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SURFICIAL GEOLOGY AND QUATERNARY HISTORY OF THE HEALY LAKE AREA, ALASKA

A

THESIS

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By

Thomas Alan Ager, B.S.

College, Alaska

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SURFICIAL GEOLOGY AND QUATERNARY HISTORY

OF THE HEALY LAKE AREA, ALASKA

Chairman

Department Head

APPROVED: ______ Date 9/22/71

Dean of the College of Earth Sciences
and Mineral Industry

Vice President for Research and Advanced Study

Abstract

Surficial geology of the Healy Lake area in the Tanana Valley, interior Alaska, records the effects of major regional climatic events of the late Pleistocene and Holocene. During the Delta Glaciation the area was subjected to severe periglacial conditions associated with ice wedge formation, solifluction, and intense eolian activity which ventifacted resistant bedrock fragments and deposited fine sand and loess over much of the area.

The Donnelly Glaciation was also characterized by periglacial conditions. Aggradation of the Tanana River floodplain by glacial outwash dammed the Healy River, impounding a large lake in the lower Healy Valley. Wave activity caused by strong southerly winds produced beaches along the north shore of the lake. The beach sediments served as a source for sand and silt which were deposited by wind on adjacent slopes, producing widespread sand sheets, dunes, and loess deposits.

During the Holocene the environment of the area changed from grassland-tundra to boreal forest. The Donnelly-age lake was drained and its lacustrine deposits incised by the Healy River. Although loess deposition continued during the Holocene, the rate of accumulation and the mean grain size decreased. Bogs formed in the lower Healy Valley in the area previously covered by lake water. Permafrost development in the bogs was associated with thermokarst phenomena. Late in Holocene time, renewed aggradation of the Tanana River floodplain again dammed the Healy River, resulting in the formation of present-day Healy Lake.

CONTENTS

ILLUSTRATIONS

(Plates 1 to 4 are in pocket)

INTRODUCTION

Healy Lake is located in the central Tanana Valley of interior Alaska about 108 miles southeast of Fairbanks (Fig. 1). The Tanana Lowlands here are bordered to the south by rugged glaciated mountains of the Alaska Range, and to the north by the lower hills and ridges of the Yukon-Tanana Upland (Fig. 2). The region is sparsely inhabited. Although the Alaska Highway follows the Tanana Lowlands just north of the Alaska Range, only a few unimproved roads extend short distances from the highway to cabin sites and sawmills. Beyond the limit of roads, access to remote parts of the region is primarily by boat, float plane, all-terrain vehicles, or snow machines in winter.

Archeological evidence and radiocarbon dates from sites around the lake suggest that man occupied the area at least intermittently since about 11,000 years ago. Significant climatic fluctuations and resulting environmental changes have taken place during that period. Knowledge of these changes is vital to the interpretation of the culture and ecology of the early inhabitants.

Healy Lake also displays unique characteristics which in themselves merit study. Aggradation of the Tanana floodplain has dammed a number of tributaries which drain from the Yukon-Tanana Uplands, resulting in the formation of Healy, Harding, Birch, George, and other lakes. Among the lakes formed in this manner, Healy Lake alone had glaciated headwaters during the late Pleistocene. The lake also displays an unusual characteristic of periodic flooding via its outlet channel by the silt-laden waters of the Tanana River.

Geologic studies at Healy Lake were initiated in 1969. The primary objective was to reconstruct the history of environmental changes in the region during late

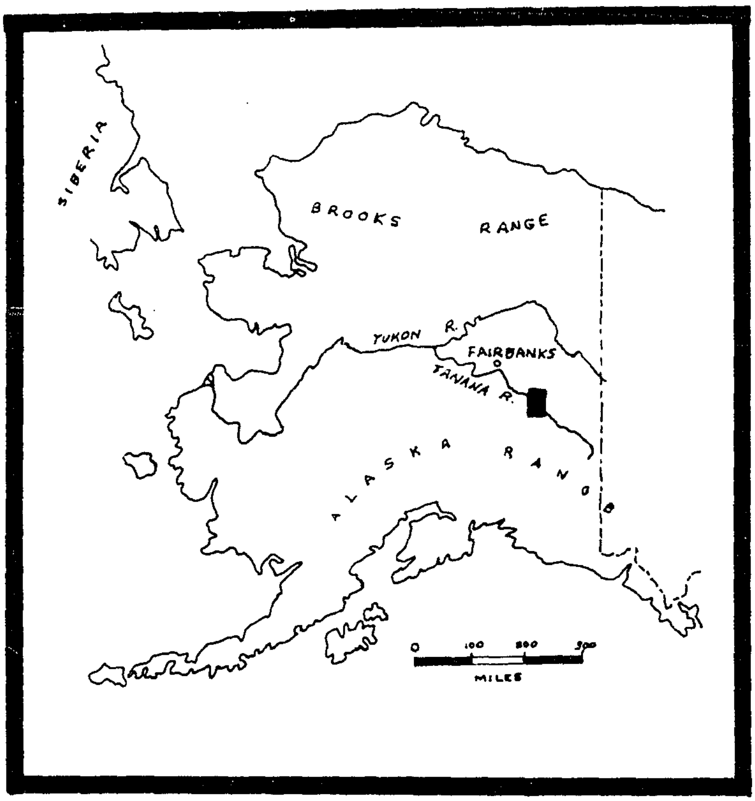
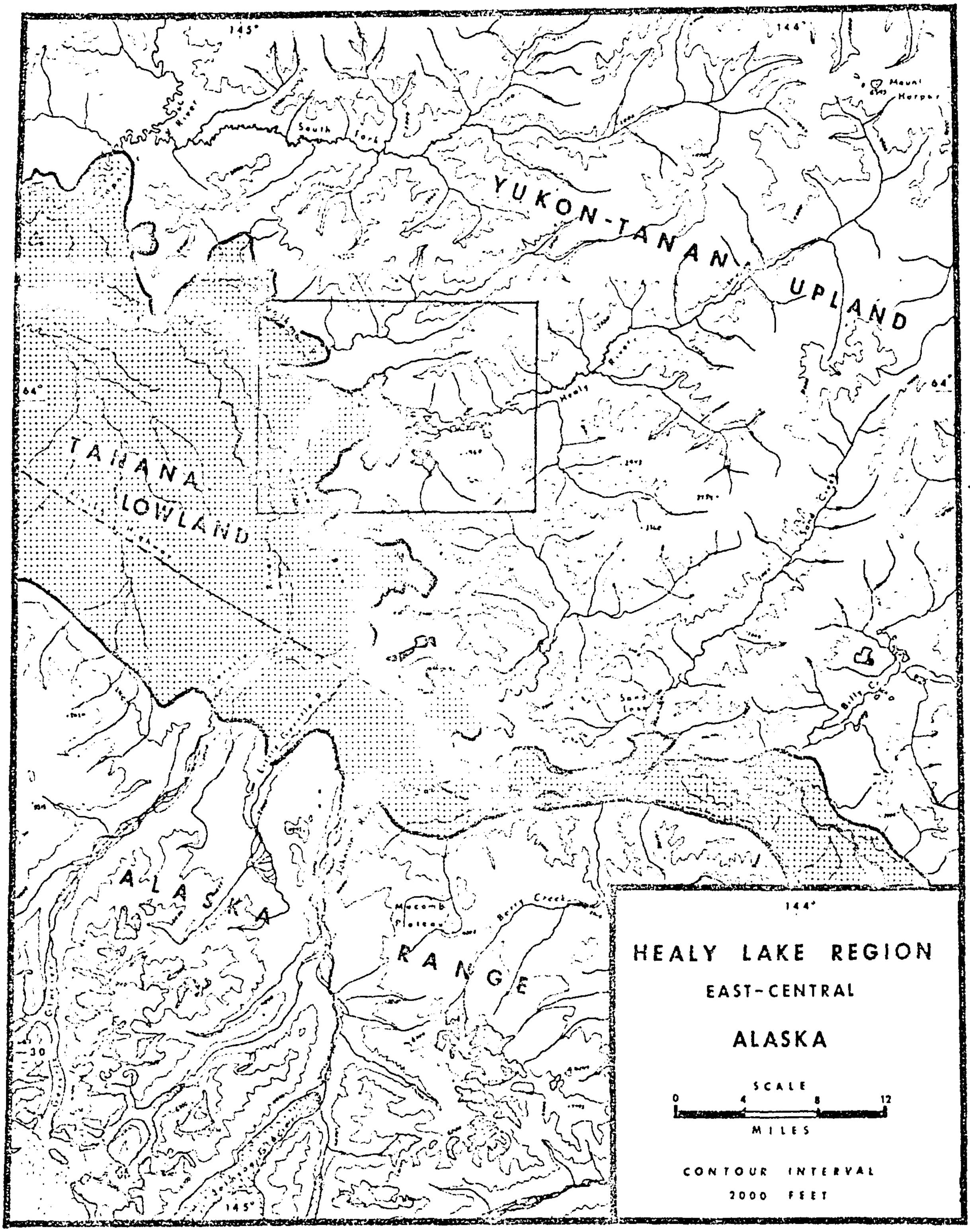


Figure 1: Index map of Alaska with location of the Healy Lake Region.



HEALY LAKE REGION
EAST-CENTRAL
ALASKA
SCALE
0 4 8 12
MILES
CONTOUR INTERVAL
2000 FEET
YUKON-TANANA UPLAND
TANANA LOWLAND
ALASKA RANGE
South Fork
Mount Harper
Macomb Plateau
Berry Creek
145°
144°
64°

Pleistocene and Holocene time. The research involved three major phases: (1) aerial photointerpretation of the region; (2) field studies of the geomorphology and surficial deposits of the lake area; and (3) sediment analysis of samples from the study area.

Previous Investigations

The first major geological reconnaissance of the central Tanana Valley, Alaska, was conducted in 1898 by Brooks and Peters (Brooks, 1900). In 1937 Mertie published a summary of reconnaissance geology of the Yukon-Tanana Uplands, but little was known of the area covered by the present report (Fig. 2). Since that time, segments of the region's uplands have been mapped where they were peripheral to geologic investigations in the Tanana Lowlands and Alaska Range (Holmes and Foster, 1968; Holmes, 1965; Foster, 1970). A terrain study carried out by the Military Geology Branch of the U.S. Geological Survey summarizes known and inferred geology of the U.S. Geological Survey summarizes known and inferred geology of the uplands within the region (Fernald et al., 1964; Weber et al., 1964). The Quaternary history of the Yukon-Tanana Upland is only partially known. Péwé and others (1967) mapped the distribution of Late Pleistocene glacial deposits in the upland by aerial photo-interpretation. Reconnaissance studies in the Tanana Lowlands have been conducted by a number of geologists, most of whom were concentrating on adjacent parts of the Alaska Range (Holmes and Foster, 1968; Holmes, 1965; Holmes and Benninghoff, 1957; Holmes and Péwé, 1965; Péwé and Holmes, 1964; Foster 1970). Moffit (1954) published a summary of geologic studies in the Eastern Alaska Range which covers part of the Healy Lake region. Surficial and bedrock geology in the Gerstle River and Johnson River areas have been mapped by Moffit (1942) and Holmes and Foster (1968).

Present Investigation

Access to the Healy Lake area was by shallow-draft motorboat via the Tanana and Healy Rivers from a boat landing near the Alaska Highway. Base camp during the 1969 field season was the archeological site ("Village Site") at the abandoned Athapaskan village which was being excavated at that time by investigators from the University of Alaska. Travel within the area was by foot, motorboat, and canoe. In August, 1969, a brief reconnaissance flight was made by floatplane up the headwaters area of the Healy River. A second flight by small plane was made in September, 1970, over the lake area for the purpose of photographing vegetational patterns and lake channels. In March, 1971, a brief trip was made to the lake by ski plane in an attempt to core frozen silts.

Natural exposures of sediments and bedrock are restricted mainly to the lake shore and river cutbanks. This necessitated digging numerous test pits and auger holes on hillsides, ridgetops, and other locations to determine the lithology and sequence of sediments, and where possible, depth to bedrock. The widespread occurrence of permafrost restricted examination of bog sediments to thawed cutbanks.

Unconsolidated sediments were exposed for examination by a combination of shoveling and augering with 10-inch diameter bit which permitted penetration to a practical maximum depth of about 12 to 15 feet, although one test hole penetrated to 23 feet. Elevations were determined by leveling with a brunton compass and when available, by use of a Paulin altimeter reading to $\pm$ 5 feet. Sediment analysis was carried out by the investigator according to standard sieving methods as described by Folk (1968) and Royse (1970). Radiocarbon samples were analyzed by Geochron Laboratories, Cambridge, Massachusetts.

Acknowledgements

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My acknowledgements would be incomplete without a special expression of gratitude to Mr. and Mrs. Paul Kirsteatter, longtime Healy Lake residents, for their generous hospitality and assistance during the field investigations and for sharing their intimate knowledge of the area.

REGIONAL SETTING

Climate

The Healy Lake region has a continental climate typical of much of interior Alaska. Although specific climatic data are lacking within the map area, inferences about local conditions can be made from weather data from Big Delta, 34 miles west of Healy Lake (Fig. 3). Winters are severe, with occasional mid-winter minimum temperatures of -60°F or colder. Snowfall averages about 36 inches in the lowlands, but increases with altitude. Most of the annual precipitation falls as rain in the summer, constituting about 75% of the estimated 11.5 inch annual precipitation. Regional winds are often quite strong, flowing downvalley to the northwest from the Upper Tanana Valley. Strong katabatic winds flow down the main river valleys from Alaska Range glaciers.

Vegetation

Northern Boreal Forest communities cover the lowlands and ridges below timberline, which occurs between 2500 and 3000 feet altitude. Near timberline the forest communities grade into brush vegetation and alpine tundra. Much of the Alaska Range and Yukon-Tanana Uplands is sparsely vegetated above about 4500 to 5000 feet, where harsh microclimatic conditions support only scattered low hardy plant species, such as lichens, mosses, herbs, and sedges. Alpine tundra is widespread between 3000 and 5000 feet, and includes, in addition to the rock desert flora mentioned above, dwarf birch (*Betula nana*), cottongrass, willow, and berry bushes. Brush vegetation near timberline is dominated by alder (*Alnus crispa*, *A. incana*), willow (*Salix* ssp.), dwarf birch (*Betula nana*) and other shrubs.

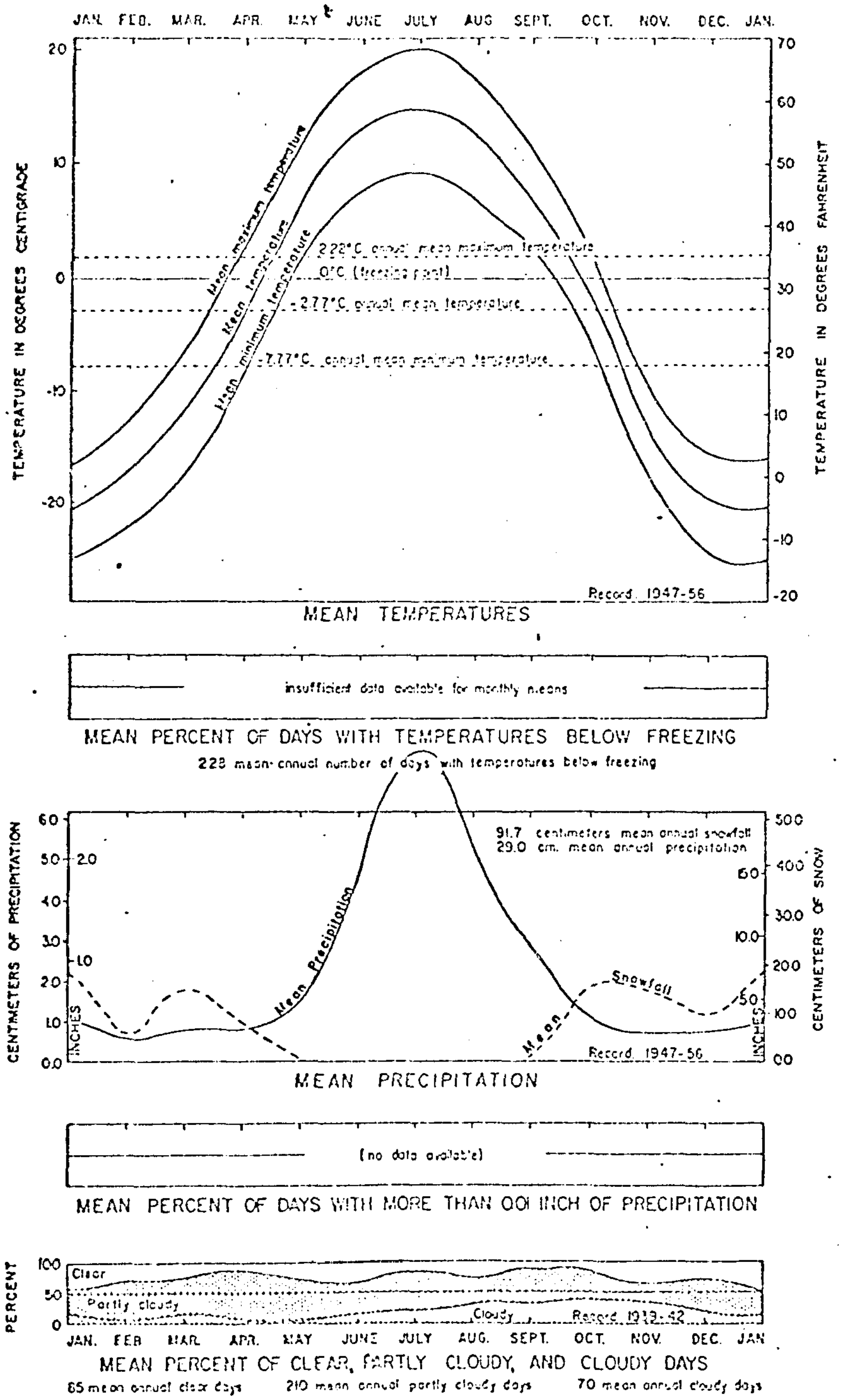


Figure 3: Mean monthly climatic data for Big Delta FAA station at Fort Greely, Alaska, 34 miles west of Healy Lake (After Church, Pewe, and Andresen, 1965).

The slopes and valley bottoms of the foothills of the Alaska Range and the valleys and ridges of the uplands support a mosaic forest vegetation of white spruce (Picea glauca), white birch (Betula resinifera), and aspen (Populus tremuloides). Black spruce (Picea mariana) occurs where cool, wet conditions prevail, such as on north facing slopes and in bogs. The largest stands of mature forests are of white spruce. These occur along the valley floors of major rivers, including the Tanana, Johnson, Gerstle, Little Gerstle, and some of the tributaries to the Tanana which flow southward from the Yukon-Tanana Uplands (Spetzman and Martin, 1961; Holmes and Foster, 1968).

Active flood plains of the major rivers are almost entirely free of vegetation, due to rapidly migrating channels, aufeis formation in winter, and dry windswept conditions. These barren areas are colonized eventually by Equisetum and willows. On older terraces and other areas where permafrost is prevalent and drainage poor, bog and muskey communities with brush, stunted black spruce, mosses, and sedges predominate.

Figure 4 illustrates the generalized relationships of major vegetation communities to influences of microclimate, altitude, slope, and drainage. Vegetation and soil conditions interact to affect the distribution of permafrost. The succession of plant communities on previously barren alluvium contributes to the concurrent development of permafrost, due primarily to development of insulating cover of vegetation, sod and peat, and to silt entrapment (Viereck, 1965, 1966, 1970a, 1970b).

In addition to the influences of microclimate, altitude, permafrost, and soil conditions, distribution of plant communities also reflects regional fire history. The ecological effects of fires in interior Alaska and their history has been studied by

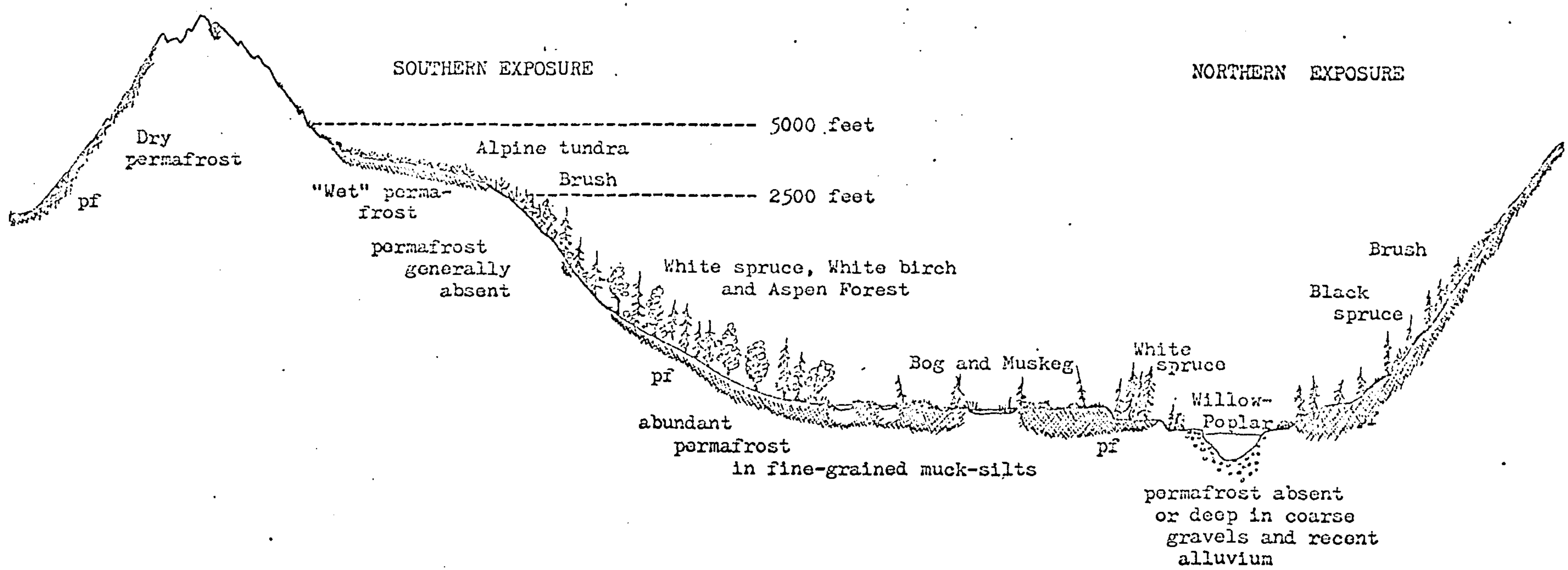


Figure 4: Diagram of Vegetation and Permafrost distribution in the Healy Lake region, interior Alaska.

Lutz (1956, 1959, 1951). In general, the mosaic forests which cover most of the uplands below timberline and extensive portions of the Tanana floodplain are largely successional stages of reforestation following numerous fires in the interior during the past century.

Permafrost

The Healy Lake region lies within the zone of discontinuous permafrost (Péwé, 1966). Although permafrost occurs in both coarse and fine-grained sediments where an adequate insulating cover permits, its geomorphic effects are most dramatic when the frozen material is supersaturated fine silt. Such sediments often contain a high percentage of ice by volume. Melting of the permafrost by destruction of the insulating mat of peat and other vegetation can produce thaw lakes and create engineering problems. The general distribution of permafrost tends to follow the diagram (Fig. 4) which applies to interior Alaska. Permafrost features in the region include solifluction sheets and lobes above about 4000 feet altitude; stone stripes and other frost sorting features are also actively forming at about the same altitudes. In silty valley bottoms of the upland pingos form at the base of slopes, and thermokarst lakes and ponds dot the lower valley flats.

