THE UNIVERSITY OF CALGARY

LATE QUATERNARY HISTORY OF THE BOW RIVER VALLEY NEAR BANFF, ALBERTA

BY

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Late Quaternary History of the Bow River Valley Near Banff, Alberta" submitted by Raymond Allan Kostaschuk in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Surficial deposits in a 39 km^2 area of the Bow River Valley bear Banff, Alberta were examined in order to (1) map Late Quaternary sediments in the area, (2) interpret the deposits with respect to their processes, and (3) to postulate a Late Quaternary history of the sediments. Data provided by exposures, auger, split-spoon, and borehole cores, and the stratigraphic position of Bridge River and Mazama volcanic ashes was used to determine the Late Quaternary history.

Late Wisconsin glaciofluvial and glaciolacustrine sediments were deposited in the lower Spray River and Cascade River valleys during the final, Canmore (Rutter, 1972), glacial advance in the Banff area. With the Canmore retreat glacial till and outwash blocked the drainage of the Bow Valley immediately west of Banff, and Lake Vermilion formed in this basin. Evidence for the existence of Lake Vermilion includes thick accumulations of glaciolacustrine sand, silt, and clay, a beach deposit, lacustrine terraces and an aeolian beach ridge. The lake surface reached a maximum elevation of 1410 m in the late glacial, then lowered and stabilized at 1360 m by 6,600 B.P.

Two distinct alluvial fan types are represented in the study area. Debris flow fans composed of large, mud supported clasts were active in the Early Holocene, becoming inactive prior to 6,600 B.P. Fluvial fans composed of well sorted gravels have remained active throughout the Holocene.

Loess deposits are common in the Banff area. Loess deposition rates from 6,600 B.P. to 2,500 B.P. are between 0.17 mm

yr^{-1} and 0.18 mm yr^{-1}, and from 2,500 B.P. to the present range from 0.16 mm yr^{-1} to 0.23 mm yr^{-1}.

With the stabilization of the lowest stand of Lake Vermilion at 6,600 B.P., a fine grained river-dominated delta prograded from the west and eventually infilled the lake. Coarsening upwards sequences in the cores, the stratigraphic position of Bridge River and Mazama ashes, and surface features such as abandoned distributaries, inter-distributary ponds and thick peat accumulations provide the evidence for the delta progradation. The present Vermilion Lakes are inter-distributary ponds formed as the delta prograded and minor distributary channels extended north into Lake Vermilion. In modern times, sedimentation into the Vermilion Lakes by flood stages of the Bow River has been retarded by the Canadian Pacific Railway.

ACKNOWLEDGEMENTS

The writer gratefully appreciates the supervision and inspiration of Dr. D.G. Smith during the development of this research. The Faculty of Graduate Studies, the Department of Geography, and the Natural Sciences and Engineering Research Council provided financial support for this study, and Parks Canada supplied the sampling permit necessary for Banff Park.

Special thanks go out to Rod Kostaschuk for his assistance during the coring program, and to Heather Field for logistical and moral support throughout the project. Finally, appreciation is extended to the Lord above for delaying a bout of mononucleosis until after my field work was completed.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 Purpose of Study

The major research objectives of the study are threefold, first to map Late Quaternary sediments in the Banff area, second to interpret the deposits with respect to their processes, and third to postulate a sequential history of sedimentation and to discuss new interpretations that may arise from the research. An improved knowledge of the geomorphology in the Banff area would be of considerable use for the interpretative program at Parks Canada. The variety of Late Quaternary landforms in the Banff town region suggested that the area has a complex depositional history that has not yet been adequately interpreted, as a result, this investigation was initiated.

1.2 Previous Studies in the Banff Area

Prior to the work of Rutter (1965, 1966a, 1966b, 1972) very little research had been carried out on the Late Quaternary sediments in the Banff area. In 1861, James Hector, with the Palliser expedition, recognized till deposits and attributed them to ice-rafting. Dawson (1861) suggested that the Bow River once discharged via the Lake Minnewanka Valley. Warren (1927) commented on the glacial geology, the possible drainage changes, and the lakes in the Banff area; he noted that thick accumulations of glacial drift were present on the lower mountain slopes, but occurred only in sheltered patches in the Bow and Spray Valleys due to post-glacial fluvial erosion. Also Warren (1927) found erratic boulders at elevations up to 8,000 feet on Sulphur and Cascade Mountains, indicating that glacial ice had reached at least that height. He postulated that the pre-glacial

Bow River may have once flowed on the north side of Tunnel Mountain, but subsequent thick deposits of till, located northeast of the mountain forced the Bow to relocate south of Tunnel Mountain. The Vermilion Lakes were interpreted as being the remnants of a much larger body of water which occupied the Bow Valley in post-glacial time.

Rutter (1965, 1966a, 1966b, 1972) examined the geomorphology and surficial deposits of the Bow Valley and postulated a late-glacial chronology for the region. He found evidence for three or four major Wisconsin glacial advances and retreats. The earliest glacial activity in the Bow Valley is represented by a thick deposit of outwash overlying bedrock. The next glacial advance, termed the Bow Valley advance, is indicated by breaks in slope on the valley sides, formed by glacial scour and lateral glaciofluvial erosion, and a thick blanket of till overlying the previously mentioned outwash. Rutter (1972) suggested that the Bow Valley advance extended well into the foothills. The Bow Valley ice retreated to the Banff town area, depositing a particularly thick layer of till in the area immediately north east of Tunnel Mountain. A readvance of the Bow Valley ice, termed the Canmore advance, is evidenced by breaks in slope on the valley sides and patches of till overlying till and outwash associated with the Bow Valley retreat. The Canmore advance probably extended as far east as Seebe. The last major advance in the Bow corridor is termed the Eisenhower Junction as indicated by breaks in slope, fresh cirques, ground, lateral, and a terminal moraine. Rutter (1972) tentatively correlates the Bow Valley, Canmore, and Eisenhower Junction advances with the three stades of the Late Wisconsin Pinedale glaciation of the western United States.

Rutter (1972) placed little emphasis on post-glacial deposits. He described the modern Bow River flood-plain as silty sand and gravel, and also noted the presence of Holocene landslides, talus, colluvium, ponds, aeolian sand dunes, loess, and alluvial fan deposits in the area. Mazama ash in association with loess in the region is also mentioned.

Roed and Waslyk (1973) examined a number of alluvial fans near Banff. The stratigraphic position of Mazama ash found near the surface of one fan indicated that most of the sediment was deposited prior to 6,600 years B.P., the date of the ash. The lower portion of the fan is composed of debris flow deposits characterized by large angular clasts supported by a fine grained matrix. Roed and Waslyk (1973) indicated that the debris flow sediments were associated with a period of marked debris flow activity in the early post-glacial period. Deposition stratigraphically above the debris flow sediments consists of better sorted alluvium. They suggest that the present inactive nature of the fans represents a distinct climatic period between the Canmore retreat (Rutter, 1972) and the altithermal. This fan history corresponds with the 'paraglacial' fan model proposed by Ryder (1971) for south-central British Columbia. Ryder (1971) also pointed to the greater magnitude of mud flow events and subsequent rapid sedimentation and fan development immediately after deglaciation, followed by relative fan inactivity in post Mazama time.

E.B.A. Engineering Consultants of Calgary (1978) performed a geotechnical investigation of sediments in the Vermilion Lakes region near Banff. Their field work consisted of a seismic survey, field reconnaissance and terrain typing, a muskeg probe survey, a drilling program and geophysical logging, and a penetrometer probe survey. Based on the data collected, they believe that the valley fill beneath the Vermilion Lakes extends to depths of 163 to 307 m. The upper 6 to 22 m. consists of silty-sand and some gravel overlying silt and clay.

The Bow Valley Naturalists (1978) produced a short field guide on the Vermilion Lakes. The depositional history for the area is outlined as follows. With the Canmore retreat (Rutter, 1972), the valley floor was covered by an outwash plain straddling Tunnel Mountain. The river course south of Tunnel Mountain eventually captured all the flow. With the subsequent reduction of sediment load supplied to the Holocene Bow River, a single meandering channel developed. Levee development impeded drainage from the Bow River and a backswamp resulting in the Vermilion Lakes formed. Influences from crevasse splays, distributary channel development, organic production, and animals and man aided in producing the present conditions of the floodplain.

A number of authors have examined the distribution of tephras in the Banff Park region (Westgate and Dreimanis, 1967; Duford, 1976; Brewster and Barnett, 1979). Tephra has been defined as all airborne clasts, including airfall and flow pyroclastic materials (Westgate and Gold, 1974), consisting of glass shards and heavy and light phenocryst mineral grains (Fulton, 1971). At least three distinct tephra types have been identified in the region, Mazama, dated at 6,600 years B.P., St. Helens Y at 3,500 years B.P., and Bridge River at 2,500 years B.P. (Westgate, et al, 1970). Two additional tephra deposits, as yet undated, appear to occur in Banff Park (Brewster and Barnett, 1979). Only a few workers in Banff Park (Smith, D. G., 1973; Smith, N. D., 1975; Roed and Waslyk, 1973) have used the tephras in stratigraphic studies. Both Smith, 1973, and Smith, 1975, used tephras to determine rates of aggradation of alluvial valley fill deposits. Roed and Waslyk, 1973, used Mazama ash as a stratigraphic marker in their studies on alluvial fans to interpret reduced sedimentation rates with time.

1.3 Present Study

A number of days were spent in the study area in the autumn of 1978 in order to determine the feasibility of the project. Upon deciding to proceed with the study, a thorough examination of appropriate panchromatic vertical aerial photographs was made. Photographs along flight lines A 20145 were acquired from the Geological Survey of Canada, and exposures of surficial deposits and potential drill sites were identified on the photographs. River patterns and the geomorphology of surface deposits were also identified and mapped from the aerial photographs, and navigation was greatly facilitated through the use of the photographs. Topographic map 82°/4 East Edition 1 ASE series A 741 at a scale of 1:50,000 was used to map sample and core locations.

The field investigation was initiated in May, 1979, and continued through August, 1979. The laboratory analysis of sediment grain size and tephra samples began in September, 1979, and was completed in January, 1980.

CHAPTER 2. PHYSICAL ENVIRONMENT

2.1. Study Area

The study area is situated in the Bow Valley near Banff, Alberta (Fig.1). The floor of the Bow Valley and a number of the side valley tributaries are the chief areas of investigation, bounded by Brewster Creek on the west and Carrot Creek on the east. The study reach is 17.5 km. in length and varies from 1.25 to 3.25 km. in width covering an area of approximately 39 $km.^2$

2.2 Bedrock Geology

A number of geologists have examined aspects of the bedrock geology of the Banff area (McConnell, 1886; Warren, 1927; North and Henderson, 1954). The Banff area is located within the Front Ranges structural Sub-Province of the Rocky Mountains (North and Henderson, 1954). The stratigraphic units in the area range in age from Cambrian to Cretaceous. The Paleozoic formations are chiefly limestones and dolomites while the Mesozoic rocks are represented by thinly bedded clastics such as sandstones, shales and argillaceous limestones (Warren, 1927). Over thrusting from the southwest caused the deeper more resistant Paleozoics to over-ride the weaker, younger Mesozoic rocks. The mountains tend to be composed of Paleozoic Units while the valley bottoms consist of Mesozoic rocks (Rutter, 1972).

2.3 Physiography

Rutter (1972) divides the Banff area into two distinct physiographic units, the Alpine Region and the Major Valleys Region. The Alpine Region comprises the higher levels of mountains bordering

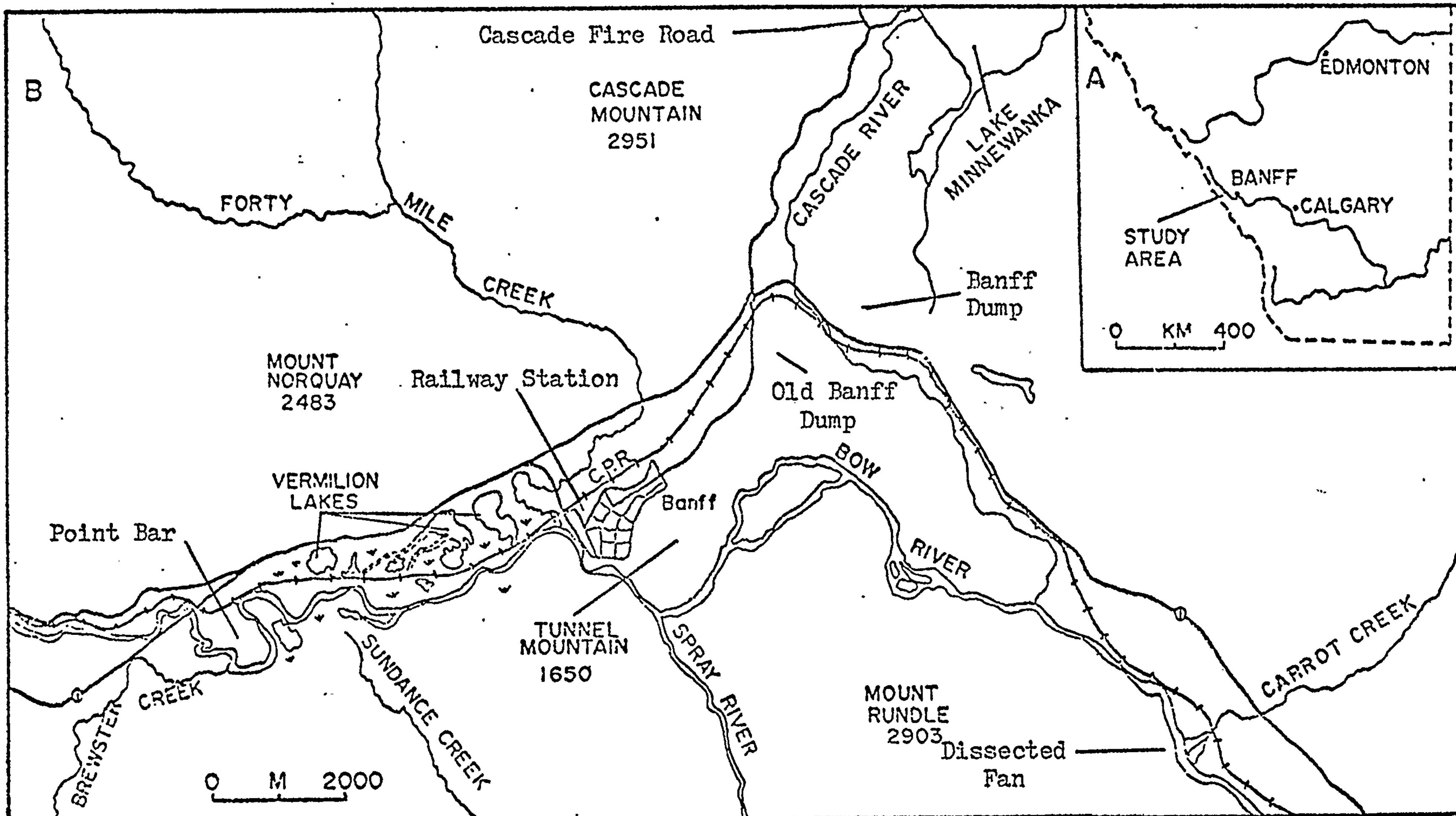

Figure 1: Study area. (A) Location in southern Alberta.
(B) Principal physiographic and cultural features.

the Bow River and some of the tributaries. The combination of southwest dipping bedding planes and narrow belts of contrasting lithology of the Front Ranges has produced serrated ridges and jagged peaks, Mount Rundle being a prime example. Assymetric valley slopes result from the lithology and structure; the southwest facing wall is usually a dip slope, whereas a variety of rocks are exposed stratigraphically on the northeast back slope.

The Major Valleys Region includes the valleys of the Bow River and adjacent major tributaries. The larger valleys are U-shaped, as are some of the hanging tributary valleys. Except for the modern floodplain and some areas associated with mass wasting processes and alluvial fan development, the Bow Valley floor is covered with till and glaciofluvial deposits.

2.4 Climate

The climate of the study area is determined by the high mountain elevations, and the western interior location which is separated from the Pacific by a series of mountain barriers (Scace, 1968). Variation in annual precipitation depends on the relative frequency and influx of maritime polar and maritime tropical air, and the degree to which this air is uplifted cyclonically, orographically and conventionally. Maritime polar air masses from the west are the dominant precipitation source while polar continental air from the northeast produces cold dry winter weather. Rare incursions of maritime tropical air from the Gulf of Mexico can produce considerable precipitation (Byrne, 1964). Great areal variation exists in annual precipitation. On the high ridges 120 to 240 cm of precipitation, mostly as snow, may fall. Lower intermontane valleys may receive as little as 60 cm, most of which falls as rain in the spring and summer months (Scace, 1968).

Gardner's (1968) comments on temperature variation in the Lake Louise area are applicable to Banff. All months have above and below freezing temperatures with the winter months having much more variable temperatures year to year, due to chinooks, as compared to the summer months. Maximum daytime temperatures on the south facing slopes exceed those of north facing slopes, while maximum night time temperatures are the same on both exposures. Fig. 2 shows thirty year averages for temperature and precipitation for Banff town at an elevation of 1375 m.

2.5 Hydrology

The Historical Streamflow Summary for Alberta (1976) provides hydrologic data from the Bow River at Banff. The Bow River drainage basin above Banff covers 2,210 km^2, and discharge records for Banff begin in 1909 and extend to the present. Figure 3 summarizes the monthly mean, maximum and minimum discharges for this station between 1909 and 1976. Discharge is lowest in the winter months, December through March. As snowmelt begins at lower elevations in April, discharge begins to increase. During May and June snowmelt at higher elevations produces a considerable increase in discharge which peaks in June. From June through November there is a general discharge decrease as snowmelt and glacier melt declines.

MONTHS	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
TEMPERATURE (°C)	-11	-8	-3	3	8	11	15	13	9	4	-3	-9	2.4
PRECIPITATION (CM)	2.5	2.8	2.5	2.8	4.3	6.5	4.0	5.0	4.0	3.8	3.3	4.0	45.3

Figure 2: Thirty year averages for temperatures and precipitation for Banff Alberta, at an elevation of 1375 m.

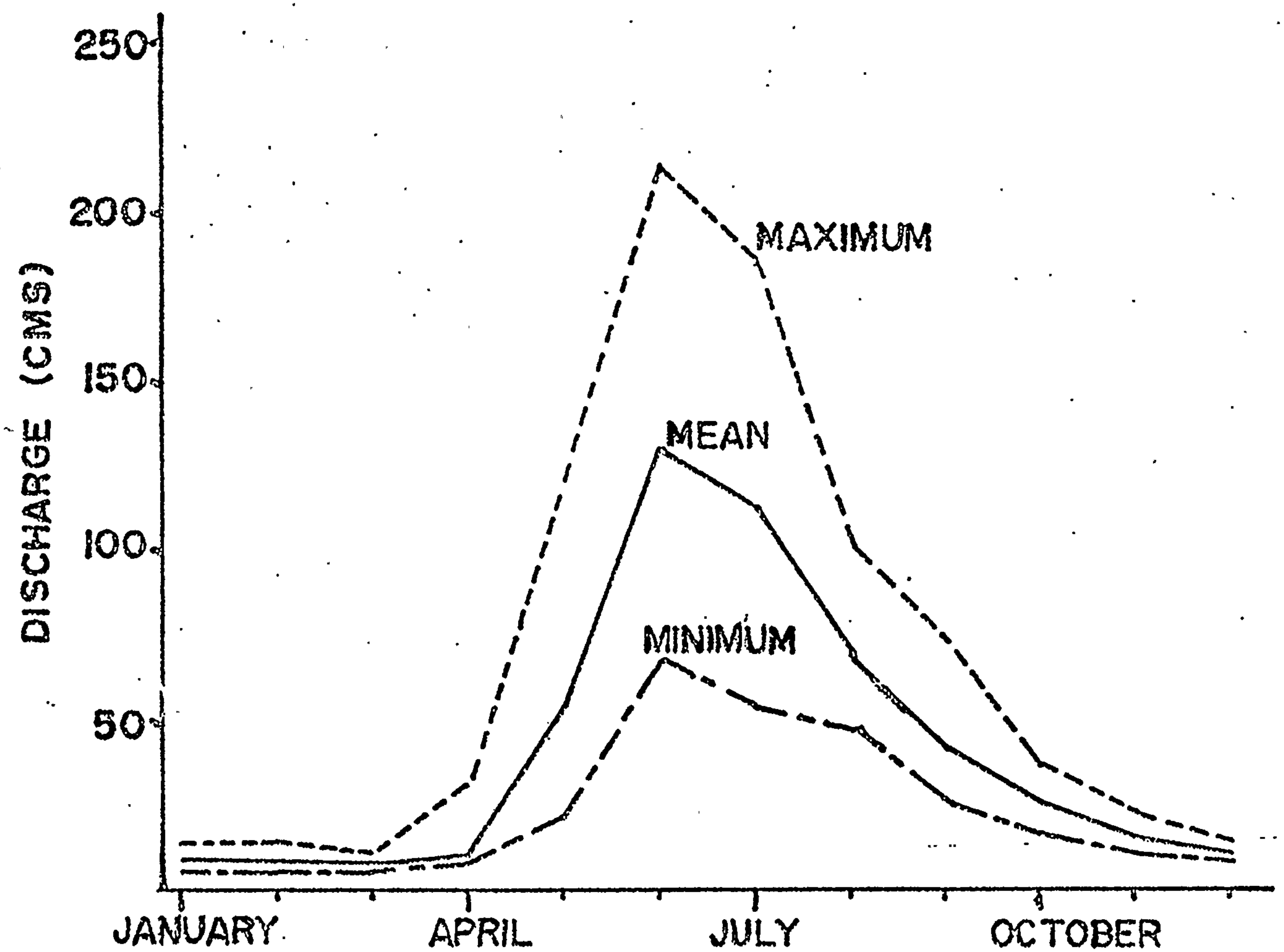

Figure 3: Monthly mean, maximum, and minimum discharges for the Bow River, Banff, Alberta, 1909-1976.

2.6 Vegetation and Soils

The vegetation and soils in the study area have been outlined by Taylor, et al (1977) as part of a biophysical land classification for Banff National Park. The vegetation is divided into three ecological zones, the montane, sub-alpine, and alpine zones. The montane vegetation is characterized by grasslands and savannas in the valley bottoms and Douglas Fir, lodgepole pine, white spruce and aspen forests on the lower valley sides. Wetlands in the Vermilion Lakes are dominated by willow and sedge fen. The sub-alpine zone occurs at elevations above the montane zone and below the alpine zone and consists primarily of lodgepole pine, spruce, buffaloberry, alpine larch, heather, Engelmann spruce, sub-alpine fir, and grouseberry. The alpine zone is above the tree line and is composed of dwarf shrub heath tundra, mountain avens tundra, and crustose lichen tundra.

Five soil orders of the Canadian soil taxonomy are found in the study area, Brunisols, Podzols, Regosols, Gleysols, and Organic soils. Brunisolic soils are likely to be found on gently sloping till deposits and are generally associated with some alpine tundra, grassland, grassy meadow, and some forest vegetation. Podzols occupy cool moist environments at high elevations in conjunction with Engelmann spruce, sub-alpine fir, and sub-alpine larch forest communities. Regosols are associated with unstable surfaces such as fans and active floodplains and occur with herbaceous meadows or shrub thickets. Gleysols and Organics are wetland soils. Gleysols are likely to be found at the contact between mineral and organic areas, and Organic soils in areas of peat accumulation such as the Vermilion Lakes.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Introduction

The following section is designed to summarize the field and laboratory techniques employed in this research. Standardized techniques were used when possible to ensure that the results were comparable to those of other researchers. Results will be discussed as they apply to the following chapters on the depositional history of the study area.

3.2 Field Work

3.2.1 Exposures

Exposures of Late-Quaternary sediments in the study area were mapped, sampled, and interpreted with respect to their origin. Stream cuts, road cuts, and construction sites provided the majority of the exposure sites. Each exposure is discussed with respect to the landform it is associated with and the position of that landform in the depositional history of the area.

