dk gray-brown, organic.
		Glacial Materials
2-33	0.6-10.0	Pebble loam, yellow-brown, oxidized, calc streaks from 2-5 feet.
		Camels Butte Member
33-37	10.0-11.2	Clay, bright yellowish gray, oxidized.
37-41	11.2-12.5	Clay, silty, lt gray with lignite frags.
41-42	12.5-12.8	Siltst.
42-46	12.8-14.0	Clay, silty, lt gray.
46-52	14.0-15.8	Sand, very fine grained, silty.
52-54	15.8-16.4	Clay, silty.
54-56	16.4-17.0	Lignite.
56-57	17.0-17.3	Clay, silty, green-gray.
57-60	17.3-18.2	Silt with very fine grained sand, lt gray.
60-64	18.2-19.5	Clay, silty, lt gray.
64-66	19.5-20.1	Lignite.
66-67	20.1-20.4	Clay, lt gray, smooth.
67-70	20.4-21.3	Sand, very fine grained, lt gray, micaceous.
70-74	21.3-22.5	Silt, clayey, med gray, micaceous.
74-80	22.5-24.3	Clay, silty, med gray.
80-82	24.3-24.9	Silt, clayey, lt gray, micaceous.
82-86	24.9-26.1	Clay, green-gray, smooth.
86-97	26.1-29.5	Silt, clayey, lt gray, micaceous.
97-108	29.5-32.8	Clay, silty, gray to dk gray, micaceous.
108-114	32.8-34.7	Sand, fine to med grained.
114-119	34.7-36.2	Sand, fine grained, carb.
119-123	36.2-37.4	Clay, med to dk gray.
123-126	37.4-38.3	Sand, fine grained, carb.
		Bear Den Member
126-129	38.3-39.2	Clay, whitish gray, smooth.
129-161	39.2-48.9	Sand, very fine grained, lt whitish gray.

Drill Hole: REAP-6, cont.

Sentinel Butte Formation

161-164	48.9-49.9	Sand, silty, carb, lignitic.
164-183	49.9-55.6	Sand, fine grained, green-gray with black specks.
183-195	55.6-59.3	Sand, very fine to fine grained, lt gray with black, some dk brown carb s streaks.
195-199	59.3-60.5	Sandst.
199-210	60.5-63.8	Sand, very fine to fine grained, lt gray.
210-212	63.8-64.4	Lignite.
212-235	64.4-71.4	Sand, silty, carb.
235-242	71.4-73.6	Sandst, calc cement.
242-249	73.6-75.7	Sand, fine grained, lt gray.
249-251	75.7-76.3	Sand, very fine grained, carb.
251-254	76.3-77.2	Sand, very fine grained, silty, lt gray.
254-256	77.2-77.8	Clay, dk gray, carb.
256-259	77.8-78.7	Lignite.
259-262	78.7-79.6	Clay, silty, gray.
262-264	79.6-80.3	Clay, carb.
264-270	80.3-82.1	Silt, clayey, gray.
270-273	82.1-83.0	Lignite.
273-278	83.0-84.5	Clay, silty, gray.
278-292	84.5-88.8	Sand, very fine grained, silty.
292-297	88.8-90.3	Silt, clayey, gray.
297-305	90.3-92.7	Clay, silty, gray.
305-309	92.7-93.9	Silt, sandy, dk gray.
309-310	93.9-94.2	Lignite.
310-314	94.2-95.5	Clay, silty, dk gray to green.
314-322	95.5-97.9	Silt, clayey, dk gray.
322-326	97.9-99.1	Lignite.
326-330	99.1-100.3	Silt, clayey, gray.
330-334	100.3-101.5	Clay, silty, gray.
334-344	101.5-104.6	Lignite.
344-345	104.6-104.9	Clay.
345-350	104.9-106.4	Sand, very fine grained, silty, reddish brown, carb.
350-354	106.4-107.6	Sand, very fine grained, silty, dk gray.
354-357	107.6-108.5	Silt, clayey, dk cray.
357-366	108.5-111.3	Sand, very fine grained, silty, dk gray.
366-380	111.3-115.5	Clay, blue-gray, smooth.
380-385	115.5-117.0	Lignite.
385-386	117.0-117.3	Clay, green.
386-387	117.3-117.6	Clay, carb.

APPENDIX B

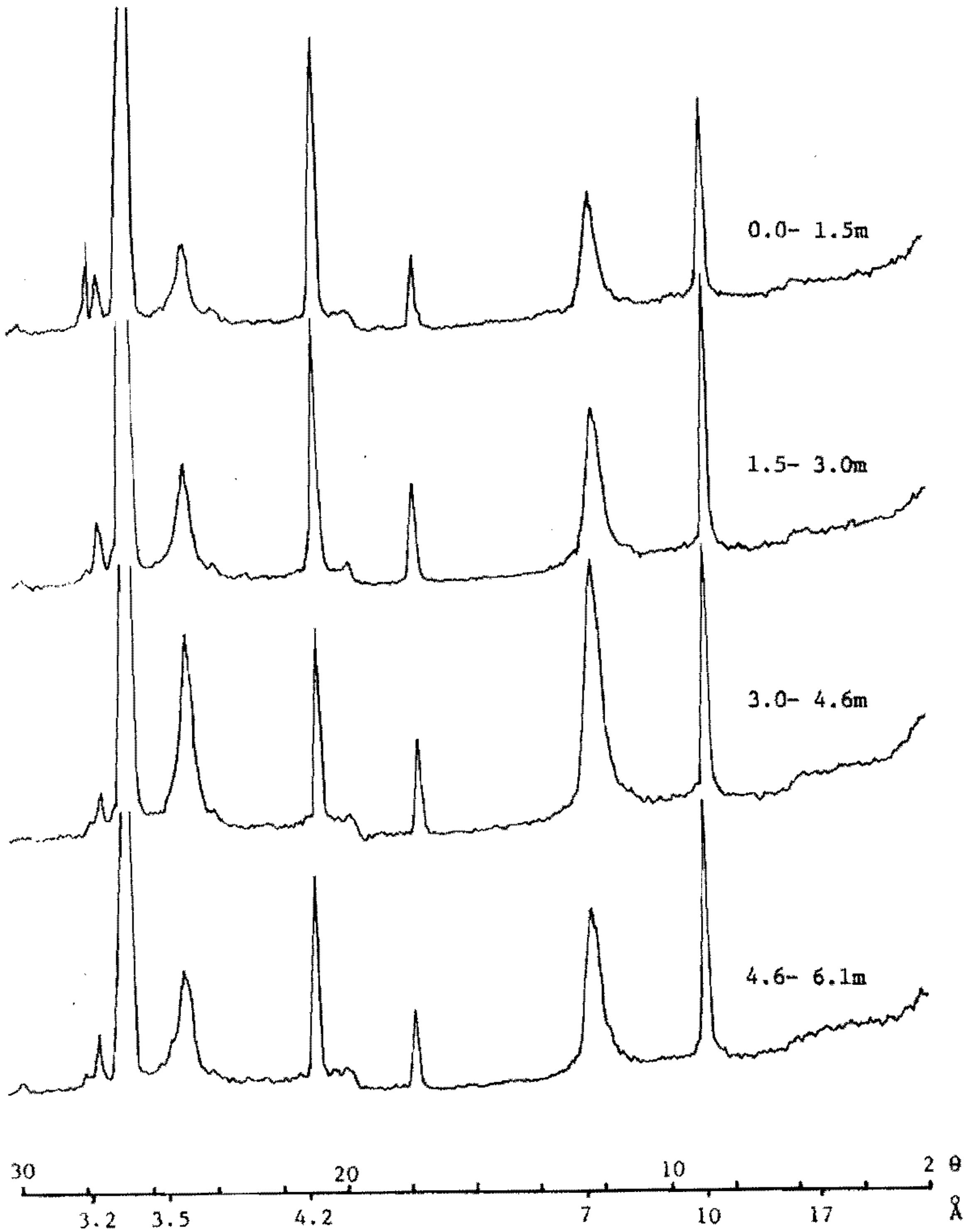
X-RAY DIFFRACTOGRAMS

X-RAY DIFFRACTOGRAMS

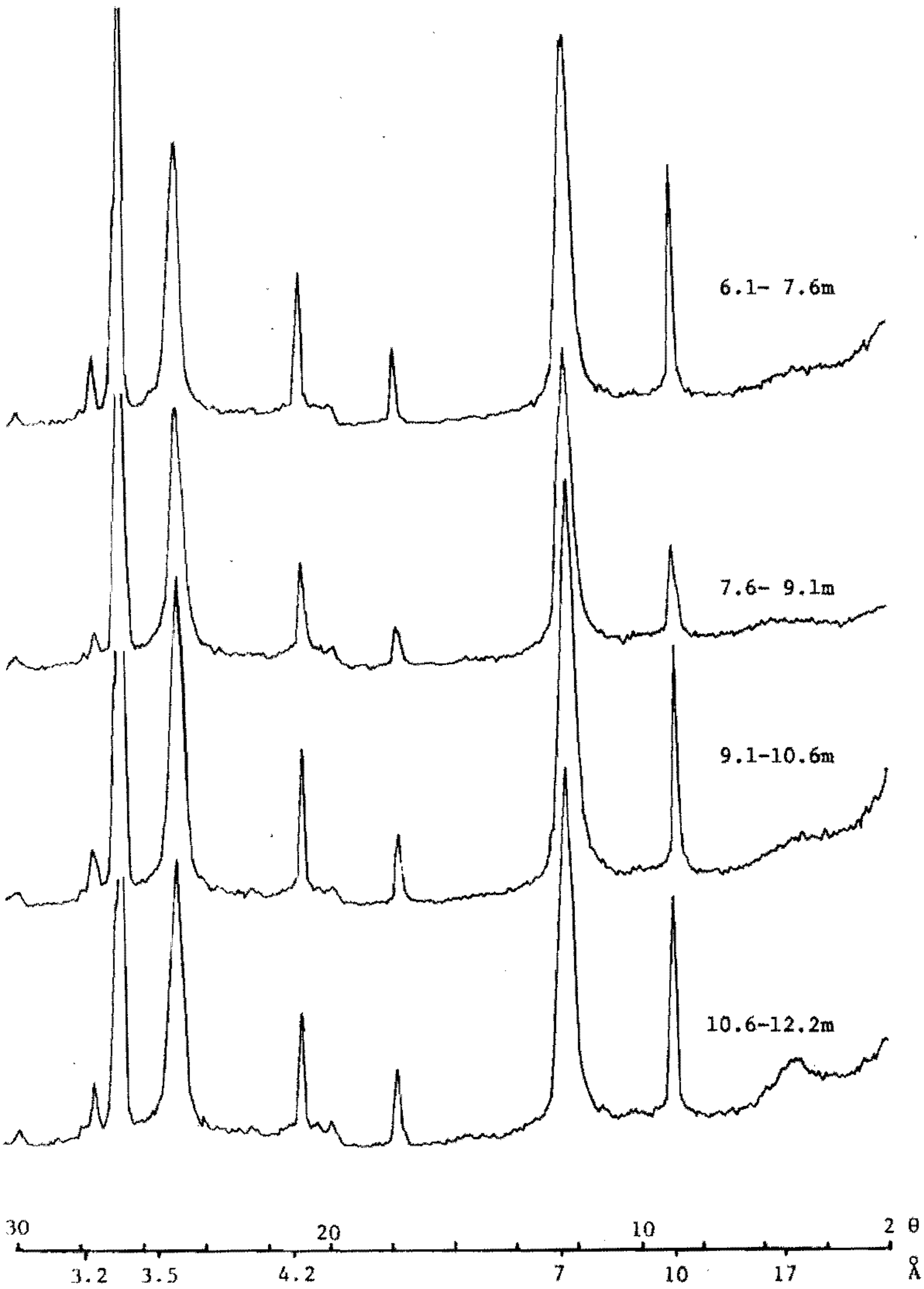
Presented in this appendix are reductions of X-ray diffractograms of samples analyzed for this study. Sample preparation and X-ray procedures are presented in the text under the heading "X-ray Analysis." Descriptions and locations of samples X-rayed are found in appendix A. Sample intervals are in metres. A letter M preceding the sample interval indicates that the sample is from a measured section.

The major peaks found in these X-ray charts are as follows: 17Å, montmorillonite; 14.4Å, chlorite; 10Å, illite and mica; 7.2Å, kaolinite; 7.1Å, chlorite; 5Å, mica; 3.9Å, mica; 3.57Å, kaolinite; 3.3Å, quartz; and 3.2Å, feldspars (1Å = 1 X 10^{-10}m.).

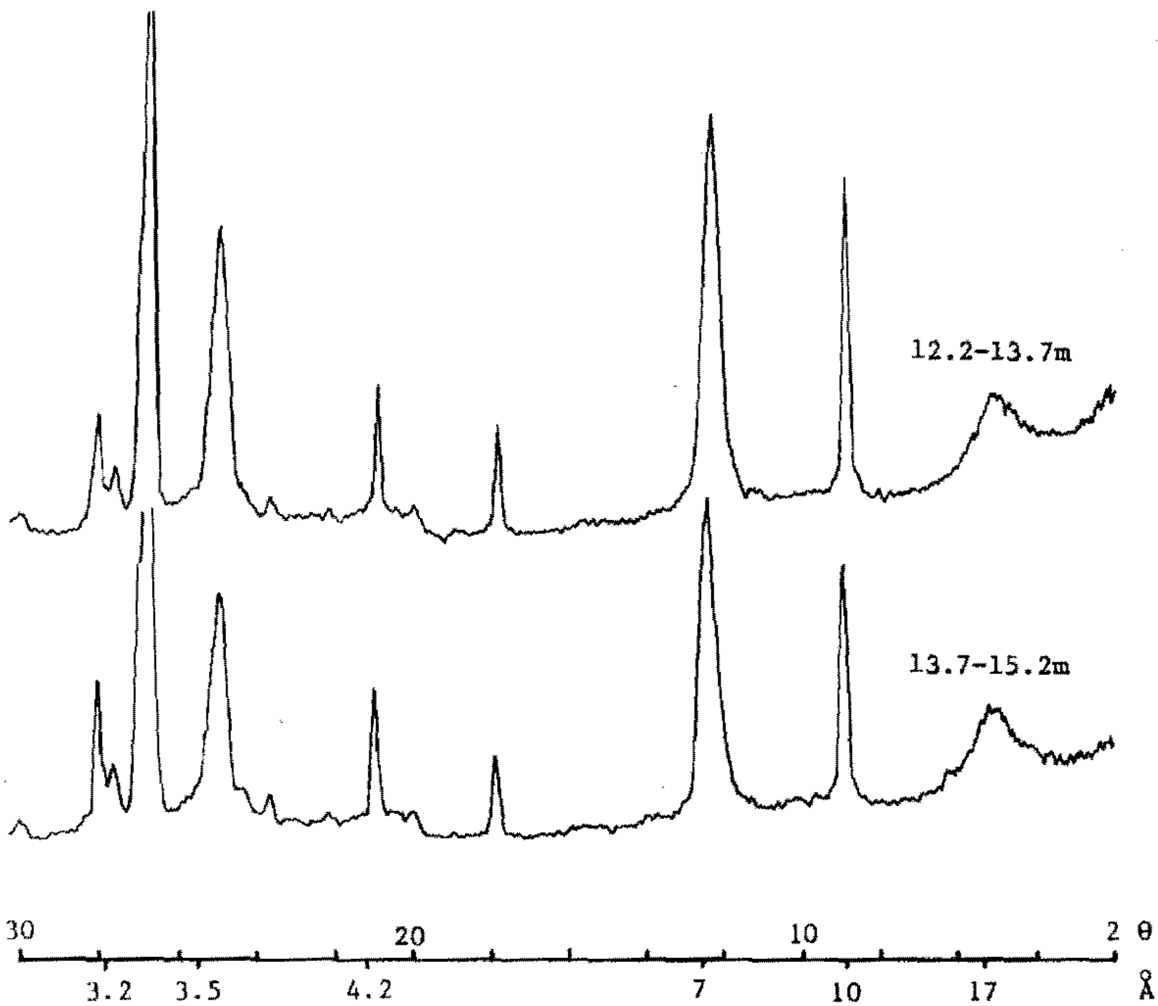
X-ray Diffractograms from Auger Drill hole GV-9



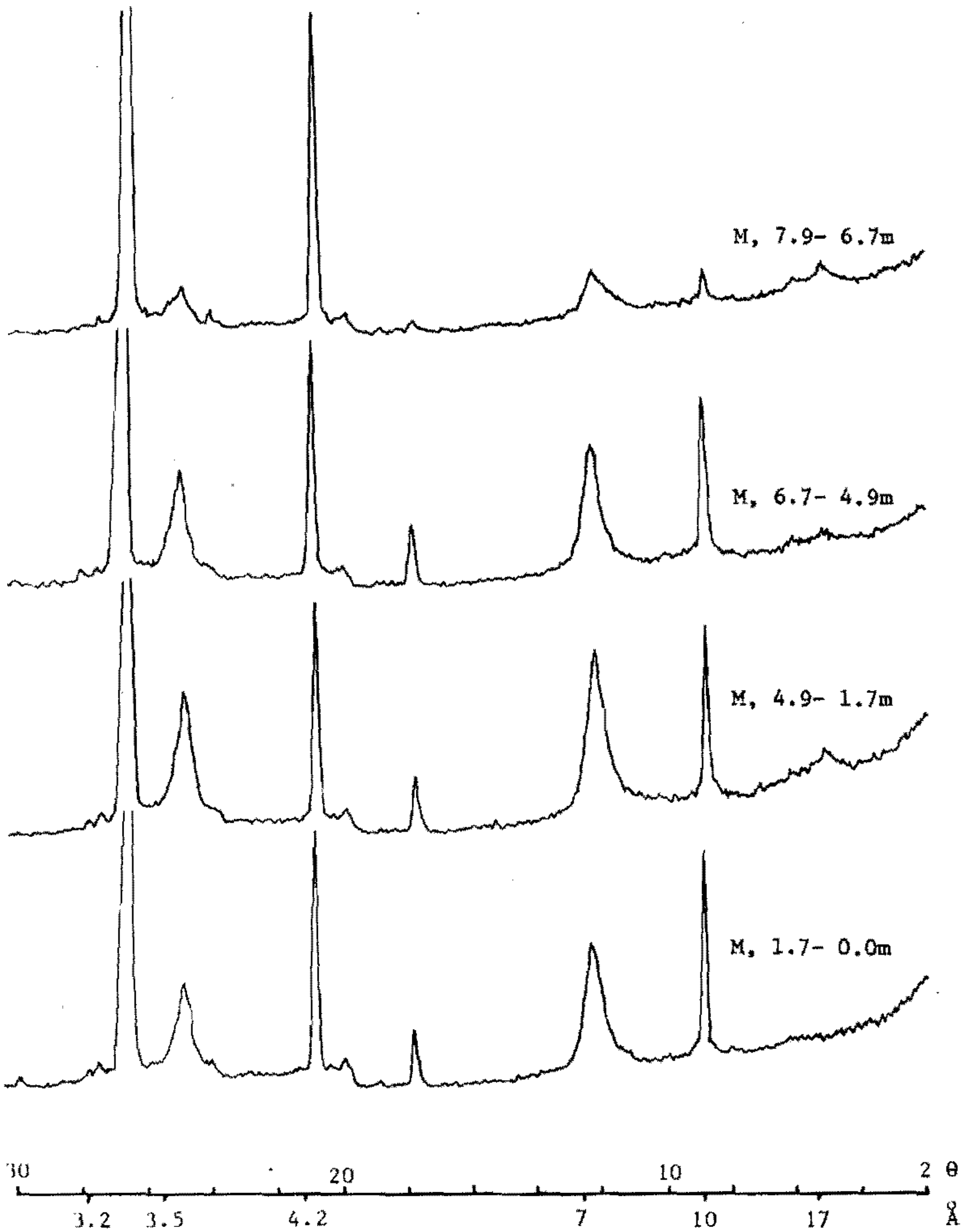
GV-9, cont.



