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VIKING DEPOSITION IN THE SUFFIELD AREA, ALBERTA

by

(C) Paul G. Tizzard

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Viking Deposition in the Suffield Area, Alberta", submitted by Paul G. Tizzard, in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

A subsurface study of the Viking Formation in southeastern Alberta between townships 19 and 26 and ranges 1 and 16 west of the 4th meridian was undertaken to determine its depositional environment and depositional history. This area is just north of the transition from the Bow Island Formation of the southern Plains to the Viking Formation of the central Plains, and is in the region of multiple sand development in the Viking Formation. Fourteen Viking cores and 250 electric logs distributed throughout the area were studied in detail.

From examination of cores, the vertical succession of structures and textures was found to be similar to barrier sands as previously described by other authors. The shape of the self-potential curves of the Viking Sabdstone in the Suffield area is the classical funnel shape to which Kruegor (1968) ascribed barrier bar deposition. Core and electric log examination shows the Viking Formation to consist of two main sands, here called the Upper and Lower Viking Sandstones.

A diagnostic 6 to 12 inch bentonite bed within the Viking Formation is correlatable throughout the study area on electric logs as a time datum. The interval between the bentonite datum and the overlying Fish Scales Sandstone was isopached, and suggests the Fish Scales may be a slightly diachronous unit rising stratigraphically eastward. The bentonite gives an average absolute potassium-argon age of

103.5±2 million years. The microfauna was studied from samples a few feet above the Viking Formation in the Lloydminster Shale. The microfauna reveal the biostratigraphic position of the Viking Formation to be just below the <u>M. manitobensis</u> Zone.

Examination of a series of cross-sections utilizing the bentonite time datum shows the depositional development of the Viking Sandstone. The Lower Viking sand was deposited as a northwest trending barrier bar with greatest thickness in the center of the study area. This sand was deposited earlier than the bentonite datum. The Upper Viking sand, deposited above the bentonite time marker, represents an eastward prograding barrier bar that has its maximum development in the northeast corner of the map area with a north-northwest trend.

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TABLE OF CONTENTS

CHAPTER | PAGE

LIST OF TABLES

LIST OF FIGURES

Figure		Page

LIST OF PHOTOGRAPHIC PLATES

CHAPTER I

INTRODUCTION

Purpose and Location of Study

The aim of this study was to map the lithofacies and interpret the depositional processes and environments of the Lower Cretaceous Viking Sandstone petroleum reservoir in an area in southeastern Alberta. The selected study region extends between ranges 1 and 16 west of the 4th meridian and between townships 19 and 26, an area of approximately 4,000 square miles without major settlements, situated immediately north of the Suffield military base (Figure 1). The study area will be designated as the Suffield area.

The Suffield area was chosen for study from an evaluation of the parameters of: density of wells, availability of core, and the characteristic Spontaneous Potential (SP) shapes of the mechanical logs of the Viking Formation. Most of the wells drilled through the Viking Formation have available an SP mechanical log. The Viking Sandstone shows classic sandstone SP shapes, particularly in the study area, from which an interpretation of the depositional environments of the sandstones can be made. The Suffield area also has a uniform distribution of wells which have Viking cored intervals.

The transition from the Bow Island Formation of the

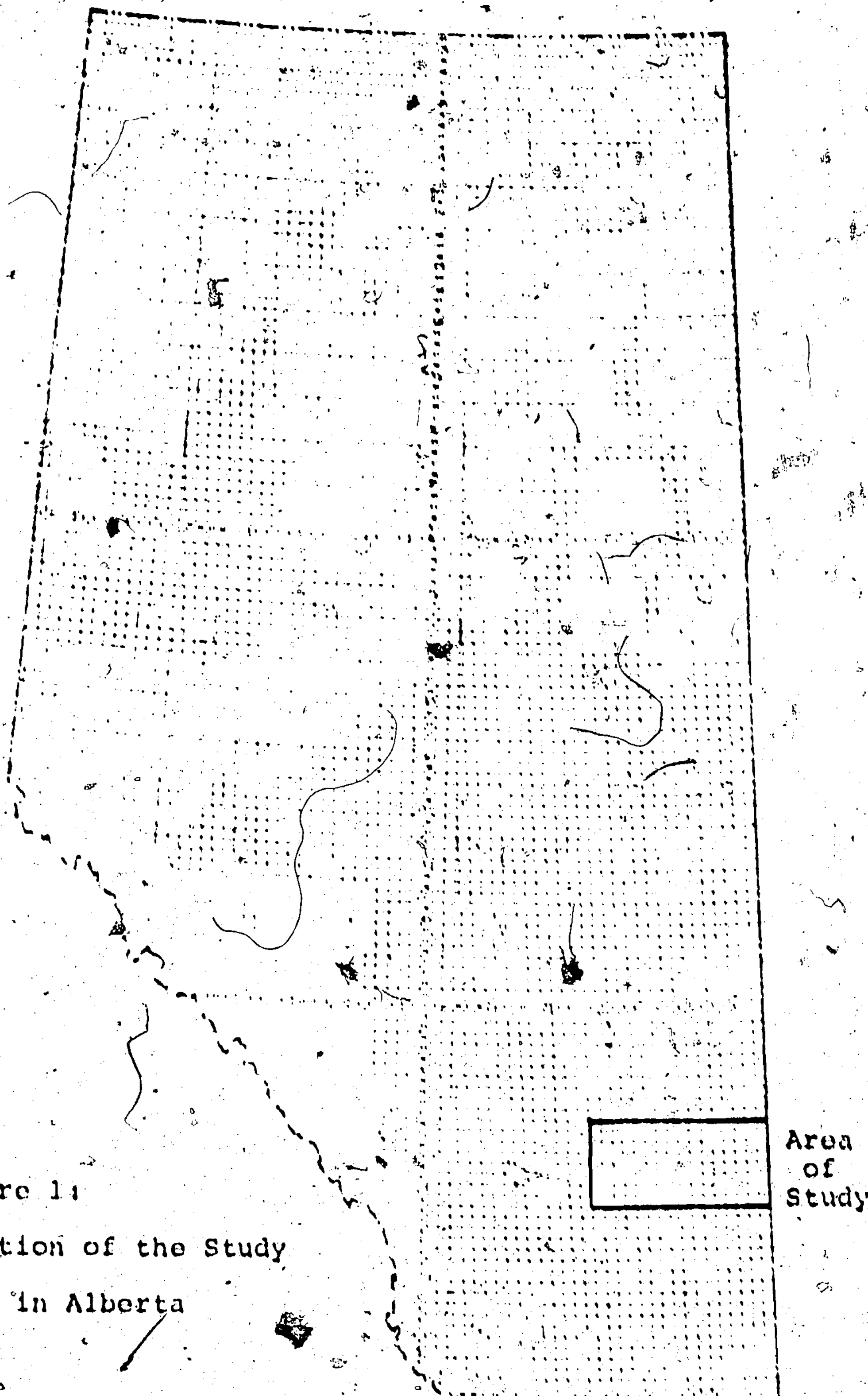
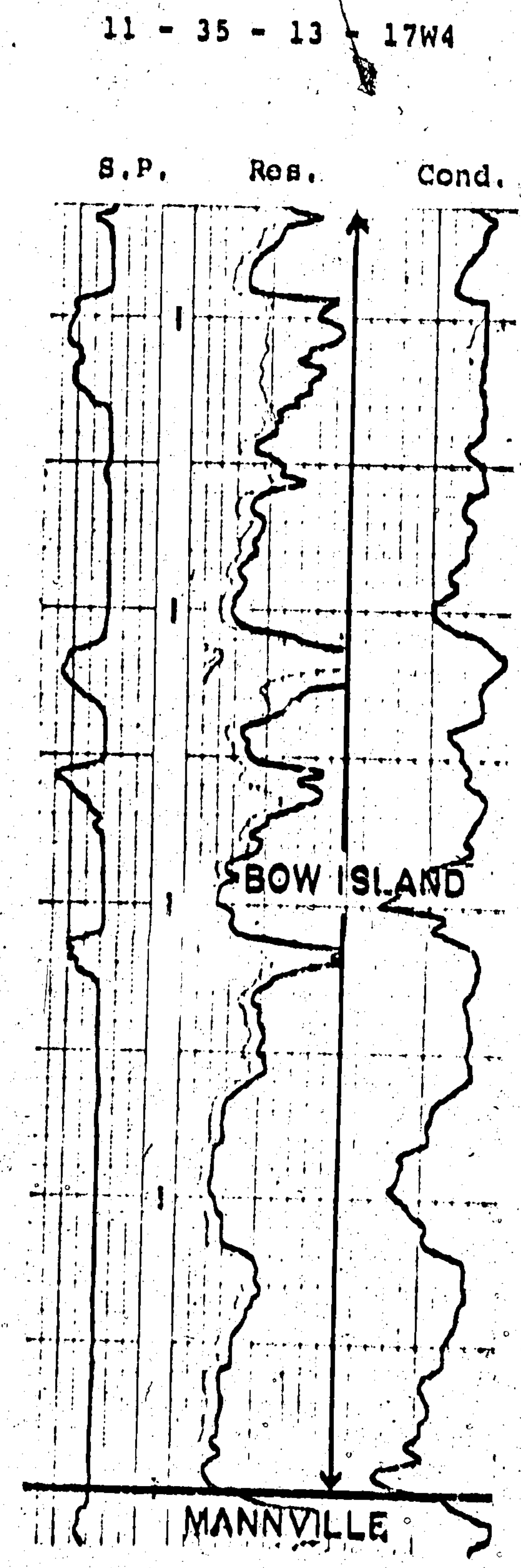


Figure 1:

Location of the Study Area in Alberta

southern Alberta Plains to the Viking Formation of the central Alberta Plains occurs in the southwest corner of the study area. The Viking Formation in the study area shows multiple sand development, generally two sands. To the north, the Viking has only one discrete sandstone unit, and south of the Suffield area the Bow Island Formation has from four to greater than ten discrete thin sand units (Glaister, 1959). The transition from the Viking to the Bow Island Formation is dependant upon the lithologic character of the Joli Fou Formation. North of township 20 the Joli Fou is a dark grey, marine shale with a lower resistivity than the overlying Viking. South of township 20 the Joli Fou becomes a s[illegible]y, sandy shale due to [illegible]cies change, and the resistivity cannot be differentiated from that of the overlying Bow Island sands and shales. In Figure 2 two wells, 84 miles apart illustrate the typical stratigraphic sections of the Bow Island and Viking Formations. The top of the Bow Island is correlative with the top of the Viking Formation. The base of the Bow Island is the top of the Mannville Formation, as the Joli Fou has become indi[illegible]uishable in the southern Plains, while the base of the Viking is the top of the Joli Fou Shale of the central Plains.

The Viking Formation is important economically as it accounts for about 11 percent of the gas reserves in Alberta and 1.4 percent of the oil reserves (A.S.P.G., 1969). Although there have been no Viking oil fields found in the



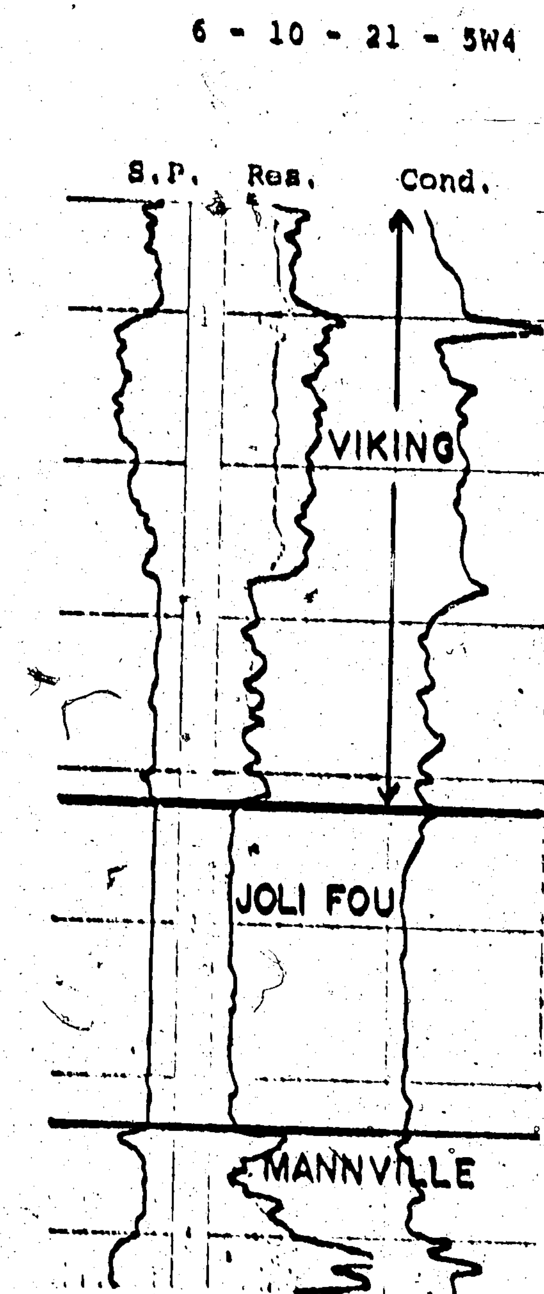


Figure 2:

A Comparison of the Bow Island and Viking Formations as Illustrated by Typical Electric Logs.

study area, there are three gas fields--Bindloss, Atlee-Buffalo, and Cessford. The location and size of these three gas fields are plotted on the structure map of the top of Viking (Figure 3).

The 40,000 acre Atlee-Buffalo field, discovered in 1953 produces gas from the top five feet of the upper sandstone of the Viking Formation. The trap type is a combination stratigraphic-structural trap, as the field is located on a slight structural high (Figure 3), and the sandstone has a porosity pinchout as it is enclosed by surrounding shales. The average porosity of the reservoir sandstone is 23.5 percent and the estimated gas reserves (in place) are 55 Bcf.

The 56,300 acre Bindloss field is the largest of the three fields. The maximum pay thickness is 28 feet (average 14.4 feet), occurring in the upper Viking Sandstone which has an average porosity of 29 percent. The trap type is again structural-stratigraphic, with a porosity pinchout of the sandstone on a structural high (Figure 3). The estimated gas reserves (in place) are 460 Bcf.

The 35,800 acre Cessford field has estimated gas reserves (in place) of 85.1 Bcf. Production is from both upper and lower Viking sand with a maximum pay thickness of 26 feet and an average of 6 feet. The average porosity is 18.6 percent. The trap is predominantly stratigraphic porosity pinchout with varying structural influence, structural highs being present in four of the six pools (Figure 3).

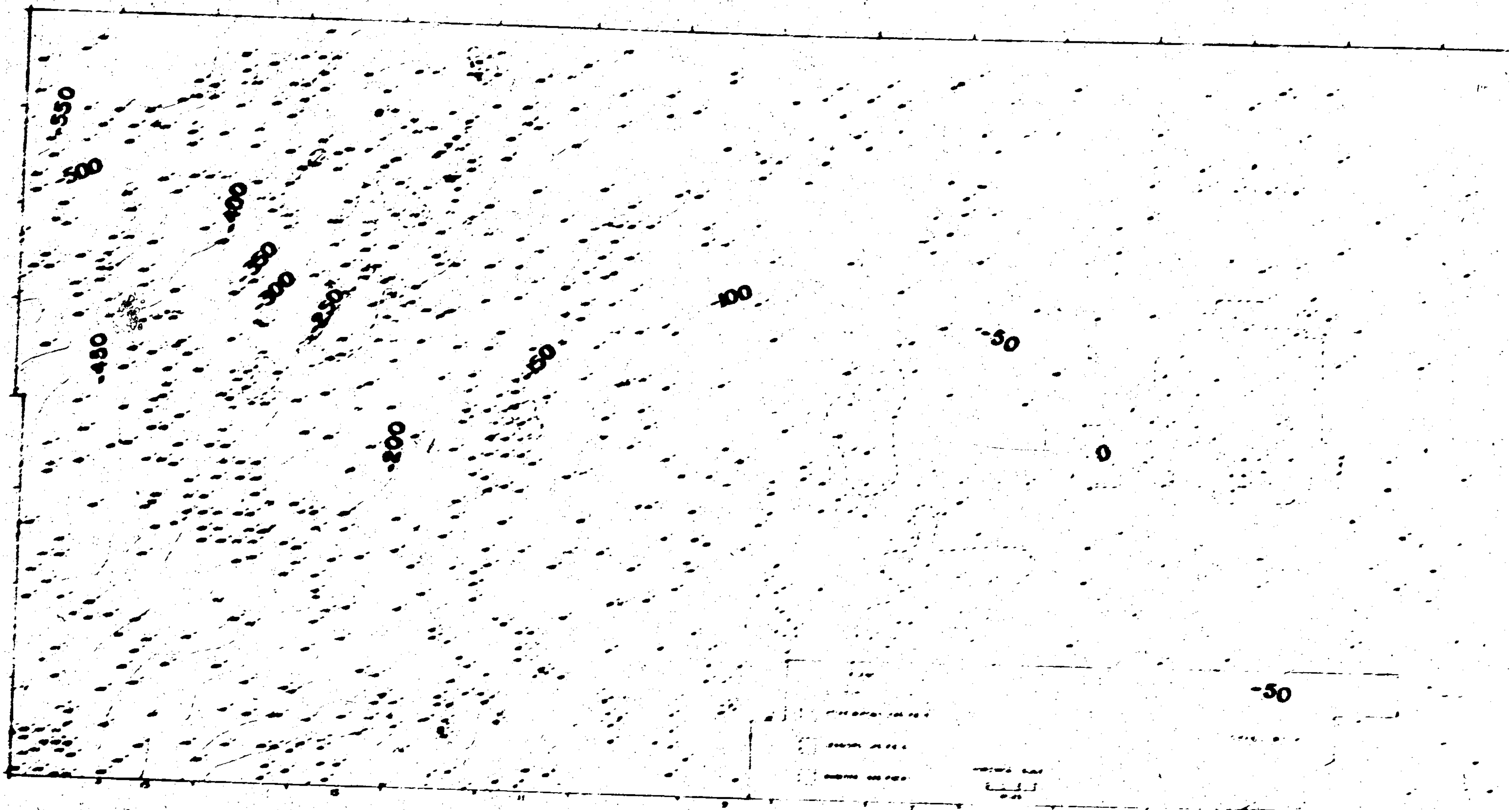


Figure 3: Computer Structure Contour Map on top of the Viking Formation.

Other major gas fields found in the Viking Formation, outside the study area, are Viking--Kinsella, Provost, Joarcam, and Bow Island. Some of the important oil fields are Joarcam, Joffre, Hamilton Lake, and in Saskatchewan, Smiley, Dewar, Eureka and Dodsland. The oil and gas discoveries in the Viking Formation have shown it to be an excellent reservoir.

Previous Work

Published work on the Viking Formation in southern and central Alberta has been mainly concerned with the mode of deposition of Viking sediments. Beach (1956) and Roessingh (1959) favoured a turbidity current explanation. Beach was concerned with the widespread extent of the chert pebble beds and their unsorted character, which he thought could not be accounted for by normal marine sedimentation. Roessingh interpreted micro-structures in the Viking cores to be slump structures associated with turbidity current deposition over a matter of hours. His correlation of bentonites occurring in "approximately" the same stratigraphic position relative to the top of the Viking seemed to contradict the concept of regression and diachronism of the Viking Sandstone. DeWiel (1956) and Jones (1961) argued against turbidity currents and suggested the Viking sands to represent conventional marine sedimentation in a broad, shallow epicontinental sea during another regressive stage in the Cretaceous history of western Canada. Jones suggested that the deformation structures described by Roessingh, are of organic origin and imply normal rates of sedimentation.

Papers by Gammel (1955), Glaister (1959), and Rudkin (1964) give petrologic descriptions of the Viking Sandstone and geological history of the Lower Cretaceous in central and southern Alberta.

Evans (1970) examined some Viking cores from the Dodsland-Hoosier area of southwest Saskatchewan and suggested that imbricate sandstone bodies with a west-southwest, east-northeast orientation are tidal current deposits, from tidal currents that carried relatively coarse clastics in an easterly direction, at a high angle to the shoreline, and not the result of a sudden swing in the shoreline from the usual northwest-southeast strike trend.

Berg and Davies (1968) used cores from the Bell Creek oil field in the Powder River Basin of Montana and Wyoming, to interpret local sedimentary environments of the Lower Cretaceous Muddy Sandstone which is correlated with the Viking Sandstone. On the basis of mineral composition, vertical textural change, bedding and gross morphology the Muddy Sandstone was interpreted to be a barrier bar. A succeeding paper by Davies, Ethridge and Berg (1971) suggests how barrier bar environments may be recognized by the vertical succession of sedimentary structures and textures.

CHAPTER 2

METHOD OF STUDY

A total of 251 wells were selected for this project from computer print-outs, giving a density of 2.4 wells per township. The writer examined 850 feet of Viking core from 14 well cores stored at the Core Storage Center of the Alberta Energy Resources Conservation Board in Calgary. Thirteen Viking cores from outside the study area were also examined. Selection of the wells to be logged was based primarily on the shape of the Spontaneous Potential (SP) curve of the Induction Electric Log of the well, in order that, as far as possible, detailed log examinations would be made for all major shape variants of the SP curve. A uniform distribution of the cored wells throughout the region was also strived for in the selection of wells for lithologic logging.

The purpose of lithologic description of the core was to define the vertical succession of sedimentary structures, lithologies and textures in order that an interpretation of the depositional environments could be made (Davies, Ethridge and Berg, 1971 and Visher, 1965). Photographs of the logged core, showing the variety of structures and textures in vertical succession, were taken for comparison with published photographs, to aid in the interpretation of the environmental subfacies.

Krueger (1968) indicated how depositional environments of sandstones can be interpreted from SP electrical measurements. By the use of the 14 lithologically logged wells as control points, the interpreted depositional environments of the Viking Sandstone were extended throughout the study area by comparison with the SP curves of the other wells.

A time horizon was found in the Viking Formation throughout most of the study area in the form of a volcanic ash. When the writer was logging the core a diagnostic six inch to one foot thick volcanic bentonite (identified by Dr. J. F. Lerbekmo), was found in four of the fourteen wells. It was decided to use the bentonite as a time horizon if it was correlatable over the study area. By the use of resistivity and conductivity curves, the bentonite was traced throughout most of the area of interest. The distribution of Viking lithofacies was mapped in both space and time using the volcanic horizon as a datum plane for cross-sections. Mineral samples from this bentonite were separated and prepared for potassium-argon dating in order that an absolute age of the Viking Formation in the Suffield area be known.

Samples for micro-paleontology were collected from three of the logged wells. It was hoped that a study of the microfaunal would reveal: (1) shaly subfacies of the Viking Formation which could not be differentiated by their textural and structural characteristics; (2) environmental implications of the microfaunal assemblages; and (3) a stratigraphic correlation of the Suffield area section to other areas.

CHAPTER 3

STRATIGRAPHY AND GENERAL DEPOSITIONAL HISTORY

This outline is intended to introduce the reader to the Lower Colorado stratigraphy in the subsurface of western Canada. The Colorado Group of marine dark grey shales and minor sandstones overlies the Mannville Group and underlies the Lea Park Formation in central Alberta. The lower part of the Colorado Group, below the "Fish Scale" sandstone contains the sandstones of the Viking and Bow Island Formations.

Figures 2 shows the correlation of the Viking and Bow Island Formations in the central and southern Plains of Alberta, respectively. In the southern and central Plains the Lower Colorado map-unit includes those beds between the top of the Mannville Group and the base of the Fish Scale zone. In the central Plains this includes the Joli Fou and Viking Formations, and those Colorado shales between the Viking and the Fish Scale zone; all are marine. In the southern Alberta Plains the map-unit includes the "Basal Colorado Sands", the Bow Island Formation, and the shales between the Bow Island and Fish Scale zone.

The Joli Fou Formation is a dark grey, marine shale that lies above the non-marine beds of the Mannville Group and below the sandy shales and sands of the Viking Formation. The Joli Fou gradually pinches out westward until the overlying Viking merges with the Mannville to become the Blairmore

Formation of the Foothills. The Joli Fou can be traced southward to about township 20, where it loses its lithologic indentity as it becomes a silty and sandy unit.

The Viking Formation consists of a succession of "salt-and-pepper" protoquartzites interbedded with grey to dark grey siltstones and shales. The top of the Viking is placed at the top of a black, chert pebble stringer or chert rich sandstone. The base of the formation is placed at the base of the sandstone or sandy shale overlying dark Joli Fou shale. From central Alberta toward the east and northeast, the Viking becomes progressively finer grained and more shaly until it virtually disappears as a sandstone unit. The arbitrary cut-off of the Viking southward at about township 20 corresponds to the Joli Fou losing its lithologic identity. The average thickness of the Viking Sandstone in the Suffield area is about 80 feet.

The Bow Island Formation consists of the entire succession of interbedded sandstones and shales lying between the Mannville Group and the first sandstone below the base of the Fish Scale marker (Glaister, 1959). Although a shale is well developed between the base of the Fish Scales and the top of the Bow Island and Viking Formations in the Plains, this interval becomes extremely thin towards the Foothills.

The following is an account of the depositional history of the Lower Colorado Group in Lower Cretaceous time from Rudkin (1964) and Stelck (1958).

During Early Albian and Middle Albian time, the boreal sea advanced into the Central Plains during the deposition of the Upper Mannville sediments. It is along the borders of this sea that the shore line and offshore sands of the Viking, Pelican and Bow Island Formations developed along with the Lower Colorado shales. Connections between the boreal and Gulf of Mexico seas were probably sporadic. The boreal advance is well documented stratigraphically; the details of the Gulfian advance are not as well known. However, Stelck (1958), in discussing the fauna of the Joli Fou Formation of the lower part of the Lower Colorado Map unit, states that the pelecypod Inoceramus comancheanus which occurs in the Joli Fou "is a migrant from the Gulf of Mexico and may be traced up the Missouri drainage into Canada".

Sandstone developments are confined to the western region, generally in areas of high subsidence and thick deposition. The sandstones thin and grade to siltstone eastward. This indicates the Cordilleran uplifts were the main source of sediments, particularly coarse clastics. The lack of sandstone in the eastern portion of the Western Canada basin also indicates that the Shield was no longer acting as a source of sediments. Rather, the western Shield was probably covered by the Lower Colorado sea. The section in eastern Saskatchewan and Manitoba is thin, but stratigraphic and paleontologic evidence indicates that a complete Lower Colorado section does exist. These beds therefore represent a condensed section deposited well out in the marine basin, a considerable distance from sediment source areas.

In Manitoba, the Swan River Group consists of shaly glauconitic sandstone in the upper part. The Swan River appears to be equivalant to the Joli Fou and Viking Formations of the Ashville Group farther south and west. The shoreline of the Lower Colorado sea probably lay in eastern or central Manitoba.

The distribution of the Paddy sandstone in the Peace River district approximates the shape of a bird's-foot delta, with a sandstone thickness greater than 100 feet. This may represent the terminus of a large river system draining the British Columbia interior. Over the stable area of central Alberta where the waters were probably shallow, southeasterly flowing sea currents, and possibly wave action, redistributed and winnowed the Peace River Formation sands, forming the great sand bars of the Viking Formation. Some of these sands may have been carried across the stable region and deposited as the Bow Island Sandstones of southern Alberta. However, it appears more likely that the Nelson uplift was the prime source of these southern sands. A thick wedge of Upper Blairmore sand similar to that of the Peace River district is located near Calgary, due west of the study area. This thick sand complex, if a delta, would be a likely source for the nearby marine sands of the Viking and Bow Island Formations. The Bow Island and Viking sands would have been deposited during repeated minor regressions of the Colorado sea (Glaister, 1959).

CHAPTER 4

VIKING LITHOFACIES

Viking core was examined in detail in fourteen wells throughout the study area. The purpose in logging the vertical succession of structures and textures was to delineate the lithofacies and compare them with recent deposits, in order to decipher the depositional environments in which the Viking Sandstone was deposited. The wells were selected with a goal of achieving a uniform distribution throughout the study area. In addition, the wells were also selected on the basis of their electrical log characteristics. The relationship of electrical log characteristics to genesis of a sandstone body is discussed in the following section.

The location of the cored wells which were examined, along with an accompanying electrical mechanical log of the Viking Formation and a brief lithologic description of the cores are found in Appendix A.

The vertical successions of sedimentary structures and textures in the Viking core examined have much in common with those of Galveston Is. Texas a recent barrier bar whose sedimentary environments have been studied by Bernard et al. (1962) and Davies, Ethridge and Berg (1971). Following is a description of the most commonly observed features of the Viking Formation in the Suffield area. The recognition of

Viking lithofacies is based on their similarity to structures and textures described and interpreted by the above authors.

Barrier beach and barrier island are terms for closely related physiographic units. These features consist of a subaerially exposed ridge or ridges above the storm limit of the waves and currents that built them. These constructional features act as barriers separating the marine environment from the shoreline environments.

An offshore bar is a term for a submerged sand ridge built some distance from the shore.

Galveston Island, Texas is a Holocene barrier island as designated by Bernard et al. (1962) and Davies, Ethridge and Berg (1971). These authors studied the internal sedimentary structures and textures of this barrier island in order that it might be used as an analogue with which the internal features of ancient sequences could be compared.

Galveston Island began as a small bar on the southwestern side of the mouth of Galveston Bay about four miles offshore in five to eight feet of water. The island emerged and grew seaward by beach and shoreface accretion and southwestward by beach spit, tidal channel and tidal delta accretion in the direction of the prevailing longshore drift. The barrier sands are lenticular, with a maximum thickness of 50 feet. They are flanked both landward and seaward by silts and clays representing typical lagoonal and offshore deposits respectively. The vertical sequence of sedimentary features from bottom to top of the island is characteristic and is subdivided into four distinct units: (1) lower shoreface, (2) middle shoreface, (3) beach-upper shoreface, (4) eolian.

The lower shoreface, or shoreface-toe sediments are deposited seaward of the break in offshore slope, within the depth interval of 30 to 40 feet. These sediments consist of interbedded, burrowed, and churned (bioturbated) very fine-grained sand, silt, and silty clay which may reach a thickness of 6 feet.

The overlying middle shoreface sediments were deposited shoreward of lower shoreface sediments. They consist of very fine grained sand which is so extensively bioturbated that sedimentary structures are only rarely preserved. Cross-laminated shelly-sand layers are present sparingly as are interlaminae of silty clay. In general, therefore, middle shoreface sands are structureless and bioturbated. They range in thickness from 10 to 34 feet and are deposited in 5 to 30 feet of water.

Upper shoreface and beach sediments gradationally succeed and lie shoreward of middle shoreface sediments. They consist of fine to very fine grained well laminated sands 3 to 10 feet thick. The most characteristic sedimentary structure is planar low-angle cross-lamination. Burrowing is scarce but shells may be locally abundant.

Bernard et al. (1962) distinguished between beach and upper shoreface sediments with the knowledge of sea level, the upper shoreface environment being restricted to shallow water seaward of low tide level. The two environments are difficult to distinguish solely on the basis of sedimentary structures and textures, and the distinction cannot be made easily in cores. As a result, the upper shoreface and beach zones were combined by Davies, Ethridge and Berg (1971).

Eolian sediments that cap Galveston Island are generally both cross-laminated (trough and planar) and parallel laminated. These structures are progressively destroyed with increasing age, as a result of plant and animal action, as well as by weathering and the movement of groundwater. Older eolian deposits tend to be structureless or massive but with definite traces of plant rooting and thin soil zones. Eolian sediments are fine to very fine grained sands, generally 2 to 8 feet thick.

Landward from Galveston barrier island are lagoonal sediments. These consist of interbedded, burrowed, and churned clay and silt with some fine sand. These shallow water deposits are commonly succeeded by rooted clay and silt of bordering marshes. Both animal burrows and roots generally are vertical and commonly obscure the parallel and cross-laminations of the sediments, but some bedding survives, especially the coarser interbeds.

This spatial and vertical sequence of structures is well developed in all cores from the Galveston barrier island. Excellent photographs of the above subfacies are shown in the

Bernard <u>et al.</u> (1962) paper.

In the Suffield area, some of the cores of the Lower Cretaceous Viking Sandstone reveal two main sandstone units. These sands have a succession of sedimentary structures and textures similar to the succession outlined for the Galveston barrier island. The Viking has three distinct subfacies that may be recognized in a vertical sequence. In ascending order, these are interpreted as (1) lower shoreface, (2) middle shoreface, and (3) beach-upper shoreface. Boundaries between each of these units are gradational, and if a unit is absent it is generally either the beach-upper shoreface or the middle shoreface.

The basal, lower shoreface, unit of the Viking Sandstone has irregular laminae, lenses and mottles of very fine grained sandstone and siltstone in a shale groundmass (Pl. III). This subfacies varies from sandstone and siltstone in distinct layers and lenses with well defined burrows (Pl. I, Fig. 2), to the indistinct stratification that has been disrupted by organic activity. Organic activity can completely rework the mud, sand, and silt to produce only indistinct mottles (Pl. I, Fig. 1b).

The middle shoreface sediments contain between 3 and 20 feet of medium to fine grained structureless sand (Pl. II, III, IV). The structureless nature of the sands is believed to reflect intense burrowing activity which has homogenized the sediment (Davies, Ethridge and Berg, 1971).