3.2.2 Soil Augers

A modified hand powered soil auger was used to bore 75 holes in the Bow River floodplain sediments in the study area. Thirty-one cores were recovered from the Vermilion Lakes reach of the Bow River, while the remaining holes were augered in reaches immediately upstream and downstream of the Vermilion Lakes. Under ideal conditions, such as relatively cohesive silts and clays, cores up to 6 m. in length were recovered. Auger core sediments were logged and sampled at each site. Auger locations in the Vermilion Lakes reach are

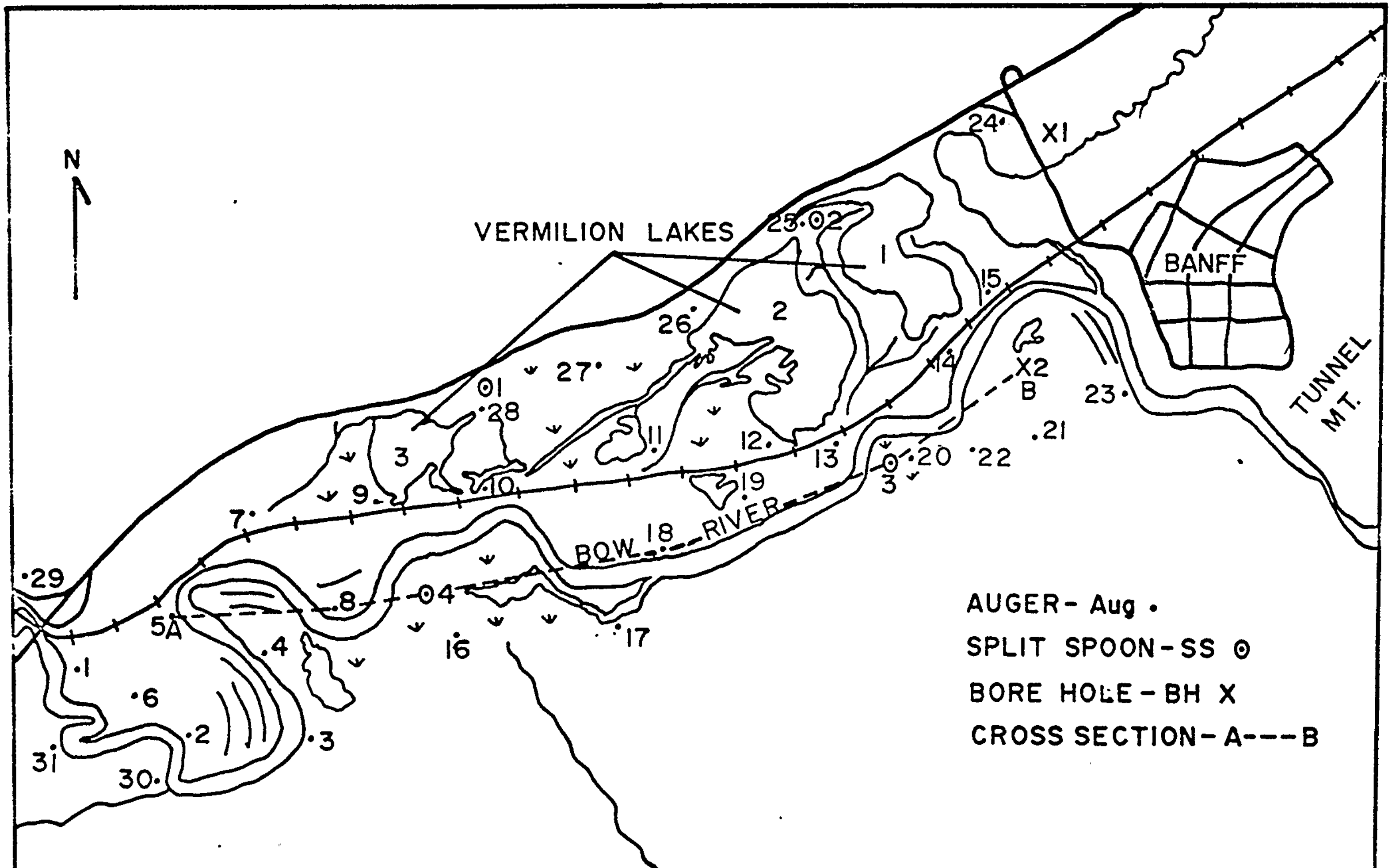

Figure 4: Core locations in the study area.

designated by the symbol Aug., and are shown on Fig.4.

3.2.3 Split Spoon Sampler

A percussion split spoon coring device which drives a core barrel down to depths of 15 m. was used at selected sites in the Vermilion Lakes reach. The location of sites was based on the favourable sites tested by the auger. Four deep cores were obtained, wrapped in plastic to prevent moisture loss, and returned to the lab for logging and textural analysis. The symbol SS is used to indicate a split spoon core, and core locations are shown on Fig.4.

3.2.4 E.B.A. Boreholes

As mentioned in Chapter 2, E.B.A. Engineering carried out a geotechnical evaluation of sediment in the Vermilion Lakes area. Of particular interest to my study are results from the two 60 m boreholes drilled at the eastern end of the Vermilion reach. I obtained the original hydrometer and sieve analysis from the borehole samples taken by E.B.A., and used them for my interpretation. Other facets of their investigation were also of considerable use to the present study. Borehole locations are designated by BH and are shown on Fig.4.

3.3 Laboratory Techniques

3.3.1 Hydrometer

The hydrometer technique, as described by Folk (1974), was used to determine the grain size distributions of silt and clay sized samples. Use of the hydrometer was prompted by three considerations. First, it is a much less time consuming method than that of the pipette. Second, the Wilcoxon Matched Pairs Signed Rank test (Siegel, 1954) was used to compare graphic statistics obtained from hydrometer and pipette analyses of identical samples, and no significant difference was found. Both methods, then, produce similar results. Third, as E.B.A. Engineering (1978) used the hydrometer method, it was felt the same technique should be used to ensure consistent results.

Material coarser than silt and clay was removed from each sample by washing the fines through a 4 ∅ sieve which represents the boundary between sand and silt fractions (Krumbein, 1934). The coarser material was retained to be analyzed with the visual accumulation tube, and the finer sediment was prepared for hydrometer analysis. Organic matter was removed from the silt and clay with a pre-treatment of a 10% solution of hydrogen peroxide (H_2O_3) which was allowed to sit for 24 hours. One hundred cc. of Calgon (NaH_6PO_4) dispersant was then added to the sample and allowed to react for 24 hours. The sample mixture was then agitated for 5 minutes with an ASTM shaker and the contents transferred to a settling cylinder which was topped up to 1 litre with distilled water. Immediately prior to sampling, the suspension was mixed with a stirring rod to ensure an even vertical distribution of sediment.

Readings were taken with the hydrometer at times representing one half ∅ intervals (Krumbein, 1934; Folk, 1974) from 30 seconds (4.0 ∅) to 24 hours (10.0 ∅). The per cent of the total sample remaining in suspension after each reading, P, was determined by the formula:

$$P = \frac{G}{G-1} \cdot \frac{V}{Ws} \; Vc\,(r - r_w)\,100$$

where:

G = 2.65 gm cc^{-1}

V = volume of the cylinder = 1000 cm^3

Ws = weight of sample in gm.

Vc = viscosity of water at 20°C = 0.998

r = sample hydrometer reading

r_w = control hydrometer reading

3.3.2 Visual Accumulation Tube and Sieving

Sand fractions were analyzed with the 180 cm Visual Accumulation tube (Folk, 1974). The setting tube has a number of limitations (Rubey, 1933; Watson, 1969), the most important being the fact that the high sediment concentration at the top of the tube may produce a 'turbidity-current' effect whereby smaller grains are dragged down by larger ones, and inaccuracies may result. In spite of the limitations, a number of authors (Schlee et al, 1965) have found this method gives precise enough results for the determination of mean grain size and sorting of the sediment. As with the hydrometer, settling tube measurements were taken at one-half ø intervals.

Sediment coarser than sand was analyzed by the sieve technique (Folk, 1974) using sieves stacked at one ø intervals. Sieve accuracy depends on the precision of calibration of the sieve screens, the size of sample, the type of mechanism used to shake the sieves, and the length of time of shaking (Ludwick and Henderson, 1968). For this study Endecott U.S. Standard Laboratory Sieves and a Soiltest CL-390-K shaker were utilized. One hundred grams of sample were shaken for 10 minutes. Pre-treatment of the sand and gravel fractions was restricted to disaggregation by mortar and pestle.

3.3.3 Graphic Statistics

The results from hydrometer, settling tube and sieve analyses were plotted on probability-normal paper, and the median, mean, standard deviation and skewness were calculated from the following equations for each sample (Folk and Ward, 1957):

$$\text{Median, } Md = \phi 50$$

$$\text{Mean, } M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$\text{Standard Deviation, } 6_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$\text{Skewness, } S_k = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

The graphic statistics outlined above are not the only way to summarize the properties of a grain size distribution, moment measures, analysis of straight line segments of the distribution (Visher, 1969), and a number of other techniques are also utilized (Blatt, et al, 1972). The use of graphic statistics is the most commonly used method and as such has been chosen for this study.

A variety of size grade scales for sediment are available, but for the purposes of this study the U.S.D.A. scale is considered the most appropriate. Material larger then -1ϕ is gravel, and particles from -1ϕ to 4ϕ in diameter are sand. Sand is further sub-divided in 1ϕ intervals into very coarse, coarse, medium, fine, and very fine sand. Sediment between 4ϕ and 8ϕ is silt, and material finer than 8ϕ is clay.

The verbal scale for sorting used in this study is that of Folk (1968). Sediment with a standard deviation, σ_I = 0.50 - 0.71 is moderately well sorted and 0.71 - 1.00 is moderately sorted. Material with σ_I = 1.0 - 2.0 is classed as being poorly sorted, and $\sigma_I > 4.0$ is extremely poorly sorted. Skewness values are described as either positive or negative according to the sign of the S_k value.

3.3.4 Tephra Analysis

A number of methods have been used to differentiate among the various tephra types (Ferguson, 1978), the most effective being the electron microprobe technique (Duford, 1976; Brewster and Barnett, 1979). This technique was used by R. L. Barnett to provide a major element analysis on magnetite particles that I had removed from tephra samples collected in the study area. Magnetite particles with an analysis of magnesium oxide (MgO) and aluminum oxide (Al_2O_3) below 2.00 weight %, and titanium oxide (TiO_2) below 8.00 weight % are classed as Bridge River, analyses with 8.00 to 14.00 % TiO_2 are classed as Mazama (R. L. Barnett, pers. comm.).

CHAPTER 4. LATE QUATERNARY DEPOSITS AND HISTORY

4.1. Introduction

This chapter deals with the Late Quaternary deposits in the study area including tephras, Late Wisconsin sediments, alluvial fans, loess, and deposits associated with Lake Vermilion. Rutter (1972) mapped the surficial deposits of the Bow Valley in considerable detail, and my study serves as a supplement to Rutter's mapping plus a re-interpretation as to the origin of some of the deposits. A detailed interpretation of the landform history of the Vermilion Lakes is reserved for Chapter 5.

4.2 Tephras

The results of the tephra analysis for ash samples recovered from the cores and exposures in the study area are summarized in Fig. 5. Most of the samples analyzed contained magnetite particles characteristic of both Bridge River and Mazama sources. A number of explanations may be offered for these results, the most probable being that there is a degree of overlap in MgO, Al_2O_3, and TiO_2 contents in magnetite particles. In all samples except the Carrot Creek fan one tephra type can clearly be determined, and this type is assigned as the tephra source for the sample. The Carrot Creek ash may represent a secondary deposition of Mazama particles during Bridge River fallout, or a new tephra type. The results summarized in Fig. 5 are interesting in that Bridge River ash had previously not been identified as far east as Banff, extending the tephra plume an additional 100 km eastward from Mosquito Creek fan (Brewster and Barnett, 1979).

TEPHRA LOCATION	NUMBER OF MAZAMA PARTICLES	NUMBER OF BRIDGE RIVER PARTICLES	INTERPRETATION
SS 3, 7.0 M	1	4	BRIDGE RIVER
SS 4, 1.25 M	3	0	MAZAMA
Aug 8, 1.05 M	0	2	BRIDGE RIVER
CARROT CREEK 0.87 M	8	8	BRIDGE RIVER OR UNKNOWN
CASCADE FIRE ROAD 1.45 M	11	3	MAZAMA
CASCADE FIRE ROAD 0.72 M	2	13	BRIDGE RIVER
OLD BANFF DUMP 0.40 M	7	12	BRIDGE RIVER

Figure 5: Results of analysis on magnetite particles from tephra samples in the study area.

4.3 Late Wisconsin Deposits

My investigation failed to uncover any new evidence to prove or disprove Rutter's (1972) sequence of glacial advances and recessions. A detailed search undertaken to locate dateable material in the tills and outwash met without success.

A thick glaciofluvial deposit was found on the north side of the present Cascade River Valley, located east of the Banff traffic circle (Fig. 6). Excavations from the Banff City Dump exposed a 10 to 15 m thick accumulation of well sorted sand (Appendix A). Climbing ripple drift cross laminations, trough cross beds and some thin clay drapes were noted in the exposure (Fig. 7). Cross stratification indicated a paleo current direction towards the east. This feature wraps around the valley side and extends a short distance up the eastern flank of the Cascade Valley towards Lake Minnewanka. The southern edge of the deposit terminates suddenly indicating the southern bank of the stream was composed of glacial ice. The grain-size characteristics, sedimentary structures, and valley side location of this deposit point to an origin as an aggrading sandy braided stream forming a kame terrace along the margin of an ice lobe. This deposit is probably associated with Rutter's (1972) Canmore advance, deposited when the ice extended down the Bow Valley.

A 15 m thick accumulation of extremely poorly sorted, positively skewed clay (Appendix A), interpreted as glacio-lacustrine in origin, is located at the lower end of the Spray Valley (Fig. 6). The lake associated with this sediment was probably formed as the Canmore advance (Rutter, 1972) moved down the Bow Valley blocking the drainage out of the Spray Valley. Associated

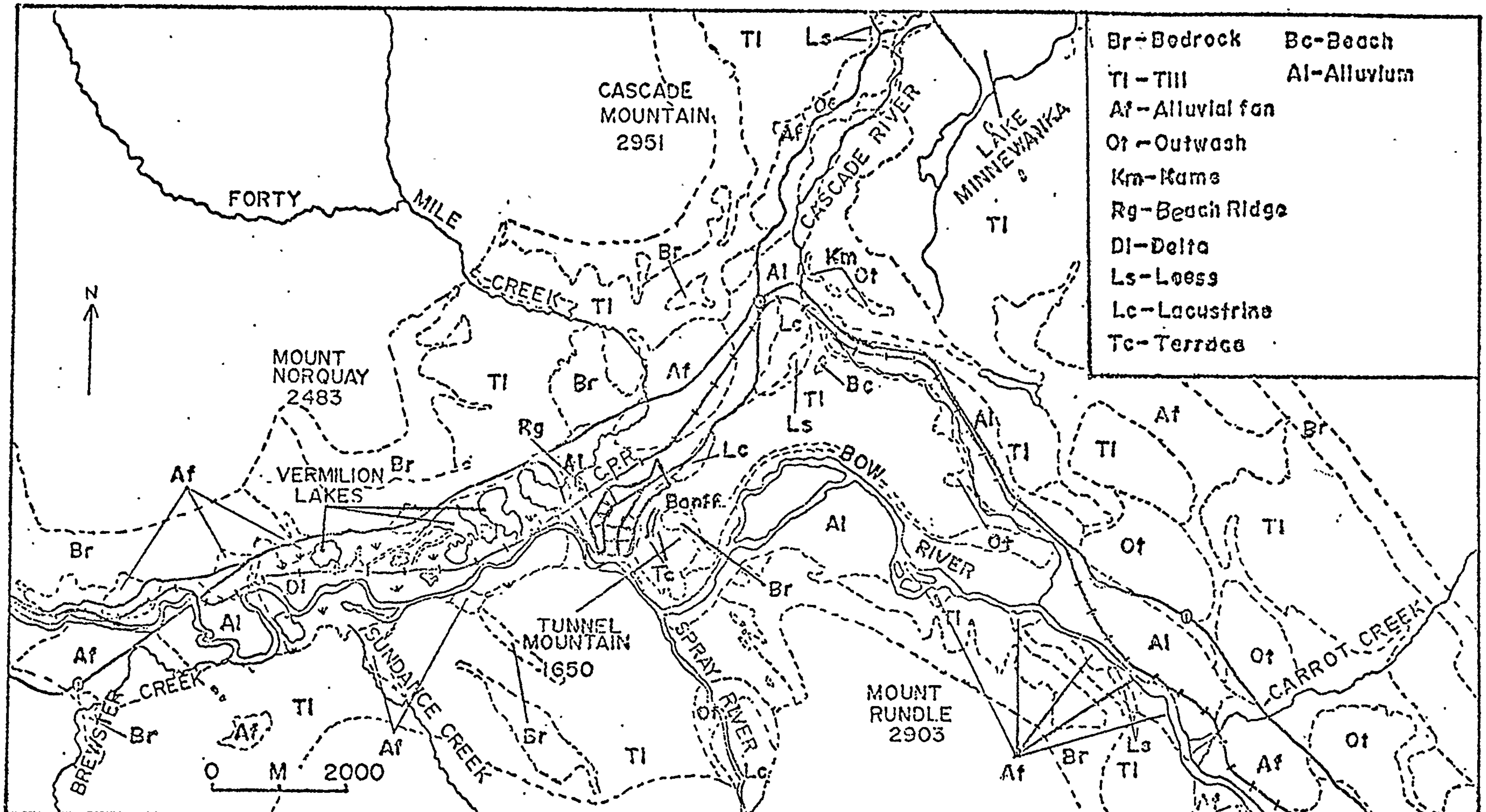

Figure 6: Surficial deposits of the study area (partly after Rutter,1972).

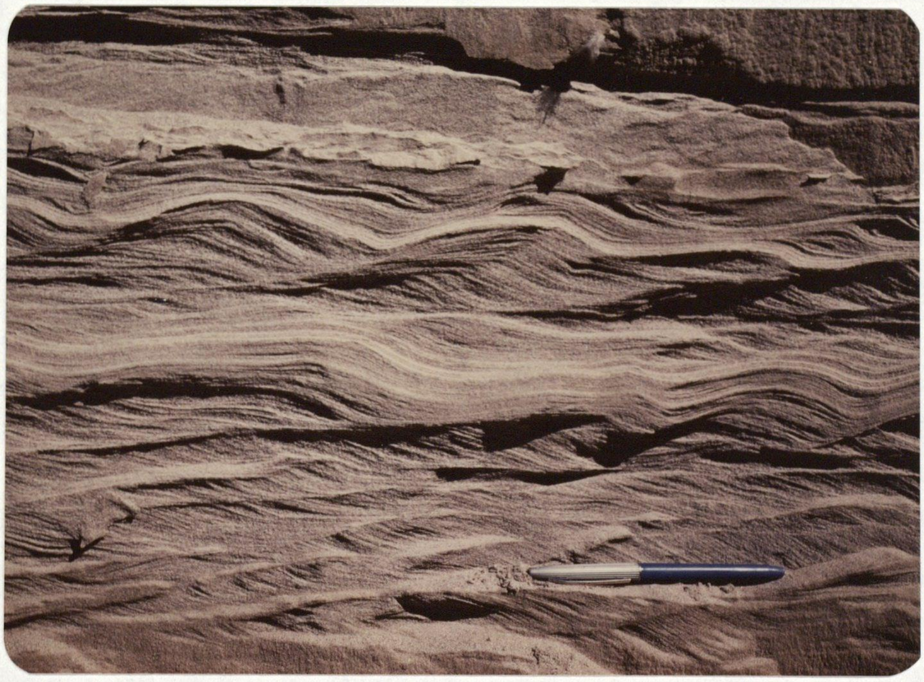

Figure 7: Ripple drift in the kame terrace east of the traffic circle. Note pen for scale.

with the lake are remnants of a high-energy delta, with foreset beds inclined at 25°, located up the Spray Valley 10 km south of the lacustrine deposit. The 1500 m elevation of the topset of the delta places the lake surface at a similar height. The lake likely drained by means of a stream flowing east between Mount Rundle and the Canmore ice sheet.

4.4 Alluvial Fans

Two alluvial fans in the study area were examined in detail, the Carrot Creek fan, and an unnamed fan located across the Bow River from the Carrot Creek outlet, termed the Dissected fan for the purposes of this study (Fig. 6). These fans were chosen because they represent two extremes in alluvial fan depositional styles common in the study area, debris flow fans and fluvial fans (Roed and Waslyk, 1973).

The Dissected fan has been so named because it appears to have been dissected by the laterally migrating and degrading Bow River. The fan is associated with an ephemeral stream with a very limited source area draining from the steep north-easterly facing slope of Mount Rundle. The fan surface is very steep (17°), typical of debris flow fans.

The southern portion of the Dissected fan has been exposed by a laterally migrating meander of the Bow River. The exposure rises 13 m vertically above the flood plain of the present Bow River (Appendix A). The base of the section is composed of 10 m of poorly sorted sediment with angular, mud supported, pebbles, and is interpreted as being debris flow in origin. A number of better sorted gravel horizons, associated with fluvial activity, are also found in this portion of the section. The upper 3 m of the exposure is primarily grey, massively structured silt that is very poorly sorted, positively skewed (Appendix A), and is interpreted as loess. A 10 cm thick accumulation of volcanic ash assumed to be Mazama is located 150 cm beneath the surface.

The portion of the Dissected fan located on the north side of the Bow River has a 2.5 m thick deposit of debris flow and fluvial gravel rising 2.5 m above the Bow. Above the gravel is a 2 m thick deposit of loess (Appendix A), that is considerably disturbed in its upper 50 cm by human activity. A thick, white ash layer, again interpreted as Mazama, is situated 80 cm below the surface. It seems apparent that the Bow channel was at a much higher elevation as late as 6,600 B.P., and was probably located north of the northern portion of the Dissected fan. A meander cutoff around this time period isolated a portion of the fan and subsequent degradation by the Bow channel produced the present situation.

Clearly, the Dissected fan was almost completely inactive well before 6,600 years B.P. The bulk of the deposition of this fan occurred in the Early Holocene, and the primary mechanism of sedimentation was that of debris flows. The abundant supply of unconsolidated till on the valley walls following deglaciation and the steep nature of the terrain produced rapid fan development. As the sediment supply dwindled and vegetation stabilized the slopes in the latter stages of the Early Holocene, fan development almost ceased. The short, intermittent stream flowing over the fan produced little deposition due to its limited source area and restricted supply of sediment. Loess capping of the inactive fan began well before 6,600 years B.P.

In contrast to the small, presently inactive Dissected fan is the active Carrot Creek fan. Carrot Creek is a relatively long, perennial stream flowing out of a mountain valley on the north side of the Bow Valley. Carrot Creek has incised to considerable depths into till and outwash deposits in the erosional reaches, and at present is located on the extreme western edge of the fan. The creek is eroding slightly into the fan and depositing a wide coarse gravel sheet, a new secondary fan, near the Bow River. The present incision of the creek into the fan surface is related to either a lowering of the base level of the creek by the degrading Bow River, or a reduction in sediment supply to the creek. The fan surface slopes very gently (9^{o}) to the south.

Creek incision has exposed the stratigraphy of the Carrot Creek fan (Appendix A). The base of the fan is coarse fluvial gravel which is overlain by 120 cm of fine grained sediment that is interpreted as being primarily of an overbank alluvial origin. Directly above the gravel is a grey horizon of fine sand. A 1 cm thick ash layer containing magnetite particles of Bridge River and Mazama origin is situated 87 cm beneath the surface, and is interpreted as representing the fan surface in 2,500 B.P. Above the ash are thin horizontal laminations of fine sand and silt that are poorly sorted, positively skewed and display a number of red coloured fire bands.

Fluvial processes are the primary depositional mechanism in the Carrot Creek fan. Carrot Creek has probably been eroding till and outwash since deglaciation, depositing sheets of gravel on the Bow Valley floor. In the early stages of fan development debris flows may have been important. The abundant sediment supply, extensive source area and perennial nature of the stream have kept the fan active up to the present. The gentle surface slope and the well sorted nature of the gravels both indicate that the Carrot Creek fan is primarily the result of fluvial deposition. The overbank fines near the present location of Carrot Creek, as indicated by the stratigraphic position of Bridge River ash, were deposited from a time slightly earlier than 2,500 B.P. up to the present.

The Dissected fan and the Carrot Creek fan represent two distinct and different alluvial fan depositional styles apparent in the study area. The debris flow fans, represented by the Dissected fan, are typically of very steep gradients and are composed of large angular clasts supported by a fine grained matrix. These fans are associated with limited sediment source areas and small intermittent streams. The depositional history of the debris flow fans follows that proposed by Roed and Waslyk (1973) and Ryder (1972) whereby sedimentation was very active in the early post-glacial period and declined rapidly prior to 6,600 B.P. The debris flow fans grade into fluvial fans as less sediment is readily available for transport with time.

The fluvial fans, represented by the Carrot Creek fan and including fans associated with Forty Mile Creek, Sundance Creek, and Brewster Creek (Fig. 6), display gentle gradients and well sorted fluvial deposits that are finer grained than those formed by debris flows. These fans are associated with extensive sediment source areas and lengthy, perennial streams. These fans follow the depositional model of Roed and Waslyk (1973) in their early histories, but remain active up to the present due to continuing fluvial deposition.

4.5 Loess

Only a few workers have examined loess deposits in Alberta. Westgate (1964) studied a loess sheet in the Cypress Hills, and Dumanski and Pawluk (1971) worked on an accumulation of loess near Hinton, Alberta. Rutter (1972) identified a thick cap of loess overlying lacustrine sand at the Old Banff Dump (Fig. 6). I examined this exposure (Appendix A) and found the material to be silt-sized, well sorted, negatively skewed, massively structured, grey in colour and 2.5 m in thickness. An 8 cm thick horizon of tephra that is interpreted as being Mazama in origin is located 109 cm below the surface. A 10 cm thick yellowish brown layer containing magnetite particles of Bridge River origin lies 40 cm from the surface. Therefore, at the Old Banff Dump, 69 cm of loess was deposited between 6,600 and 2,500 years B.P., for an average sedimentation rate of 0.17 mm yr^{-1}. Between 2,500 B.P. and the present, 40 cm of deposition occurred for an average sedimentation rate of 0.16 mm yr^{-1}.

Jackson (1978) identified a number of loess deposits in the Kananaskis Valley 50 km east of Banff. His loess is fine sand to silt in size, poorly to very poorly sorted, and is positively skewed (Appendix A). Loess deposits, as indicated by the results from the Old Banff Dump and the samples taken by Jackson (1977), can be quite variable in their size distributions. Jackson (1977) maintains that loess can be distinguished from lacustrine deposits by its distinct silt-sized textural range, but I found that grain size parameters from a variety of environments, including lacustrine and fluvial, may be very similar to loess. Perhaps of more use in identifying loess deposits are a number of other characteristics outlined by Jackson (1978) including a massive structure, the mantling of underlying topography, and the presence of buried soils, fire bands, Mazama ash, and root horizons.

I located a number of suspected loess deposits in the study area using criteria summarized by Jackson (1978). The thick loess cap mantling the Dissected fan has a horizon of Mazama ash 1.5 m from the surface, indicating an average loess depositional rate of 0.23 mm yr^{-1} from 6,600 years B.P. to the present. Of particular interest is an exposure of loess located on the western end of a gravel pit near the Cascade fire road (Fig. 6). Fluvial gravel of outwash or fan origin is overlain by 185 cm of massive, silt-sized loess that is poorly to very poorly sorted and positively skewed (Appendix A). This loess deposit contains 9 fire bands, wood, and 2 thin (3.0 cm) fine gravel lenses representing minor fluvial activity. Of importance is a 14 cm thick band of volcanic ash, identified as Mazama, located 145 cm from the surface. A 5 cm reddish-brown band 72 cm from the surface contains magnetite particles identified as being Bridge River. At the Cascade fire road site, then, 73 cm of deposition, primarily loess, occurred between 6,600 and 2,500 years B.P. indicating an average depositional rate of 0.18 mm yr^{-1}. Between 2,500 and the present there was 72 cm of loess sedimentation occurring at an average rate of 0.29 mm yr^{-1}.