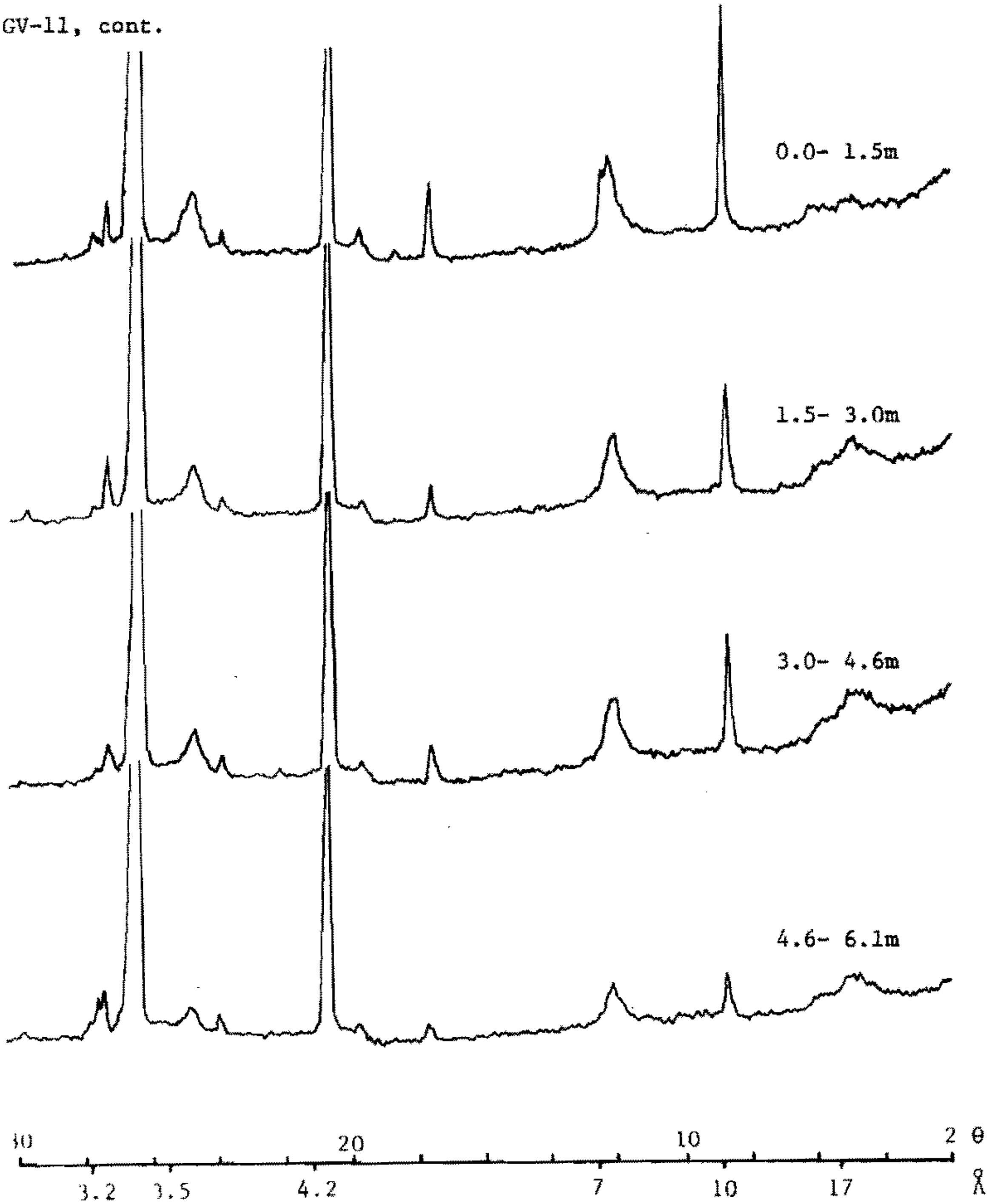
GV-9, cont.



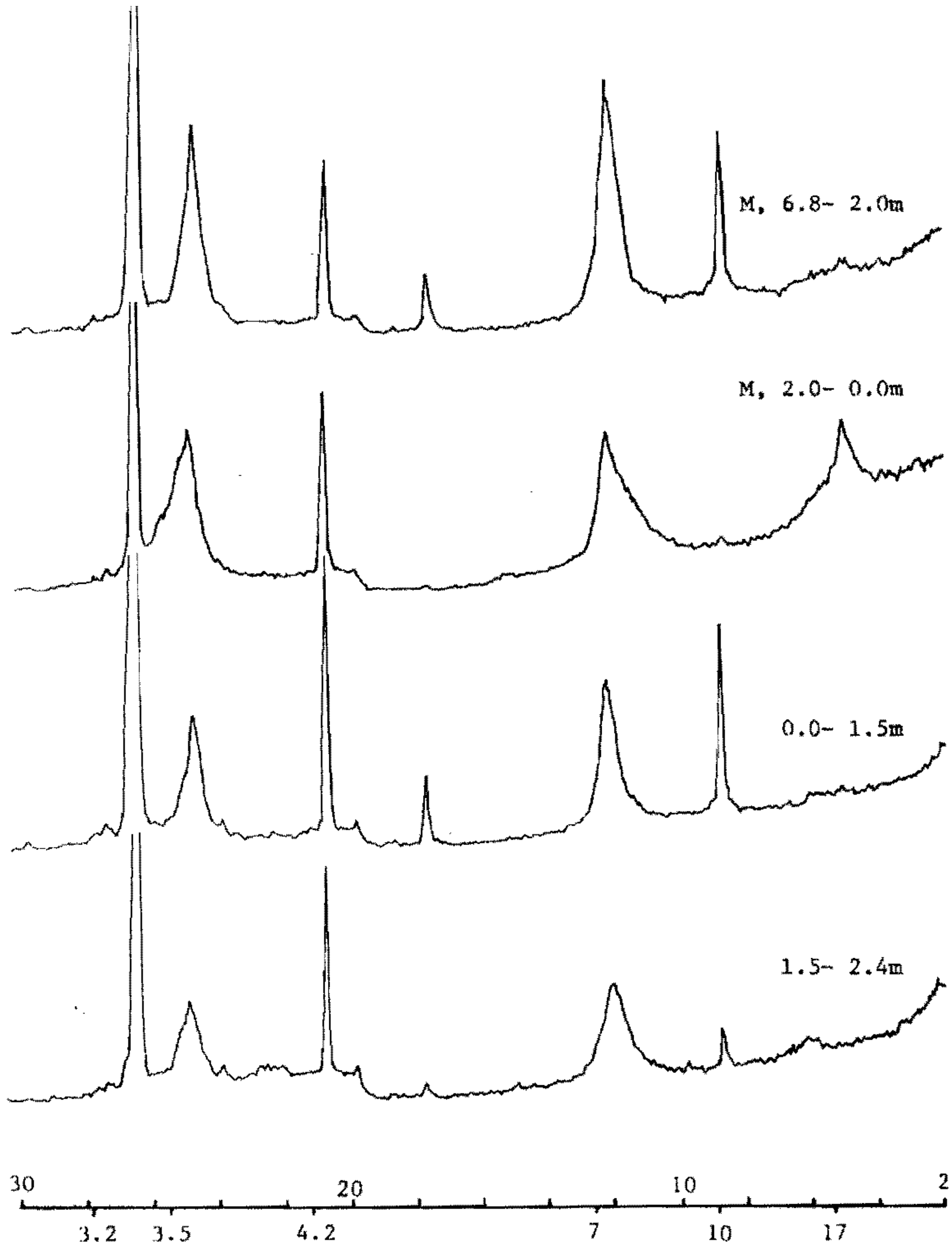
X-ray Diffractograms from Measured Section GV-11M
and Auger Drill Hole GV-11



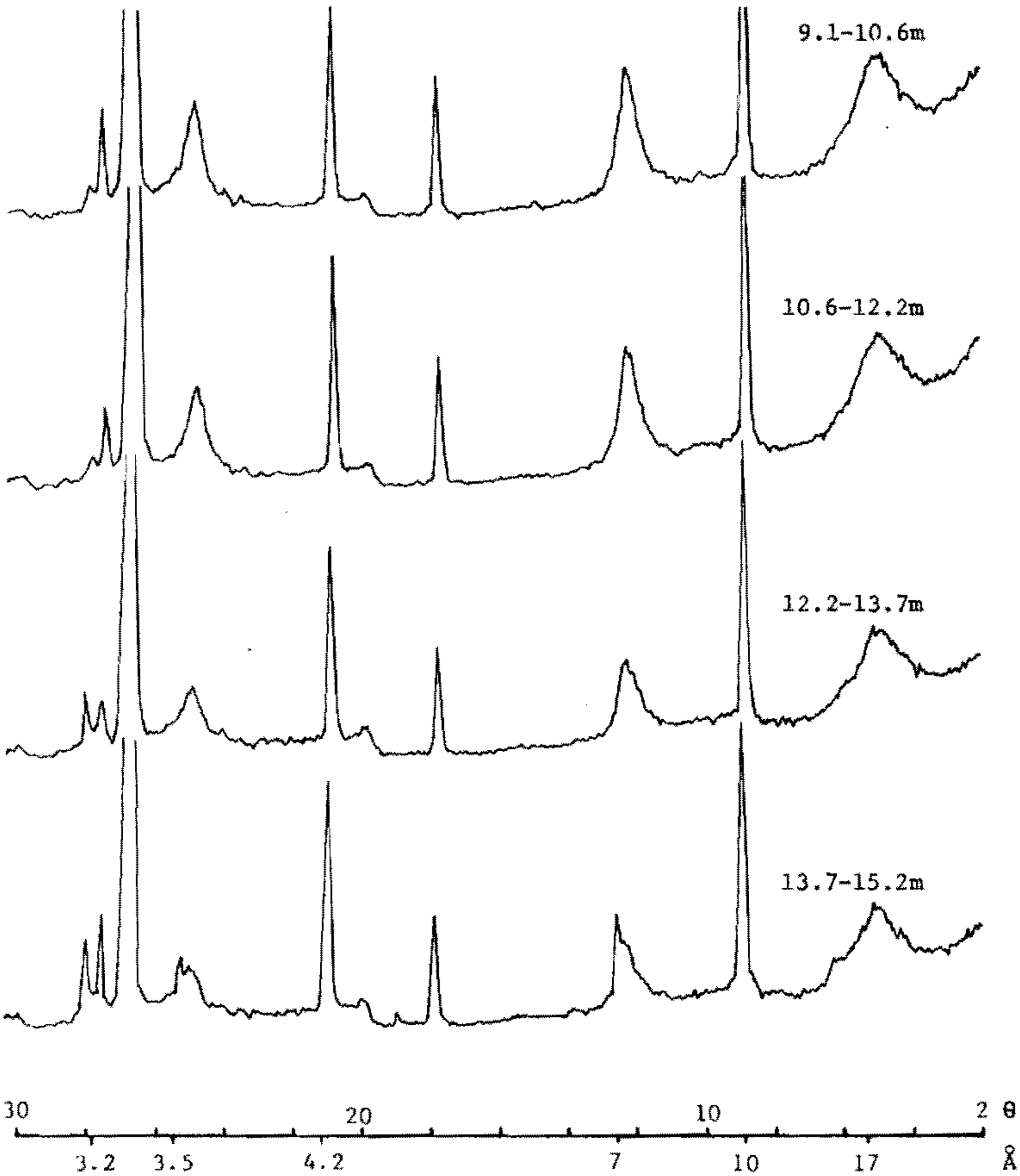
GV-11, cont.



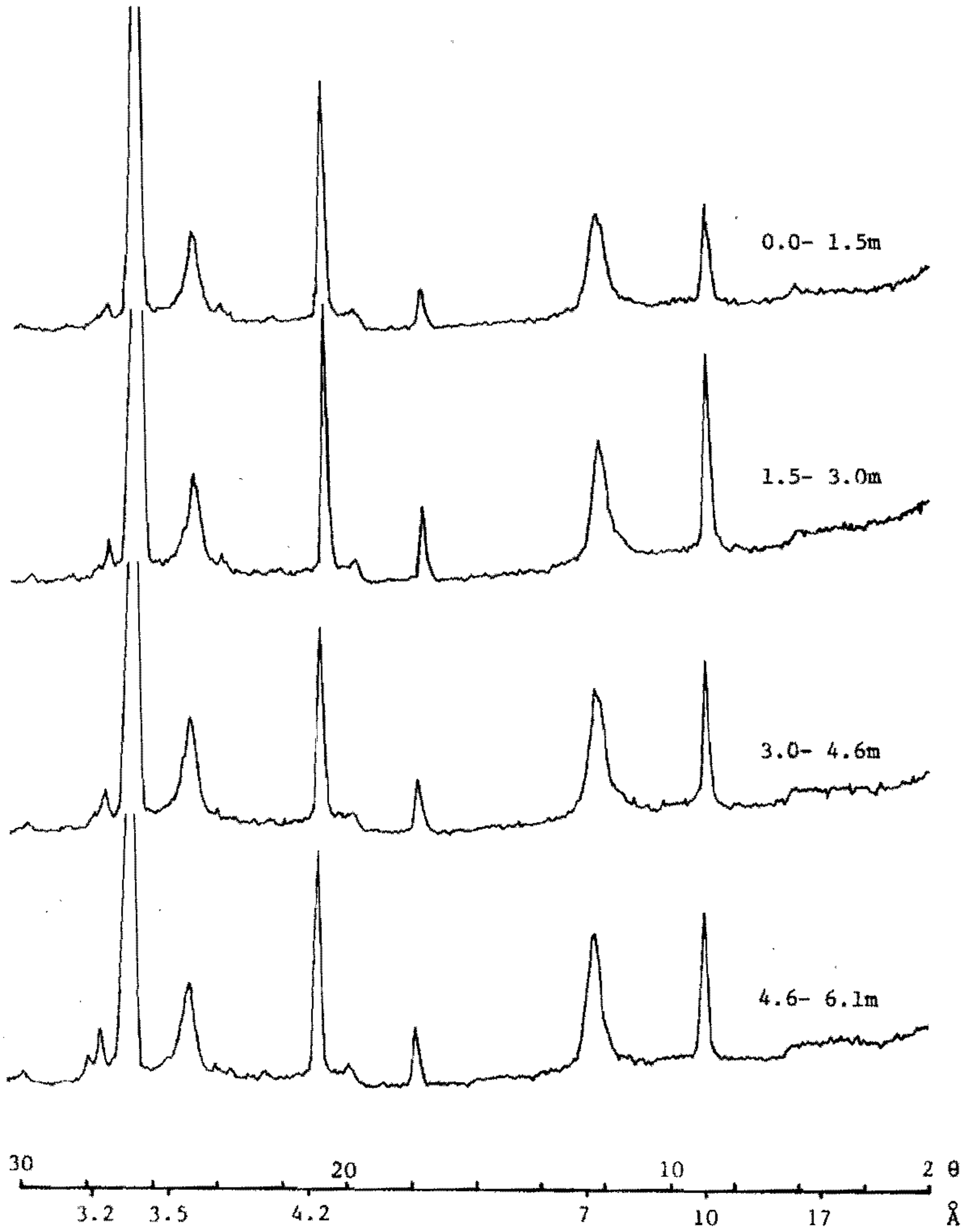
X-ray Diffractograms from Measured Section GV-12M
and Auger Drill Hole GV-12



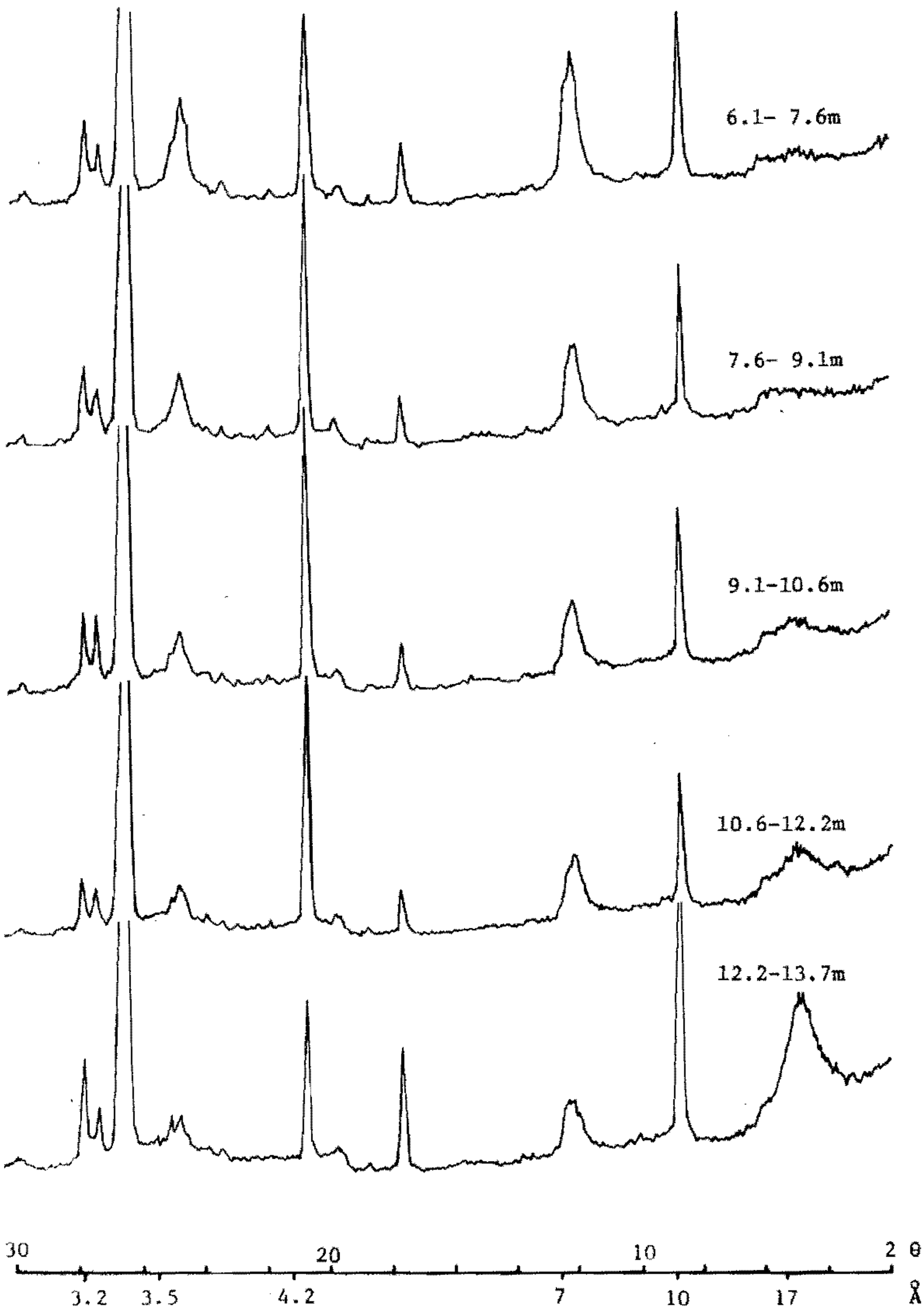
GV-12, cont.