The presence of indistinct mottling and a few discontinuous or broken laminae (Pl. I, Fig. 1c) is a common feature of the middle shoreface sands of the Viking in the Suffield area.

The structureless sands of the Viking middle shoreface grade upward into well laminated fine grained sand about 4 to 10 feet thick of the upper shoreface-beach zone (cf. Pl. II & IV). This zone is characterized by plane tabular cross-laminations separated by erosion surfaces bevelled across underlying units at a low angle (Pl. I, Fig. 1a). Ripple cross-lamination is of lesser importance and burrowing is sparse.

Galveston Island also has an eolian subfacies capping the beach, but in none of the Viking cores examined was an eolian subfacies recognized. The Viking beach-upper shoreface sands are not capped with lagoonal sediments as at Galveston, but rather by either marine shales (Pl. IV) or an irregular laminated, reworked sandy and silty shale (Pl. III). This latter shale is not believed to record lagoonal conditions as it has little if any organic detritus or the greasy look usual to lagoonal muds. This facies has similar structures and textures to that of other lower shoreface sediments, and, in addition, the microfauna (described later) from this facies is similar to the fauna of the lower shoreface facies. The Galveston sands (Bernard <u>et al.</u>, 1962), the Muddy Sandstone (Davies, Ethridge and Berg, 1971) and the

Cardium Sandstone (Achtman, 1972) all have eolian sands and lagoonal muds overlying their beach-upper shoreface sands. These barrier bars were situated close to the shoreline, forming effective barriers between the open marine and the lagoonal waters.

The Viking sands, with no overlying lagoonal sediments, suggest deposition occurring relatively far from the shoreline with a surrounding open marine environment. Davies, Ethridge and Berg (1971) described a Lower Jurassic barrier sand in Wales that also lacks lagoonal sediments. This barrier bar does, however, have washover sediments from the tidal channel environment overlying the beach-upper shoreface sands. This was a subaerially exposed bar interpreted to have been deposited in a relatively open marine environment.

The question arises whether these Viking sands deposited in the open sea were emergent barrier islands or submerged offshore bars.

If the Viking was an exposed barrier sand then the eolian facies was never developed or was deposited and later eroded. The beach-upper shoreface zone contains planar cross-laminations which are produced in the upper flow regime. This structure is typically produced by the oscillating wash swash action on the exposed beach. However, there is the question of whether or not this structure can also be produced in a submerged offshore bar. Relatively little is known of the internal structure of offshore bars, due to their relatively inaccessible sites of deposition. Campbell (1971) interpreted some of the Upper Cretaceous Gallup sand bodies of northwestern New Mexico as offshore bars. The internal structure of these sands consists of wavy parallel beds with planar cross-laminae dipping 20 to 25 degrees, convex downward and becoming tangential to the base of the bed. These sands are commonly churned by burrowing organisms. The cross-laminae in the Viking core are rarely dipping as much as 20 degrees and burrowing is uncommon in this facies. The Viking sands do not seem to compare closely with the interpreted offshore bar sand facies of the Gallup Sandstone as described by Campbell.

It is concluded that the Viking in the Suffield area is a barrier bar complex situated some distance from the shoreline, surrounded by open marine seas, but there is still some question as to whether these barriers were submergent or emergent.

CHAPTER 5

INTERPRETING THE GENESIS OF SANDSTONES USING SPONTANEOUS POTENTIAL CURVES

The 14 cored wells examined, provide an interpretation that the Viking Formation in the Suffield area is a barrier complex. In order that the mapping of the Viking lithofacies could be extended from 14 control points to 250 control points, the Spontaneous Potential (SP) curves, which are available for all the wells in the study area, were studied.

The SP curve of an Induction Electric log is a measure of a spontaneous potential generated across the interface between shale and permeable sandstone or limestone beds (Schlumberger, 1969). This SP curve shows a minimum value opposite thick shale units (shale line), and when permeable beds are encountered the line peaks to the left. In the study area the permeable Viking Sandstone causes the SP to move markedly to the left, and thus is an indirect method of recording sand and shale lithologies.

The magnitude of the SP curve deflection is affected by (1) the ratio between mud resistivity and formation water resistivity. If the hole is filled with a non-conductive mud, the mud does not provide an electrical connection between the SP electrode and the formation. If the resistivity of the mud filtrate and formation water are about equal, the SP deflections will be small and the curve will be featureless (Schlumberger, 1969); (2) hole size. If the diameter is constant, the intensity of the SP current is constant, and the SP baseline will be a straight line; (3) depth of invasion. When a very permeable salt water sand is invaded by a fresh mud filtrate, the mud being lighter than the salt water will float up towards the upper boundary of the sand. The resulting invasion profile is shallow near the lower boundary and deeper near the upper boundary. The SP curve then rounds off at the upper boundary because of the deep invasion. When there are impervious shale breaks the SP will have a serrated profile; (4) bed thickness. The static SP in a sand bed is approximately equalled when the thickness of the sand is more than twice the hole diameter. For smaller thicknesses, the maximum value given by the peak is reduced and the SP log no longer reaches the Static SP value (Krueger, 1968); (5) lithology. A succession of thin sand and shale beds causes a smaller average deflection of the SP log and, therefore, the true lithologic content may be misinterpreted (Krueger, 1968); (6) formation resistivity. When the permeable bed resistivity equals that of the adjacent formation resistivity and the mud resistivity, the SP curve gives a better definition of the boundaries of the permeable beds and the SP deflections are greater than in the case where the permeable bed resistivity is greater than the adjacent formation and mud resistivities (Schlumberger, 1969).

Krueger (1968) studied the relationship of the size distribution of sediments and the energy involved in the depositional process, which is directly related to the environment of deposition. A simplified general sedimentological relationship is that the fine grained sediments (muds) are deposited in deep water environments with low energy, and the coarser grained sediments (sands) are deposited in higher energy shallow water environments. The SP curve of an Induction Electric log can differentiate between lithologies using the factor of grain size to distinguish the permeable sandstones from the impervious shales, and thus indirectly depositional energy and, with less certainty, water depth.

Krueger (1968) has categorized sand to shale transitions into three general types--a, b, c (Fig. 4). Type "a" has a sharp or abrupt sand-shale contact with the slope of the SP approaching infinity; type "b" sand to shale transitions has sand and shale laminations with the percentage of sand increasing towards the center of the interval giving a serrated transition; and type "c" has a gradual slope from shale to sand values without any indication of shale laminations.

Type "a" exemplifies a rapid change from one grain size to another indicating an abrupt environmental change or an erosional or non-depositional surface. Type "b" is a fluctuating transition of sand and shale laminations which

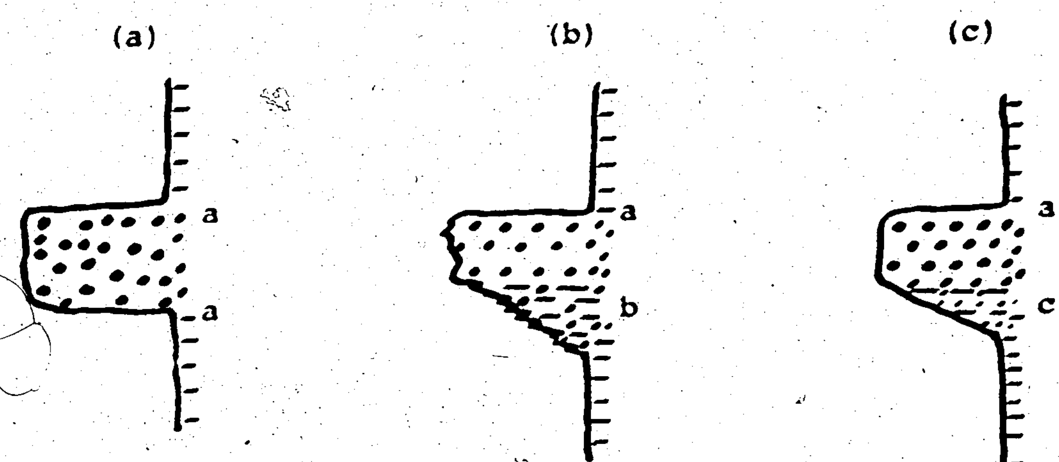


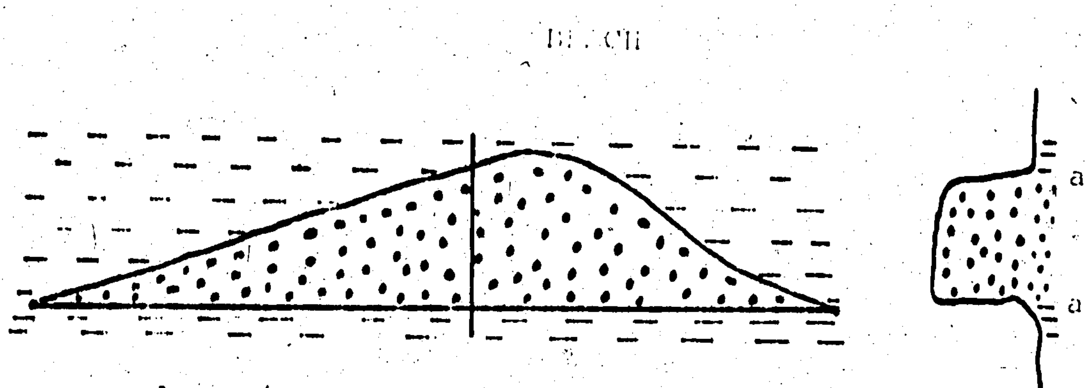
Figure 4: Types of Sand-Shale Transitions Categorized by SP Curve Shape.

may be produced by a gradual oscillating regression or transgression. Type "c" is the least common and suggests a gradual size change (graded bedding), due to steadily decreasing depositional energy.

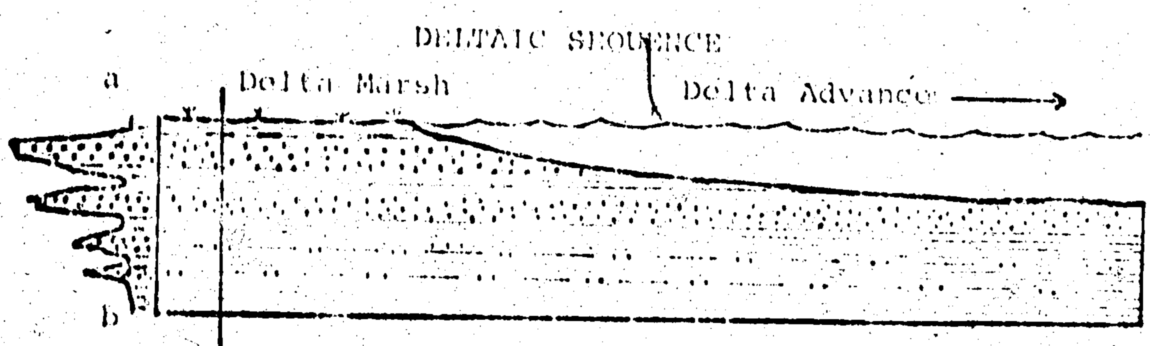
Figures 5 and 6 are graphical examples of four different genetic sand units, and the corresponding shape of the SP curve that one would expect to find with these sand bodies.

Figure 7 shows four SP curves that are found within the study area. A comparison of these four SP curves with those of figures 5 and 6 which display textbook examples of SP shapes for various depositional environments shows that the SP curves from the study area are similar in shape to the example of the barrier bar. This SP shape is a half funnel with an abrupt upper "a" contact and a transitional "b" or "c" lower contact. Krueger (1968) finds the funnel shape of the SP curve to be harmonious with the depositional processes of barrier bar development which reflect the increasing energy distribution of regressive marine processes. Higher energy nearshore sediments are progressively deposited over lower energy offshore sediments. The sedimentation pattern is illustrated by a silty shale unit overlain by a more massive coarser grained sand-silt unit. The upper contact is depicted by an abrupt transition to quieter water sedimentation ("a" type contact).

Wells H. B. Home Highcrest Berry Creek #1 (16-23-22-



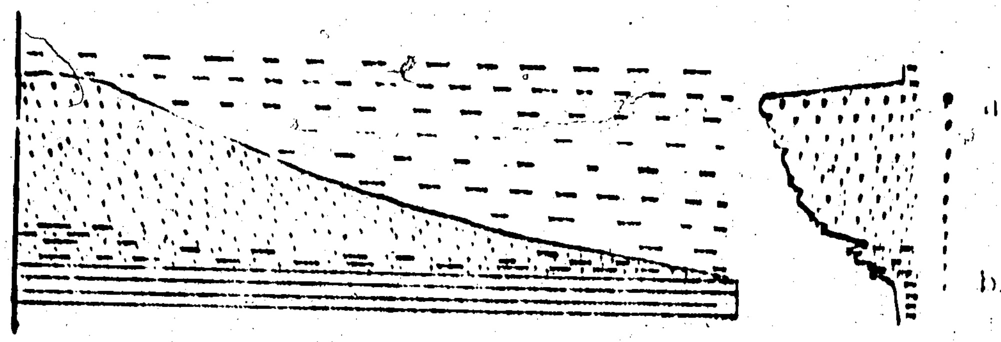
A. a/a contact
Abrupt upper and lower contact. Sands generally are well sorted by wave action.



B. a/b contact
Interbedded sand-shale sequence. The sands are fine grained.

Figure 5: Classic SP Shapes of Depositional Environments.

BARRIER BAR



A. a/c or a/b contact
Grain size increases upward in section. Gradation in grain size is probably related to increasing wave energy with decreasing water depth as the bar is built up.

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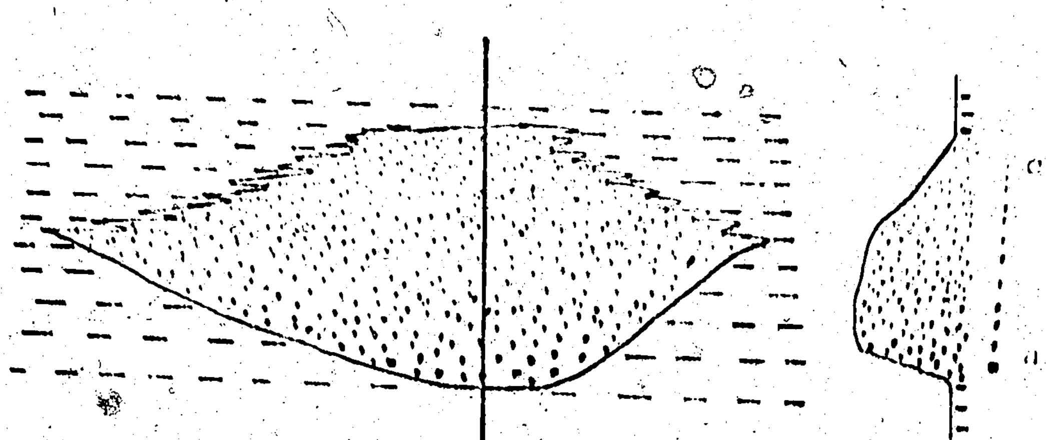

B. c/a contact
Characterized by an abrupt lower contact and gradual upward decrease in grain size.

Figure 6: Classic SP Shapes of Depositional Environments.

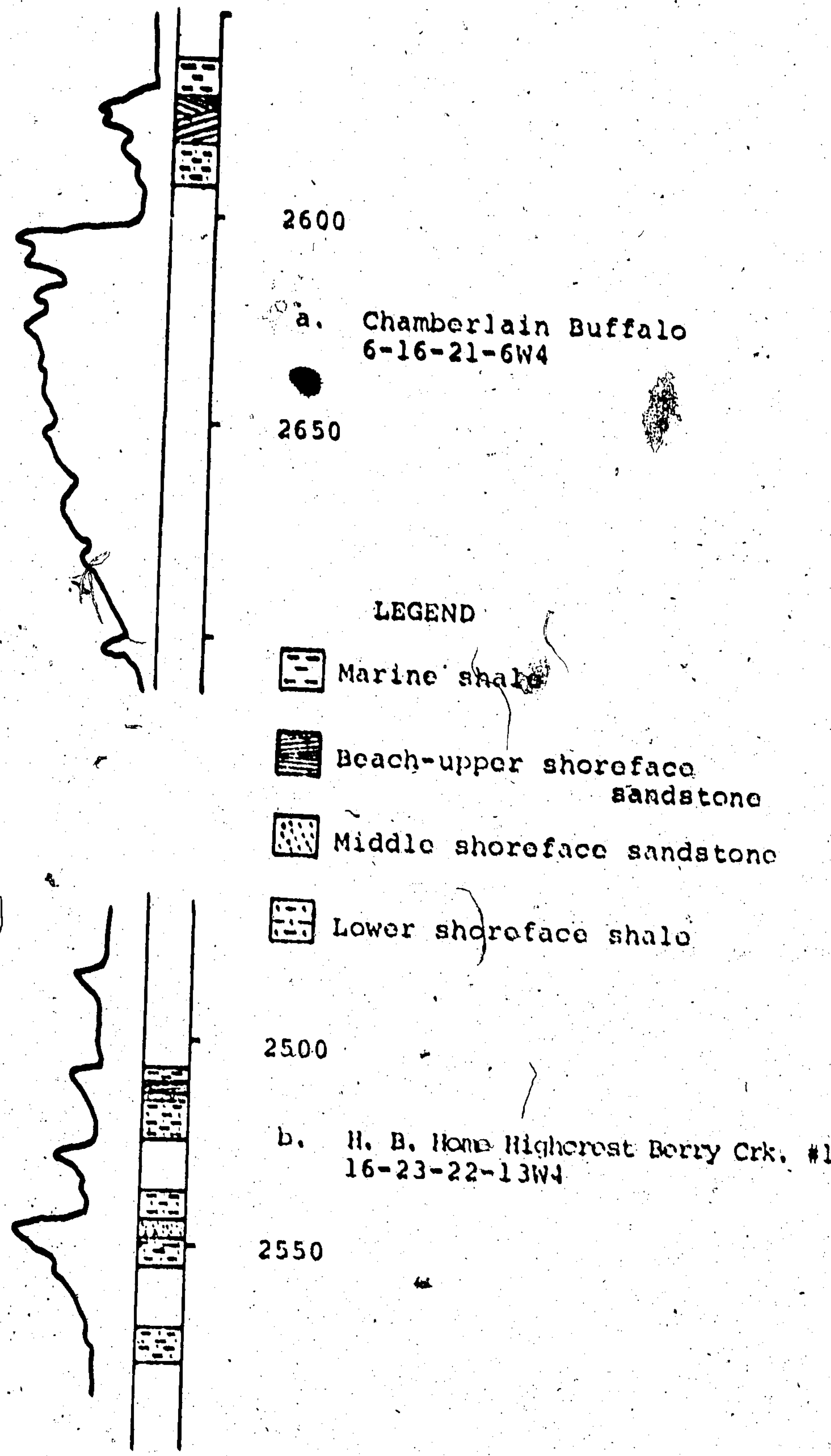

Figure 7: Examples of Viking SP Shapes from the Suffield Area.

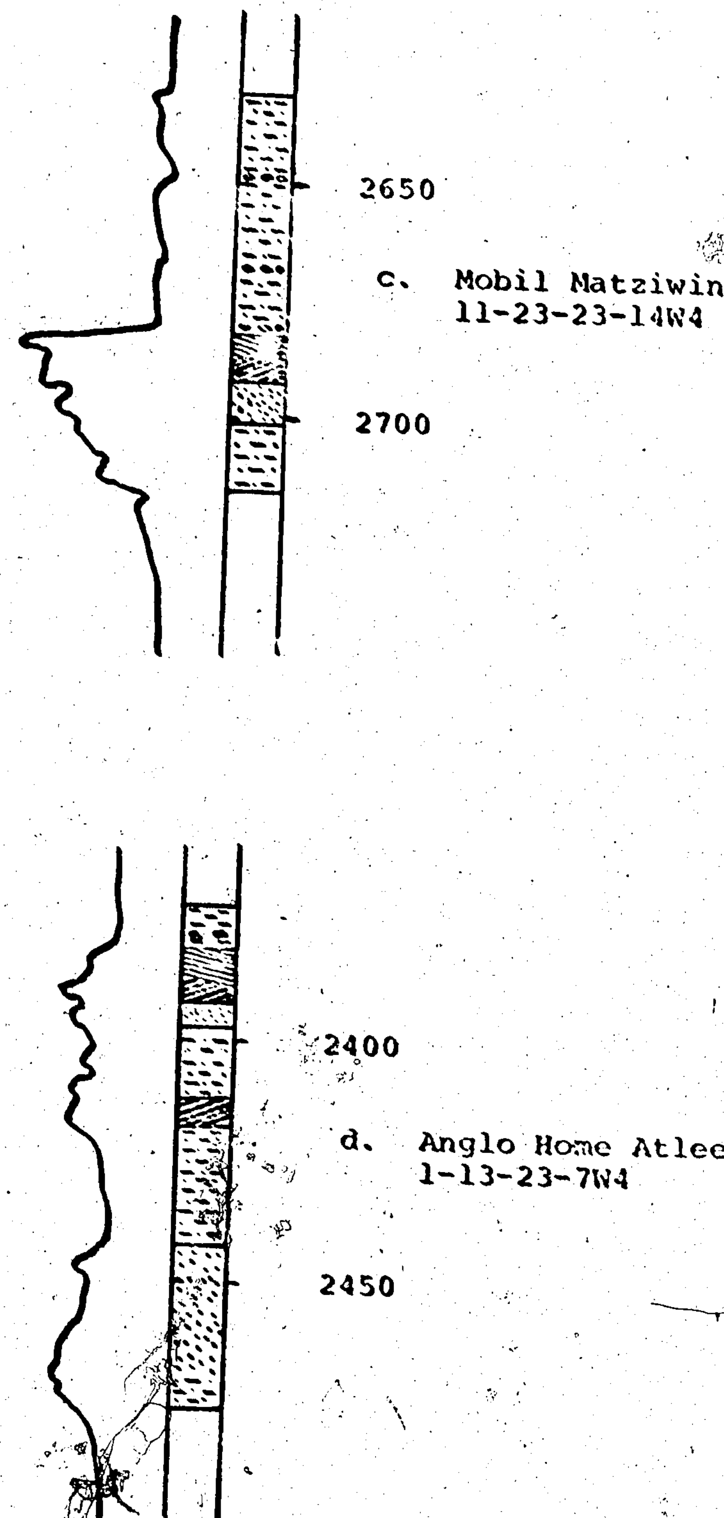

Figure 7 (cont.)

13W4), Chamberlain Buffalo (6-16-21-6W4), Mobil Matziwin (11-23-23-14W4) and Anglo Home Atlee (1-13-23-7W4) shown in figure 7 have core which was examined by the writer. The vertical succession of structures and textures found in these cores, lead to the interpretation that they are the product of barrier bar development. These four wells represent the typical range of SP shapes found within the study areas.

Well and Location

Chamberlain Buffalo (6-16-21-6W4)

The SP log of the Viking Formation of this well is representative of many of the wells in the Suffield area. The SP log shows an upper and a lower sand unit or multiple sand development. The writer examined the core of the thin upper sand only, and found it to be a planar laminated beach sand, with no structureless middle shoreface sand developed. It was found that the thick lower sand had only wireline core with very poor recovery, hence, no core of this sand unit was examined.

The SP curve shows the well developed funnel shape typical of a barrier bar for the two sand units. The upper contacts of both bar sands are the abrupt "a" type, while the lower contacts are the transitional slightly serrated "b" types.

Well and Location

H. B. Home Highcrest Berry Creek #1 (16-23-22-13W4)

This well has an excellent example of an SP log depicting multiple sand development. Four sand units each produce a funnel shape on the SP log suggesting barrier bar development. All four of the sands have abrupt upper "a" type contacts and gradational lower "c" type contacts. The second bar sand from the top was cored, and shows an upper, middle and lower shoreface. The transitions from upper to middle shoreface and middle to lower shoreface cannot be distinguished on the SP log. An examination of the core through the fourth and thickest bar sand reveals that the upper shoreface subfacies is missing, yet the SP log has the classical funnel shape of a barrier bar.

Multiple well separated sand development as found in the Berry Creek #1 well is of local extent only in the study area.

Well and Location

Mobil Matziwin (11-23-23-14W4)

The SP log for the Mobil Matziwin well has the pronounced funnel shape typical of a barrier bar with the abrupt upper "a" type contact and the slightly serrated lower gradational "b" type contact. The changes from upper to middle shoreface and middle to lower shoreface cannot be seen on the SP curve.

Well and Location

Anglo Home Atlee (1-13-23-7W4)

This well has an SP log shape similar to that of many wells in the study area. The shape is not typical of a barrier bar, so it would be expected to represent another depositional environment. However, examination of the core reveals this interval to have lithofacies similar to others interpreted as barrier bars. The SP curve also shows multiple development of two sand units. The lower sand is a thick, structureless, dirty, fine grained sandstone which belongs to the middle shoreface zone. This middle shoreface facies grades into silty, sandy shales above and below. The resulting effect on the SP curve is to produce a blocky shape for the middle shoreface interval. This example shows why it is advisable to do a core study to back up and aid the interpretation of depositional environments from SP curves.

Figure 8 illustrates the SP curves of sandstones in other Cretaceous formations interpreted as barrier bars by various authors.

In summary, the writer feels confident that, in the Suffield area, SP curves can be used to interpret the genesis of the Viking Sandstone if some caution is used. It has been found that in most wells, the SP curve has a funnel shape with abrupt upper "a" type contact and the lower gradational "b" or "c" type contact, expected of a barrier bar, but that occasionally similar sandstone developments do not show this characteristic shape. The SP curve cannot distinguish the subfacies of a barrier bar such as the upper shoreface from the middle shoreface because the only difference between these two subfacies is that the upper shoreface is a

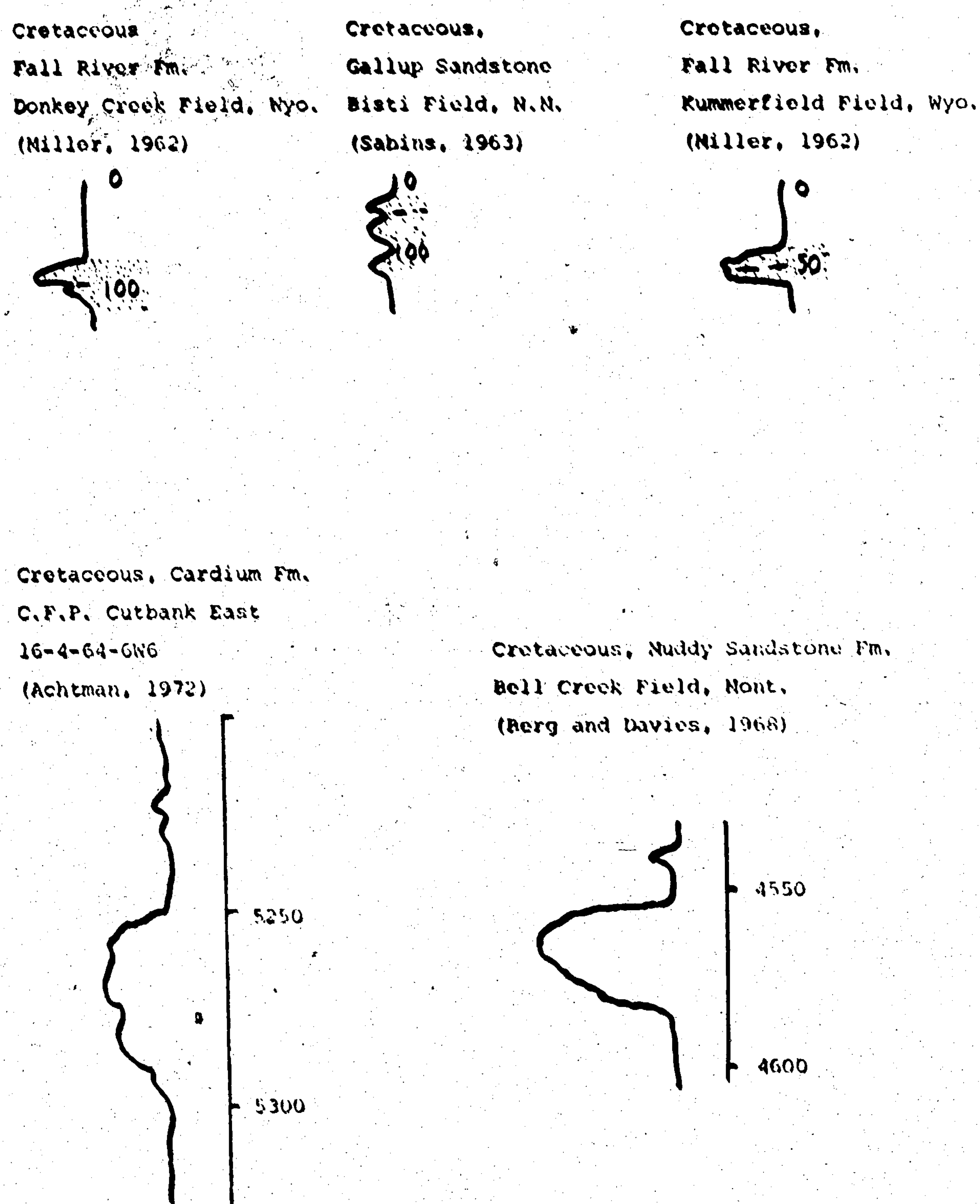

Figure 8: Interpreted Subsurface Examples of Other Cretaceous Barrier Bars.

cross-laminated sand while the middle shoreface is usually a structureless sand. The SP log is not directly a measure of these characteristics, being instead a measure of the permeability of a unit. Ideally, the permeability gradually decreases from a maximum value in the clean upper shoreface sands to a minimum value in the lower shoreface shales with no indication of the subfacies boundaries.

The SP curves indicate that multiple bar development is a common feature in the study area, the Viking Formation usually consisting of two main sand units.

CHAPTER 6

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The microfaunal assemblages were separated from the cores of the following wells stored at the Calgary Core Storage Center of the Energy Resources Conservation Board: Nobil Matziwin 11-23-23-14W4; Anglo Home Atlee 1-13-23-7W4; and Chamberlain H. Buffalo 6-16-21-6W4.

The microfaunal assemblages provide some information on the various subfacies of the Viking, in particular the problem of discriminating the lower shoreface of a barrier bar from the lithologic unit which usually overlies the upper shoreface of the bar. Campbell (1971) in working on the Upper Cretaceous Gallup shoreline had difficulty in distinguishing the offshore siltstone and mudstone facies on the basis of structures and textures from such other mudstone environments as lagoons and bays. Foraminiferal fauna were found to be especially useful in identifying the offshore facies of the Gallup beach shoreline. Details of the drilling depths from which the samples were collected, and the microfaunal assemblage from each sample are given in Appendix B.

The samples with the greatest number of species came from Chamberlain H. Buffalo 6-16-21-6W4 and Anglo Home Atlee 1-13-23-7W4, one foot and four feet, respectively, above the top of the Viking, in the overlying shale unit. The foraminiferal fauna obtained from these shale horizons consist of the following forms.

Trochammina alcanensis Stelck, 1974
* Trochammina umiatensis Tappan, 1957
Trochammina cf. gatesensis Stelck and Wall, 1956
Trochammina sp.
* Verneuilina canadensis canadensis Cushman, 1937
Verneuilina howchina Crespin, 1953
Verneuilinoides borealis Tappan, 1957
Gaudryina sp.
Gaudryina canadensis Cushman, 1943
Gaudryina cf. hectori Nauss, 1947
* Reophax sikanniensis Stelck, 1974
* Reophax tundraensis Chamney, 1969
Reophax minuta Tappan, 1940
* Ammobaculites sp. A (var. long)
* Ammobaculites sp. cf. A humei Nauss, 1947
Saccammina sp.?
* Saccammina alexanderi Loeblich and Tappan, 1950
* Psamminopelta sp. cf. bowsheri Tappan, 1957
Miliammina awunensis Tappan, 1957
Glomospira tortuosa Eicher, 1960
Glomospira sp.
Ammodiscus anthosatus Guliov, 1966
Textularia sp.

Pelosina ?

Haplophragmoides (3 chambered)

Eight of the named species (marked *) are found to be common to both wells.

The samples collected from shale breaks in the upper sand unit in wells Mobil Matziwin 11-23-23-14W4 and Anglo Home Atlee 1-13-23-7W4 have a sparse microfauna as compared to the shale overlying the Upper Viking sand. The assemblage consists of the following forms:

Trochammina gatosensis Stelck and Wall, 1956

Reophax sp. (A trans. to B cf. Crespin)

Reophax cf. eckernex Vieaux, 1941

Reophax (juveniles)

Verneuilinoides borealis Tappan, 1957

Glomospira tortuosa Eicher, 1960

Ammobaculites tyrrelli Nauss, 1947

Saccammina alexanderi Loeblich and Tappan, 1950

Psamminopelta sp.

Sporitoid bodies of unknown local origin and fish fragments are the most abundant elements found in these samples.