A thick loess accumulation occurs over 50 m of outwash gravel west of the Cascade River near Lake Minnewanka (Fig. 6). The loess deposit is 230 cm in thickness, is composed primarily of very fine sand that is poorly sorted, slightly positively skewed, and massively structured (Appendix A). This exposure lacks fire bands, indicating fires were much less active at this site than at the nearby Cascade Fire Road site, perhaps reflecting different vegetation covers. This site also lacks tephra horizons and as a result the determination of loess depositional rates is impossible.

Loess depositional rates between 6,600 and 2,500 years B.P. at the Old Banff Dump and Cascade Fire Road sites are almost identical at 0.17 mm yr^{-1} and o.18 mm yr^{-1} respectively, indicating that these rates may apply to the Banff area is general for this time period. Between 2,500 and the present the sedimentation rate of 0.16 mm yr^{-1} at the Old Banff Dump is similar to the rate between 6,600 and 2,500 years B.P. at that site. At the Cascade Fire Road site the depositional rate after 2,500 B.P. is considerably higher at 0.29 mm yr^{-1}. This increased rate may reflect burning by European and pre-European inhabitants near this site (Nelson and Byrne, 1969) resulting in increased aeolian erosion and deposition. Sedimentation in the vicinity of the Dissected fan is more rapid in post-Mazama time at 0.23 mm yr^{-1} than at the other sites, but the lack of a Bridge River horizon makes it impossible to determine the subsequent temporal distribution of the sediment. It is not possible at present to speculate on the possible climatic changes that the variations in loess sedimentation rates may reflect.

4.6 Lake Vermilion

Considerable evidence points to the existence of a large lake located in the Bow Valley near Banff during late Wisconsin and Early and Mid Holocene times. The lake was likely ice dammed on the western edge during the final Canmore retreat. Rutter (1972) interpreted a 12 m thick deposit of gently dipping horizontally laminated very fine sand that is poorly to very poorly sorted, positively skewed (Appendix A) and located at the base of the Old Banff Dump as being glaciolacustrine in origin (Fig. 6). The presence of Mazama ash in loess above the lacustrine sand indicates that the lake surface had dropped well below this level prior to 6,600 B.P.

E.B.A. Engineering (1978) has determined, on the basis of seismic surveys and borehole data, that up to 307 m of interbedded silt and clay lie beneath the Vermilion Lakes reach of the Bow River. I obtained the hydrometer analyses of this sediment from the base of BH2 (Appendix C) and found it to be clay sized, very poorly sorted and negatively skewed. I interpret this sediment as being primarily glaciolacustrine and lacustrine in origin. The Bow Valley advance probably scoured this basin to bedrock, and the glaciolacustrine sediment was deposited during the final deglaciation of the area. Such a thick accumulation of sediment is typical of proglacial lakes.

Fulton (1965) found 150 m of silt deposited by a late-glacial lake in southern British Columbia and estimated that up to 6 m of silt was deposited in a single year. At a sedimentation rate similar to that determined by Fulton (1965) it would require only 50 years to deposit the sediment in the Vermilion basin.

A deposit of moderately sorted gravel located about 0.5 km east of the Old Banff Dump (Fig. 6) at an elevation of 1,410 m is interpreted as a beach gravel of glacial lake origin. This deposit overlies till, and is composed primarily of a 1 m thick accumulation of gravel laminations 5 to 10 cm in thickness that dip gently to the west (Appendix A). There are also a number of sand lenses displaying symmetrical ripple marks in the exposure. This deposit is distinct from local outwash gravels in both grain size characteristics and sedimentary structures, and is interpreted as being a beach associated with a glacial lake.

Two lacustrine terraces are situated at elevations of 1,374 and 1,368 m on the western side of Tunnel Mountain (Fig. 6). These terraces probably represent strandlines resulting from successive lowerings of the lake.

An excavation south of Banff Avenue on the eastern edge of town exposed a 6 m thick accumulation of sand (Fig. 6). The very fine sand is moderately sorted, positively skewed and displays laminations dipping gently to the northwest (Appendix A). This deposit is interpreted as being lacustrine in origin, similar to the deposit at the Old Banff Dump.

North of the Banff railway station at an elevation of 1,359 m (Fig. 6) is a 3 m thick exposure of moderately sorted, positively skewed fine sand (Appendix A). This deposit features thin laminations dipping to the west and is interpreted as an aeolian beach ridge associated with the final phases of the lowering of the lake. Of importance in this deposit is a 10 cm thick deposit of Mazama ash located 150 cm from the ridge surface. This feature can therefore be dated at approximately 6,600 B.P., indicating that the lake level had reached the approximate level of the present Vermilion Lakes, 1,357 m, prior to that time. The eastern edge of the lowest stand of the lake must have been just to the west of this ridge, near the site of the Banff Recreation Centre.

The western extent of the low stand of Lake Vermilion is determined by the presence of Mazama ash near the surface of the large point bar at the western edge of the Vermilion reach (Fig. 6). Sand of clearly fluvial origin, exhibiting trough crossbeds and ripple drift, is beneath the Mazama ash (Fig. 8). In 6,600 B.P., then, the lake was located east of this point bar.

Given the evidence just presented, the following Late Quaternary history of Lake Vermilion is proposed. The probable extents and position of the highest and lowest stands of the lake are shown on Fig. 9. With the Canmore retreat (Rutter, 1972) in the Banff area thick accumulations of outwash were deposited in the lower portions of the Spray and Cascade Valleys, blocking drainage out of the Bow Valley in these directions. Till deposited in the Tunnel Mountain area by Rutter's (1972) Bow Valley and Canmore retreats restricted drainage along the Bow Valley to the east. With the further, rapid, Canmore retreat to

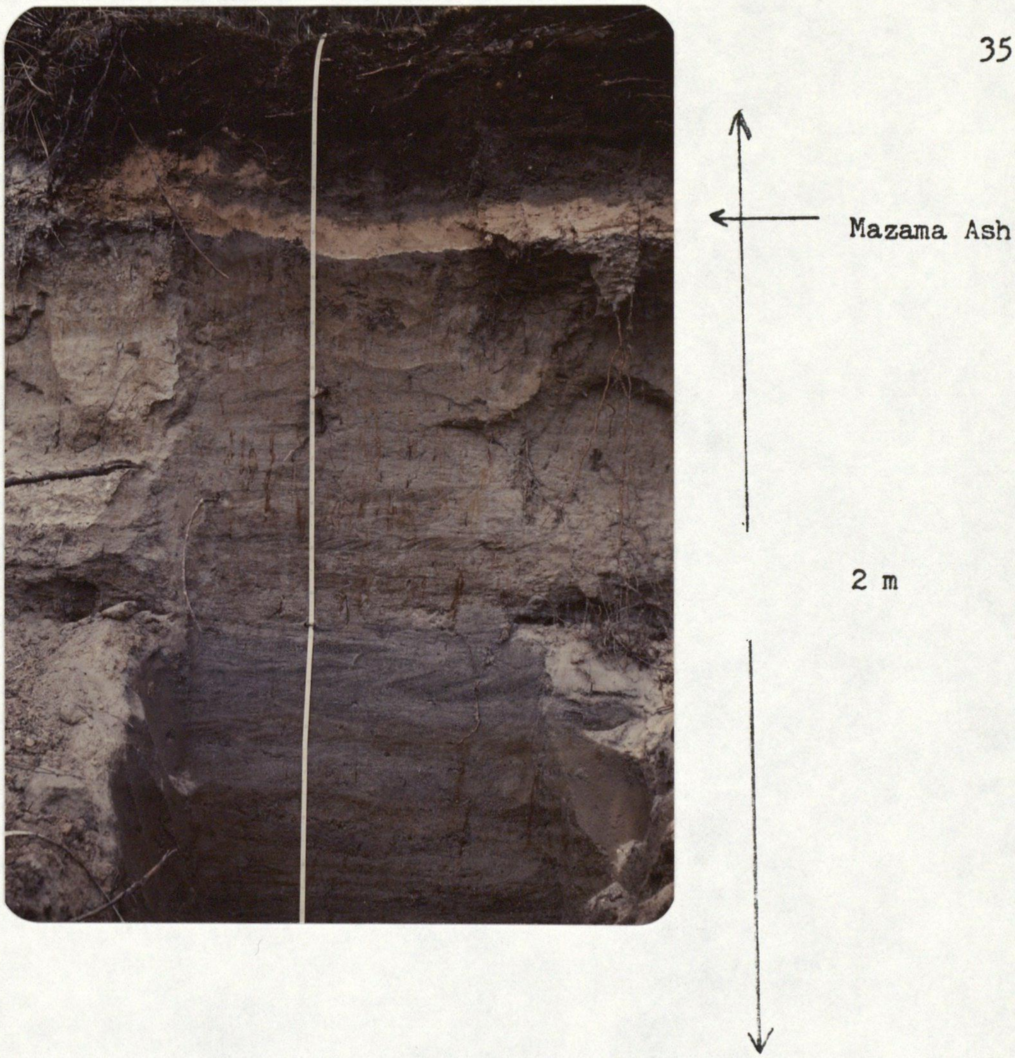

Figure 8: An exposure of the point bar which marks the western extent of Lake Vermilion.

the west, water began to accumulate in the deep ice scoured structural basin immediately north and west of Banff, the water surface reaching a maximum elevation of 1,410 m. Outlet streams probably drained the lake both to the north and south of Tunnel Mountain following the present courses of the Bow River and Cascade River to the east. During the early stages of the lake the outlet streams incised rapidly into the till and outwash and the lake level dropped accordingly. The lake continued to lower rapidly until the outlets encountered the relatively more resistant Mesozoic bedrock present at Bow Falls. Stream incision continued to slow until it stabilized at a position comparable to the present valley bottom, approximately 1,357 m, about 6,600 B.P. At some point prior to 6,600 B.P., the stream south of Tunnel Mountain captured all the lake drainage and the stream draining Lake Minnewanka began to follow the outlet course north of Tunnel Mountain. This drainage change probably occurred when the Lake Vermilion level dropped below the level of lacustrine sediments deposited northwest of Tunnel Mountain, making it impossible for the lake to continue to drain in this direction.

CHAPTER 5. THE VERMILION DELTA AND VERMILION LAKES

5.1 Introduction

Both sedimentologic and morphologic evidence point to the formation of the Vermilion Lakes by a low energy, river-dominated delta prograding from the west into the final low stand of Lake Vermilion. Prograding low energy deltas in general, are characterized by coarsening upwards trends (Coleman, 1976). Sediments associated with these deltas become progressively finer away from the distributary mouth, silty clay in the distal prodelta environment and silty sand in the proximal delta front. The coarsest surficial sediment, consisting of various grades of sand and silt, is associated with distributary mouth bars, distributary channel and levee deposits, and crevasse splays (Coleman, 1976). Surface morphologic characteristics of low-energy river dominated deltas include numerous distributary channels that often exhibit low sinuosities in distal reaches, interdistributary ponds surrounded by marsh and peat accumulations, levees flanking the distributary channels, and crevasse splays (Coleman, 1976; Blatt et al, 1972).

5.2 The Low Stand of Lake Vermilion

The extent of the lowest stabilized stand of Lake Vermilion is shown on Fig. 9. This water body was approximately 5 km in length and 2 km in width and had a surface area of 10 km^2. Stabilization of the lake surface occurred slightly prior to 6,600 years B.P. The depth of the lake at that time is difficult to determine, but the sedimentologic evidence as discussed in Section 5.3 indicates the lake may have been greater than 60 m deep at the location of

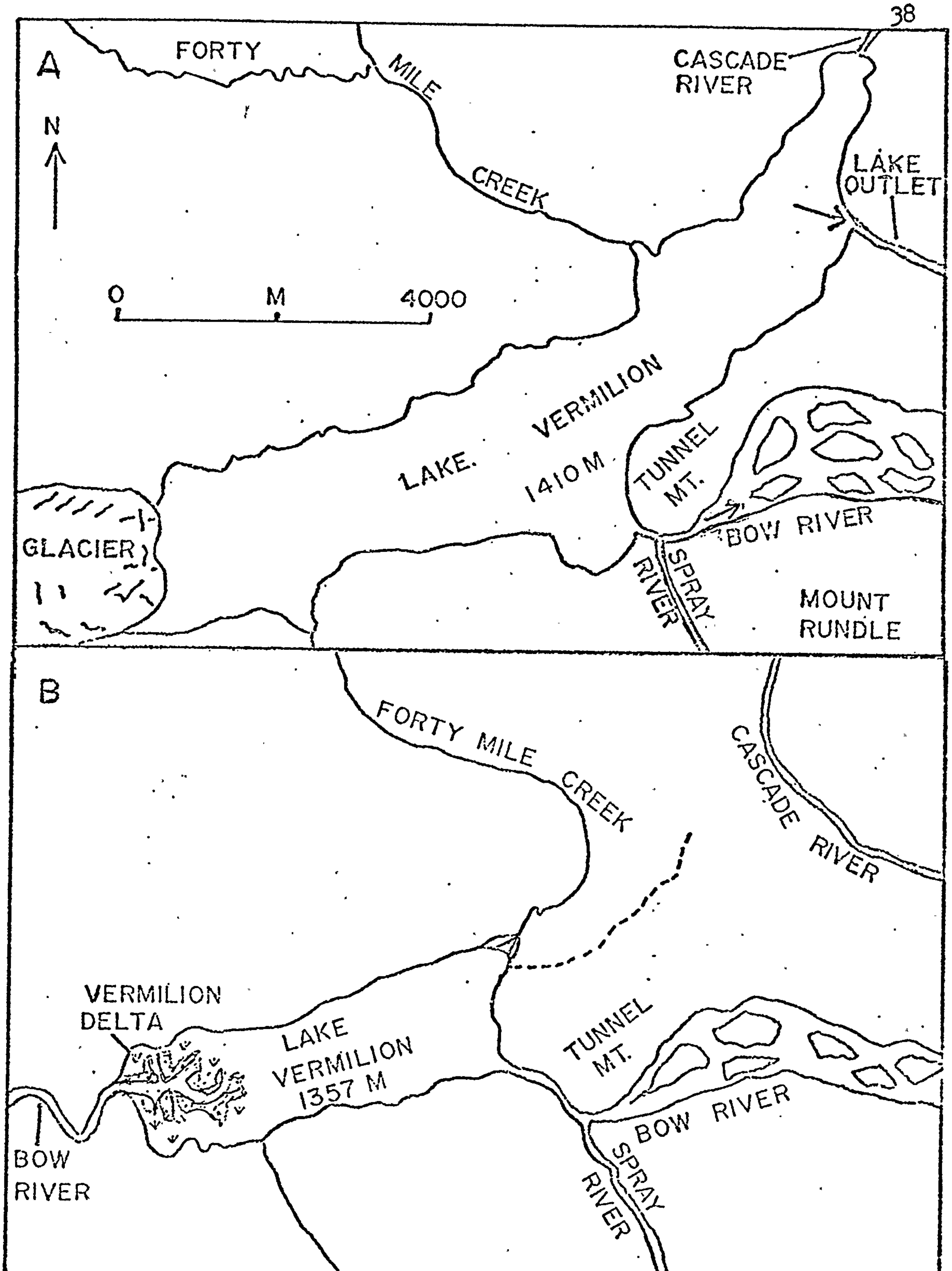

Figure 9: Lake Vermilion: (A) in Late Glacial time.
(B) in 6,600 B.P.

BH1 and 35 m deep at the site of BH2 (Appendix C). The subsequent filling of this water body by a low energy delta led to the present Vermilion Lakes reach of the Bow River.

5.3 Sedimentology of the Vermilion Delta

Cutbanks exposed by the Bow River and soil auger, split-spoon and borehole cores were used to determine the stratigraphy of the Vermilion Lakes reach. Exposures of Mazama ash in a large point bar of the Bow River located at the western end of the Vermilion reach, indicate that the point bar was developed prior to 6,600 B.P., and meander scroll ridges indicate that the channel has migrated to the southeast since that time. Other cutbank sections down-river are lacking in Mazama ash, indicating that the formation of this portion of the Bow channel is post-Mazama in age.

Soil auger locations are shown in Fig. 4. Auger cores located on point bars and near the north side of the Bow channel (Aug. 1, 6, 8, 10, 13, 14, 18, 19, 29) display fining upwards sequences of fine to medium sand at the base to silt near the surface. The sediments are extremely poorly sorted to very poorly sorted and display a positive skew (Appendix B). Interpretation of these cores suggests deposition in point bars, channels, and levees of a laterally migrating Bow River. A number of auger cores located between the present Vermilion Lakes and the Bow River (Aug. 9, 11) show similar fining upwards trends (Appendix B) indicating that the Bow may have been located at least as far north as these auger sites and has since shifted south.

Auger cores near the northern edge of the Vermilion lakes and on the south side of the Bow River (Aug. 17, 25, 26, 27) display silt-sized sediment that is poorly to extremely poorly sorted, positively skewed and shows little grain size variation with depth (Appendix B). These sediments were probably deposited in a low energy delta-front environment as indicated by the grain sizes, and the lack of a coarser surface layer indicates distributary channel, levee, or crevasse splay deposition was relatively unimportant in these areas. Augers 3 and 23 displays distinct coarsening upwards sequences, the basal portion of the cores being silty-sand and representing delta front deposition, the surface of the cores being medium sand resulting from levee sedimentation (Appendix B). Of particular interest is Aug. 8 which has a layer of Bridge River ash located 1.05 m beneath the surface, indicating that much sedimentation has occurred at this site in the past 2,500 years (Appendix B).

A 15 m core was recovered from SS1 located along the eastern edge of the Third Vermilion Lake (Fig. 4). The upper 4 m of core displays a distinct fining upwards sequence from medium sand to silt and probably represents deposition by a migrating distributary channel (Appendix C). The lower 11 m of SS1 are primarily silt and very fine sand interbeds with numerous organic horizons, and are interpreted as representing delta-front deposition. Two coarse sand lenses near the base of the core probably represent extreme flood discharges and subsequent influxes of coarse sediment. Sorting in the lower 10 m of core ranges from poorly to very poorly sorted, and it is positively skewed. Sorting improves slightly in the upper portion of the core representing the improved sorting ability of the higher energy distributary channel environment.

SS2 is situated between the First and Second Vermilion

Lakes (Fig. 4). The core displays very little variation with depth (Appendix C). The sediments are consistently silt-sized, very poorly sorted and positively skewed. Thin interbeds and peat horizons abound in the core. Although this core is located on the edge of an abandoned distributary channel (Fig. 4), the coarsening upwards trend that was expected did not appear. This may be related to the fact that at this site the levee grain sizes differ little from the delta-front deposits which compose the majority of the SS2 core.

Of particular interest is SS3 located in a marshy area on the south east edge of the basin (Fig. 4). The core displays a distinct coarsening upwards sequence from silty-clay at 12 m depth to very fine sand at 1.0 m (Appendix C). Below 12.8 m in the core is gravel probably representing deposition from the nearby valley side. A relatively coarse silt lens at 10.0 m is probably due to a major flood event. Thin interbeds and organic deposits, including large pieces of wood, are common in the column. Of major importance at 7.0 m depth is the presence of a 4 cm thick deposit of volcanic ash which has been identified as being Bridge River in origin. The presence of the ash indicates open water 7.0 m deep existed at this site in 2,500 B.P., assuming the ash settled on the lake bottom, and 7.0 m of sedimentation, resulting from the eastward progradation of a fine-grained delta, has occurred since that time. Aggradation as an explanation for deposition over the ash is ruled out by the presence of Mazama ash near the surface in the upper and lower sections of the Vermilion reach, bedrock control of the basin outlet at Bow Falls, and the clear evidence associated with delta front deposition with some channel and levee influence near the surface. The bulk of the surficial portion of the core related to deposition from the fine grained delta appears to have been removed by the Forty Mile Creek fan. Throughout the core the sediments are very poorly sorted and positively skewed.

BH2 is situated south of the Bow River near the Banff recreation grounds (Fig. 4). There is a clear coarsening upwards trend from 35 m to the surface, representing deltaic deposition (Appendix C). Sorting is very poor and there is a positive skew in this section of the column. Sediments above 35 m are interbedded and organic rich. From 35 to 60 m the grain sizes are remarkably consistent, organic matter disappears, and the skewness values become negative. The thinly bedded silt and clay below 35 m is interpreted as being glaciolacustrine in origin. At this site, then, the delta prograded into and filled a lake 35 m deep. The prodelta is represented in this core by silt and clay between 35 and 32 m depth. Delta front sediments extend between 32 and 6 m and are silt and sand in nature. Silt and sand, from 6.0 m to the surface is representative of point bar and levee deposition.

5.4 Surface Morphology of the Vermilion Delta

A number of surficial features of the Vermilion Lakes reach of the Bow River are typical of low-energy, river-dominated deltas (Fig. 10). The western proximal portion of the Vermilion reach is dominated by a sinuous, laterally migrating Bow River. Downstream in this reach the Bow channel loses much of this sinuosity as the gradient decreases, a common occurrence in low-energy deltas. A number of abandoned distributary channels are present, as are levee

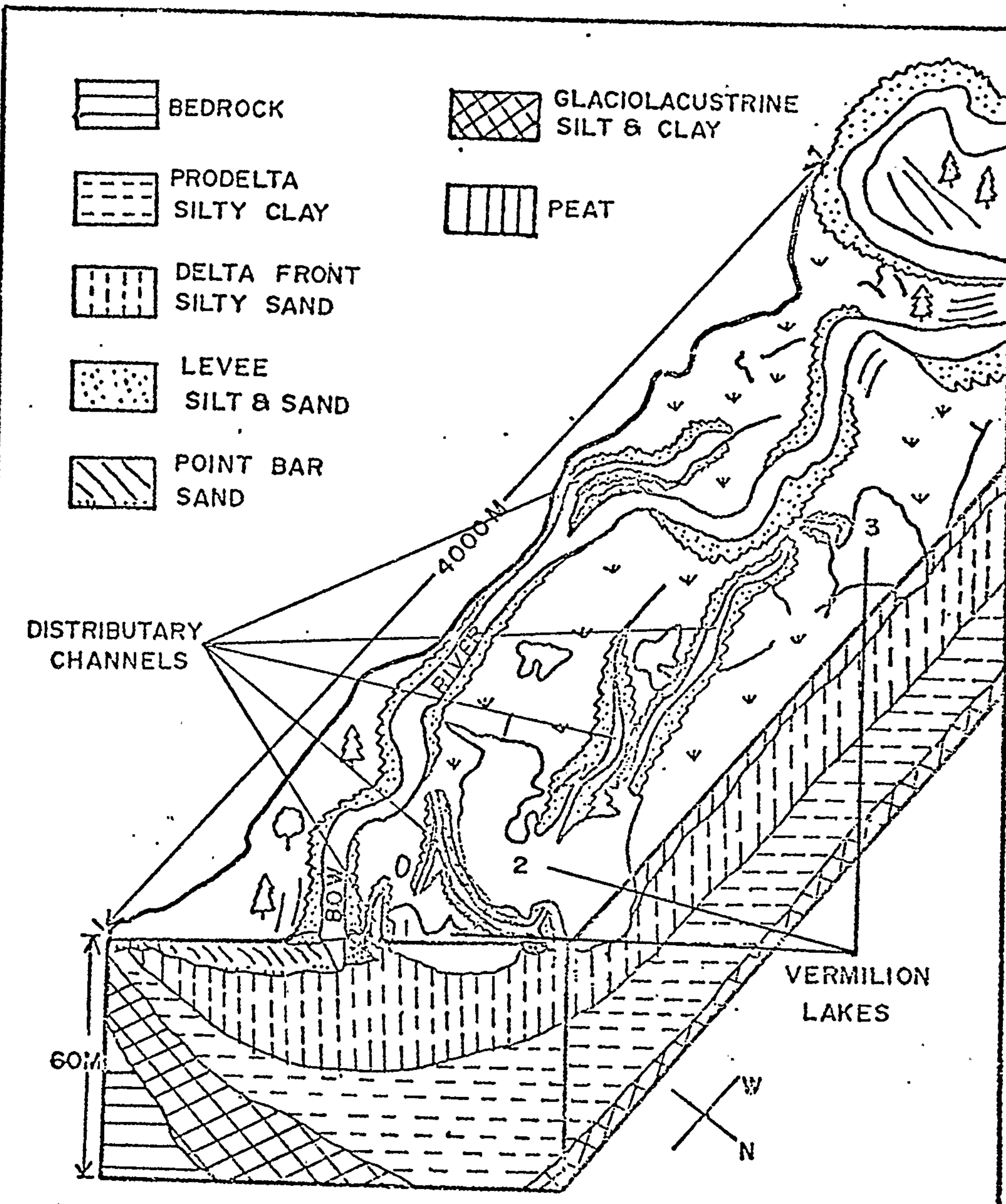

Figure 10: Surface morphology and depositional environments of the Vermilion Lakes reach of the Bow River.

for the lowering of Lake Vermilion in the post-glacial period. Sediment located between 9.0 and 12.8 cm is primarily silty clay and is interpreted as being associated with a prodelta environment. Between 9.0 and 2.5 m the deposits are silt and silty sand resulting from deposition in a delta front setting. From 2.5 m to the surface the sediments are silt and fine sand which were probably deposited by distributary channel levees or crevasse splays. The sediments are very poorly to extremely poorly sorted and positively skewed throughout the column.

SS4 is located south of the Bow River in the western portion of the Vermilion reach (Fig. 4). This core shows almost no variation with depth in grain size parameters (Appendix C). The sediment is silt sized, very poorly sorted, and positively skewed. Thin interbeds and organic horizons are common. The deposits in this core represent delta front sedimentation. A layer of volcanic ash identified as Mazama is situated 1.2 m from the surface, indicating that the bulk of the deposition by the prograding delta at this site occurred prior to 6,600 B.P.

BH1 is located east of the First Vermilion Lake (Fig. 4). The upper 2.5 m of the core is coarse gravel deposited as part of the Forty Mile Creek fan (Appendix C). From 60 m to 2.5 m there is a consistent coarsening upwards sequence from clay to fine sand and silt. The sediments display thin interbeds and numerous organic layers. This core presents clear evidence of a prograding delta filling a lake greater than 60 m deep at this site. Sediments from 60 to 36 m are clay and silty clay and are prodelta in origin. Between 36 and 2.5 m the deposits are silt and sand and are probably deposits along the flanks of the main and distributary channels. Thick organic deposits occur in the marshy areas surrounding the Vermilion Lakes, the lakes themselves being interdistributary ponds.