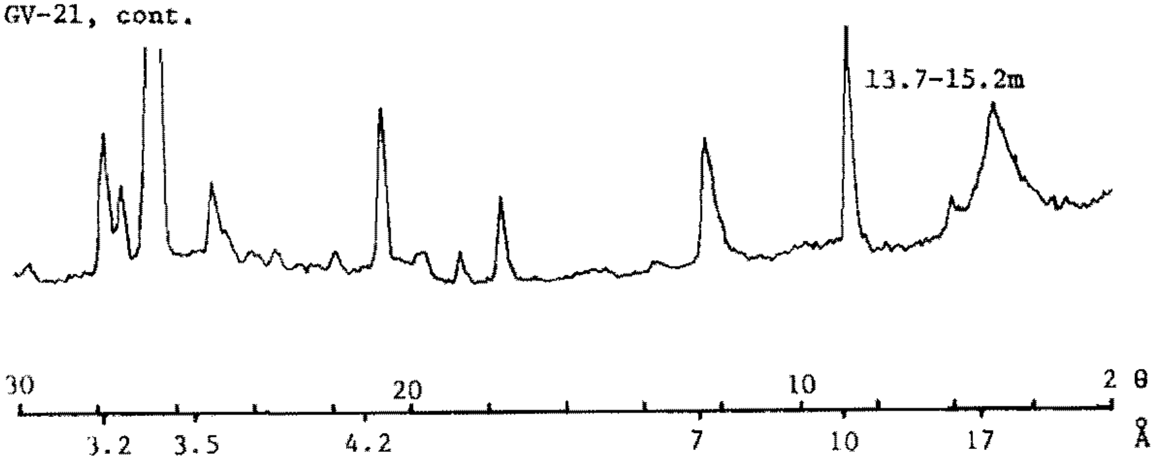
X-ray Diffractograms from Auger Drill Hole GV-21



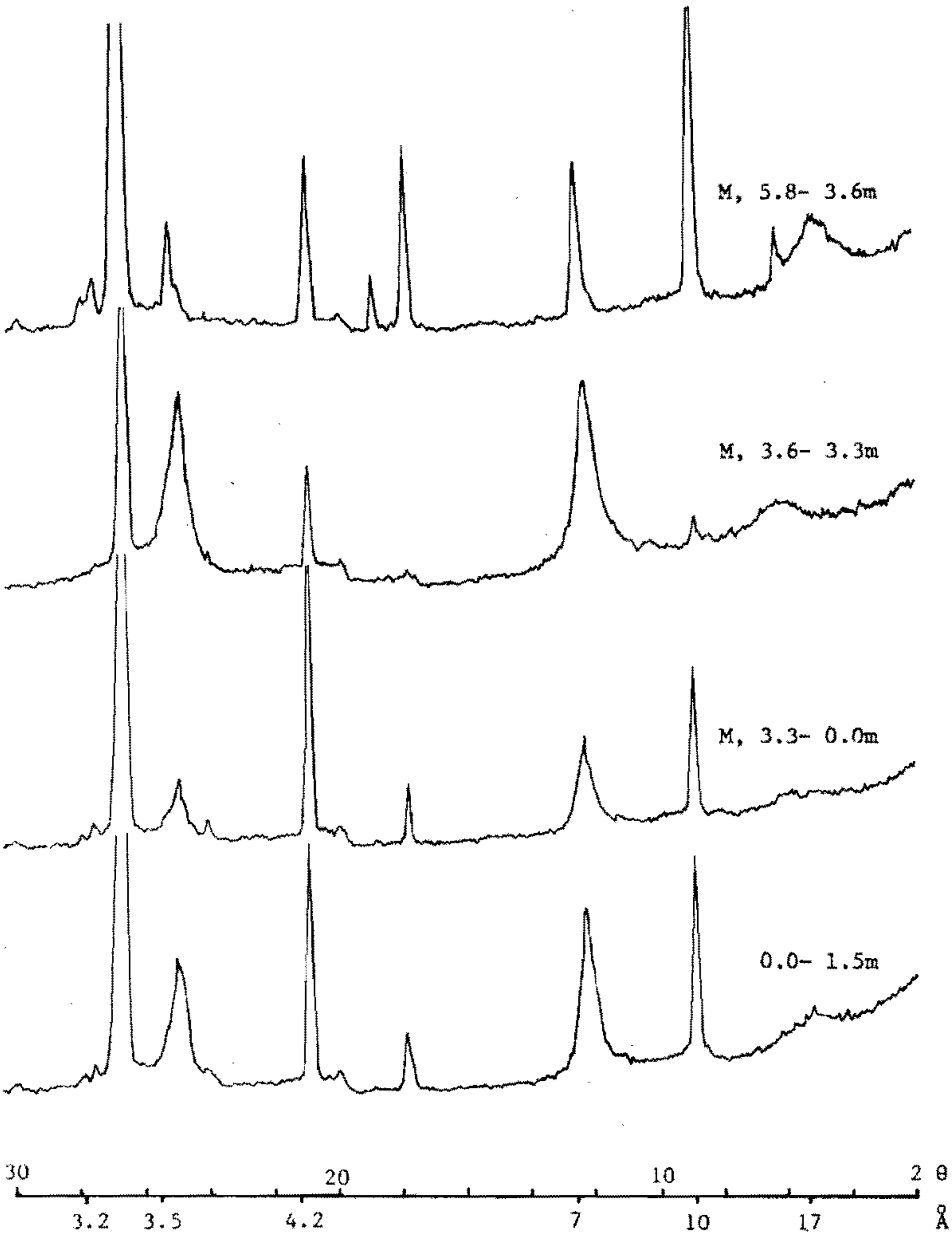
GV-21, cont.


6.1- 7.6m
7.6- 9.1m
9.1-10.6m
10.6-12.2m
12.2-13.7m
30
20
10
2 θ
3.2
3.5
4.2
7
10
17
Å

GV-21, cont.

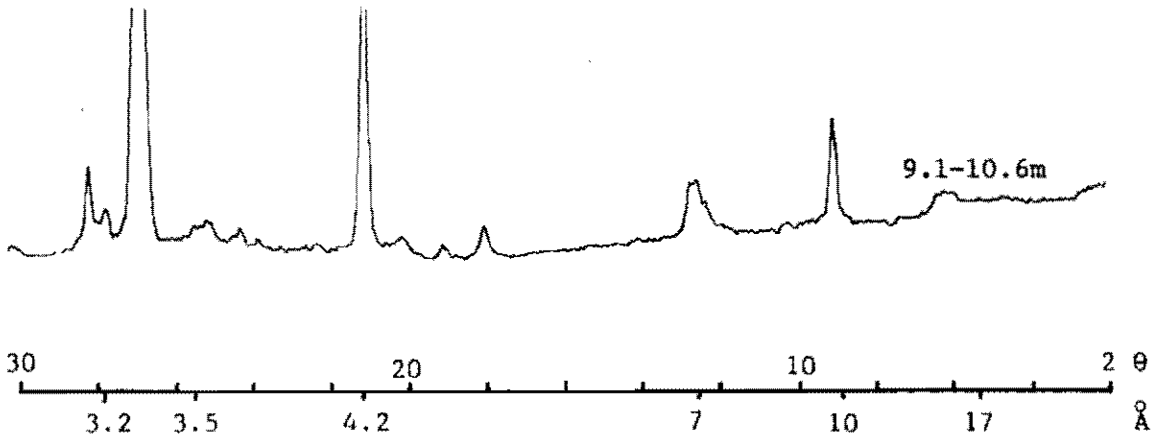


X-ray Diffractograms from Measured Section GV-22M
and Auger Drill Hole GV-22

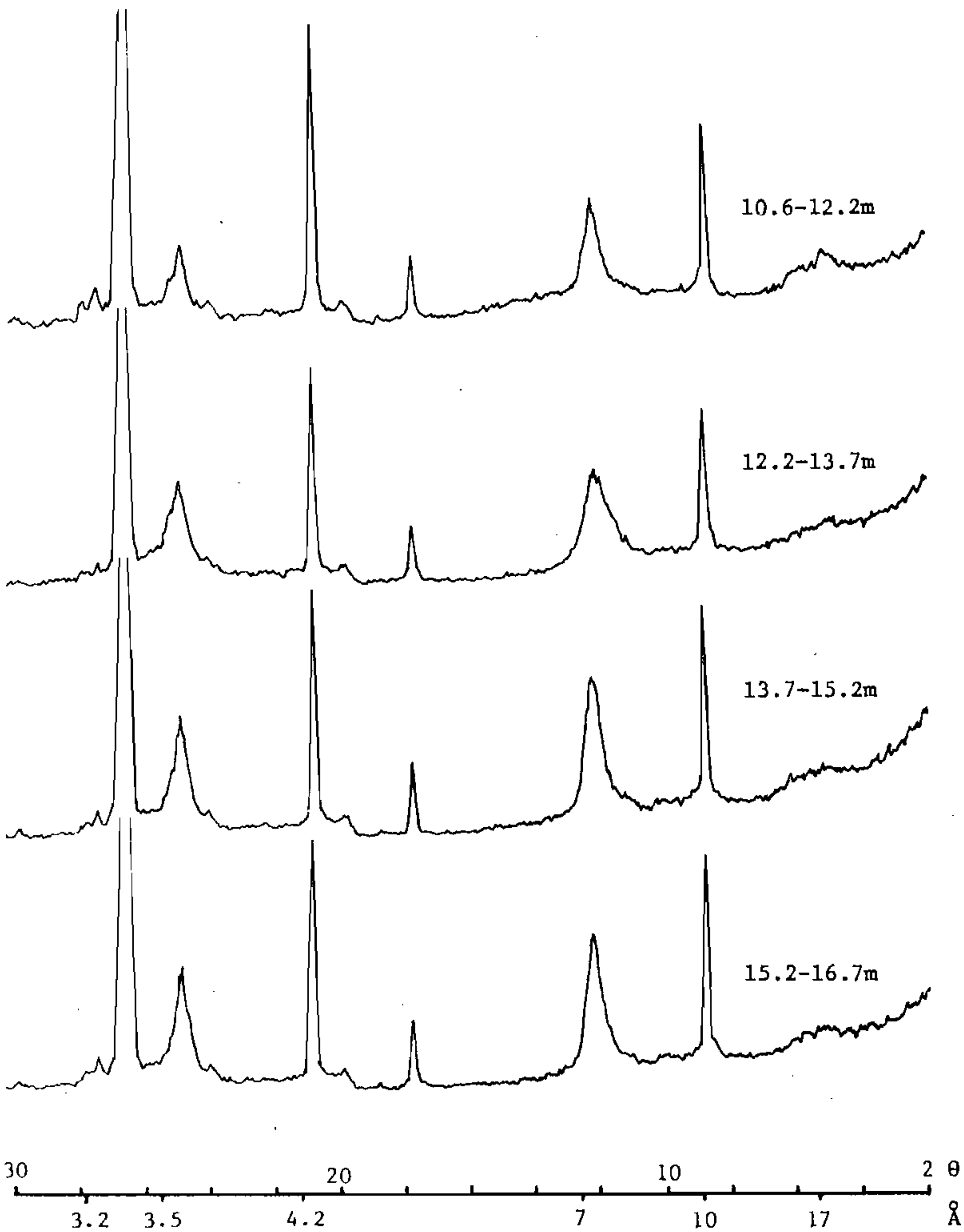


GV-22, cont.

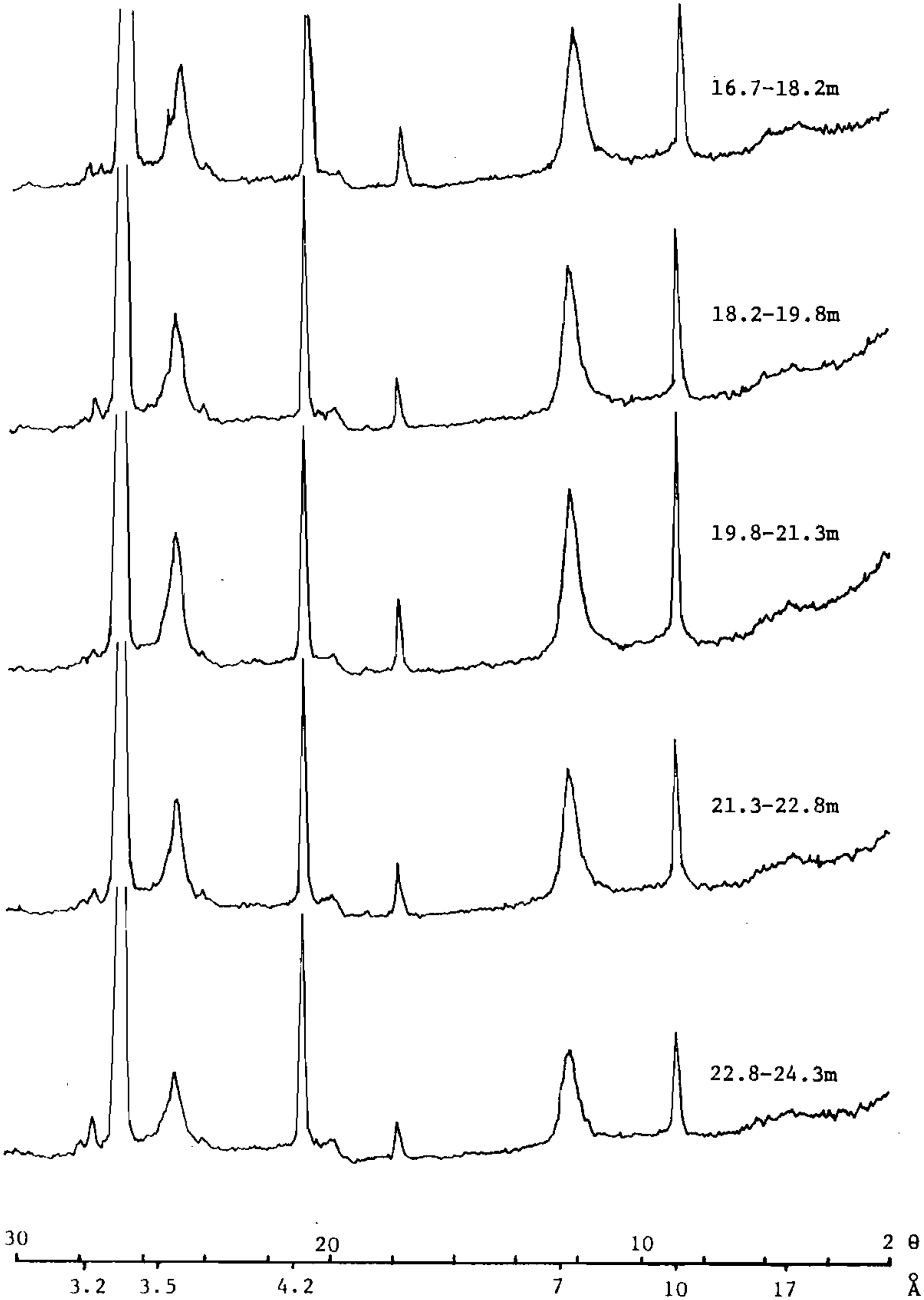
GV-22, cont.