Certain of the faunal assemblages found in this area have been reported from other localities. The post-Viking shales from the Suffield area contain a fauna similar to those previously reported in the following units:

1. The basal Lloydminster Shale in the Lloydminster area, Alberta (Bullock, 1950);

2. The Upper Buckinghorse Formation in the Sikanni Chief River area, British Columbia (Stelck, 1974);

3. The Shell Creek Shale in the Big Horn Basin of Wyoming (Eicher, 1962);

4. The Tuktu and Grandstand Formations north of the Brooks Range in Northern Alaska (Bergquist, 1966);

Table 1 shows the correlation of these sections and the Miliammina manitobensis Zone of the Lower Cretaceous, an important subsurface biostratigraphic marker in western Canada, Montana and Wyoming. The M. manitobensis Zone contains a suite of arenaceous foraminifera which usually includes M. manitobensis.

Table 2 lists 20 species found in the wells Chamberlain H. Buffalo 6-16-21-6W4 and Anglo Home Atlee 1-13-23-7W4 from immediately above the Viking Sandstone, which also occur in Alaska, northeastern British Columbia, and the central Plains of Alberta and Wyoming.

Forty species of arenaceous foraminifera occur in the M. manitobensis Zone of the Sikanni Chief River section (Stelck, 1974). The Shell Creek Formation in the Big Horn Basin of Wyoming carries 12 species (Eicher, 1962). Thirty-eight species occur in the Tuktu Formation of northern Alaska, but specimens of 19 of these species were extremely rare (Bergquist, 1966). The writer had access to Bullock's (1950) collections from the Lloydminster Shale, 6 feet and 16 feet above the top of the Viking sand. Thirteen species

Table 1

Correlative Sections of the Upper Albian Substage

	BROOKS RANGE ALASKA	NORTHEAST BRITISH COLUMBIA	CENTRAL PLAINS OF ALBERTA	BIG HORN BASIN WYOMING	
Upper Cretaceous					
Lower Cretaceous			FISH SCALES	MOWRY SHALE	Late Albian
	TUKTU AND GRANDSTAND FORMATIONS (M. MANITOBENSIS ZONE)	SIKANNI FORMATION	LLOYDMINSTER SHALE (M. MANITOBENSIS ZONE)	SHELL CREEK SHALE (M. MANITOBENSIS ZONE)	
	VERNEUILINOIDES BOREALIS ZONE / TOROK FORMATION	BUCKINGHORSE FORMATION	VIKING FORMATION	MUDDY SST.	
	(cont.)	(cont.)	JOLI FOU SHALE	THERMOPOLIS SHALE	

Table 2

COMPARISON OF FORAMINIFERAL SPECIES FROM BRITISH COLUMBIA, ALASKA, AND WYOMING TO THIS STUDY

	Central Plains of Alberta	Brooks Range Alaska	North-East British Columbia	Big Horn Basin Wyoming
Trochammina alcanensis	x		x	
Trochammina umiatensis	x	x	x	x
Trochammina cf. *gatesensis*	x			x
Verneuilina canadensis canadensis	x			x
Verneuilina howchina	x			
Verneuilinoides borealis	x	x	x	
Gaudryina canadensis	x			
Gaudryina cf. *hectori*	x			
Reophax sikanniensis	x		x	
Reophax tundraensis	x	x	x	
Reophax minuta	x	x	x	
Ammobaculites sp. cf. *A humei*	x		x	
Ammobaculites sp. A (var. long)	x			
Saccammina alexanderi	x		x	
Psamminopelta sp. cf. *bowsheri*	x	x	x	
Milliammina awunensis	x	x	x	
Glomospira tortuosa	x		x	
Ammodiscus anthonatus	x			
Textularia sp.	x			
Pelosina	x			

and/or subspecies of foraminifera from the Suffield area were found to be present in Bullock's assemblages.

The M. manitobensis Zone is recognized below the Fish Scale marker and above the Viking Sandstone of the Colorado Group in the subsurface of the Plains of western Canada (Stelck, 1974). The writer's suite of arenaceous microfossils is assigned to the lowermost part of the M. manitobensis Zone considering it in a homotaxial sense of the introductory phase of the fauna. Stelck's (1974) suite of microfossils from the lower part of the M. manitobensis Zone of the Sikanni Chief River section has abundant Miliammina manitobensis, Tritaxia manitobensis and Gravellina chamneyi foraminifera, which do not appear in the writer's suite.

With the advent of the initial phase of the transgressing Mowry Sea over the Suffield area, the Lloydminster Shale was deposited over the underlying Viking sand, in a shallow neritic environment, marking the beginning of the M. manitobensis Zone. The M. manitobensis Zone was also being deposited as the Upper Buckinghorse Shale in northeastern Bitish Columbia and was marked by the dominance of the three species mentioned above. The faunal assemblage points to an offshore, neritic, somewhat turbid cool environment for the Buckinghorse Formation (Stelck, 1974). At the same time in the Suffield area the shallow transgressing sea could not support M. manitobensis, T. manitobensis and Gravellina chamneyi until the transgression had proceeded to a stage equivalent to the already existing environment represented by the Buckinghorse Shale at the beginning of *M. manitobensis* Zone time.

Ammobaculites, the dominant genus of the writer's suite is also dominant in the Sikanni Chief River suites (Stelck, 1974) but does not appear in Eicher's (1962) suite from the Shell Creek Shale. Bergquist (1966) points out that the uppermost part of the *Verneuilinoides borealis* Zone of Alaska coast is also lacking in *Ammobaculites*. It appears that the Shell Creek Formation represents a slightly more saline envrionment than the equivalent beds of the Suffield and Sikanni Chief River areas.

Ammobaculites spp., some of them of extraordinary length, are known from the *M. manitobensis* Zone at the base of the Shaftesbury Shale in northwestern Alberta and at the base of the Labiche Shale immediately above the Pelican Sandstone in northeastern Alberta and immediately above the Viking Sandstone in the subsurface in east-central Alberta (Stelck, 1974). The present writer also found similar *Ammobaculites* extraordinary length immediately above the Viking Sandstone at the base of the Lloydminster Shale in the Suffield area.

Sporitoid bodies are the dominant fossils in the Upper Viking Sandstone, whereas foraminifera occur in only minor numbers. In Mobil Matziwin (11-23-23-14W4) and Anglo Home Atlee (1-13-23-7W4) the shaly units above and below the sandstone unit appear similar both structurally and texturally--i.e., irregular laminations of silt and sand in a bioturbated shale groundmass. Relying upon the vertical succession of structures and textures common to barrier bar sands, the shaly unit occurring below the structureless sandstone unit is the lower shoreface. The problem is to identify the shaly unit overlying the upper shoreface interval. Davies, Ethridge and Berg (1971) concluded that true barrier sands will be flanked on their landward side by lagoonal sediments. The occurrence of abundant sporitoid bodies, a few fish bones and a very limited number of foraminifera in both the lower shoreface zone and this shaly unit above the upper shoreface sandstone suggests these two shaly units to represent the same environment. One would expect a different kind of microfauna to be found in the shallow possibly brackish, protected waters of a lagoon. The upper shaly unit contains a very small amount of organic detritus and lacks coaly beds which might be expected in a lagoonal environment. This unit is therefore concluded to be equivalent the lower shoreface zone of a barrier bar in terms of structures, textures, lithology and the microfauna that it contains. However, because of topographic location, it might be better termed inter-bar zone.

The environmental implication of sporitoid bodies found in the lower shoreface samples of the Viking

Sandstone, is that they are of local origin and have not been transported far from their source.

CHAPTER 7

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A time plane, preferably in the Viking Formation or close stratigraphically either above or below the Viking, is needed as a datum to show the depositional development of the Viking Sandstone.

The base of the "Fish Scale" sandstone, which overlies the Viking Formation by approximately 180 feet in the Suffield area, is an attractive possibility, as this sandstone is considered to be a time-rock unit (Glaister, 1959). The "Fish Scale" sandstone is a concentration of fish scales, bones and teeth. Williams and Burk (1964) suggested that volcanism poisoned the sea and killed the fish, or else this zone of fish remains is a lag deposit representing a period of slow deposition. The base of the "Fish Scales" forms both a paleontological and lithological marker horizon that is taken to be the boundary between the Upper and the Lower Cretaceous in western Canada. The base of the "Fish Scale" sandstone is indicated by a well developed "kick" on the resistivity curve of electric logs, and a high positve reading on the gamma curve of radioactivity logs. Only electric logs were used in this study as they were universally available. The base of the "Fish Scales" is commonly used as a marker horizon in subsurface studies as it is sharply defined on electric logs over a widespread area.

Ammonites of the genus <u>Neogastroplites</u> are found just below the "Fish Scales" sandstone. <u>Neogastroplites</u>, an index fossil indicating an uppermost Lower Cretaceous age, is a more reliable time indicator than the fish scales (Glaister, 1959). The "Fish Scales" sandstone bears a constant stratigraphic relation to the underlying <u>Neogastroplites</u> Zone; therefore, it may be considered a time-rock unit according to Glaister.

However, a few bentonites were found in the Viking Formation while the writer was examining Viking cores. Bentonites were found in 9 of the 14 cored wells examined. Table 3 lists the 9 wells, the depths at which the bentonites occur, and the thickness of each bentonite. Four wells (10-28-24-13W4, 11-23-23-14W4, 14-26-25-12W4 and 1-13-23-7W4) each have one bentonite that is between six inches and one foot thick. This bentonite is very light grey, medium to coarse grained, biotite rich and is much thicker than the other bentonites observed. The other bentonites are about one-half inch to one inch thick, fine grained, light grey and have little or no biotite.

When these bentonites occur in the silty sandy shales of a lower shore facies of the Viking Sandstone, they produce a distinct shale "kick" on an electrical mechanical log; i.e., the resistivity curve becomes less resistive and the conductivity curve has a positive "kick". The SP curve

Table 3

Location and Thickness of Bentonites

Examined in Viking Cores

Well Location	Depth to Bentonite (ft)	Thickness of Bentonite (in)
6 - 15 - 23 - 14W4	2628	1
	2630.5	1
1 - 13 - 23 - 7W4	2373	1
	2441	12
11 - 23 - 23 - 14W4	2647	12
	2665	1
	2680	1
10 - 16 - 24 - 15W4	2684	1
	2698.5	4
10 - 14 - 22 - 6W4	2255	.5
	2266	1
14 - 26 - 25 - 12W4	2715	1
	2785	12
7 - 25 - 26 - 15W4	3101	6-12
6 - 1 - 23 - 12W4	2491	6
10 - 28 - 24 - 13W4	2712	12

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to the shale line when a bentonite is encountered.

A bentonite is a montmorillonite clay rich bed formed from the deco[illegible] volcanic ash; thus a bentonite represents geologically instaneous deposition. If a single bentonite can be correlated throughout an area such as the Suffield area, an ideal time horizon is defined.

Roessingh (1959) found bentonites to be common in his area of study of the Viking Formation. He attempted correlation of the bentonites in the well Parkland 4-12-15-27W4 and some of the Grassy Island Lake wells in Township 32, Range 7W4. Roessingh describes these bentonites as occurring in approximately the same stratigraphic position relative to the top of the Viking, and concludes that the occurrence of bentonites in the same stratigraphic position contradicts the concept of regressive deposition, and favours the idea of the Viking being a time-stratigraphic unit. The correlation, as put forward by Roessinah, is rather vague in that it is hung on some bentonites occurring at "approximately the same stratigraphic level", in a few widely separated wells.

Jones (1961) did a detailed correlation of bentonitic beds in the Viking Formation in Saskatchewan and found the Viking to have definite, if only slightly, diachronous tendencies. In well Husky Phillips Prolate 11-28-23-25W4, a one inch bentonitic shale immediately overlies the Viking Formation, and in well Imperial Marengo 11-21-29-27W4, a correlated one-half inch bentonite bed occurs two feet above the Viking Formation. This difference of two feet of shale may not represent a great time lag, but it occurs in two wells 38 miles apart in a north-northwest direction, approaching parallelism with the major strand-line direction. Jones concluded that at right angles to the shifting strand-line one would expect a greater diachronism.

The possibility of correlating the distinct thick, coarse grained, biotite-rich bentonite throughout the Suffield study area depends upon the distinctive "kicks" it produces on the resistivity and conductivity curves.

Similar "kicks" were searched for in cored intervals of wells which the writer had not examined previously. It was hoped that such "kicks" would be produced by bentonites. Table 4 lists seven wells in which bentonites were expected from electric log characteristics, and in which core was examined for presence of bentonite. A thick, medium to coarse grained biotite-rich bentonite was found at the indicated depth of the resistivity "kicks" in the wells except for those with lost core or very poor core recovery; thus these "kicks" indicate the presence of a substantial bentonite.

Cuttings were examined in wells without core of the intervals where the resistivity "kicks" occur. In most cases no bentonite cuttings were found. Occasionally a very few cuttings were found, but these would range up to 100 feet above or below the appropriate "kick" where the bentonite was expected, and may have come from thin bentonites not seen on the electric log. Judging from the behavior of the bentonite in water in the laboratory, it is believed they are generally not lithified enough to withstand

Table 4

Location of Bentonites Determined by

Electrical Log Characteristics

Well Location	Depth of Expected Bentonite (ft) From E-Log	Depth of Bentonite in core (ft)	Comments
14 - 23 - 26 - 14W4	2986	2986	1" thick, coarse, biotite rich
10 - 7 - 26 - 14W4	3037	3037.5	6" thick, coarse, biotite rich
8 - 10 - 25 - 14W4	2853	----	very poor core recovery from 2849'-2857'
11 - 17 - 24 - 13W4	2678	----	very poor core recovery from 2663'-2685'
	2704	2704	a 3", fine grained bentonite
7 - 20 - 26 - 13W4	2964	----	lost core 2960'-2[illegible]5'
11 - 07 - 26 - 13W4	----	2931	a 1" bentonite
	2935	2933	medium-grained, biotite rich, 9" thick
6 - 29 - 25 - 11W4	2772	2772	12", coarse biotite rich

the action of the drill bit and the disaggregation effect of the drilling mud.

Figure 9 shows five wells with multiple bentonites and their stratigraphic relationship. The datum line is the thick, coarse grained, biotite-rich bentonite which gives a characteristic resistivity "kick". Well 11-23-23-14W4 has the thick bentonite with two thin, underlying bentonites 16 feet and 31 feet below it. Well 10-16-24-15W4 has a thin sand zone at a position 16 feet above the upper of the two corresponding thin bentonites, at the stratigraphic level where the thick bentonite is expected. A volcanic ash would be expected to be reworked and removed if deposited in a high energy environment suitable to sand deposition.

In the eastern half of the study area the thick bentonite datum is found in wells 14-26-25-12W4 and 1-13-23-7W4, and is inferred to be present in well 10-14-22-6W4 from the electric log. There was no core recovery in this well over the interval where the thick bentonite is expected. Well 10-14-22-6W4 has two thin bentonites overlying the assumed thick bentonite by 60 feet and 68 feet. Wells 14-26-25-12W4 and 1-13-23-7W4 have one thin bentonite 68 feet above the thick bentonite. These thin bentonites are above the Viking Formation in the overlying marine shales. The correlation of these upper bentonites into the western part of the study area could not be made as they would be located well up in the overlying marine shale where no core exists.

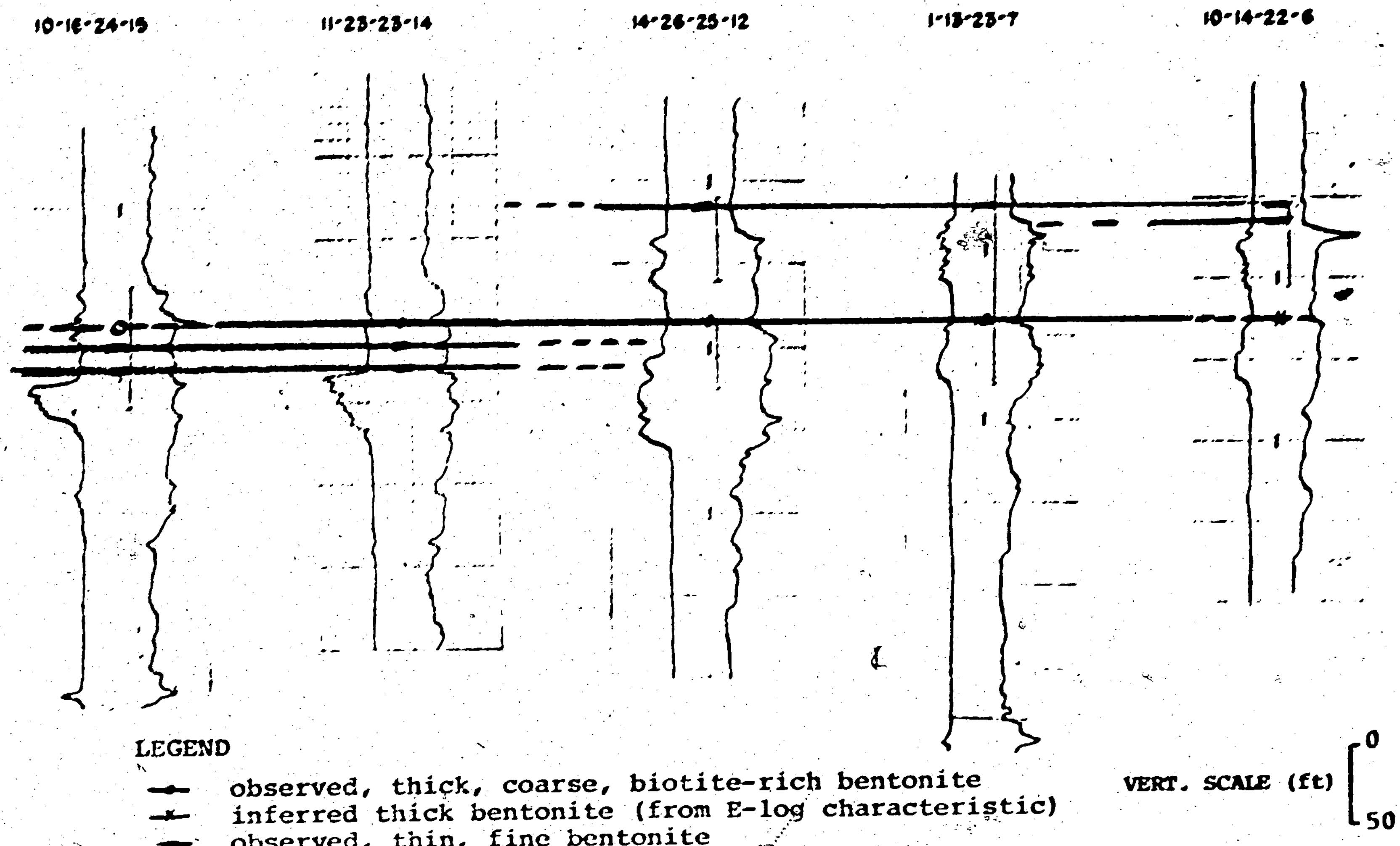


Figure 9: St[illegible]hic relations of observed and inferred bentonites.

The [illegible] of the two thin bentonites in wells 10-16-24-15W4 and 11-23-23-14W4 into the eastern part of the study area cannot be made as these bentonites are absent there. In the eastern wells, a massive organically reworked sandstone occupies positions 16 feet and 31 feet below the thick bentonite. The expected two thin bentonites were either winnowed away or were reworked into the sandstone by burrowing organisms.

The use of the thick bentonite as a time horizon throughout the study area depends upon how widely the resistivity "kicks" may be correlated from the control points where the thick bentonite is found in core. A good time horizon is essential in the construction of cross-sections that will illustrate the depositional development of the Viking Sandstone in time.

Eight cross-sections (figures 10-17, in the pocket) have been constructed using the thick bentonite with its characteristic "kicks" as a datum. These cross-sections show that positive correlation of the bentonite is achievable on the basis of its E-log characteristic.

The bentonite datum, representing geologically instantaneous deposition, is an essentially horizontal stratigraphic time datum reflecting the depositional surface, and is shown as a horizontal datum on the cross-sections. The base of the "Fish Scale" Sandstone, which overlies the bentonite datum, is not a horizontal line on these cross-sections and therefore is not a strict time marker if constant depositional rates are assumed across the study area. The four east-west cross-sections, A-A', B-B' C-C' and D-D', located on the base map (Fig. 18) are oriented approximately perpendicular to the north-northwest trending strand line (Jones, 1961), and should show the greatest diachronism of the base of the "Fish Scale" if the sandstone was being deposited by a regressing sea. The "Fish Scales" at the eastern limit of the study area is situated at a stratigraphic level about one hundred feet above its position at the western edge of the area, according to the bentonite datum.

Figure 19 is an isopach map of the interval between the bentonite datum and the base of the "Fish Scale" Sandstone. This map has 90 control points that have definite resistivity "kicks" representing the bentonite datum. The sediment wedge thickens from 160 feet in the west to 272 feet in the east. The isopachous lines have a north-northwest trend, and are regularly spaced in the west but become slightly irregular in the central and eastern part of the study area. The bentonite, which reflects the paleotopography, was deposited under an isopach thin of 15 foot magnitude in the north central regions. Due south of this thin is an isopach thick of the same magnitude. The irregularities of the isopachous lines which show a relief of about ±15 feet, probably represent the paleotopography at the time of

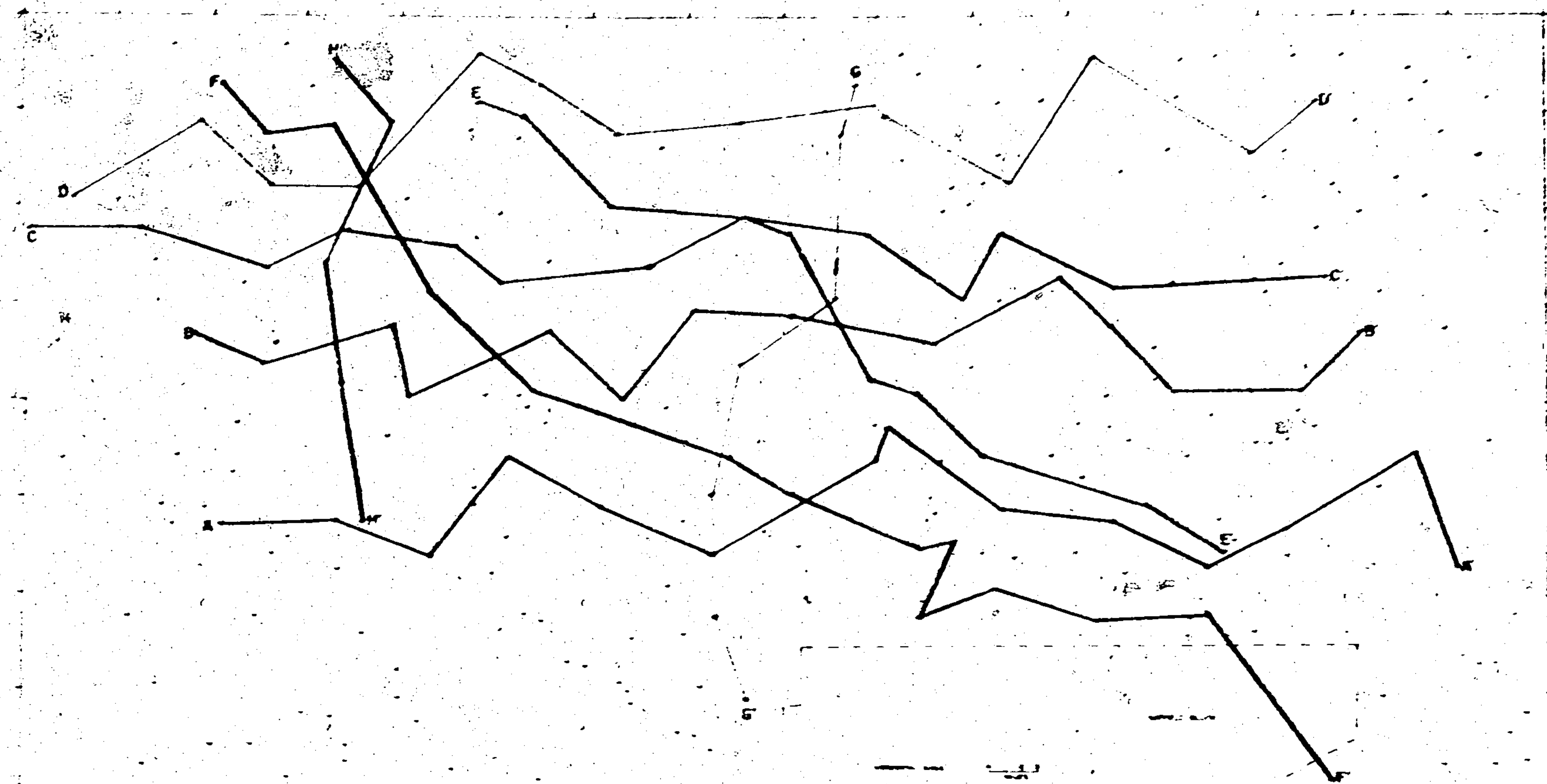


Figure 18: Base Map

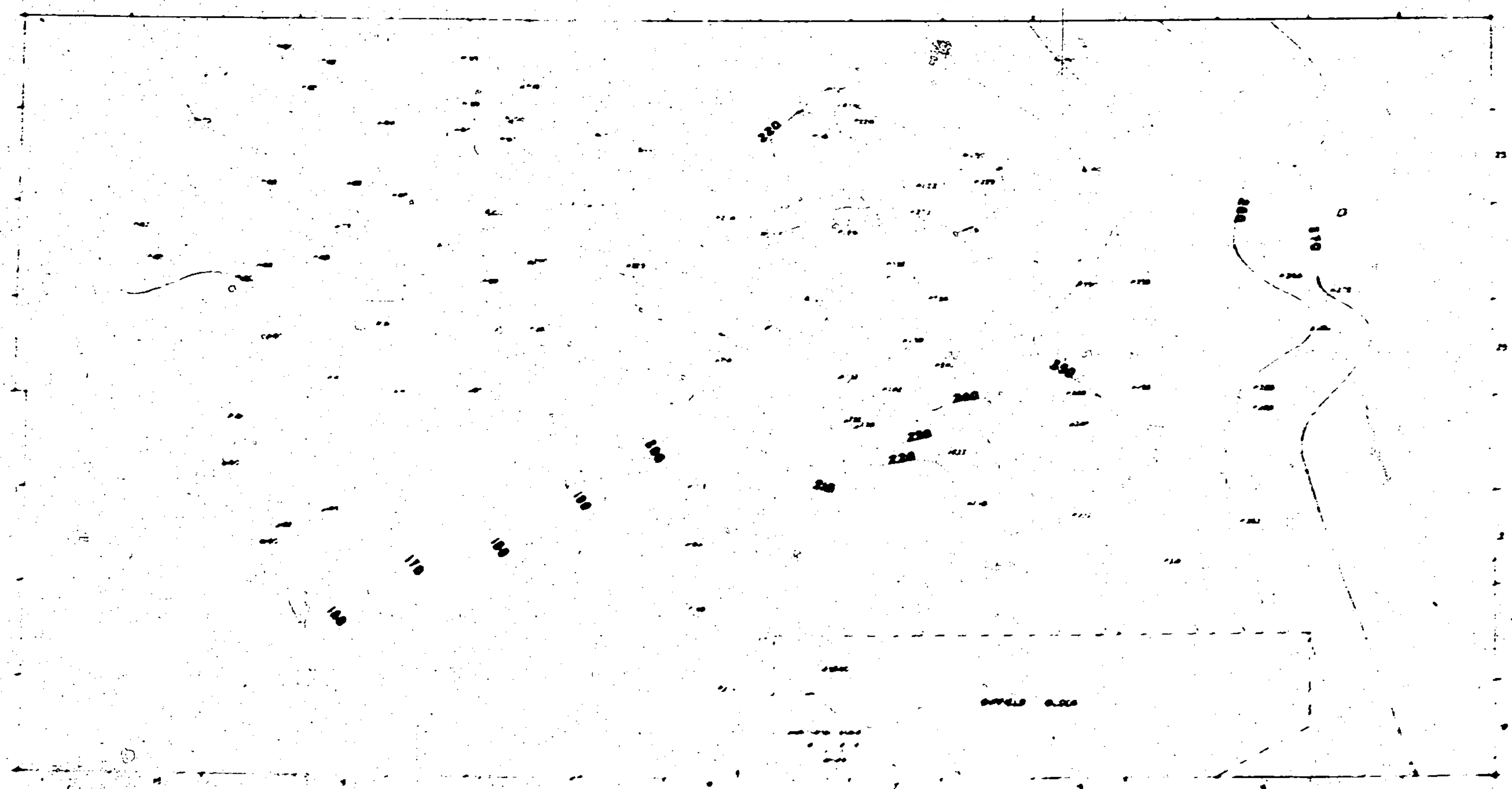


Figure 19: Isopach Map of the Interval from the Base of the "Fish Scales" to the Bentonite Datum.

bentonite deposition, assuming the base of the "Fish Scales" is a horizontal plane.

The divergence of the "Fish Scales" and the bentonite amounts to a thickness difference of 110 feet, suggesting diachronety of the "Fish Scales" rising to the east. However, the Upper Viking Sand increases in thickness from about 20 feet in the west to 115 feet in the east. The deposition of this sand represents a minor time interval as compared to the time represented by the overlying Lloydminster Shale which is only about 50 feet thicker in the east. The possible occurrence of diastems in the shale in the west and/or greater shale deposition in the east towards the center of the basin, makes it difficult at the moment ot evaluate this seeming diachronety of the base of the "Fish Scales".

Figure 19 contains some areas devoid of control points where the bentonite datum cannot be traced with certainty. One of these areas is in the eastern extremity of the study area. The bentonite datum here is found below the Viking Sandstone in the lower Viking shale. There appears to be little if any difference between absolute resistivities of a shale and a bentonite, so the two lithologies cannot be differentiated on the basis of mechanical electrical logs.

The south central part of the study area is missing the bentonite datum. It should be located in the upper shoreface or middle shoreface sand facies of the lower Viking sandstone unit.

The upper shoreface-beach zone and the middle shoreface zone deposited sands in relatively high energy environments. The middle shoreface is also a zone of intense organic burrowing. It is likely that a volcanic ash falling in the above environments would be reworked by either the burrowing organisms of the middle shoreface or the waves and currents of the upper shoreface-beach zone. The Suffield Block is in this area and contributes to the lack of information, as it is a military base with no wells and consequently no subsurface data.

The bentonite datum is lost in the western extremity of the study area also. The datum level here is above the Viking Formation in the overlying Lloydminster Shale. The bentonite cannot be located on E-logs in the Lloydminster Shale because of the similar responses.

The bentonite datum is well developed along the northern edge of the study area and it should be traceable north of the study area. The writer looked at several randomly selected well logs between townships 27 and 31 and was able to locate the bentonite datum in all of them.

Geochronology

A few bentonite samples were collected for the purpose of potassium-argon age determinations in order to obtain a better absolute age for the Viking Formation. Mineral separations were made from four bentonite samples for dating.

The thick, course, biotite-rich bentonite was sampled at Mobil Matziwin (11-23-23-14W4) at a depth of 2647 feet and at Anglo Home Atlee (1-13-23-7W4)at 2444 feet. Two other bentonite samples were compounded by mixing small samples of thin bentonites found within the Viking Formation from the following well locations and depths:

Well Location	Bentonite Depth (ft.)
14-23-26-14W4	2986
10-7-26-14W4	3037.5
6-29-25-11W4	2772
11-17-24-13W4	2704
1-13-23-7W4	2373

These thin bentonite samples were combined in order that there would be a sufficient quantity of material to do age determinations.

The +230 U.S. Standard Sieve Mesh fraction of the bentonites was used for the potassium-argon age determination. The biotite from this fraction was separated using a Frantz Magnetic Separator. The non-magnetic fraction was then separated into potassium feldspar (sanidine) and plagioclose by using a heavy liquid. A potassium-argon age as determined by H. Baadsgaard (University of Alberta), on the sanidine from one of the compound samples is 103.5±2 m.y.

Stansberry (1957) collected bentonite and glauconite samples from the Imperial 6-IIV (6-11-48-21W4) core from depths 3300.5 feet to 3305.4 feet and 3308.9 feet to 3309.1 feet in the Viking Formation of the Joarcam field. The potassium-argon ages that he received were 45 my for the bentonite and 63 my for the glauconite. Stansberry realized that these physical ages were distinctly low compared to the stratigraphic position and correlation of the Viking

Formation based on paleontological evidence. Reasons given for the anomalously young age were potassium adsorption and argon leakage.

[illegible]

[illegible]

It has been shown from core examination and study of the SP curves, that the Viking Sandstone in the Suffield area was deposited as barrier type sand bodies. The deposition of this Viking barrier complex will now be discussed with the aid of eight cross-sections, two isopach maps and a fence diagram.

Cross-Sections

The eight cross-sections, A to H, (figures 10 to 17 in pocket) were constructed to show the vertical position of the Viking sand in relation to the bentonite datum, so that development of this barrier bar complex could be visualized throughout the study area. The locations of these cross-sections are shown on the base map (Figure 18). The four east-west cross-sections (A,B,C,D) are oriented nearly at right angles to the northwest trending strand line.

Cross-sections A and D will be discussed to show how Viking deposition proceeded, beginning with the Lower Viking Sand and continuing to the stratigraphically higher Upper Viking Sand.

Cross-section A-A' is the most southerly east-west section, situated along township 21. The first sand body to appear is found in wells 11-18-22-11W4, 11-31-21-10W4 and 11-17-21-9W4 as a thin local, isolated bar sand. Laterally this sand body grades into shale and is also overlain by shale.