Soils

Soils of the Healy Lake region can be differentiated into six broad soil groups: Lithosols; Tundra soils; Subarctic Brown Forest soils; Low-Humic Gley soils; and Alluvial soils. Soils develop as a result of a complex interaction of regional climate, microclimate, type of parent material, vegetational cover, relief, drainage, and time (Tedrow and Cantlon, 1958). The influence of altitude can be expressed by the zonal distribution of the major soil groups, as illustrated in Figure 5.

Lithosols are essentially azonal soils which occur mostly at higher altitudes, particularly above about 5000 feet, where frost action and other erosional processes are intense, and runoff is rapid. The parent material is largely talus and rock rubble overlying bedrock. A thin humus layer may be derived from lichens and other plants which sparsely inhabit the zone (Tedrow, 1965).

Tundra soils occur on ridgetops and plateaus, mostly between altitudes of 3000 to 5000 feet where gradients are not excessive. These intrazonal soils tend to form under conditions of poor drainage, with a rather high permafrost table, and alpine tundra vegetation. The soil above the permafrost table usually displays evidence of gleization due to saturated conditions and high organic content due to active frost churning (Tedrow and Cantlon, 1958; Tedrow, 1965).

Subarctic Brown Forest soils develop under forest cover on loess-mantled south-facing slopes. These soils are well-drained, and permafrost is generally absent. Typically they develop a brown upper soil horizon under a weakly leached layer, and often display undulating thin clay bands. On ridgetops where the loess layer is thin, bedrock may directly underlie the soil. Elsewhere, thick accumulations of unaltered loess lie beneath the soil horizons. Toward the base of south-facing slopes, Subarctic Brown Forest soils grade into Low-Humic Gley soils (Dement, 1962; Rieger et al., 1963).

Low-Humic Gley soils are widespread on north-facing slopes, near the base of south-facing slopes, and in the valley bottoms of the Yukon-Tanana Uplands where thick organic-rich colluvial and alluvial silts have accumulated. These soils are underlain by permafrost, usually within three feet of the surface. The high permafrost

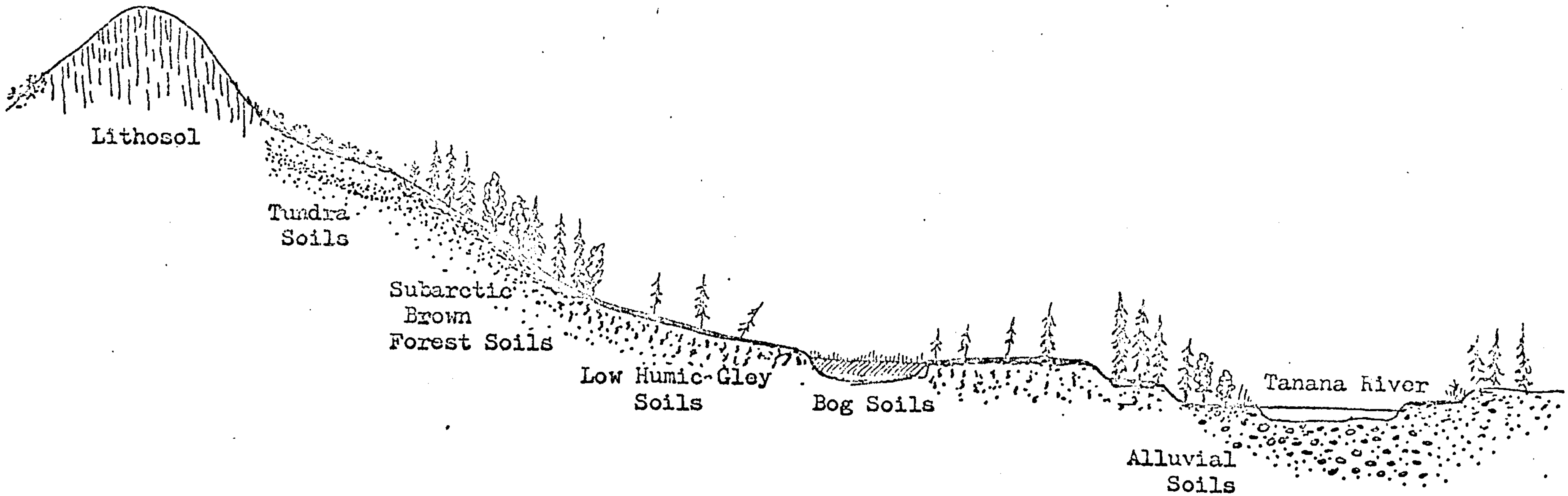


Figure 5: Diagram of generalized soils distribution in the Healy Lake region, interior Alaska.

table impedes drainage, thus the soils are often near or at the saturation point. They are characterized by soil profiles displaying thin organic horizons, mottled mineral horizons and gleyed appearance (Rieger et al., 1963). These soils are covered with vegetation consisting of black spruce, willow, mosses, sedges, various shrubs, and sometimes white spruce and white birch.

Bog soils develop in the widespread thermokarst areas which lace the valley bottoms of the Yukon-Tanana Upland. They also occur around kettles in moraine deposits in the Johnson River and Gerstle River areas. They are formed largely from organic material, including sphagnum/sedge peat, where permafrost is close to the surface (usually within 1 to 2 1/2 feet), with a perched water table above. The vegetation which grows in and around bogs include the species common to Low-Humic Gley soils (Rieger et al., 1963; Tedrow and Cantlon, 1958).

Alluvial soils are immature, well drained to excessively drained soils which occur on the alluvial plains of major rivers, such as the Tanana, Gerstle, and Johnson. They usually can be described as slightly altered to unaltered silts and sands overlying coarse gravels. This alluvium is relatively recently deposited, but may include sediments upon which white spruce, poplar, and birch forests have developed. Permafrost is deep or absent in alluvial soils (Rieger et al., 1963).

PHYSIOGRAPHIC PROVINCES

The environment of the Healy Lake area was profoundly affected by glaciation, changes in river regimens, and other geomorphic events which occurred in the surrounding region. Interpretation of the lake's history, therefore, must be placed within a context of regional geology and Quaternary events. The area which most directly affected the lake area includes parts of three major physiographic provinces: the Alaska Range; the Tanana Lowland; and the Yukon-Tanana Upland (Fig. 2).

Alaska Range

The Alaska Range rises southward from the low foothills bordering the Tanana Lowland into broad plateaus and sharp ridges which culminate in high rugged peaks mantled by cirque and valley glaciers. Altitudes range from about 1400 feet at the base of the foothills to more than 10,000 feet at the crest of the range.

The major drainages originate in cirque and valley glaciers north of the range crest. These drainages include the Gerstle, Little Gerstle, and Johnson Rivers, Berry Creek, and Bear Creek (Fig. 2). Johnson and Gerstle Glaciers are the largest glaciers in the map area. The major trunk glaciers are fed by a number of unnamed tributary ice streams derived from adjacent cirques. Present snowline occurs between about 6000 and 6500 feet. The rivers derived from the glaciers carry heavy sediment loads through braided channels which flow northward to the Tanana River. Winter stream flow is greatly reduced in the Alaska Range, as elsewhere in the region. High water levels accompany spring breakup in May. Water levels then drop until warm summer temperatures accelerate glacier ablation, causing high stages again in June and July. Streamflow also varies diurnally, reflecting temperature changes and variations in the amount and intensity of incoming solar radiation, all of which affect the rate of snowmelt and glacier ablation.

Surficial geology of the range reflects the effects of past episodes of glaciation. The glaciers which flowed northward and northeastward from the centers of ice accumulation in the Alaska Range gouged deep U-shaped troughs along pre-existing drainages during the late Pleistocene advances. The distribution and character of glacial deposits in the region suggest two late Pleistocene glaciations (Holmes and Foster, 1968; Moffit, 1942; Holmes, 1965). Moraines close to the termini of existing glaciers attest to Neoglacial advance(s). Ice marginal drainage channels, kettles, and crevasse fillings are common features in the glacial deposits.

Rock glaciers typically occur on Neoglacial end moraines (Foster and Holmes, 1965). Their formation and relation to Neoglacial history are described in a study of central Alaska Range rock glaciers by Wahrhaftig and Cox (1959).

Frost riving produces an abundance of rock rubble and talus which accumulates in extensive sheets over plateaus and gentle slopes, and forms fans and aprons along the bases of ridges throughout the range. Frost riving accounts in part for the sharp rugged topography of the higher peaks and ridges which stood above the icefields even during the glacial maxima of the Pleistocene. Headward erosion of cirque walls produced sharp arete ridges and a number of steep horns, such as Mount Kimball.

Regional bedrock geology has been mapped in reconnaissance studies by Moffit (1954), Holmes (1965), and Holmes and Foster (1968). The lithology of the range within the map area is probably a continuation of the bedrock of the adjacent Yukon-Tanana Upland. Foliated metamorphic rocks predominate, comparable to the Birch Creek Schist of the uplands, (Moffit, 1954, p. 94). The metamorphic rocks consist largely of gneiss and schist of varying texture and composition. The major components of the schist are quartz, muscovite, and accessory minerals. Gneiss compositions and characteristics range widely, but usually include about 50% quartz. Oligoclase or andesine, K-feldspar, mica, garnet, and occasional hornblende, epidote, and clinozoisite contribute to the remaining 50% (Holmes and Foster, 1968, p. 21). The metamorphic rocks of the region are intruded by granitic plutons and dikes, and dikes of ultramafic and rhyolitic composition. Granitic rocks vary compositionally from granite and quartz monzonite to quartz diorite and diorite (Holmes and Foster, 1968, p. 16).

Tanana Lowland

The Tanana Lowland separates the Yukon-Tanana Upland to the north from the Alaska Range to the south (Fig. 2). This lowland includes portions of two physiographic provinces, the Tanana-Kuskokwim Lowland, west of the Johnson River area, and the Northway-Tanacross Lowland to the east (Wahrhaftig, 1965). The section of the lowlands near George Lake is narrow, only 1.7 miles wide near Berry Creek and broadening to about 4 to 6 miles several miles to the east and west. The lowlands west of the Little Gerstle River are much wider, broadening to over 20 miles within the map area between Granite Mountain and Healy Lake.

The major river of the region, the Tanana, flows in a northwesterly direction across the lowland, often cutting against the bedrock hills and bluffs of the Yukon-Tanana Upland. The major tributaries are the glacier-fed Johnson, Gerstle, and Little Gerstle Rivers, Berry Creek, and Bear Creek, all of which originate in the Alaska Range, small streams flowing through poorly drained silt-filled valleys. These include the Volkmar and Healy Rivers, and George and Sand Creeks. The latter contribute relatively little alluvium and water to the Tanana system.

A rough estimate of average annual discharge of the Tanana River may be inferred from hydrologic reconnaissance studies in the Tanana basin by Anderson (1970). An estimate of 7500 cubic feet per second for the Tanana near Healy Lake can be made on the basis of his projections, but Anderson discourages such estimates of specific stream discharges because they are based upon little specific data. Of the major tributaries, the Johnson and Gerstle Rivers contribute the largest volume of water, alluvium, and dissolved solids to the Tanana.

Major surficial deposits of the Tanana Lowland include glacial moraines and outwash, alluvium, and scattered eolian units. Enormous volumes of gravels have accumulated in a number of coalescent alluvial fans which slope gently northward from the base of the Alaska Range. This thick wedge of sediments has forced the Tanana River against the uplands flanking the north side of its valley. The gravels grade into sands and silts with increasing distance from the Alaska Range. Accumulation of these deposits is largely a consequence of Pleistocene glaciations, when much greater volumes of glacier ice were actively eroding more of the range than at present. The thickness of sediments in the Tanana Valley is unknown for this region. In the Upper Tanana Valley, known depths of alluvium and lacustrine deposits extend to at least 128 feet, and according to Foster (1970), probably more than 250 feet.

Extensive flood plain deposits lie beyond the margin of the moraines and outwash accumulations, into which the Tanana has cut a number of low terraces about 20 feet above the present river level. Downcutting in southern tributaries to the Tanana has been more extensive, up to 75 feet in places.

Eolian deposits in the form of sand sheets and parabolic sand dunes occur in the central part of the lowland, particularly near the lower Gerstle River. These eolian deposits, mostly stabilized by vegetal cover, are thought to overlie alluvium deposited since the last major glaciation of the Pleistocene (Holmes and Foster, 1968, p. 46). The sand in these deposits was derived from the windswept barren floodplains of the Gerstle and Johnson Rivers. Loess derived from the same sources is widely distributed north of the Alaska Range.

Yukon-Tanana Upland

The area north of the Tanana Lowland is part of a broad region of rounded bedrock hills known as the Yukon-Tanana Upland. The upland landscape has evolved, evidently, from an older land surface eroded during late Tertiary and Quaternary time (Mertie, 1937, p. 23). In many parts of the upland, drainage patterns reflect former drainage conditions subsequently altered by stream piracies. The upland is dissected by innumerable stream valleys, many of which have small underfit streams flowing through them, particularly where the valley floors broaden to muck-filled flats in their lower segments near the Tanana Lowland. Upper stream valleys are steeper and more canyonlike, with more active stream channels. Ridges are, for the most part, rather gently rounded or somewhat flat-topped, probably the result of solifluction. Reworking of loess, sand, and weathered bedrock on valley slopes contributes to the asymmetrical cross sections of valleys. South-facing slopes tend to develop gentler sloping surfaces than the northern exposures, largely due to the relative absence of permafrost on upper southern slopes.

Within the map area, average relief in the uplands is roughly 2000 feet. Maximum relief occurs near Mount Harper, where the peak rises 3500 feet above the floor of the upper Healy River. Altitudes range from 1200 feet at the base of the lowlands near Healy Lake to 6543 feet at the top of Mount Harper, the highest point in the Yukon-Tanana Upland.

Bedrock geology of the Yukon-Tanana Uplands portion of the region is largely unmapped, except in reconnaissance fashion in the southern portion adjacent to the Alaska Highway north to the Lake George and Twelvemile Lake areas (Holmes and Foster, 1968; Holmes, 1965; Foster, 1970). Although Mertie's reconnaissance map of the bedrock geology of the Yukon-Tanana Upland covers part of the region (1937) only large-scale major units are sketched in, perhaps in part by regional inference.

In general, the upland is underlain by Birch Creek Schist intruded by granitic rocks in a number of stocks and batholiths, one of which underlies Mount Harper and accounts for its relative resistance to erosion. The schist includes a number of compositional varieties, including quartzite schist, quartz-mica schist, feldspathic schist, and chloritic schist (Moffit, 1954, p. 93). Gneissic rocks are widespread within the unit mapped as Birch Creek Schist by Mertie (1937). Acidic igneous rocks range from granite to diorite.

Structural influence of bedrock jointing and faulting are suggested by a number of regional drainage trends, particularly by the course of Sand Creek (Fig. 2). Topographic expression of contacts between rock units of differing lithologies is slight, with the possible exception of the Mount Harper batholith.

A number of small tributaries to the Tanana flow from the Yukon-Tanana Uplands within the map area. These include the Goodpaster, Volkmar, and Healy Rivers, and George, Sand, and Billy Creeks. With the exception of the Goodpaster drainage which mostly lies outside of this study area, all the streams are quite sluggish and underfit. The Healy, George, and Sand drainages have been dammed by aggradation of the Tanana Lowlands, resulting in the formation of lakes. This impoundment probably occurred in the late Pleistocene. George Lake is the deepest, with an estimated maximum depth of 55 feet (Holmes and Foster, 1968, p. 7). Sand Lake is about 10 feet or less in maximum depth, and Healy Lake has an estimated maximum depth of about 15 feet, with an average depth of about 3 feet in early June. The streams are navigable for varying distances, but log jams, beaver dams and periods of low water greatly impede travel.

The slopes of the Yukon-Tanana Upland are mantled with a layer of loess which thins with increasing elevation and distance from the Tanana Lowland. In general ridgetops are either thinly blanketed by loess, or devoid of it. Fluvial processes and mass movement have transported much of the loess to lower slopes and valley bottoms, incorporating organic matter during the process. The valley floor silt or "muck" deposits support muskeg and bog vegetation and are permanently frozen. Since the ice content of these frozen silts is often high, thawing of the permafrost due to breaks in the vegetal cover leads to the development of numerous thaw ponds and lakes, forming thermokarst terrain such as that seen in the lower Healy River (east of Healy Lake), near Lake George, and near Sand Lake. Open system pingos commonly occur in the permafrost areas adjacent to sediment-mantled slopes (Holmes and Foster, 1968; Holmes et al., 1968).

Eolian sand blankets bedrock hills adjacent to the Tanana Lowland, occasionally forming stabilized sand dunes. The sand deposits have been mantled by a layer of loess and overgrown with vegetation; they are of late Pleistocene age.

Upstream from the areas of broad muck-filled valley floors, streams such as the Volkmar and Healy display considerably greater competence, transporting sands and gravels and depositing these in conspicuous point bars.

Although only a small part of the upland shows signs of having been glaciated in the past, and no glaciers exist there today, higher domes and peaks display numerous cirques of late Pleistocene age. Mount Harper supported a number of cirque glaciers, many of which coalesced into trunk glaciers extending as much as 9 miles down the valleys radiating from the peak (Péwé et al., 1967). The area displays abundant evidence of former glacial action: end moraines; probable lateral moraines; cirques; U-shaped valleys; and isolated till remnants.

Frost shattered bedrock mantles most of the uplands. It often occurs in rubble sheets on the broader interstream divides, and forms aprons and fans of rock debris along the flanks of headward sections of the river valleys.

REGIONAL HISTORY

Existing knowledge of the early geologic evolution of the Alaska Range and Yukon-Tanana Upland is fragmentary. The Birch Creek Schist, which underlies much of the Healy Lake Region, is thought to be, in large part, derived from Precambrian and/or perhaps early Paleozoic marine(?) sediments which have been folded and metamorphosed. Three or more major orogenic events occurred in the Alaska Range prior to the Cretaceous, when widespread intrusion of granitic plutons took place throughout the region (Wahrhaftig, 1970).

In early to mid-Tertiary time the Alaska Range was eroded to low relief and deposition of alluvial sediments and coal occurred in widespread structural basins. According to Wahrhaftig (1970):

> The present Alaska Range began to grow as fault-block, box-fold, and broad-fold mountains, with essentially vertical displacements, in latest Miocene or earliest Pliocene, shedding continental gravels to basins to the north and possibly also to the south. This episode of deformation, which probably gave the range at least half its present height, ended before 3 million years ago. Deformation since then has been by broad epeirogenic uplift complicated by minor faulting along several east-trending faults.

The most recent episode of uplift in the eastern Alaska Range is thought to have occurred prior to the late Pleistocene Delta Glaciation (Holmes and Foster, 1968, p. 47). The amount of uplift which occurred during the early and middle Pleistocene is, however, unknown. According to Wahrhaftig (1958), the central Alaska Range was uplifted at least 2000 feet following the oldest known glacial advance.

Uplift of similar magnitude in the eastern Alaska Range may explain the absence of early Pleistocene glacial deposits in the Healy Lake region. If the altitude of the range was much lower during the early and middle Pleistocene than at present, glacial ice may have been, at least locally, of lesser extent than during late Pleistocene.

Wahrhaftig (1965, p. 24) suggests that during the early Pleistocene, headward erosion of the Tanana River may have captured the Northway-Tanacross Lowland from the Yukon River drainage system, which now heads only a few miles north of the Tanana Lowland in the Tanacross Quadrangle. The Northway-Tanacross Lowland is that section of the Tanana Lowland east of the Johnson River.

Late Quaternary Events

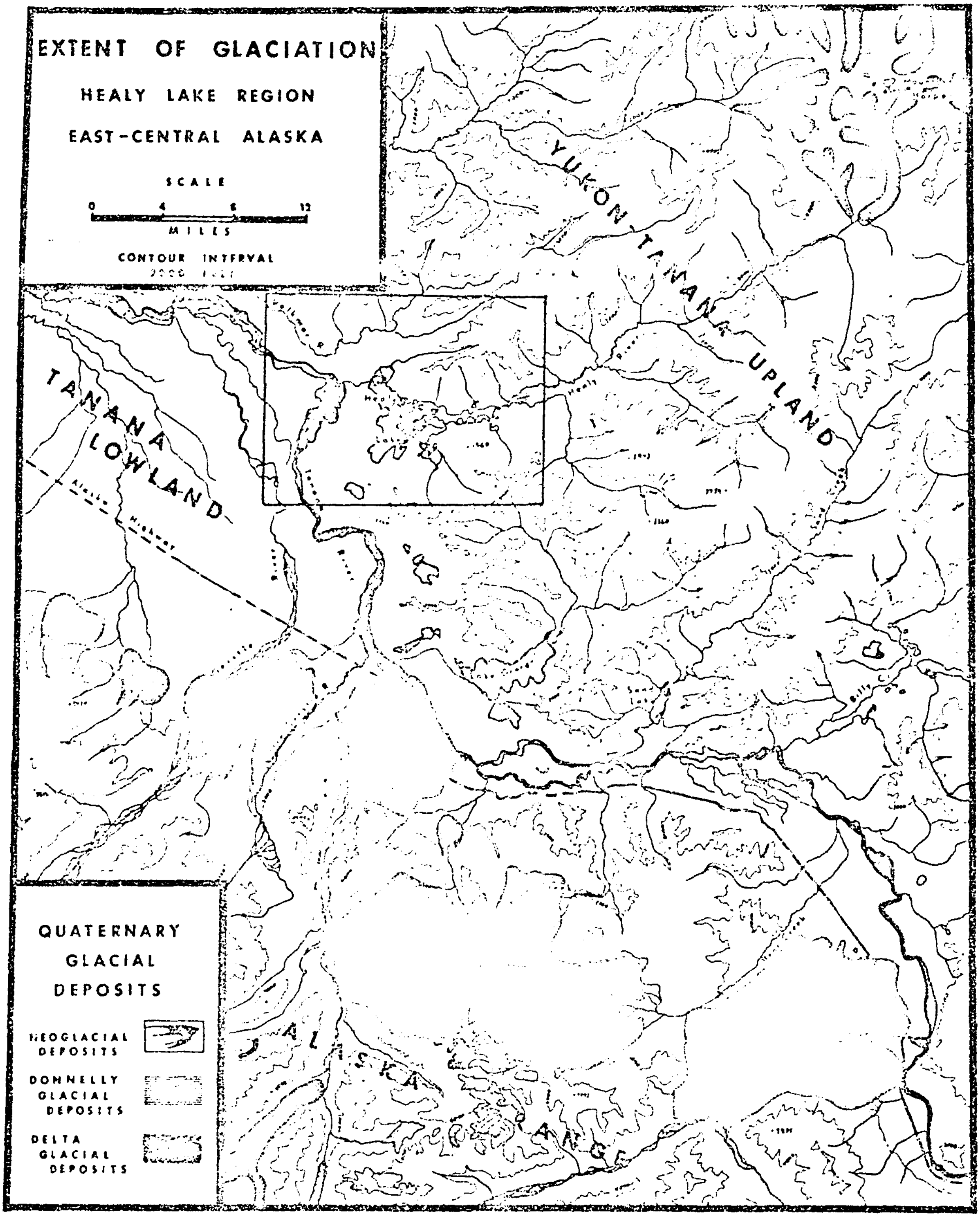
The glacial sequences from several areas of the Alaska Range and the Yukon-Tanana Upland are correlated in Table 1. The geographic extent of Quaternary glaciers in the Healy Lake region is summarized in Figure 6. The correlation chart, largely adapted from Péwé and others (1965), is generalized, and perhaps somewhat inaccurate because few radiometric dates are available for glacial events in the Alaska Range.