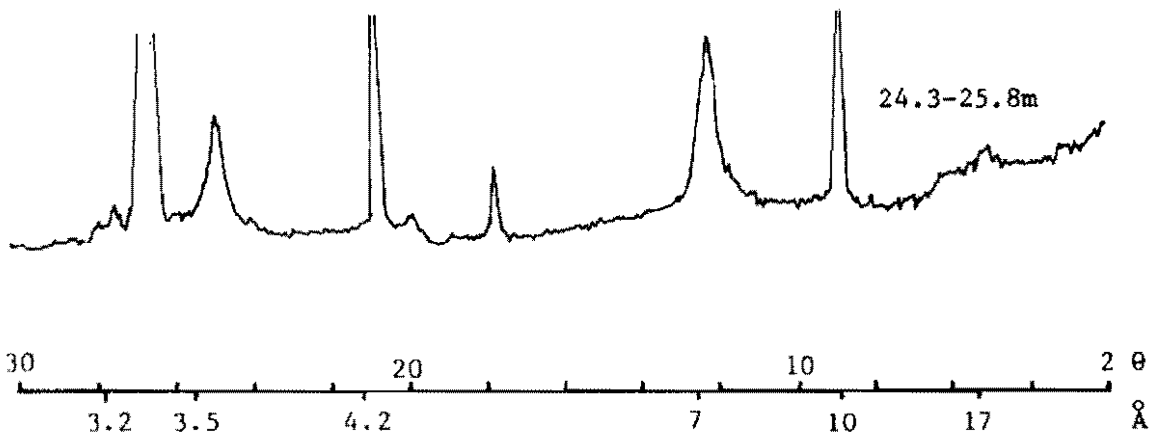
X-ray Diffractograms from Auger Drill Hole GV-27



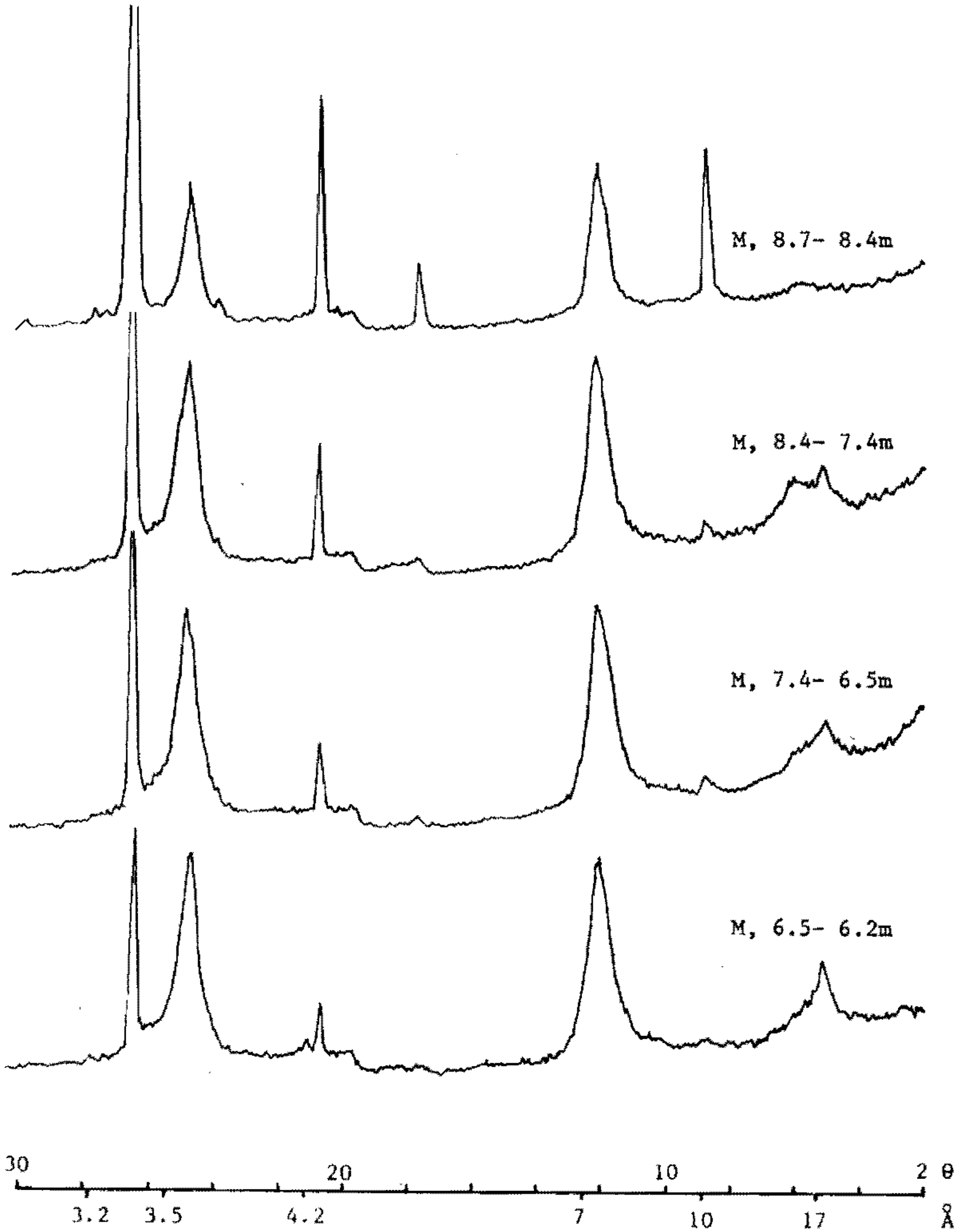
GV-27, cont.


16.7-18.2m
18.2-19.8m
19.8-21.3m
21.3-22.8m
22.8-24.3m
30
20
10
2 θ
3.2
3.5
4.2
7
10
17
Å

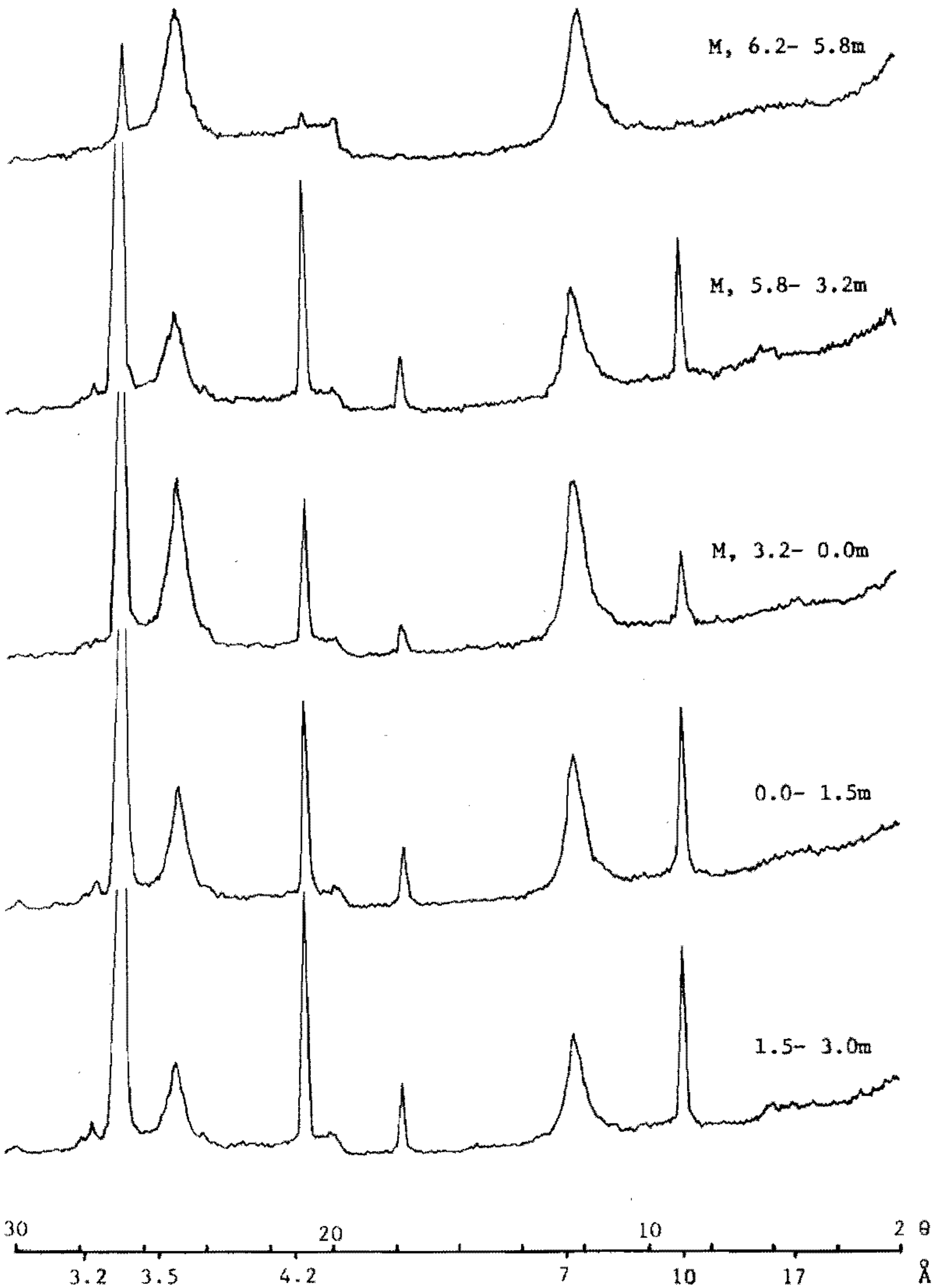
GV-27, cont.



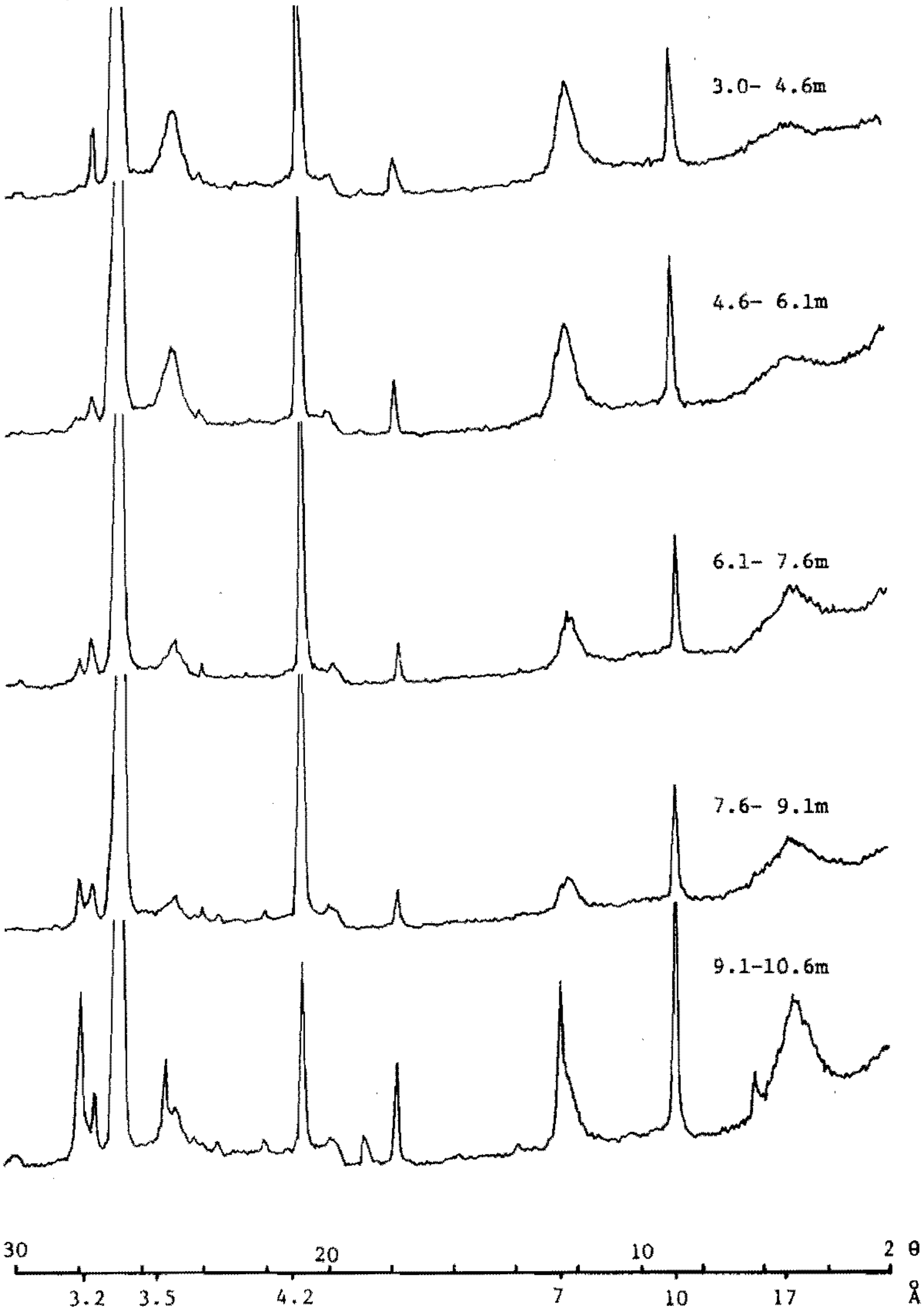
X-ray Diffractograms from Measured Section GV-33M and Auger Drill Hole GV-33



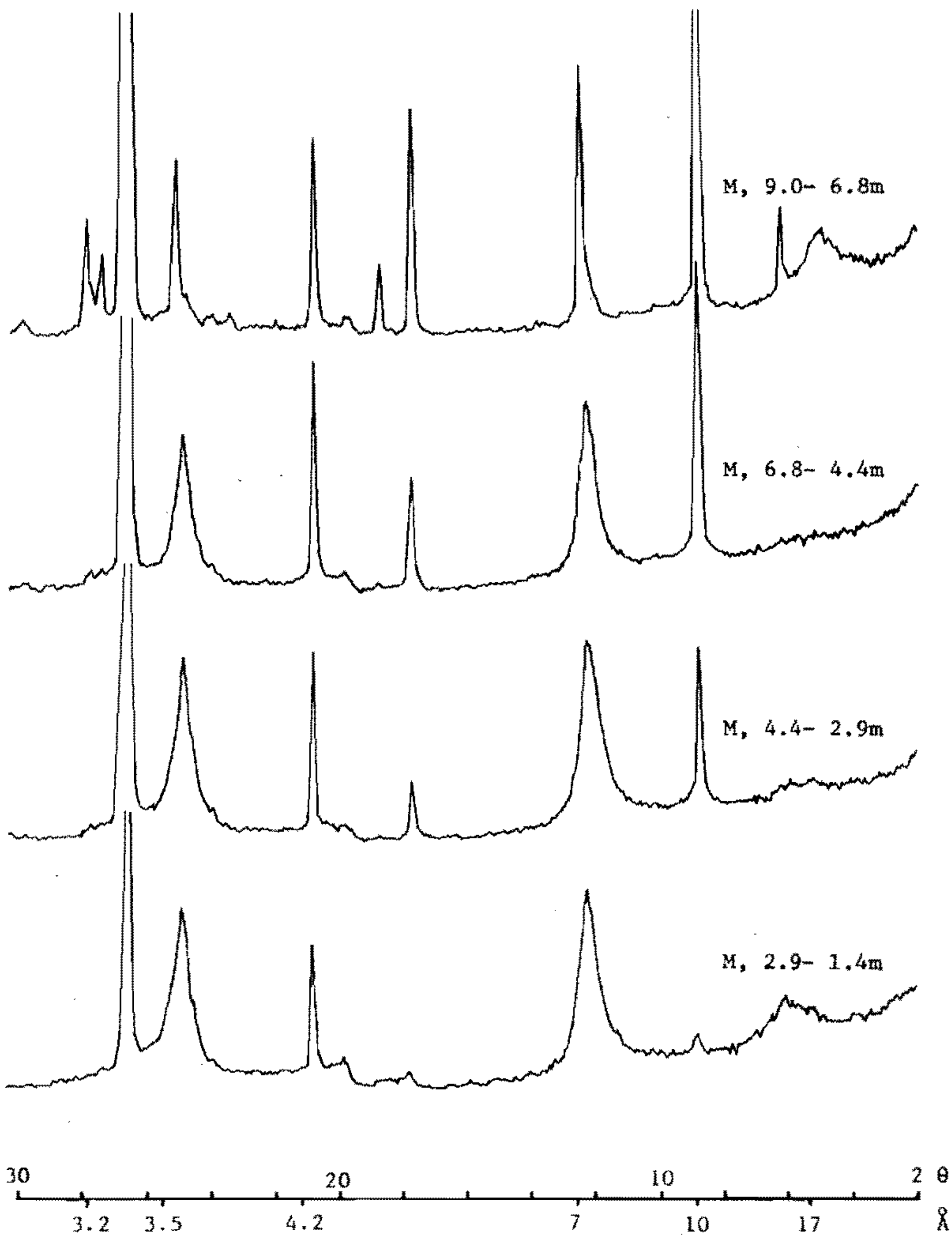
GV-33, cont.

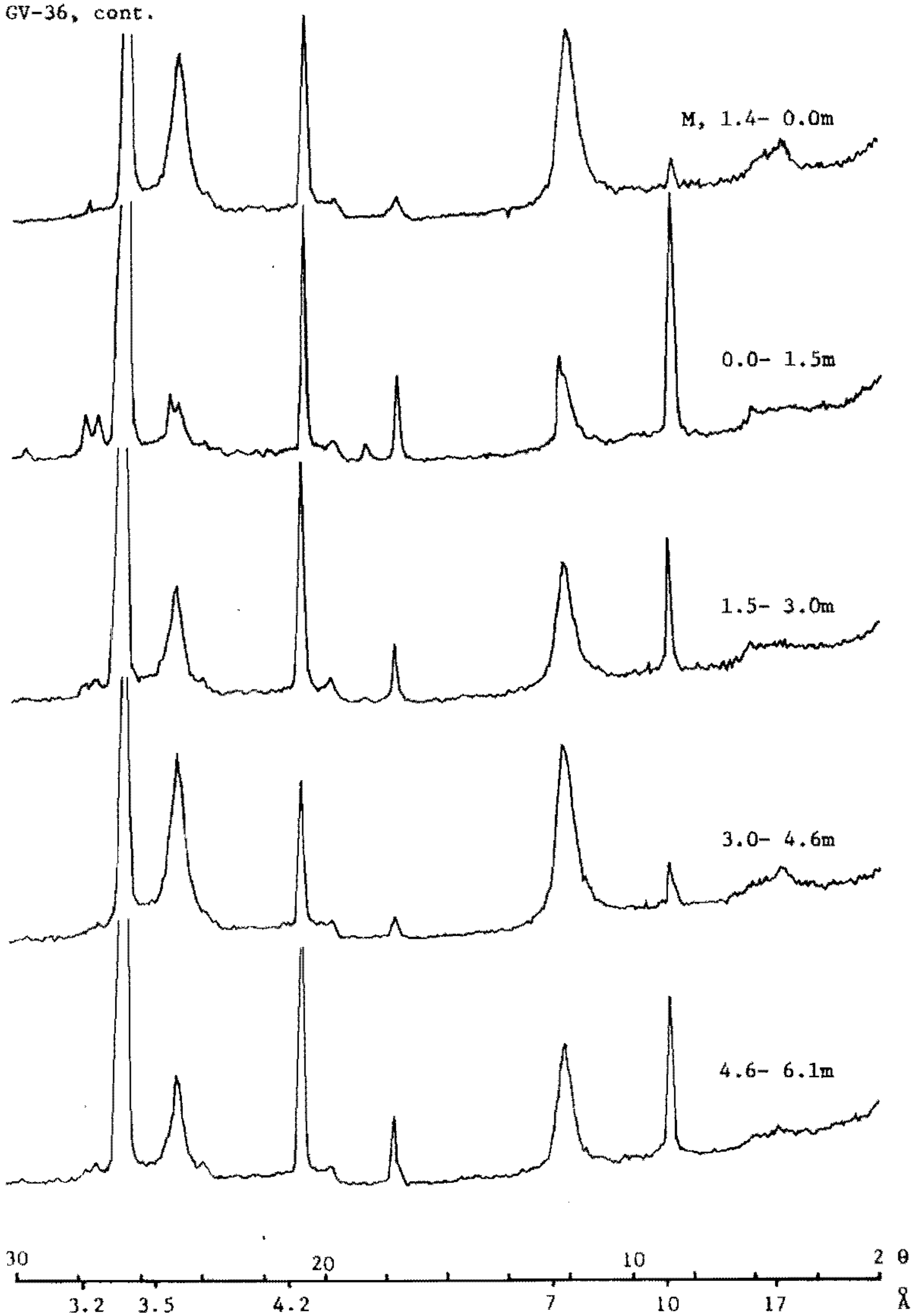


GV-33, cont.