The next clean sand unit to develop is encountered in well 10-29-21-13W4, where the SP curve forms the diagnostic funnel shape of a barrier bar. This sand marks the beginning of what will be called the "Lower Viking Sand" situated beneath the bentonite datum. This sand, which is 45 feet thick at 10-29-21-13W4, quickly pinches out to the west or backshore side before it reaches well 6-30-21-14W4, but on the foreshore or eastern side the beach-upper shoreface and middle shoreface sand is laterally equivalent to the lower shoreface shales of well 7-17-21-12W4.

This Lower Viking sand bar shifted slowly and intermittently eastward to well 7-17-21-12W4 where the bentonite datum is situated immediately above the beach-upper shoreface sands. Intermittent rather than steady shift is suggested by the double sand development above the main sand in well 10-29-21-13W4. These sandy units when traced north into wells 10-25-23-13W4 and 10-28-24-13W4 of cross-sections B-B' and C-C', respectively, become one 25 foot thick bar which overlies the main sand unit. Local well separated multiple bar development occurs between townships 21 and 24 near range 13 in the Suffield area.

The Lower Viking Sand when traced eastward from 7-17-21-12W4 thickens from 55 feet to a 70 foot well-developed sand at 7-32-21-6W4. The bentonite datum is located a few feet above the Lower Viking Sand unit throughout the area, hence the top of the sand body is essentially contemporaneous in age from well 7-17-21-12W4 to well 7-32-21-6W4. This suggests that the bar sands in this region prograded eastward very quickly. Eastward from well 10-28-21-5W4 the Lower Viking Sand begins to pinch out, and disappears beyond well 10-9-21-4W4 into lower shoreface shales, indicating some limiting factor to eastward migration, possibly increase in slope, sudden increase in subsidence, or loss of sand supply.

Cross-section D-D' extends along the northern limit of the study area in townships 25 and 26. At well 6-36-25-15W4 the barrier bar of the Lower Viking Sand is about 50 feet thick. The bentonite datum overlies the bar by 20 feet, with intervening lower shoreface sediments. The top of the Lower Viking rises stratigraphically eastward to well 10-9-26-11W4 where the sand has thickened to 75 feet and the bentonite datum is only 5 feet above the sand. East of well 10-29-25-10W4 the Lower Viking Sand again shales out into sandy, silty shales of the lower shoreface zone. Beyond well 10-20-26-5W4 the lower shoreface shales grade into offshore normal marine shales.

Late stage progradation of the Lower Viking Sand body from west to east is shown by the rising top. By the time of deposition of the bentonite datum, Lower Viking bar development had ceased and a minor marine transgression had already deposited a few feet of shale. This shale separates the Lower Viking from the Upper Viking sediments.

In cross-section A-A' the first barrier type sand to be encountered above the bentonite datum is at well 10-28-21-5W4. The development of the Upper Viking Sand begins here a few feet above the bentonite datum and reaches about 25 feet in thickness. West of this well there are some thin bar or shoal sands about 5 feet thick that occur anywhere from this lowest stratigraphic level up to about 50 feet above the bentonite datum. These bar sands most likely represent local bar development.

The 25 foot thick sand at well 10-28-21-5W4 progrades eastward, thickening to 40 feet of middle to upper shoreface sand at well 10-15-22-2W4, separated from the bentonite datum below by 35 feet of lower shoreface shales. The top of the sandstone has an abrupt "a" type contact with the overlying Lloydminster Shale. To the southeast at well 11-7-21-[illegible], the SP curve shows no sandstone at all in what appears to have been an embayment into the barrier bar, as shown by the isopach map (Figure 22).

In cross-section D-D' the first sand unit of the Upper Viking Sand to be encountered above the bentonite datum occurs at well 11-9-25-6W4, just a couple feet above the bentonite. This is a local bar sand about 5 feet thick which grades laterally into shales within a mile or two.

The next locus of sand deposition seems to have been a little farther to the west at well 7-1-26-8W4. Sandstone development here is several feet above the bentonite datum. The sand in this well consists of two distinct units about 10 to 20 feet thick and well separated. This is a characteristic of the Upper Viking Sand in the north-central part of the study area (cf. fence diagram Figure 20). As in cross-section A-A', there are several bar sands west of the initial sand development that are stratigraphically higher in the section and developed later.

These thin sand bars most likely represent local bar development while the main progradation of the Upper Viking sand is continuing to the east.

The sands at well 7-1-26-8W4 can be traced eastward to well 10-3-26-3W4 where they coalesce to form a thick barrier of continuous sand deposition depicted by the classic funnel shape of the SP curve. Here the barrier is 80 feet thick from the abrupt upper "a" type contact to the lower gradational "b" type contact with underlying shale where the bentonite datum is situated.

Cross-sections E to H show a different view of Viking deposition as they are oriented close to the north by northwest strand line direction.

Cross-section F-F' has a northwest-southeast orientation. This cross-section lies along the axis of the Lower Viking bar sand to show its maximum development. The thickest sand occurs in the region between wells 5-5-21-6W4 and 6-6-22-8W4 with a maximum of 125 feet. From this locus of deposition the bar sand thins gradually to a thickness of 50 feet at well 10-7-26-14W4 in the northwest and 70 feet at well 6-2-19-3W4 in the southeast. The sand is easy to correlate along this line of section as its stratigraphic position is essentially constant. It is also interesting to note the initial sand development occurring in well 6-6-22-8W4. This initial bar sand is about 10 feet thick and shales out to the east and west. In cross-section A-A', as previously mentioned, an initial development of sand occurred in wells 11-17-21-9W4 and 11-31-21-10W4. These thin bar sands developed a northwest trend which is the same as that of the later Lower Viking Sand. These earliest bar sands also occur very close to the area of maximum thickness attained by the Lower Viking Sand as shown in cross-section F-F' and the isopach map of the Lower Viking Sand (Figure 21).

The bentonite datum is difficult to correlate southeasterly because the diagnostic resistivity "kick" is not present. The bentonite datum position was interpreted to be in the upper part of the Lower Viking Sand unit where the ash itself would not have survived. [illegible] of the exact position, the datum is represented by a dashed line in the southeast.

The overlying Upper Viking Sand is a 10 foot thick unit with a subdued SP expression compared to that of the Lower Viking Sand. It is found 10 to 20 feet above the bentonite datum and is a relatively minor feature on this cross-section.

Cross-section H-H' is a north - south oriented section along range 13. The Lower Viking Sand is first developed in the south at well 27-11-21-13W4. The bentonite datum here overlies the top of the sand unit by 40 feet. The sand is seen to gradually prograde northward to well 7-20-26-13W4 where the bentonite datum overlies the Lower Viking Sand by only 10 feet. The bentonite datum is well defined in this cross-section.

The Upper Viking Sand is found only in the northern two wells. It is 20 feet thick here and overlies the bentonite datum by 20 feet.

Fence Diagram

A fence diagram of the Viking Sandstone has been constructed (Figure 20) to give a pictorial representation of Viking deposition. The dotted symbol is representative of the upper shoreface and middle shoreface sandstones and the dash symbol is for the lower shoreface shales.

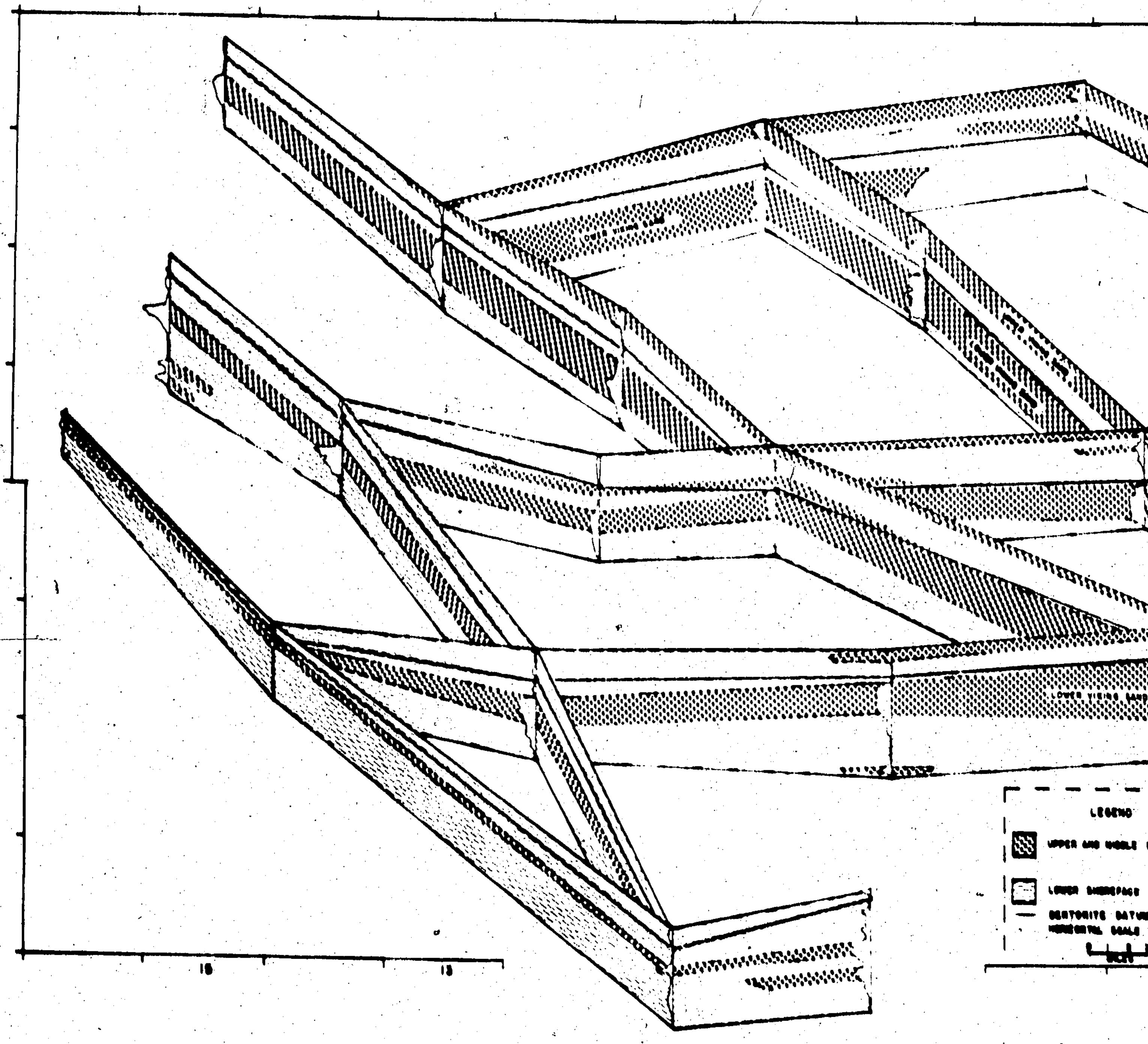
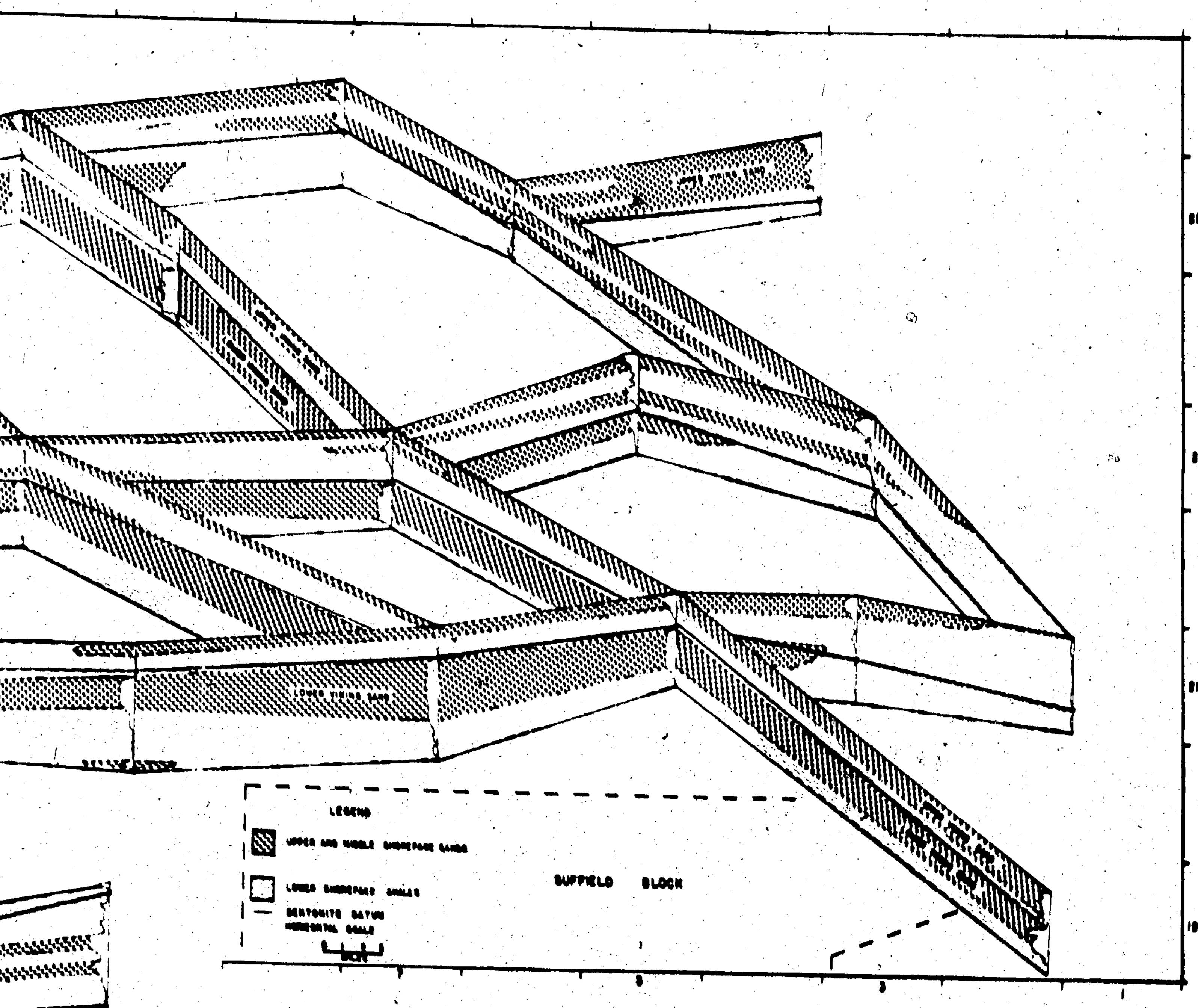


Figure 20: Fence Diagram of the Upper and Lower Viking Sands



[redacted]

Consequently [illegible] the upper to middle shoreface and the lower shoreface shales had to be made. This is difficult to do on the E-log, but the writer placed the contact at a significant SP deflection about five to ten millivolts above the shale line. The bentonite datum in each of the wells marks the geographic location of the wells.

The fence diagram shows the Lower Viking sand to be thickest in the central region, to gradually thin westward, and to quickly shale out toward the east. The Upper Viking sand is thickest in the northeast part of the study area. Toward the west the sand thins and splits to become a multiple sand, and toward the south it progressively thins.

Some generalization of the cross-section detail has been necessary in construction of the fence diagram.

Isopach Maps

Individual isopach maps of the Lower and Upper Viking Sandstones were drawn to better illustrate thickness variations and shape of the respective barrier sand bodies which were formed during the deposition of the Viking Sandstone in the Suffield area.

The sandstone thicknesses which were used for the two maps were obtained by taking the total interval between an arbitrarily judged significant departure of the SP curve from the "shale line" above and below the whole sand unit.

Figure 20: Fence Diagram of the Upper and Lower Viking Sands.

Consequently, a division [illegible] the upper to middle shoreface and the lower shoreface shales had to be made. This is difficult to do on the E-log, but the writer placed the contact at a significant SP deflection about five to ten millivolts above the shale line. The bentonite datum in each of the wells marks the geographic location of the wells.

The fence diagram shows the Lower Viking sand to be thickest in the central region, to gradually thin westward, and to quickly shale out toward the east. The Upper Viking sand is thickest in the northeast part of the study area. Toward the west the sand thins and splits to become a multiple sand, and toward the south it progressively thins.

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The Lower Viking isopach [illegible] (Figure [illegible]) shows this barrier bar sand to have a northwest - southeast orientation. The thickness maximum is located in the center of the map area just north of the Suffield Block. The sand is 125 feet thick here and thins to 50 feet along strike in the northwest corner. The sand thins quickly to zero in the northeast corner perpendicular to the strike, and thins to about 30 feet within the map area in the extreme southwest.

The Cessford Field has three small gas pools located in the Lower Viking Sand. These pools are trapped by porosity pinchouts on minor structural highs.

The isopach map of the Upper Viking Sand (Figure 22) shows the maximum thickness of 115 feet in the northeast corner of the study area. The 70 foot contour line outlines a north by northwest oriented linear "thick" of a barrier bar compared to the thinner and more uniform distribution of sand throughout the rest of the map area. However, all the contour lines have a definite general northwest orientation and show the barrier sands to be gradually decreasing in thickness westward from 70 feet to zero.

The three gas fields previously mentioned in the introduction--the Atlee-Buffalo Field, the Bindloss Field and the Cessford Field produce from this Upper Viking Sand. Bindloss and Atlee-Buffalo produce entirely from the Upper Viking while Cessford produces from both sands. The Atlee-Buffalo and Bindloss Fields which are combination

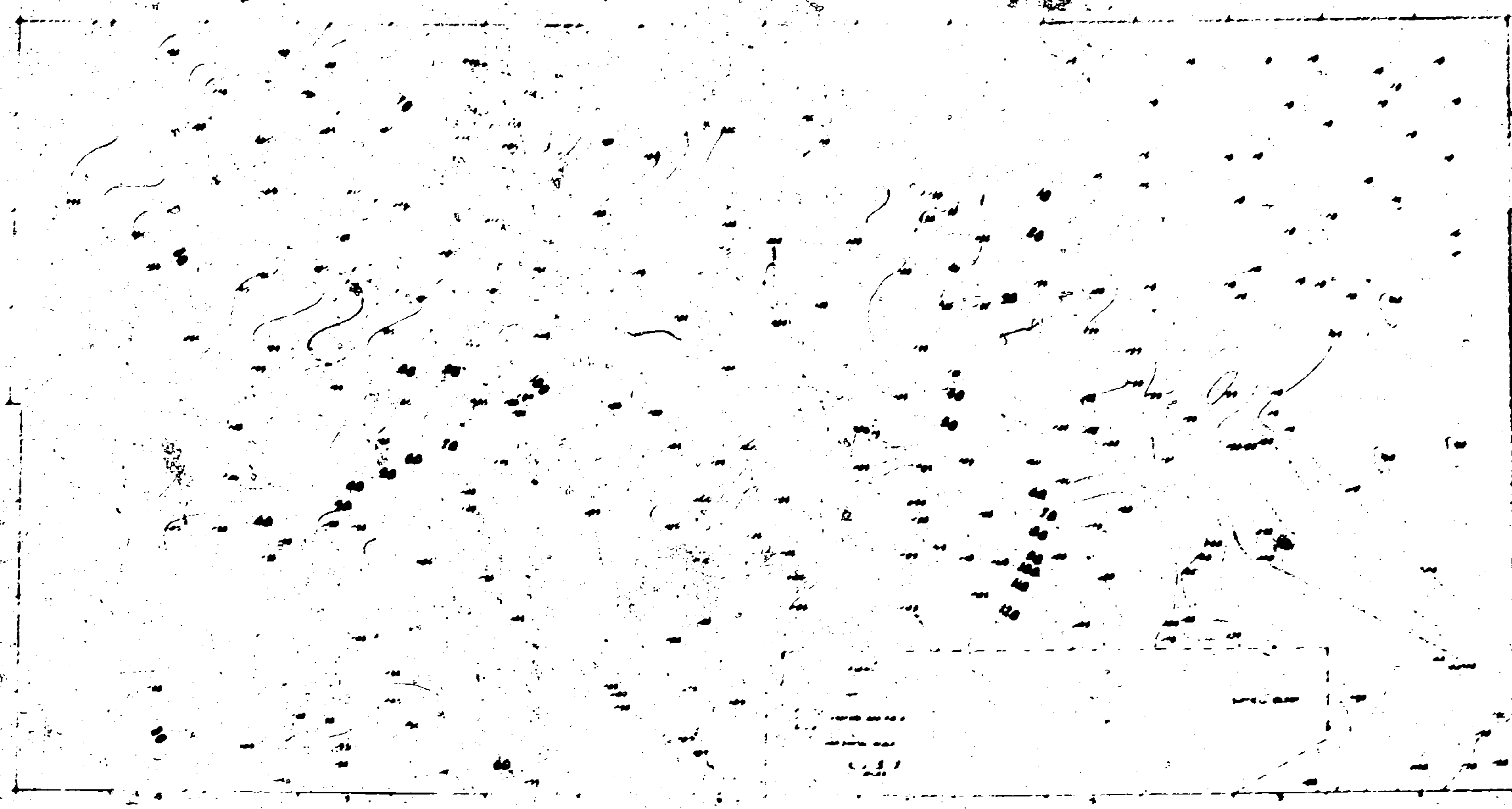

Figure 21: Isopach Map of the Lower Viking Sand.

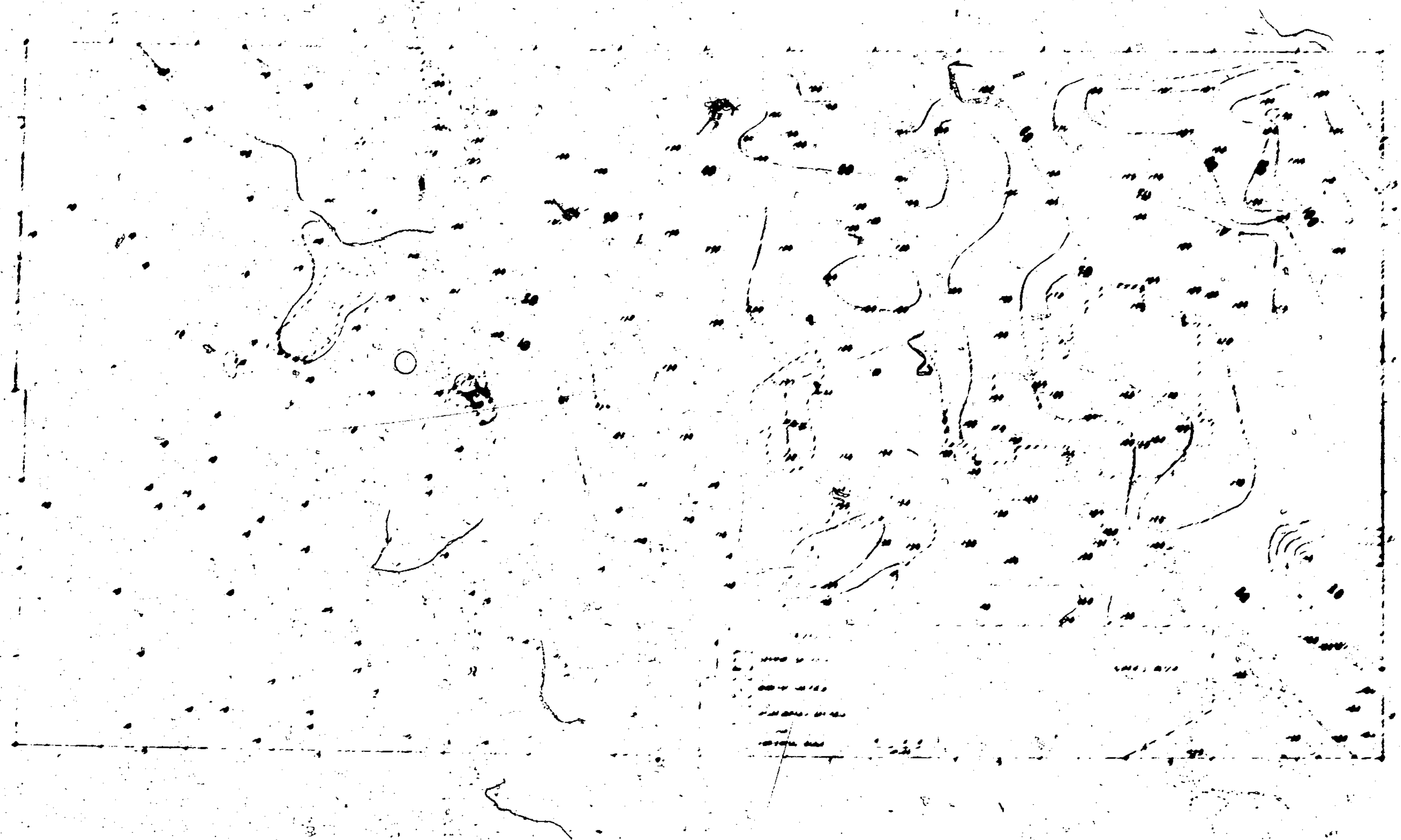

Figure 22: Isopach Map of the Upper Viking Sand.

stratigraphic-structural traps shown to be located on structural highs, and the Upper Viking isopach map shows that two of these fields are also located on isopach thicks. The Cessford Field, which produces from three small pools in the Upper Viking sandstone, is predominantly a stratigraphic trap, and two of these pools are located on the edge of the Upper Viking sand where it grades into inter-bar shales, resulting in porosity pinchouts.

The Lower and Upper Viking barrier sand bodies are considerably larger than the present development of Texas barrier islands such as Galveston. Galveston Island is 30 miles long and has a maximum width of 2.5 miles above sea level and an equal width below sea level. This size has been attained through only 5000 years of development (i.e., about one mile of width per thousand years). In the study area the Lower Viking Sand has a maximum width of about 80 miles and its length is 90 miles. The Upper Viking Sand has a width of about 65 miles and a length of 85 miles. The time required to develop these large features was greater than that for Galveston Island but at present the exact time span is not determinable. A comparable rate of progradation of about one mile per thousand years does not seem unreasonable.

CHAPTER 9

SUMMARY

Examination of Viking core and electric logs has shown that the Viking Formation in the study area is a barrier bar complex consisting of two main sand units--here called the Upper Viking and Lower Viking sands--usually separated by a bentonite time marker with an absolute age of 103.5±2 m.y.

The Joli Fou Shale underlying the Viking Formation was deposited during a major transgression that joined the boreal and Gulfian seas. After the Joli Fou marine transgression had been completed the first sand to be deposited occurred as a thin bar sand with a northwest trend in townships 21 and 22 and ranges 7 to 11. The next sand to be deposited is found in the western limits of the study area. This barrier complex prograded rather quickly eastward and attained its maximum development in the south-central part of the area as a northwest trending barrier sand. Some strong control on the limit of eastern migration was operative because progradation ceased and well sorted sands thin rapidly eastward beyond this region. The areal relationship of the maximum thickness of the Lower Viking Sand to that of the initial thin sand bars first developed in the area is very close. Lower Viking sand bar deposition terminated by a short-lived marine transgression which deposited shale over the area and preserved a thick ash, now traceable through most of the area as a bentonite marker and time datum.

Renewed major sand deposition returned to the area after this short interruption, in the form of the Upper Viking Sand, a few feet above the bentonite datum, but in a new locus in the eastern part of the study area. This barrier bar sand prograded more gradually to the northeast corner of the map area where it attains a maximum thickness of 115 feet in the north by northwest trending sand body. During development of the main Viking Sand in the east, local thin bar sands were being formed on the backshore side of the main barrier, in the central and western parts of the study area.

Viking deposition was finally terminated by the rapid major marine transgression which covered the sands with the Lloydminster Shale in a deeper water environment.

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APPENDICES

APPENDIX A

Interpretation of vertical succession of structures and textures in 14 Viking cores.

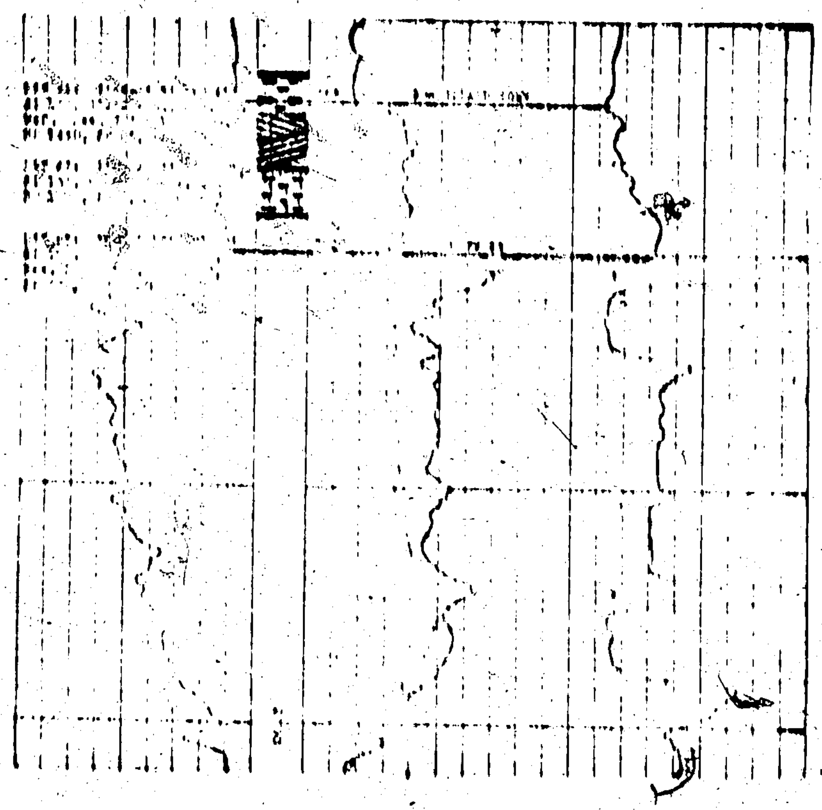
LEGEND

- Marine Shale
- Beach-Upper Shoreface Sands
- Middle Shoreface Sands
- Lower Shoreface Shales

CHAMBERLAIN BUFFALO

6 - 16 - 21 - 06 W4

KB 2579'



Core: 3" good recovery

Depth (ft.)

2562 - 2573 Shale: dark grey, regular silt laminae and lenses; bioturbation present; bentonites, grey, fine grained, 1/2" to 1" thick at 2564' and 2573'.

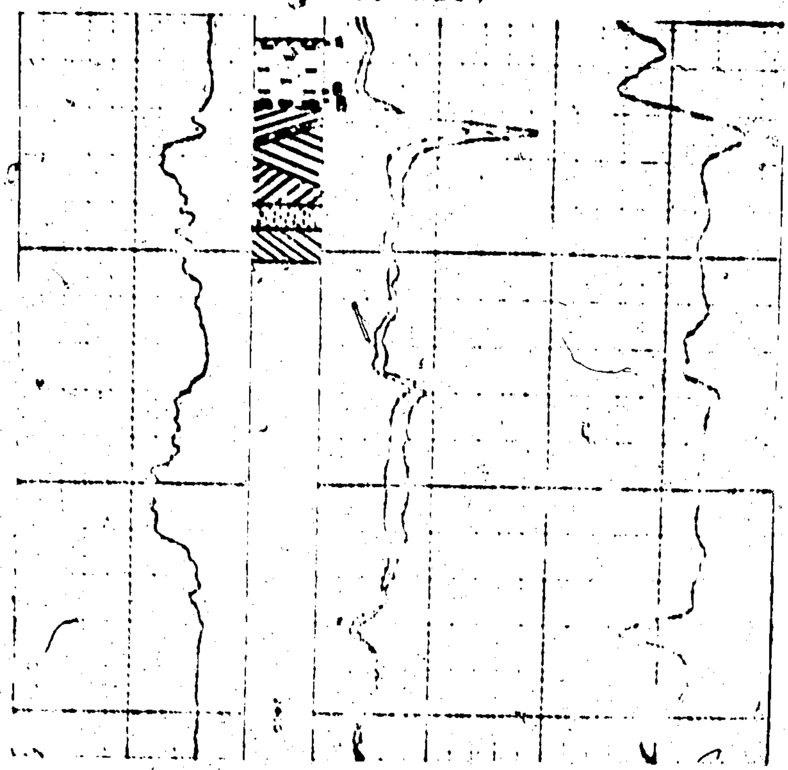
2573 - 2582 Sandstone: fine grained, moderate sorting; low angle planar cross-laminations; some zones showing organic activity.

Depth (ft.)	
2582 - 2593	Shale: shale with very fine grained sandstone and siltstone intermixed in lenses and irregular laminae by organic reworking.

SUPERTEST BIRK BIND BUFFALO

10 - 14 - 22 - 6 W4

KB 2264'



Core: 3" good recovery

Depth (ft.)

2255 - 2268 Shale: dark grey, regular silt laminae and lenses; Bentonites, light grey, 1/2" to 1" thick at 2255', 2266' and 2268'.