5.5 Depositional Processes and Environments

Galloway (1975) has classified deltas as river, wave, or tide-dominated. Tidal forces are of no importance in the Vermilion basin, and limited fetch is likely to restrict the impact of waves. The low-energy river-dominated type delta, of which the Mississippi (Coleman, 1976), Laiture (Axelsson, 1967), Kvikkjok (Dahlsborg, 1966) and Waterfowl (Smith, N. D., 1976) are modern examples, is the most analogous to the Vermilion case. The depositional processes associated with these modern examples, and those identified from sedimentologic and morphologic evidence from the Vermilion Delta, are summarized as follows.

During progradation the delta builds into open water by extension of a number of distributary channels which are flanked by levees of silt and fine sand deposited from suspension during floods. Traction load sand is restricted to channels and channel mouths where it is deposited in distributary mouth bars. In a lacustrine situation a river with a high suspended load is likely to travel along the subaqueous delta as a continuously flowing density current. Sediments become progressively finer away from the distributary mouth, silty clay in the distal prodelta environment and silty sand in the proximal delta front.

During flood discharges, levee crevassing occurs and inter-distributary areas fill with crevasse splay deposits of silt and sand. Inter-distributary ponds become colonized by marsh vegetation as they fill with sediment, the marshes being replaced by drier vegetation which begins on the flanks of levees and spreads toward the pond centre. Thick peat deposits may thus be formed, interfingering with levee deposits.

Destructional phases are associated with the shifting in position of major distributaries. As one sub-delta builds up, adjacent areas continue to subside and as they are receiving little sediment they become topographically low. Eventually the river shifts by avulsion into these low areas and a new sub-delta begins. Subsidence and lacustrine erosion may then modify the old delta.

The cross-section AB on Fig. 4 is shown on Fig. 11, and the depositional environments comprising the Vermilion Delta are summarizedoon Fig. 10.

5.6 The Late Holocene History of the Vermilion Lakes Reach of the Bow River

With the lowering and stabilization of Lake Vermilion in early pre-Mazama time, the Vermilion Delta prograded from the west. The western portion of the delta, as evidenced by the near surface location of Mazama and Bridge River ashes, received the bulk of sediment prior to or immediately after 6,600 B.P. The south-eastern portion of the delta was deposited primarily after Bridge River time. The lack of near surface tephra horizons, probably due to the fact that they are located too deep to be reached by the coring devices, and the relative expanse and depth of the

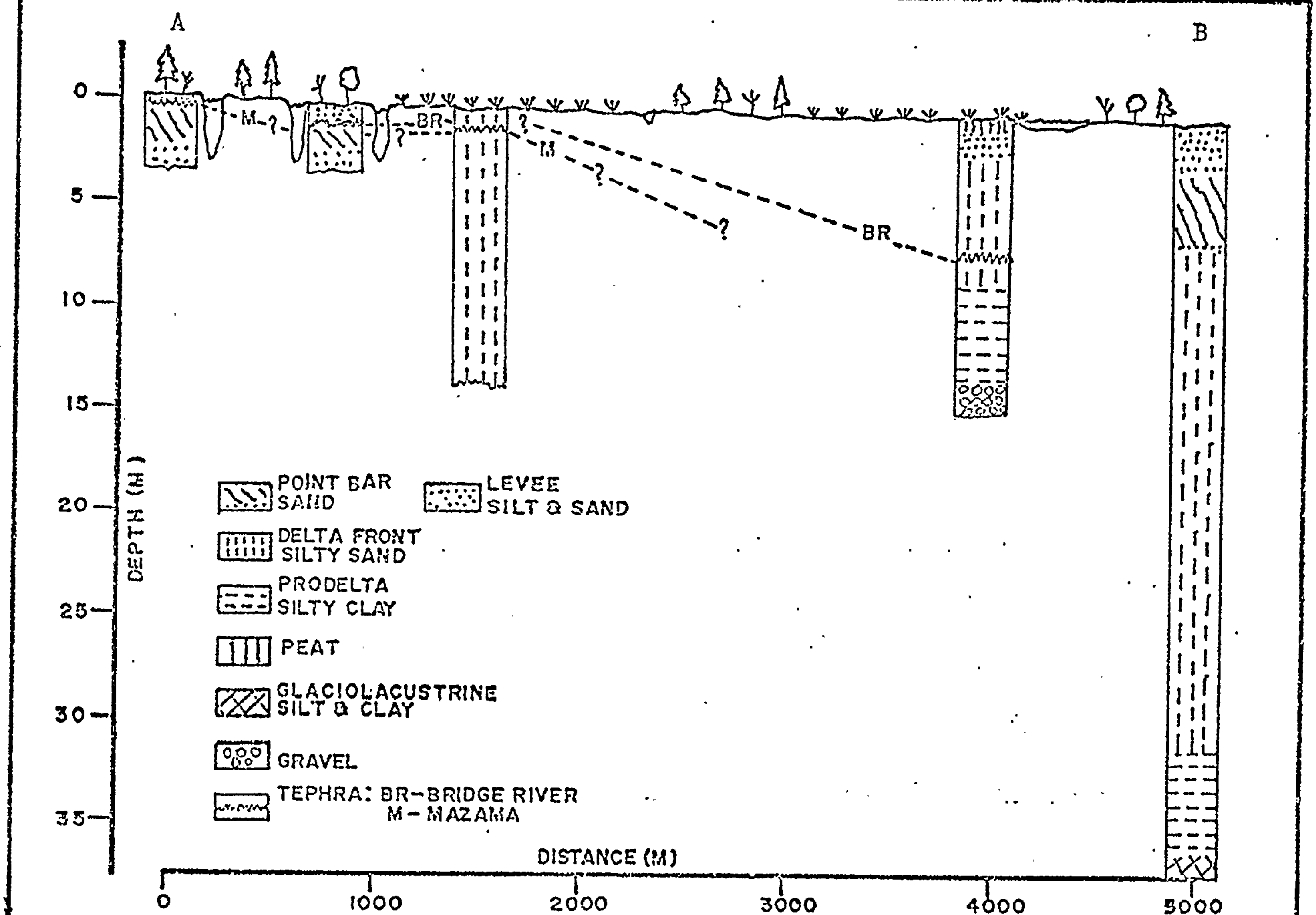

Figure 11: Cross section A-B from Figure 4.

Vermilion Lakes on the north side of the basin indicates that sedimentation has been much less effective, or perhaps more recent, on the north side as compared to the south side of the Vermilion basin. The development of the Bow as a single channel and the subsequent shifting from the centre to the south side of the valley is clearly of post Bridge River, 2,500 B.P., time. The entire 5 km progradation of the delta is then a Late Holocene phenomenon.

The present Vermilion Lakes evolved as the delta prograded to the east. The Third Vermilion Lake was the first to be formed as the large distributary channel, evident to the east of the lake, separated the Third Vermilion Lake from the open water of Lake Vermilion. Overbank sedimentation from this distributary channel gradually filled in the area between the Third and Second Vermilion Lakes. As the delta continued progradation, a smaller distributary channel extended to the north east from the main distributary channel and isolated the Second Vermilion Lake from the western portion of Lake Vermilion. With continued progradation, the First Vermilion Lake was formed as another small distributary channel extended to the north from the main channel. Deltaic sedimentation continued to the east of the First Vermilion Lake, and these sediments were eventually covered by the southwesterly expansion of the Forty Mile Creek fan. As progradation was completed the modern Bow River became the major drainage channel of the reach.

Eventually, with continued sedimentation and peat development in the Vermilion Lakes, they would be filled in completely and this reach of the Bow River would become a flat relatively dry alluvial plain. Bankfull discharge of the Bow River at Banff has been determined to be 283 cms (Kellerhals, et al, 1972). Flood discharges over this amount occur at approximately 9 year intervals, and would provide the sediment necessary to fill the lakes. The natural development of the reach, however, is being impeded by the Canadian Pacific Railway which separates the Vermilion Lakes area from the Bow River. The railway acts as an unbreachable levee which restricts most of the over-bank discharge of the Bow to the south side of the railway, thus preventing flood water and sediment from reaching the Vermilion Lakes. Since there are no other important sources of sediment input to the Vermilion Lakes, the rate of infilling of the lakes will be very slow. Expansion of marsh vegetation into the Vermilion Lakes will also be retarded in the future due to restricted infilling by sediment.

CHAPTER 6. SUMMARY AND CONCLUSIONS

Late Wisconsin Bow Valley Ice (Rutter, 1972) advanced down the Bow Valley to the foothills and extended up to 2460 m along the valley walls. The ice withdrew to the Banff area depositing a considerable thickness of till east of Tunnel Mountain. Bow Valley Ice re-advanced as the Canmore advance (Rutter, 1972) and extended to the east as far as Seebe, a short distance up the Cascade Valley towards Lake Minnewanka and southeast into the Spray Valley. Considerable quantities of ice-contact and non ice-contact glacio-fluvial debris were deposited in the lower portions of the Cascade and Spray Valleys during deglaciation, blocking drainage out of the Bow Valley in these directions. Till deposited by the Bow Valley and Canmore retreats restricted drainage to the east down the Bow Valley. With the rapid retreat of Canmore Ice to the west, water began to accumulate in the deep ice-scoured structural basin west of Banff.

Lake Vermilion occupied the basin from the late glacial period to the Late Holocene. One of its highest stands is represented by a beach deposit at 1410 m on the west flank of Tunnel Mountain. From 160 to 307 m of primarily glaciolacustrine silt and clay was deposited in the basin at this time, as was 12 m of glaciolacustrine sand near the eastern edge of the lake. Initial lowering of the lake was rapid as the two outlets north and south of Tunnel Mountain incised into till and outwash. Two lacustrine terraces at 1374 and 1368 m represent successive, later lake stands. As the outlets encountered bedrock degradation slowed, eventually stabilizing at the present level of Bow Falls. An aeolian beachridge associated with Mazama ash marks the eastern edge of the lowest, 1360 m stand of the lake. Mazama ash located near the surface of fluvial deposits delineates the western extent of the lake and places the date of the lowest stand at approximately 6,600 B.P.

Two distinct styles of alluvial fan sedimentation are apparent in the study area. Debris flow fans are of very steep gradients and the deposits are large angular clasts supported by a fine-grained matrix. These fans were very active in the Early Holocene, becoming predominantly inactive prior to 6,600 B.P. In contrast to the debris flow fans are the fluvial fans. Fluvial fans display gentle gradients and well sorted fluvial gravels and are associated with lengthy perennial streams and large sediment source areas. These fans have remained active throughout the Holocene.

Extensive loess deposits, identified on the basis of their massive structure, the mantling of underlying topography, the presence of buried soils and firebands, and the fine sand to silt size sediment range, were located in the study area. In the Banff town area, loess deposition rates between 6,600 and 2,500 B.P. range between 0.17 mm yr^{-1} and 0.18 mm yr^{-1}. Depositional rates between 2,500 B.P. and the present vary from 0.16 mm yr^{-1} and 0.23 mm yr^{-1}. Increased sedimentation rates after 2,500 B.P. may reflect increased wind erosion and deposition due to burning by local inhabitants.

With the stabilization of the lowest stand of Lake Vermilion at approximately 6,600 B.P., a fine grained river-dominated delta prograded from the west into the lake. Evidence for this deltaic progradation includes coarsening-upwards sequences, the stratigraphic position of Bridge River and Mazama ashes, and surface features such as abandoned distributaries, interdistributary ponds, and thick peat accumulations. The delta had completed progradation between 2,500 B.P. and the present with subsequent sedimentation occurring in interdistributary areas during flood conditions. With the completion of progradation, the Bow River developed a single channel as it increased the gradient and constructed more durable levees. Fining upwards trends in the valley centre indicate that the Bow River was once located in this area and has since shifted south.

The present Vermilion Lakes are inter-distributary ponds which were produced as the delta prograded and minor distributary channels extended towards the north into Lake Vermilion. Present sedimentation in the Vermilion Lakes consists of overbank fine grain clastics from the Bow River, and production of organic material by the wetland vegetation along the flanks of the lakes. The eventual infilling of the Vermilion Lakes is being retarded by the Canadian Pacific Railway which prevents flood discharges of the Bow from reaching these areas.

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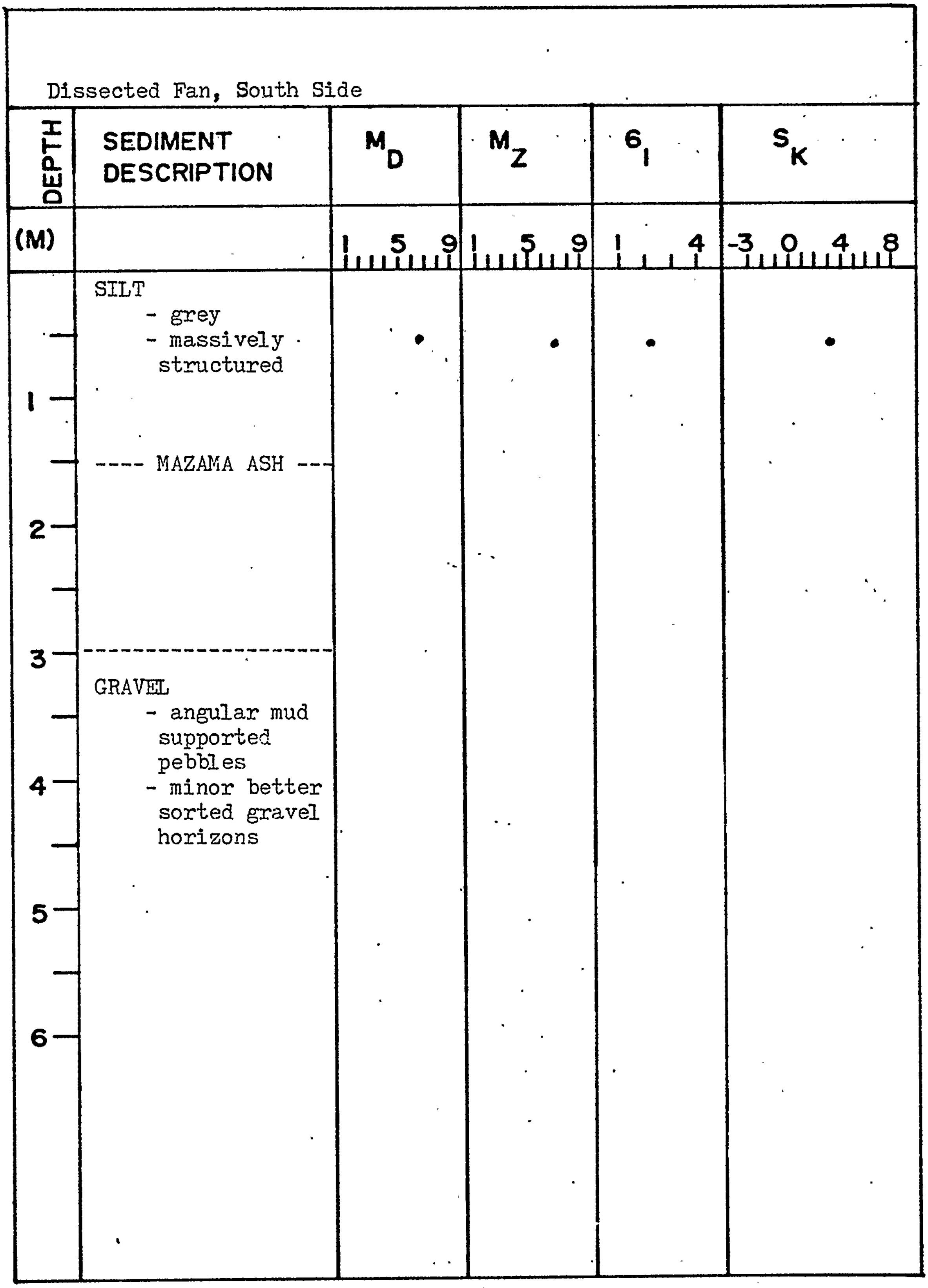
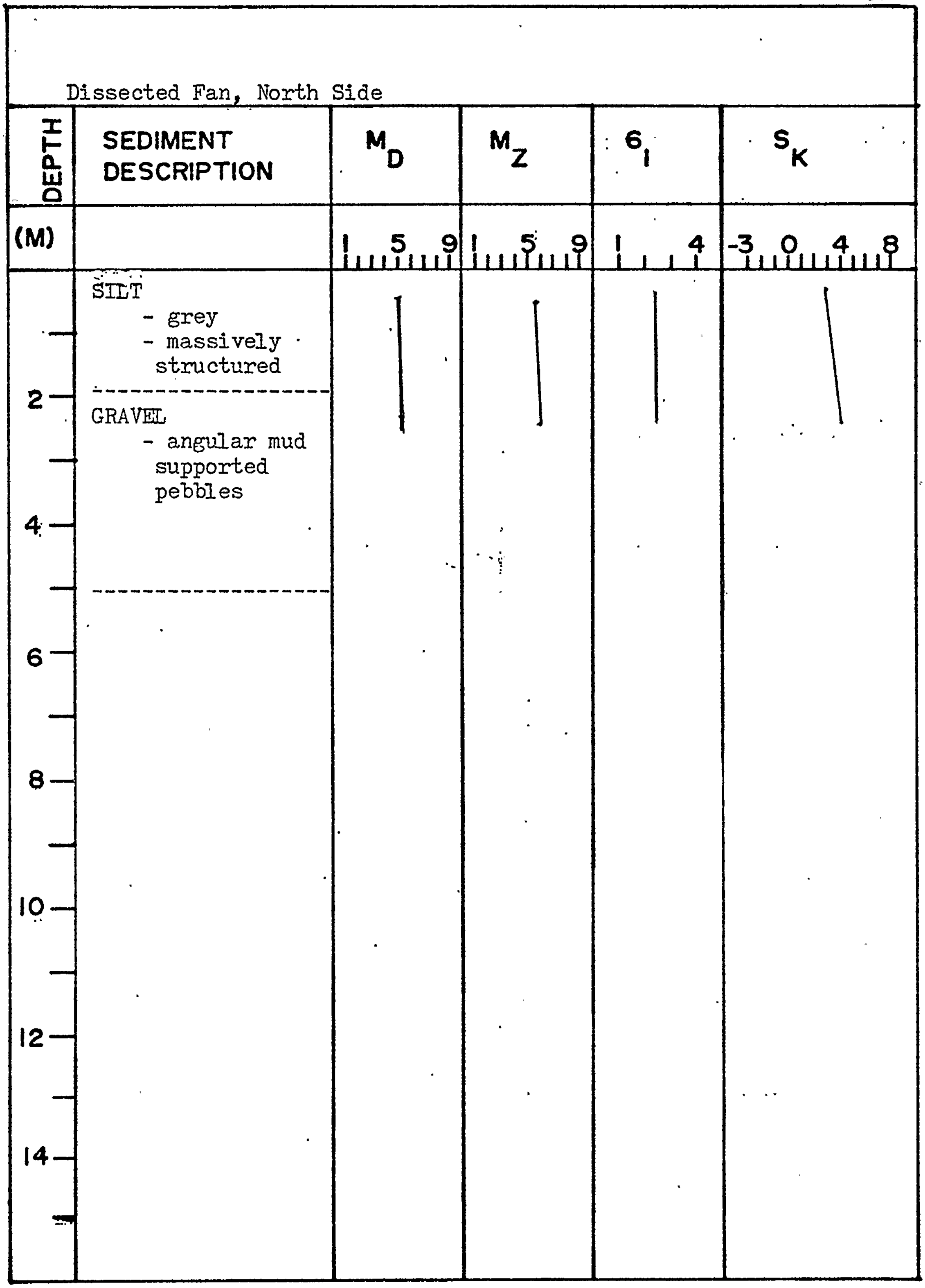
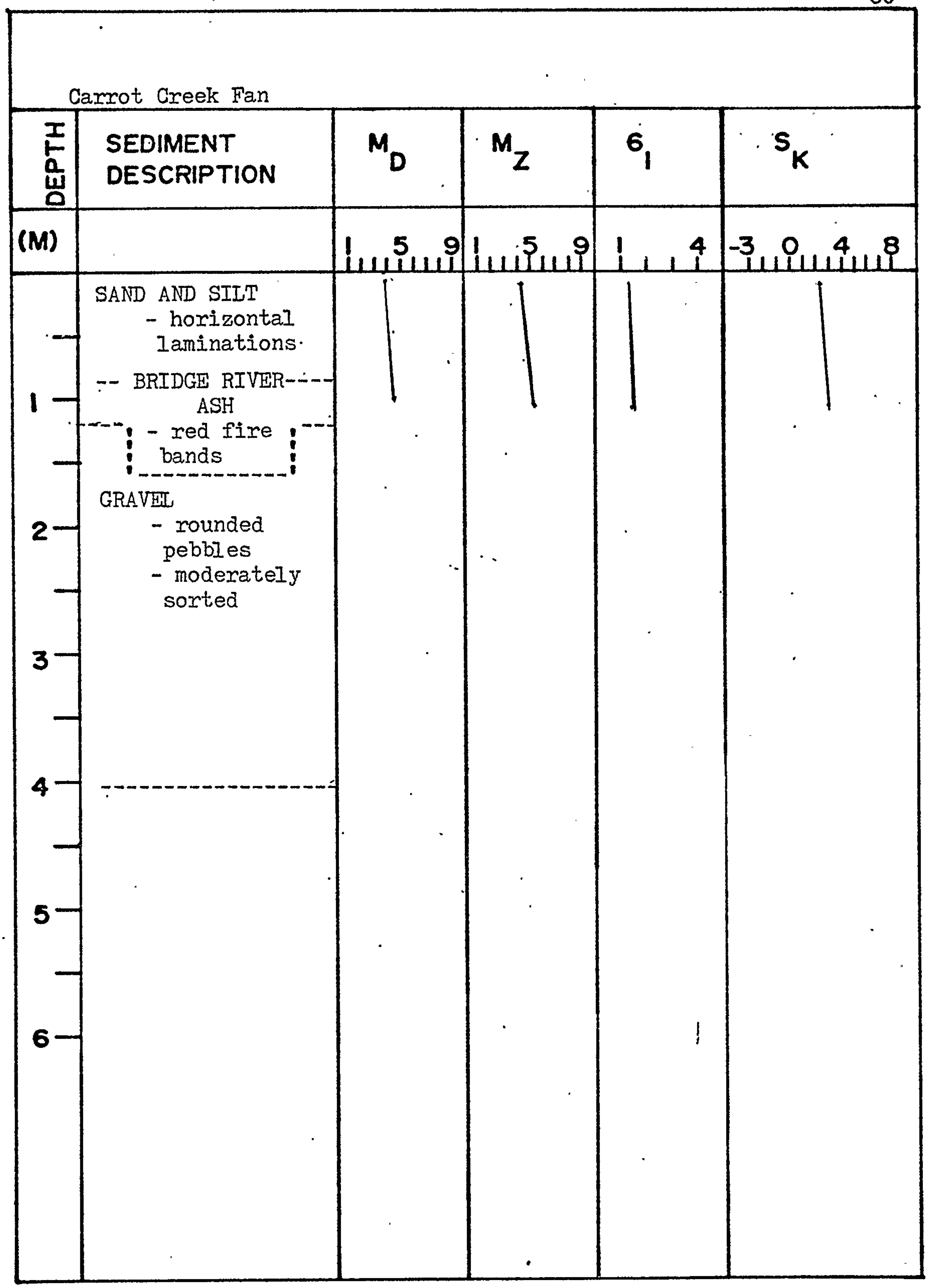
APPENDIX A

EXPOSURES


Dissected Fan, South Side
DEPTH
(M)
SEDIMENT DESCRIPTION
MD
MZ
6I
SK
1 5 9
1 5 9
1 4
-3 0 4 8
SILT
- grey
- massively structured
---- MAZAMA ASH ---
GRAVEL
- angular mud supported pebbles
- minor better sorted gravel horizons
1
2
3
4
5
6

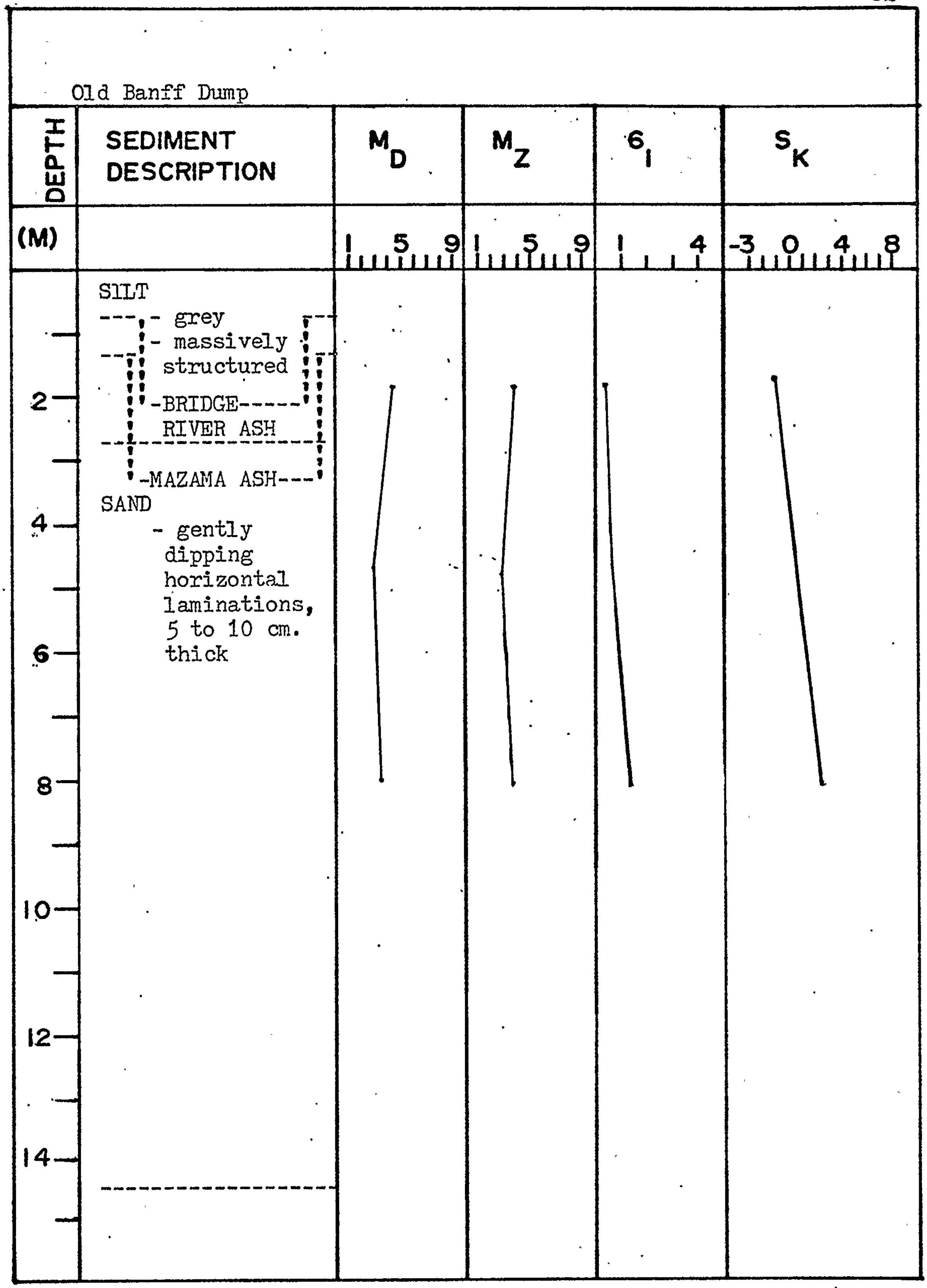

Dissected Fan, North Side
DEPTH
(M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
SILT
- grey
- massively structured
GRAVEL
- angular mud supported pebbles
2
4
6
8
10
12
14