The unnamed glacial advance in the Johnson River area ascribed by Holmes and Foster (1968) to a time shortly after the stagnation of Donnelly ice may represent a final stade of late Wisconsin Glaciation. Although the boundary between the Wisconsin and the Holocene is usually drawn at about 10,000 years B.P., there is considerable evidence that suggests a time lag of perhaps two or three thousand years in northern latitudes. Portions of the Laurentide Ice Sheet persisted in northern Canada until about 7200 years B.P. at Hudson Bay (Andrews, 1969, p. 1263) and perhaps as late as 5000 years B.P. in northeastern Canada (Bryson et al., 1969). In Alaska, glacial advances representing a final stade of the Wisconsin Glaciation

Table 1: Glacial Chronology of the Alaska Range and Yukon-Tanana Upland

	Yrs. x 10^3	McKinley Park	Nenana River	Delta River	Johnson River	Nebesna River	Y-T Upland
Neoglacial Hypsithermal	1 2 3 4 5 6 7		Rock glaciers	Black Rapids	Rock glaciers' prob. advance		
	8 9		Carlo Stade	Summit Lake	advance		
	10						
Wisconsin		Wonder Lake II	Riley Creek	Donnelly	Donnelly	Jatahmund	Donnelly
		Wonder Lake I		Delta (?)	Delta (?)		Delta (?)
Sangamon	70						
Illinoian		Slow Fork	Healy	Delta (?)	Delta (?)	Black Hills	Delta (?)
Yarmouth	200						
Early Pleistocene		Advance	Dry Creek Browne	Darling Creek	?	?	?

Chart modified from Péwé et al., 1965, with additions from Péwé et al., 1967, Fernald, 1965b, and the writer.


EXTENT OF GLACIATION
HEALY LAKE REGION
EAST-CENTRAL ALASKA
SCALE
0 4 8 12
MILES
CONTOUR INTERVAL
TANANA LOWLAND
YUKON-TANANA UPLAND
ALASKA RANGE
QUATERNARY GLACIAL DEPOSITS
NEOGLACIAL DEPOSITS
DONNELLY GLACIAL DEPOSITS
DELTA GLACIAL DEPOSITS

have been recognized in the Brooks Range and on the Kenai Peninsula, as well as the Alaska Range. Karlstrom dates the Tanya Stade of the Naptown Glaciation in the Kenai Peninsula at about 6000 years B.P. (Karlstrom, 1964). The Carlo Stade of the Riley Creek Glaciation in the Nenana River area of the Alaska Range probably is correlative with these events (Wahrhaftig, 1958; Péwé et al., 1965).

Glacial sequences in the eastern Alaska Range have been correlated with the Delta (Illinoian?)-Donnelly (Wisconsin) Glaciation sequence established by Péwé (1961) for the Delta River area. These correlations have been made largely on the basis of surface morphology, relief, and weathering profiles in the glacial deposits. In the absence of radiometric dates on these sequences of glaciations, their correlation must remain tenuous. The major problem inherent in the interpretation of the two-fold glacial sequences as Illinoian-Wisconsin is that it recognizes no Wisconsin Interstadial, in spite of mounting evidence that such an event did occur in interior Alaska (Fernald, 1965a, 1965b; Sellman, 1967). Most recently, a radiocarbon date of 25,300 ± 950 years B.P. was obtained from wood fragments immediately underlying Donnelly age till in the Gerstle River bluffs south of the Alaska Highway. The date provides strong evidence that the Donnelly Glaciation of the Gerstle River-Johnson River areas, at least, represents a late Wisconsin event (T. D. Hamilton, pers. comm., 1971). The onset of the late Wisconsin Glaciation is also recorded in a terrace sequence in the upper Tanana Valley. Two thick deposits of fluvial sediments thought to represent an early Wisconsin-late Wisconsin sequence are separated by an organic-rich layer dated at 25,800 years B.P. (W-1174) in an exposure near Bitters Creek (Fernald, 1965b, p. 122).

The question remains as to where the Delta Glaciation fits into the moraine sequence in the Johnson River-Gerstle River area. It is still possible that the Delta moraines are of Illinoian age, but it is more likely that they are of early Wisconsin age, in view of the radiocarbon dates.

The Delta Glaciation is the earliest known glacial event in the Healy Lake region. During that time, icefields covered most of the Alaska Range south of the foothills, which were only partially ice-covered. High peaks stood as nunataks above the icefields of the range. Glaciers advanced through the river valleys northward and northeastward, expanding into piedmont lobes in the lowlands in the Gerstle and Johnson River areas. In the Mount Harper area of the Yukon-Tanana Upland, cirque glaciers expanded and flowed into a number of trunk glaciers radiating outward from the peak down to altitudes as low as 2100 feet in the upper Healy River area.

The Delta Glaciation was a period of massive aggradation in the Tanana River floodplain and its tributaries. Well preserved sequences of terraces in the Harding Lake-Birch Lake area have been correlated with the Delta-Donnelly Glaciations (Blackwell, 1965). This was a period of widespread and intensive eolian activity, resulting in the accumulation of massive deposits of wind-blown sands and loess in the Tanana Lowland and adjacent Yukon-Tanana Upland. Ventifact cutting was widespread during the Delta Glaciation on wind-swept surfaces (Péwé, 1965b). The Delta Glaciation was followed by a period of warmer temperatures (Sangamon Interglacial or mid-Wisconsin Interstadial) during which incision of valley floodplains occurred, permafrost levels receded, and presumably at least some reforestation took place. In addition to the interstadial deposits (Wisconsin) preserved in terraces at Bitters Creek, a basal sequence of organic mucks containing mammal fossils has been attributed by Fernald to the Sangamon Inte glacial (1965b).

The Donnelly Glaciation was, evidently, of more limited extent in the region, than the preceding Delta Glaciation. Highland icefields were smaller and some of the valley glaciers advanced shorter distances than during the Delta Glaciation. This pattern was repeated in the Mount Harper area due to a higher snowline during the Donnelly event (4800 feet) than during the preceding Delta Glaciation (4500 feet) (Péwé et al., 1967).

The Donnelly Glaciation was accompanied by massive deposition of glaciofluvial sediments and aggradation of the Tanana River floodplain. A thick apron of glacial and glaciofluvial deposits formed along the flank of the Alaska Range during the Pleistocene Glaciations. Aggradation of the Tanana River resulted in the damming of a number of tributary streams from the Yukon-Tanana Upland, producing lakes, including Lake George, Sand Lake, Black Lake, and Healy Lake. Blackwell (1965) cites evidence that the damming of most of the lakes in the middle Tanana Valley, including Harding, Birch, Quartz, and others, occurred during the Delta Glaciation. This may also be true for most of the lakes within the Healy Lake region, particularly Lake George, which is separated from the Tanana River by a threshold of outwash sediments rising about 25 feet higher than the present floodplain. The history of Healy Lake is thought to be more complex, largely due to the fact that its headwaters were glaciated during the Delta and Donnelly events.

Eolian activity was also extensive during the Donnelly Glaciation, resulting in renewed deposition of sand and silt in the lowland, in the foothills of the Alaska Range, and parts of the Yukon-Tanana Uplands adjacent to the Tanana Valley source areas.

During the waning stages of the Donnelly Glaciation the stagnating piedmont lobes of Alaska Range glaciers developed a widespread knob and kettle terrain. Much of the morainal deposits of the Delta glaciation were covered by Donnelly age morainal debris. The Donnelly age Johnson Valley glacier, which had extended at least to the present position of the Tanana River, deposited a thick layer of till and outwash. Part of the terminal moraine complex of that event has been eroded away by the Tanana River. It is likely that the Donnelly advance deflected the Tanana River toward Lake George. It is not known if the Delta glacial advance extended farther than the Donnelly advance here.

Paleoecology

Biological aspects of the late Pleistocene and Holocene environments of interior Alaska have been reconstructed, in part, from studies of fossil mammal remains (Repenning, et al., 1964; Guthrie, 1968a, 1968b), pollen (Hansen, 1953; Matthews, 1970), and plant macrofossils (Chaney and Mason, 1936) and insect assemblages (Matthews, 1968).

The available evidence suggests that although most of the plant species found in the interior today were also present during the Pleistocene, their distribution was drastically reduced by a harsher climate during the glacial stages. Study of late-Pleistocene ice wedge casts near Donnelly Dome in the Delta River area led Péwé (1965a) to estimate that the mean annual temperatures during the time of ice-wedge formation and active growth was 21.2° F (-6° C) or colder. On the basis of pollen spectra from the interior and northern Alaska, Matthews (1970, p. 248) suggests a mean annual temperature as low as 10° to 14° F (-12° to -10° C) through the Alaskan interior during the late Pleistocene glacial periods. These temperatures are considerably colder than the present day mean annual temperature of about 26.7° F. Tree line was lowered an estimated 1500 to 1800 feet (Péwé, 1965a), nearly eliminating forest vegetation during glacial periods.

Pollen evidence from the interior (Matthews, 1970) and from the Seward Peninsula (Colinvaux, 1964) suggests tundra-like plant communities with forest species present only in scattered favorable areas. The tundra may have differed from much of present day Alaskan tundra in that grasses and herbs may have been much more prevalent. The hypothesis of a grassland-tundra environment in interior Alaska during the late Pleistocene glaciation remains to be proven, since the few paleobotanical and palynological studies here have not concentrated on the seeds or pollen of grass.

The strongest evidence in support of grassland to date comes from paleoecological studies of late Pleistocene mammal communities. Thousands of fossil mammals have been collected from late Pleistocene mucks in the Yukon-Tanana Upland, particularly in the Fairbanks area. An analysis of these collections by Guthrie (1968a, 1968b) strongly suggests a large mammal community overwhelmingly dominated by grazing mammals, in terms of both biomass and numbers of individuals. The most abundant large mammals were giant bison (*Bison priscus*), horse (*Equus caballus*), and mammoth (*Elephas primigenius*). Most of the species identified from fossil remains are now extinct; many other species that survived into the Holocene are no longer found in interior Alaska.

Guthrie's (1968b) analysis of late Pleistocene small mammal fossils from the Fairbanks region revealed that a number of species which were common then in the interior are now absent. Knowledge of the present range and habitat preferences of these species suggests that they became locally extinct in the interior between 8500 and 7300 years ago due to a change in habitat. The habitat change probably resulted from an early Holocene climatic warming which permitted the expansion of forests at the expense of the inferred grassy tundra (Guthrie, 1968b, p. 241).

Insect fossils collected from late Pleistocene organic silt deposits near Fairbanks were studied by Matthews (1968). Many of the species identified are no longer found in the interior, except perhaps at higher altitudes. Habitat preferences of these species suggest that the Fairbanks area, and presumably most of interior Alaska was essentially tundra-like, without forests.

These studies provide a useful insight into the probable environment in the interior during the late Pleistocene glaciations. There remains a great need, however, for detailed pollen and seed studies to determine the precise nature and distribution of vegetational communities.

Holocene Environment

Donnelly Glaciation was followed by a period of warming probably corresponding to that described by Broecker and others(1960) and McCulloch and Hopkins (1966). During this period, recession of Alaska Range glaciers was probably quite rapid, and forests which had been severely restricted during Delta and Donnelly Glaciations expanded to approximately their present distribution. Tree line probably rose slightly higher than at present, with a spruce-dominated vegetation similar to present forest patterns. The tundra/grassland environment, which had evidently prevailed during the major glaciations, was replaced by forest and modern tundra vegetation. There seems to be a rather sharp break in the faunal record at about 8000 years B.P. over much of Alaska. At that time a number of mammal species became extinct, and the ranges of many surviving species were reduced, perhaps in response to the change in vegetation (Guthrie, 1968b).

Streams downcut through morainal deposits, outwash, and floodplain deposits during the early Holocene in response to the reduced discharge and load of the region's rivers. Gorges were eroded through the Johnson River and Gerstle River moraines, and incision of Donnelly age sediments of the Tanana River floodplain occurred (Holmes, 1965; Holmes and Foster, 1968). In the uplands, loess was reworked and redeposited in valley bottoms as thick much deposits. Although eolian activity was greatly reduced in comparison to the periods of glaciation, active deposition of sand and loess continued adjacent to floodplains of the Gerstle River and other major rivers in the lowlands. Parabolic sand dunes, now stabilized by a cover of loess and vegetation, overlie post-Donnelly river terraces, and loess blankets moraine deposits of Donnelly age (Holmes and Foster, 1968). Loess deposition has continued in the Yukon-Tanana Upland throughout Holocene time, but at a much slower rate of deposition. The warming trend may have been interrupted by a cooler period centering around 8000 years B.P. which would correspond to a number of minor glacial advances in other parts of the Alaska Range, the Brooks Range, and elsewhere (Péwé et al., 1965).

This was followed by the Hypsithermal, a warm period, which lasted until perhaps about 4000 years B.P. At that time a resurgence of glacial activity, termed the Neoglaciation, occurred in response to a cooling climate. Neoglaciation has continued to the present, with a number of climatic fluctuations marked by minor glacial advances and recessions. End moraines within several miles of existing valley and cirque glaciers in the Alaska Range probably were formed during Neoglacial advances, or perhaps earlier during the cold period thought to have occurred about 8000 years B.P. Activation of rock glaciers in the morainal deposits of Holocene age is thought to be a result of Neoglacial conditions (Foster and Holmes, 1965; Wahrhaftig and Cox, 1959). Increased glacial activity since the onset of Neoglaciation probably has resulted in renewed aggradation by the Tanana River. This aggradation, although minor in comparison with that associated with late Pleistocene glaciation, is the probable cause for the formation of present day Healy Lake.

HEALY LAKE AREA

Local Setting

The Healy River basin drains an area of about 418 square miles of the Yukon-Tanana Upland. From Mount Harper the Healy River flows southeast for about five miles, then swings to the southwest, flowing an additional thirty miles to Healy Lake (Fig. 2, p. 4). The lake waters drain into the Tanana River via an outlet channel at the north end of the lake.

Healy Lake is shallow, with an average depth of about three feet during late summer. The lake bottom is irregular, with some depressions as deep as sixteen feet and a number of channels ranging in depths of 5 to 10 feet. The lake covers an area of about 5 square miles and has maximum dimensions of 5.2 miles long by 1.5 miles wide. The northern and southern shores of the lake border bedrock ridges of the upland. The eastern shore of the lake blends into the marshes and bogs of the Healy River flood plain. Most of the western shore of Healy Lake consists of deltaic deposits. The lake is separated from the Tanana River by a dam of terrace and deltaic deposits which narrows from 4 miles in width at the south end to 1.6 miles at the north end of the dam.

A generalized seasonal cycle of events at the lake can be made based upon several decades of observations by local inhabitants Paul and Margaret Kirsteatter. Spring break-up begins in early May generally. By May 20 most of the lake ice is gone. In years of heavy snowfall and/or heavy spring rains the Healy River flood-plain is inundated by runoff waters. During such times the lake level rises several feet, then gradually recedes during the summer. In most years, however, spring flooding is not as widespread, and the lake level remains rather low in May and

Figure 7: Aerial view of Healy Lake region from the north. Note location of Village Site (V), active (D) and inactive (UD) distributaries of delta, silty Tanana River water entering Lake (S), and lake channels (C).

early June. By late June and early July increased runoff due to glacial ablation in the Alaska Range and heavy regional rainfall causes a rise in the level of the Tanana River. This results in the reversal of flow direction in the outlet channel connecting Healy Lake to the Tanana. Tanana River waters then flow into the lake via its outlet channel, depositing silt and causing a rise of three to five feet in the lake level. The lake level usually rises gradually over a period of about six weeks, attaining its maximum height by about the end of July. The lake level then slowly recedes during August. By late August the lake level drops to "normal" levels with an average lake depth of about three feet. Often lake levels drop even further, exposing large areas of silt flats normally inundated by lake waters.

In the fall, freeze-up occurs in about mid-October. The lake channels, however, often remain free of ice until November. Winter ice thicknesses often exceed three feet, probably freezing to the lake bottom over the shallowest areas. Strong winds from the southeast predominate in winter. Less commonly, winter winds accompanied by severe cold sweep down on the lake area from the northeast. Summer winds, however, are predominantly from the northwest.

Vegetation and Permafrost

The distribution of major vegetation communities in the Healy Lake area is mapped in Plate 1. The characteristics of the vegetational communities are summarized in Table 2. In general, the distribution of vegetation and permafrost in the area reflect the relationships illustrated in Figure 4 (p.10).

A number of fires have swept parts of the area during the past century. The low forests and high brush which cover most of the ridges are largely stages of regrowth following those fires. Fire scars can be seen on some mature birch trees in the area.

One of the largest bogs in the region (Fig. 2) occurs in the lower Healy River floodplain east of the lake (Plate 1). The bog covers an area of about 14 square miles and extends upvalley 10 miles from Healy Lake. Upstream from the bog the valley floor is forested by mature white spruce which extend up to the vicinity of the lower terminal moraine in the Mount Harper area (Fig. 6) at an altitude of about 2100 feet. The processes of bog formation have contributed to the development of a number of geomorphic features which are of importance in interpretation of the Holocene history of the lake area. These processes and features will be discussed later.

Table 2: VEGETATION UNITS FOR HEALY LAKE AREA (Plate 1)*

High Forest	Mature white spruce stands with trees 6-18 inches in diameter and heights between 50 and 100 feet. Some intermixture of Balsam Poplar on sandy soil near channels. Undergrowth moderately dense, consisting of deciduous shrubs and a thick carpet of moss. Permafrost widespread, with some ice segregation lenses under peat.
Low Forest:	Mosaic forest of white spruce, white birch, and aspen 3 to 6 inches in diameter, 20 to 30 feet high covering south facing slopes. Black spruce forests predominate on silty river terraces and north facing slopes. Permafrost absent on mid to upper south-facing slopes, present on north-facing.
High Brush:	Mixed spruce and deciduous trees and shrubs 5 to 20 feet high, 1 to 3 inches in diameter. Includes spruce, aspen, poplar, birch, willows, alder, grasses, low shrubs. Permafrost generally at least several feet deep or absent.
Low Brush:	Deciduous shrubs 3 to 5 feet high, mostly willows, alder, dwarf birch, with thick ground cover of mosses, lichens, grasses. Generally above timberline. Permafrost common but discontinuous.
Muskeg:	Low wetland shrubs 1 to 5 feet high including dwarf birch, heath shrubs, berry bushes, cottongrass tussocks 1 to 2 feet high, scattered dwarf spruce. Wet, spongy ground cover of peat moss. Shallow permafrost table.
Bog:	Mosses and sedges, black spruce, with some mixed white spruce, white birch, and balsom poplar along levees and higher areas. Includes areas of aquatic vegetation colonizing thaw ponds. Permafrost deep to absent under ponds and lakes. Permafrost widespread in peat and silts of floodplain. High ice contents common.
Marsh:	Aquatic vegetation growing in shallow ponds and in shallow swamped portions of the bog flats. Also prevalent in deltaic areas of the lake where silts have filled in portions of the lake. Permafrost probably restricted to islands and levees with thick vegetal cover.
Barren:	Alluvium on active floodplains mostly free of vegetation except scattered patches of willows. No permafrost.
Tundra:	Tundra occurs above about 3500 feet, consisting of mosses, lichens, sedge cottongrass, willows, berry bushes, and heath shrubs. Permafrost table shallow.

*Modified from Spetzman and Martin, 1961.

Bedrock Geology

Although mapping of the bedrock geology of the Healy Lake area was not attempted during this investigation, general field observations of outcrops in the area permit some generalizations about the major rock types. Most outcrops occur along the shores of Healy and Hidden Lakes, and occasionally on steep ridge slopes. Some test pits dug in the area reached bedrock, providing additional evidence for the general distribution of rock types.

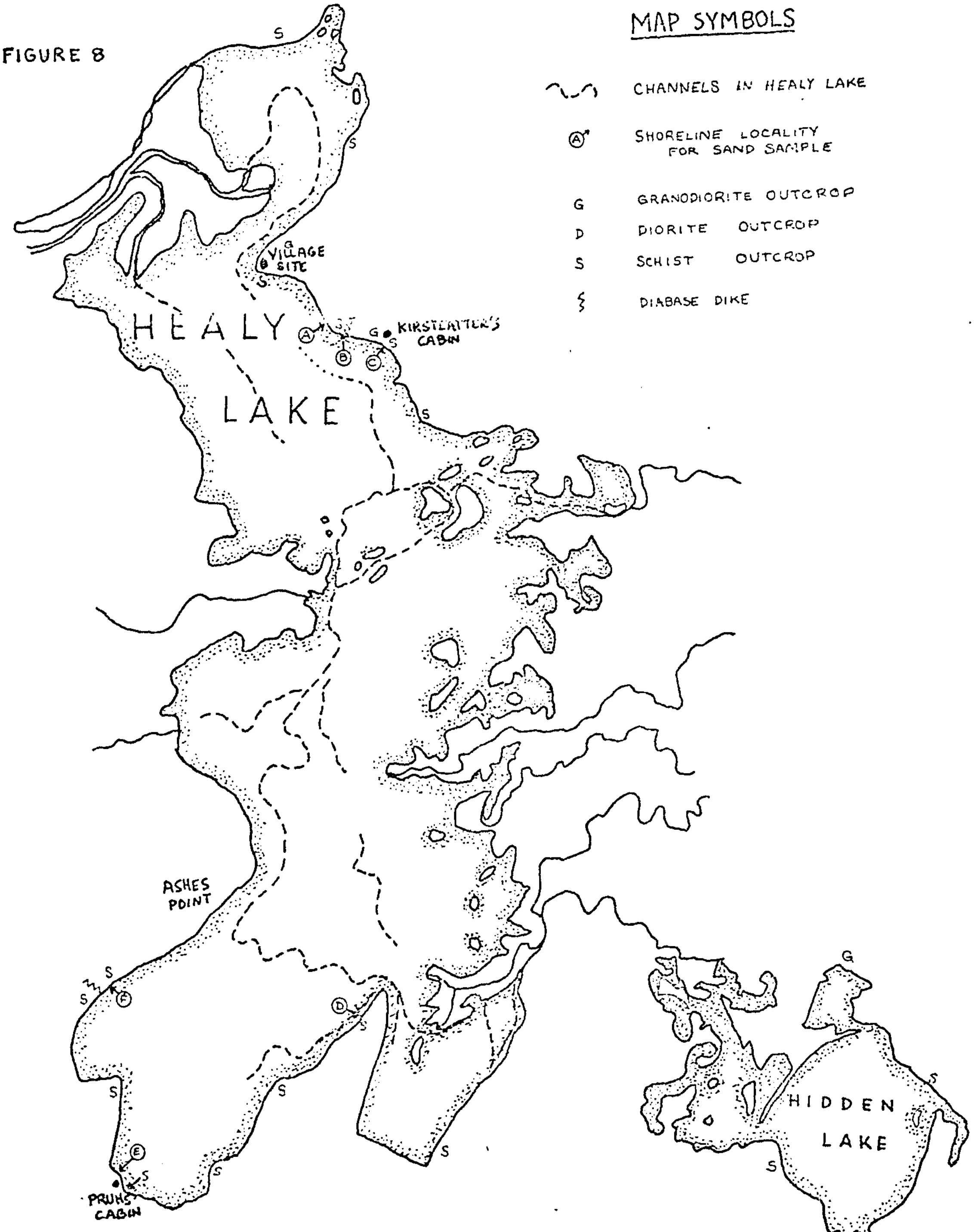
The most widespread rock type in the area is quartz-mica schist. The schists vary somewhat in texture and accessory minerals, but all are quite typical of the range of composition described for the Precambrian (?) Birch Creek Schist which underlies much of the Yukon-Tanana Upland and parts of the Alaska Range (Mertie, 1937). The schists in the area are generally medium to coarse grained due to the abundance of micas, mostly muscovite. Accessory minerals identifiable from hand specimens include biotite, garnet, and tourmaline. The schists contain numerous veins of quartz, some up to several feet in width. The greater resistance of quartz to weathering and mechanical breakdown is responsible for the concentration of quartz pebbles and cobbles, often ventifacted, along the weathered surface of the bedrock. The schist weathers to a brown or tan color and breaks down in slabs and plates parallel to the foliation produced by mica layers. On lower and middle slopes of schist ridges a layer of colluvium and residuum has accumulated as a result of weathering and breakdown of the schist. The residuum characteristically is a micaceous, clayey yellow-orange soil containing angular schist fragments and ventifacted quartz. Much of the material has probably been reworked by slope processes.