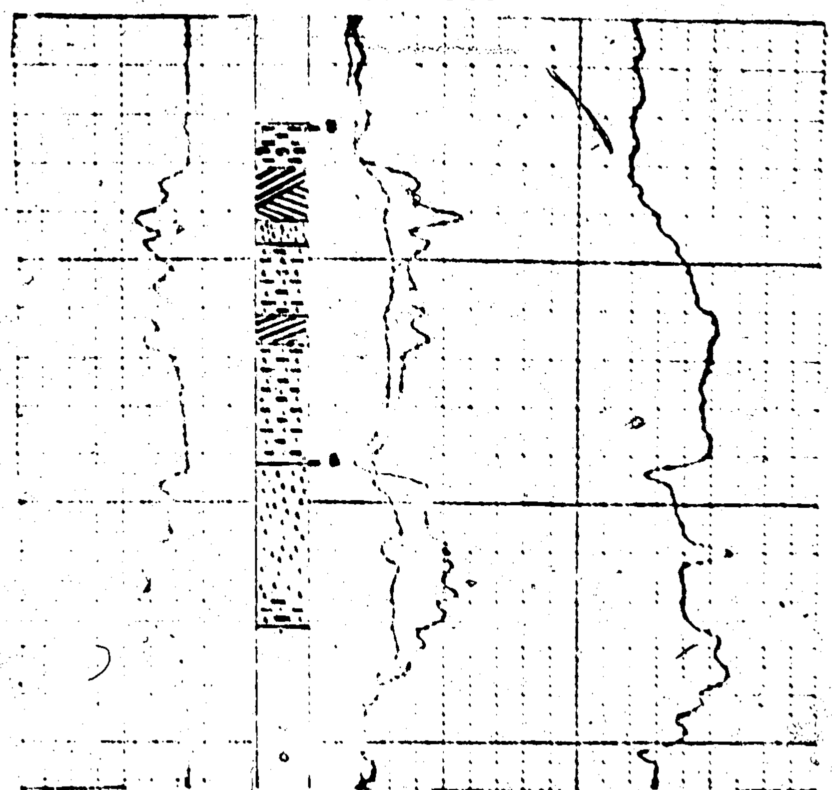
2268 - 2268.5 Conglomerate: chert pebbles coated with black patina in poorly sorted coarse grained sandstone matrix.

Depth (ft.)	
2268.5 - 2290	Sandstone: medium to fine grained, well sorted; planar high angle cross-laminations; a few ripples and thin zones of massive sandstone due to burrowing; at 2275' - 2276.5' the sandstone has low angle cross-laminations; chert pebbles and heavy minerals are concentrated in the laminations.
2290 - 2295	Sandstone: massive by reworking, fine grained; a few ripples.
2295 - 2302	Sandstone: fine grained, well sorted; planar high angle cross-laminations.

ANGLO HOME ATLEE

1 - 13 - 23 - 7 W4

KB 2340'



Core: 3" good recovery

Depth (ft.)

2372 - 2377.5 Shale: dark grey, regular silt laminae and lenses; Bentonites, light grey, very fine grained, 2" and 1/2" thick at 2373' and 2374'.

2377.5 - 2378.5 Conglomerate: coarse, well rounded chert pebbles in a poorly sorted coarse grained sandstone matrix.

2378.5 - 2390.5 Sandstone: fine grained, well sorted; planar low angle cross-laminations; a few scour and fill structures.

Depth (ft.)

2390.5 - 2396 Sandstone: medium grained; massive by reworking.

2396 - 2412 Shale: shale with very fine grained sandstone and siltstone in irregular laminations and lenses; bioturbation and ripples present; sand content increases towards the top of this interval.

2412 - 2417 Sandstone: fine grained; planar low angle cross-laminations.

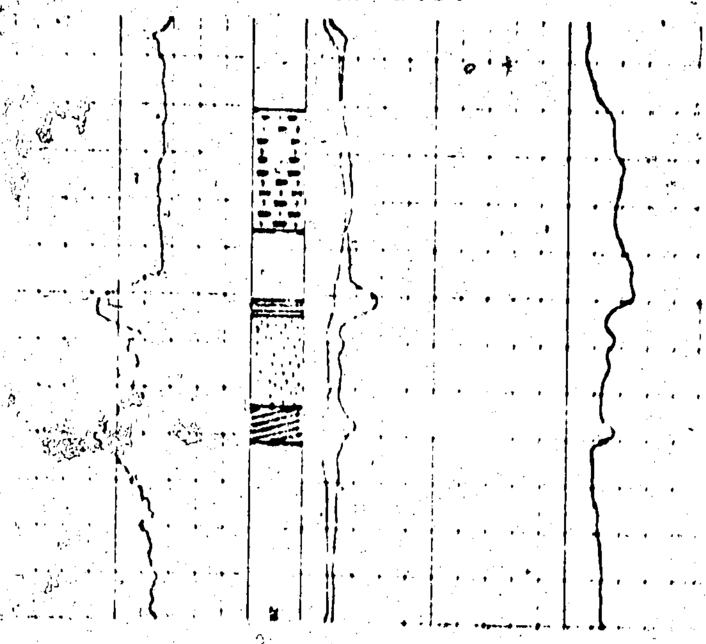
2417 - 2442 Shale: shale with very fine grained sandstone and siltstone in irregular laminations and lenses; bioturbation present; sand content increases towards the top of interval; Bentonite at 2441' is 1' thick, white, coarse grained and biotite rich.

2442 - 2475 Sandstone: medium grained; horizontal beds and laminations of sandstone with interbeds of siltstone and shale; bioturbation where present reworks sediment into lenses and pods; sandstone decreases in abundance and size towards bottom of interval.

FLOCK C.P.R. DENHART

15 - 29 - 20 - 11 W4

KB 2434'



Core: Wireline poor recovery

3" good recovery

Depth (ft.)

2491 - 2517 Shale: silty shale; (this interval is wireline core with poor recovery, thus impossible to log structures).

2532 - 2536 Sandstone: fine grained sandstone; appears massive but slabbing reveals low angle planar cross-lamination.

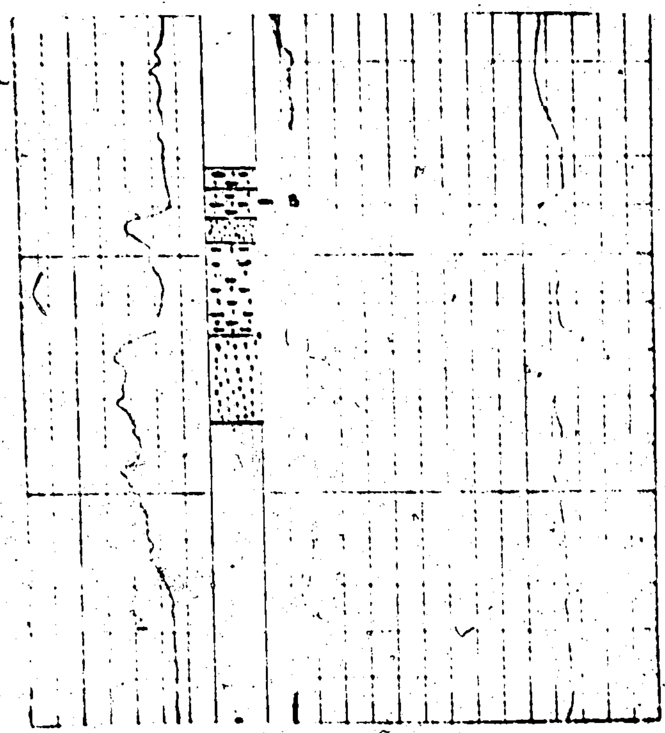
2536 - 2552 Sandstone: fine grained, massive sandstone; mottled texture due to worm burrowing; some thin irregular shale partings; lower contact is gradational.

Depth (ft.)	
2552 - 2562	Sandstone: medium grained, salt and pepper sandstone; low angle planar cross-laminated; some orange clay pebbles.

H.B DELHI CESSFORD #28

6 - 1 - 23 - 12 W4

KB 2303'



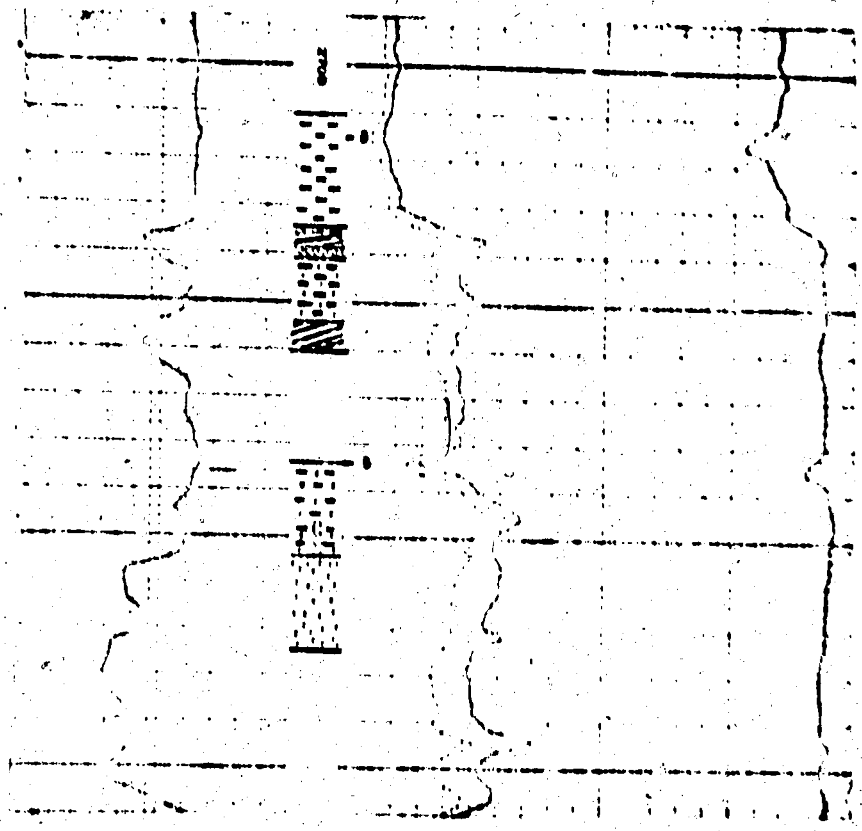
Core: wireline, fair recovery

Depth (ft.)	
2481 - 2493	Shale: shale with siltstone and very fine grained sandstone completely intermixed by bioturbation; Bentonite, 6" thick, light grey, biotite rich at 2491'.
2493 - 2501	Sandstone: light grey, fine grained sandstone; structureless sandstone due to intense burrowing.
2501 - 2517	Shale: shale with lenses of light grey, very fine grained sandstone; burrowing is present.
2517 - 2535	Sandstone: light grey, fine grained, massive; some worm burrows present; slightly glauconitic.

H. B. CESSFORD

14 - 26 - 25 - 12 W4

KB 2452'



Core: 3" good recovery

Depth (ft.)

2710 - 2733.5 Shale: dark grey; Bentonite, light grey, 1" thick at 2715'.

2733.5 - 2734 Conglomerate: well rounded size assortment of elongated pebbles up to 1 cm. long; calcareous cement.

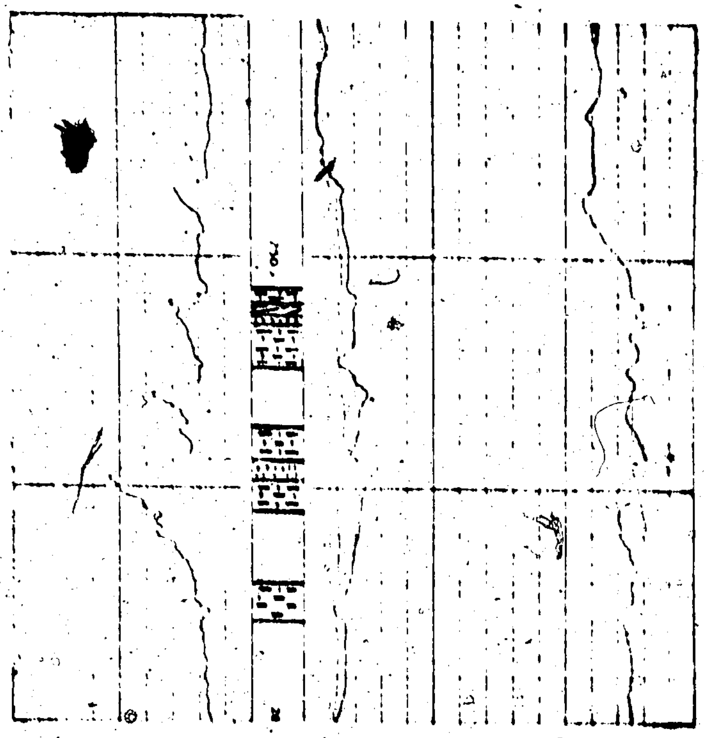
2734 - 2740 Sandstone: fine grained sandstone; alternating beds 1' to 2.5' thick of massive, structureless sandstone and low angle planar cross-laminated sandstone.

Depth (ft.)	
2740 - 2754	Shale: shale with siltstone and very fine grained sandstone laminae completely reworked by bioturbation.
2754 - 2760	Sandstone: fine grained, cross laminated sandstone; some thin zones of massive, reworked sandstone.
2784 - 2805	Shale: shale with siltstone and very fine grained sandstone that has been completely reworked giving a mottled texture; Bentonite, light grey, biotite rich, 1' thick at 2785'; lower contact of this interval is transitional.
2806 - 2825	Sandstone: grey, fine grained, massive sandstone; worm burrowing is extensive.

H.B. HOME HIGHCREST BERRY CREEK #1

16 - 23 - 22 - 13 W4

KB 2274'



Core: wireline, poor to fair recovery

Depth (ft.)

2509 - 2513 Sandstone: fine grained; cross-laminations; 2 layer of small, well rounded, well sorted, chert pebbles at 2509'.

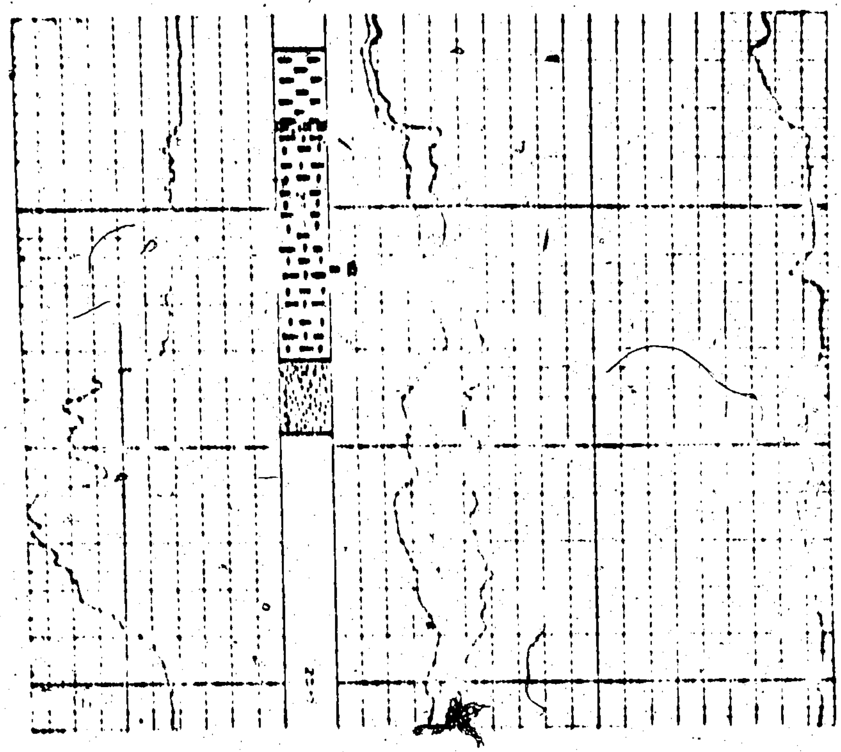
2513 - 2524 Shale: shale with irregular laminations, pods and lenses of very fine grained sandstone and siltstone; some bioturbation; sandstone content increases towards top of interval.

2537 - 2543 Shale: shale with irregular laminations of siltstone; bioturbation present.

Depth (ft.)

2543 - 2546	Sandstone: medium grained, light grey; structureless due to organic reworking.
2546 - 2555	Shale: shale with fine grained sandstone and siltstone in irregular laminations, lenses and pods giving a mottled texture; bioturbation present.
2570 - 2578	Shale: dark grey shale with a few laminae of siltstone.

H.B. DELHI CESSFORD
10 - 28 - 24 - 13 W4
KB 2392'



Core: 3" good condition

Depth (ft.)

2667 - 2683 Shale: dark grey shale with a few rippled laminae.

2683 - 2684 Conglomerate: well rounded chert pebbles up to 1 cm.; sandstone matrix and calcite cement.

2684 - 2733 Shale: shale with pods, lenses and irregular laminae of siltstone and sandstone; bioturbation is present; becomes more sandy towards base of interval where the contact is transitional into the next interval; Bentonite, light grey coarse grained, mica rich, 1' thick at 2712'.

2733 - 2747 Sandstone: fine grained, structureless sandstone, except a few irregular shale laminae.

BANFF MOBIL MATZIWIN
6 - 15 - 23 - 14 W4
KB 2320'

Core: 3" good recovery

Depth (ft.)

2610 - 2614 Shale: dark grey shale with some laminations of light grey siltstone; burrows present.

2614 - 2615 Conglomerate: well rounded, poorly sorted pebbles; matrix is poorly sorted medium grained sandstone and mudstone.

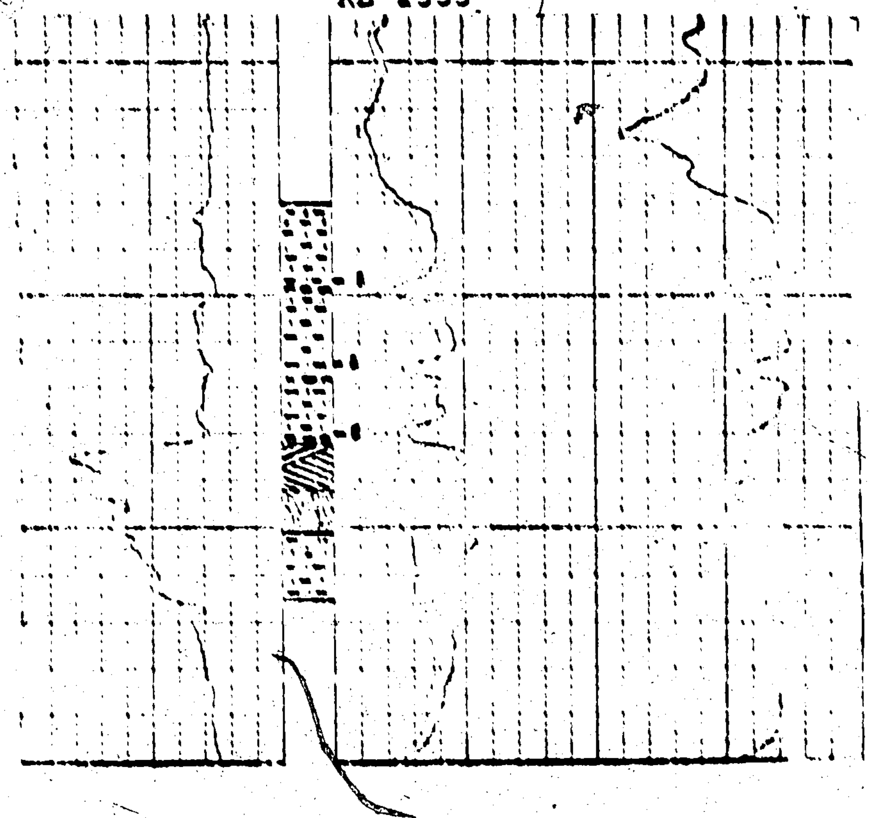
2615 - 2625 Sandstone: light grey, medium grained sandstone; massive and structureless except for some imbricated elongate red clay pebbles in bands.

2625 - 2636 Shale: shale with reworked sandstone and siltstone giving a mottled texture; burrowing is visible; Bentonites, light grey, 1" thick, at 2628' and 2631'.

MOBIL MATZIWIN

11 - 23 - 23 - 14W4

KB 2355'



Core: 3" good recovery

Depth (ft.)

2630 - 2681 Shale: shale with very fine grained sandstone and siltstone in irregular laminae and lenses; considerable bioturbation; Bentonites at 2647', 2665' and 2680' are 1.5', 1" and 1" thick respectively; white, coarse grained biotite-rich bentonite at 2647' and grey, fine grained bentonite at 2665' and 2680'; Chert pebble conglomerates at 2649', 2668' and 2680' are 1-1.5' thick with well rounded chert pebbles, silt to sand matrix, and are poorly

Depth (ft.)

to moderately sorted.

2681 - 2692 Sandstone: alternating zones of low angle planar laminated fine grained sandstone and massive structureless sandstone; some ripples.

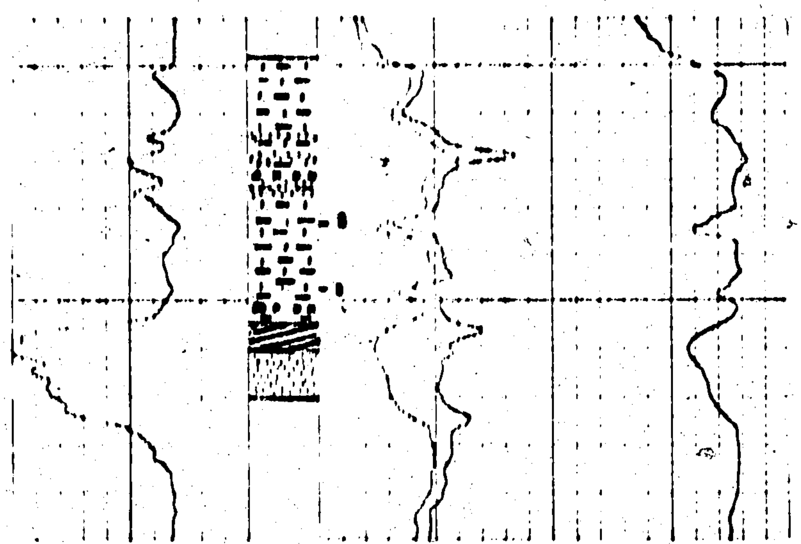
2692 - 2700.5 Sandstone: massive, structureless, fine grained.

2700.5 - 2715 Shale: shale with very fine grained sandstone and siltstone in irregular laminations and lenses; bioturbation present; sand content increases towards the top of this interval.

NORTEX MOBIL HUTTON

10 - 16 - 24 - 15 W4

KB 2434'



Core: 3" good recovery

Depth (ft.)

2848 - 2905 Shale: shale with lenses, pods and irregular laminations of siltstone and sandstones burrowing is common; Bentonites, light grey biotite rich, 2" and 4" thick, fine grained and medium grained respectively, at 2884' and 2897'.

Conglomerate, well rounded chert pebble up to 1 cm. in size with poorly sorted sandstone matrix at 2900' to 2900.5'.

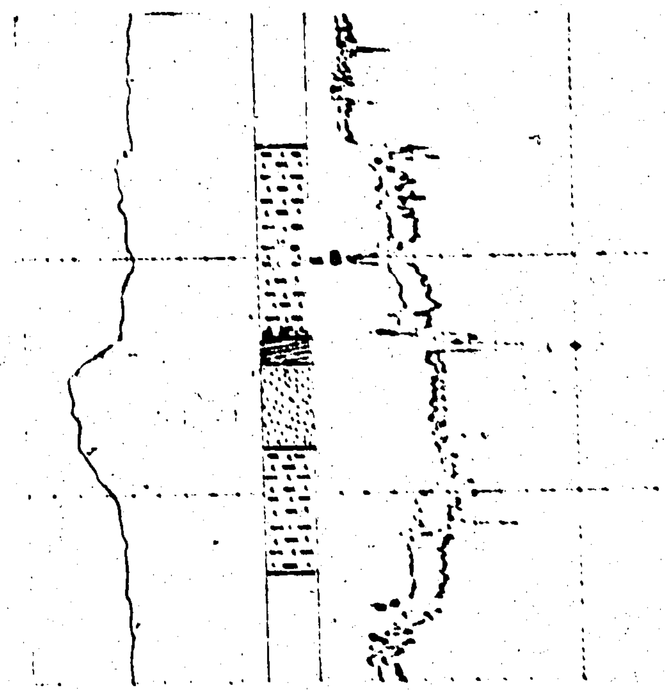
2905 - 2909 Sandstone: fine grained, low angle, planar cross-laminations.

2909 - 2920 Sandstone: fine grained, massive, structureless, a few worm burrows present.

AMERADA CROWN

7 - 25 - 26 - 15 W4

KB 2634'



Core: wireline, fair to good recovery

Depth (ft.)

3079 - 3015 Shale: shale with irregular laminae of siltstone and very fine grained sandstone; Bioturbation increases towards the bottom of interval; ripples present; Bentonite, light grey, biotite rich at 3101', 6" thick.

3015 - 3019 Sandstone: fine grained at base to medium grained at top; small, well rounded, pebbles up to 1 cm diameter arranged in low-angle cross beds in this interval.

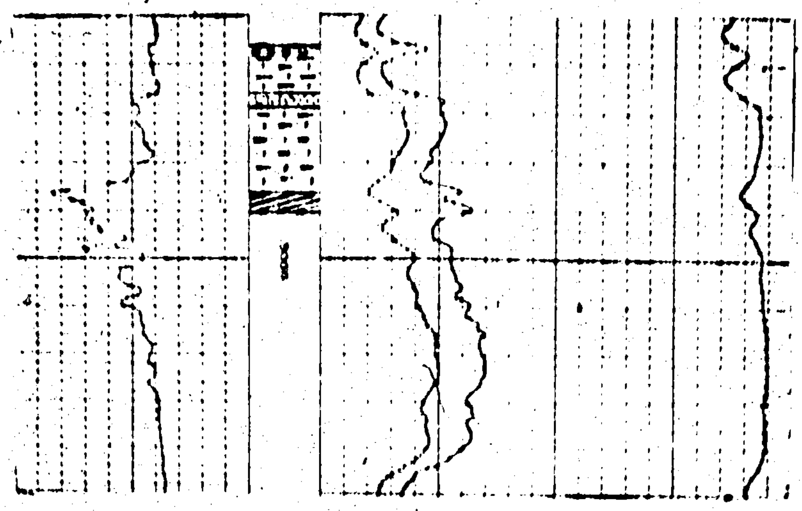
3019 - 3040 Sandstone: medium grained, massive, sandstone; burrowing is present; shale becomes more

Depth (ft.)	
	abundant downward.
3040 - 3067	Shale: shale with pods and lenses of siltstone and very fine grained sandstone giving an indistinct mottled appearance.

CANADIAN DELHI COUNTESS

10 - 4 - 21 - 16 W4

KB 2530'



Core: 3" good condition

Depth (ft.)

2957 - 2957.5 Conglomerate: well rounded chert pebbles with a black patina; medium grained sandstone matrix.

2957.5 - 2966.5 Shale: shale with irregular siltstone laminae and ripples of fine grained sandstone.

2966.5 - 2968.5 Sandstone: medium grained, massive sandstone; organic burrowing present.

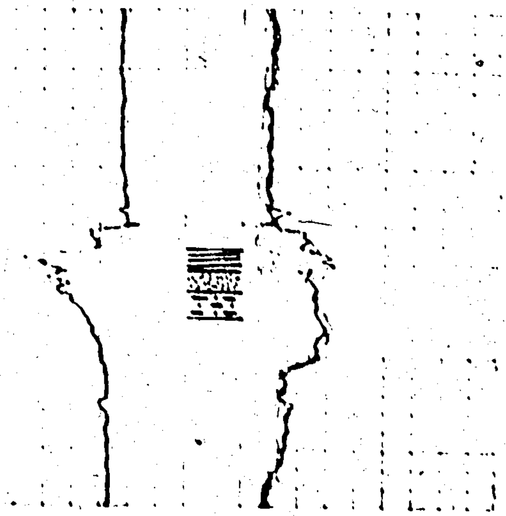
2968.5 - 2986 Shale: shale with interbeds of light grey, very fine grained sandstone; ripples and bioturbation are present.

2986 - 2989 Sandstone: light grey, fine grained; low angle planar cross-lamination.

DELHI SOCONI COUNTESS #1

7 - 8 - 21 - 16 W4

KB 2466'



Core: Wireline good recovery

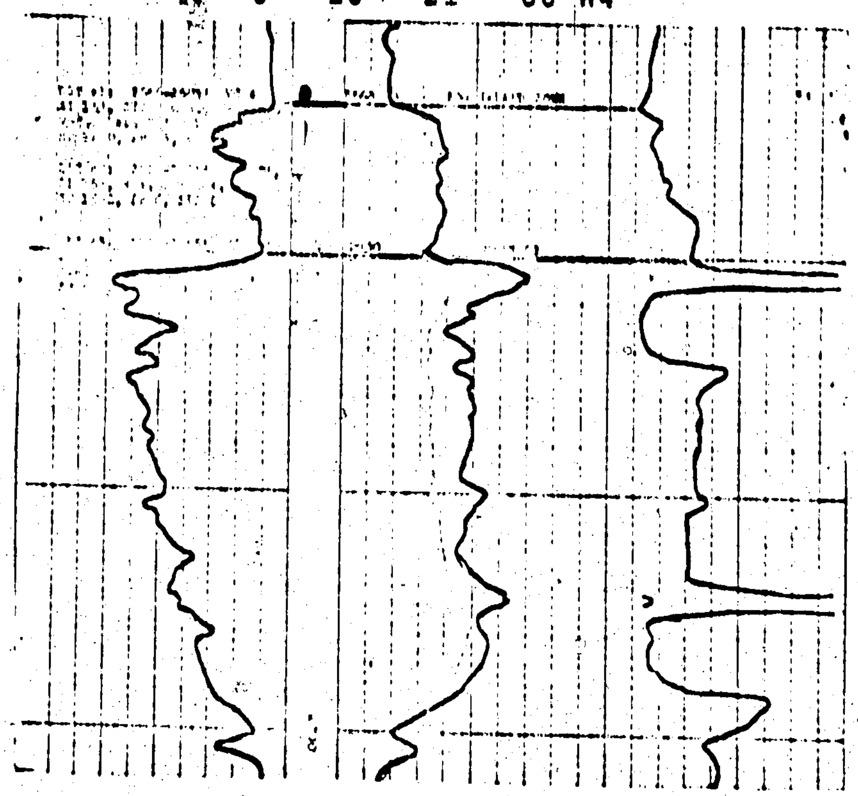
Depth (ft.)	
2895 - 2901	Sandstone: light grey, fine grained; low angle planar cross-lamination; transitional lower contact.
2901 - 2915	Sandstone: light grey, fine grained structureless; transitional lower contact.
2915 - 2928	Shale: shale with lenses, pods and irregular laminae of siltstone and sandstone; mottled texture due to bioturbation.

APPENDIX B

Location and depths of microfauna samples and microfaunal list.

CHAMBERLAIN H. BUFFALO

6 - 16 - 21 - 06 W4



Sample depth (ft.): 2567

1' below Viking Formation

186' below Fish Scales

339' above Mannville Formation

Foraminiferal Fauna:

<u>Trochammina</u> <u>alcanensis</u> Stelck, 1974

<u>Trochammina</u> <u>umiatensis</u> Tappan, 1957

<u>Verneuilina</u> <u>canadensis</u> <u>canadensis</u> Cushman, 1937

<u>Gaudryina</u> <u>canadensis</u> Cushman, 1943

<u>Ammodiscus</u> <u>anthosatus</u> Chamney, 1969

<u>Reophax</u> <u>sikannensis</u> Stelck, 1974

<u>Reophax</u> <u>tundraensis</u> Chamney, 1969

Reophax sp. A

Ammobaculites sp. A

Ammobaculites sp. A (var. long)

Glomospira tortuosa Eicher, 1960

Saccammina alexanderi Loeblich and Tappan, 1950

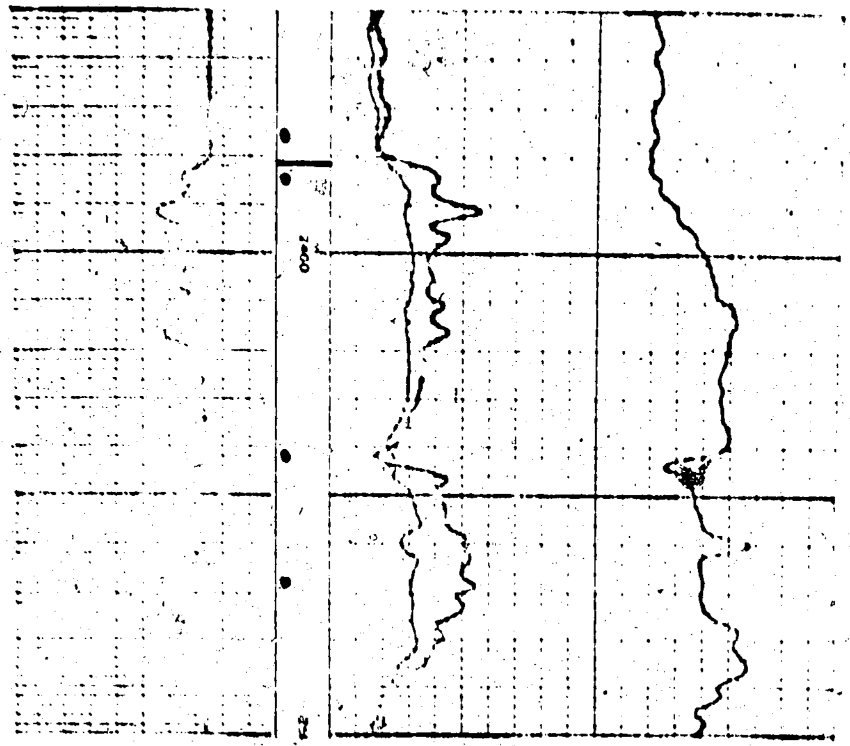
Psamminopelta bowsheri Tappan, 1957

Miliammina awunensis Tappan, 1957

Haplophragmoides (3 chambered)

ANGLO HOME ATLEE

1 - 13 - 23 - 7 W4



Sample depth (ft.): 2376

4' above Viking Formation

176' below Fish Scales

304' above Mannville Formation

Foraminiferal Fauna:

Reophax sikannensis Stelck, 1974

Reophax tundraensis Chamney, 1969

Verneuilina canadensis canadensis Cushman, 1937

Verneuilinoides borealis Tappan, 1957

Verneuilina howchina Crespin, 1953

Gaudryina hectori Nauss, 1947

Ammobaculites humei Nauss, 1947

Psamminopelta bowsheri Tappan, 1957

Trochammina umiatensis Tappan, 1957

Trochammina gatesensis Stolck and Wall, 1956

Saccammina alexanderi Loeblich and Tappan, 1950

Pelosina sp

Sample depth (ft.): 2385

5' below Viking top

185' below Fish Scales

295' above Mannville Formation

Foraminiferal Fauna:

Psamminopelta sp

Sporitoid bodies

Sample depth (ft.): 2442

62' below Viking top

242' below Fish Scales

238' above Mannville Formation

Foraminiferal Fauna:

Reophax sp (juveniles) A to B?