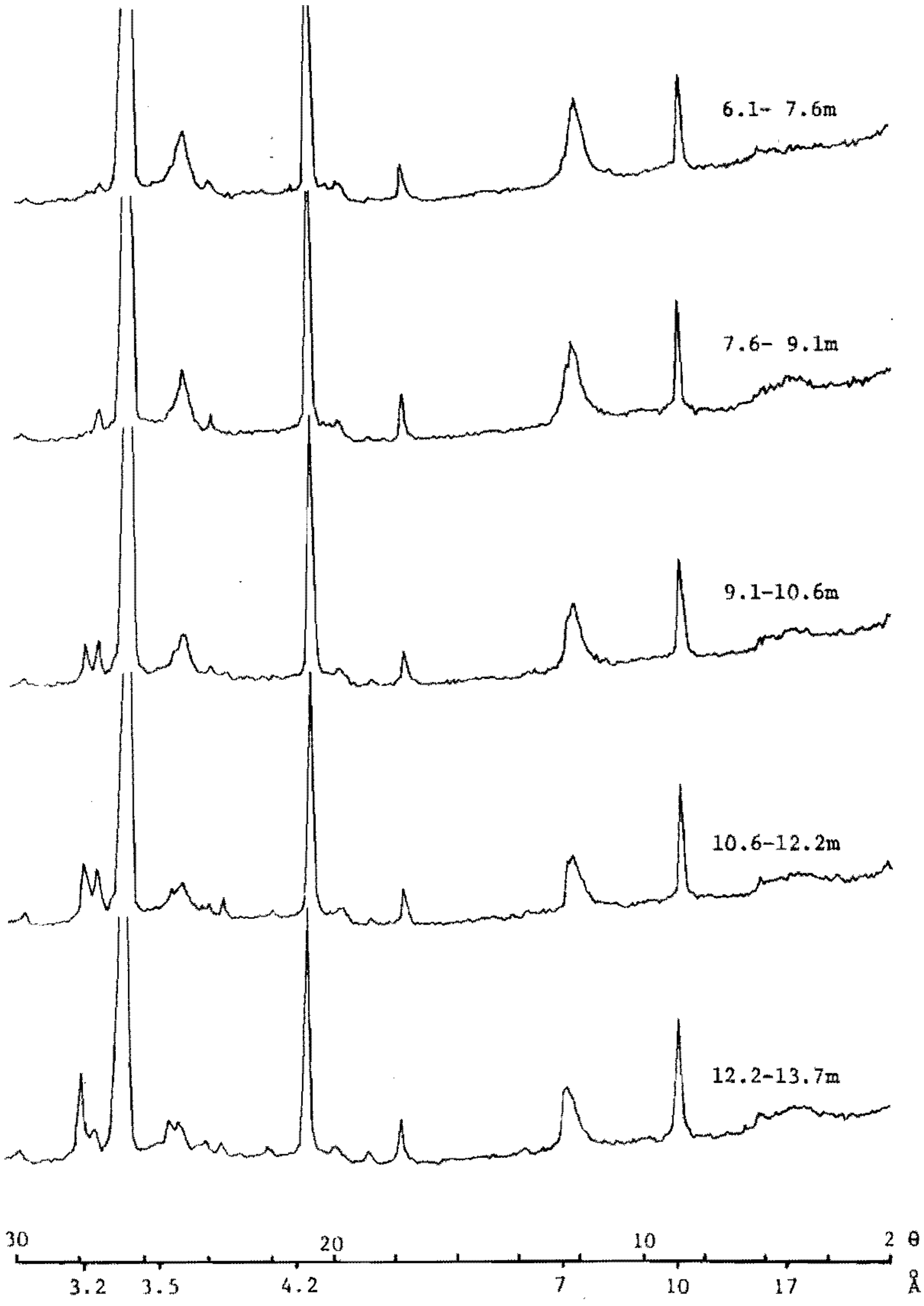


X-ray Diffractograms from Measured Section GV-36M
and Auger Drill Hole GV-36

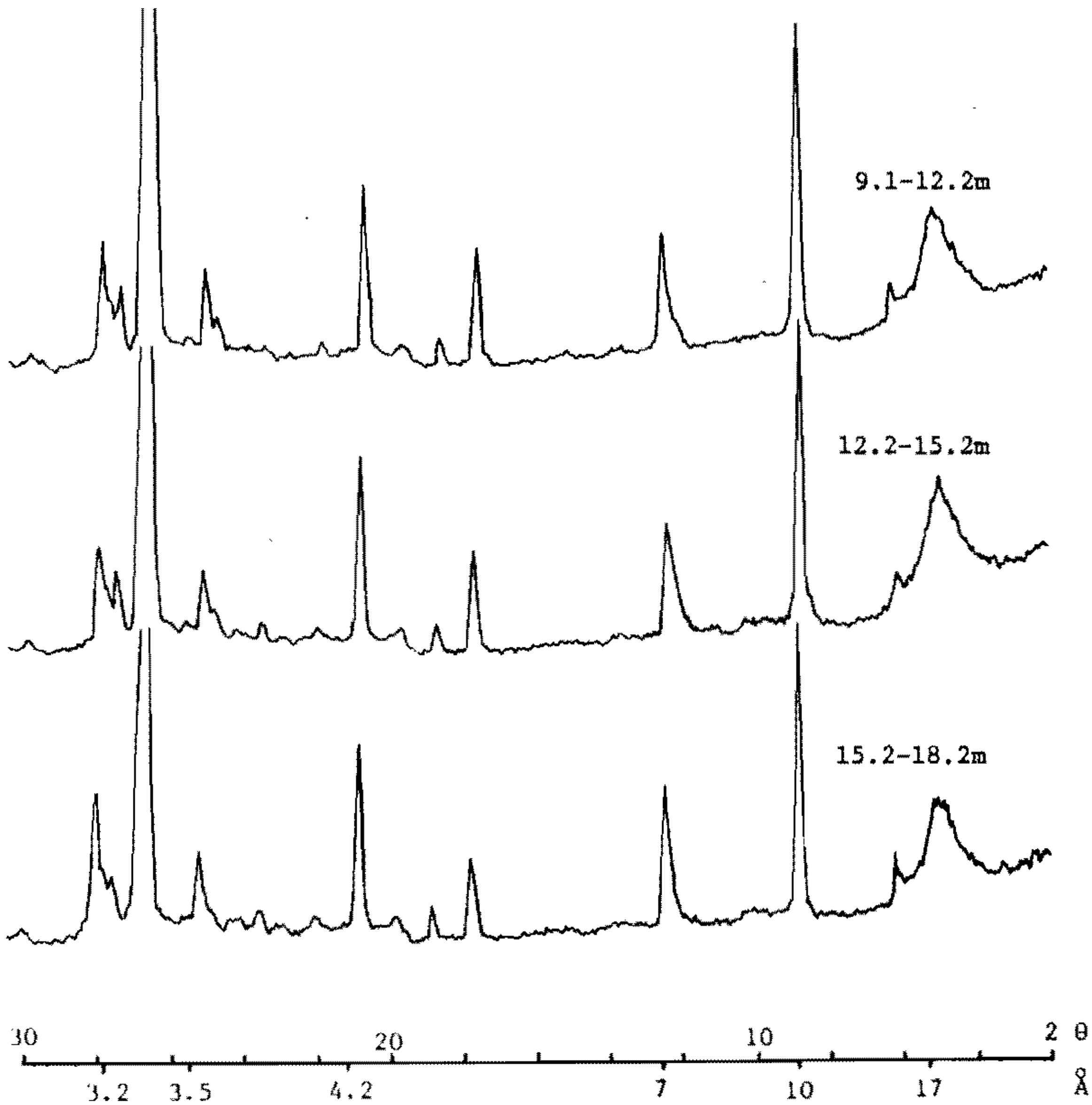



GV-36, cont.
M, 1.4- 0.0m
0.0- 1.5m
1.5- 3.0m
3.0- 4.6m
4.6- 6.1m
30
20
10
2 θ
3.2
3.5
4.2
7
10
17
Å

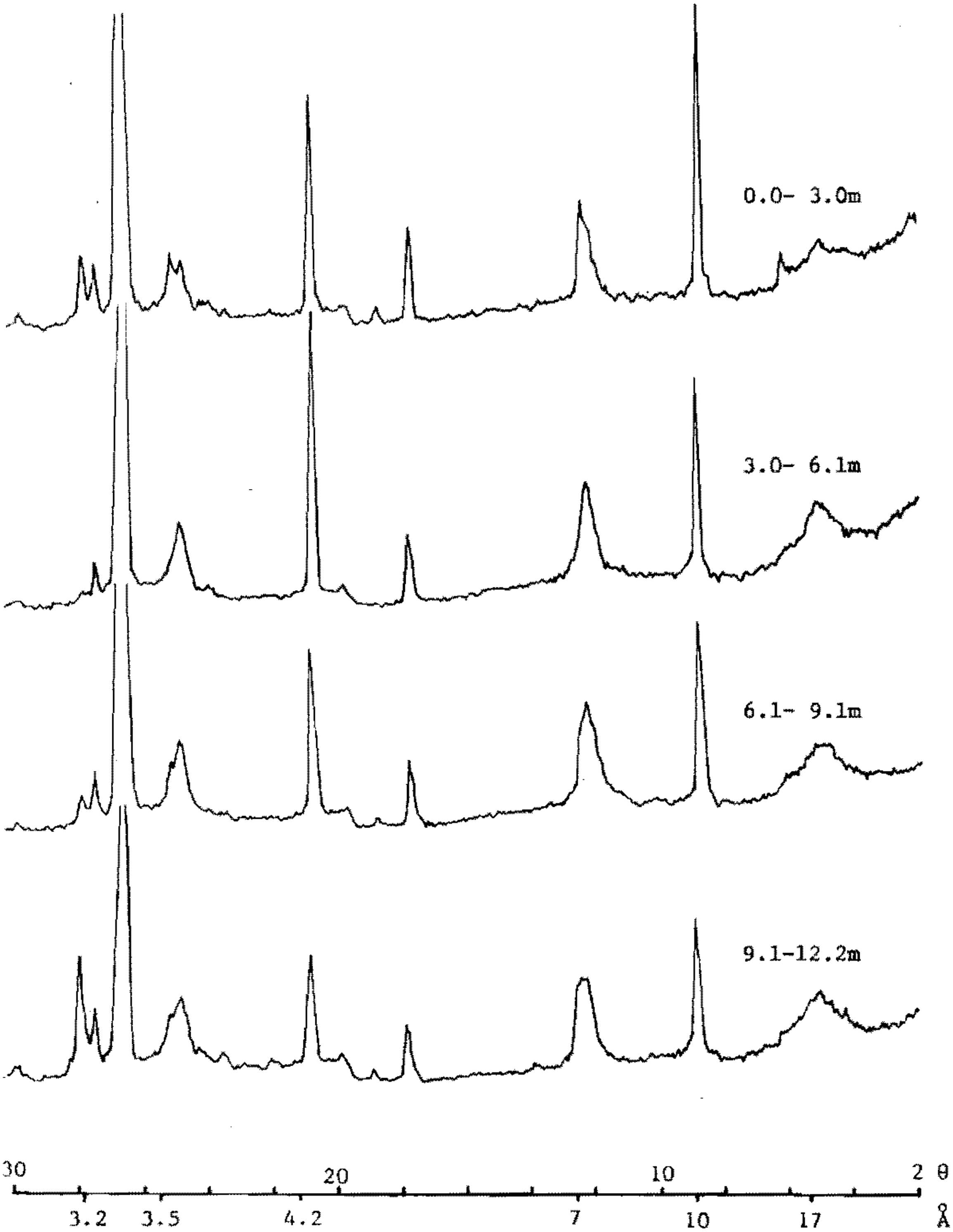
GV-36, cont.

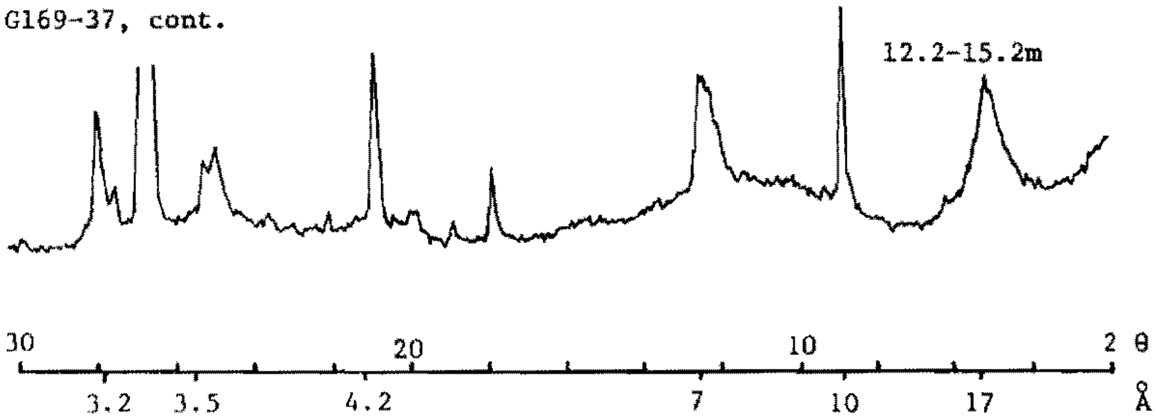

6.1- 7.6m
7.6- 9.1m
9.1-10.6m
10.6-12.2m
12.2-13.7m
30
20
10
2 θ
3.2
3.5
4.2
7
10
17
Å