Solifluction may have played an important role in the transport of the colluvium downslope during the Pleistocene glaciations. The thickness of the deposits varies from a few inches to at least three feet on some lower slopes.

The schists of the Healy Lake area have been intruded by several igneous bodies. Small stocks of diorite and granodiorite are present in several localities (Fig. 8). Deep weathering of these igneous rocks has produced a thick mantle of grus on lower slopes and benches. In some test pits more than three feet of grus was excavated without encountering solid bedrock. Comparable weathered bedrock in the Harding Lake-Birch Lake area is interpreted by Blackwell (1965, p. 26) to have weathered largely during Tertiary time. His conclusion is based in part on the observation that the weathered bedrock is overlain by solifluction deposits thought to be of early to middle Pleistocene in age (Péwé, 1965, p. 14). The colluvium/residuum layer which overlies weathered bedrock in the Healy Lake area could be a solifluction deposit of comparable age.

Mafic dikes crop out along the shore of Healy Lake in two areas (Fig. 8). They are medium to coarse grained altered dacites (?) with a high chlorite content that weather to a greenish brown color. Fresh outcrops of the dikes are not visible, but fragments of dike rock litter the beaches over areas 40 to 100 feet wide. The outcrops are usually obscured by a thick overhanging mat of vegetation and peat.

FIGURE 8


MAP SYMBOLS
CHANNELS IN HEALY LAKE
SHORELINE LOCALITY FOR SAND SAMPLE
G GRANODIORITE OUTCROP
D DIORITE OUTCROP
S SCHIST OUTCROP
DIABASE DIKE
HEALY LAKE
VILLAGE SITE
KIRSTEATTER'S CABIN
ASHES POINT
PRUHS CABIN
HIDDEN LAKE
1 MILE

Sediment Analysis

Grain size analysis was performed on 60 sediment samples from the Healy Lake area. The resulting data were used to assist in the interpretation of geologic processes responsible for the deposition of the sediments. Following the procedures in Royse (1970), samples of 50 to 75 grams were sieved in Tyler screens stacked in one-half phi (Ø) intervals for 10 minutes in a Soiltest shaker. The contents of each screen were weighed, and the weight percentage of each size interval computed for each sample.

Sedimentologists have long debated the usefulness of grain size distributions as potential indicators of specific environments of deposition. In recent years numerous investigators have attempted to apply various statistical parameters of grain size distributions to interpretation of environments of deposition (e.g., Royse, 1968); Hails, 1967; Greenwood, 1969; Visher, 1969; Solohub and Klovan, 1970). Of the various methods employed, factor analysis demonstrates reproduceability of results and the greatest potential for identifying depositional processes from grain size data (Solohub and Klovan, 1970).

Factor analysis as described by Klovan (1966) was applied to the sediment data from Healy Lake samples. This was accomplished by means of an IBM 360/40 computer, first using an R-mode analysis (Cameron, 1967) for data reduction, then Q-mode analysis to cluster the samples (Klovan, 1968). Selected portions of the printout are included in Appendix II.

Five of the seventeen factors derived from R-mode analysis account for 79.4 percent of the total variability of the grain-size data for the 60 samples. These five factors can be considered as new or constructed variables which contain 79.4 percent

Table 3: Factor Interpretations

Factor		Depositional Environment	Type Sediment
I	+	Low Energy Eolian	Sandy Loess
	-	Low Energy Beach	Medium Beach Sand
II	+	High Energy Eolian	Dune Sand
	-	High Energy Beach	Very Coarse Beach Sand
III	+	Moderate Energy Eolian	Fine Sand
	-	Moderate Energy Beach	Coarse Beach Sand
IV	+	Very Low Energy Eolian	Silty Loess
	-	Mixed High & Low Energy Environments	Reworked sands, fluvial sands
V	+	Moderate Energy Eolian Poorly Sorted	Reworked slightly fine sands
	-	Moderate Energy Mixed	Very Poorly Sorted Sands

of the information contained in the original 17 variables. These factors (Table 3) were found to be most useful for determining the probable geologic processes involved in the deposition of 59 samples. A sixth factor was found to be associated with a single sample (A-107), a coarse pebble colluvium, and therefore was not useful for interpreting the other samples.

In the Q-mode varimax factor matrix the samples are clustered in terms of the five factors retained from R-mode analysis. Those samples with the highest positive and negative Q-mode factor loadings for a given factor approximate end members for that factor. Interpretation of the geologic significance of that factor can then be based upon the characteristics of the end-member samples. Q-mode factors from grain-size data are thought to reflect energy conditions of a particular environment of deposition in this application of factor analysis (Solohub and Klovan, 1970, p. 81). Over half of the 60 samples analyzed were collected from known environments of deposition within the lake area. The remaining samples with uncertain field relationships were interpreted through the clustering of known and "unknown" samples by Q-mode analysis. Most samples can be interpreted with a fairly high degree of confidence by this method, but some ambiguity remains where samples are described in terms of two or more factors. In addition, the interpretation of the significance of some factors is complicated by those factors which have end members with relatively poor sorting and uncertain origins.

Samples which do not cluster closely with end member samples must be interpreted with special caution, as a number of influences may be responsible for their relative dissimilarity. They may be mixtures of sediments from different but adjacent depositional on energy environments such as beach and nearby dune. They may be mixtures arising from post-depositional slope processes, mixing during sampling with soil augers, or sediments with their depositional characteristics altered prior to burial by processes such as deflation.

Some approximate end members do seem to represent mixtures (Factors IV-, V-). Such factors tend to cluster samples with relatively poor sorting and/or polymodal size distributions resulting from reworking or mixing by many possible processes. Frost churning, solifluction, slope wash, disturbance by burrowing animals or root penetration, collapse due to thawing of ice-rich permafrost, and other processes could account for mixing of sediments after deposition. Field relationships must be relied upon in the interpretation of these sediments more than for the less ambiguous samples. Often the mixing is rather slight and may be caused by some mixture of adjacent lenses of sediments of similar origin but varying texture.

Interpretations of the depositional-energy environments of the 60 samples subjected to factor analysis are summarized in Appendix III. The interpretations are the result of combining the factor analysis groupings with the field relationships.

Samples from known environments of deposition were consistently clustered into groupings with similar grain size distributions. Sixteen loess samples were clustered into two overlapping groups, reflecting a continuum from sandy silt to fine silt. Since the mode of deposition of these samples was known they were of little value in interpreting "unknowns" because there were few unknowns with such fine grain size distributions. The value of the clustering of loess samples is simply establishing a degree of confidence in the factor analysis application to this problem, since clustering is entirely consistent.

Fifteen sand samples from known and unknown or uncertain environments were clustered into two overlapping groupings typified as dune sands and fine eolian sands. Several samples which were interpreted in the field as probable beach sands were reinterpreted as eolian sands because they were clustered with known dune sands. The fine eolian sands typically occurred in widespread sand sheets.

Twelve beach sands were consistently clustered into three groups which evidently reflect increasing grain size from medium to very coarse sands. Eight of the samples were known beach samples collected from the present beaches of Healy Lake. The four uncertain samples were clustered closely with the known beach samples and therefore provide strong evidence for an ancient higher lake level.

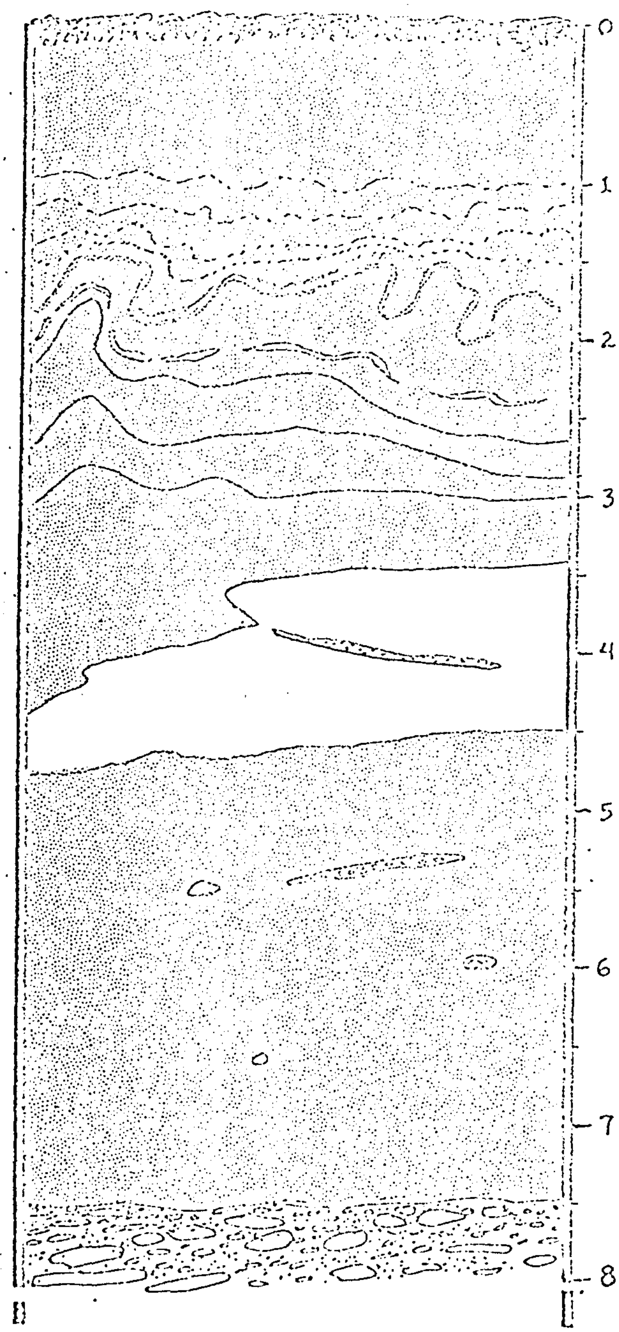
The remaining samples were clustered into several somewhat ambiguous groups of poorly sorted or mixed samples. Fluvial sands could not be distinguished from reworked sands since their grain size distributions were often similar.

Test Pit Profiles

Test pits dug in the lake area provide sediment and soil profiles from which past environmental conditions can be inferred. The composition and characteristics of sediment units provide means of interpreting their mode of deposition. Structures such as ice wedge casts and convoluted layers suggest past conditions unlike those existing today in the area, and sometimes provide a means of correlating units with regional climatic events. Several profiles described in detail here reveal especially significant features or sequential relationships between units. The remaining profile descriptions appear in Appendix I.

Test Pit 13 (Figure 9): This pit and several others dug along the saddle separating the Volkmar and Healy drainages reveal a sequence of fine eolian sediments which may have begun to accumulate during the Delta Glaciation. The sediment sequence consists largely of silty loess lacking obvious boundaries between units. It is likely that the upper foot or perhaps two feet have been deposited during Holocene time, judging from the quantity of loess which accumulated in the Village Site during the Holocene. Thin clay layers appear in the profile beginning at a depth of about 12 inches. According to Dement (1962), clay layers or skins are common in Subarctic Brown Forest Soils and are thought to form on top of a permafrost table which prevents further downward movement of clay particles, thus concentrating the clay in a thin layer. As the permafrost table rises or lowers, new clay skins form. No permafrost was encountered in the several test pits dug along the crest of the saddle, but the presence of clay skins and convoluted layers of sediments suggests that permafrost was present at some time in the past.

Figure 9 TEST PIT 13: Crest of saddle, ridge north of Healy Lake



Organic mat

Oxidized loess

Thin clay bands in loess

Highly convoluted layer, clay band overlain by thin lenses of gleyed silt

Reworked volcanic ash lenses in loess

Clay bands in buff loess; thin reddish layers of iron oxides

Volcanic ash layer, fine white glass, somewhat convoluted; thin lense of mixed ash and loess

Fine loess unit with scattered lenses of small pebbles and sand, some quartz ventifacts

Residuum of small schist and quartz fragments in a micaceous clayey matrix

Depths in feet

Assymetric convolutions imply downslope movement on top of a permafrost table. There seems to be two zones of convolutions in the profile, an upper zone concentrated between depths of about 1.5 and 2.5 feet and a lower zone between about 3.5 and 4.5 feet. The upper zone may have formed during the Donnelly Glaciation when the climate was sufficiently severe to permit permafrost formation on the well drained ridge crest. The lower zone may have formed during the preceding Delta Glaciation. Alternatively, the upper convoluted zone may have formed during the Holocene, under local forest conditions sufficiently different from the present to permit permafrost to exist. The saddle is covered with an immature forest of aspen and birch which suggests that the area was subjected to fire in recent time. Under a forest cover of mature spruce and moss ground cover, permafrost could have existed during Holocene time in this locality.

The only volcanic ash encountered in the Healy Lake area occurs along the saddle where this test pit was dug. The ash layer occurs at a depth of about 3.5 to 4.5 feet in Test Pit 13, and varies in thickness from 0.5 to 1 foot. The variation in thickness seems to have resulted from downslope movements, perhaps by solifluction during the Delta Glaciation. The absence of ash elsewhere around the lake suggests that it is preserved only in very favorable locations and at considerable depths. Petrographic examination of the ash reveals that it consists almost entirely of fine glass shards. Spectrographic analysis shows a low Fe, Mg, and Ca content for the ash. This suggests extensive leaching (D. Stevens, pers. comm., 1970), or winnowing of heavier minerals during eolian transport from a distant source (Hess and Poldervaart, 1967, p. 52).

Table 4: Semiquantitative Spectrographic Analysis of Volcanic Ash from Healy Lake Area

Fe	-	.940%	Bi	-	N	P	-	N
Mg	-	.086%	Cd	-	N	Pb	-	N
Ca	-	.980%	Co	-	N	Sb	-	N
Ti	-	950.0 ppm	Cr	-	4.3 ppm	Sc	-	N
Mn	-	295.0 ppm	Cu	-	25.0 ppm	Sn	-	N
Ag	-	N	Ge	-	N	Sr	-	295 ppm
As	-	N	In	-	N	V	-	<10 ppm
Au	-	N	La	-	N	W	-	N
B	-	7.8 ppm	Mo	-	N	Y	-	N
Ba	-	540.0 ppm	Nb	-	N	Zm	-	N
Be	-	N	Ni	-	N	Zr	-	157 ppm

The ash is underlain by loess containing lenses of eolian sand and pebbles derived from nearby schist outcrops. This lower loess unit was probably deposited during the Delta Glaciation. At a depth of 7.5 feet, the loess is underlain by a deposit of residuum derived from weathering of quartz-mica schist bedrock. The age of the deposit is probably pre-Delta.

Test Pit 32 (Figure 10): This wave cut embankment along the northeastern shore of Healy Lake exposes a cross section of an ice wedge cast. The cast is overlain by 4 sediment units: organic mat 3 inches thick (top of exposure), loess 12 inches thick of probably Holocene age, fine eolian sand layer 3 inches thick, and coarse well rounded beach (?) sand mixed with finer eolian sand and silt 3 to 4 inches thick. The latter unit also fills the ice wedge cast below it. The wedge penetrates 18 inches of colluvium and additional 12 inches of grus underlying the colluvium. The colluvial layer consists of angular stones up to 3 inches in length in a finer matrix of micaceous and clayey weathering products. The stones are derived from fine textured quartz-mica schist bedrock uphill from the exposure; they are oriented with their longest axes roughly parallel with the dip of the slope of the ridge north of the lake.

Ice wedges were forming actively in interior Alaska during the late Pleistocene glaciations; subsequent melting of the ice wedges during periods of warmer climate caused some to become filled with the overlying sediments to produce wedge-shaped casts. The ice wedge cast in this exposure probably formed during the early part of the Donnelly Glaciation. The colluvial deposit it penetrates may be a solifluction deposit from the Delta Glaciation. The rise in lake level that probably occurred during the Donnelly Glaciation inundated the area where the ice

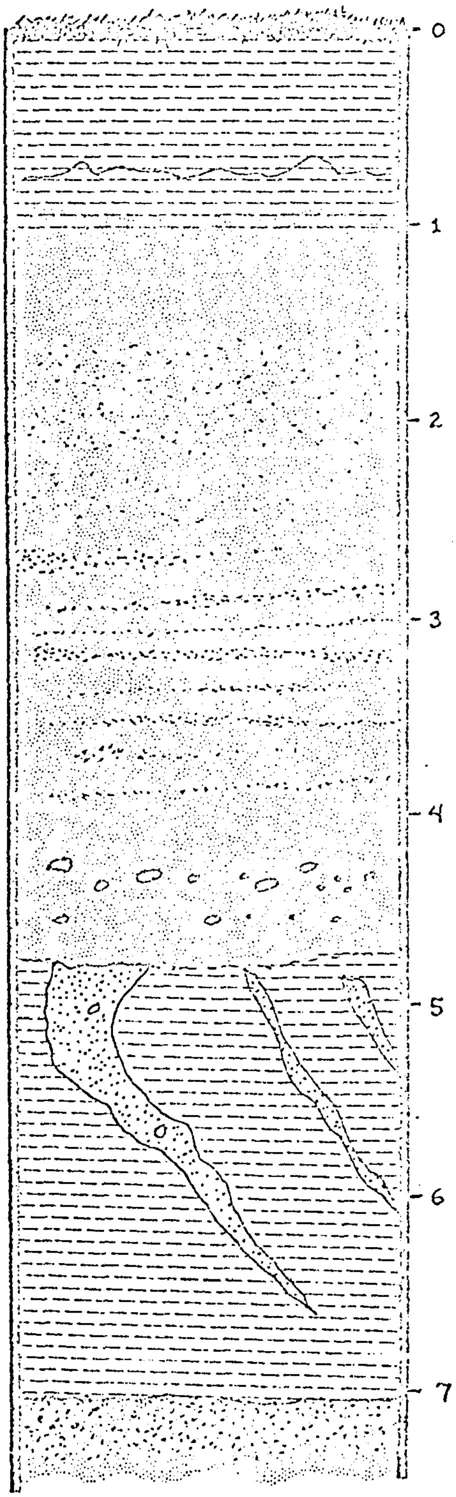
Figure 10: Test Pit 32, ice wedge cast in wave cut bank southeast of Village Site on shore of Healy Lake. Length of tape measure, 24 inches. Cast penetrates grus (G) and colluvium of stone fragments in finer matrix (C). Cast filling is coarse beach and eolian sand (S).

wedge was formed, depositing beach sand on top of it. Contact with lake waters melted the ice wedge, causing slump of the overlying sand and subsequent filling of the void left by the ice wedge. Lowering of the lake level probably at the end of the Donnelly Glaciation permitted eolian sand and loess to be deposited on top of the beach sediments.

Test Pit 43 (Figure 11): This test pit exposed a sequence of eolian sediments deposited along the north side of the Healy River during late Pleistocene and Holocene time. The pit was dug downslope from a steep vegetated sand dune which rises about 70 feet above the surrounding slope. The excavation penetrated 12 feet of loess and sand without encountering permafrost or reaching bedrock.

The upper 12 inches of the profile consists of loess underlying a thin organic mat about 2 inches thick. The loess has a slightly sandy texture which suggests that most of it was deposited during the first half of the Holocene, judging from the Village Site loess profile (Figure 15). The uppermost several inches is finer in texture and is oxidized as part of a Subarctic Brown Soil profile. The clay layer at a depth of about 9 inches may represent a permafrost table from some time in the past. Since it was formed in what are thought to be Holocene sediments, the permafrost may have formed at some time in the past 8000 years when spruce forest and thick sphagnum covered the area. Although permafrost is generally absent on south-facing slopes under present climatic conditions, permafrost can form there when an insulating mat of vegetation becomes sufficiently thick. Periodic forest fires destroy such upland stands of spruce, thus permitting thaw of underlying frozen sediments. The present forest cover consists of aspen, white birch, scattered small spruce, and brush. The thin organic mat covering the soil today provides insufficient

Figure 11: TEST PIT 43 : Tributary valley,
North side Healy River,
Altitude 1275 feet



Organic mat

Sandy loess, upper 3 inches oxidized; thin clay layer at 9 inches depth

Sand, fine to medium grained; no visible stratification, somewhat mottled

Interlayered lenses of well-sorted medium to fine eolian sands, probably somewhat reworked

Pebbly layers in sand (Sample A-6, sand, 54 in.)

Probable unconformity

Clayey silts, faintly stratified, transected by ice wedge casts filled with coarse eolian sands and some pebbles (Sample A-80, coarse sand from wedge cast)

Pebbly sand to at least 12 feet deep below surface
(All depths in feet)

insulation to permit permafrost formation.

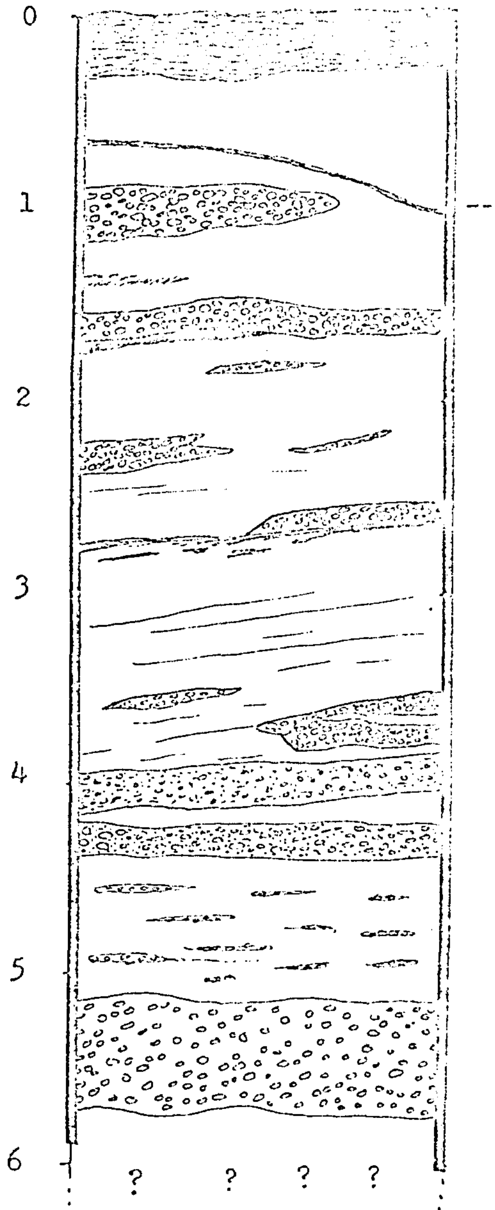
Fine to medium grained eolian sand beneath the loess unit changes with increasing depth from a uniform texture to laminated sands of varying textures. The upper layers which lack structure probably have been disturbed by frost action, roots, or downslope movements. The sand was probably deposited during the Donnelly Glaciation and subsequently reworked somewhat by slope processes.

A probable unconformity exists in the profile at a depth of 4.7 feet. A rather sharp boundary occurs here between eolian sand above and silt below. The underlying silt unit contains ice wedge casts filled with coarse eolian sand. The silt unit probably was deposited as loess during the waning stages of the Delta Glaciation, or perhaps during the warmer period between Delta and Donnelly time. The cold conditions of the Donnelly Glaciation permitted ice wedges to form in the silt; coarse sand derived from Donnelly-age beaches less than a mile to the south was deposited on top of the silt unit. Subsequent melting of the ice wedges at the end of the Donnelly Glaciation caused filling of the void by the overlying sand. A period of erosion following the Donnelly Glaciation may have removed some of the overlying coarse sand.