Reophax eckernex Vieaux, 1941

Reophax A to B Crespin

Trochammina sp

Pyrite balls

Pyrite rods

Fish tooth

Fish bones

Sample depth (ft.): 2468

58' below Viking top

268' below Fish Scales

212' above Mannville Formation

Foraminiferal Fauna:

Reophax (A to B)

Ammobaculites ?

Saccammina alexanderi Loeblich and Tappan, 1950

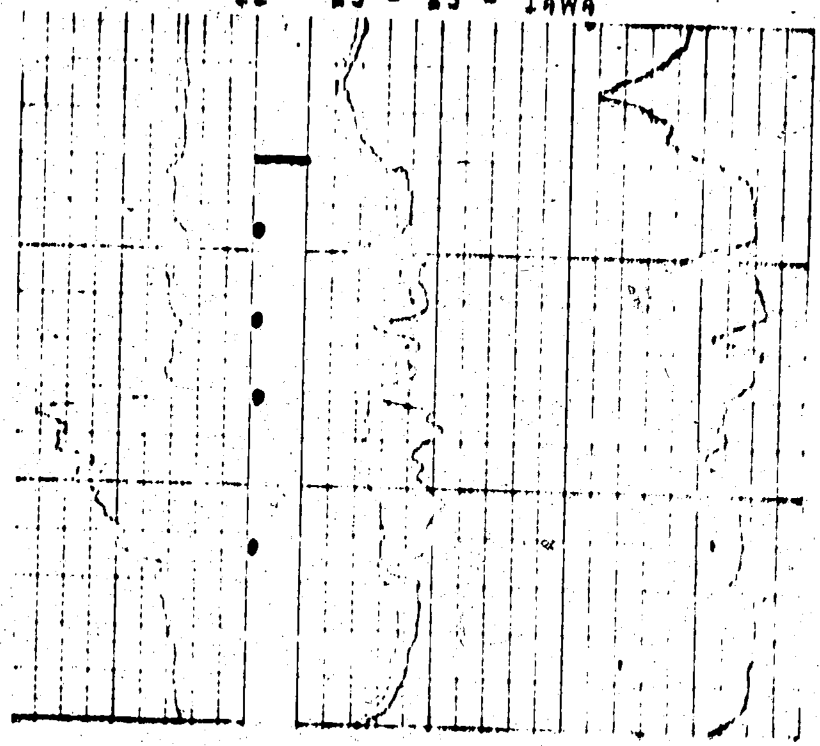
Haplophragmoides ?

Diatoms

Sporitoid bodies (large)

MOBIL MATZIWIN

11 - 23 - 23 - 14W4



Sample depth (ft.): 2644

14' below Viking top

154' below Fish Scales

Foraminiferal Fauna:

<u>Trochammina</u> <u>gatesensis</u> Stelck and Wall, 1956

Fish fragments

Sporitoid fragments

Pyrite clusters

Sample depth (ft.): 2664

34' below Viking top

174' below Fish Scales

Foraminiferal Fauna:

Reophax A to B Crespin

Reophax (juveniles)

Trochammina gatesensis Stelck and Wall, 1956

Verneuilinoides borealis Tappan, 1957

Glomospira tortuosa Eicher, 1960

Sporitoid bodies

Fish fragments

Sample depth (ft.): 2681

51' below Viking top

191' below Fish Scales

Foraminiferal Fauna:

Sporitoid bodies

Sample depth (ft.): 2713

83' below Viking top

223' below Fish scales

Foraminiferal Fauna:

Saccammina alexanderi Loeblich and Tappan, 1950

Ammobaculites tyrrelli Nauss, 1947

Sporitoid bodies

Fish fragments

PLATES

PLATE I

1. (left to right)

   a. Sequence of plane laminae resting on a beveled surface which cuts obliquely across underlying laminae at a low angle. Upper shoreface sand, Mobil Oil Delacour 3-5-26-27W4; 5637ft.

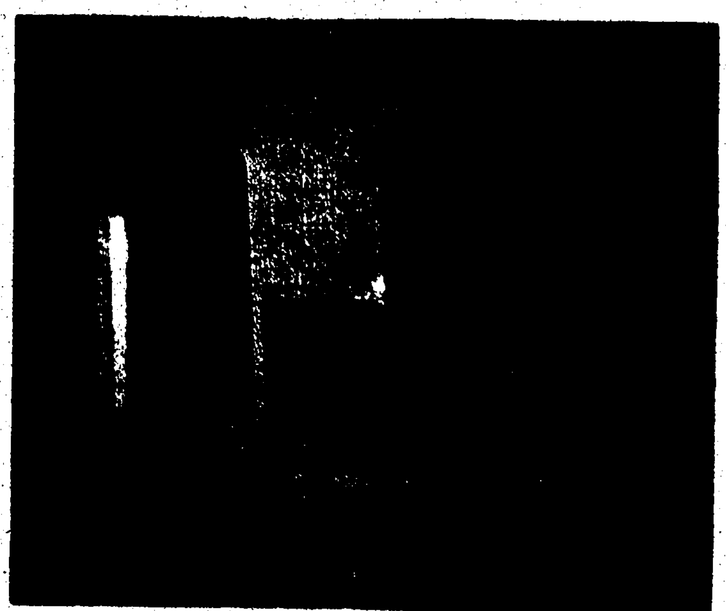
   b. Silt and mud almost completely mixed with small burrows filled by silt. Lower shoreface zone, Mobil Oil Delacour 3-5-26-27W4; 5649 ft.

   c. Mottled sandstone due to burrowing. Middle shoreface sand, Mobil Oil Delacour 3-5-26-27W4; 5639 ft.

   d. Layer of silt breaking up from reworking by organisms. Lower shoreface, Mobil Oil Delacour 3-5-26-27W4; 5653 ft.

2. Primary laminae breaking up by organic reworking; sand filled burrows present. Lower shoreface zone, C.P.O.G. Hussar 7-30-24-19W4; 3853 ft.

PLATE I.



1.

2.

PLATE II

Core shows multiple sand bar development with repetitious upper and middle shoreface sands. Flock C.P.R. Denhart 15-29-20-11W4; 2532-2563 ft.

(NOTE: The terms "lower shoreface", middle shoreface", and "beach-upper shoreface" refer to lithofacies determined by sedimentary structures and textures, and are not necessarily restricted to the corresponding geomorphological profile zonation.)

PLATE II.

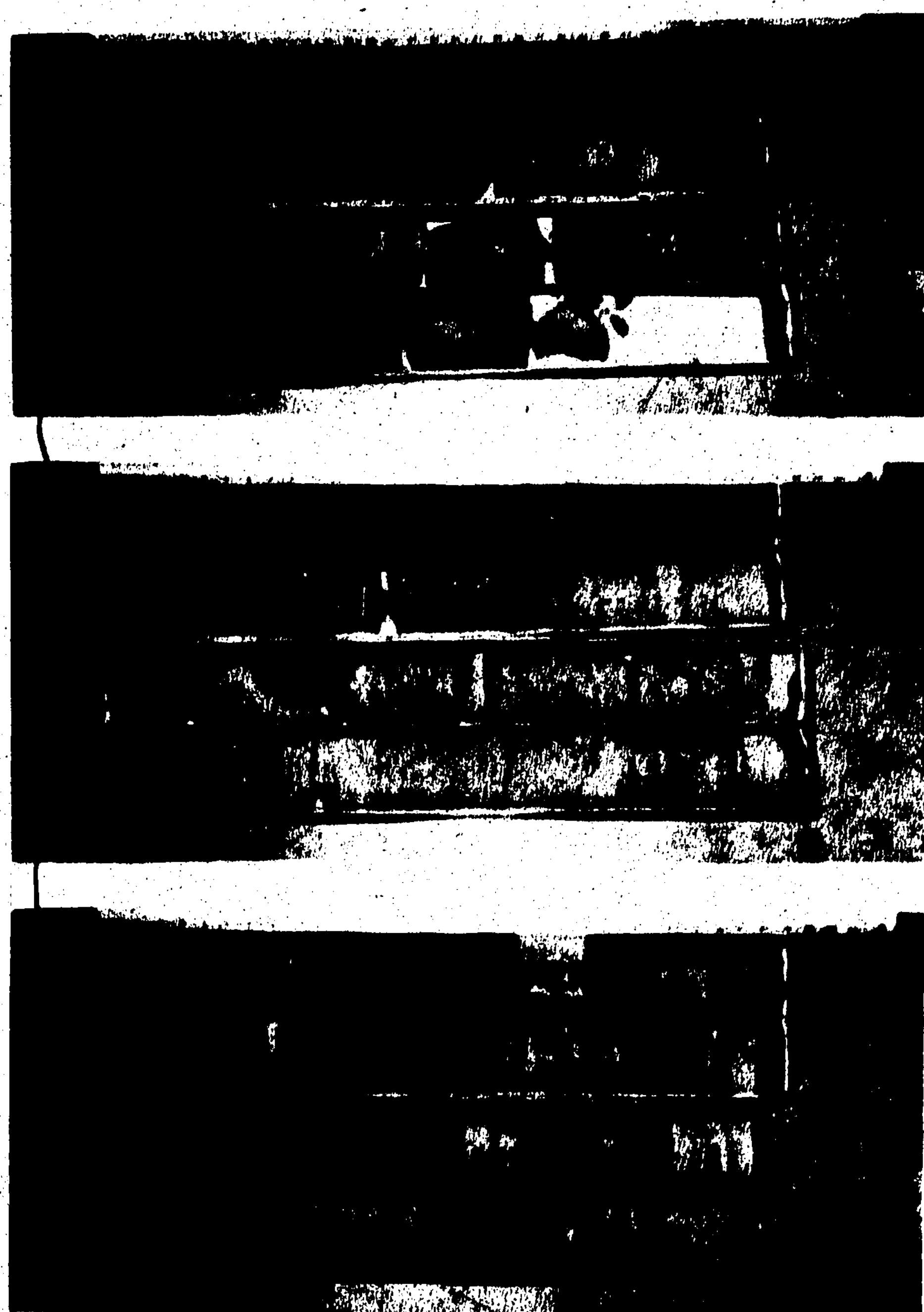


PLATE III

Core shows upper and middle shoreface sands of the Lower Viking Sandstone unit overlain by lower shoreface (inter-bar) shales. Two bentonites are shown.

Nortex Mobil Hutton 10-16-24-15W4; 2882-2920 ft.

(NOTE: The terms "lower shoreface", "middle shoreface", and "beach-upper shoreface" refer to lithofacies determined by sedimentary structures and textures, and are not necessarily restricted to the corresponding geomorphological profile zonation.)

PLATE III.

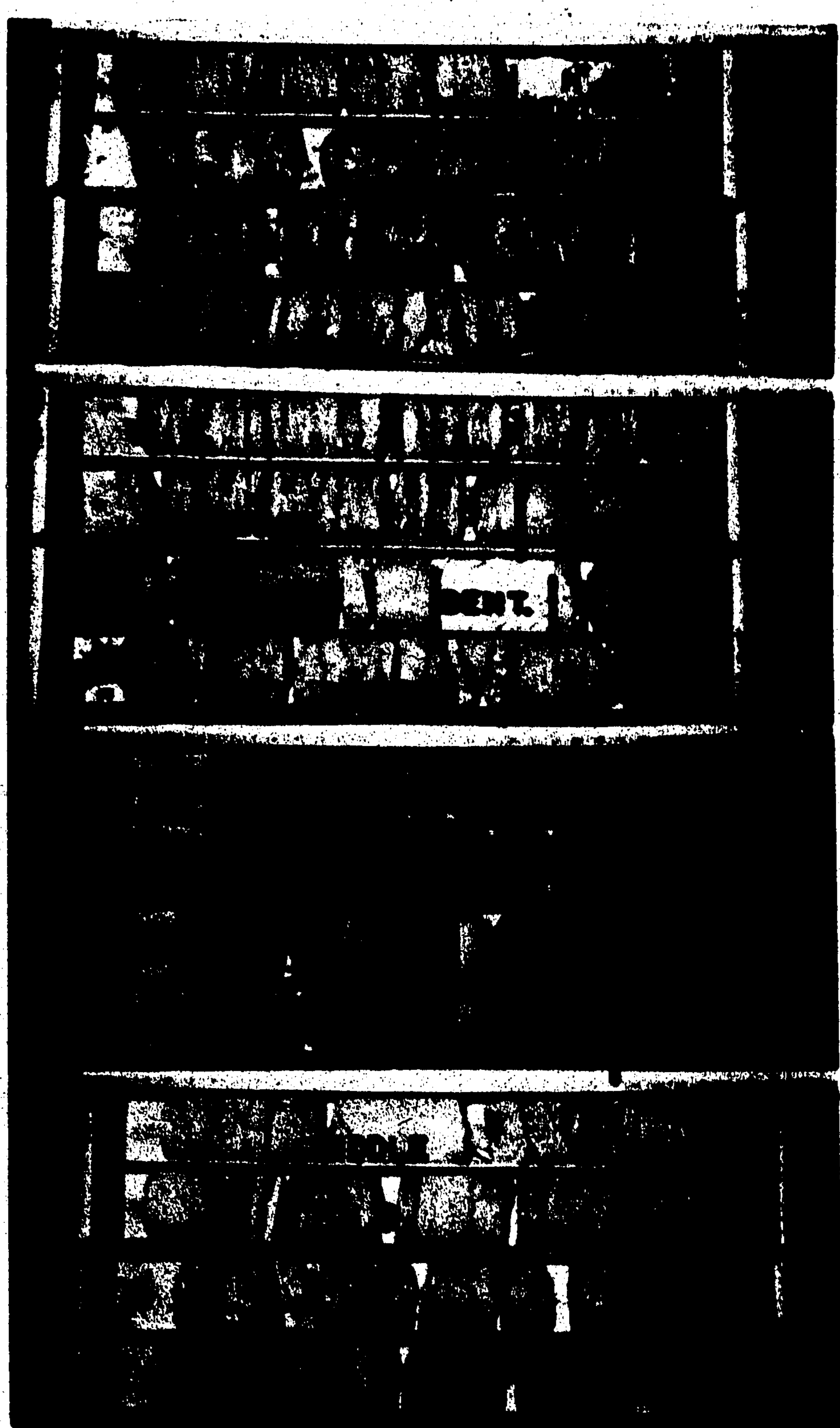


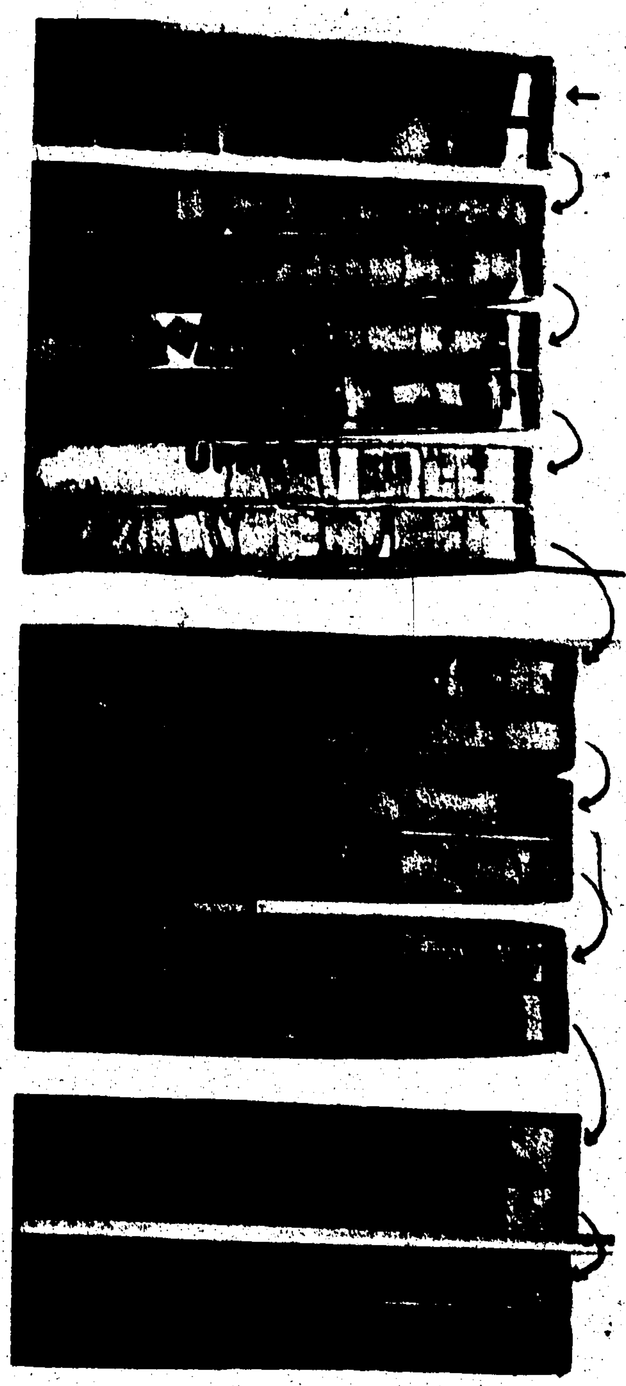
PLATE IV

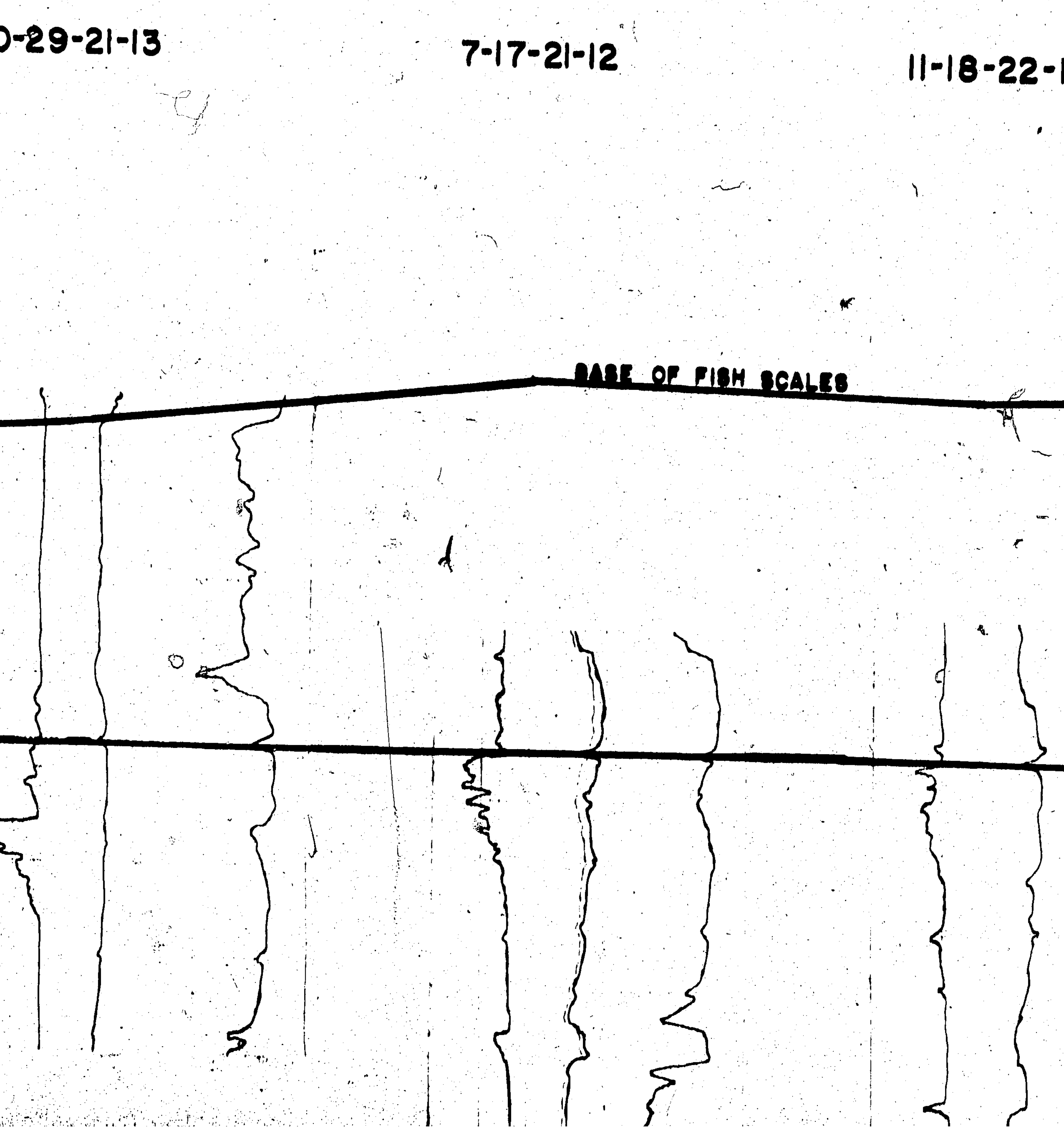
Core shows upper and middle shoreface zones of the Upper Viking Sandstone unit abruptly overlain by marine shales.

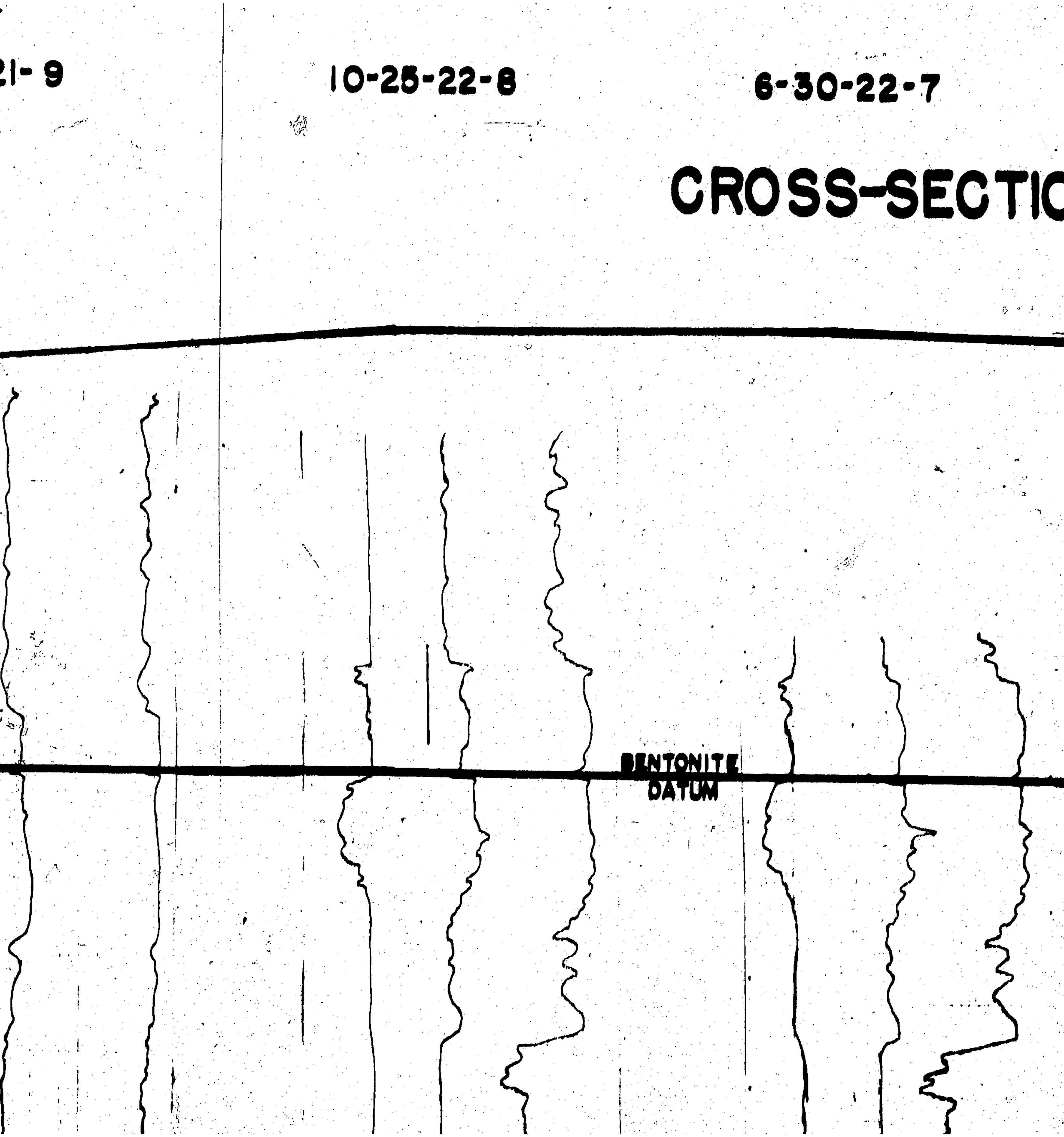
Supertest Birk Bind Buffalo 10-14-22-6W4; 2255-2302 ft.

(NOTE: The term "lower shoreface", "middle shoreface", and "beach-upper shoreface" refer to lithofacies determined by sedimentary structures and textures, and are not necessarily restricted to the corresponding geomorphological profile zonation.)

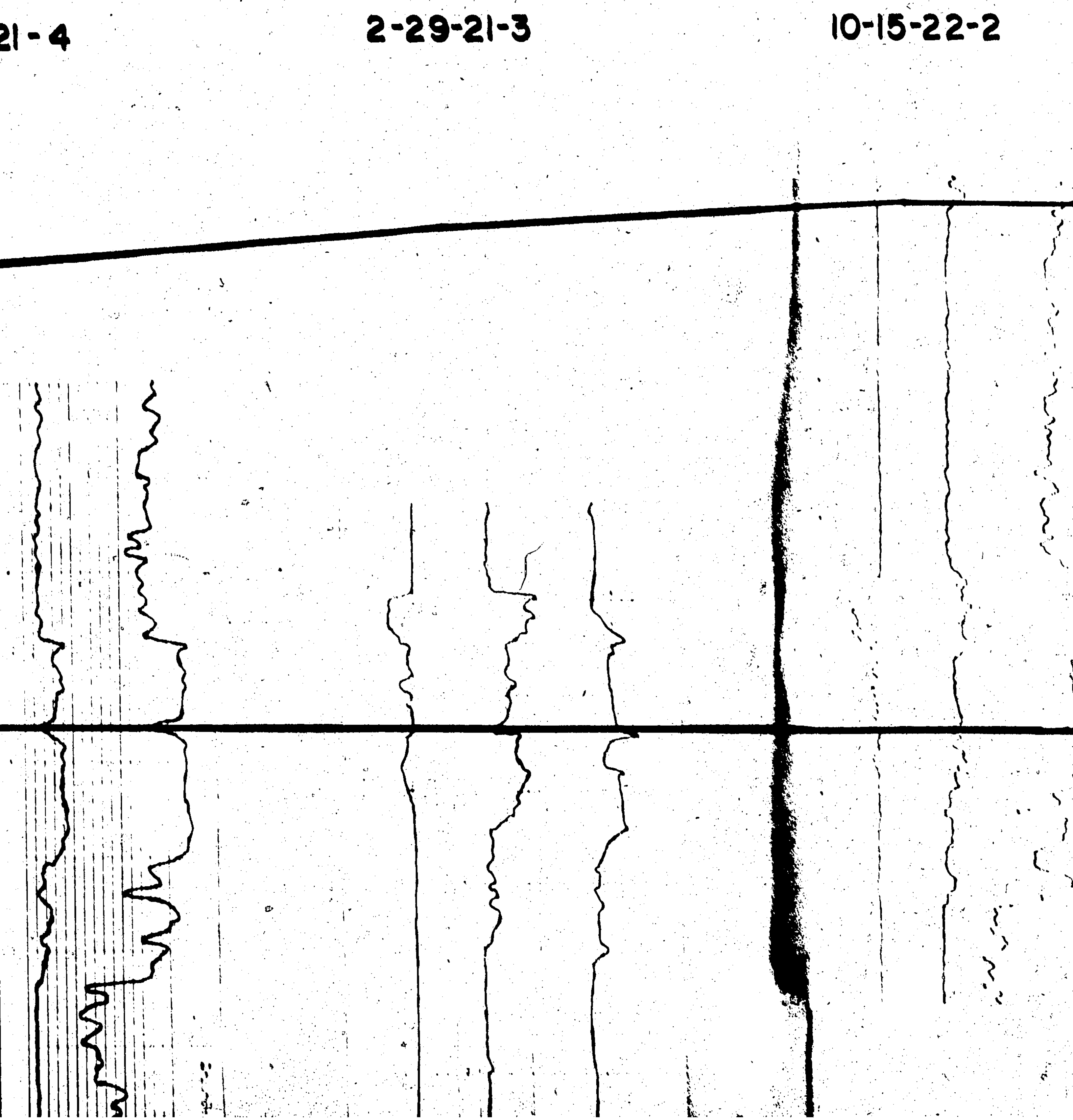
PLATE IV.