X-ray Diffractograms from Drill Hole G169-36

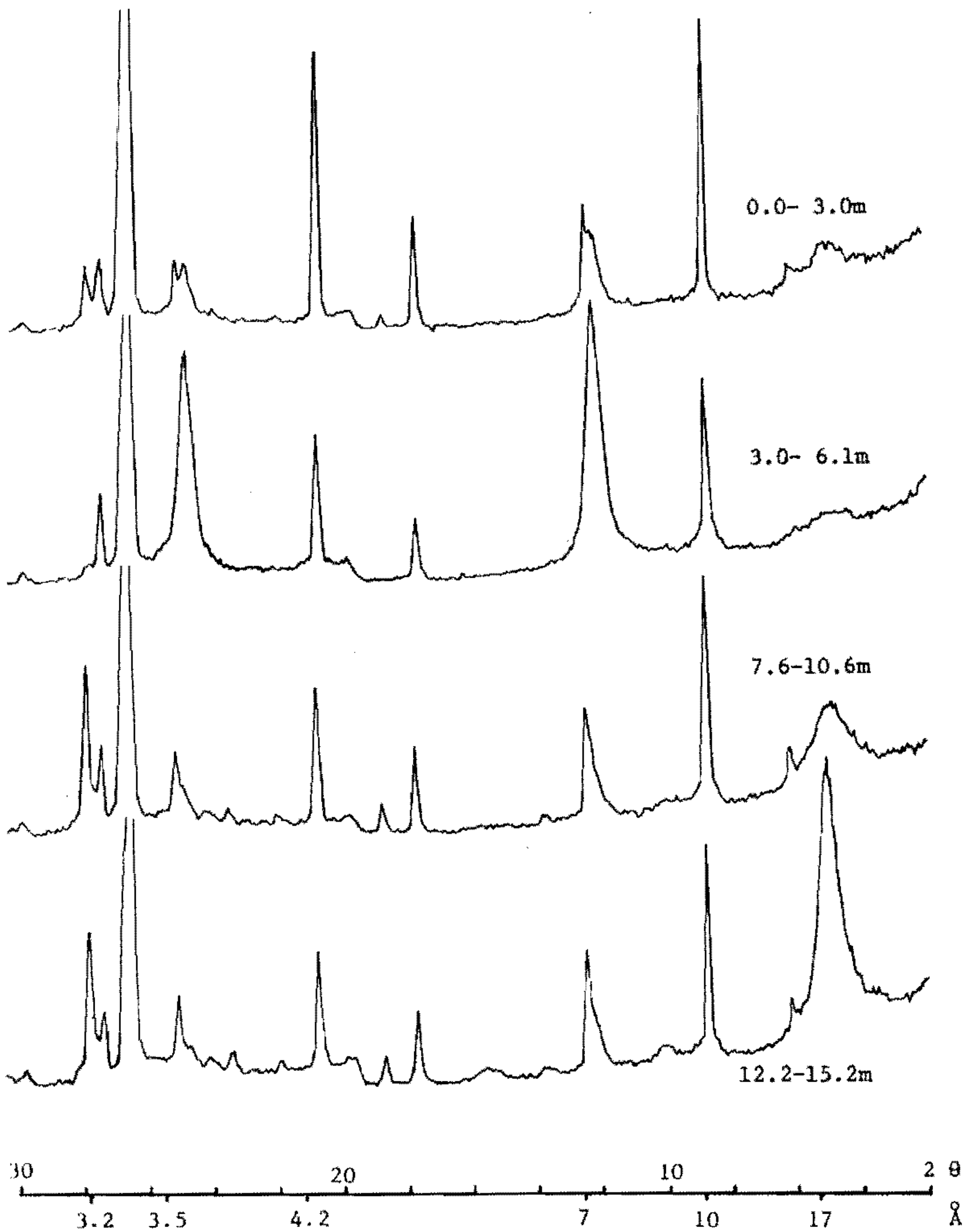


X-ray Diffractograms from Drill Hole G169-37

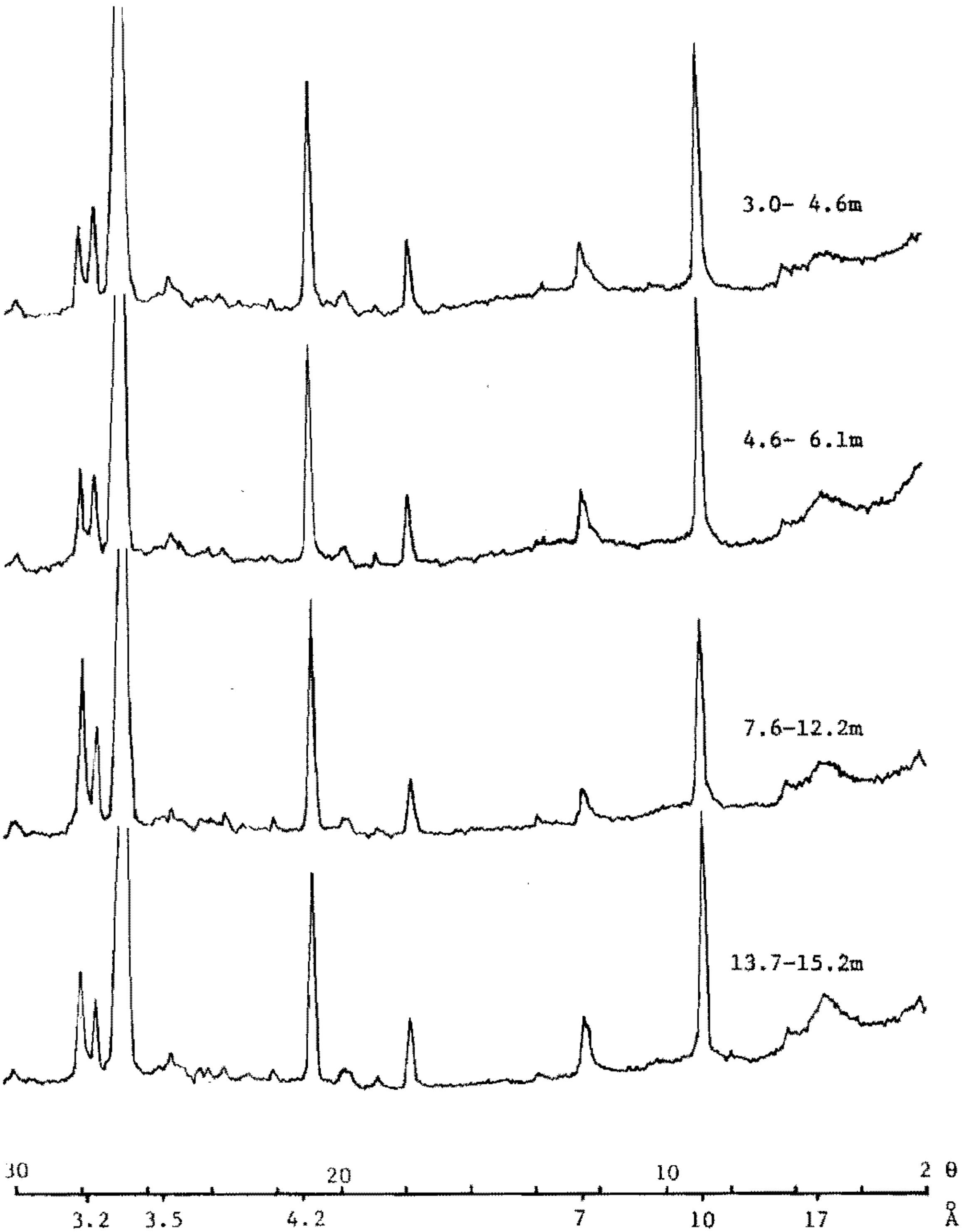



G169-37, cont.
12.2-15.2m
30
20
10
2 θ
3.2
3.5
4.2
7
10
17
Å

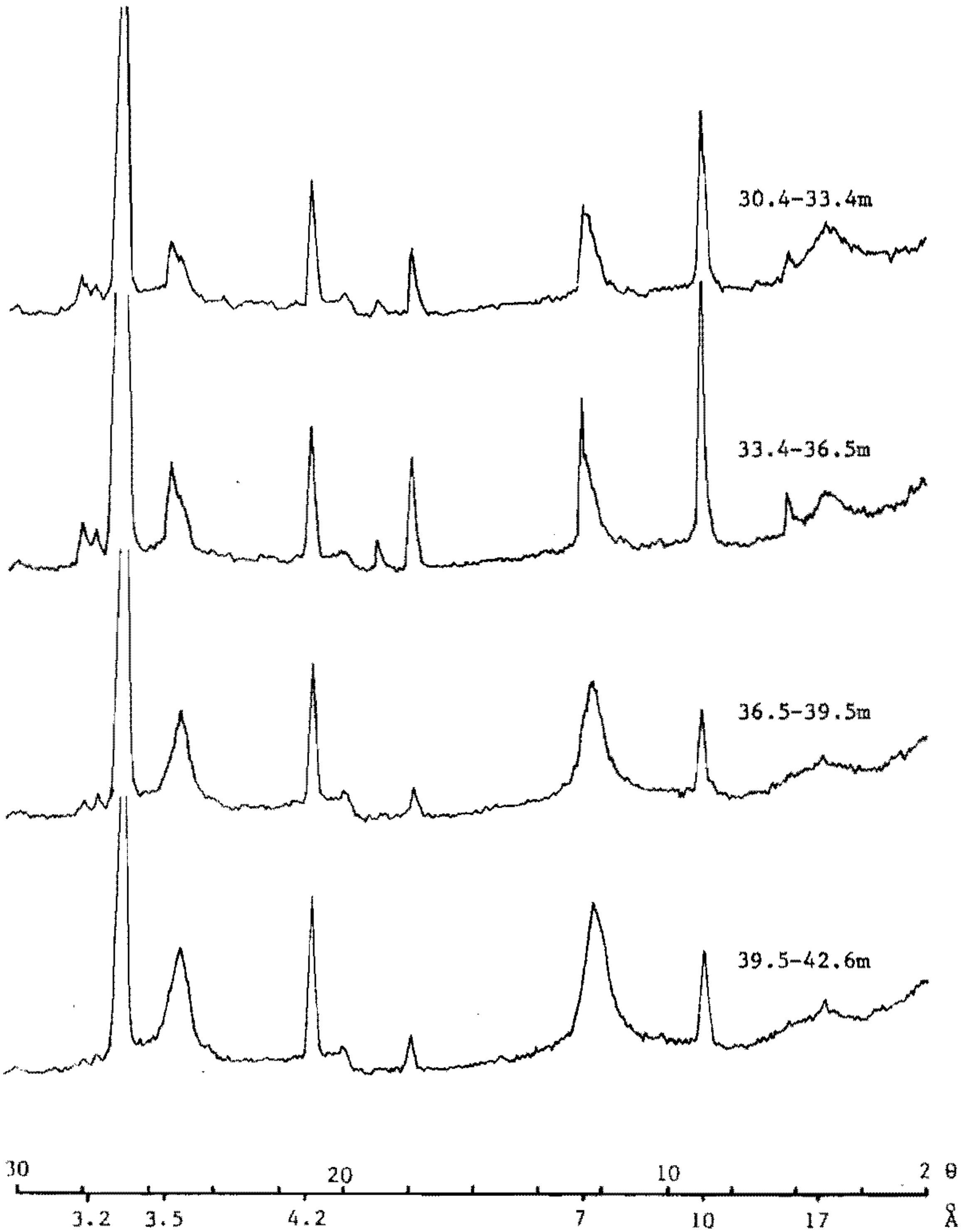
X-ray Diffractograms from Drill Hole 306-L24

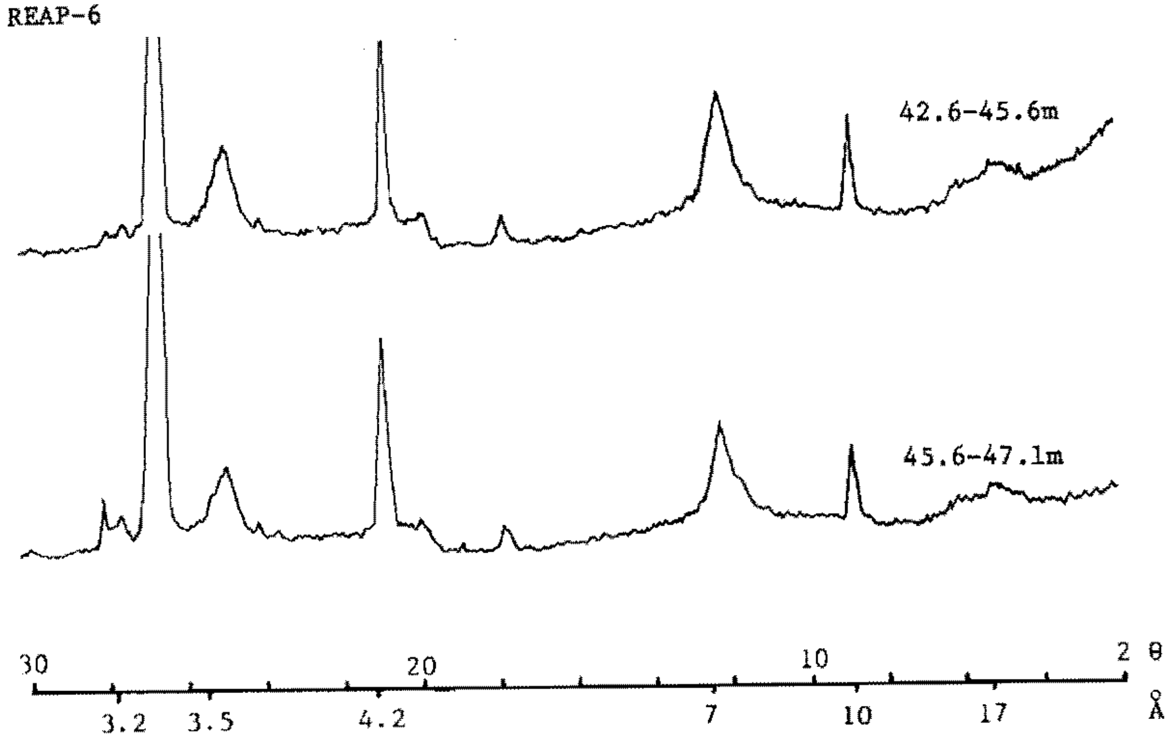


X-ray Diffractograms from Drill Hole 306-L25



X-ray Diffractograms from Drill Hole REAP-6




REAP-6
42.6-45.6m
45.6-47.1m
30
20
10
2 θ
3.2
3.5
4.2
7
10
17
Å

APPENDIX C

PERCENTAGES OF CLAY MINERALS IN X-RAYED GOLDEN VALLEY FORMATION SAMPLES

PERCENTAGES OF CLAY MINERALS IN X-RAYED GOLDEN VALLEY FORMATION SAMPLES

This appendix lists the percentages of clay minerals and the area under the major clay and feldspar peaks in the Golden Valley Formation samples, as derived from the X-ray charts presented in appendix B. The procedure for determining the percentages and areas is described in the text under the heading "X-ray Analysis." Descriptions and locations of the samples are found in appendix A. The letter M preceding the sample interval indicates that the sample is from a measured section.

The following abbreviations were used for the units: BDM, Bear Den Member; CBM, Camels Butte Member; SBF, Sentinel Butte Formation; SW, slope wash. Abbreviations for the minerals are: K, kaolinite; Mo, montmorillonite; I, illite; C, chlorite; F, feldspar.

TABLE 6

SAMPLE NUMBER: GV-9

Unit	Interval (feet)	Interval (metres)	Percentages of Clay Minerals K	Mo	I	C	Area Under Clay and Feldspar Peaks 10^{-4} m^2 F	D	M	I	C
	0- 5	0.0- 1.5	76	6	18	0	1.310	3.632	0.303	0.406	0.000
	5-10	1.5- 3.0	74	6	20	0	0.910	4.942	0.406	0.606	0.000
	10-15	3.0- 4.6	69	11	20	0	0.606	8.471	1.413	1.110	0.000
	15-20	4.6- 6.1	72	11	17	0	0.807	5.749	0.910	0.606	0.000
BDM	20-25	6.1- 7.6	73	11	16	0	1.007	10.284	1.613	1.007	0.000
	25-30	7.6- 9.1	77	13	10	0	0.503	9.575	1.613	0.606	0.000
	30-35	9.1-10.6	78	10	12	0	0.606	14.117	1.916	1.007	0.000
	35-40	10.6-12.2	68	18	14	0	0.910	10.788	3.026	1.007	0.000
	40-45	12.2-13.7	59	31	10	0	2.019	9.072	4.942	0.703	0.000
	45-50	13.7-15.2	55	35	10	0	2.523	7.762	5.039	0.606	0.000

TABLE 7

SAMPLE NUMBER: GV-11 AND GV-11M

Unit	Interval (feet)	Interval (metres)	Percentages of Clay Minerals K	Mo	I	C	Area Under Clay and Feldspar Peaks 10^{-4} m^2 F	D	M	I	C
	26-22	7.9-6.7	39	30	31	0	0.103	1.916	1.510	0.703	0.000
BDM	M, 22-16	M, 6.7-4.9	73	9	18	0	0.303	4.639	0.606	0.503	0.000
	M, 16-5.5	M, 4.9-1.7	71	18	11	0	0.303	5.749	1.510	0.406	0.000
	M, 5.5-0	M, 1.7-0.0	85	0	15	0	0.406	4.839	0.000	0.406	0.000
	0-5	0.0-1.5	59	19	19	3	0.807	2.755	0.910	0.406	0.000
	5-10	1.5-3.0	42	49	9	0	0.910	1.916	2.316	0.200	0.000
SBF	10-15	3.0-4.6	37	51	12	0	0.503	1.916	2.723	0.303	0.000
	15-20	4.6-6.1	31	51	18	0	1.213	1.110	1.916	0.303	0.000

TABLE 8

SAMPLE NUMBER: GV-12 AND GV-12M

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	C	F	D	M	I	C
	M, 22.5-6.5	M, 6.8- 2.0	68	15	17	0	0.103	7.762	1.716	0.910	0.000
	M, 6.5-0.0	M, 2.0- 0.0	63	33	4	0	0.303	7.362	3.929	0.200	0.000
	0- 5	0.0- 1.5	71	9	20	0	0.406	5.542	0.703	0.703	0.000
	5- 8	1.5- 2.4	75	15	10	0	0.200	4.839	1.007	0.303	0.000
BDM	8-10	2.4- 3.0	70	20	10	0	0.103	5.949	1.716	0.406	0.000
	10-15	3.0- 4.6	78	13	9	0	0.103	7.562	1.310	0.406	0.000
	15-20	4.6- 6.1	74	8	18	0	0.303	9.278	1.007	1.007	0.000
	20-25	6.1- 7.6	72	9	19	0	0.703	6.652	0.807	0.807	0.000
	25-30	7.6- 9.1	50	35	15	0	1.007	6.052	4.439	0.807	0.000
	30-35	9.1-10.6	41	49	10	0	1.413	4.536	5.542	0.503	0.000
SBF	35-40	10.6-12.2	39	48	13	0	1.213	4.136	5.245	0.606	0.000
	40-45	12.2-13.7	29	56	15	0	1.413	2.523	5.142	0.606	0.000
	45-50	13.7-15.2	19	57	20	4	2.420	1.523	4.639	0.703	0.703

TABLE 9

SAMPLE NUMBER: GV-21

Unit	Interval (feet)	Interval (metres)	Percentages of Clay Minerals K	Mo	I	C	Area Under Clay and Feldspar Peaks 10^{-4} m^2 F	D	M	I	C
BDM	0- 5	0.0- 1.5	73	6	21	0	0.303	3.729	0.303	0.503	0.000
	5-10	1.5- 3.0	72	7	21	0	0.503	3.832	0.406	0.503	0.000
	10-15	3.0- 4.6	78	10	12	0	0.703	4.439	0.606	0.303	0.000
	15-20	4.6- 6.1	74	14	12	0	0.807	4.136	0.807	0.303	0.000
	20-25	6.1- 7.6	60	18	22	0	1.813	4.233	1.310	0.703	0.000
	25-30	7.6- 9.1	46	25	29	0	1.716	2.826	1.613	0.807	0.000
SBF	30-35	9.1-10.6	40	43	17	0	2.116	2.116	2.316	0.406	0.000
	35-40	10.6-12.2	20	56	21	3	1.310	1.058	3.026	0.503	0.394
	40-45	12.2-13.7	10	70	18	2	2.116	0.987	7.058	0.807	0.426
	45-50	13.7-15.2	7	72	16	5	2.620	0.561	6.149	0.606	0.987

TABLE 10

SAMPLE NUMBER: GV-22 AND GV-22M

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	C	F	D	M	I	C
CBM	M, 19-12	M, 5.8- 3.6	5	61	27	7	1.007	0.355	4.536	0.910	1.342
	M, 12-11	M, 3.6- 3.3	68	22	10	0	0.103	7.459	2.523	0.503	0.000
BDM	M, 11- 0	M, 3.3- 0.0	70	14	16	0	0.200	2.923	0.606	0.303	0.000
	0- 5	0.0- 1.5	64	15	21	0	0.303	5.245	1.310	0.807	0.000
	5-10	1.5- 3.0	53	25	22	0	0.303	4.136	2.019	0.807	0.000
	10-15	3.0- 4.6	42	37	21	0	1.007	2.219	2.019	0.503	0.000
	15-20	4.6- 6.1	46	40	14	0	1.110	1.813	1.613	0.252	0.000
	20-25	6.1- 7.6	50	33	17	0	1.613	1.310	0.910	0.200	0.000
	25-30	7.6- 9.1	52	28	19	0	2.219	1.813	1.007	0.303	0.000
SBF	30-35	9.1-10.6	25	44	26	5	1.613	0.826	1.510	0.406	0.497

TABLE 11

SAMPLE NUMBER: GV-27

Unit	Interval (feet-metres)		Percentages of Clay Minerals K	Mo	I	C	Area Under Clay and Feldspar Peaks 10^{-4} m^2 F	D	M	I	C
	35-40	10.6-12.2	50	32	18	0	0.703	3.123	2.019	0.503	0.000
	40-45	12.2-13.7	68	12	20	0	0.200	4.439	0.807	0.606	0.000
	45-50	13.7-15.2	62	20	18	0	0.406	5.142	1.716	0.703	0.000
	50-55	15.2-16.7	66	14	20	0	0.406	4.536	1.007	0.606	0.000
BDM	55-60	16.7-18.2	68	20	12	0	0.406	5.039	1.510	0.406	0.000
	60-65	18.2-19.8	63	22	15	0	0.406	4.736	1.716	0.503	0.000
	65-70	19.8-21.3	66	16	18	0	0.303	5.646	1.413	0.703	0.000
	70-75	21.3-22.6	59	15	26	0	0.303	4.536	1.213	0.910	0.000
	75-80	22.8-24.3	60	23	17	0	0.606	3.123	1.213	0.406	0.000
	80-85	24.3-25.8	58	25	17	0	0.606	4.336	1.916	0.606	0.000

TABLE 12

SAMPLE NUMBER: GV-33 AND GV-33M

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	C	F	K	M	I	C
BDM	M, 28.5-27.5	M, 8.7- 8.4	70	9	21	0	0.303	5.342	0.703	0.703	0.000
	M, 27.5-24.5	M, 8.4- 7.4	68	27	5	0	0.000	9.072	3.632	0.303	0.000
	M, 24.5-21.5	M, 7.4- 6.5	75	20	5	0	0.000	9.375	2.620	0.303	0.000
	M, 21.5-20.5	M, 6.5- 6.2	70	28	2	0	0.000	9.072	3.729	0.103	0.000
	M, 20.5-19.0	M, 6.2- 5.8	84	13	3	0	0.000	5.749	0.910	0.103	0.000
	M, 19.0-10.5	M, 5.8- 3.2	77	12	11	0	0.200	4.536	0.703	0.303	0.000
	M, 10.5- 0.0	M, 3.2- 0.0	83	9	8	0	0.103	6.652	0.703	0.303	0.000
	0- 5	0- 1.5	74	10	16	0	1.303	5.142	0.703	0.503	0.000
	5-10	1.5- 3.0	70	13	17	0	0.406	3.632	0.703	0.406	0.000
	10-15	3.0- 4.6	59	25	16	0	0.807	3.426	1.510	0.406	0.000
	15-20	4.6- 6.1	52	28	20	0	0.703	3.426	1.916	0.606	0.000
SBF	20-25	6.1- 7.6	28	58	14	0	0.910	1.813	3.832	0.406	0.000
	25-30	7.6- 9.1	22	62	16	0	1.413	1.213	3.426	0.406	0.000
	30-35	9.1-10.6	15	68	12	5	3.426	1.381	6.555	0.503	1.368