Pebbly sand underlies the silt layer at depths of 7 to at least 12 feet. The sand is probably a Delta-age eolian deposit derived from floodplain sands from the lower Healy River and the Tanana River. The pebbles suggest that the material has been subjected to downslope movement and incorporation of colluvial pebbles derived from weathered bedrock uphill from the deposit.

<u>Test Pit 70</u> (Figure 12): This test pit serves as a typical example of the sediment profiles exposed in several excavations made at the south end of Healy Lake near

Figure 12: Test Pit 70; Pruhs' Cabin area, south end of Healy Lake



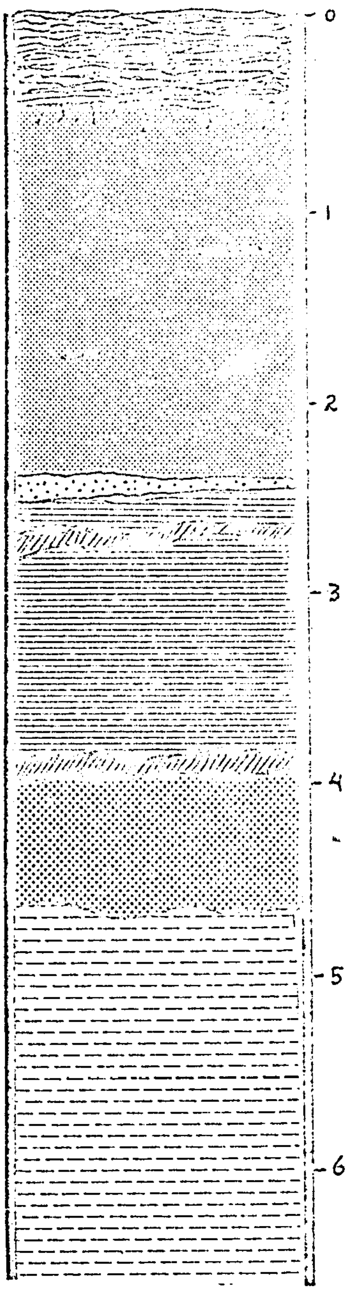
Pruhs' cabin (Plate 3). The pits were excavated on the lower and middle slopes of a bedrock spur extending from a steep ridge south of the lake. The slopes are forested predominantly with spruce and white birch.

The sediments consist of colluvial silt containing lenses and layers of poorly sorted pebbles and micaceous sand. The silt contains numerous thin layers of oxide and organic staining, and scattered concentrations of charcoal. Some of the charcoal lenses are overlain by pebble and sand layers, suggesting that periods of gullying and sheetwash may have resulted in redeposition of eroded pebble concentrations following forest fires. The upslope source of the pebbles was not located, but could be a beach pebble concentration deposited during the Donnelly-age high lake stage. The pebble layers are very poorly sorted, however, and consist of angular quartz pebbles and schist fragments. If the pebbles are derived from a beach deposit, considerable mixing has occurred during their transport and redeposition. Alternatively, the pebbles could be derived from weathered bedrock exposed to erosion periodically by gullying.

The apparent changes in slope of the ground surface suggested by the organic stained layer 8 to 12 inches deep may relate to a small alluvial fan building out from the low spur to the east of the test pit. Otherwise the sediment units dip northeastward toward the lake.

Test Pit 75 (Figure 13): This bank exposure along the southeastern shore of Healy Lake consists of organic-rich silt and woody peat. The sediments are overlain by a 6 inch layer of forest litter grading downward to a woody peat. This insulating layer has permitted the formation of permafrost in the sediments. Excavation of the face of the exposure revealed ice lenses up to one inch thick in the saturated muck

Figure 13: Test Pit 75; Southeast shore of Healy Lake



Organic mat containing peat, wood, and birch bark

Roots

Gray silt containing fragments of wood, birch bark

Gray clayey silt

Buff silt

Woody peat layer with birch bark (C-14 dated at 230 ± 120 years B. P., GX-1971)

Gray gleyed silt with plant fragments; poorly stratified

Woody peat with birch bark, twigs; (C-14 dated at 1160 ± 110 years B. P., GX-1972)

Brown-black gleyed silt with organics

Dark brown-black perennially frozen silt with ice lenses up to 1 inch thick

Water line

Depths in feet

several feet below the surface. Exposure to lake water has thawed the permafrost for several feet back from the shore, causing collapse of the silts. Several thaw lakes have formed in the forest within several hundred feet of the lake shore in the vicinity of this test exposure. The silt contains numerous plant fragments, including wood and birch bark. Two woody peat layers occur at depths of about 2.7 feet and 3.8 feet. Radiocarbon dating provides a time range of 230 $\pm$ 120 years B. P. for the upper layer and 1160 $\pm$ 110 years B. P. for the lower layer. This suggests that in this particular locality at least, and probably in many comparable small tributary valleys and gullies of the area, deposition of silt has been perhaps as rapid as 1 foot per century during the past 200 to 300 years. The underlying foot of silt was deposited over a time span of nearly a millenia. The probable explanation for the variation in accumulation rates is the exposure's location near a small gully which may carry silt occasionally when erosion is active following forest fires. Several fire scars appear on the hillsides near the gully, so it is possible that fires during the past two centuries may have resulted in this locally rapid rate of deposition.

Test Pit N 20 E 10 (Figure 14): This excavation is one of many made in the Village Site in the course of archeological investigations. Although the thickness of individual units varies considerably in the numerous test pits because of slight differences in elevation and random cultural disturbances, this pit serves as a representative example of the general stratigraphic sequence in the site.

The soil is covered by a thick organic mat of plant fragments, roots, and abundant cultural refuse which has accumulated within the last century. The base of the organic mat usually overlies a thin discontinuous layer of spruce needles. These probably accumulated at a time within the last several hundred years when spruce forest covered the site. It is now vegetated by grass, brush, and a few small aspen. The organic mat and spruce needle layer is underlain by about 30 inches of loess which grades to a coarser texture with depth (Figure 15). Most of the cultural materials are concentrated in the upper 20 inches of loess, which has accumulated within the past 11,000 years, according to the radiocarbon dates from the site (Figure 15). The loess does not seem to be disturbed except by occasional animal burrows and refuse pits. The upper 12 to 14 inches of loess displays oxidation which is common to Subarctic Brown Forest Soil profiles. There seems to be two soil profiles present, however, representing an upper "modern" soil profile and an underlying paleosol (J. Cook, pers. comm., 1971). Clay layers present in the site's profiles probably formed during a period of spruce and sphagnum vegetational cover on the site which permitted permafrost to form. The permafrost table prevented further downward migration of clay particles and thus concentrated the clay on top of the permafrost. Fluctuation of the depth of permafrost table resulted in the formation of new clay bands.

The loess unit is underlain by eolian sand which varies in thickness considerably within the site. The sand is fine to medium grained in texture, with a tendency to become coarser with depth. The sand was probably deposited at the end of the Donnelly Glaciation after the lake level had dropped at least below the Village Site. The eolian sediments in the site show a general trend of grading upward into finer grained sediments. This trend reflects the environmental changes which accompanied the waning of the Donnelly Glaciation and the onset of the Holocene. With glaciers retreating farther from the lake, and disappearing in the upper Healy River, sources of eolian sediments become more distant and restricted

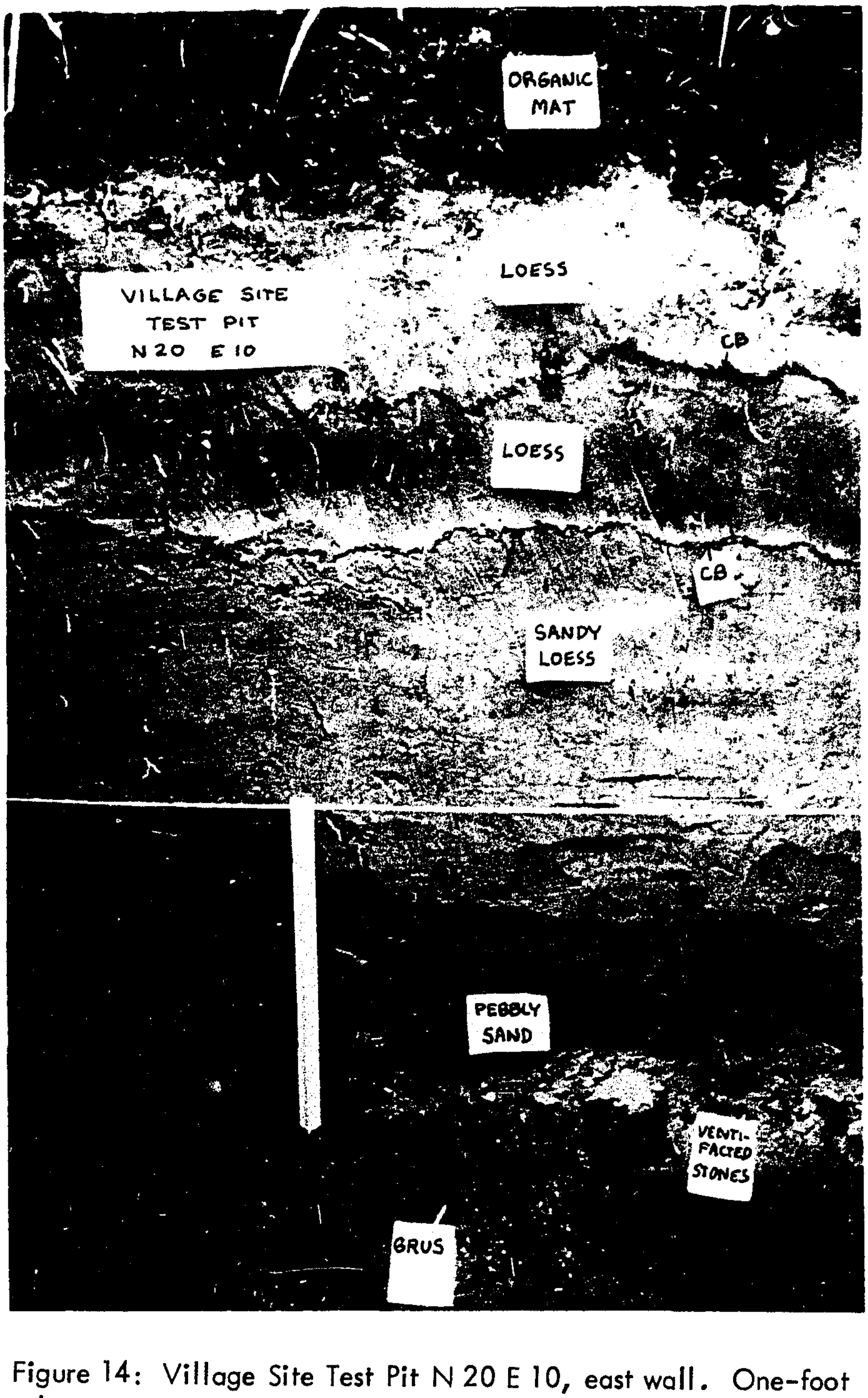


Figure 14: Village Site Test Pit N 20 E 10, east wall. One-foot ruler provides scale. Clay "bands" or skins (CB) may indicate a past permafrost table.

Figure 15: VILLAGE SITE TEST PIT N 75 E 0

GRAIN SIZE ANALYSIS : LOESS

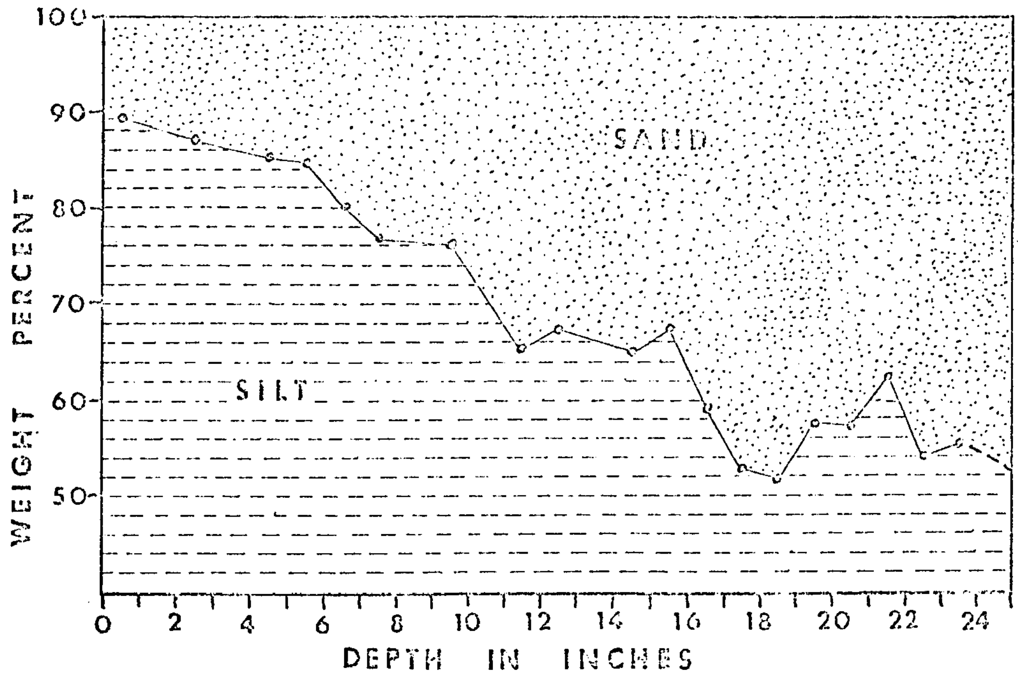
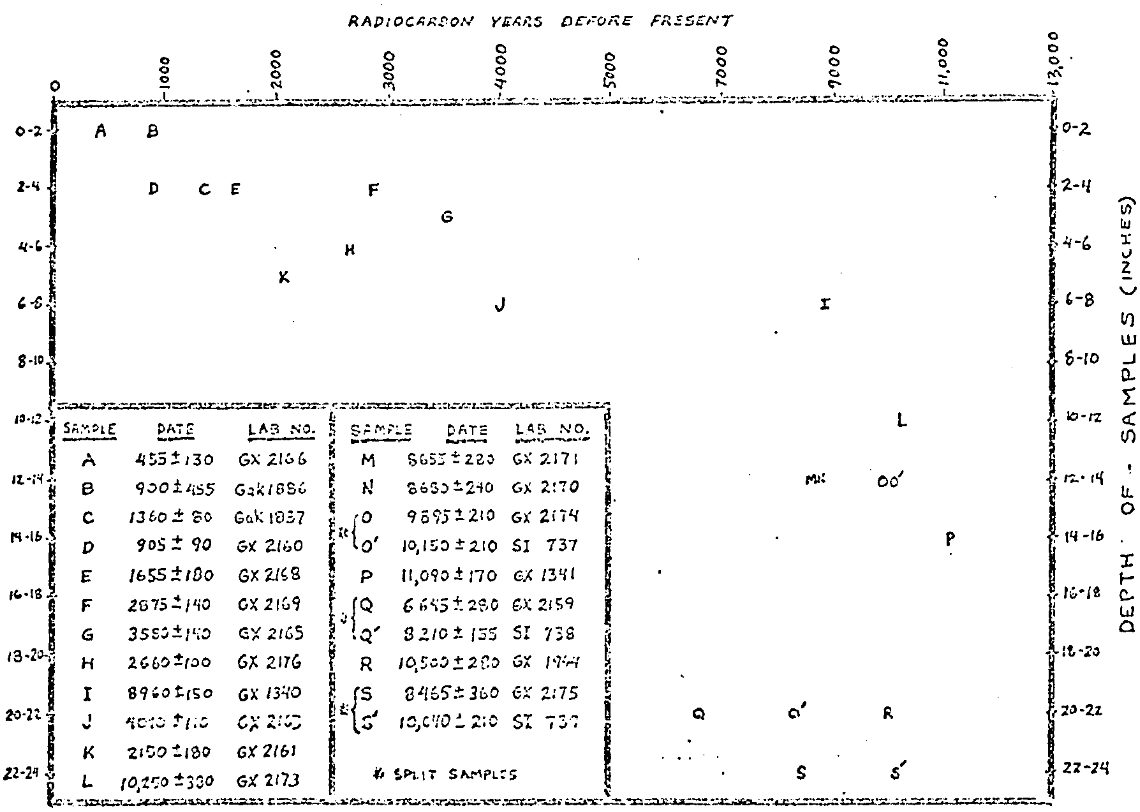


Figure 16: Village Site radiocarbon dates



SAMPLE	DATE	LAB NO.	SAMPLE	DATE	LAB NO.
A	455±130	GX 2166	M	8655±220	GX 2171
B	900±455	GaK 1886	N	8680±240	GX 2170
C	1360±80	GaK 1837	* O	9595±210	GX 2174
D	905±90	GX 2160	* O'	10,150±210	SI 737
E	1655±180	GX 2168	P	11,090±170	GX 1341
F	2875±140	GX 2169	* Q	6655±280	GX 2159
G	3580±140	GX 2165	* Q'	8210±155	SI 738
H	2660±100	GX 2176	R	10,500±280	GX 1944
I	8960±150	GX 1340	* S	8465±360	GX 2175
J	4010±110	GX 2163	* S'	10,040±210	SI 737
K	2150±180	GX 2161			
L	10,250±330	GX 2173			

* SPLIT SAMPLES

in geographic extent. Reforestation during the Holocene inhibited eolian activity also, and beaches no longer were a significant source of eolian sediments.

The eolian sand is underlain by a discontinuous pebbly sand layer which contains fossil vertebrate fragments of probable Donnelly age. This layer probably represents beach deposition during the rise or fall of the Donnelly-age lake.

Under the beach sediments is a gravel layer derived from the underlying weathered bedrock. The gravel includes fragments of resistant vein quartz, granodiorite, diorite, and sometimes quartz-mica schist. Many of the rock fragments are ventifacted, probably the result of severe eolian activity during one or more harsh climatic episodes of the late Pleistocene. It is likely, however, that the ventifacts were produced during the Delta Glaciation, as they were elsewhere in the middle Tanana Valley at that time (Péwé, 1965b).

Underlying the ventifact layer is an accumulation of grus which probably formed in situ by weathering granodiorite and diorite bedrock prior to the Delta Glaciation.

Surficial Geology

Surficial geology of the Healy Lake area was studied by field techniques combined with laboratory analysis and photogeologic mapping. General distributions of surficial units were determined from natural exposures along lake shores and river cutbanks, from archeological excavations, and from more than 80 test pits dug in the area. Field observations of structures and geomorphic associations were combined with laboratory data to infer modes of deposition of the surficial units. Field mapping was supplemented by photogeologic interpretation. Aerial photographs (about 1:50,000 scale) obtained from the U.S. Geological Survey were of particular value in determining approximate boundaries between major surficial units and identifying large-scale geomorphic features. Larger scale color photographs of certain areas were taken with a hand-held camera from a low flying aircraft. These photographs were of particular value in delineating lake channels and vegetational units, because many were taken during September, when the lake level was low and autumn foliage provided high contrast between vegetation types.

A number of useful airphoto identification criteria help delineate surficial units. Each unit displays a unique combination of geomorphic features, vegetation, geographic associations, and photographic tone which permit differentiation on areial photographs (Table 5).

Eolian Deposits

The bedrock hills surrounding Healy Lake are mantled with eolian sediments deposited during late Pleistocene and Holocene time. Sand sheets and dunes have accumulated on lower slopes and within tributary valleys. Loess forms a widespread blanket on gentle and moderate slopes of bedrock ridges around the lake.

Table 5: Aerial photo identification criteria for surficial units

Surficial Unit	Geomorphic Form	Vegetation	Locale	Tone
EOLIAN DEPOSITS				
Sand	Dunes and sand sheets	Mosaic forest, with aspen and birch abundant on dunes	Gentle to moderate slopes	Mottled gray
Loess	Widespread but discontinuous sheets; gully erosion	Mosaic forest	Gentle to moderate slopes	Medium gray
FLUVIAL DEPOSITS				
Terrace deposits	Linear strips adjacent to floodplains; meander scars	Mature white spruce or black spruce-muskeg on Tanana River terraces	Flat surfaces adjacent to floodplain and standing 6 to 15 feet above it	Medium to dark gray
Bog silt-peat	Thermokarst features on floodplain	Bog and marsh species	Low depressions on Healy River floodplain	Mottled white to med. gray
Overbank deposits	Natural levees and adjacent backswamps	Forests dominated by birch and spruce	Adjacent to river channels	Dark gray
Alluvial-colluvial silt and sand	Alluvial fans, aprons, and gullies	Muskeg or low brush species	Gentle to moderate slopes, thickest at bases of slopes	Light gray
Alluvium	Sand and gravel bars cut by anastomosing channels of Tanana River	None	Active floodplain	White to very light gray
LACUSTRINE DEPOSITS				
Beach deposits	Ice shove ramparts	Marsh, species and willows	Lake shore	Light gray
Deltaic silt	Active and abandoned distributaries along western shore	Marsh species	Lake margins near outlet channels	Light gray

Sand was concentrated on the north side of the Healy River Valley by wind and wave action during the late Pleistocene. A lake larger than present-day Healy Lake occupied the lower Healy River Valley during the Donnelly Glaciation (?). Southerly winds transported sands from the beaches of the Donnelly-age lake and from the barren floodplains of the Tanana and Healy Rivers, and deposited it as sheets and dunes on south-facing slopes of bedrock ridges. In winter, sand may have blown northward across the frozen surface of the lake to the accumulating sand deposits.

Transverse dunes were formed approximately at right angles to the prevailing southerly wind direction. The dunes generally are linear, with relief ranging from a few feet to a maximum of 70 feet. Some dunes initially were as much as 1200 feet in length, but most have been segmented by gullying during the Holocene.

Dunal sediments observed in test trenches show a general lack of crossbedding. Lamination is prominent, particularly with increasing depth. Laminae consisted of thin parallel or subparallel layers and lenses of sands of varied texture, implying fairly rapid fluctuation of energy conditions in the eolian environment. Finer, more uniform sands overlie the laminated sediments. Frost action, disturbance by plant roots, or deposition under more stable energy conditions could account for the absence of lamination in the upper sands. The decrease in grain size may reflect greater distance from source areas.

Coarse sand encountered in numerous test pits north of the present Healy River probably were blown uphill from an immediately adjacent source area by strong winds from the south. Bedrock ridges south of the lake area would have been an effective barrier to eolian transport of coarse sand from outside the lake basin.

The coarse sand is highly quartzose, unlike the sand derived from the Alaska Range glaciers which contains a higher proportion of mafic minerals. The coarse sand in the lake area was probably derived from glaciofluvial sediments transported downstream from the Healy River headwaters. Some coarse sand samples collected from dunes and other eolian deposits displayed some of the sorting characteristics of beach sand (Samples A-74, A-3, A-12: Appendix III). It is likely that late Pleistocene beach sand was an important source of eolian sediments to the areas leeward of the beaches.

Stabilization of the dunes around Healy Lake was accomplished by the development of vegetal cover and a loess mantle. Estimates of the time range during which dunes became stabilized in the middle and upper Tanana Valley vary from about 12,000 years B.P. (Fernald, 1965c) to about 5,000 years B.P. (Holmes and Foster, 1968).

Loess mantles most of the Healy Lake area, absent only on steep slopes and the highest ridgetops. Solifluction, gully erosion, and sheetwash are the major slope processes involved in the reworking of the loess deposits. Reworking has resulted in the loess blanket thinning to a few inches on upper slopes and thickening to perhaps several tens of feet on lower slopes where the silts have been concentrated. Evidence for reworking of eolian silt by slope processes includes thin layerings of iron-oxide and organic stains, convoluted layers and clay bands, and incorporated rocks (including ventifacted vein-quartz fragments) derived from bedrock upslope. Solifluction during the late Pleistocene glaciations and Holocene gullying and slopewash probably account for most of the observable downslope transport.