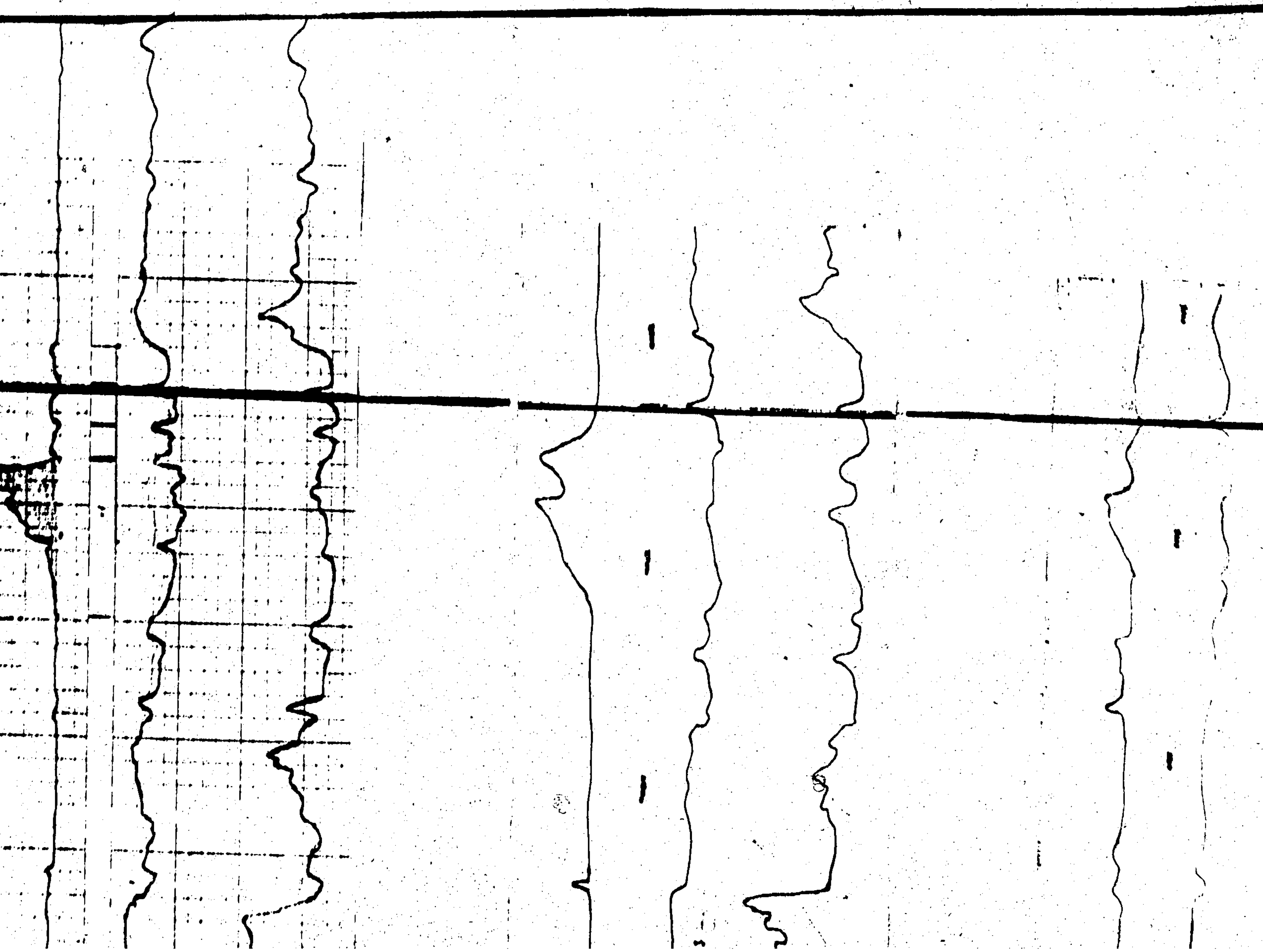

0-29-21-13
7-17-21-12
11-18-22-1
BASE OF FISH SCALES

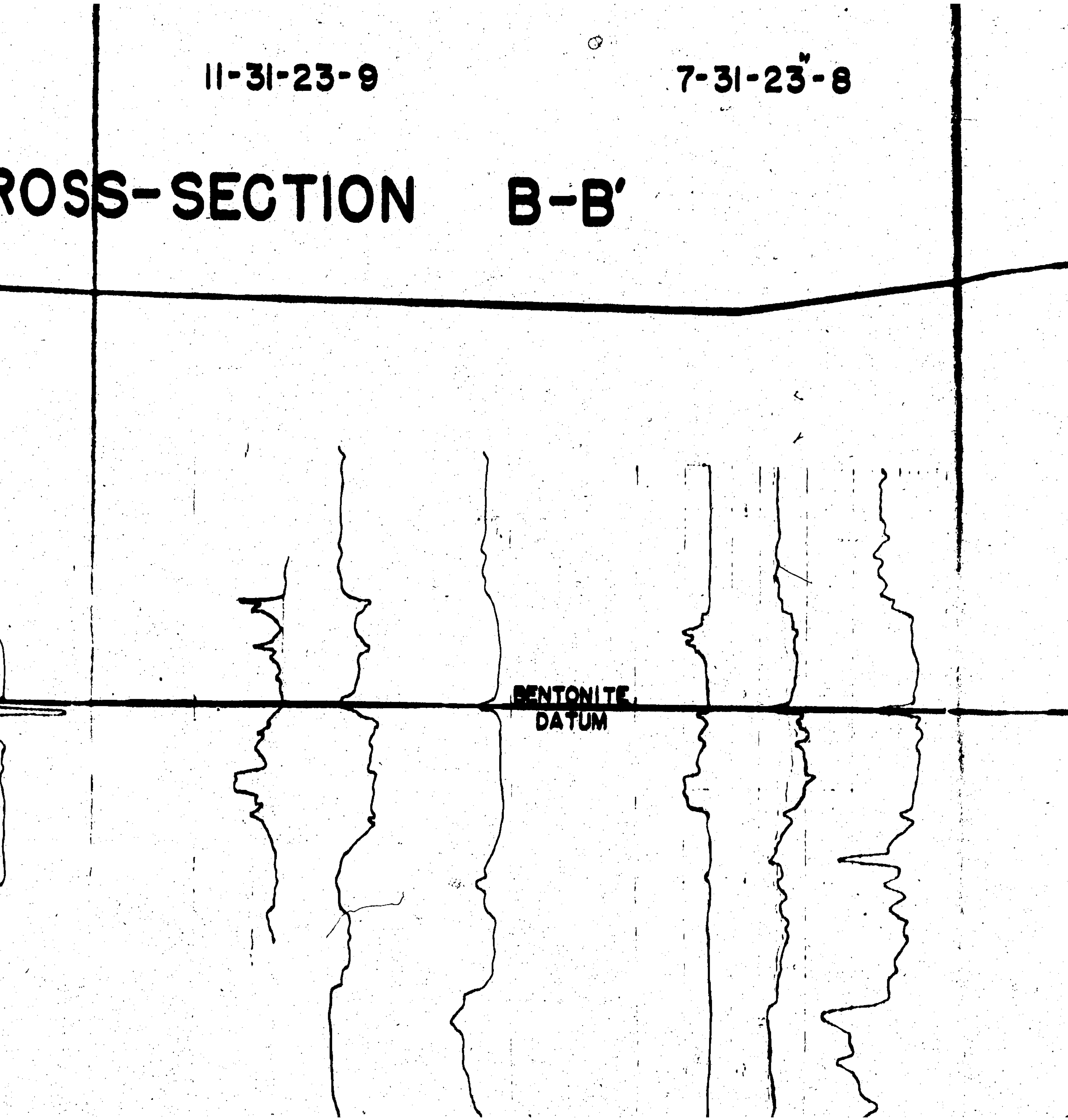


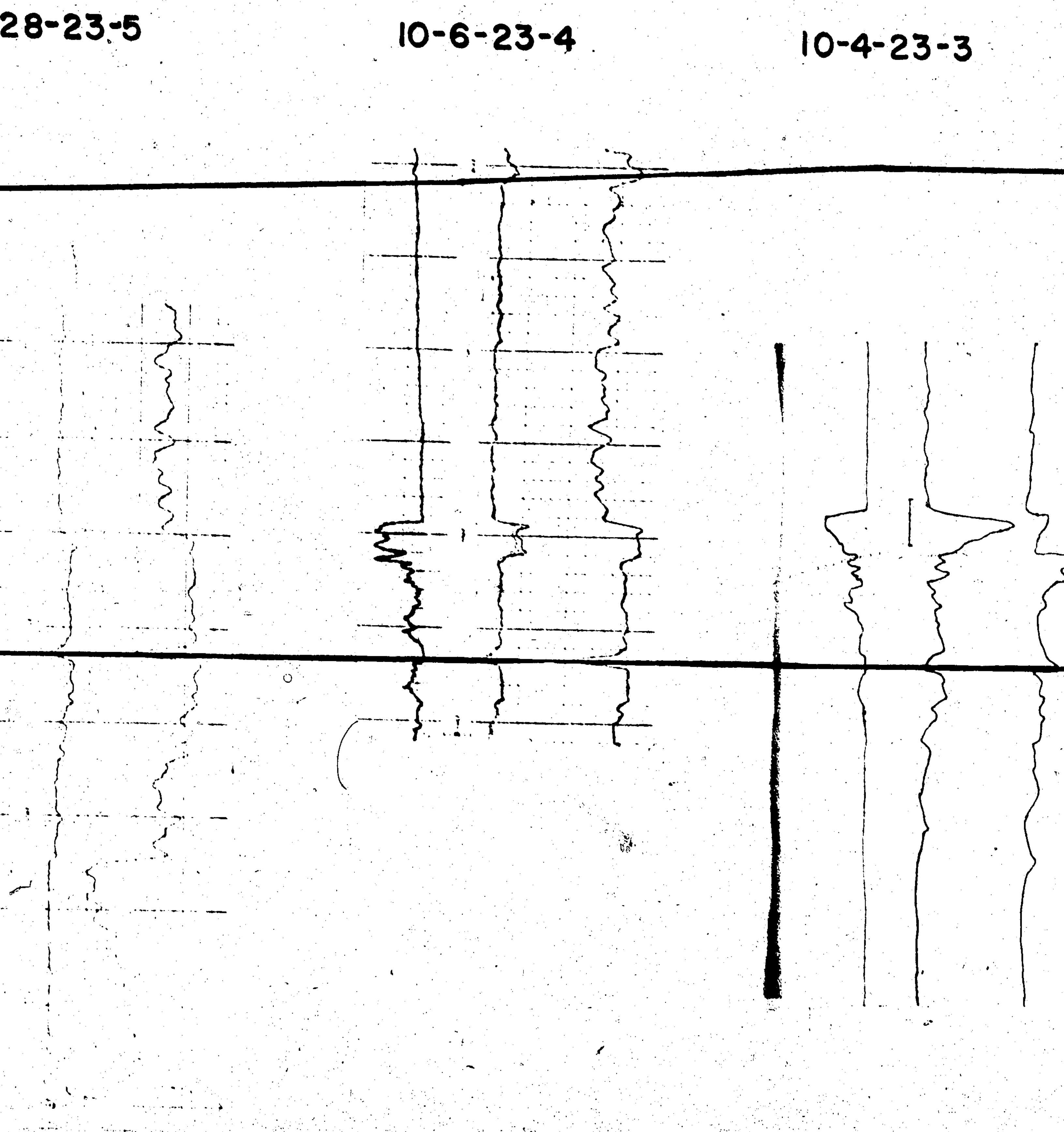
21- 9
10-25-22-8
6-30-22-7
CROSS-SECTIO
BENTONITE
DATUM

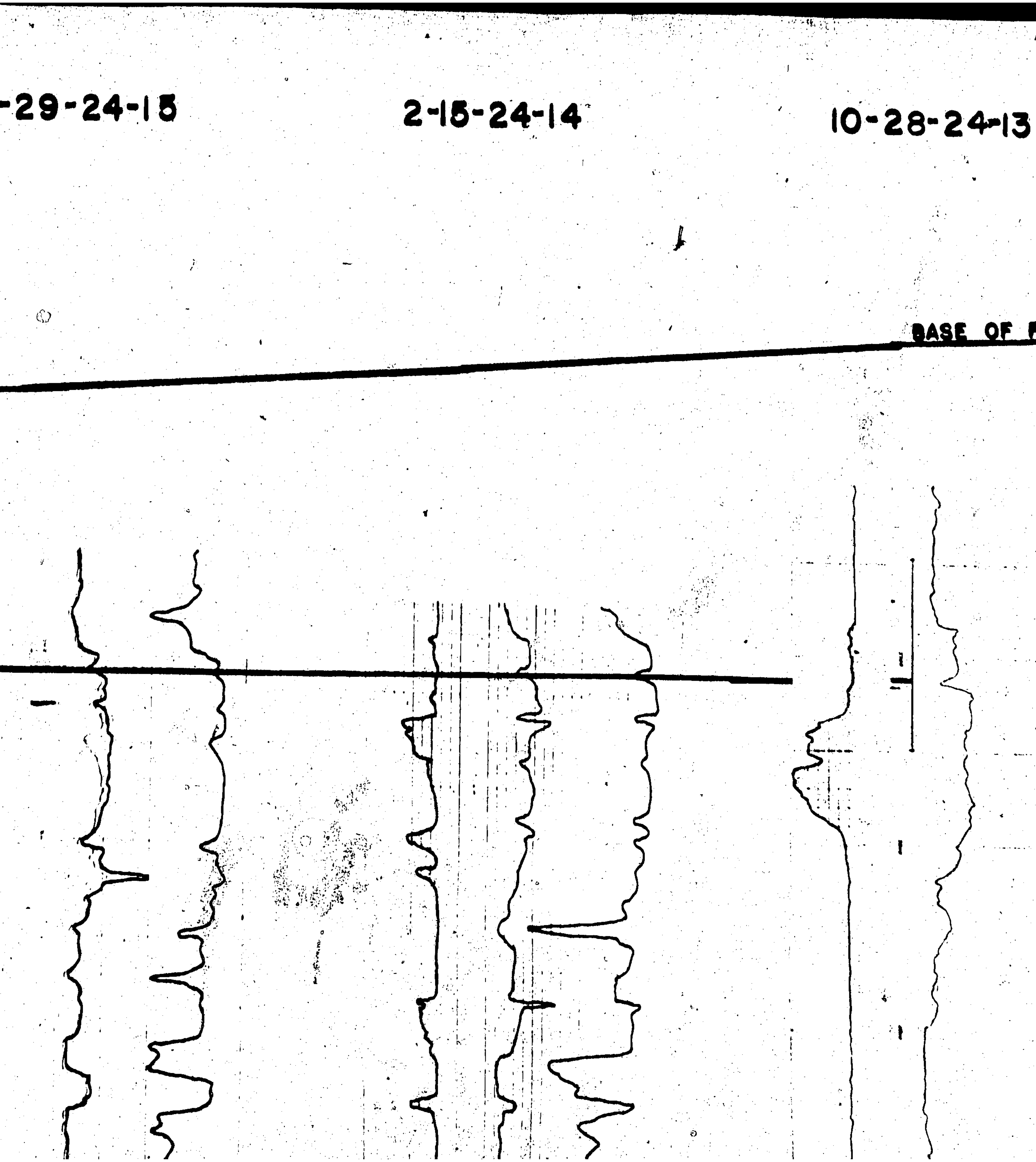

21-4
2-29-21-3
10-15-22-2

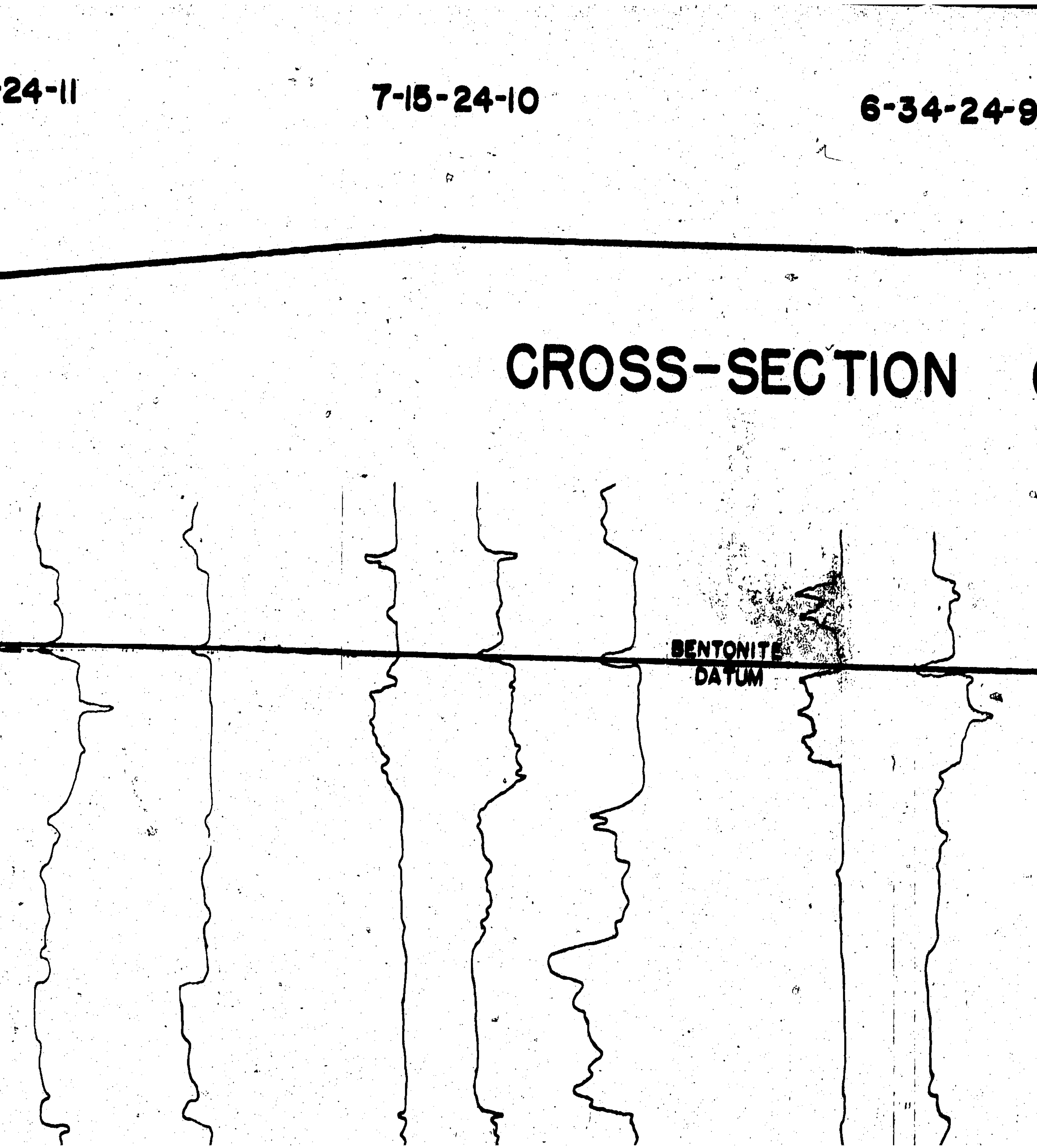
11-23-23-14 10-25-23-13 7-6-23-




11-31-23-9
7-31-23-8
ROSS-SECTION B-B'
BENTONITE
DATUM


28-23-5
10-6-23-4
10-4-23-3


-29-24-15
2-15-24-14
10-28-24-13
BASE OF F



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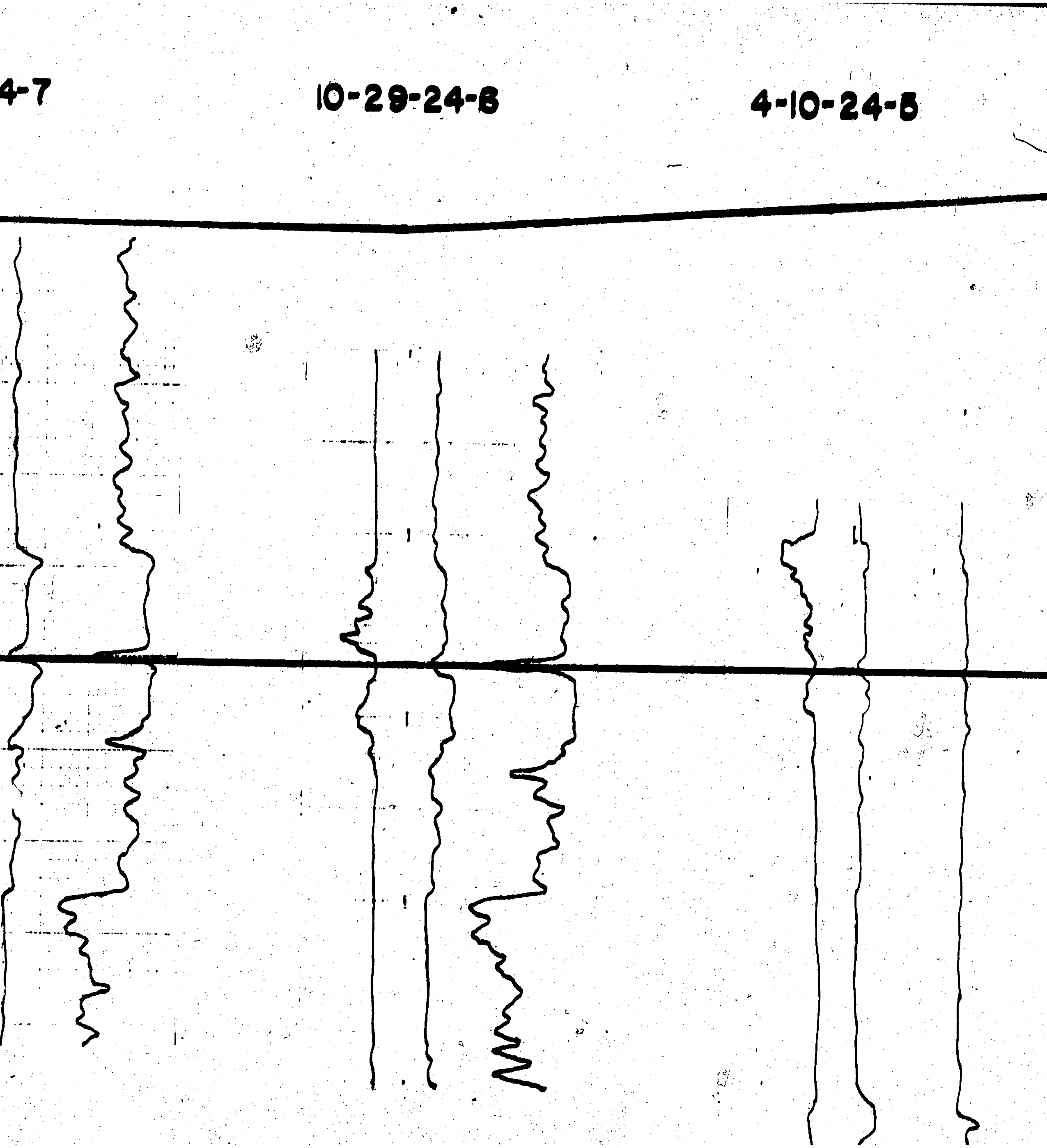
7-15-24-10
6-34-24-9
CROSS-SECTION
BENTONITE
DATUM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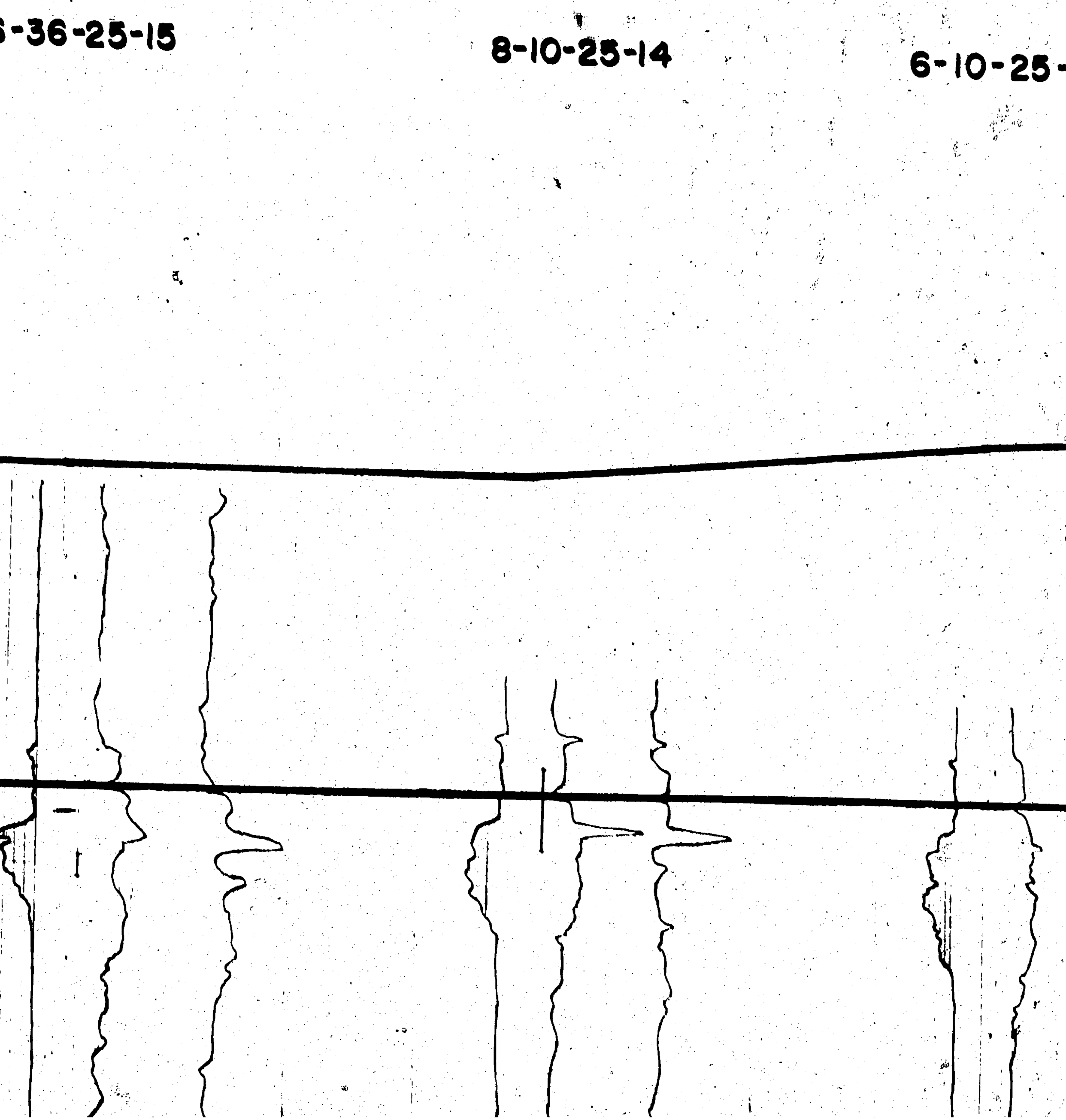
10-29-24-8
4-10-24-5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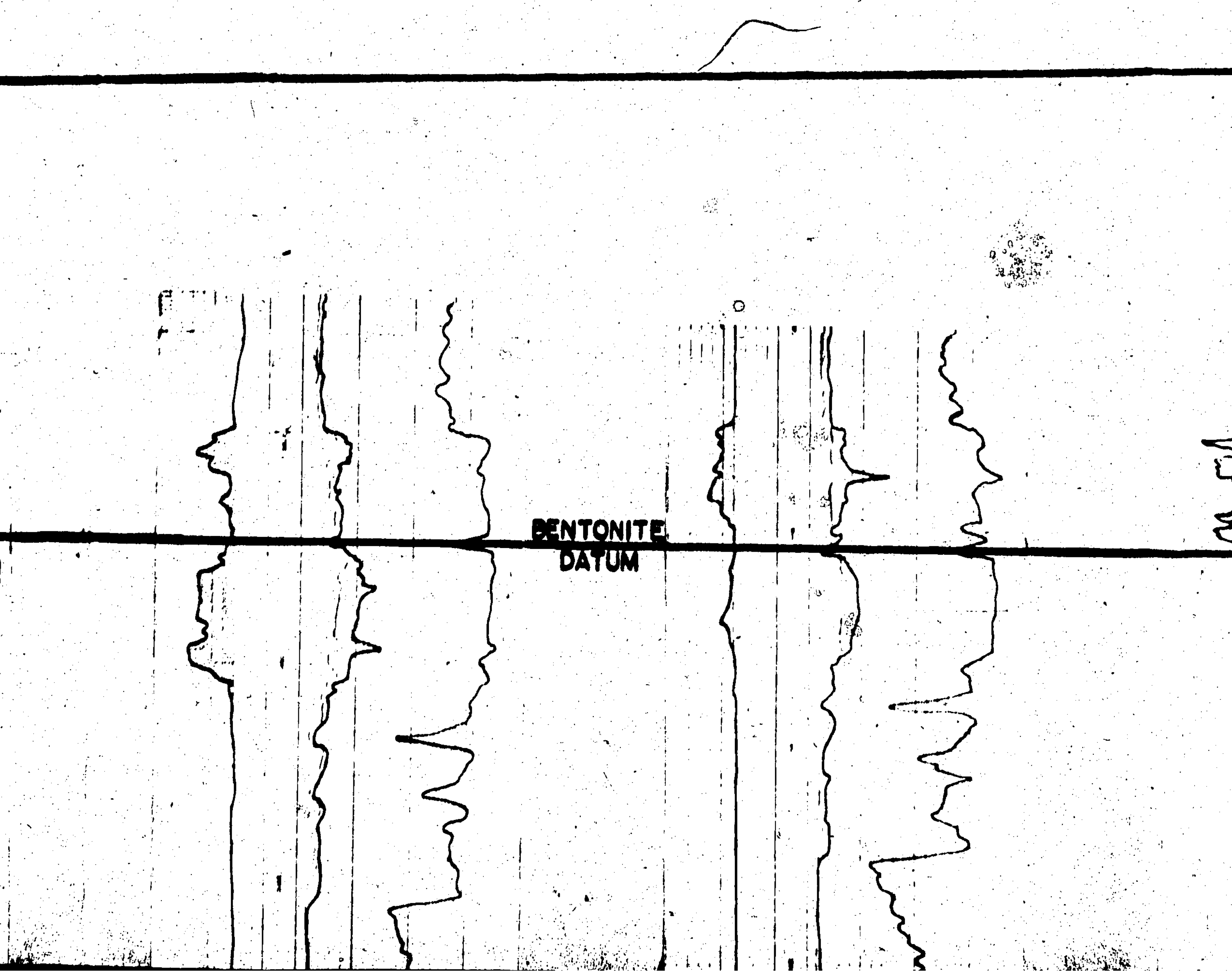
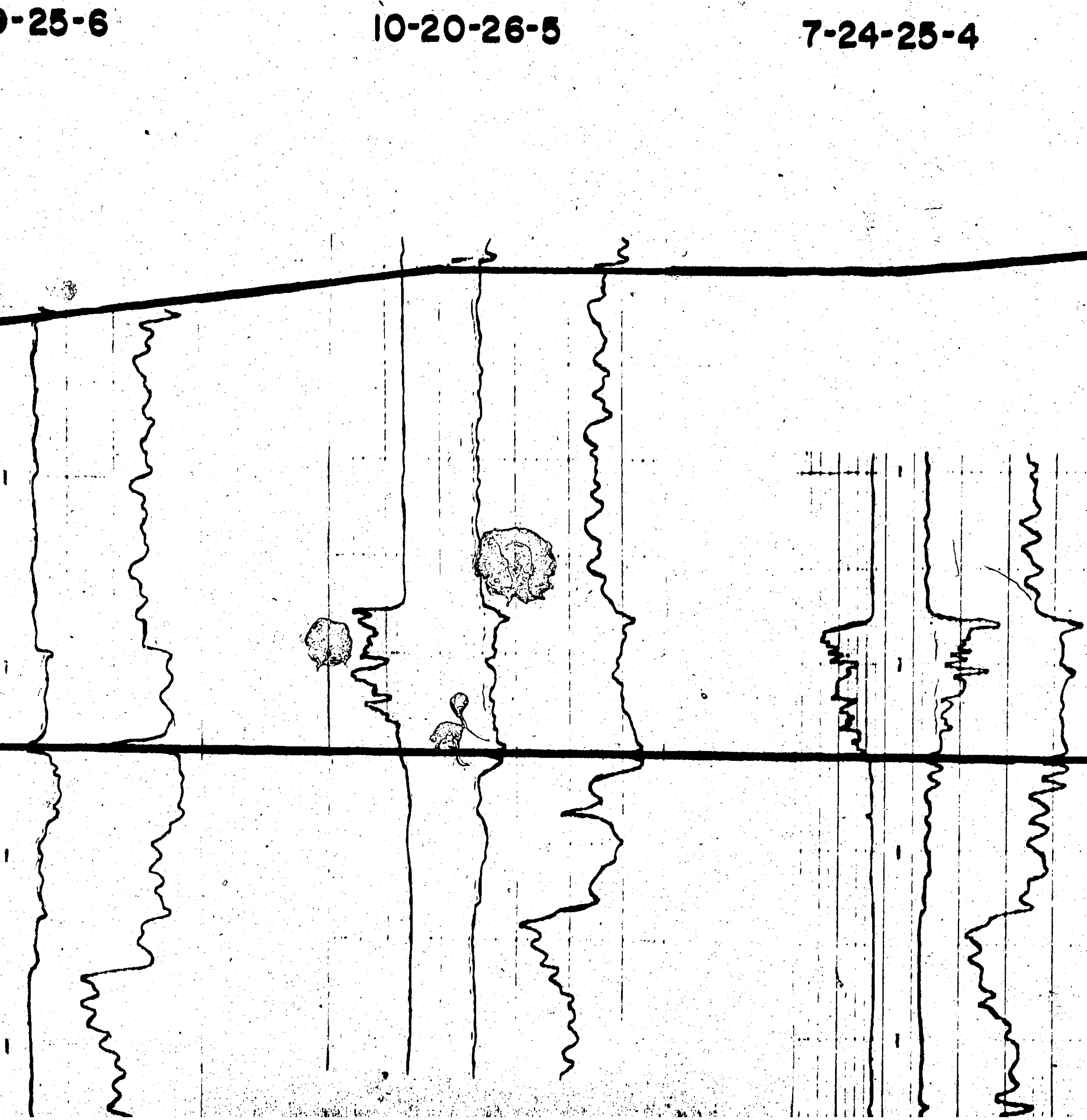
8-10-25-14
6-10-25-

10-29-25-10 6-34-25-9 7

CROSS-SECTION D-D'