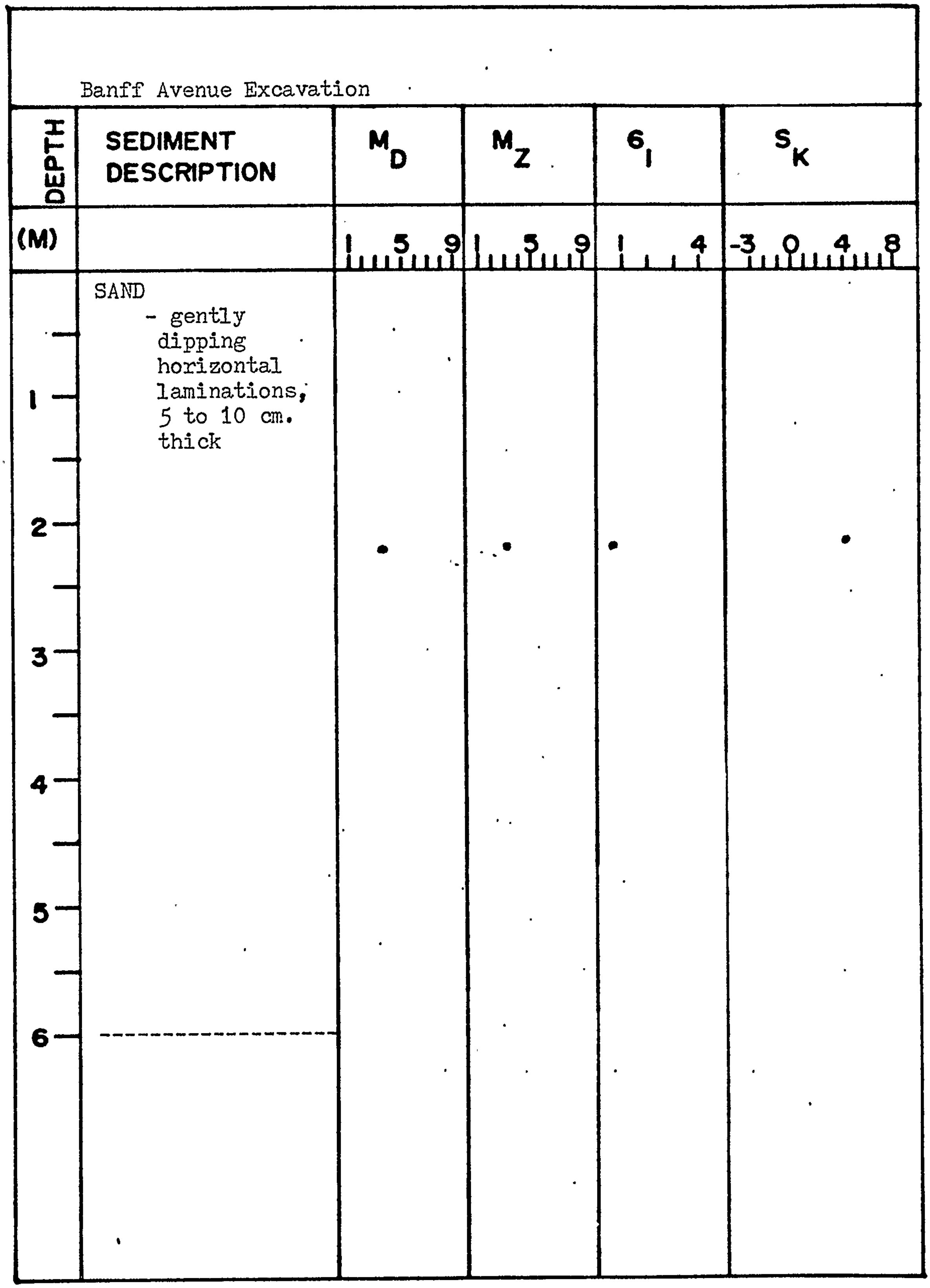


Carrot Creek Fan
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
SAND AND SILT
- horizontal laminations
-- BRIDGE RIVER ASH
- red fire bands
GRAVEL
- rounded pebbles
- moderately sorted
1
2
3
4
5
6

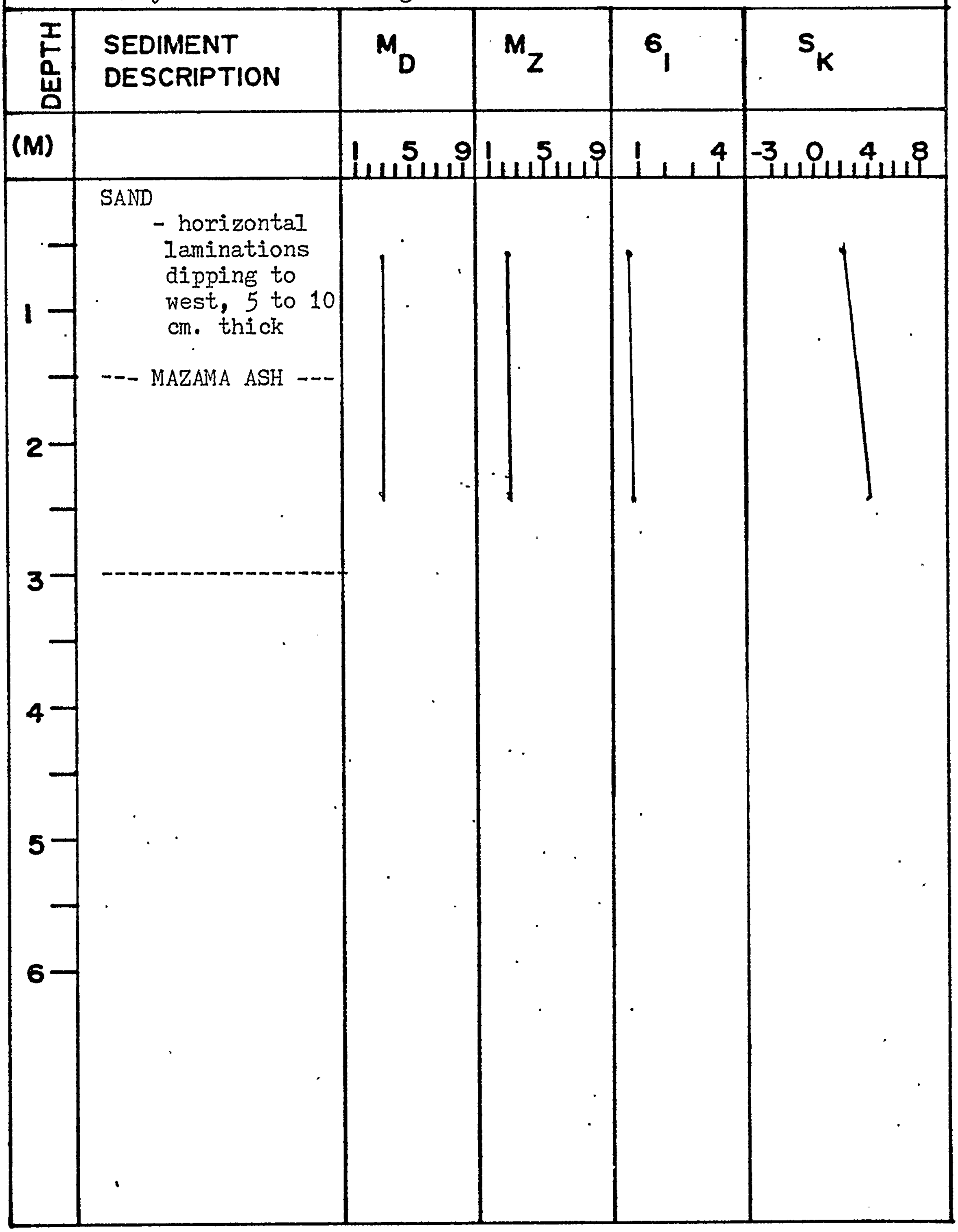
Beach, 1410 m.

DEPTH	SEDIMENT DESCRIPTION	M_D	M_Z	σ_I	S_K
(M)		1 5 9	1 5 9	1 4	-3 0 4 8
	GRAVEL - laminations 5 to 10 cm. thick				
1	- minor sand lenses with symmetrical ripples				
2	TILL - yellowish grey				
3					
4					
5					
6					


Old Banff Dump
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
σ_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
SILT
- grey
- massively structured
-BRIDGE-RIVER ASH
-MAZAMA ASH
SAND
- gently dipping horizontal laminations, 5 to 10 cm. thick
2
4
6
8
10
12
14

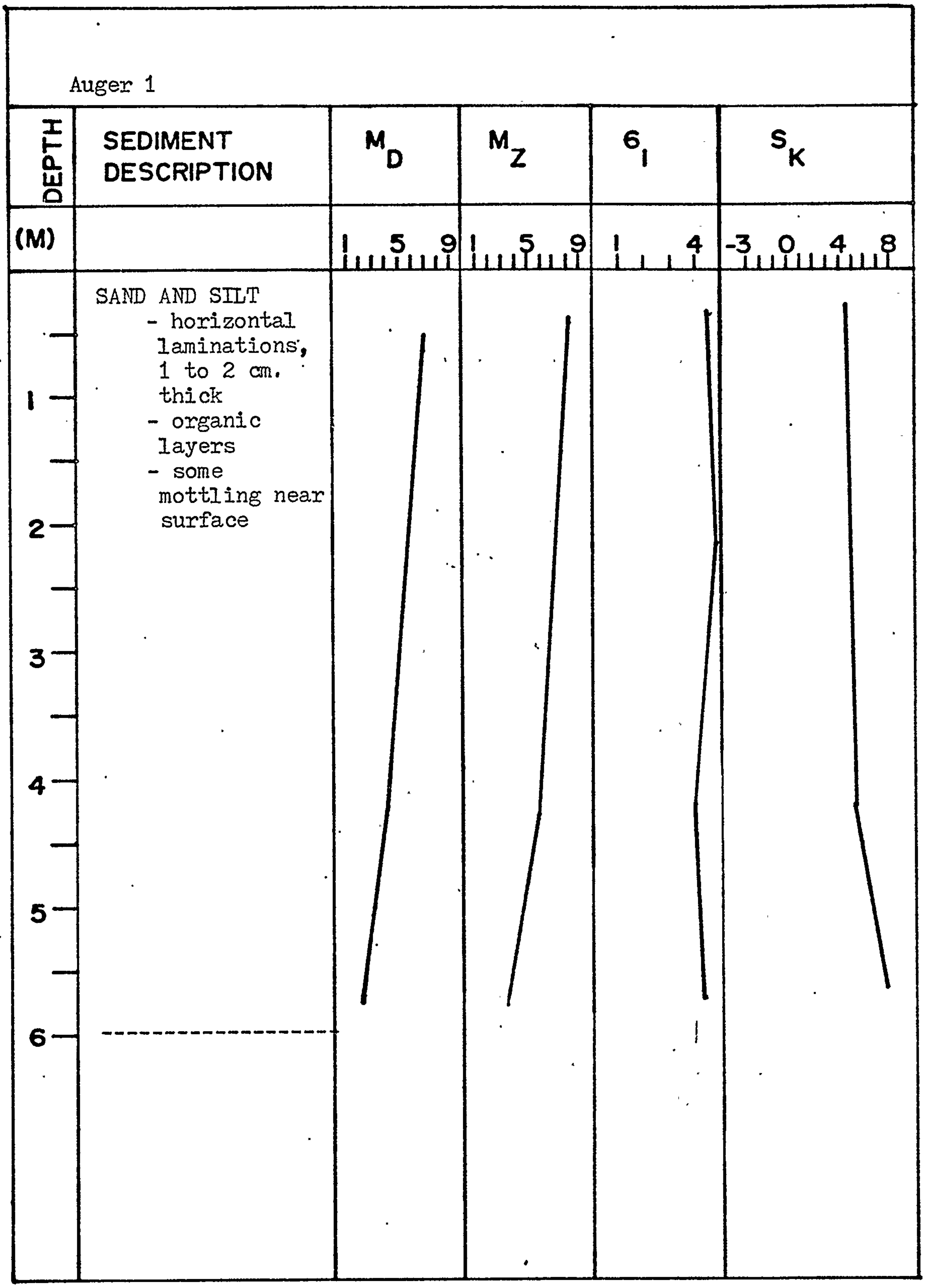

Banff Avenue Excavation
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
SAND
- gently dipping horizontal laminations, 5 to 10 cm. thick
1
2
3
4
5
6