In Test Pit 43 (p. 55, Fig. 11) reworked loess of apparent late Pleistocene (Delta?) age is transected by ice wedge casts. The ice wedges probably formed during the Donnelly Glaciation and subsequently were filled with overlying coarse eolian sand as the ice melted at the close of Donnelly time.

The thick accumulation of silt encountered in Test Pit 14 (Appendix I) on the crest of a saddle probably records the history of loess deposition and reworking from Delta time to the present. The brown clayey silt encountered at about 18 feet may be either a mid-Wisconsin interstadial soil or a Sangamon soil.

Throughout the area, the upper 3 to 12 inches of loess display a red-brown iron-oxide staining which is typical of Subarctic Brown Forest Soil profiles formed under conditions of good drainage and forest cover (Dement, 1962).

Radiocarbon-dated horizons in the Village Site archeological excavations suggest that loess has continued to accumulate in the area during much of Holocene time (Figs. 14, 15, and 16). The upper 12 to 20 inches of loess here evidently were deposited after the waning stages of the Donnelly Glaciation, about 10,500 to 11,000 years B.P. The percentage of sand increases with depth, becoming more than 90 percent at about 36 to 48 inches below the surface. The progressive upward decrease in grain size from medium sand to silt reflects the transition from the essentially unforested windswept environment of the late Pleistocene to the forested Holocene landscape with more distant and limited sources of sediments. The loess which mantles the dunes in the area evidently is a Holocene deposit overlying late Pleistocene sands. Much, but not necessarily all, of the loess blanketing the hills and ridges probably was deposited in Holocent time.

Fluvial deposits

Fluvial deposits in the area include terrace deposits bordering the Tanana River floodplain, barren alluvium of the Tanana's active floodplain, bog and natural levee deposits of the Healy River floodplain, silty alluvium in tributaries of the Healy River, and auriferous gravels underlying frozen mucks in Canyon Creek.

Terrace deposits of the Tanana River consist of interlayered fine to coarse sand and gravel, mantled with silt and sand with a cover of forest vegetation. The terraces, according to Holmes and Foster (1968) are of post-Donnelly age and stand 6 to 15 feet above present river level. Their surfaces bear numerous scars of abandoned sloughs which have been filled with fine silt, peat, and bog vegetation. The terrace deposits are usually underlain by permafrost. Those terrace sediments which separate Twelvemile Lake, Lake George, and Moosehead Lake from the Tanana River consist largely of late Pleistocene outwash gravels (Holmes, 1965). Elsewhere in the Johnson River-Gerstle River area, the terraces along the Tanana River are thought to be Holocene in age (Holmes and Foster, 1968). Tanana River terraces near Healy Lake are probably of comparable Holocene age.

Alluvium of the Tanana's active floodplain is largely barren of vegetation and is not underlain by permafrost. The actively migrating channels of the Tanana continuously deposit and erode sand and gravel bars. Silt layers are deposited as overbank deposits during high water stages. Cutbanks reveal sand and gravel layers sometimes thinly mantled with silt. The gravels are well rounded and often display a high degree of sphericity. The sands observed in the Gerstle and Tanana Rivers between the Alaska Highway and Healy Lake have a gray color, in contrast to the yellow sand of the Healy Lake area. This is due to a generally higher content of mafic minerals in the Tanana and Gerstle River sands than in the highly quartzose sand around Healy Lake.

The Healy River and its tributaries have produced a diverse suite of fluvial deposits which reflect the influences of varied parent material, climatic conditions, and distance from source areas. The mean size of the sediments changes markedly over the length of the river, from coarse gravels in the headwaters to fine silts in the lower river near the lake.

In the upper Healy River vegetation is sparse, frost action severe, and stream profile steep. The river flows through coarse gravels deposited during the late Pleistocene glaciations. The large volume of glacial outwash deposited then is reflected in the convexity in the Healy River's longitudinal profile immediately downstream from the known limit of glaciation (Plate 4). During the glaciations when the snow line descended to between 4800 and 4500 feet, Healy River discharge remained high throughout the short summer due to continous snowmelt and glacial ablation. Today, however, runoff resulting from snowmelt is concentrated between late April and early June. By midsummer or earlier all snow is melted from the drainage basin, leaving the Healy River's discharge dependent upon summer rainfall.

The gravelly streambed of the upper Healy River grades to a more sandy one downstream. Sandy point bars, gentler profile, and mature white spruce forests typify the middle Healy River. Whereas the upper Healy River maintains a rather straight channel, the middle Healy River meanders more freely.

The Healy River changes character rather abruptly between about 9 and 12 miles upstream from Healy Lake. Sandy point bars become less conspicuous as the dominant texture of the sediments underlying the floodplain changes from sand to silt. The lower Healy River has a very gentle slope, approaching about 1 to 2 feet per mile (Plate 4). This lower section of the floodplain is covered by bog vegetation and thaw lakes, and interlaced with active and inactive channels with forested natural levees (Fig. 18). The overbank deposits which form the levees typically consist of sandier material than the surrounding flats, often displaying layers of silt, sand, and organic sediments. The levees stand higher than the surrounding bogs and exhibit better drainage; depth to permafrost usually is greater than in the bogs.

The processes of bog formation are important to the interpretation of lowland terrain features and Holocene lake history. Unlike normal floodplain sediments which, once deposited, are not likely to be disturbed until the meandering river returns to the place of deposition, bog sediments can be profoundly affected by thawing of ice-rich perennially frozen silt and peat. The loss of volume resulting from the melting of ice causes depressions which become water-filled. Such thaw lakes are very widespread in the permafrost regions of Alaska, and have been discussed widely in the literature (Black, 1969). The most detailed study of bog processes published to date is that of Drury (1956), who worked primarily in the upper Kuskokwim Valley. Based on Drury's research, the following generalizations about bog processes appear to be applicable to the bog flats around Healy Lake:

1. The deposits of bog flats consist of peat and silt. Often the peat and silt are preserved as distinct layers in exposures, and sometimes the organic material is mixed with the silt in a rather uniform structureless muck. The mixing results form thaw and collapse of frozen banks along streams and ponds. Some mixing occurs when silt is reworked on lower slopes of ridges adjacent to the bog flats and redeposited in the bogs by tributary streams.

2. The silt is derived from three major sources: (1) loess deposited directly on the bog flats, (2) fluvial silt deposited on the flats during floods, and (3) reworked loess derived from hillsides adjacent to the bogs.

3. Bog processes tend to be cyclical. Complex interactions between plant succession, silt deposition, permafrost formation, thaw lake development, and migration of channels result in a roughly cyclical sequence of bog stages (Fig. 17).

4. Permafrost plays an important role in the development of landforms and drainage characteristics of bog flats. A thick insulating cover of vegetation, particularly sphagnum mosses, is vital to the development of permafrost. The fine silty texture of the bog sediments, in addition to the peat accumulations themselves, permits a significant increase in the volume of saturated sediments upon freezing. Disturbance of the insulating vegetal cover by fire, blowdowns, or other agents permits thawing of underlying ice-rich silt and peat. Thaw lakes thus form and gradually expand and coalesce by continued thaw and collapse along the shores where water comes in contact with frozen sediments. Permafrost thaws to considerable depths under thaw lakes; it may be entirely absent under lakes larger than about 300 feet in diameter.

5. Bog drainage is impeded by numerous log jams, beaver dams, and microrelief features. This results in the frequent abandonment of channels and the development of new ones, particularly during periods of high water (Fig. 18; Fig. 19).

6. Bog flats tend to remain bogs for thousands of years. Although specific bog features are constantly undergoing change, the bogs are essentially stable for long periods of the time unless a major change occurs in climate or other environmental controls.

Alluvial sediments deposited in Healy River tributaries are mostly reworked sand and silt, commonly underlain by permafrost. Covering the valley floors of these tributaries are muskeg communities consisting of cottongrass tussocks, stunted black spruce, low brush, and other plants. The absence of thaw lakes suggests a relatively low ice content, perhaps due to more effective drainage than that in bogs. These deposits often are extensively gullied. The sediments removed by erosion from these tributaries are deposited along the flanks of the lower Healy River floodplain as alluvial fans and aprons (Plate 2). Since the fan and apron deposits overlie floodplain deposits of probable Holocene age, they were formed later in the Holocene.

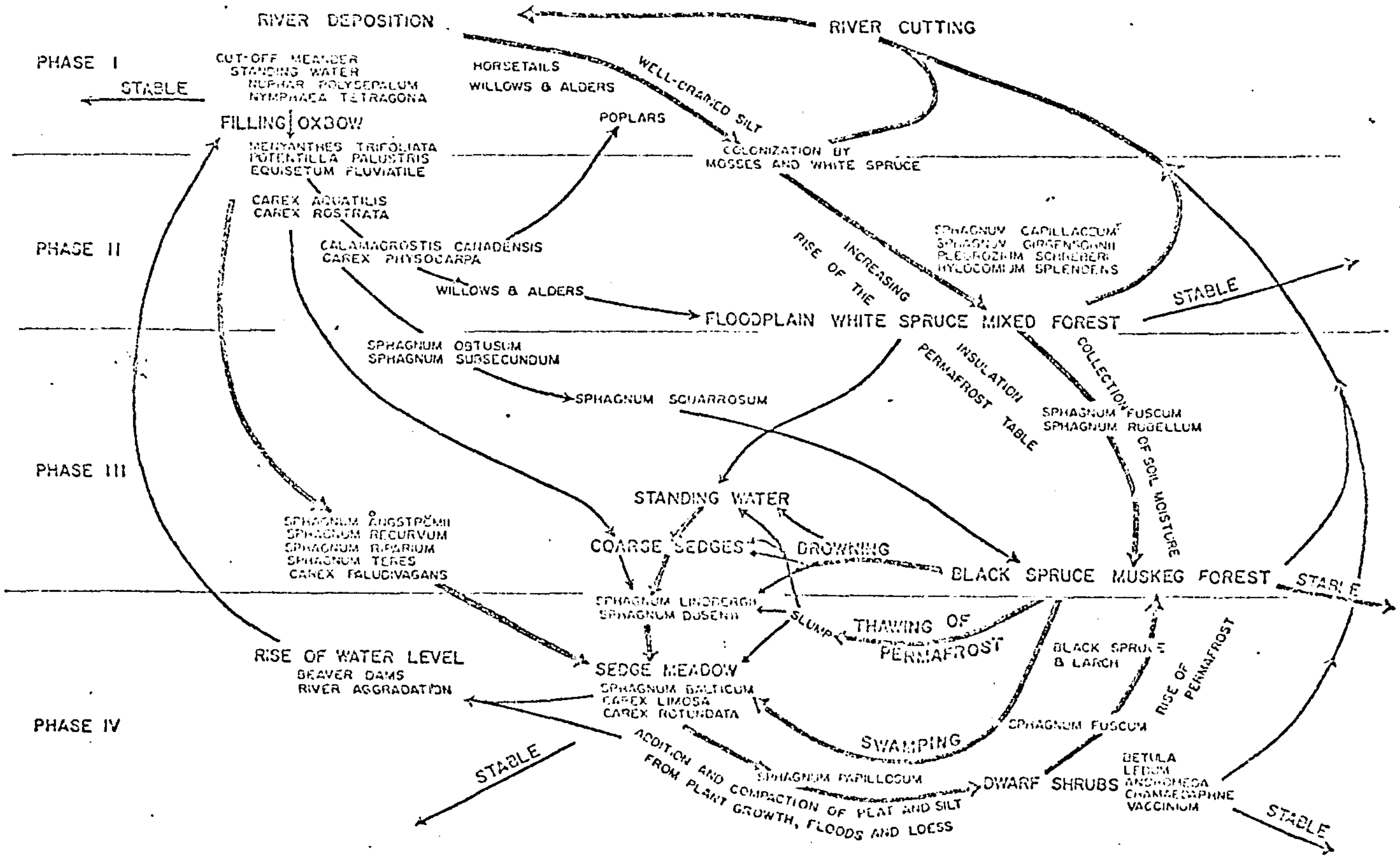


Figure 17: Flow diagram of physiographic processes in the Healy River floodplain. Diagram emphasizes the cyclical tendencies of bog processes and the relationships between processes and vegetation (After Drury, 1956).

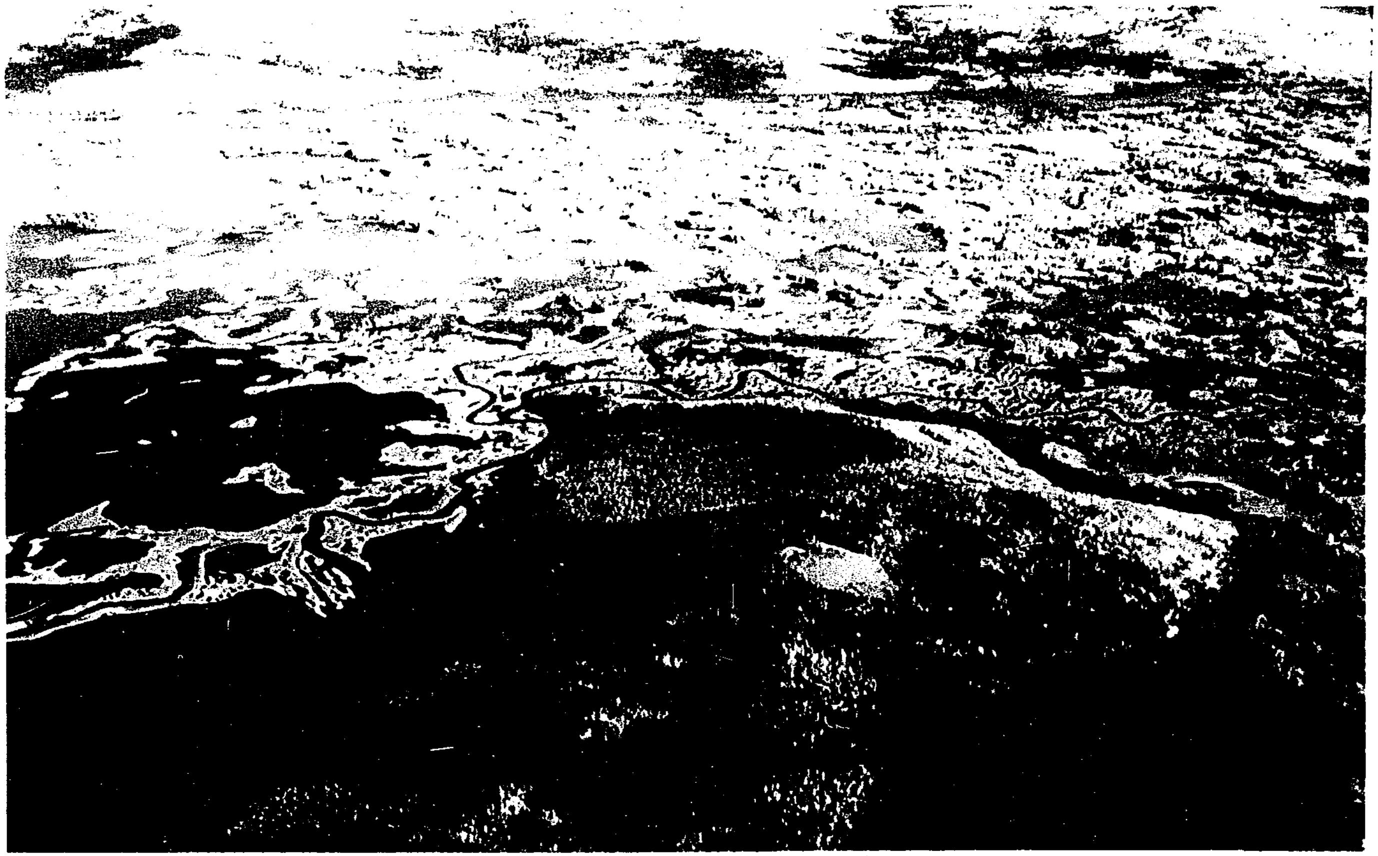


Figure 18: Aerial view of lower Healy River bog flats from the south. Note channels with adjacent forested natural levees, thaw lakes, and islands. Bedrock ridge in foreground displays typical mosaic vegetation pattern of spruce, white birch, and aspen dominant.

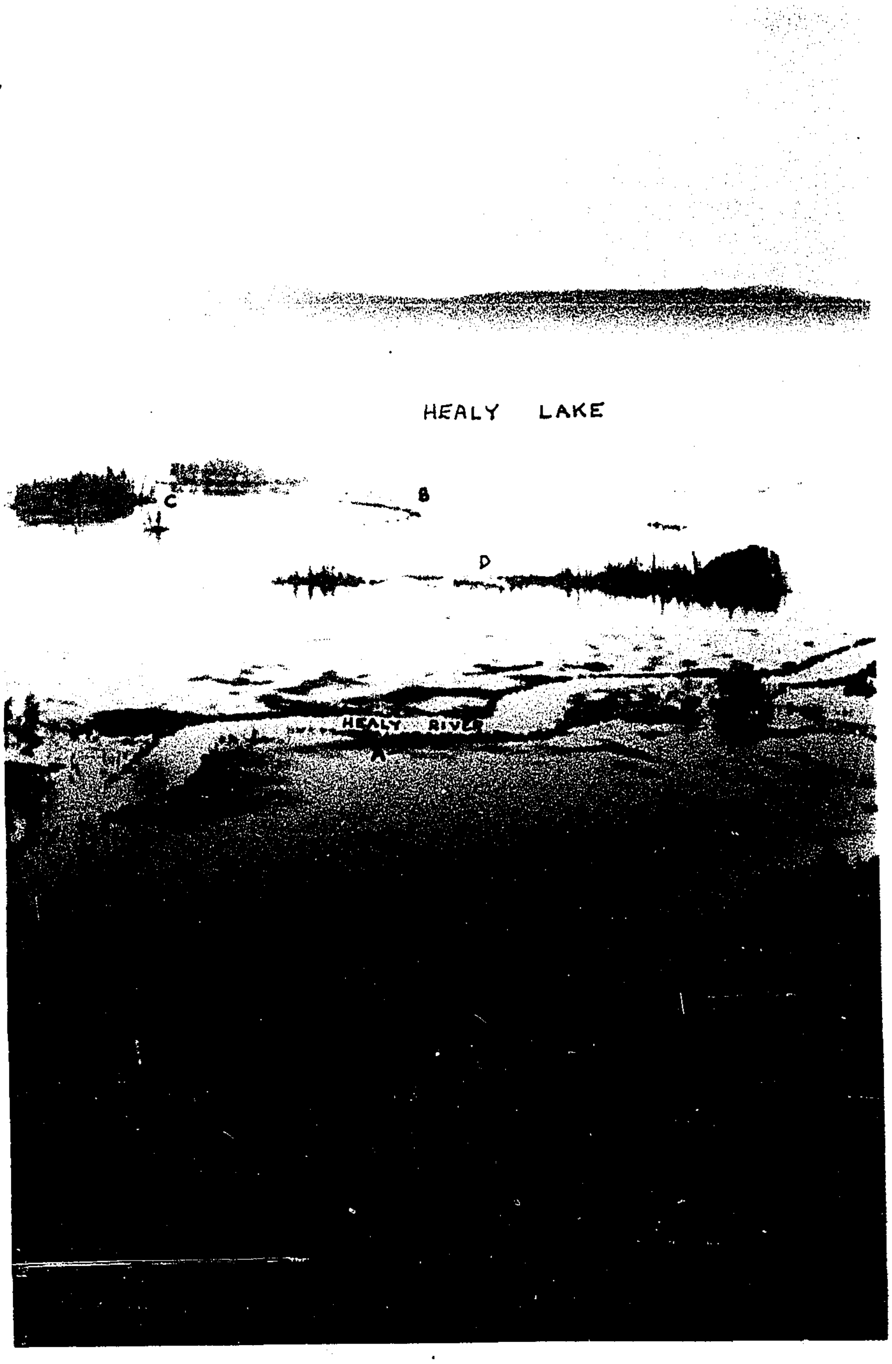


Figure 19: Aerial view, lower Healy River bog flats east of Healy Lake during high water stage. Note emergent natural levees (A, B), inundated bogs surrounding levees, islands with tilting trees along thawing banks (C), tree stumps and trunks partially submerged adjacent to linear island undergoing subsidence from thawing of underlying frozen peat and silt (D).

The present sluggish channels of the lower Healy River are not actively removing fan and apron deposits along the valley flanks, but rather are deflected by them.

Auriferous fluvial gravels of probable pre-Delta age underlie thick muck deposits in at least one stream within the Healy River drainage system. Canyon Creek, which drains into the north end of Healy Lake, was the site of a brief gold stampede around 1911 or 1912. Discovery of gold-bearing gravels in its headwaters attracted an estimated 200 miners to the area. A number of vertical mineshafts were dug into the valley floors of Canyon Creek and the adjacent Ruby Creek which drains into the Volkmar River. Although some shafts penetrated 70 feet of frozen muck and sand, none reached auriferous gravels or bedrock. The depths of their mineshafts provide a minimum estimate for the thickness of valley fill in Canyon Creek.

Lacustrine and Related Deposits

Unconsolidated deposits associated with Healy Lake include bottom sediments, ancient and modern beach deposits, deltaic sediments, and ice-push ramparts.

Lake sediments were observed in offshore coring and near shore during low water stages. Coring near Ashes Point (Test Pit 67, Appendix I) penetrated about 4.5 feet of dark brown silt and clay containing wood fragments and spruce needles. In that locality the silt is underlain by well-rounded gravel of probable fluvial origin. The pebble lithology from the core sample (Table 6) suggests that the gravel was transported into the lake basin by an ancient slough of the Tanana River, since there are no known sources of basalt, chert, and chert-sandstone within the drainage basin. These lithologies are commonly found in gravels flanking the Alaska Range near the Johnson and Gerstle Rivers, however (Holmes, 1965, p. 13). The quartz-mica schist pebbles recovered from the core consist of much finer grained minerals

Table 6: Pebble Types from Ashes Point Offshore Coring

Rock Type	Number of Pebbles	Percent Sample
Quartz	34	54%
Quartz-mica schist	24	38%
Miscellaneous	5	8%
Basalt	1	
Chert	2	
Diorite	1	
Chert-quartz sandstone	1	
Total	63	100%

than observed in the quartz-mica schist outcrops in the lake area.

Several shallow cores from the south end of Healy Lake and Hidden Lake consisted of rather uniform fine black organic muck (J. Anderson, pers. com., 1971). The bottom silts in the southern half of the lake have the approximate texture of the loess which blankets the hillsides in the area. The lacustrine sediments are dark brown to black and often contain plant fragments. Submerged mats of peat, logs, and tree stumps were observed under several feet of water in many localities near thawing banks of bog deposits. The lake bottom sediments from the northern half of the lake are finer, light gray silt and clay with low organic content.

At least the upper several feet of lake bottom sediments are thought to be derived from (1) loess transported from adjacent hillsides by gullies and sheetwash, (2) direct loess deposition on the lake surface, (3) collapse and subsidence of bog deposits thawed by contact with lake waters, and (4) widespread deposition of fine silt and clay by sediment-laden Tanana River waters during periods of reversed flow in the Healy Lake outlet channel.

The sediments in the numerous thermokarst lakes which dot the Healy River floodplain consist of mixed silt, peat, and finely divided organic material. Recolonization of the ponds results in a thick mat of bog vegetation including mosses, sedges, and brush, with an occasional stunted spruce. Mixing is accomplished by thawing and slumping of perennially frozen bog deposits along the shores of the ponds, and reworking of bog and pond sediments by meandering channels of the Healy River.

Beach sediments along the present shores of Healy and Hidden lakes are quite variable in texture and lithology. During periods of high lake levels, wave action erodes outcrops of quartz-mica schist and granodiorite along portions of the lake shore.

In these localities large slabs of bedrock and finer detritus derived from the outcrops form the beaches. Elsewhere, where waves erode banks of thawing silt and peat, beaches usually consist of muck or they are absent entirely. Silt and sand exposed during lower lake levels form beaches and flats along much of the lake margin. In early and late summer in particular, extensive areas of deltaic silt are exposed along the northern and western borders of the lake.