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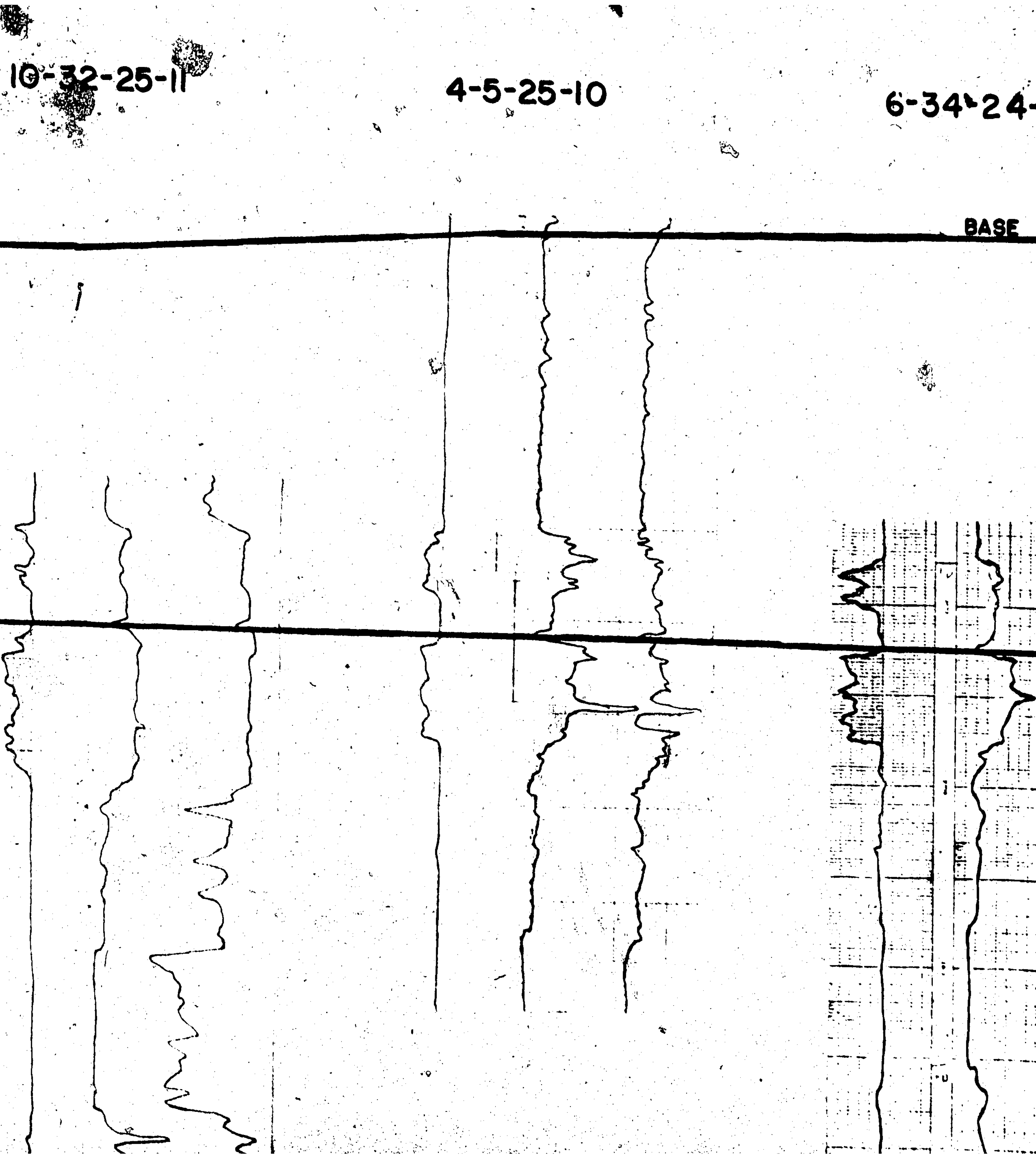
7-24-25-4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4-5-25-10
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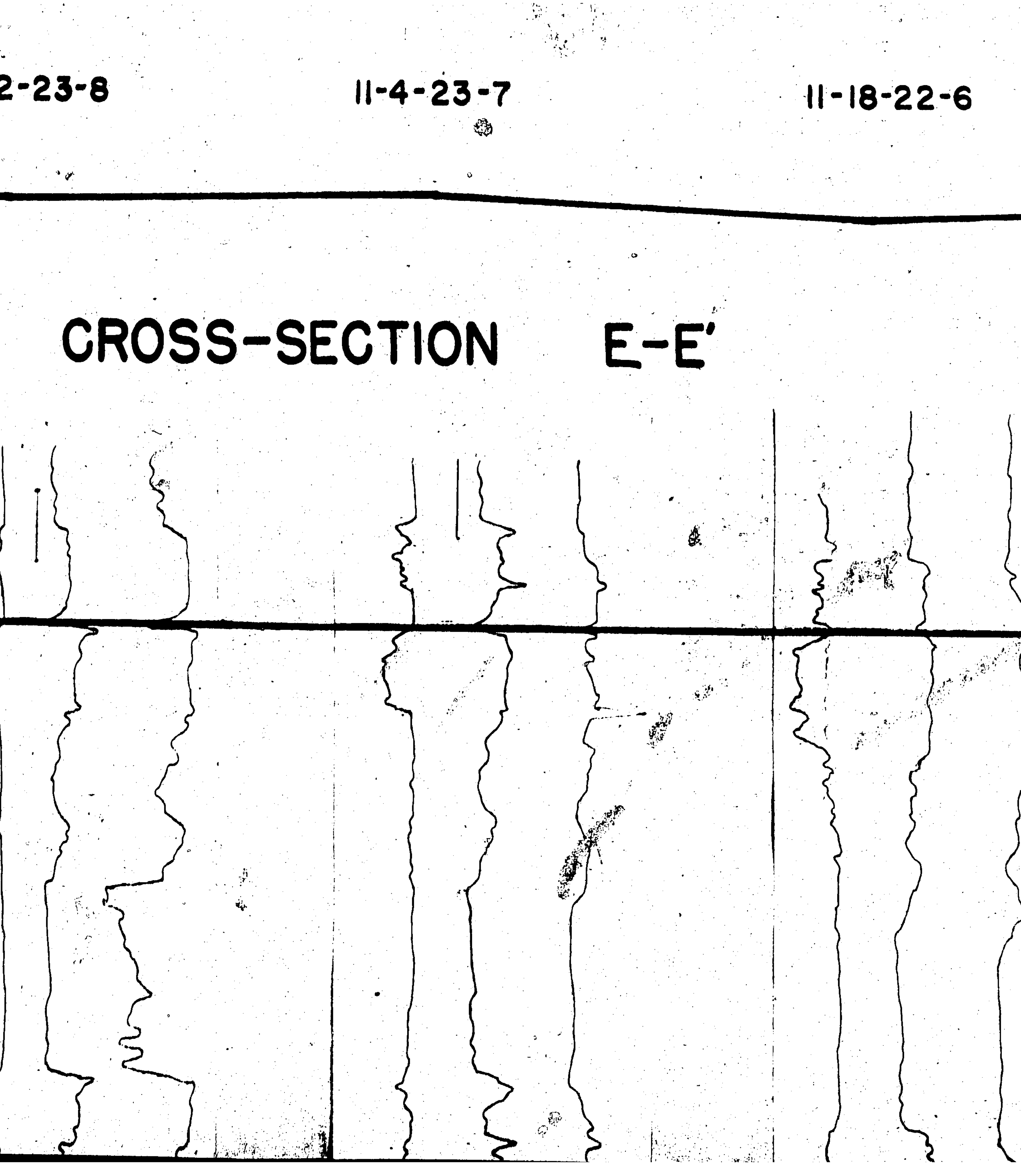
BASE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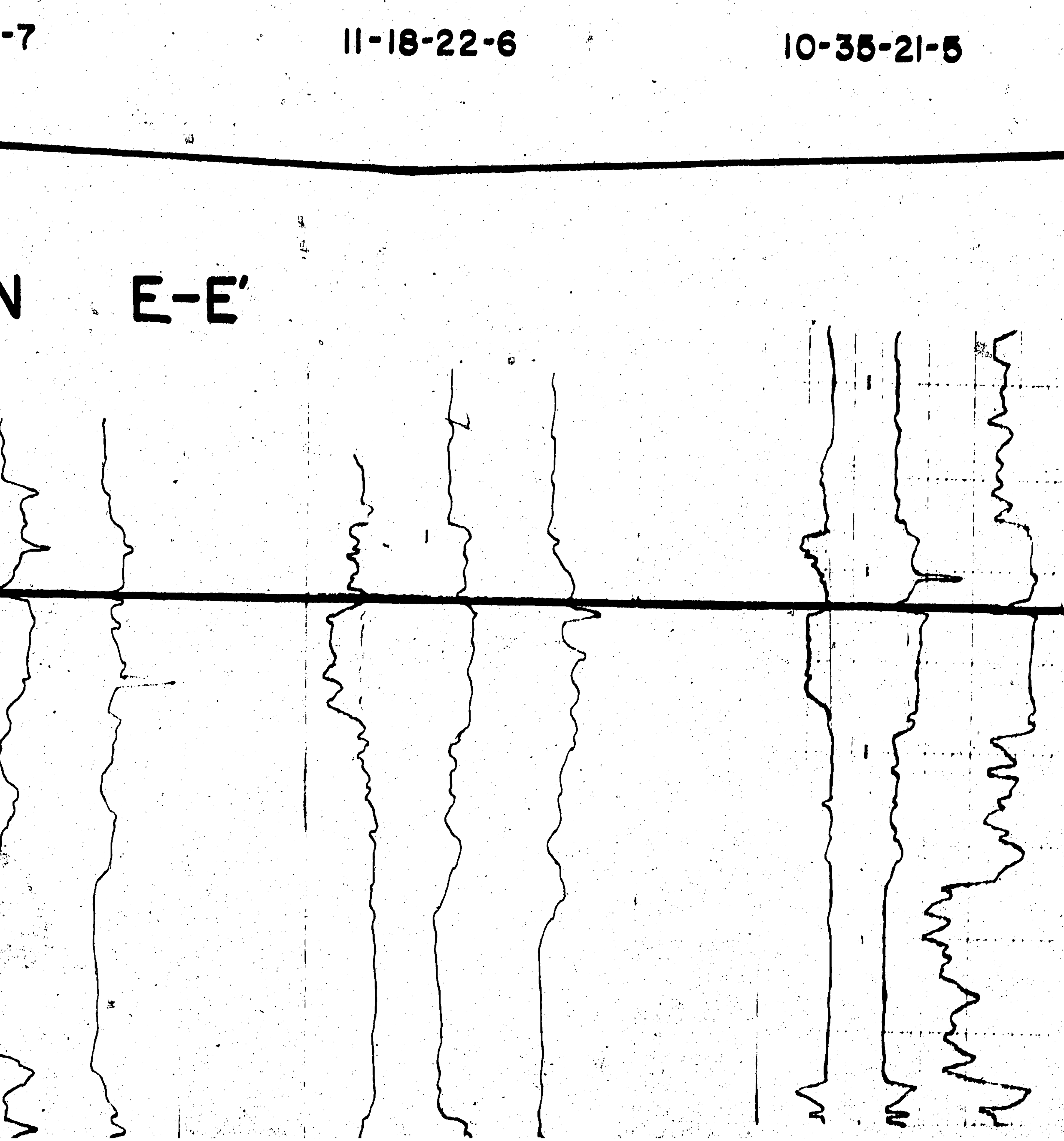
11-4-23-7
11-18-22-6
CROSS-SECTION E-E'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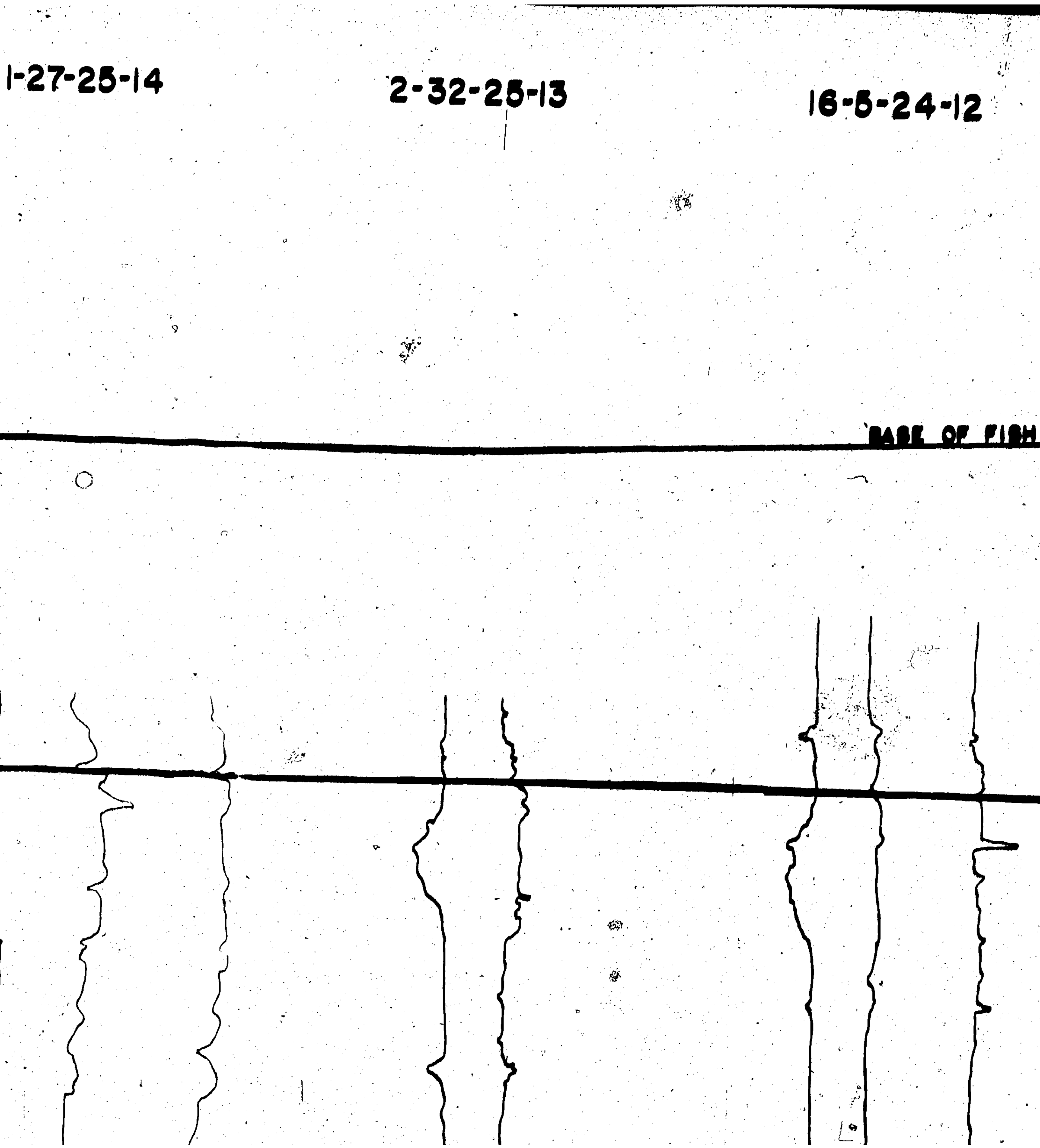
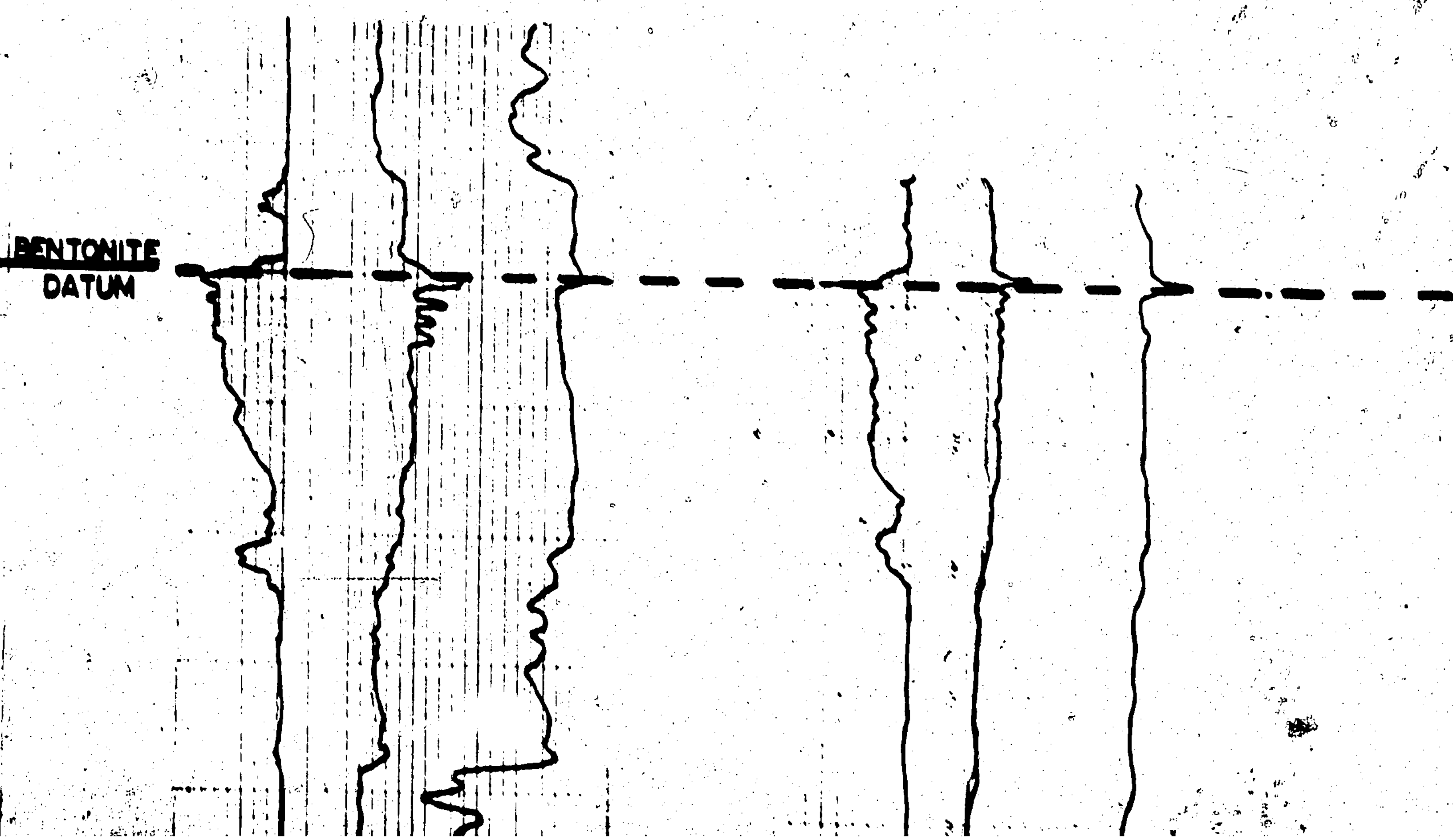
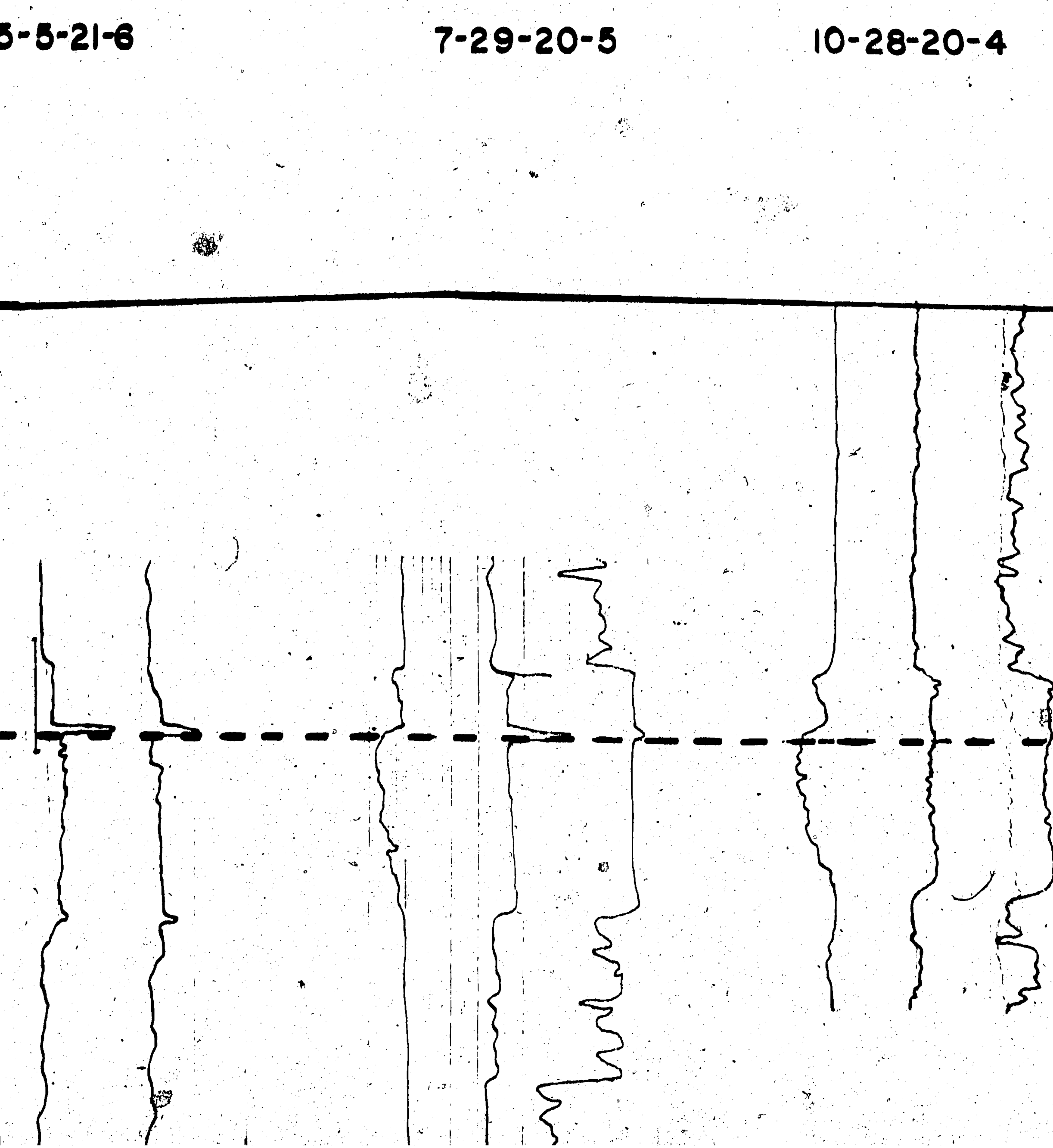
10-35-21-5
N E-E'


1-27-25-14
2-32-25-13
16-5-24-12
BASE OF FISH

6-6-22-8 15-16-21-7

CROSS-SECTION F-F'

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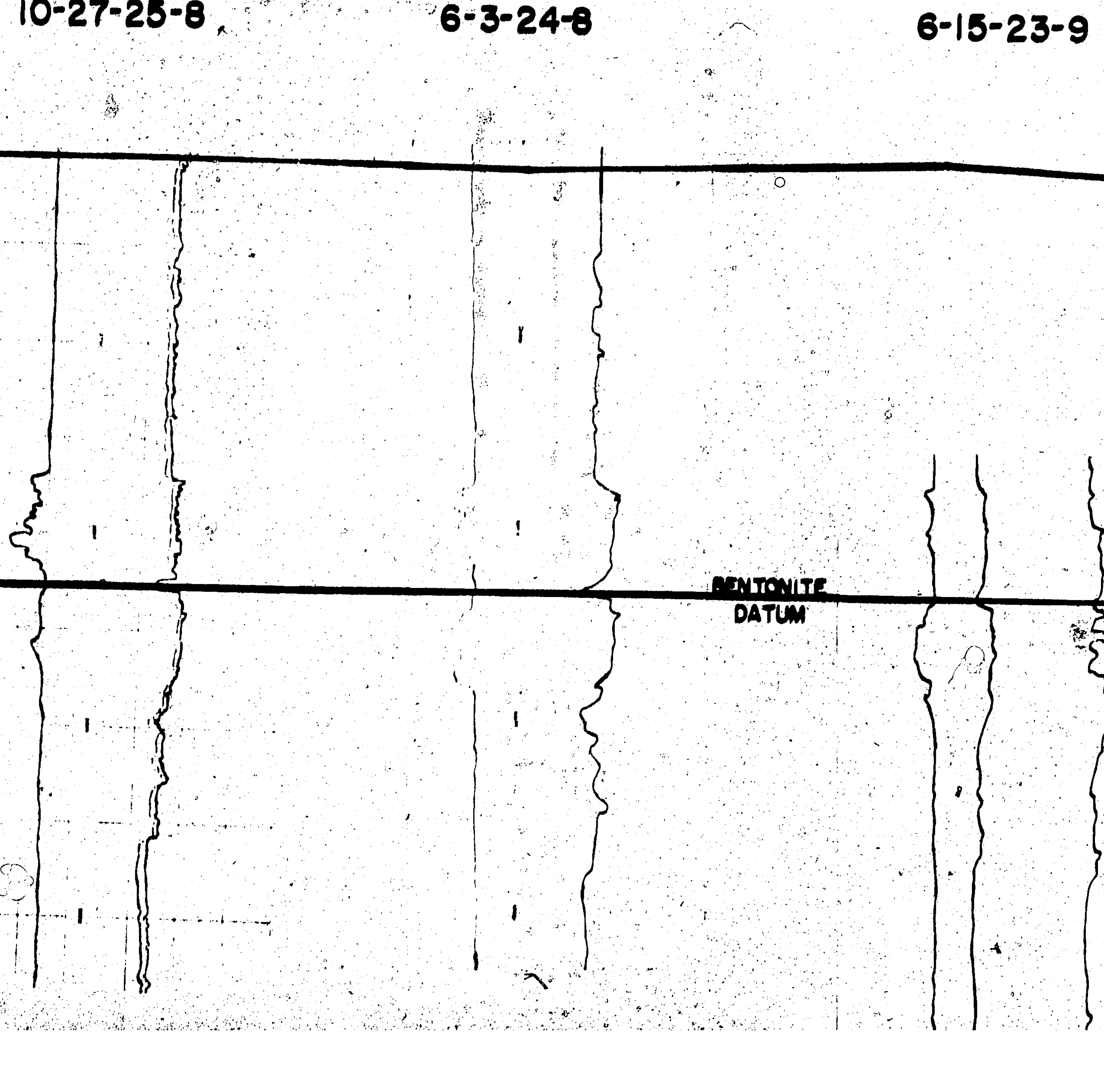
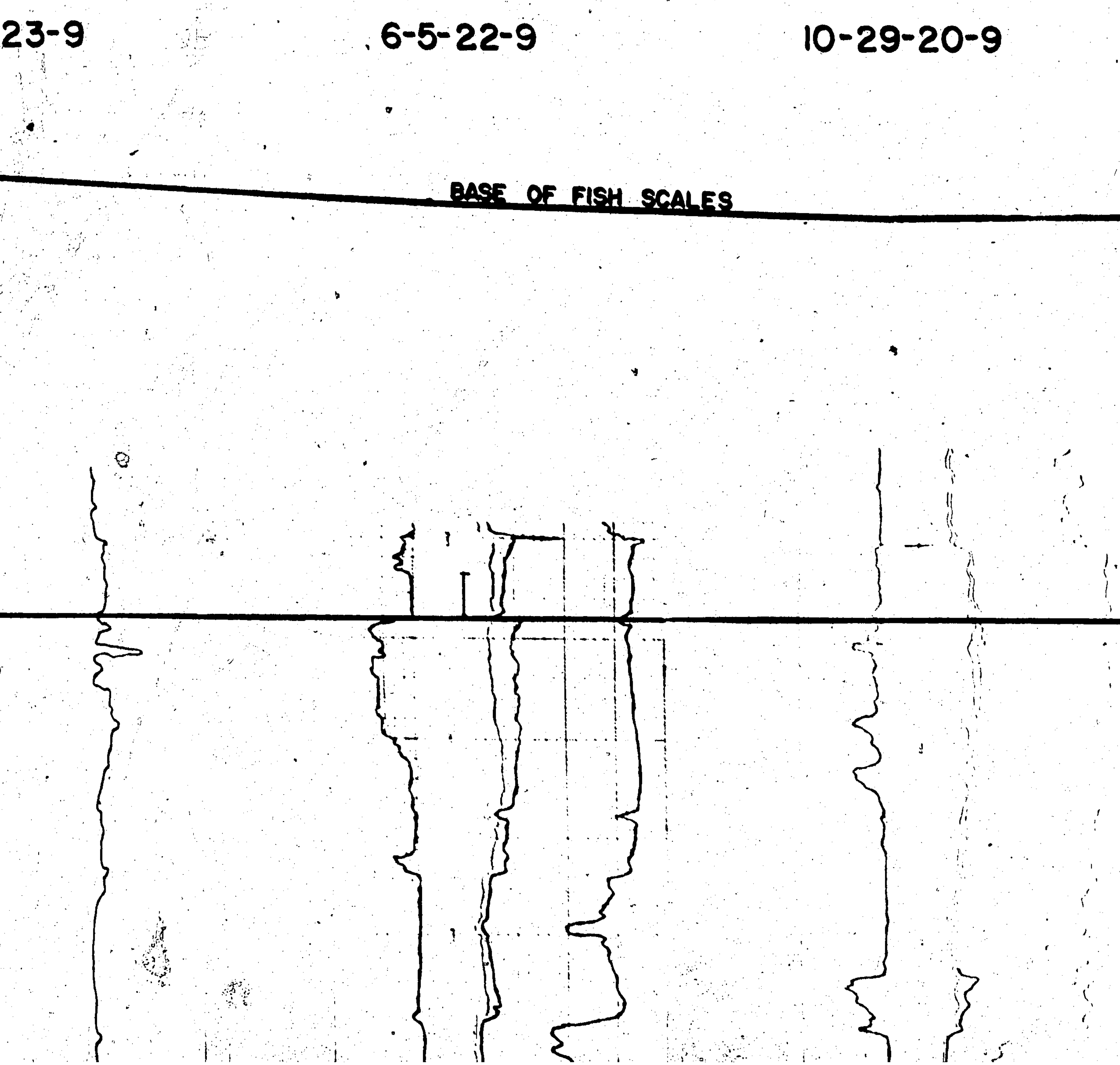
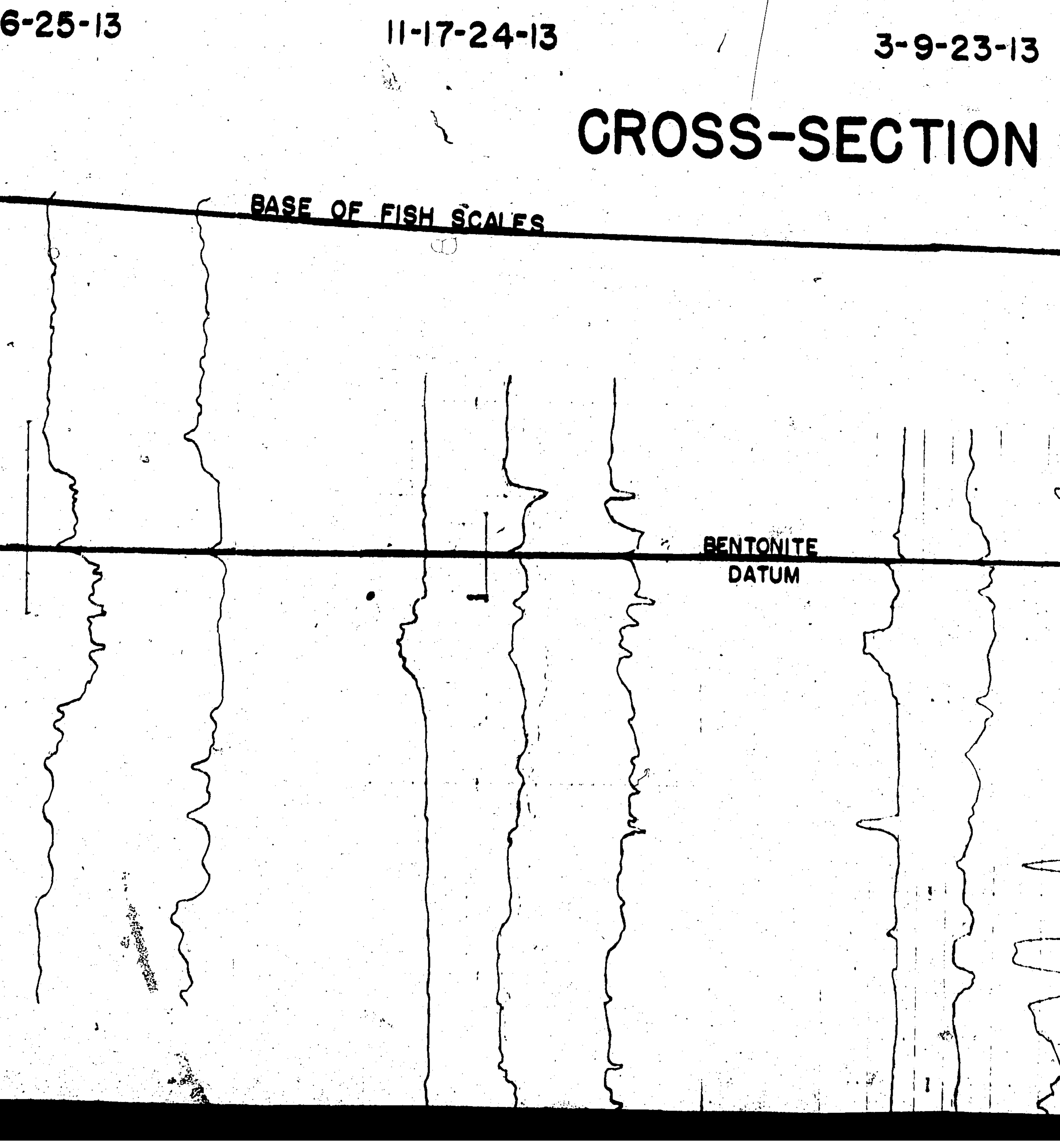
CROSS-SECT



ECTION G-G'




6-25-13
11-17-24-13
3-9-23-13
CROSS-SECTION
BASE OF FISH SCALES
BENTONITE
DATUM