TABLE 13

SAMPLE NUMBER: GV-36 AND GV-36M

Unit	Interval (feet)	Interval (metres)	Percentages of Clay Minerals K	Mo	I	C	Area Under Clay and Feldspar Peaks 10^{-4} m^2 F	K	M	I	C
CBM	M, 29.5-22.5	M, 9.0- 6.8	7	47	35	11	2.620	0.516	3.426	1.110	2.007
	M, 22.5-14.5	M, 6.8- 4.4	82	3	15	0	0.303	5.949	0.200	0.503	0.000
	M, 14.5- 9.5	M, 4.4- 2.9	80	11	9	0	0.200	7.762	1.110	0.406	0.000
	M, 9.5- 4.5	M, 2.9- 1.4	69	25	6	0	0.000	7.562	2.826	0.303	0.000
	M, 4.5- 0.0	M, 1.4- 0.0	74	16	10	0	0.103	6.652	1.510	0.406	0.000
	0- 5	0.0- 1.5	30	36	24	10	1.110	1.129	1.413	0.406	0.955
BDM	5-10	1.5- 3.0	71	19	10	0	0.303	4.736	1.310	0.303	0.000
	10-15	3.0- 4.6	69	18	13	0	0.103	7.259	1.916	0.606	0.000
	15-20	4.6- 6.1	68	14	18	0	0.200	4.233	0.910	0.503	0.000
	20-25	6.1- 7.6	66	17	17	0	0.303	2.620	0.703	0.303	0.000
	25-30	7.6- 9.1	51	37	12	0	0.406	2.723	2.019	0.303	0.000
	30-35	9.1-10.6	48	30	21	0	1.110	2.019	1.310	0.406	0.000
SBF	35-40	10.6-12.2	26	39	30	5	1.813	0.774	1.213	0.406	0.426
	40-45	12.2-13.7	23	45	27	5	1.916	0.955	1.916	0.503	0.594

TABLE 14

SAMPLE NUMBER: G169-36

Unit	Interval (feet-metres)		Percentages of Clay Minerals K	Mo	I	C	Area Under Clay and Feldspar Peaks 10^{-4} m^2 F	K	M	I	C
	30-40	9.1-12.2	5	60	31	4	2.523	0.452	5.342	1.213	0.916
SBF	40-50	12.2-15.2	5	65	26	4	2.420	0.426	5.846	1.007	0.916
	50-60	15.2-18.2	5	67	23	5	2.523	0.355	5.342	0.807	1.181

TABLE 15

SAMPLE NUMBER: G169-37

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	C	F	K	M	I	C
CBM	0-10	0.0- 3.0	19	44	30	7	1.716	0.987	2.316	0.703	0.916
BDM	10-20	3.0- 6.1	43	42	15	0	0.503	3.226	3.226	0.503	0.000
	20-30	6.1- 9.1	43	40	17	0	1.007	3.832	3.632	0.703	0.000
SBF	30-40	9.1-12.2	35	43	22	0	2.420	3.123	3.929	0.910	0.000
	40-50	12.2-15.2	16	61	20	3	2.420	1.413	5.749	0.807	0.845

TABLE 16

SAMPLE NUMBER: 306-L24

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	C	F	K	M	I	C
SW	0-10	0.0- 3.0	22	51	20	7	1.716	0.987	2.316	0.406	0.703
BDM	10-20	3.0- 6.1	71	10	19	0	0.910	9.072	1.310	1.110	0.000
SBF	25-35	7.6-10.6	9	66	21	4	3.426	0.784	5.646	0.807	0.845
	40-50	12.2-15.2	4	84	9	3	3.529	0.632	13.007	0.606	1.110

TABLE 17

SAMPLE NUMBER: 306-L25

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	0	F	K	M	I	C
SBF	10-15	3.0- 4.6	9	45	41	5	2.219	0.323	1.510	0.606	0.426
	15-20	4.6- 6.1	12	53	32	3	2.316	0.426	1.916	0.503	0.323
	35-40	7.6-12.2	7	60	29	4	3.329	0.200	1.916	0.406	0.355
	45-50	13.7-15.2	5	54	38	3	2.420	0.284	2.923	0.910	0.426

TABLE 18

SAMPLE NUMBER: REAP-6

Unit	Interval (feet-metres)		Percentages of Clay Minerals				Area Under Clay and Feldspar Peaks 10^{-4} m^2				
			K	Mo	I	C	F	K	M	I	C
CBM	100-110	30.4-33.4	17	55	23	5	0.807	0.987	3.329	0.606	0.774
	110-120	33.4-36.5	20	37	34	9	1.007	1.200	2.219	0.910	1.413
BDM	120-130	36.5-39.5	62	22	16	0	0.406	5.245	1.916	0.606	0.000
	130-140	39.5-42.6	62	23	15	0	0.200	5.342	2.019	0.606	0.000
	140-150	42.6-45.6	60	24	16	0	0.303	3.929	1.613	0.503	0.000
	150-155	45.6-47.1	51	34	15	0	1.007	3.026	2.116	0.406	0.000

APPENDIX D

CHEMICAL ANALYSES

CHEMICAL ANALYSES

The chemical analyses presented in this appendix were made using a microprobe in conjunction with a scanning electron microscope. The procedure used is described in the text under the heading "Microprobe Analysis." Sample descriptions and locations are found in appendix A.

TABLE 19

CHEMICAL ANALYSES FROM MEASURED SECTION GV-12M AND AUGER HOLE GV-12

	Interval (Metres) Followed by Percent Oxide									
Oxide	6.8-2.0M	2.0-0.0M	0.0-1.5	2.4-3.0	4.6-6.1	6.1-7.6	7.6-9.1	10.6-12.2	13.7-15.2	16.7-18.2
SiO_2	63.78	63.22	64.71	67.61	65.06	75.06	70.95	70.05	77.75	66.03
Al_2O_3	28.98	31.62	27.68	27.50	20.98	18.86	20.54	19.04	13.65	18.86
Fe_2O_3	2.21	1.95	3.49	1.71	9.92	2.50	4.39	6.21	4.38	8.19
MgO	0.85	0.55	0.70	0.28	0.56	0.42	0.74	1.25	0.80	1.68
CaO	0.04	0.09	0.17	0.12	0.21	0.12	0.12	0.11	0.26	0.15
Na_2O	0.52	0.46	0.18	0.20	0.36	0.17	0.28	0.57	0.46	0.88
K_2O	1.87	0.30	1.39	0.41	0.99	1.63	1.87	2.07	1.80	2.10
TiO_2	1.46	1.32	1.21	1.75	0.85	0.82	0.83	0.64	0.52	0.72
P_2O_5	0.06	0.00	0.09	0.11	0.12	0.18	0.09	0.00	0.00	0.11
MnO	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.10	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_3	0.17	0.43	0.31	0.11	0.88	0.13	0.12	0.00	0.21	1.22

M designates samples from the measured section.

TABLE 20

CHEMICAL ANALYSES FROM MEASURED SECTION GV-22M AND AUGER HOLE GV-22

Oxide	3.6-3.3M	3.3-0.0M	1.5-3.0	4.6-6.1	7.6-9.1
SiO_2	61.54	71.13	67.70	66.45	64.70
Al_2O_3	32.34	22.04	23.78	18.96	20.57
Fe_2O_3	2.60	2.23	3.46	6.73	6.41
MgO	0.86	1.09	0.91	1.63	2.47
CaO	0.21	0.00	0.18	0.13	0.13
Na_2O	0.26	0.37	0.25	0.74	0.36
K_2O	0.59	1.56	1.88	1.49	2.90
TiO_2	1.08	1.12	1.44	2.28	1.58
P_2O_5	0.21	0.07	0.02	0.00	0.01
MnO	0.01	0.14	0.02	0.00	0.01
Cl	0.01	0.00	0.02	0.00	0.01
SO_3	0.23	0.19	0.27	1.52	0.80

M designates samples from the measured section.

TABLE 21

ADDITIONAL CHEMICAL ANALYSES, SAMPLES AS INDICATED

Oxide	GV-33M 6.5-6.2	GV-33M 6.2-5.8	GV-11M 6.7-4.9
SiO_2	52.20	56.20	59.55
Al_2O_3	28.35	36.76	26.16
Fe_2O_3	16.36	3.37	8.67
MgO	0.68	0.80	0.95
CaO	0.04	0.14	0.24
Na_2O	0.53	0.47	0.43
K_2O	0.49	0.56	1.67
TiO_2	0.89	1.22	1.25
P_2O_5	0.12	0.00	0.00
MnO	0.00	0.00	0.00
Cl	0.00	0.00	0.00
SO_3	0.28	0.42	1.03

M designates measured sections.

APPENDIX E

SCANNING ELECTRON MICROPHOTOS

Fig. 9. Fragile book of kaolinite plates. Halloysite tubes are present in the center-bottom and upper-right of this microphoto. Sample GV-14M, 0.0-2.1 metres, X2000.

Fig. 10. Curved and broken plates of kaolinite. Deformed structure resembles "ball clay" of Keller (1976b). Sample GV-14M, 2.1-5.5 metres, X2000.

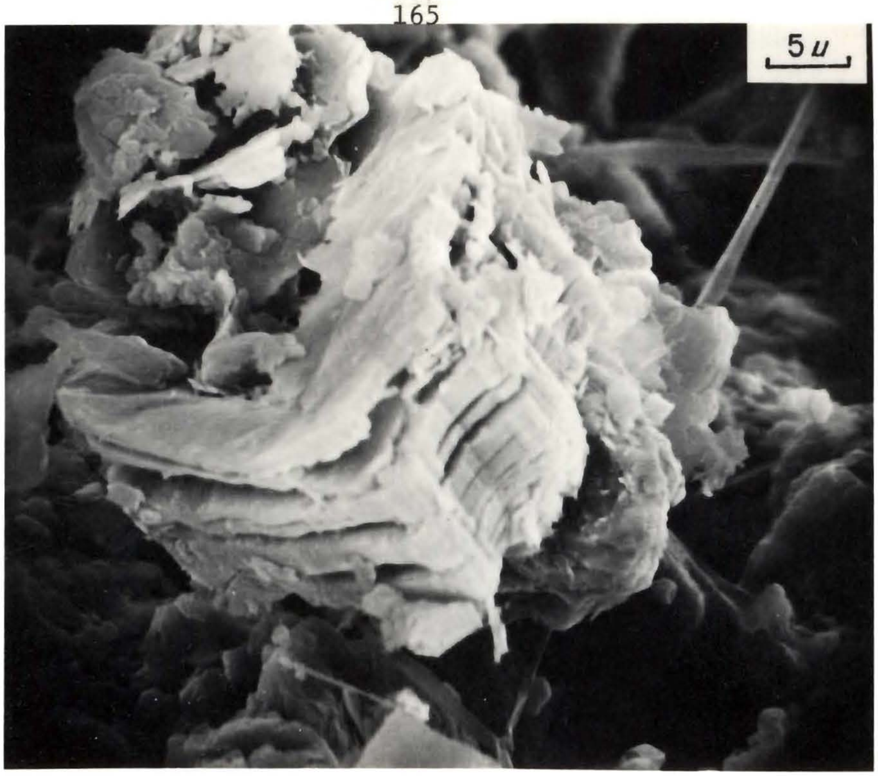


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Fig. 11. Poorly crystallized kaolinite plates. Ragged book-like structure near the center. Sample GV-12M, 2.0-6.7 metres, X2000.

Fig. 12. Moderately crystallized kaolinite plates surrounding and attached to a muscovite flake. Samples GV-22, 1.5-3.0 metres, X1200.

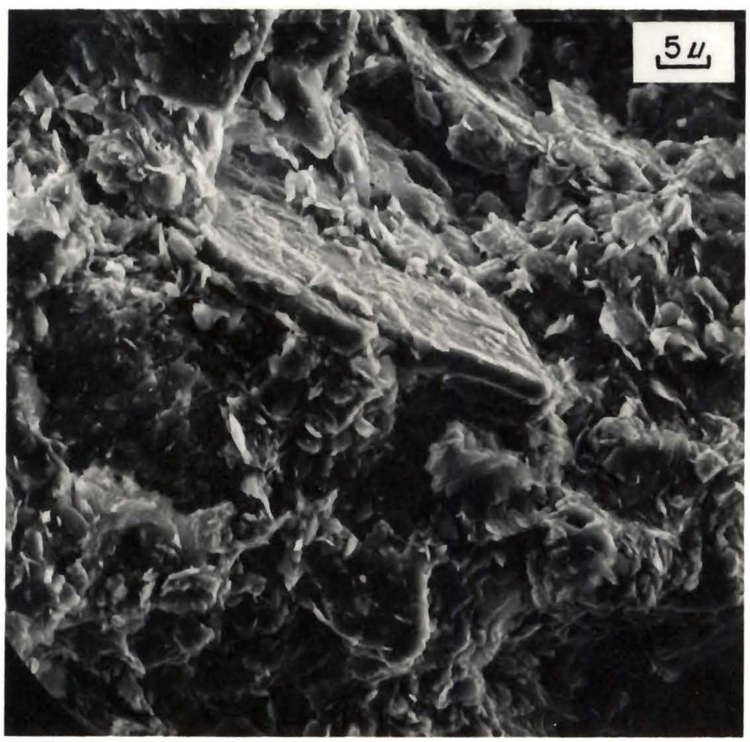

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Fig. 13. Moderate to well crystallized kaolinite plates with silt size quartz grains. Sample GV-14M, 0.0-2.1 metres, X2000.

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REFERENCES

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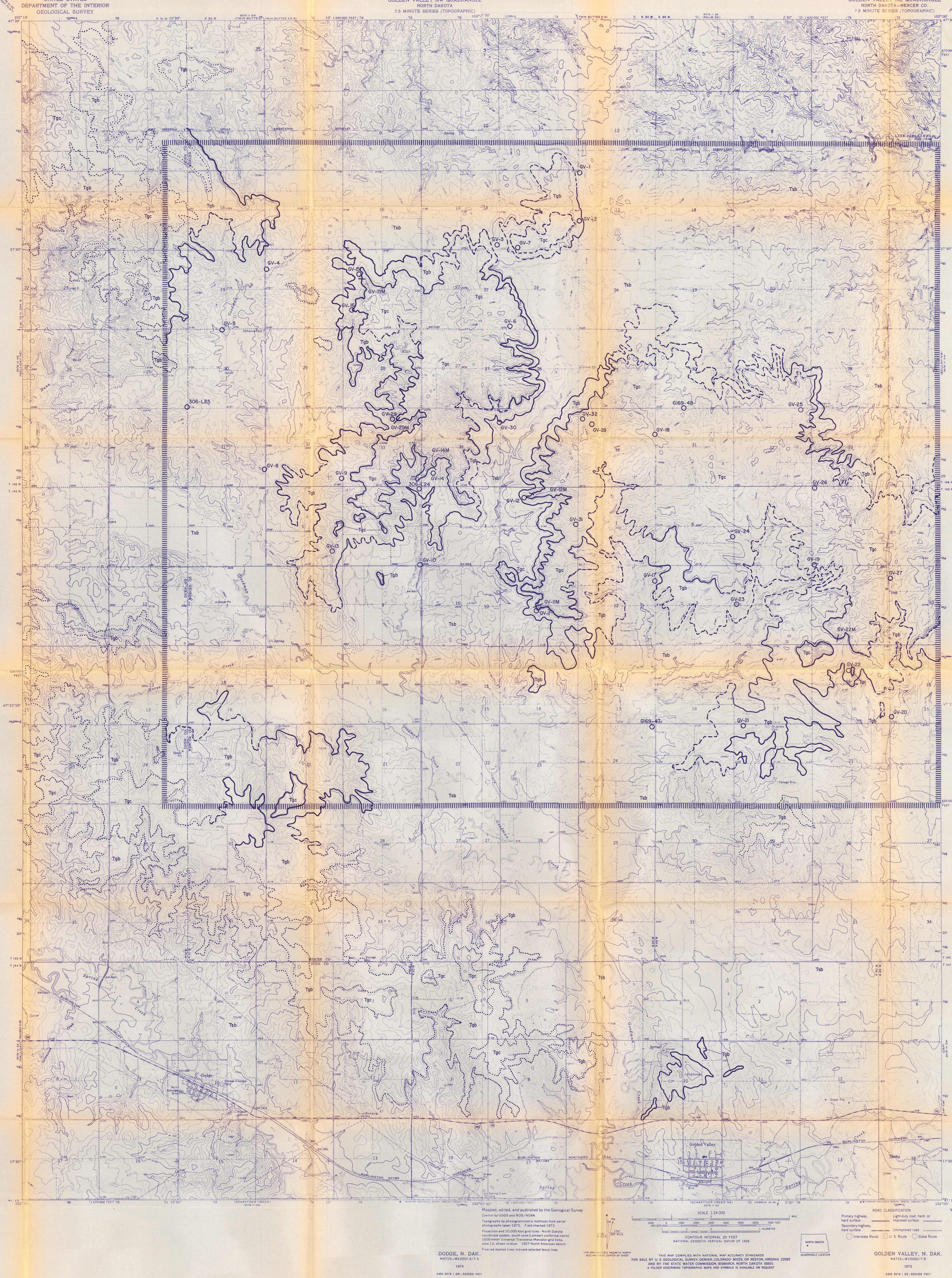
GEOLOGICAL SURVEY

GOLDEN VALLEY NW QUADRANGLE
NORTH DAKOTA
7.5 MINUTE SERIES (TOPOGRAPHIC)

GOLDEN VALLEY NE QUADRANGLE
NORTH DAKOTA—MERCER CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

PLATE I
PRICHARD, 1980

BEDROCK GEOLOGIC MAP OF THE GOLDEN VALLEY AREA NORTH DAKOTA



EXPLANATION

UNIT CONTACTS

Formation Contact
Covered Contact
Inferred Contact

GEOLOGIC UNITS

TERTIARY—EOCENE

Tgc

Golden Valley Formation
Camels Butte Member

Clay, silt, and sand, very micaceous; laminated with small and large scale cross laminations; somber grays and yellows.

TERTIARY—PALEOCENE

Tgb

Golden Valley Formation
Bear Den Member

Clay, silt, and sand, massive with few lamintions; light gray to white with bright yellows and purples.

Tsb

Sentinel Butte Formation

Clay, silt, and sand with common lignites; laminated with small and large scale cross laminations; somber grays and yellows.