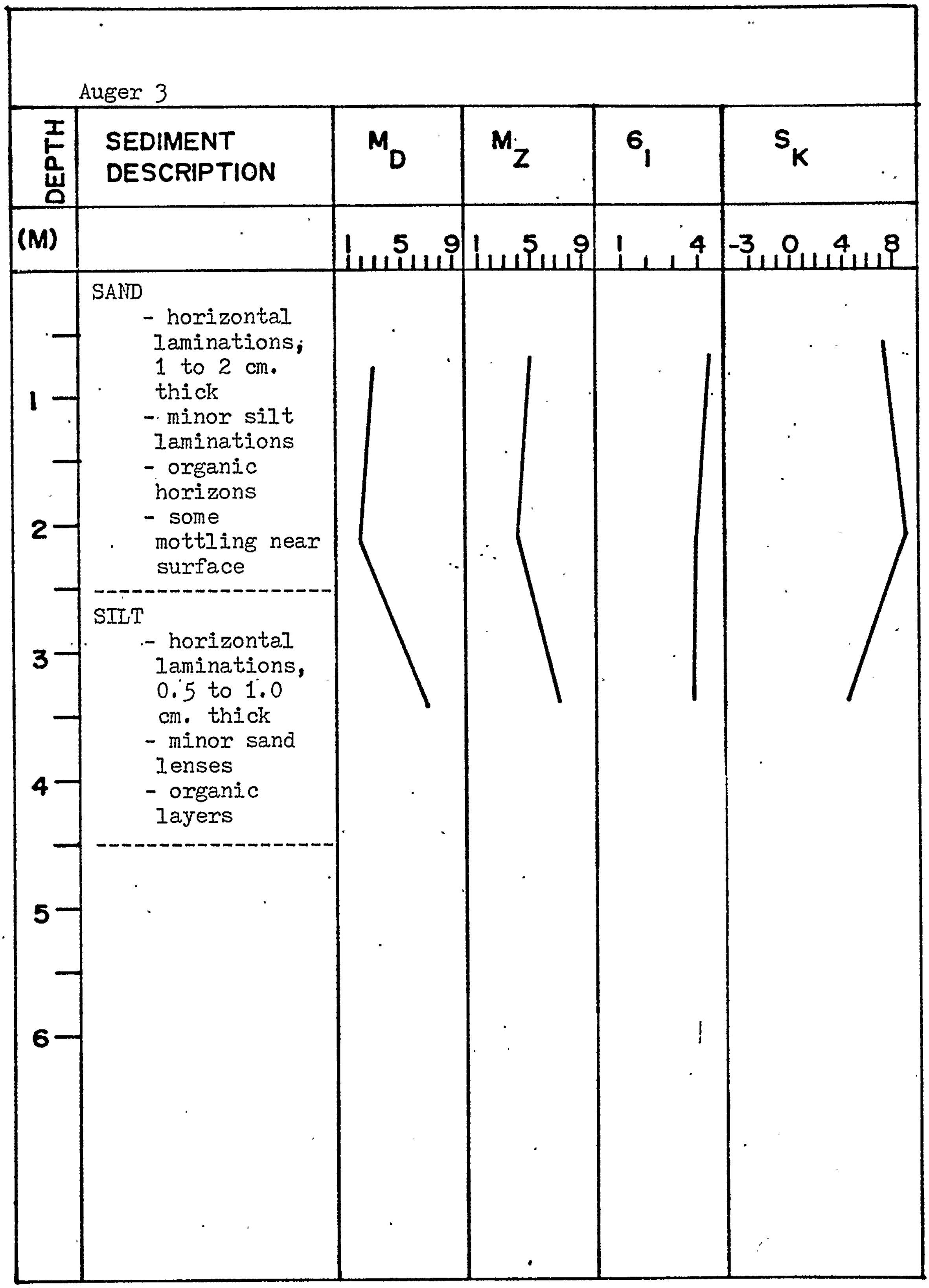
Railway Station Beach Ridge



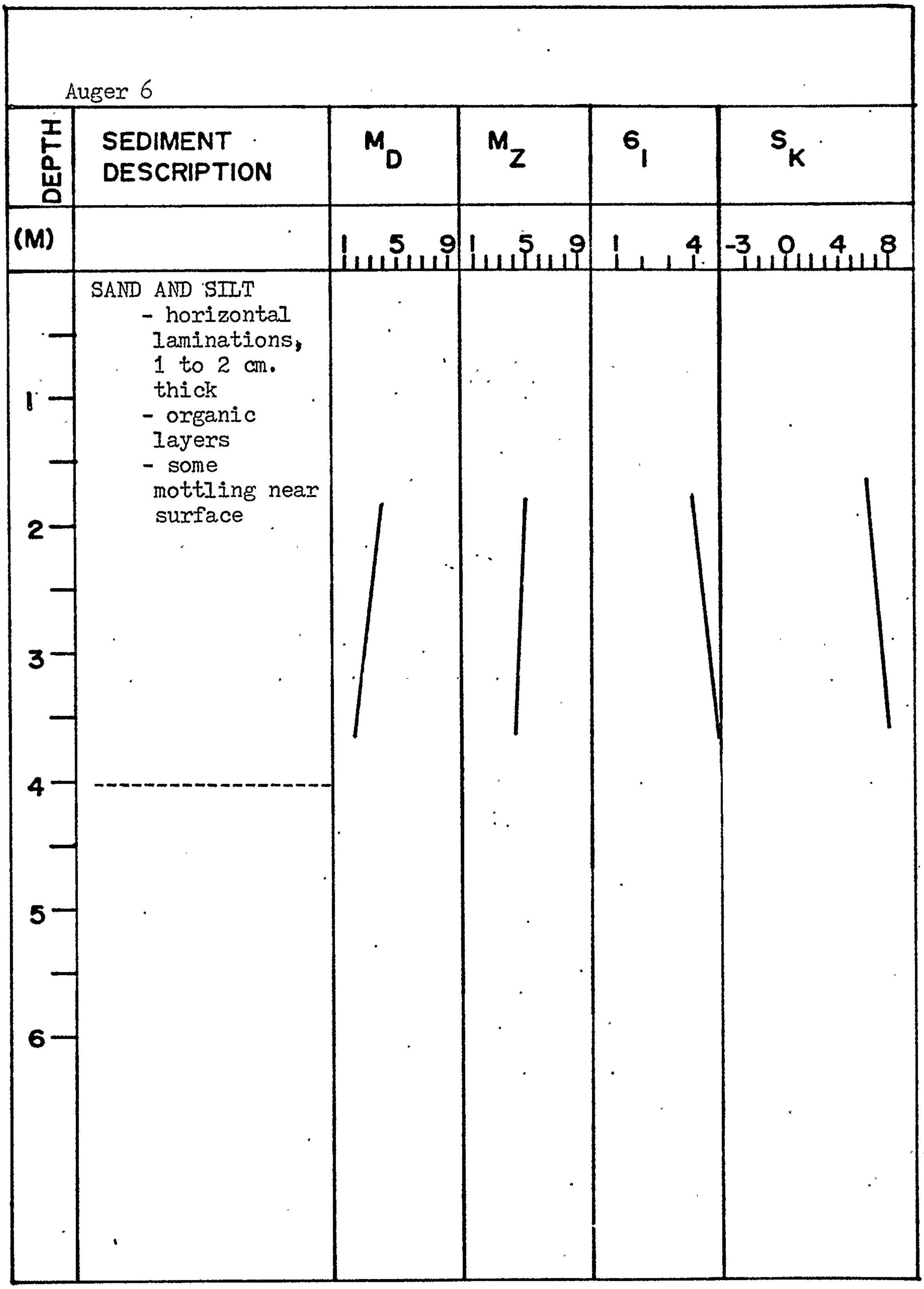
APPENDIX B

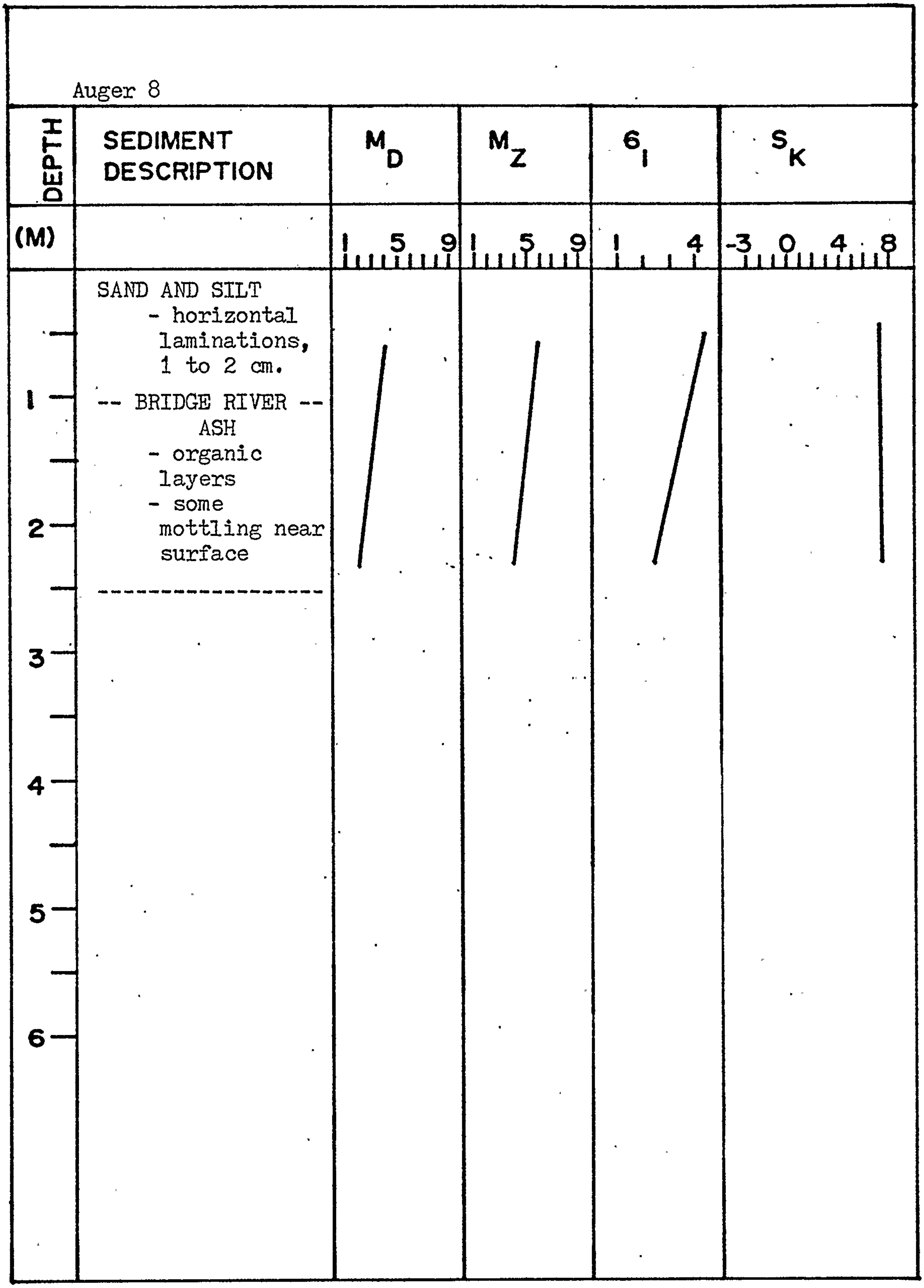
SOIL AUGERS


Auger 1
DEPTH (M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

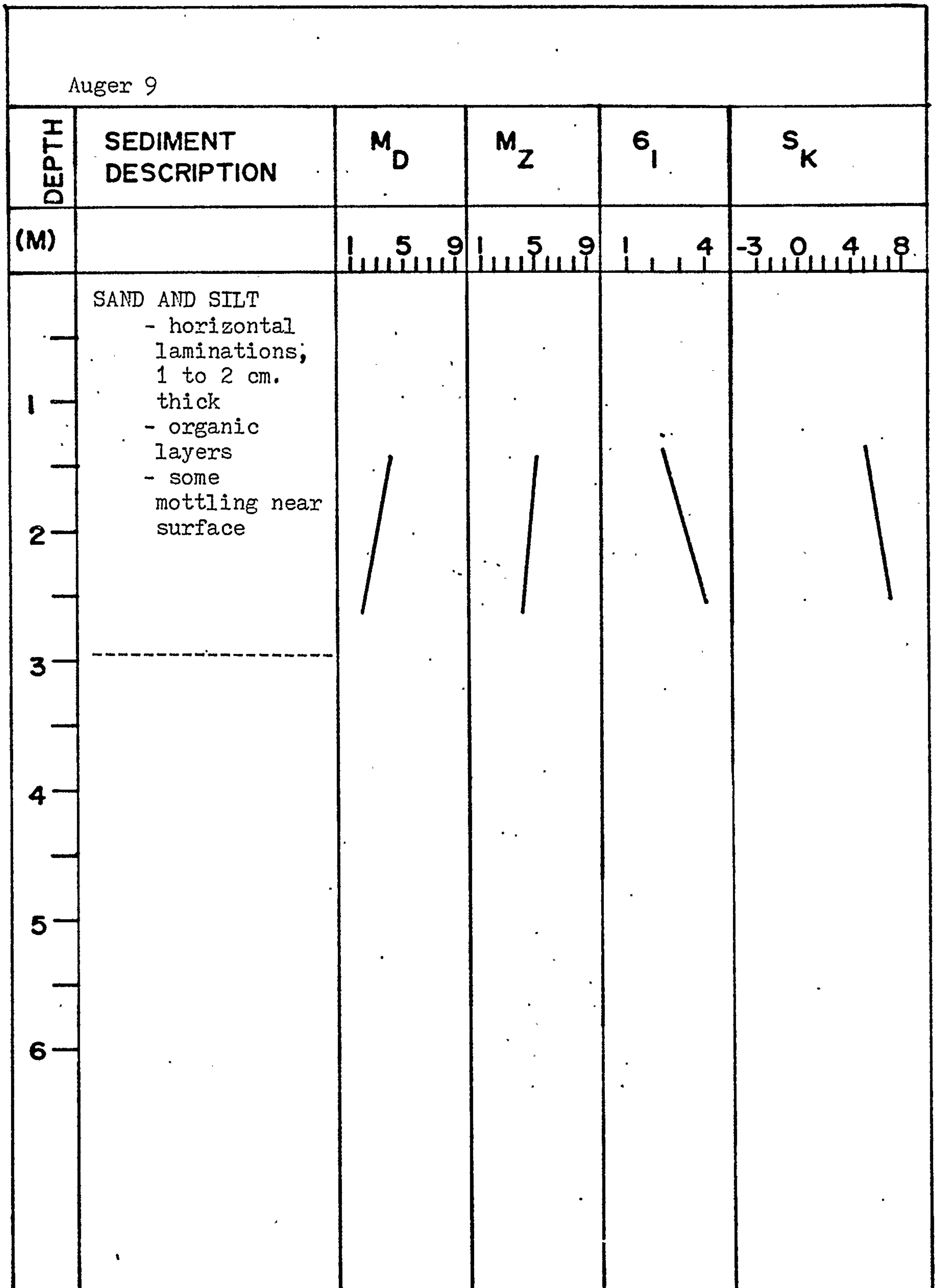


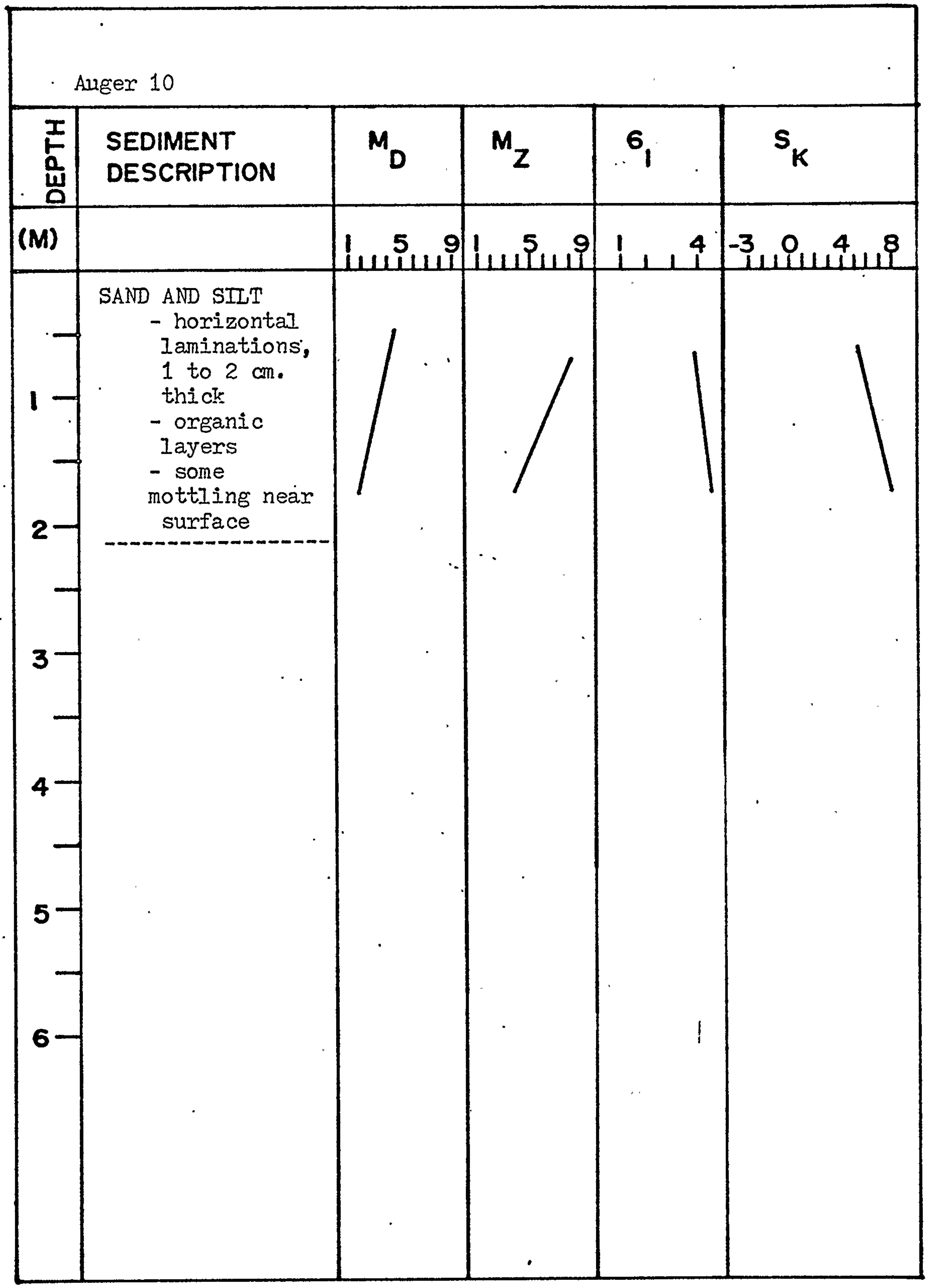
Auger 3
DEPTH
(M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND
- horizontal laminations, 1 to 2 cm. thick
- minor silt laminations
- organic horizons
- some mottling near surface
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- minor sand lenses
- organic layers


Auger 6
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
σ_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface
1
2
3
4
5
6

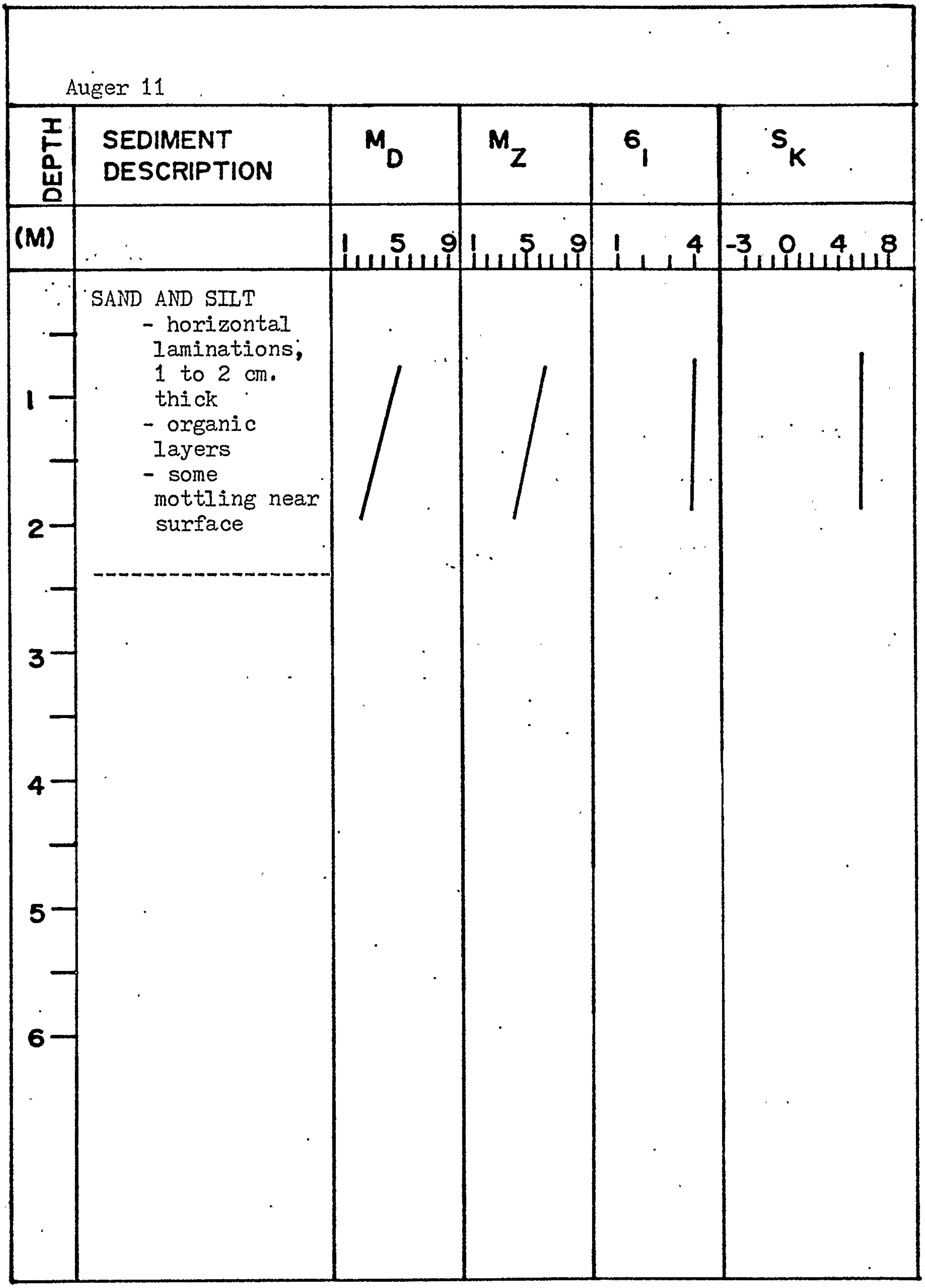


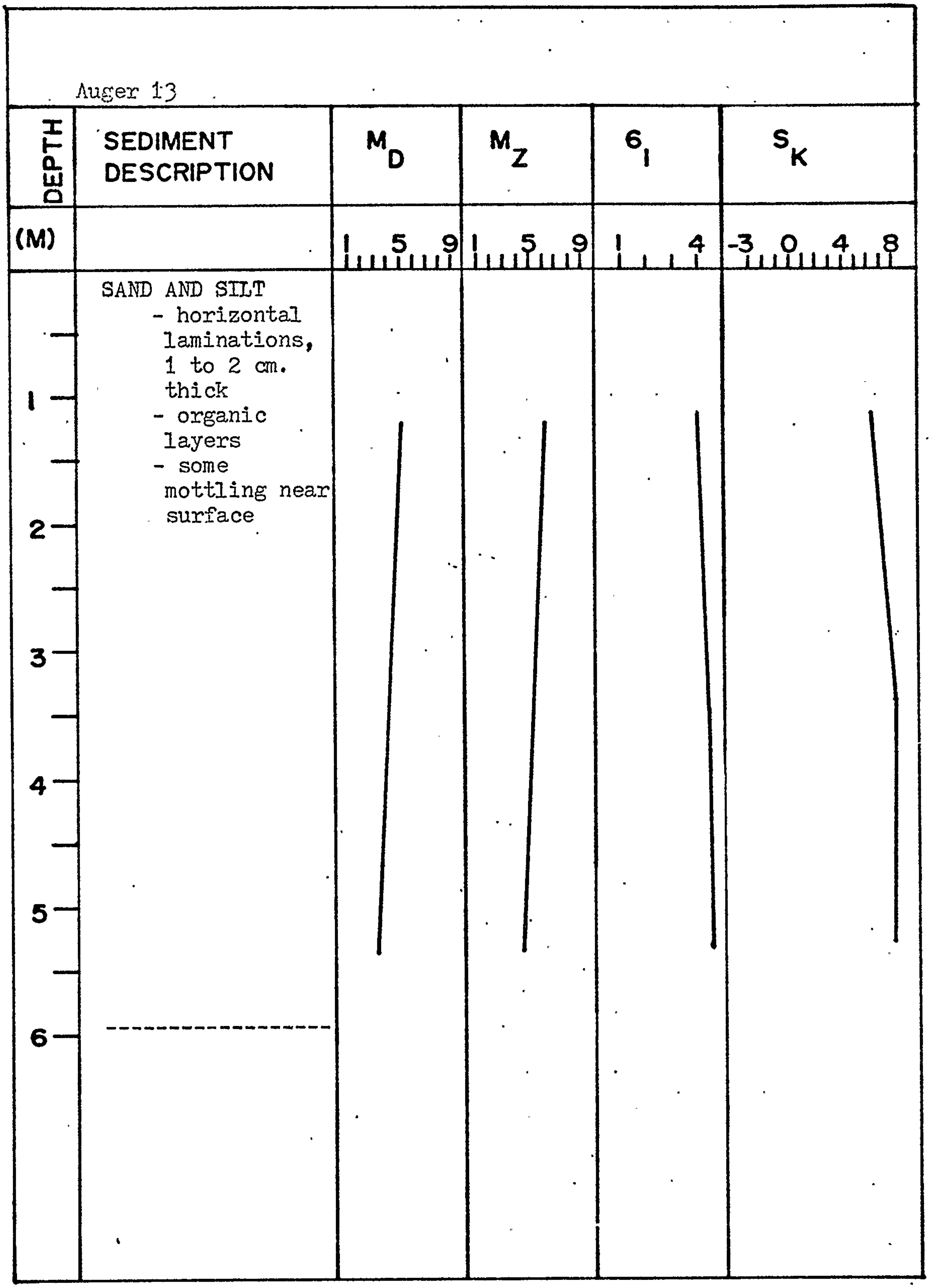
Auger 8
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
$б_I$
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm.
-- BRIDGE RIVER -- ASH
- organic layers
- some mottling near surface

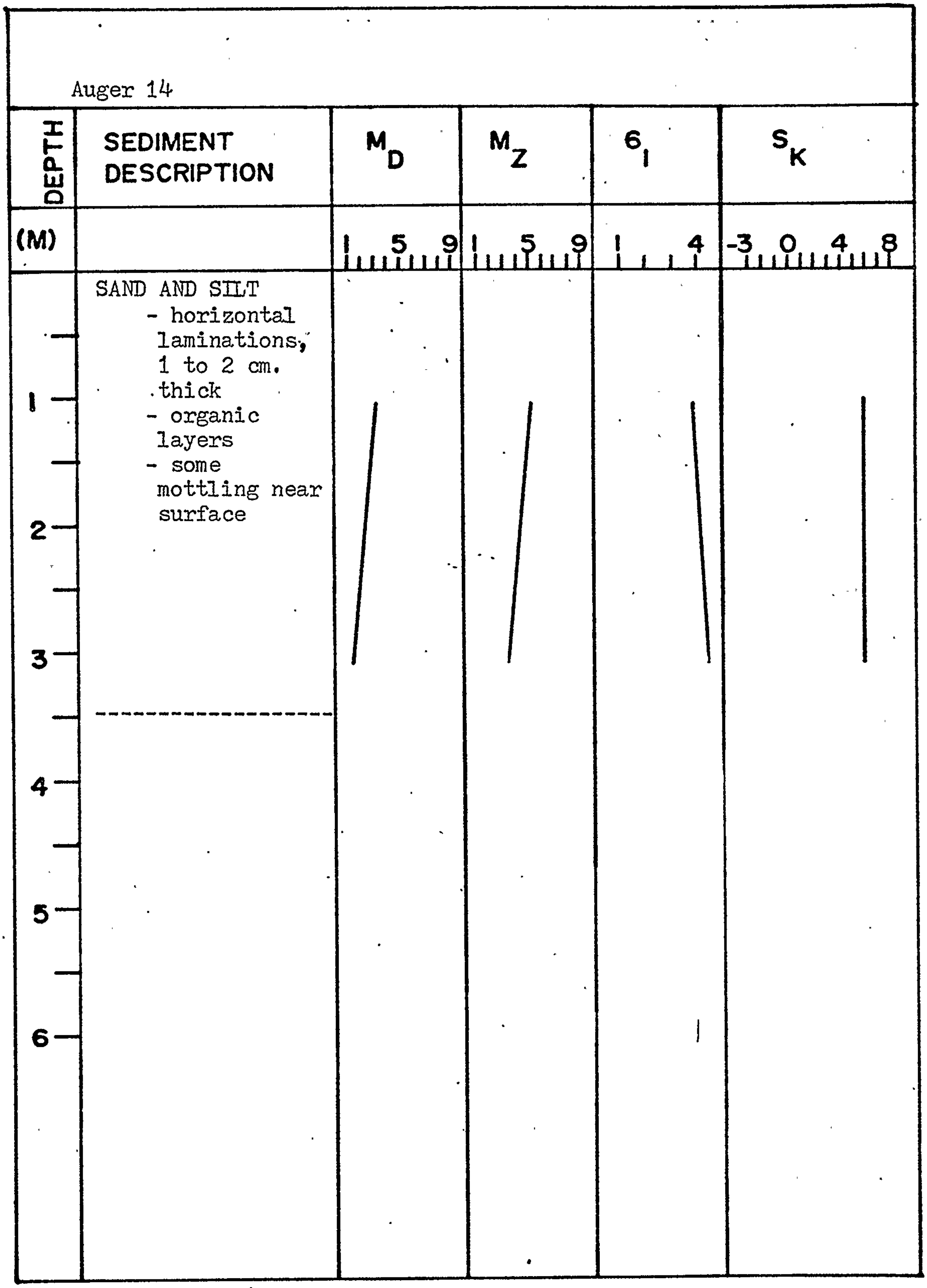

Auger 9
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
$б_I$
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

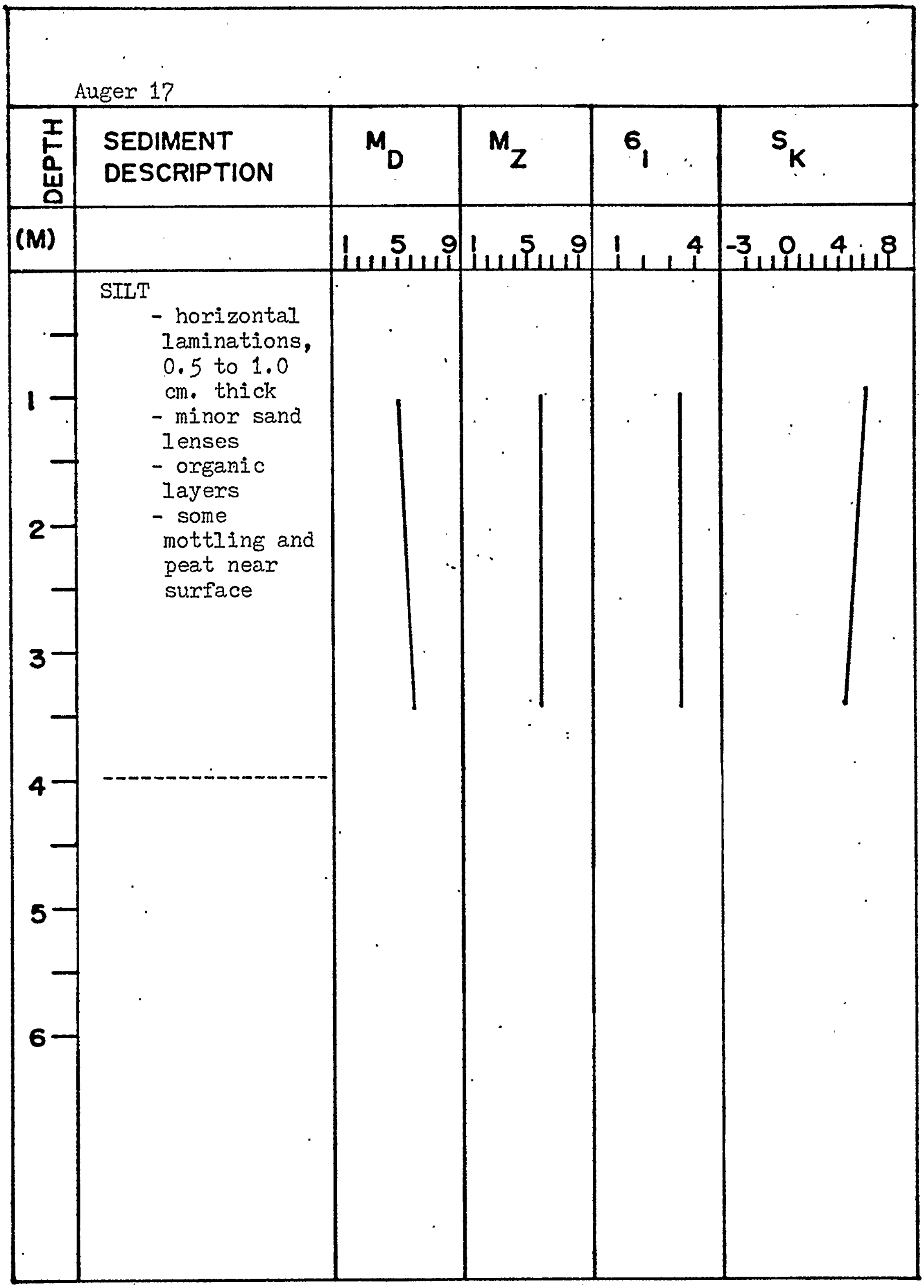


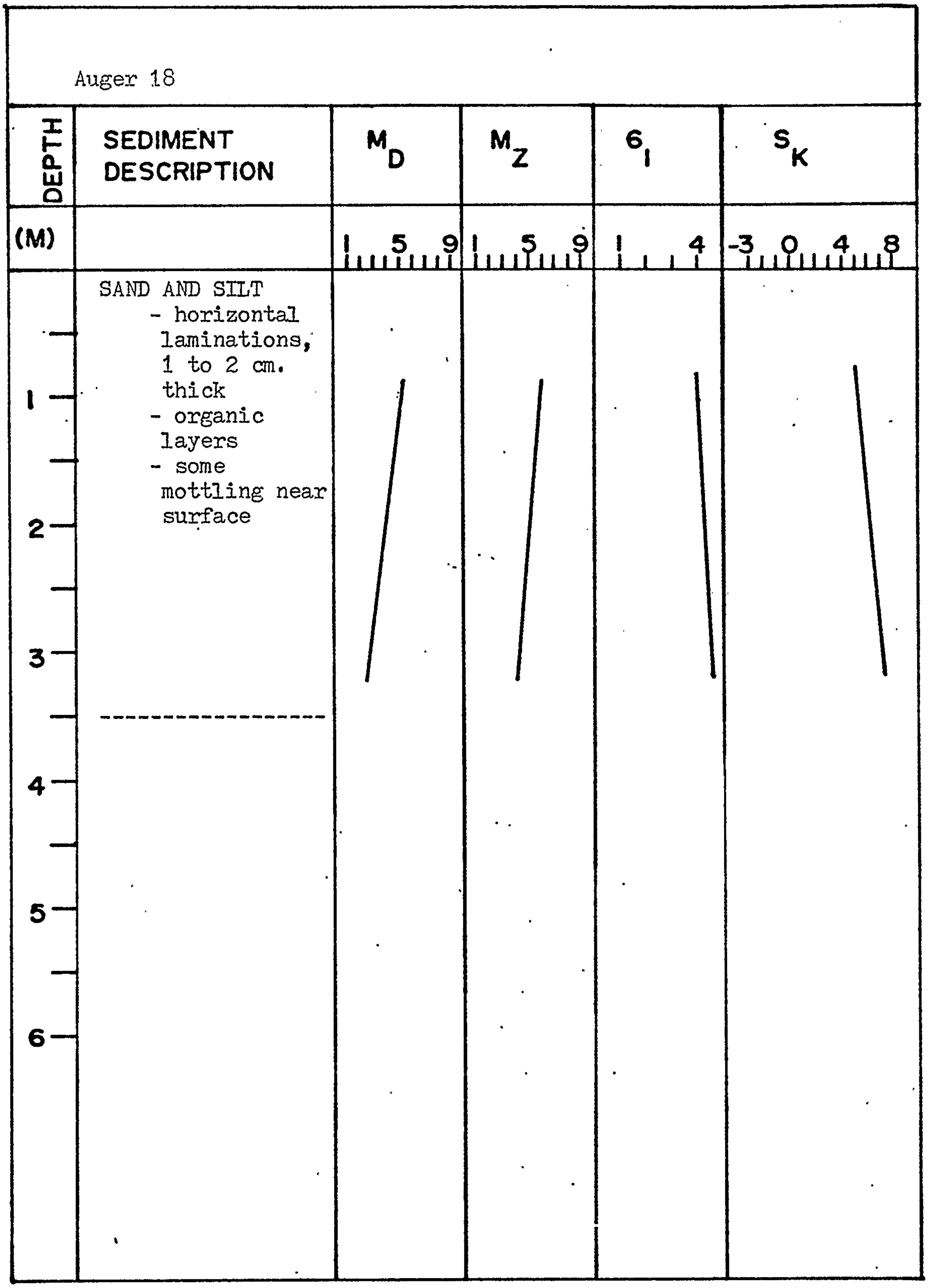
Auger 10
DEPTH
(M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