The sands subjected to wave action along the shore display good sorting (Appendix III), and thus would be classified as mature beach sediments. They lack compositional maturity, however, in that they contain abundant feldspar and mica. By contrast, sand collected from late Pleistocene beach deposits about 15 feet above the present lake level are almost pure quartz and display a higher degree of roundness and sphericity than "modern" sand. This probably can be explained by the likelihood of longer transport of these late Pleistocene sands, perhaps from the glaciated headwaters of Healy River, followed by more vigorous and/or prolonged wave action reaching the Donnelly-age Healy Lake.

Healy Lake today receives little sand sized sediment from either Healy River or the Tanana. Sand found along the shore is largely derived locally from schist and granodiorite outcrops subjected to occasional wave action. The relatively short period of high water in mid-summer limits this time during which sand and gravel are subjected to severe abrasion and mechanical breakdown. The immaturity of the sand suggests that high water beaches have not been subjected to wave action for a great period of time, since short episodes of wave action over many thousands of years eventually would produce a mature sand.

The deltaic sediments along the west side of the northern two-thirds of the lake are light gray fine silt and clay derived from the silt-laden waters of the Tanana River which periodically enter the lake basin. The influx of silty Tanana River water shows up dramatically in air photos as it mixes with the clearer lake water. Deposition is fairly rapid in the north end of the lake, which an extensive distributary has almost filled. Residents have observed significant silt deposition along the northeastern shore during the past two decades (P. Kirsteatter, pers. comm., 1969).

Plant colonization on the open silt flats of the delta's active distributary is largely restricted to levees where Equisetum, willows, and other low colonizers have taken root. Aquatic and semi-aquatic plants invade the silt flats during periods of high water but are exposed to dessication and cold temperatures the remaining part of the year. The general absence of plant cover has prevented the formation of permafrost in the deltaic deposits.

The gradual expansion of deltaic silts into the lake basin has widened the dam of sediments separating the present lake from the Tanana River. Traces of abandoned sloughs and distributaries in the deltaic deposits suggest a history of repeated entry of silty Tanana River water into the lake. The abandoned distributary in the central portion of the deltaic deposits (Fig. 7) may have formed initially as a meandering slough of the Tanana River. On the basis of altitudes interpolated from the Tanana River longitudinal profile (Plate 4), it appears that the abandoned delta channel falls about 5 to 7 feet per mile towards the lake, making it unlikely that this channel ever served as an outlet channel for the lake waters. The present outlet channel at the north end of the dam separating lake from the Tanana flows at a very gentle gradient towards the Tanana River, since the altitudes of the lake level and the river are almost identical at the point of confluence with the outlet channel from the lake.

Ice-push ramparts around Lake George, Moosehead Lake, and Twelvemile Lake tend to be concentrated on their northwest shores (Holmes and Foster, 1968). The arcuate ramparts are usually composed of gravel and sand, but sometimes form in muck. Floating pans of winter lake ice are driven ashore by wind action during spring, often pushing up ridges of sediments. An arcuate shoreline feature on the northwest shore of Hidden Lake is about 0.7 miles in length and consists of organic-rich silt. It probably has an origin similar to ramparts recognized elsewhere in the region. Its orientation, consistent with that of ramparts on the other lakes, reflects the influence of southeasterly spring winds.

Holocene Lake Formation

Healy Lake, as it exists today, probably was formed during late Holocene time. Supporting evidence includes geomorphic features, botanic data, sediment distribution and character, and archeological remains.

A number of features suggest that the lake covers an area that was once an extension of the present bog flats of the lower Healy River floodplain east of Healy Lake. The lake's shallow bed is incised by a number of meandering channels, some connected with active and inactive channels of the Healy River (Figure 20). The eastern section of the lake bed is quite irregular because of numerous shallow depressions and low discontinuous ridges. These features may represent submerged thaw lakes and remnants of natural levees.

Islands within the lake increase in size and number eastward toward the bogs of the Healy River floodplain. They tend to be linear in form and clustered along the submerged channels in the lake. The islands are underlain by silt and peat deposits similar to those of the natural levees and bogs of the lower Healy River floodplain east of the lake. Observations by local inhabitants indicate that a number of islands have disappeared within the past several decades due to gradual subsidence and collapse along their shores (P. Kirsteatter, pers. comm., 1969). This results from thawing of perennially frozen peat and silt underlying the islands (Figure 22). On at least two islands thaw lakes have formed similar to those observed in the Healy River floodplain. In his study of thaw lake development in the upper Tanana Valley, Wallace (1948) measured rates of shoreline retreat resulting from thaw and collapse that varied from about 2 to 7 inches per year. This general rate of retreat may apply also to the banks of thaw lakes and islands

Figure 20: Aerial view of northern half of Healy Lake. Note locations of the Village Site, channels in lake bottom (C), islands, and the active distributary of the delta (D).

Figure 21: Aerial view of lower Healy River bog flats east of Healy Lake. Upper half of photograph shows lower and middle slopes of bedrock ridge north of flats. Note thaw lakes, partially recolonized (TL) and completely recolonized by vegetation (R), forested natural levees surrounded by bogs (F), abandoned channel (A), lacustrine terrace (T) with ancient meander scar (M), and part of alluvial fan (A′).

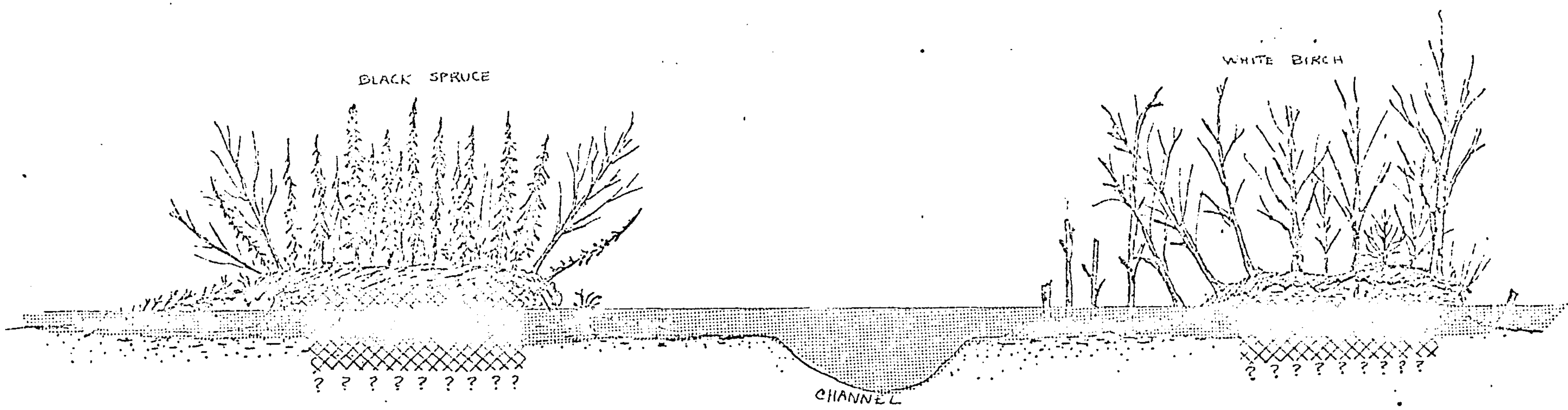


Figure 22: Cross section of thawing islands in Healy Lake. Permafrost indicated by cross hatching; lake waters by stippling. Note submerged vegetal mat and tree stumps and gradually tilting trees along banks.

in the Healy Lake area.

Numerous tree stumps and trunks are present in shallow water near the islands, and often extend hundreds of feet beyond their shores. Trees near the islands' shores are often tilted outward toward the lake as the underlying sediments and peat collapse as they thaw, undermining the roots and organic mat (Fig. 22). The tree tops are sometimes bent upward, indicating growth adjustment to the gradual tilt of the trunks, and suggesting that the shoreline retreat occurs over a period of years rather than suddenly. Large spruce trees near the shore, however, are subject to sudden blowdown when their root systems are undermined by thaw and collapse.

The islands appear to be undergoing subsidence and collapse; those which have been exposed to lake waters for the longest period of time tend to be the smallest islands. Some are completely submerged, leaving only standing tree trunks to indicate their locations.

The islands clustered along the lake channels, the submerged depressions and ridges, the tree trunks standing in water, and the character of the deposits underlying the islands suggest that they are remnant bog features. The submerged channels were probably once part of the Healy River, the islands are remnants of forested levees formed adjacent to the channels, and the depressions and low ridges in the lake bottom may be submerged thaw lakes and levees.

The archeological site at Ashes Point (Fig. 8) is submerged to a depth of several feet, except during periods of exceptionally low lake level. Artifact typology and the presence of copper in the archeological assemblage suggest that the site was occupied in late prehistoric time, perhaps within the past 600 to 800 years (J. Cook, pers. comm., 1971). This suggests that the lake level has risen at least several feet since that time. Since the lake is quite shallow, a drop of several feet considerably diminishes the area covered by its waters. This suggests that much of the lake has formed since the occupation of the Ashes Point Site, and that the remaining portions of the lake, if any, which may have existed prior to the site occupation could have formed within the preceding thousand or two thousand years.

The latest episode of lake formation which produced present day Healy Lake seems to be related to renewed aggradation of the Tanana River floodplain. Only slight aggradation or incision would be necessary to flood or drain the lake basin, since the altitude of the Tanana River at its confluence with the Healy Lake outlet channel is almost the same as the altitude of the lake (Plate 4). As the Tanana floodplain aggraded it created a dam of alluvial gravel, sand, and silt across the mouth of the Healy River. The ponded waters rose behind the dam, inundating gradually the bog flats that covered the present lake area. Eventually an outlet channel formed, breaching the dam and permitting outflow from the lake to the Tanana River. Continued aggradation probably accounts for the phenomenon of periodic reversal of flow through the outlet channel into the lake. During periods of high discharge, the silt-laden Tanana waters flood into the lake, depositing their sediment load to create expanding delta distributaries along the western margins of the lake. Péwé (1965b) correlates periods of floodplain aggradation with glaciations and incision of floodplain deposits with interglacials or interstadials, at least as applies to the Tanana Valley. Since the formation of Healy Lake as it is today seems to have occurred within the past several thousand years, Neoglaciation may be related to the formation of the lake. The onset of Neoglaciation about 3500 years ago may have resulted in renewed aggradation of the Tanana River floodplain, causing damming of the lake basin. Since the Neoglacial glaciers are smaller than those of the Late Pleistocene the present episode of aggradation of the Tanana is probably of much more limited extent than during the major glaciations, but nevertheless sufficient to block the Healy River drainage.

Tectonic Considerations

Episodes of aggradation of the Tanana River floodplain during the late Pleistocene would suggest that a terrace sequence of that age should be present in the vicinity of Healy Lake. Delta and Donnelly age terraces have been recognized in the middle Tanana Valley near Harding Lake and Birch Lake (Blackwell, 1965), and in the upper Tanana Valley near Bitters Creek (Fernald, 1965a). Late Pleistocene terraces are absent in the Tanana Valley between Twelvemile Lake south of Healy Lake, and the Delta River area farther down valley.

Glacial deposits older than Delta age also are absent in the Healy Lake region and Delta River area, although they are found commonly elsewhere in Alaska (Péwé et al., 1965). The absence of these terrace and glacial deposits suggests that tectonics may have played an important role in this section of the valley, at least. Subsidence of the Tanana Valley floor may be the cause for the absence of terraces which, if they formed at all, may have been buried under accumulating Holocene sediments.

Published geophysical data for the area is restricted to an aeromagnetic survey which covers part of the Healy Lake region (Brosgé et al., 1970) and plotted earthquake epicenters by the Geophysical Institute, University of Alaska (Berg, 1970).

Aeromagnetic contour maps suggest a large area of thick sediment accumulation in the Tanana Valley near the Delta River. Continued tectonic adjustment is reflected not only by the thick valley fill, but also by fault traces which cut across late Pleistocene glacial deposits north of Donnelly Dome near the Delta River (Péwé and Holmes, 1964), and near Jack Warren Road north of Delta Junction (F. Weber, pers. comm., 1971). A number of earthquake epicenters are concentrated in the area of Donnelly Dome with a scattering of other low energy quakes occurring occasionally along the northern border of the Tanana Valley. Three earthquakes of magnitudes of 2 to 2.9 on the Richter Scale occurred in the Healy Lake area between April and October, 1969 (Berg, 1970).

Although the evidence is scant, it suggests that active subsidence is taking place in the Tanana Valley between the Delta River area and Healy Lake, and that faulting has occurred since the Donnelly Glaciation in the valley (Péwé and Holmes, 1964).

Quaternary History of the Healy Lake Area: Summary

The drainage basin of the Healy River probably evolved to about its present configuration during Pliocene and early Pleistocene time. Auriferous gravels, known to exist in at least one tributary of the Healy River, are overlain by thick deposits of muck and sand which probably accumulated largely during the late Pleistocene and Holocene. The gravels may be comparable in age to the gold-bearing gravels of the Fairbanks area which Péwé (1965b) considers to be early to mid-Pleistocene. Weathering of schist and granitic bedrock prior to the late Pleistocene produced a mantle of residuum on the ridges of the area. The residual layer was modified during the late Pleistocene by the addition of frost-shattered rubble, by colluvial mixing and downhill transport, and by ventifacting of resistant vein quartz fragments.

The earliest recognized evidences of glaciation in the region are till of Delta age south of the Tanana River and drift northeast of Healy Lake in the Mount Harper area of the Yukon-Tanana Upland. During the Delta Glaciation, the severe climate and glacial activity were reflected in the Healy Lake area by intensive wind action and widespread fluvial deposition. Forest vegetation probably was scarce or absent, and tundra-grassland species predominated. The floodplains of the Tanana and Healy Rivers were aggraded due to the influx of coarse detritus from their glaciated head-waters. During Delta time, the Healy River either flowed directly into the Tanana or into a Delta age lake, evidence for which may have been buried by continued subsidence and sedimentation. If a lake did exist at that time, its shores probably stood at or below present lake level. Eolian sand and silt were deposited in the area during the Delta Glaciation. These sediments subsequently were modified by soli-fluction on the slopes of bedrock ridges.

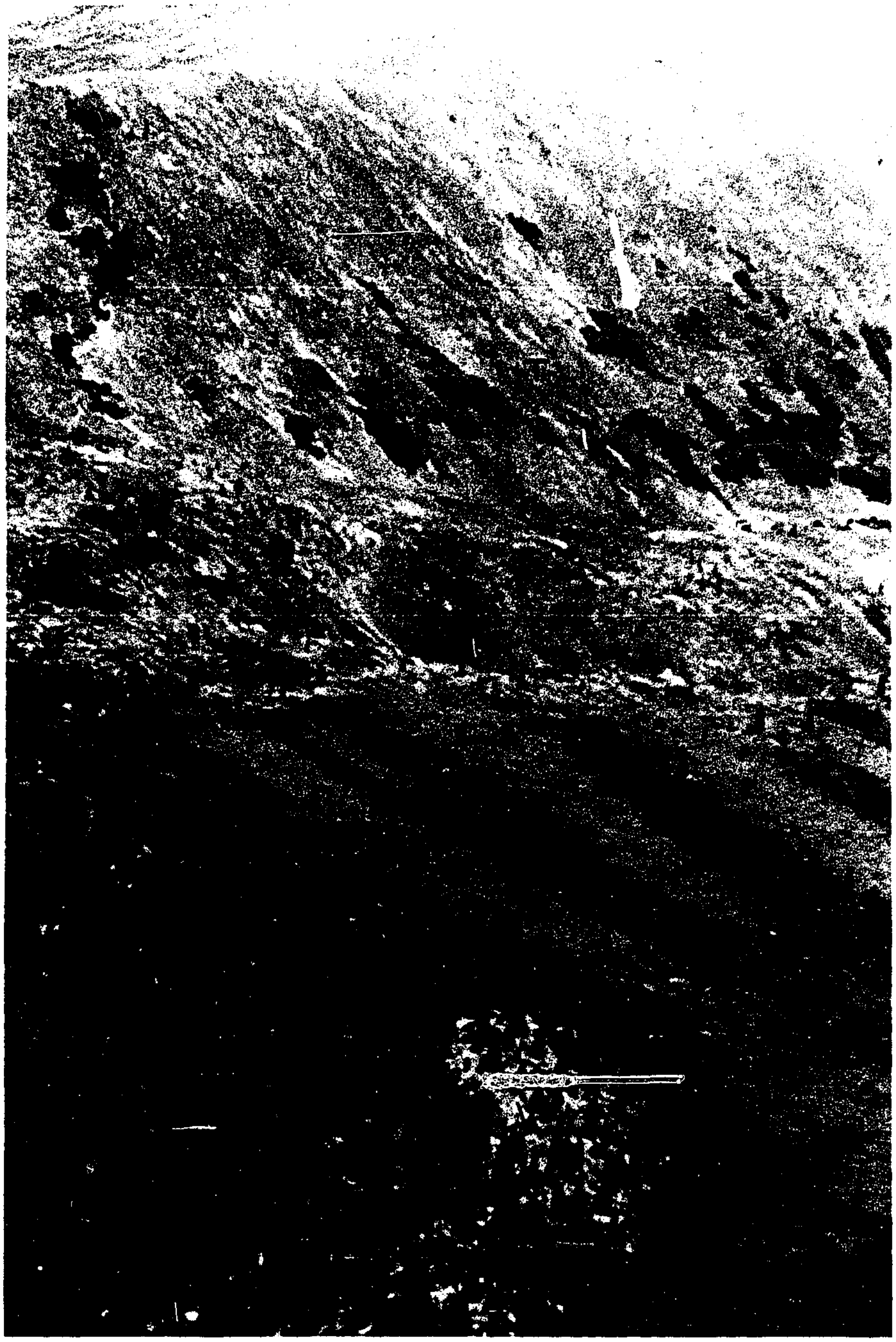


Figure 23: Aerial view of moraine remnants, upper Healy River Valley. Note Delta age terminal moraine (T.M.) and probable lateral moraine (L.M.), talus slopes (T), and upvalley limit of forest vegetation marked by terminal moraine.

Figure 24: Aerial view of terminal moraine remnants, upper Healy River Valley. Note Donnelly age moraines (M), talus slopes, and brush vegetation adjacent to stream.

The Delta Glaciation was followed by a warm episode which corresponds either to a mid-Wisconsin interstadial or to the Sangamon Interglacial. Glaciers in the upper Healy River Valley probably disappeared at this time, and stream downcutting probably occurred in the floodplains of the Tanana and lower Healy Rivers. Forest vegetation probably became more extensive, and erosion of thawing eolian deposits occurred on hillsides.

The advance of Donnelly age glaciers began about 25,000 years ago. Although glaciers reformed or expanded in many localities previously occupied by glacial ice during Delta time, the Donnelly Glaciation was less extensive than the preceding advance. Glaciers developed again in the Healy River headwaters, transforming the river to a glacial stream with much increased sediment load. Aggradation again accompanied the advance of glaciers in the Alaska Range and the Yukon-Tanana Upland. The Tanana and Healy River floodplains evidently did not aggrade at the same rate, however. The Tanana aggraded faster, damming the Healy River near its mouth. A lake formed where present day Healy Lake now lies, but the Donnelly age lake was a larger and deeper water body. The lake stood at least 15 feet above the present lake level, and perhaps rose an additional 5 to 10 feet for a brief time. It extended about 5 miles up the Healy River beyond the present east shore of Healy Lake. Its upvalley margin probably coincided roughly with the limit of lacustrine terraces along the north side of the Healy River (Plate 2). Glaciofluvial sediments, mostly sand and silt, entered the lake from the Healy River near the upstream terrace limit, probably forming a delta which has since been removed by erosion or buried. Severe katabatic winds from the Alaska Range blew northward across the lake area, resulting in concentration of wave energy against its north shore. Extensive beaches of glaciofluvial sand reworked by wave action were developed here. Wind transported some of the sand northward from the beaches to form sand sheets and dunes on the lower and middle slopes of the adjacent ridges. Finer eolian sediments were deposited as loess extensively over the upland near the lake. Loess deposits are most extensive on south-facing slopes, reflecting transport by southerly winds from source areas along the Tanana floodplain. Although middle and lower slopes became mantled with eolian sediments, accumulations of frost-shattered rock rubble predominated on most ridgecrests and some windswept upper slopes.

Later in the Donnelly Glaciation, probably during its waning stages, the lake level dropped or the lake drained completely. This probably resulted either from downcutting or lateral erosion of the Tanana River into the lake basin. Tectonics may have played a role in the lake drainage as it probably did at Harding Lake (Blackwell, 1965). Eolian sediments deposited during the waning of the Donnelly Glaciation tend to be finer grained than those deposited during the high lake stage. This reflects the probable change toward a finer and perhaps reduced sediment load carried by the Healy River, and decreasing wave activity as the lake level dropped. Downcutting along the lower course of the Healy River caused erosion and redeposition of former floodplain and lacustrine deposits. The meandering Healy River removed by lateral erosion much of the beach deposits concentrated on the north side of its floodplain. The discontinuous terrace there today probably is a remnant of the eolian and beach deposits of the Donnelly-age lake.

The warmer Holocene climate which followed the Donnelly Glaciation permitted extensive reworking of Pleistocene sediments. Gully erosion was particularly active in the small tributaries of the Healy River, and gullies also dissected many of the sand dunes which had been deposited during Donnelly time. Although eolian deposition continued during the Holocene, the wind-transported sediments consisted almost entirely of silt and very fine sand. The decrease in grain size reflects increasing distance from source areas, possible decrease in wind activity due to more restricted katabatic winds, and the effects of reforestation. Archeological data (Cook, 1969) and faunal evidence (Guthrie, 1969a, 1968b) suggest that reforestation did not completely supplant grassland-tundra vegetation until perhaps about 8000 years B.P. Bogs began to form during the Holocene after reforestation of the lake area, and permafrost gradually developed in the accumulating peat and silt deposits of the lower Healy River floodplain. Eventually, anastomosing bogs interlaced with river channels, forested natural levees, and thaw lakes covered all or most of the lower floodplain, including the area now occupied by Healy Lake.

Slight cooling of the climate marked the onset of Neoglaciation about 3500 years B.P. Alpine glaciers expanded and advanced in the Alaska Range, but not in the Yukon-Tanana Upland. Cooler temperatures may have slightly reduced the elevation of timberline, but vegetation in general probably was not affected. Neoglaciation has continued, with oscillations, to the present. The periods of glacial activity may have contributed to a relatively minor episode of aggradation of the Tanana River floodplain. This aggradation was sufficient, however, to dam the Healy River near its mouth, eventually flooding about 6 square miles of bog flats to produce present day Healy Lake. Inundated bog features such as channels, partially submerged forested levees, and flooded forest vegetation attest to the rising lake waters. Contact of lake waters with ice-rich bog sediments has caused thaw, subsidence, and collapse of banks. This results in continual expansion of the lake along the shores of the bogs. The present altitude of the lake surface nearly coincides with that of the Tanana River at its confluence with the Healy Lake outlet channel. As a consequence, the Tanana River overflows into the lake periodically when discharge is high. This raises the lake level temporarily and results in extensive deposition of Tanana River silt in the lake. Repeated influxes of Tanana silt have built an extensive barrier of deltaic deposits between the lake and the Tanana River. The expanding deltas have advanced across several square miles of the lake's western portion, changing its shape considerably since the initial flooding of the lower valley during the Holocene.