DATA POINTS

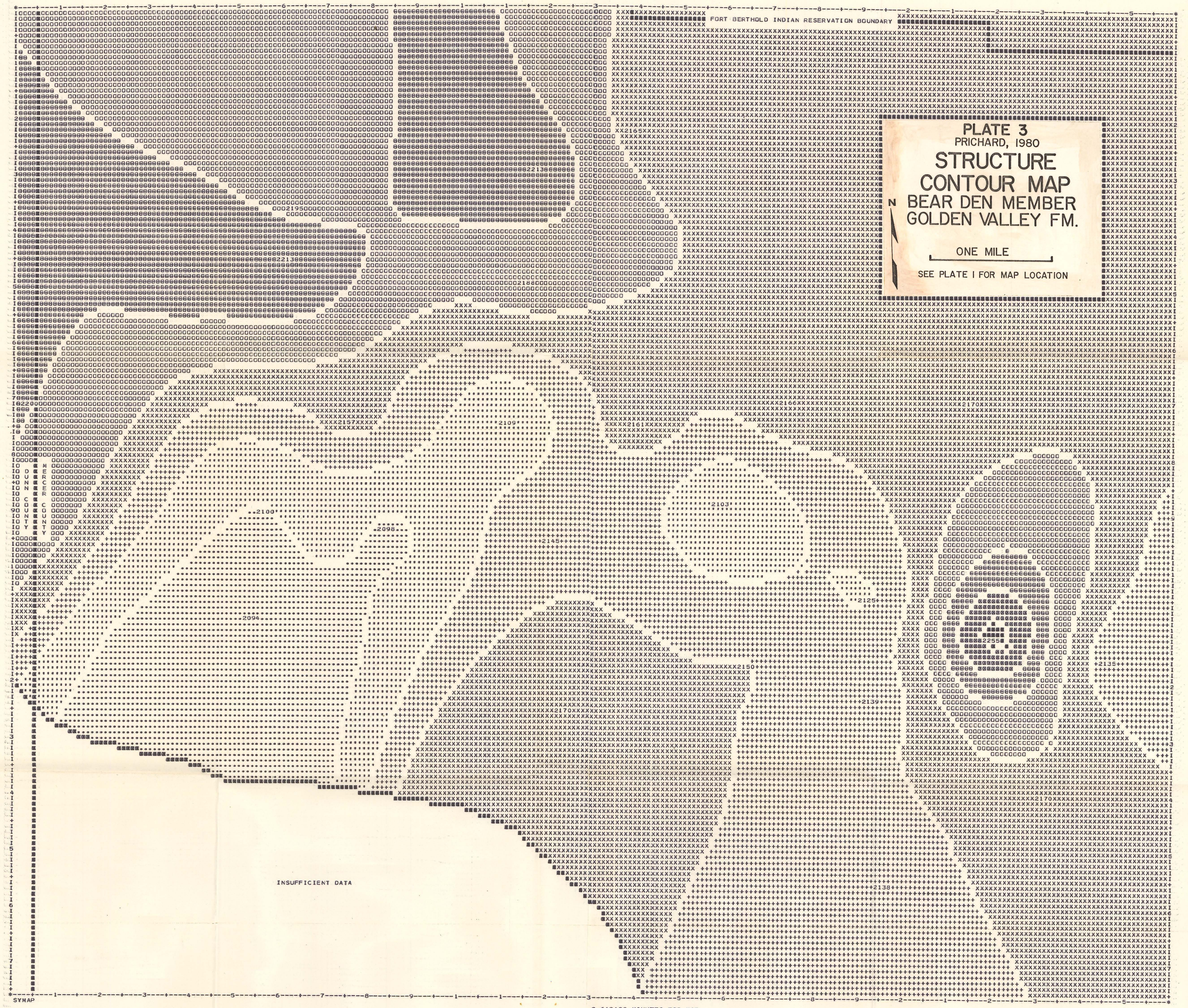
(See Appendix A)

GV-12 Drill Hole
GV-12M Measured Section
Outline of Plates 3, 4, 5, and 6.

PLATE 2
PRICHARD, 1980

STRATIGRAPHIC CROSS SECTION NORTH OF GOLDEN VALLEY, NORTH DAKOTA

GEOL. T1980 P93 plate 3



2.649488 MINUTES FOR MAP

STRCTURE CONTOUR AT THE BASE OF THE GOLDEN VALLEY FORMATION

DATA VALUE EXTREMES ARE 2094.00 2255.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	2075.00	2100.00	2125.00	2150.00	2175.00	2200.00	2225.00	2250.00
MAXIMUM	2100.00	2125.00	2150.00	2175.00	2200.00	2225.00	2250.00	2275.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

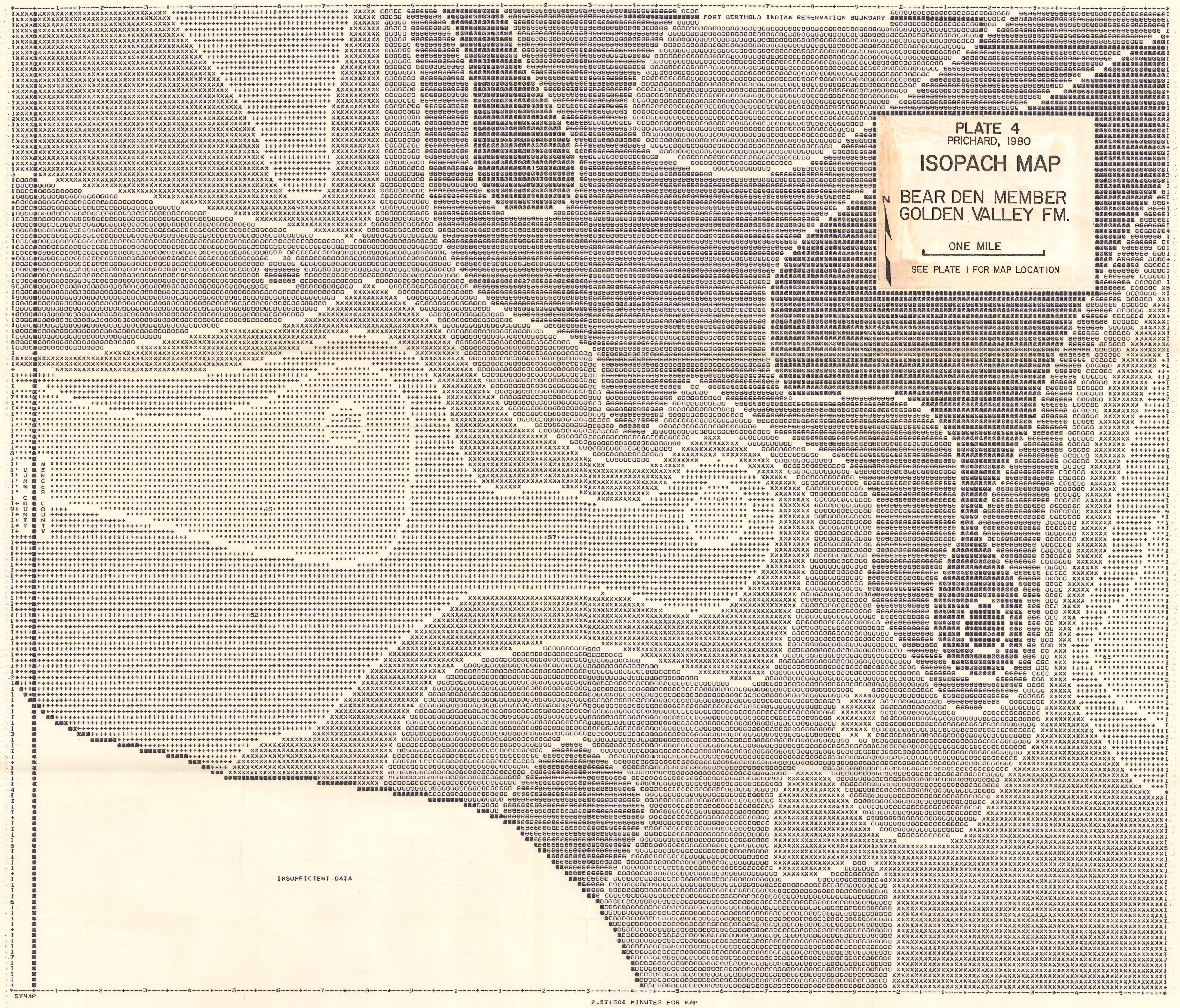
12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

```
LEVEL        1          2          3          4          5          6          7          8
         ==========================================================================================
          .........  '''''''''  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ▩▩▩▩▩▩▩▩▩  ■■■■■■■■■
          .........  '''''''''  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ▩▩▩▩▩▩▩▩▩  ■■■■■■■■■
SYMBOLS   ....1....  ''''2''''  ++++3++++  XXXX4XXXX  OOOO5OOOO  ØØØØ6ØØØØ  ▩▩▩▩7▩▩▩▩  ■■■■8■■■■
          .........  '''''''''  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ▩▩▩▩▩▩▩▩▩  ■■■■■■■■■
          .........  '''''''''  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ▩▩▩▩▩▩▩▩▩  ■■■■■■■■■
         ==========================================================================================
FREQ.        2          3          5          8          2          3          0          1
       1  I..1..I    I''2''I    I++3++I    IXX4XXI    IOO5OOI    IØØ6ØØI               I■■8■■I
       2  I..1..I    I''2''I    I++3++I    IXX4XXI    IOO5OOI    IØØ6ØØI
       3             I''2''I    I++3++I    IXX4XXI               IØØ6ØØI
       4                        I++3++I    IXX4XXI
       5                        I++3++I    IXX4XXI
       6                                   IXX4XXI
       7                                   IXX4XXI
       8                                   IXX4XXI
```

0.011333 MINUTES FOR HISTOGRAM

GEOL T1980 P93 pl. 4



2.571508 MINUTES FOR MAP

ISOPACH OF THE LOWER MEMBER OF THE GOLDEN VALLEY FORMATION

DATA VALUE EXTREMES ARE 6.00 71.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.0	10.00	20.00	30.00	40.00	50.00	60.00	70.00
MAXIMUM	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

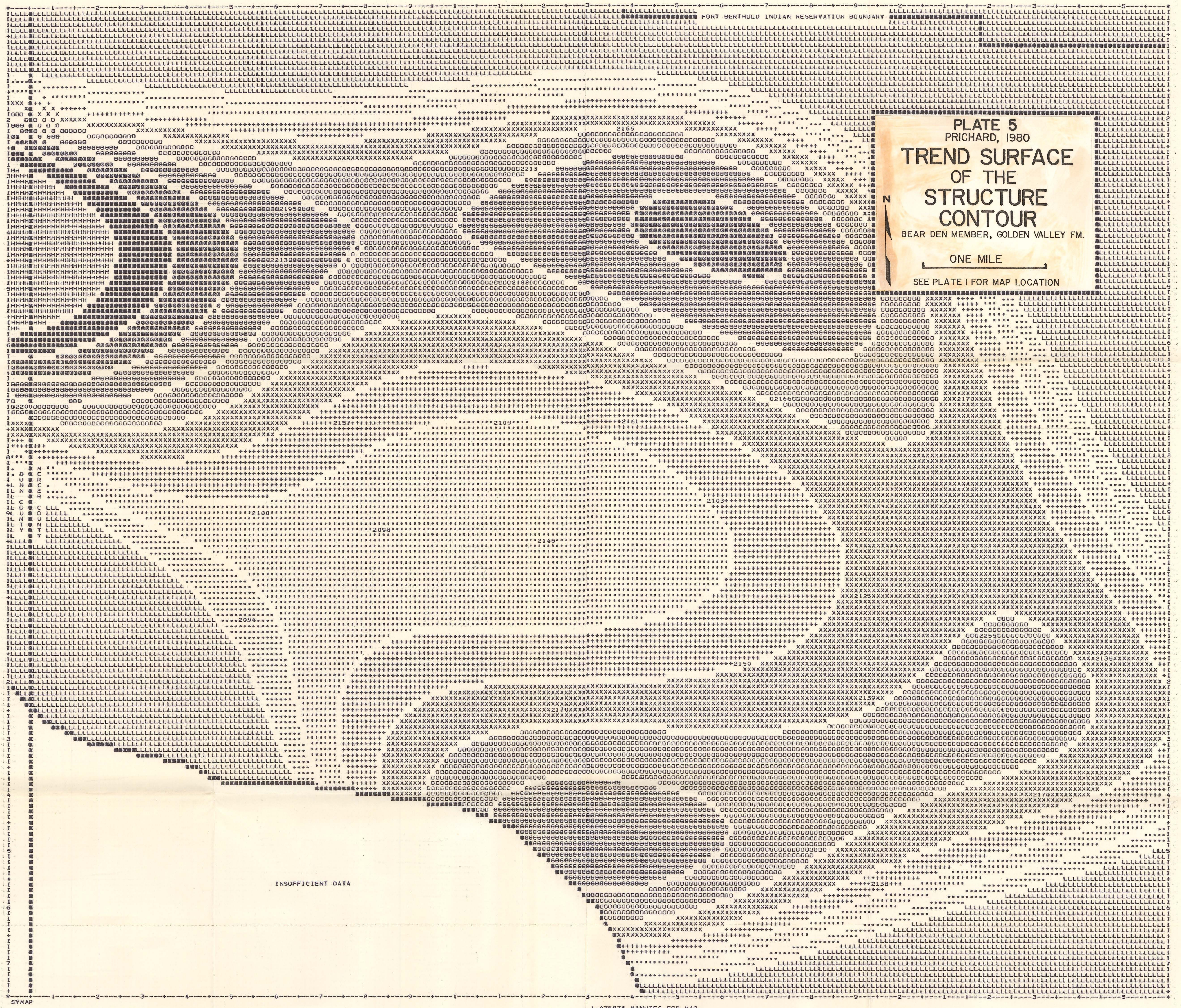
12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5	6	7	8
SYMBOLS	■■■■1■■■■	▩▩▩▩2▩▩▩▩	88883888	00004OOOO	XXXX5XXXX	++++6++++	''''7''''	....8....
FREQ.	1	1	3	4	5	2	3	1
1	I■■1■■I	I▩▩2▩▩I	I88388I	IOO4OOI	IXX5XXI	I++6++I	I''7''I	I..8..I
2			I88388I	IOO4OOI	IXX5XXI	I++6++I	I''7''I	
3			I88388I	IOO4OOI	IXX5XXI		I''7''I	
4				IOO4OOI	IXX5XXI			
5					IXX5XXI			

0.011101 MINUTES FOR HISTOGRAM

GEOL- T1980 P93 plate 5



1.475876 MINUTES FOR MAP

TREND SURFACE MAP FROM THE STRUCTURE CONTOUR MAP
AT THE BASE OF THE GOLDEN VALLEY FORMATION

DATA VALUE EXTREMES ARE 2094.00 2255.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

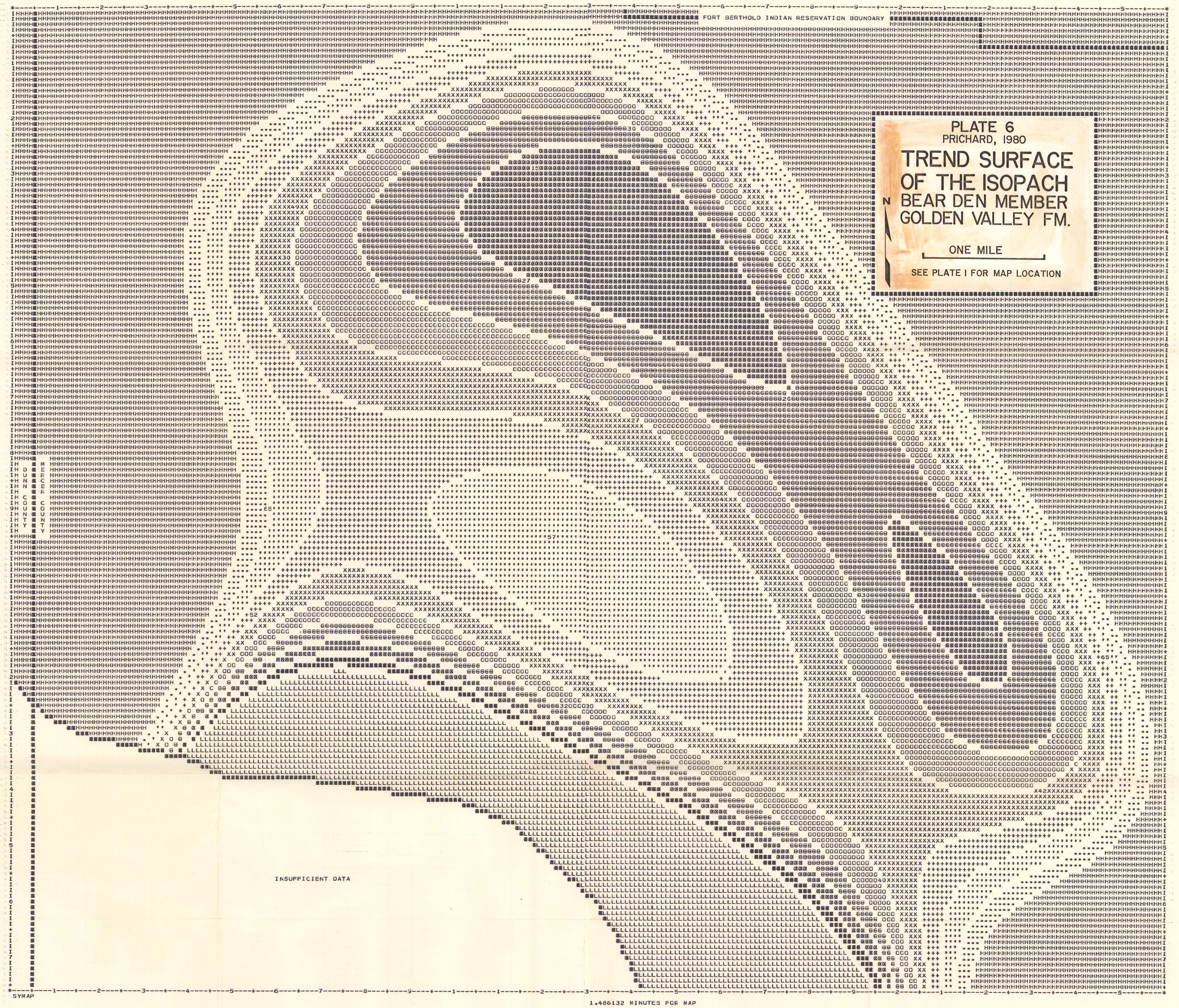
MINIMUM	2075.00	2100.00	2125.00	2150.00	2175.00	2200.00	2225.00	2250.00
MAXIMUM	2100.00	2125.00	2150.00	2175.00	2200.00	2225.00	2250.00	2275.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5	6	7	8
SYMBOLS	....1....	''''2''''	++++3++++	XXXX4XXXX	OOOO5OOOO	ØØØØ6ØØØØ	####7####	####8####
FREQ.	2	3	5	8	2	3	0	1
1	I..1..I	I''2''I	I++3++I	IXX4XXI	IOO5OOI	IØØ6ØØI		I##8##I
2	I..1..I	I''2''I	I++3++I	IXX4XXI	IOO5OOI	IOO6OOI		



1.486132 MINUTES FOR MAP

TREND SURFACE MAP FROM ISOPACH OF THE LOWER
GOLDEN VALLEY FORMATION

DATA VALUE EXTREMES ARE 6.00 71.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.0	10.00	20.00	30.00	40.00	50.00	60.00	70.00
MAXIMUM	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5	6	7	8
SYMBOLS	■■■■1■■■■	◙◙◙◙2◙◙◙◙	ΘΘΘΘ3ΘΘΘΘ	OOOO4OOOO	XXXX5XXXX	++++6++++	''''7''''	....8....
FREQ.	1	1	3	4	5	2	3	1
1	I■■1■■I	I◙◙2◙◙I	IΘΘ3ΘΘI	IOO4OOI	IXX5XXI	I++6++I	I''7''I	I..8..I