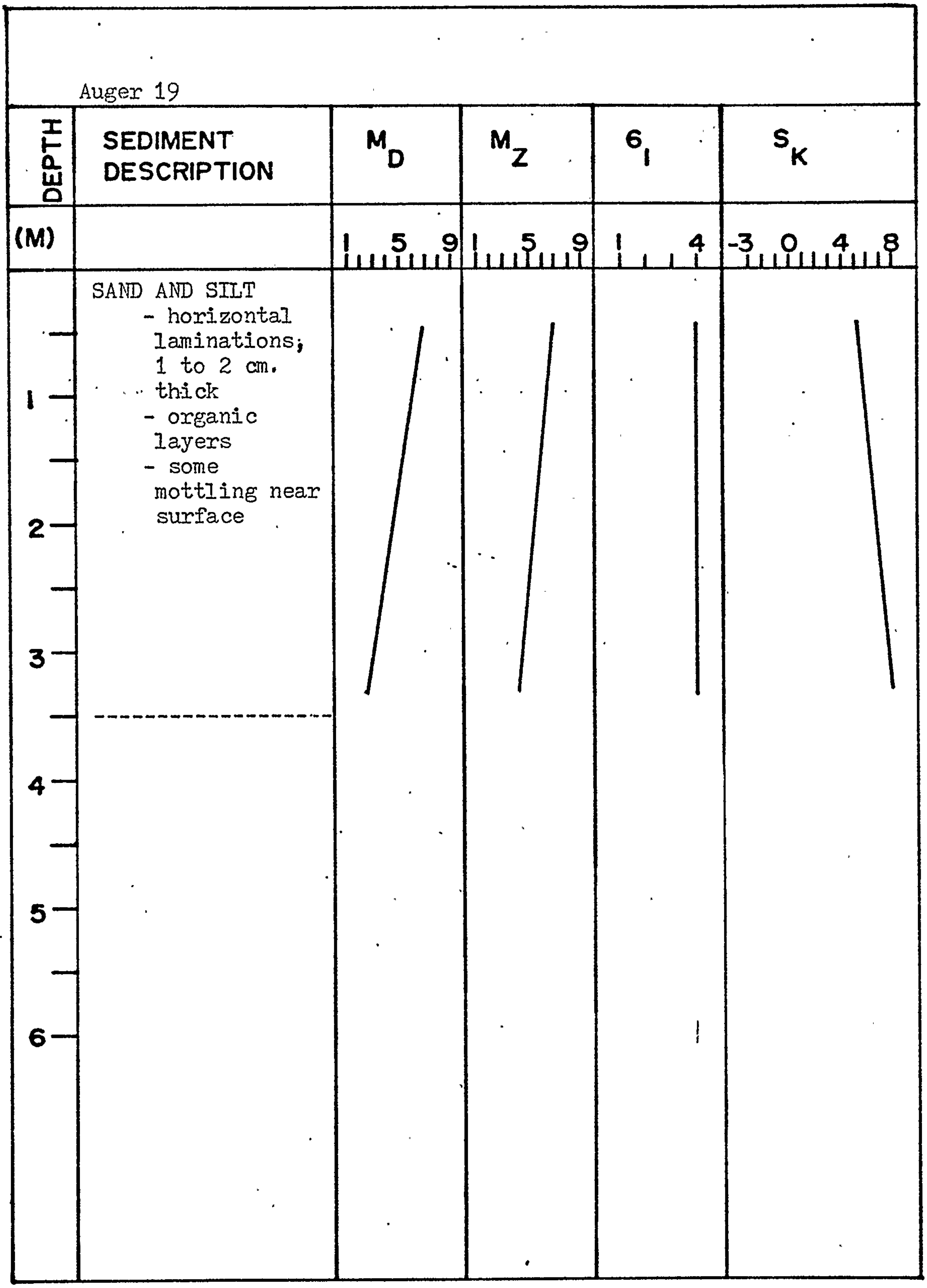

Auger 11
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

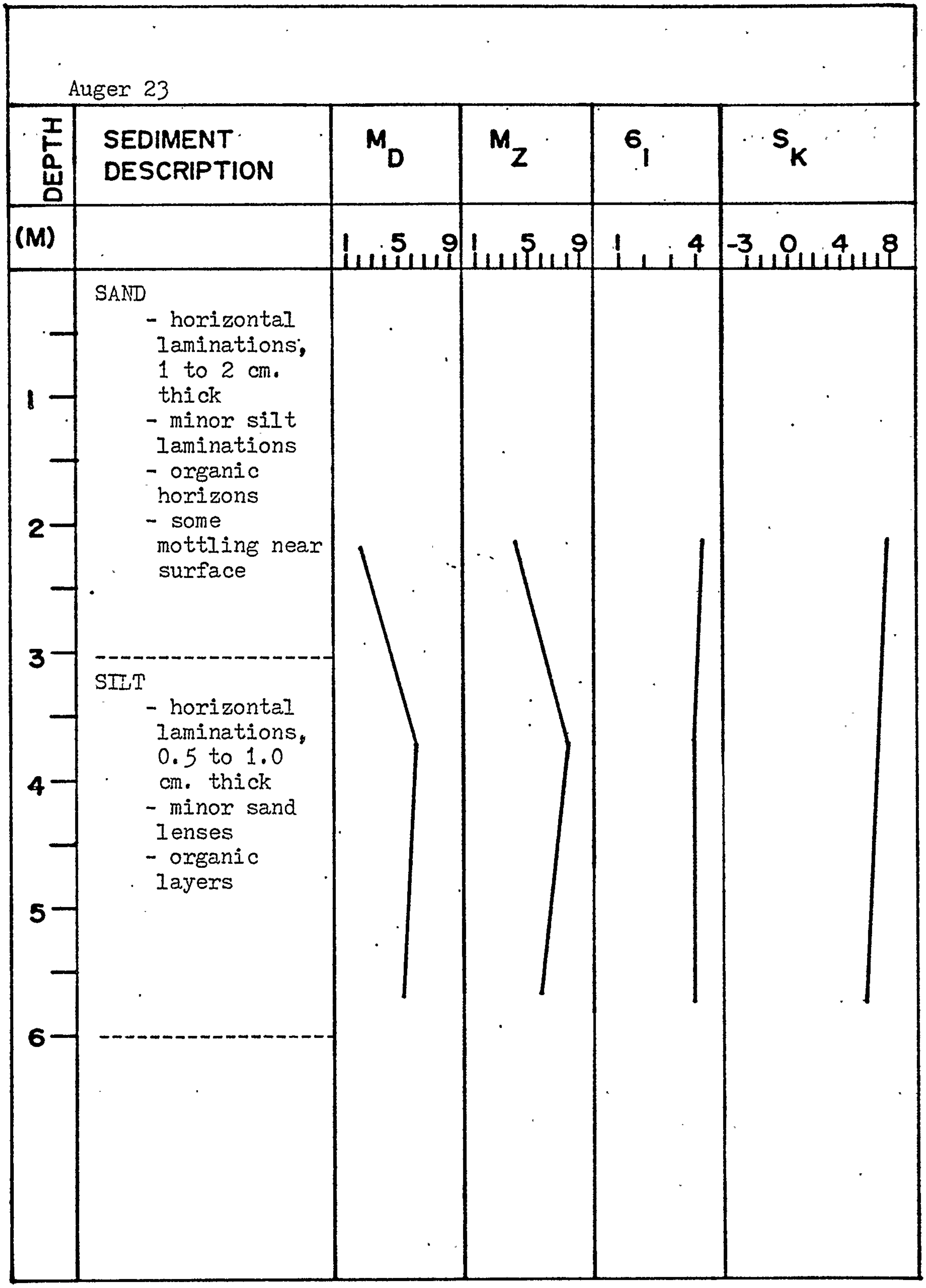

Auger 13
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

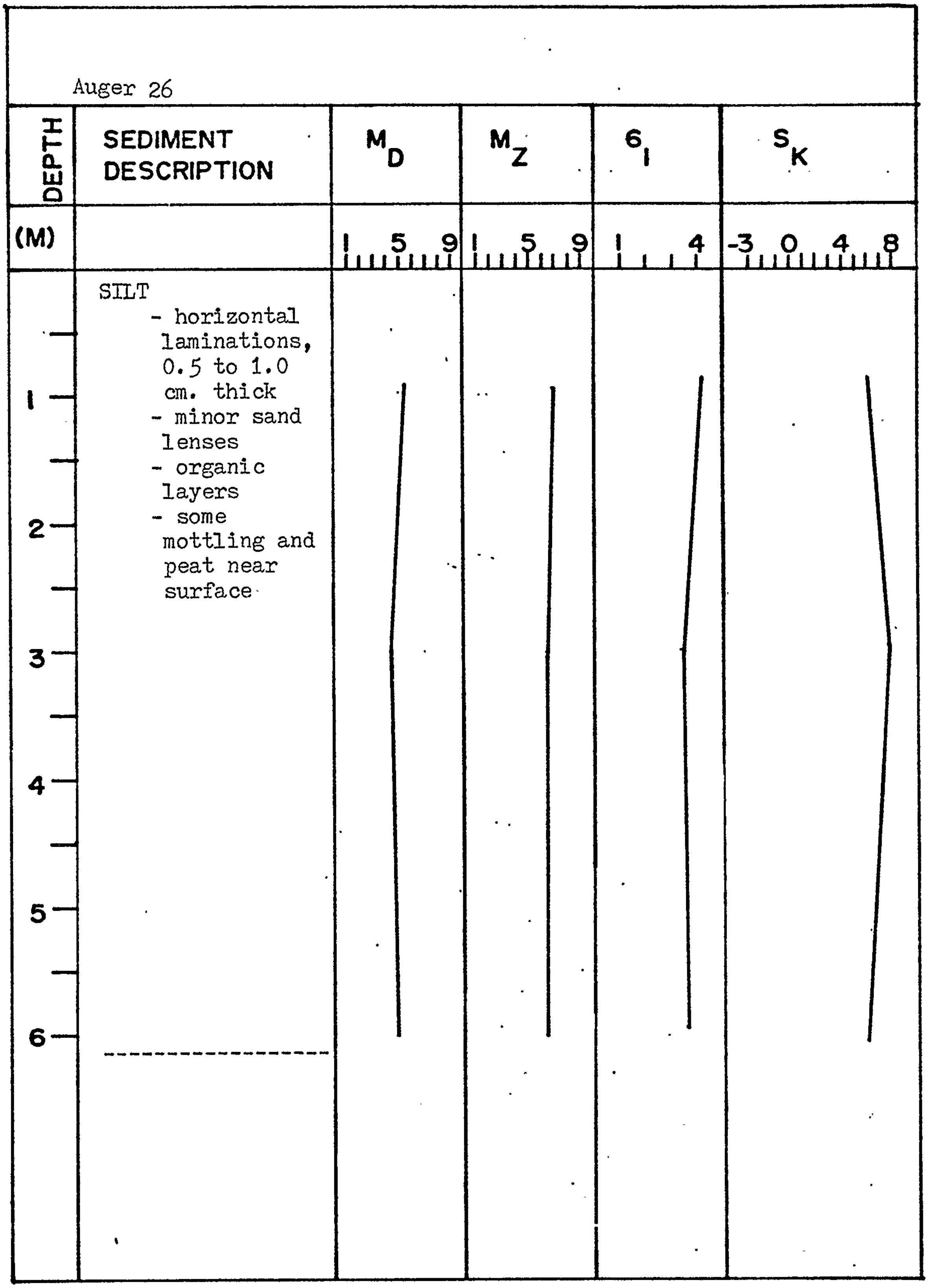

Auger 14
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface


Auger 17
DEPTH (M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- minor sand lenses
- organic layers
- some mottling and peat near surface

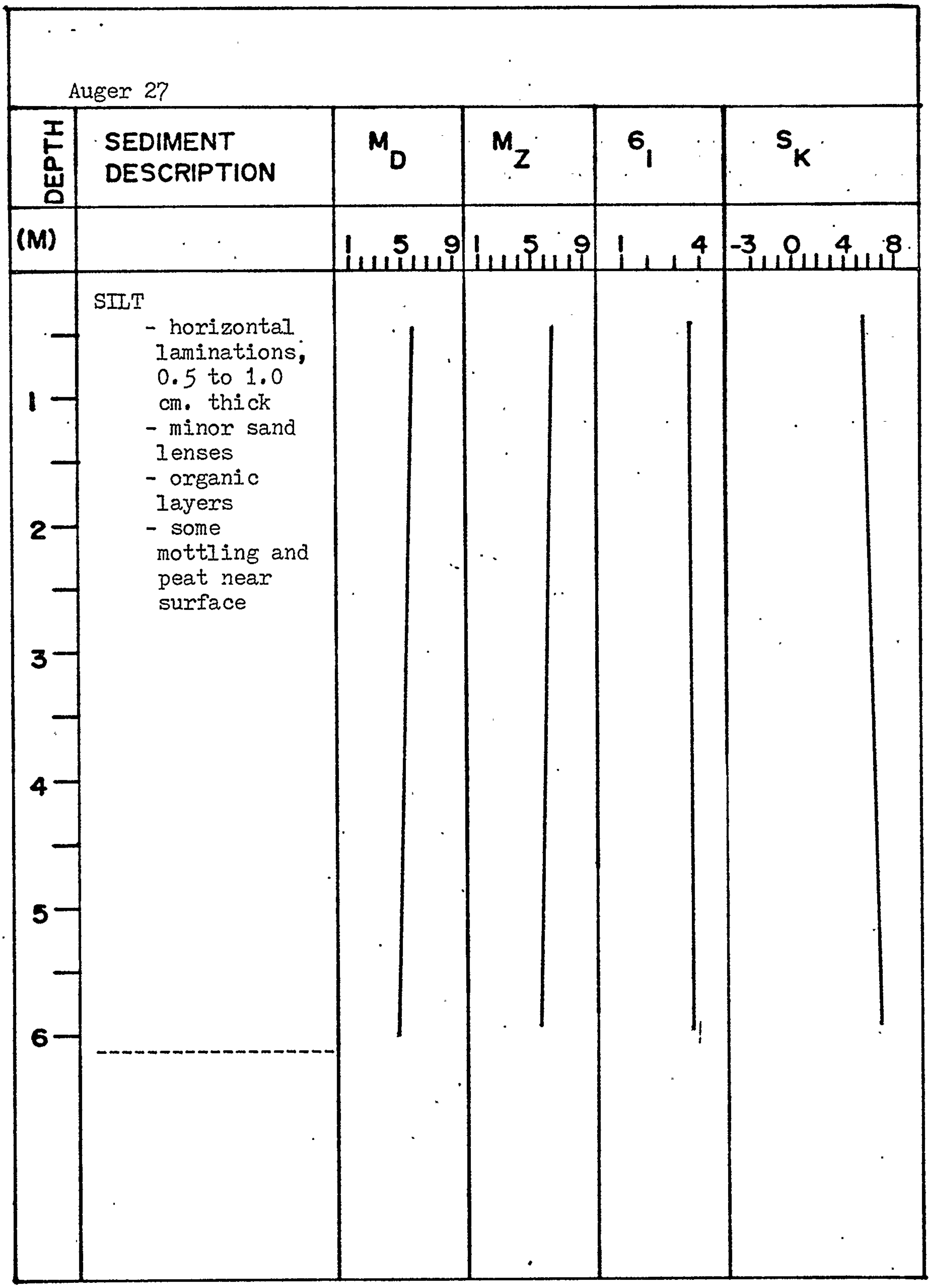

Auger 18
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface
1
2
3
4
5
6


Auger 19
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

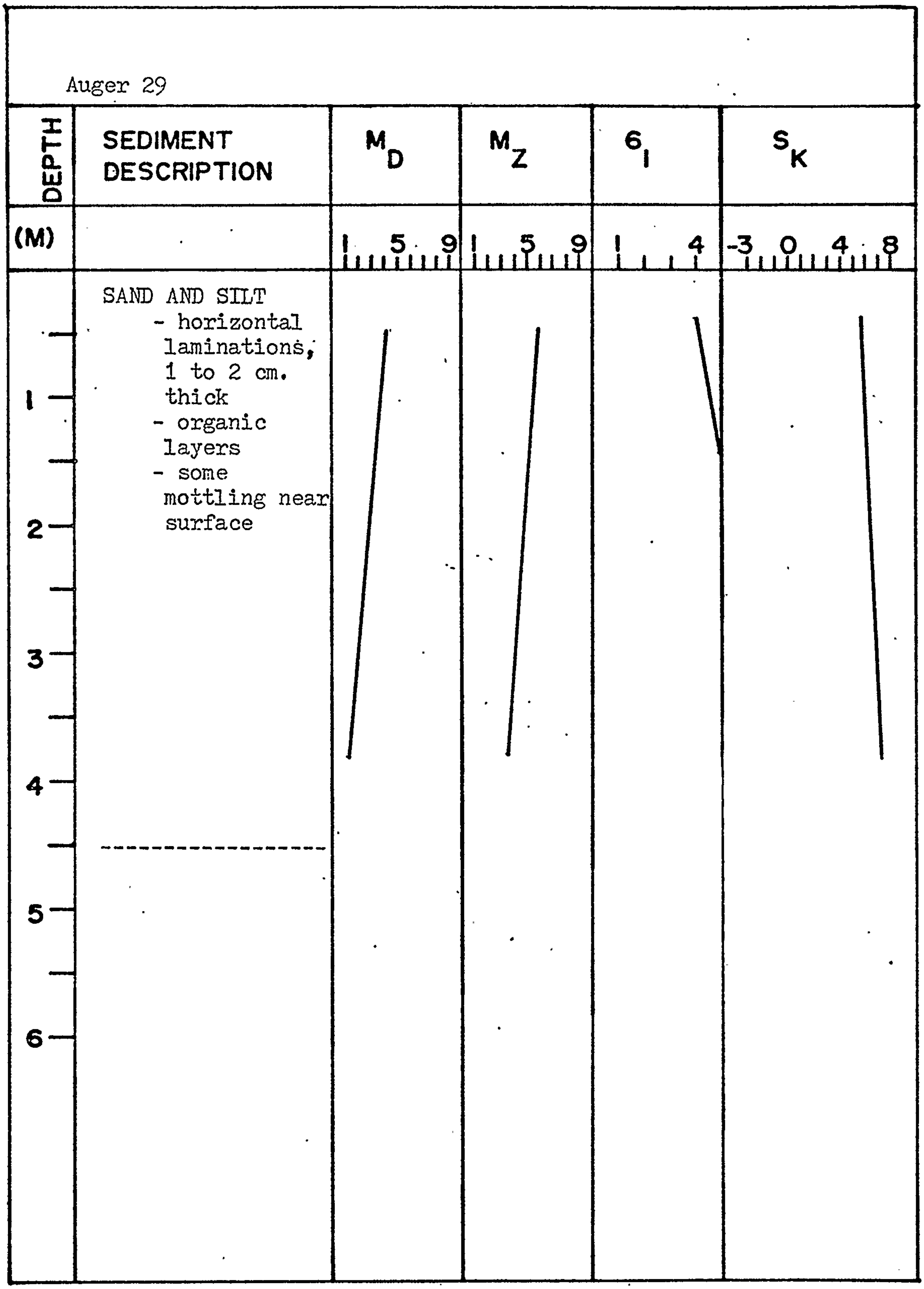

Auger 23
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND
- horizontal laminations, 1 to 2 cm. thick
- minor silt laminations
- organic horizons
- some mottling near surface
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- minor sand lenses
- organic layers



Auger 26
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- minor sand lenses
- organic layers
- some mottling and peat near surface

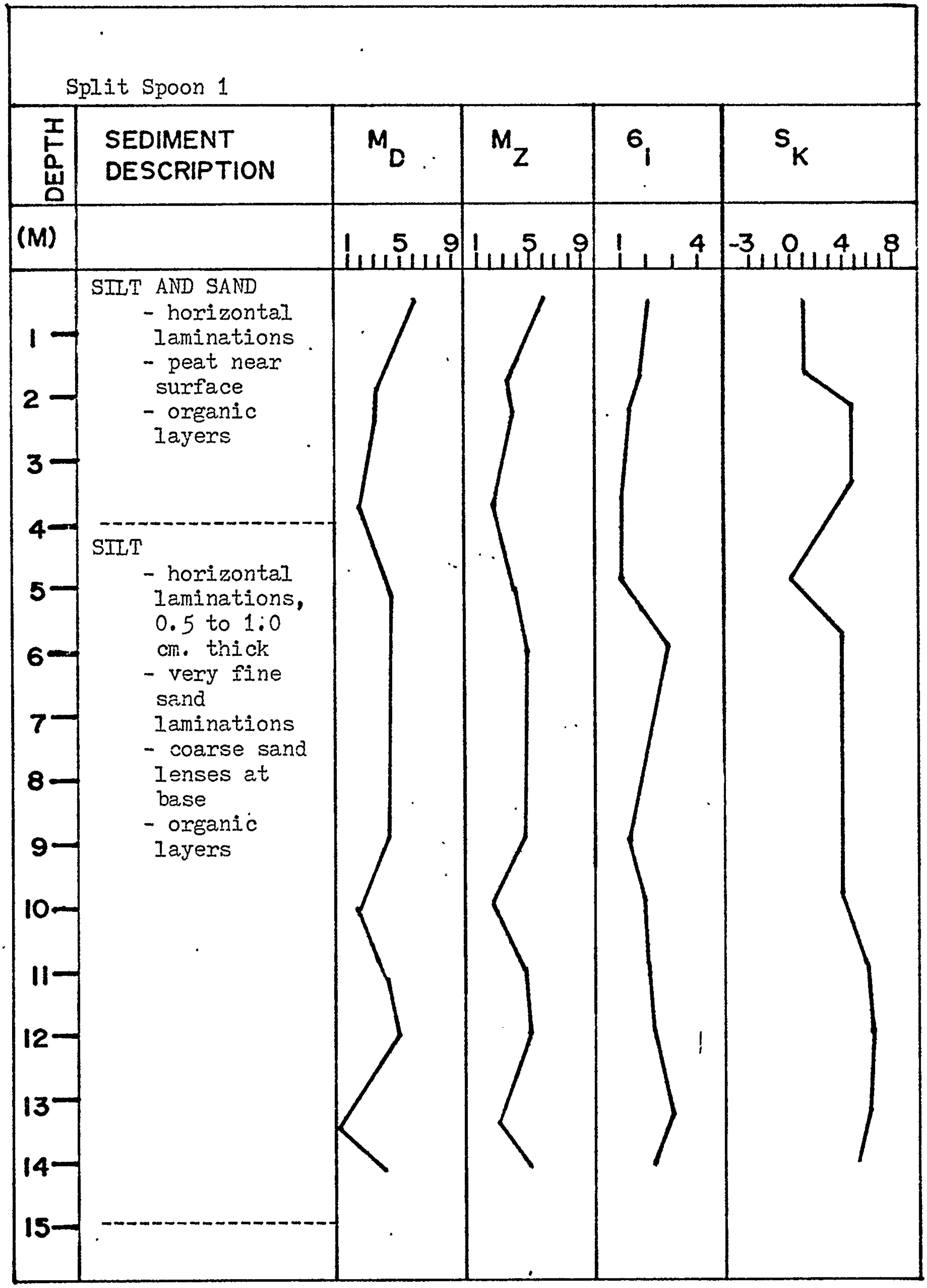


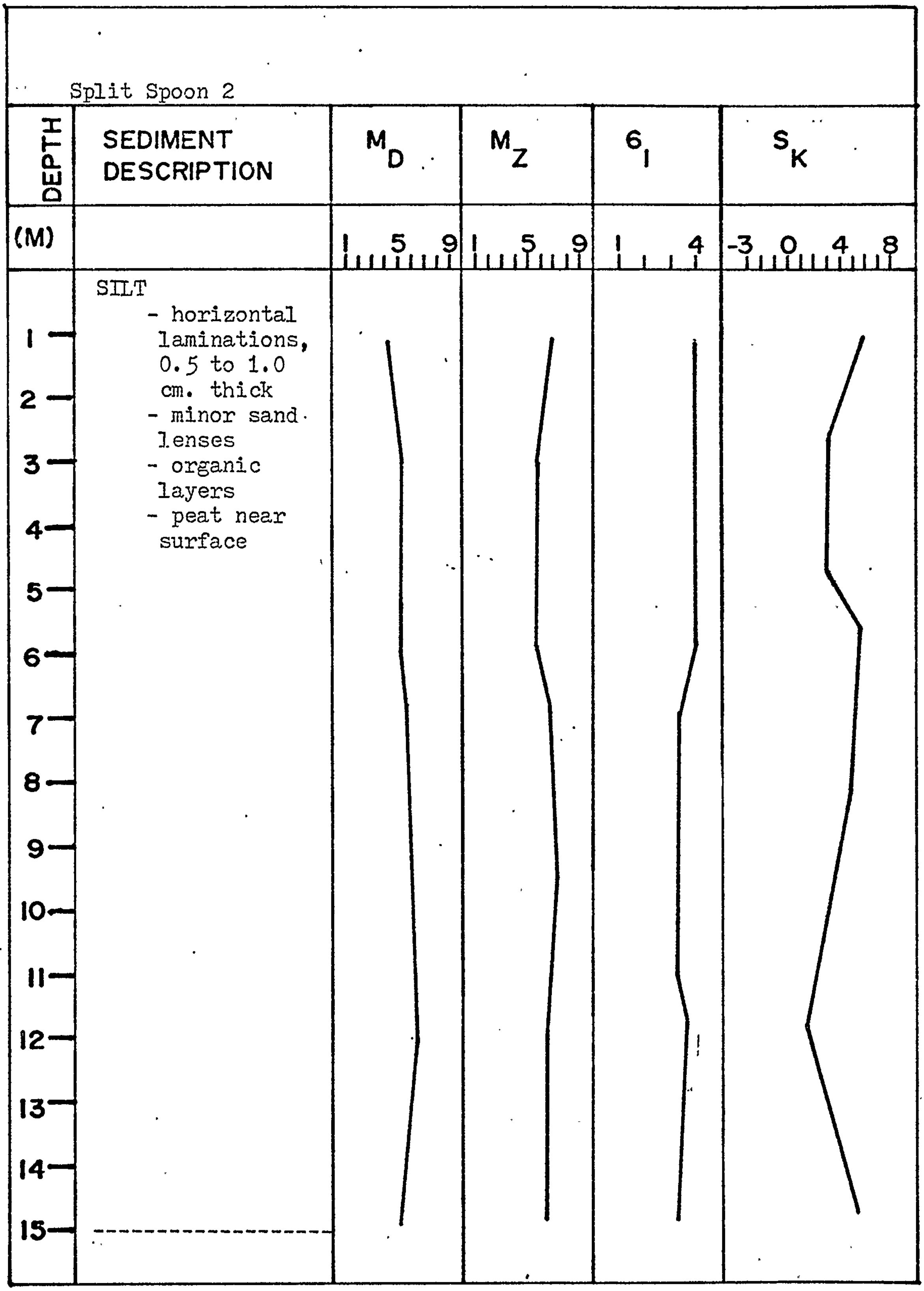
Auger 27
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- minor sand lenses
- organic layers
- some mottling and peat near surface

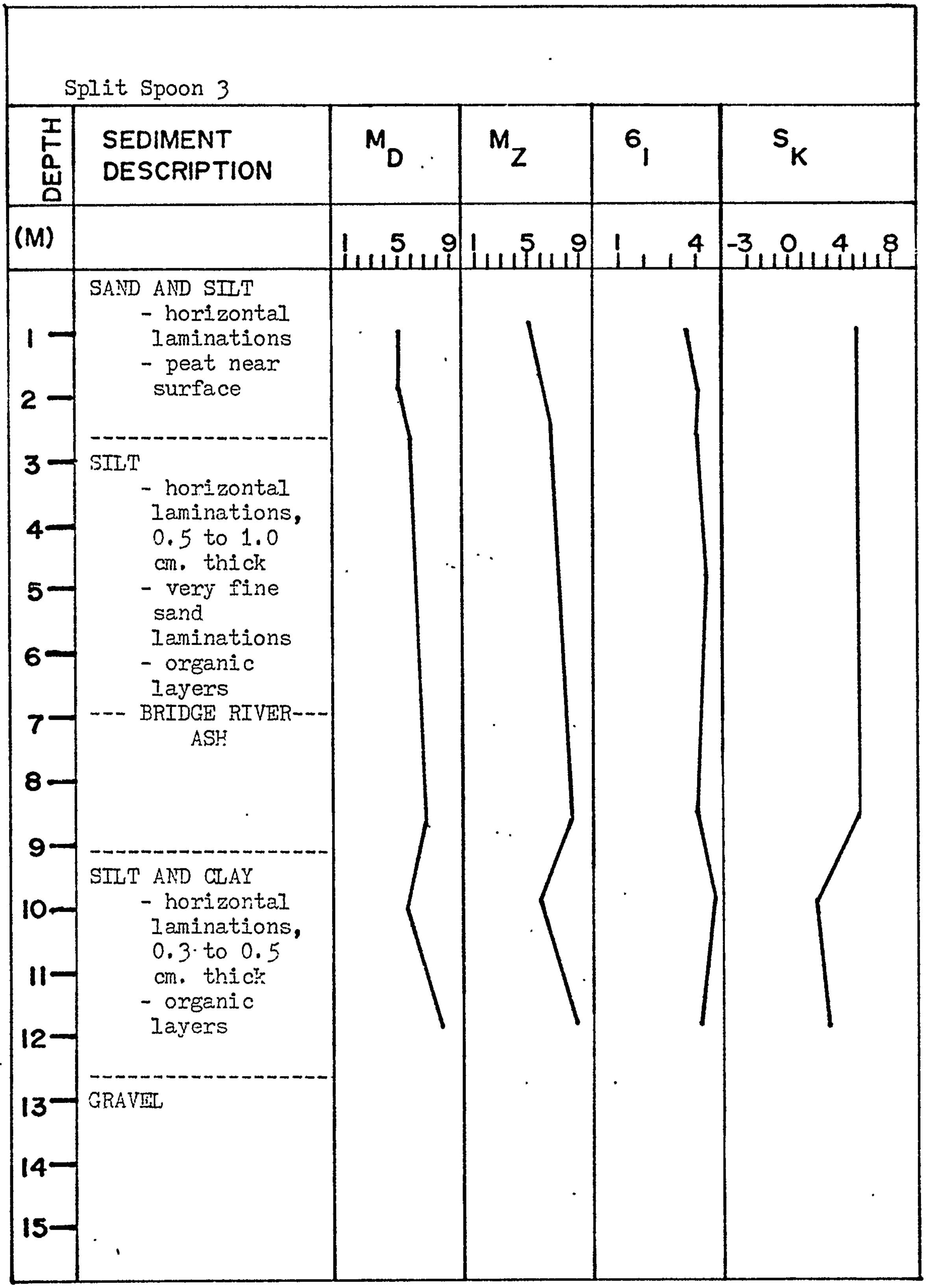

Auger 29
DEPTH
(M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
SAND AND SILT
- horizontal laminations, 1 to 2 cm. thick
- organic layers
- some mottling near surface

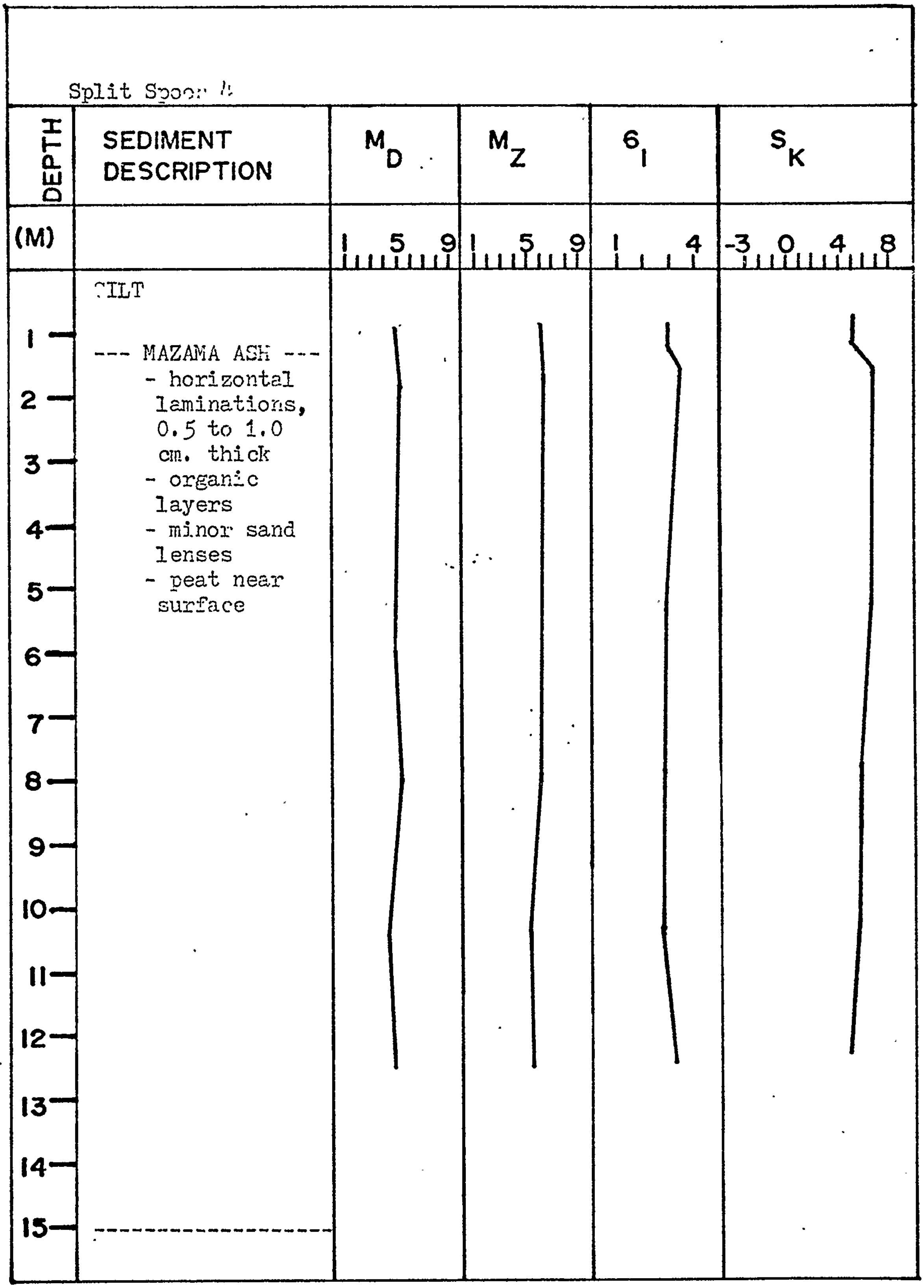
APPENDIX C

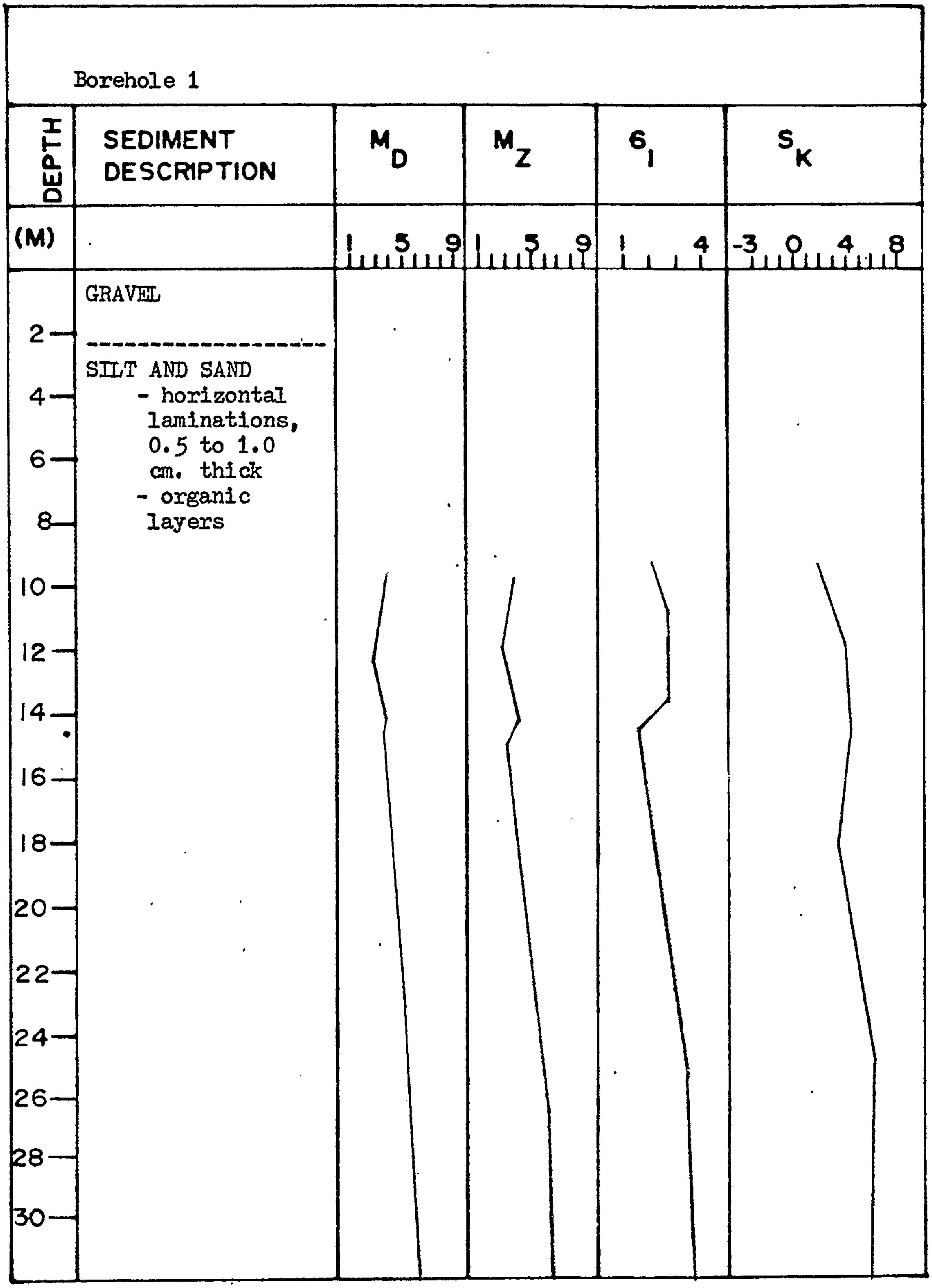
SPLIT SPOON AND BOREHOLES

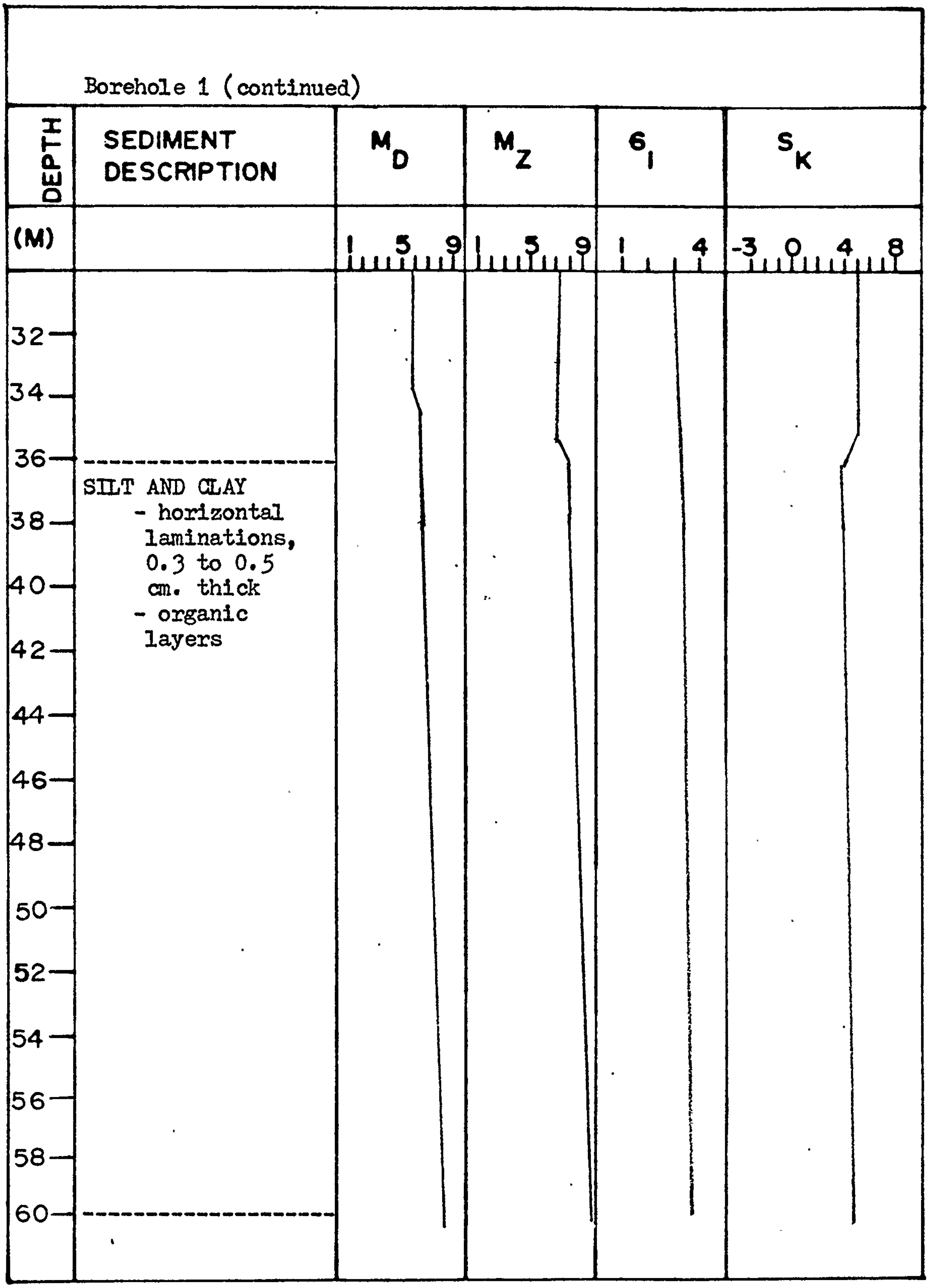

Split Spoon 1
DEPTH (M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
SILT AND SAND
- horizontal laminations
- peat near surface
- organic layers
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- very fine sand laminations
- coarse sand lenses at base
- organic layers
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

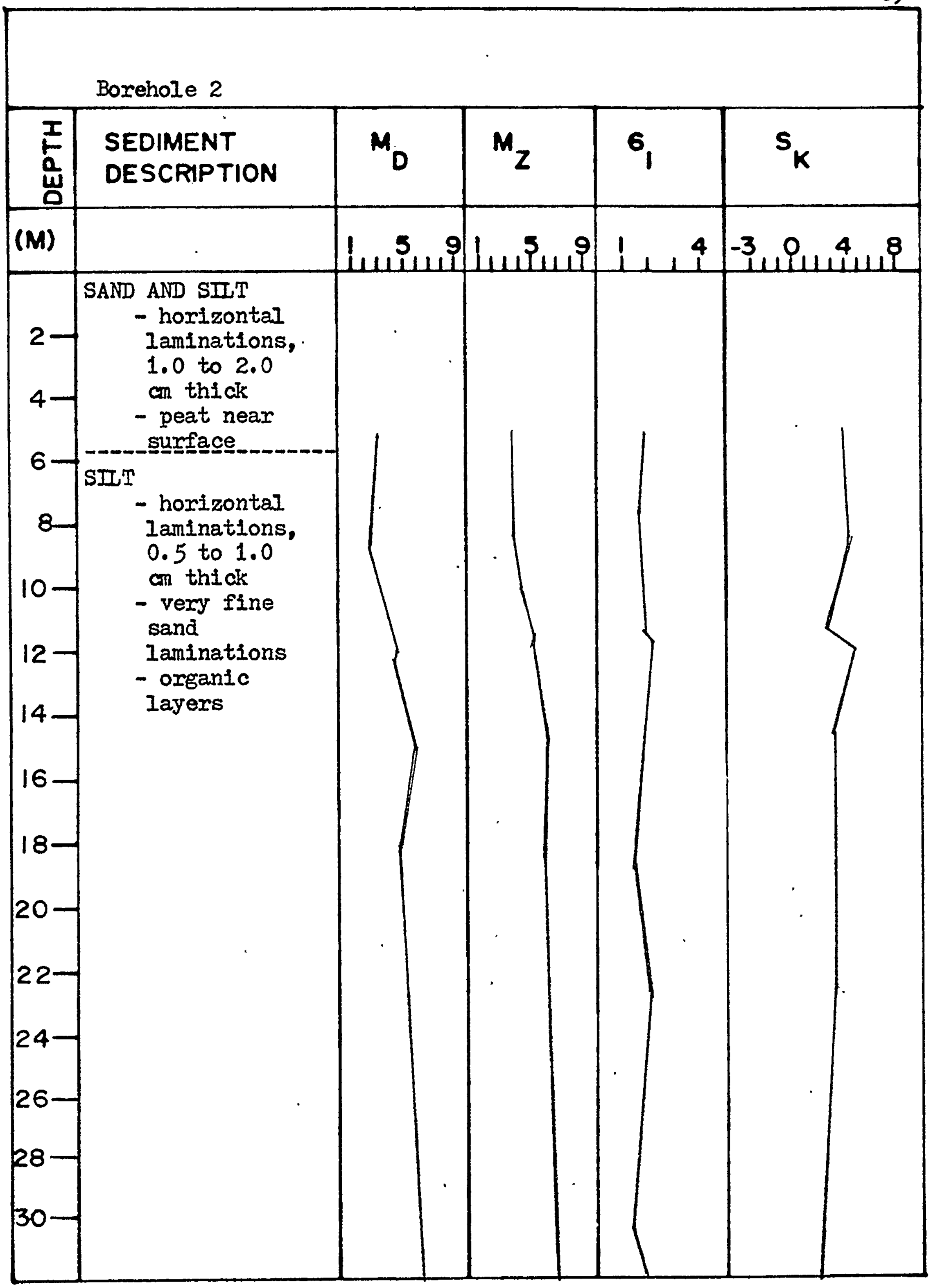

Split Spoon 2
DEPTH (M)
SEDIMENT DESCRIPTION
M_D
M_Z
σ_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- minor sand lenses
- organic layers
- peat near surface

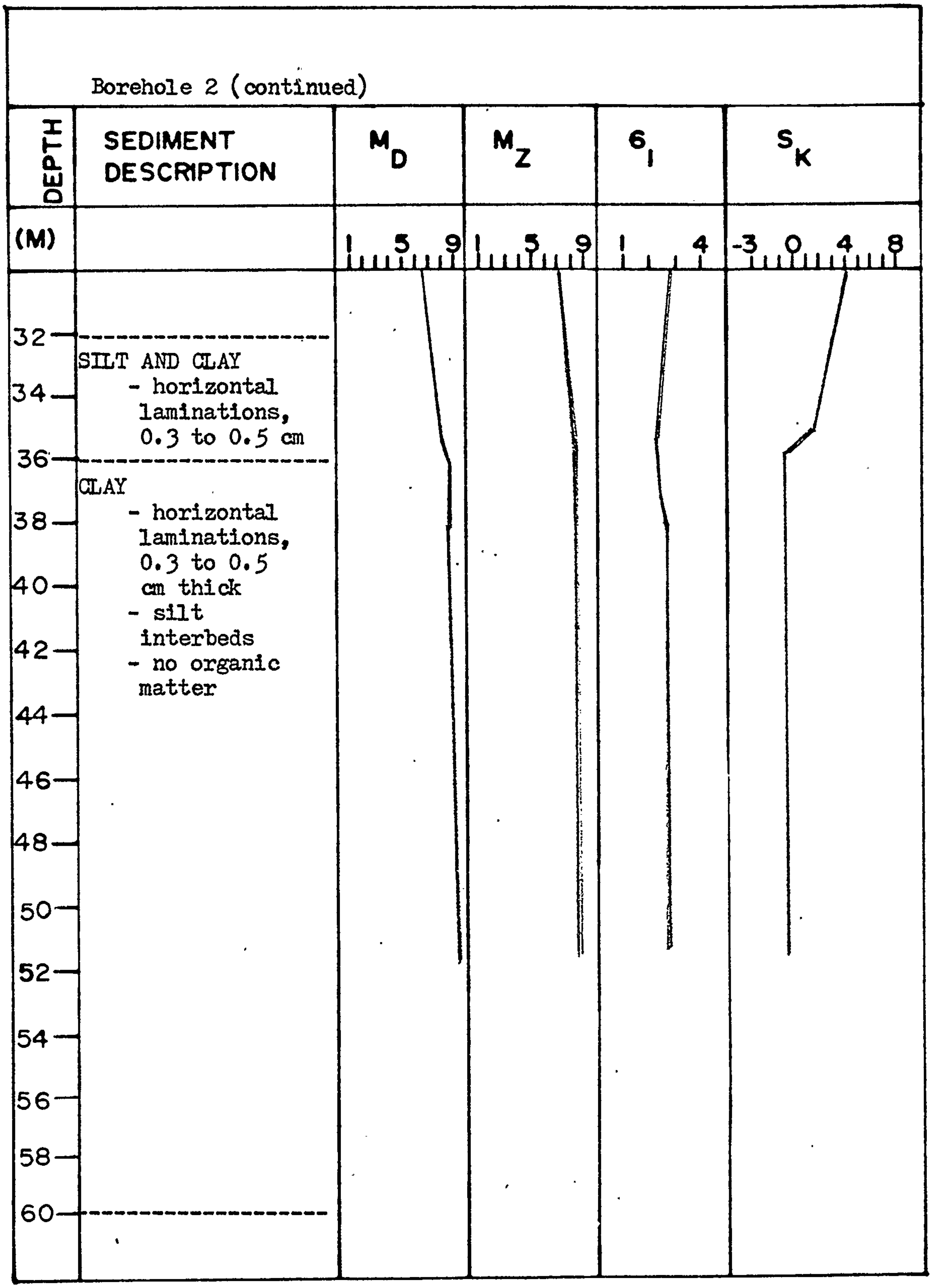

Split Spoon 3
DEPTH (M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
SAND AND SILT
- horizontal laminations
- peat near surface
SILT
- horizontal laminations, 0.5 to 1.0 cm. thick
- very fine sand laminations
- organic layers
--- BRIDGE RIVER--- ASH
SILT AND CLAY
- horizontal laminations, 0.3 to 0.5 cm. thick
- organic layers
GRAVEL


Split Spoon 4
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
SILT
--- MAZAMA ASH ---
- horizontal laminations, 0.5 to 1.0 cm. thick
- organic layers
- minor sand lenses
- peat near surface
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


Borehole 1
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
6_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
GRAVEL
SILT AND SAND
- horizontal laminations, 0.5 to 1.0 cm. thick
- organic layers
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30


Borehole 1 (continued)
DEPTH
(M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
SILT AND CLAY
- horizontal laminations, 0.3 to 0.5 cm. thick
- organic layers


Borehole 2
DEPTH
(M)
SEDIMENT DESCRIPTION
M D
M Z
6 I
S K
1 5 9
1 5 9
1 4
-3 0 4 8
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
SAND AND SILT
- horizontal laminations, 1.0 to 2.0 cm thick
- peat near surface
SILT
- horizontal laminations, 0.5 to 1.0 cm thick
- very fine sand laminations
- organic layers


Borehole 2 (continued)
DEPTH
(M)
SEDIMENT DESCRIPTION
M_D
M_Z
σ_I
S_K
1 5 9
1 5 9
1 4
-3 0 4 8
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
SILT AND CLAY
- horizontal laminations, 0.3 to 0.5 cm
CLAY
- horizontal laminations, 0.3 to 0.5 cm thick
- silt interbeds
- no organic matter