APPENDIX I

Test Pit Profiles from the Healy Lake Area, Alaska

Unit	Thickness (inches)	Lithology
Test Pit 1: Altitude 1355 feet; Ridgecrest, west of Healy Lake		
A	3	Organic mat (Forest litter, root network, and decomposed plant remains)
B	9	Fine silty loess; upper 3 inches oxidized to reddish-brown color
C	?	Quartz-mica schist bedrock
Test Pit 2: Altitude 1320 feet; Top of slump block on bedrock ridge west of Healy Lake		
A	6	Organic mat
B	6	Silty loess; upper 4 inches oxidized
C	12	Sandy loess containing fragments of quartz
D	3	Layer of vein quartz fragments; stones up to 4 inches in maximum dimension; ventifacted
E	12+	Weathered layer of quartz-mica schist fragments with highly micaceous matrix
Test Pit 3: Altitude 1225 feet; Lower slope of ridge northwest of Village Site		
A	4	Organic mat
B	74	Silty to sandy loess, poorly stratified, probably colluvial
C	10+	Eolian sand in fine and medium grained lenses and laminae (e.g. Sample A-24, Appendix III)
Test Pit 4: Altitude 1215 feet; Gully in eolian sediments near Test Pit 3		
A	4	Organic mat
B	18 +	Colluvial loess, frozen at 18 inches depth in mid-July
Test Pit 5: Altitude 1290 feet; Lower slope, bedrock ridge north of Healy Lake in Volkmar River drainage		
A	5	Organic mat
B	10	Silty loess grading to sandy loess, probably colluvial
C	4 +	Weathered schist fragments

Unit	Thickness (inches)	Lithology
Test Pit 6: Altitude 1160 feet; Lower slope of saddle northwest of Kidney Hill		
A	2	Organic mat
B	34	Buff sandy loess grading downward to medium sand
C	48 +	Fine eolian sand grading downward to medium sand (Sample A-4 from 36 inches depth; A-6 from 48 inches; A-5 from 60 inches; A-7 from 84 inches)
Test Pit 7: Altitude 1175 feet; near Test Pit 6		
A	3	Organic mat
B	33	Sandy loess, upper 4 inches oxidized
C	12	Eolian silty sand, probably colluvial
D	60 +	Interlayered fine to medium eolian sand, (Sample A-58 from 84 inches depth; A-64 from 108 inches)
Test Pit 8: Altitude 1200 feet; Saddle northwest of Kidney Hill		
A	2	Organic mat
B	46	Buff sandy loess, upper 3 inches oxidized
C	36	Silty eolian sand and silt layers, poorly stratified, probably colluvial
D	6 +	Medium eolian sand (Sample A-61)
Test Pit 9: Altitude 1210 feet; Near Test Pit 8		
A	3	Organic mat
B	7	Silty loess, upper 3 inches oxidized
C	38	Sandy loess
D	36 +	Fine eolian sand grading with depth to medium sand (Sample A-59 from 60 inches depth); lower 20 inches interlayered with lenses of sand and sandy silt.
Test Pit 10: Altitude 1215 feet; Near Test Pit 8		
A	3	Organic mat
B	13	Silty loess, upper 4 inches oxidized; thin clay layers at depths of 9 and 11 inches below surface
C	12	Colluvial sandy loess, admixed with rocks up to 6 inches in length; size of stones tends to decrease with depth
D	6 +	Coarse weathered schist fragments and residuum overlying schist bedrock

Unit	Thickness (inches)	Lithology

Test Pit 11: Altitude 1160 feet; Lower slope of saddle, north of Kidney Hill

Unit	Thickness (inches)	Lithology
A	2	Organic mat
B	4	Silty loess, oxidized
C	8	Sandy loess with admixed small stones, probably colluvial
D	8 +	Coarse weathered schisty colluvium including schist slabs up to 9" in length

Test Pit 12: Altitude 1320 feet; west end of Volkmar saddle, north of Healy Lake

Unit	Thickness (inches)	Lithology
A	2	Organic mat
B	15	Silty loess, upper 4 inches oxidized; grades downward to sandier buff loess
C	4+	Coarse shisty colluvium overlying highly weathered quartz-mica schist bedrock

Test Pit 13: Altitude 1275 feet; Near Test Pit 12: See Figure 9

Test Pit 14: Altitude 1250 feet; Center of Volkmar Saddle north of Healy Lake

Unit	Thickness (inches)	Lithology
A	4	Organic mat
B	14	Buff silty loess, upper 3 inches oxidized
C	2	Dark gray-brown loess overlying thin highly convoluted clay layer
D	156 (13 ft)	Compact yellowish brown loess, poorly stratified with thin clay skins, organic and oxide stains; admixed pebble size fragments of quartz and schist; probably largely colluvial
E	24	Gray silt, probably eolian
F	6	Silty sand, probably eolian
G	24	Brown clayey silt
H	36+	Blue-gray silt, gleyed; possibly of eolian origin

Test Pit 15: Altitude 1270 feet; Eastern Volkmar Saddle, north of Healy Lake

Unit	Thickness (inches)	Lithology
A	3	Organic mat
B	96 (8 ft)	Loess, poorly stratified; thin clay skins and oxide stain layers
C	24	Volcanic ash, white, fine-grained glassy
D	18+	Loess

Test Pit 16: Altitude 1290 feet; Near Test Pit 15

Unit	Thickness (inches)	Lithology
A	2	Organic mat
B	24	Loess, probably colluvial
C	24	Colluvial volcanic ash and layers of loess with thin layers of oxide stains and clay skins; admixed fragments of quartz and schist, some ventifacted

Test Pit 17: Altitude 1330 feet; Near Test Pit 15

Unit	Thickness (inches)	Lithology
A	2	Organic mat
B	9	Silty loess, upper 5 inches oxidized
C	3 +	Colluvium of schist rock fragments and micaceous residuum overlain by a concentration of ventifacted vein quartz fragments

Test Pit 18: Altitude 1210 feet; North of crest of Volkmar Saddle

Unit	Thickness (inches)	Lithology
A	4	Organic mat
B	56 +	Loess, poorly stratified, with admixed organic fragments, probably colluvial; frozen at a depth of 55 inches in late July

Test Pit 19: Altitude 1233; Island, north end of Healy Lake

Unit	Thickness (inches)	Lithology
A	6	Woody peat layer
B	21	Fine very light gray alluvial silt containing wood, peat, and bark fragments
C	75+	Blue-gray frozen silt; gleyed; numerous ice lenses up to 1 inch thick under layer of loose thawed silt

Test Pit 20: Altitude 1420 feet; North-facing middle slope of bedrock ridge of Village Site.

Unit	Thickness (inches)	Lithology
A	7	Moss and peat layer
B	11+	Gray silt, somewhat gleyed; frozen at 18 inches depth in late July

Test Pit 21: Altitude 1325 feet; Crest of bedrock ridge of Village Site

Unit	Thickness (inches)	Lithology
A	3	Organic mat
B	6	Silty loess, upper 4 inches oxidized, grading to buff loess
C	2+	Angular grandiorite bedrock fragments

Unit	Thickness (inches)	Lithology
Test Pits 22, 23, 24: Altitudes 1455, 1475, 1525; Near Test Pit 21		
A	2-3	Organic mat
B	6-15	Silty loess, upper 4-6 inches oxidized
C	2-3+	Colluvium of weathered quartz-mica schist and quartz fragments
Test Pit 25: Altitude 1560 feet; Near Test Pit 21		
A	2	Organic mat
B	10	Buff silty loess, upper 4 inches oxidized
C	6+	Schist slabs tilted in many orientations, slabs about 10 x 6 x 2 inches in size; interstices partially filled with poorly sorted sand, some coarse grained
Test Pit 26: Altitude 1575 feet; Near Test Pit 21		
A	2	Organic mat
B	4	Silty loess, oxidized
C	5+	Schist slabs up to 8 inches in maximum dimension in matrix of weathered schisty colluvium and residual
Test Pit 27: Altitude 1580 feet; Near Test Pit 21		
A	2	Organic mat
B	7	Buff silty loess, upper 5 inches oxidized
C	3+	Schist slabs and schisty colluvium; one quartz ventifact
Test Pits 28, 29, 30, 31: Altitudes 1625, 1850, 1900, 1880 feet, respectively. Upslope from Test Pit 21, crest of Village Site bedrock ridge		
A	1.5-2	Organic mat
B	2-4	Silty loess, oxidized
C	4-6+	Large schist slabs overlying schist bedrock; slabs tilted at various angles
Test Pit 32: Altitude 1130; Northeastern shore of Healy Lake: See Figure 10		

Unit	Thickness (inches)	Lithology
Test Pit 33: Altitude 1143 feet: Kirsteatter's well, Northeast end of Healy Lake		
A	20	Loess (estimated thickness)
B	36	Eolian sand (estimated thickness)
C	132 (11 ft)	Beach sand, well sorted, well rounded; bedded in layers up to 9 inches thick; coarse to medium grained sands (Sample A-2)
C	6+	Bedrock, granodiorite
Test Pit 34: Altitude 1170 feet; Near Test Pit 33 on lower slope of bedrock ridge		
A	2	Organic mat
B	34	Silty loess grading downward to sandy loess with loess with depth; upper 9 inches of unit oxidized
C	30	Coarse sand and pebbles, probably eolian sand, silt, and admixed colluvial pebbles
D	6+	Colluvial weathered bedrock fragments and grus derived from underlying granodiorite
Test Pit 35: Altitude 1170 feet; Lower slope near Test Pit 32		
A	2	Organic mat
B	34	Loess, grading downward from silty to sandy texture; upper 9 inches oxidized
C	30	Coarse eolian sand and silt layers admixed with colluvial pebbles
D	6+	Colluvial weathered bedrock fragments and grus derived from underlying granodiorite bedrock
Test Pit 36: Altitude 1185 feet; Lower slope near Test Pit 33		
A	4	Organic mat
B	96 (8 ft)	Sandy loess
C	8+	Medium sand, eolian
Test Pit 37: Altitude 1220; Middle slope of ridge, northeast of Test Pit 33		
A	6	Organic mat
B	108 (9 ft)	Silty and sandy loess layers, probably colluvial
C	6+	Medium sand, eolian

Unit	Thickness (inches)	Lithology

Test Pit 38: Altitude 1385 feet; Near Test Pit 37

A	6	Organic mat
B	36	Silty loess
C	48+	Silty eolian sand; frozen patches below 5 feet depth still present in late August, (Mature white spruce-sphagnum vegetal cover)

Test Pit 39: Altitude 1145 feet; Cliff's well, northeast end of Healy Lake

A	20	Loess (estimated thickness)
B	36	Eolian sand (estimated thickness)
C	83 (7 ft)	Beach sand, coarse and medium grained layers of well-sorted, well-rounded quartz sand
D	72	Gleyed silt with clayey texture; perennially frozen
E	84+	Sand (Eolian ?)

Test Pit 40: Altitude 1145; Terrace, northeast end of Healy Lake

A	3	Organic mat
B	46	Buff loess, upper 4 inches oxidized; grades downward from silty to sandy texture
C	12+	Coarse well sorted sand, probably mixed beach and eolian (Sample A-18, depth 56 inches)

Test Pit 41: Altitude 1132 feet; cutbank along north channel of Healy River, east of Healy Lake

A	9	Organic mat
B	12	Alluvial silt and fine sand, poorly stratified (overbank deposits)
C	24	Silty sand
D	7+	Fine silt

Test Pit 42: Altitude 1135: Near Test Pit 41

A	8	Organic mat
B	29	Silt and silty sand layers (overbank deposits)
C	10+	Thin layers and lenses of clay, silt, and fine sand

Test Pit 43: Altitude 1330 feet; Tributary valley north of lower Healy River flood-plain: See Figure 11

Unit	Thickness (inches)	Lithology
Test Pit 44: Altitude 1410 feet; Crest of vegetated sand dune, north of lower Healy River		
A	2	Organic mat
B	8	Silty loess, oxidized; clay band at 10 inches depth
C	24	Buff sandy loess, grading with depth to silty sand; slightly mottled, perhaps due to disturbance by roots; occasional lenses of medium grained eolian sand
D	120+ (10 ft)	Layers of eolian sand varying in texture from fine to medium; thin gleyed silt lens at 5 feet depth; thin dark gray stain (Mn ?) at 3 feet
Test Pit 45: Altitude 1160 feet: Terrace, north side Healy River		
A	2	Organic mat
B	40	Sandy loess
C	42+	Medium sand, occasional pebbles, probably reworked eolian sands (Samples A-25, A-26, A-30, A-140)
Test Pit 46: Altitude 1250: Vegetated sand dune, north side Healy River		
A	2	Organic mat
B	8	Loess, reddish stained, silty texture
C	12+	Medium grained eolian sand
Test Pit 47: Altitude 1175: Terrace, north of Healy River		
A	3	Organic mat
B	24+	Eolian sand and silt, probably colluvial
Test Pit 48: Altitude 1275: Swale between vegetated dunes, north of Healy River		
A	2	Organic mat
B	15	Sandy loess, upper 3 inches oxidized
C	54	Medium to coarse sand with interlayered silt lenses, reworked by slope processes; contains admixed pebbles, some ventifacted; sediments frozen at 68 inches in mid-July
D	1	Black organic-stained gleyed silt, frozen
E	4	Brown clayey silt
F	4+	Coarse sand

Unit	Thickness (inches)	Lithology
Test Pit 49: Altitude 1310 feet: Crest of vegetated sand dune, north of Healy River		
A	2	Organic mat
B	18	Loess; clay band at 15 inches depth
C	168 (14 ft)	Eolian sand, interlayered medium and fine sand in upper several feet; Very coarse sand layer at *seven feet depth (Sample A-74)*
Test Pit 50: Altitude 1350; Lower slope north of dunes, north of Healy River		
A	2	Organic mat
B	28	Sandy loess, probably colluvial, with admixed admixed ventifacted quartz fragments
C	12	Thin layers of silt, fine sand, and medium sand, probably colluvial
D	6+	Eolian sand, mottled yellow-buff, medium grained
Test Pit 51: Altitude 1300: Crest of sand dune north of Healy River		
A	3	Organic mat
B	54	Silty loess grading with depth to sandy loess containing scattered lenses of fine to medium sand
C	18+	Silty loess
Test Pit 52: Altitude 1310: Crest of sand dune adjacent to sediment-mantled bedrock slope, north of Healy River		
A	1	Organic mat
B	12	Silty loess, upper 3 inches oxidized
C	42	Sandy loess with quartz ventifacts and rounded pebbles, probably transported from adjacent ridgeslope; occasional fine sand lenses
D	2	Gleyed silt, frozen in mid-July
E	16+	Eolian sand, fine grained, with occasional pebbles
Test Pit 53: Altitude 1340: Lower slope, uphill from Test Pit 52		
A	1	Organic mat
B	3	Silty loess, oxidized
C	7	Colluvial schist and quartz fragments, up to 6 inches in maximum dimension, some ventifacted
D	?	Quartz-mica schist bedrock

Unit	Thickness (inches)	Lithology
Test Pit 54:	Altitude 1180 feet: Lower south-facing slope, 6 miles east of Healy Lake, north of Healy River	
A	4	Organic mat
B	12	Silty loess, upper 3 inches oxidized
C	2+	Colluvial schist, quartz fragments
Test Pit 55:	Altitude 1310 feet: Upslope from Test Pit 54	
A	2	Organic mat
B	34+	Silty loess with quartz ventifacts, clay skins, and charcoal fragments
Test Pit 56:	Altitude 1340 feet: Upslope from Test Pit 55	
A	2	Organic mat
B	4	Silty loess, oxidized
C	9	Colluvial schist, contains quartz fragments, some ventifacted
D	6+	Schist slabs overlying bedrock
Test Pit 57:	Altitude 1380 feet: Upslope from Test Pit 56	
A	2	Organic mat
B	6	Silty loess contains quartz fragments
C	10	Weathered schist rubble with fragments of ventifacted quartz
D	?	Weathered schist bedrock
Test Pit 58:	Altitude 1430 feet: Upslope from Test Pit 57	
A	2	Organic mat
B	9	Silty loess, oxidized in upper 6 inches; contains ventifacted quartz fragments
C	6+	Colluvium of weathered schist fragments and ventifacted quartz pebbles and cobbles
Test Pit 59:	Altitude 1130 feet: Island, thawing bank exposure, northeast end of Healy Lake	
A	6	Woody peat layer
B	2	Black clayey organic muck
C	46	Gray poorly stratified alluvial silt containing plant fragments
D	6	Buried woody peat, including mosses and birch bark; radiocarbon dated at 515 ± 110 years B.P. (GX-1970)
E	4+	Black organic muck containing plant fragments and inseck parts; radiocarbon dated at 5530 ± 140 years B.P. (GX-1969)

Unit	Thickness	Lithology
Test Pit 60: Altitude 1130 feet: Island, northeast end of Healy Lake		
A	15	Peat layer
B	3+	Fine alluvial gray silt, frozen; silt contains plant fragments and finely divided organic material; minimum estimate of silt thickness about 5 feet based upon observations along thawing banks of island
Test Pit 61: Altitude 1131 feet: Island, northeast end of Healy Lake, SIPRE auger coring (winter, 1971)		
A	8	Forest litter, grass and peat mat
B	52+	Poorly stratified, fine gray, gleyed silt containing organic flecks; solidly frozen at 60 inches, with some thin ice segregation layers
Test Pit 62: Altitude 1133 feet: Island, eastern Healy Lake, SIPRE auger coring (winter, 1971)		
A	30	Peat, mostly sphagnum moss at base of fallen mature black spruce; frozen, compact
B	8+	Gray fine alluvial silt frozen with thin ice segregation layers; some plant fragments
Test Pit 63: Altitude 1130 feet: Island, northeastern Healy Lake, auger hole		
A	14	Peat layer
B	3+	Gray gleyed alluvial silt, frozen in early July; contains some plant fragments
Test Pit 64: Altitude 1170 feet, west of Ashes Point, lower slope of bedrock ridge		
A	3	Organic mat
B	12	Loess, upper 5 inches oxidized
C	6+	Schisty colluvium overlying schist bedrock
Test Pit 65: Altitude 1205 feet, lower slope of bedrock ridge, Ashes Point		
A	2	Organic mat
B	8	Silty loess, upper 4 inches oxidized
C	4+	Concentration of red quartz ventifacts in schisty colluvium, small pebble size schist fragments in clayey micaceous matrix.

Unit	Thickness	Lithology
Test Pit 66:	Altitude 1128 feet, wave cut bank, southwest shore of Healy Lake at Ashes Point	
A	6	Organic mat with oxidized loess layers
B	5	Gray silt (loess ?), fine grained
C	3	Black organic muck-silt layer containing plant fragments
D	6+	Brown-buff silt containing small lenses of sand and pebbles, sand grains well-rounded
Test Pit 67:	Altitude 1125; Ashes Point, offshore coring 150 feet from shore	
	40	Lake water (mid-August)
A	36	Brown-gray silt
B	18	Brown-gray silt containing wood and bark fragmemts; spruce needle concentration at top of unit
C	12+	Pebbles grading to aoarser gravel with depth; well rounded, mostly quartz and fine grained quartz-mica schist, also lithologies from outside Healy River drainage basin (Table 5)
Test Pit 68:	Altitude 1240 feet; Bully bank on lower slope of schist bedrock ridge, southwest end of Healy Lake	
A	5	Organic mat
B	38 +	Colluvial loess, poorly stratified; frozen at depth of 18 inches adjacent to gully
Test Pit 69:	Altitude 1133 feet: Pruhs' well, south end of Healy Lake	
A	2	Organic mat
B	14	Buff silty loess; organic stained layers and lenses 2-3 mm thick in lower 6 inches of unit
C	156 (13 ft)	Interlayered silt, pebbles, and sand; thicknesses of layers 1 to 6 inches; deposit is probably largely colluvial; organic stains and charcoal fragments common in silt layers; many thin oxide layers
D	36	Poorly sorted sand and pebbles
E	36	Blue-gray gleyed silt, dense; organic odor
F	48	Gravel of coarse angular schist and quartz pebbles; poorly sorted, probably colluvial
Test Pit 70:	Altitude 1139 feet; Upslope from Test Pit 69: See Figure 12.	

Unit	Thickness (inches)	Lithology
Test Pit 71: Altitude 1143 feet: Upslope from Test Pit 69		
A	4	Organic mat containing spruce needles and charcoal
B	96+	Colluvial loess containing numerous lenses and layers up to 20 inches thick of poorly sorted micaceous sands and angular pebbles; organic stained silt layers at depths of 12 and 36 inches; charcoal fragments common in silt layers
Test Pit 72: Altitude 1180: Upslope from Test Pit 69		
A	3	Organic mat
B	84+	Colluvial loess, poorly stratified, uniform texture; scattered quartz and schist fragments
Test Pit 73: Altitude 1132 feet: Thawing bank, southwestern shore of Healy Lake*		
A	6	Organic mat
B	12	Buff sandy loess
C	12	Stratified gray silt with thin clay skins and layers of clayey silt up to 1 inch thick, perhaps a shallow pond deposit (thaw lake?)
D	4	Woody peat layer with twigs and birch bark fragments*
E	5	Clayey silt, gray gleyed
F	36+	Gray brown gleyed silt with occasional pebbles; perennially frozen, with ice lenses up to 1 inch in thickness
Test Pit 74: Altitude 1132 feet: Wave eroded bank near Burgess Point, south shore, Healy Lake		
A	5	Organic mat
B	20	Loess, upper 8 inches oxidized, grading downward to sandier buff loess
C	9	Gravelly loess, probably colluvial
D	36+	Weathered schist; Slabs of schist and abundant vein quartz in unconsolidated matrix of micaceous residual derived from schist

* In an adjacent exposure Dr. James Anderson collected peat samples from layers at depths of 45 inches and 81 inches from the surface. Radiocarbon dates are 760 $\pm$ 80 years B.P. for the upper layer (GX-2026) and 1685 $\pm$ 90 years B.P. for the lower (GX-2025). The upper layer is probably comparable to the woody peat layer in Test Pit 73. If the lower peat layer was parsent in TP 73, it was probably under water at the time of inspection due to fluctuating lake levels.

Unit	Thickness (inches)	Lithology

Test Pit 75: Altitude 1131 feet; thawing silt bank exposure southeast shore of Healy Lake: See Figure 13.

Test Pit 76: Altitude 1136 feet: Thawing silt bank exposure, south shore of Hidden Lake

Unit	Thickness (inches)	Lithology
A	8	Organic mat; grades downward into peat
B	12	Buff silt, poorly stratified
C	4	Light tan silt
D	9	Brown silt with finely divided organic material, including fragments of wood and mosses
E	96 + (8 ft)	Gray-brown silt; permafrost table is 15 inches below top of unit; ice lenses up to 2 inches thick; water content of frozen silt samples was 60.7% by weight

VILLAGE SITE TEST PITS

Test Pit V-1: Altitude 1143: See Figure 25

Unit	Thickness (inches)	Lithology
A	5	Organic mat containing historic cultural refuse
B	28	Loess, grading downward in texture from silt to fine eolian sand
C	6	Layer of residual rock fragments derived from breakdown of underlying granodiorite

Test Pit V-2: Altitude 1140 feet

Unit	Thickness (inches)	Lithology
A	5	Organic mat, charcoal, spoil, cultural refuse
B	8	Clayey loess with strong oxidized Subarctic Brown Forest soil profile
--------------------		Buried ground surface
C	11	Silty loess grading to fine sand
D	16	Fine sand, oxidized
--------------------		Stone layer, some ventifacted
E	11	Stony oxidized sand grading downward to grus

Test Pit V-3: Altitude 1158 feet; Lower slope of bedrock ridge adjacent to Village Site

Unit	Thickness (inches)	Lithology
A	5	Organic mat
B	24	Buff loess; upper 4 inches weakly oxidized; clay skin at depth of 18 inches
C	12+	Grus, probably colluvial; coarse sand lense at 33 inches depth; sand probably wind blown from adjacent beach during Donnelly Glaciation (Sample A-12)

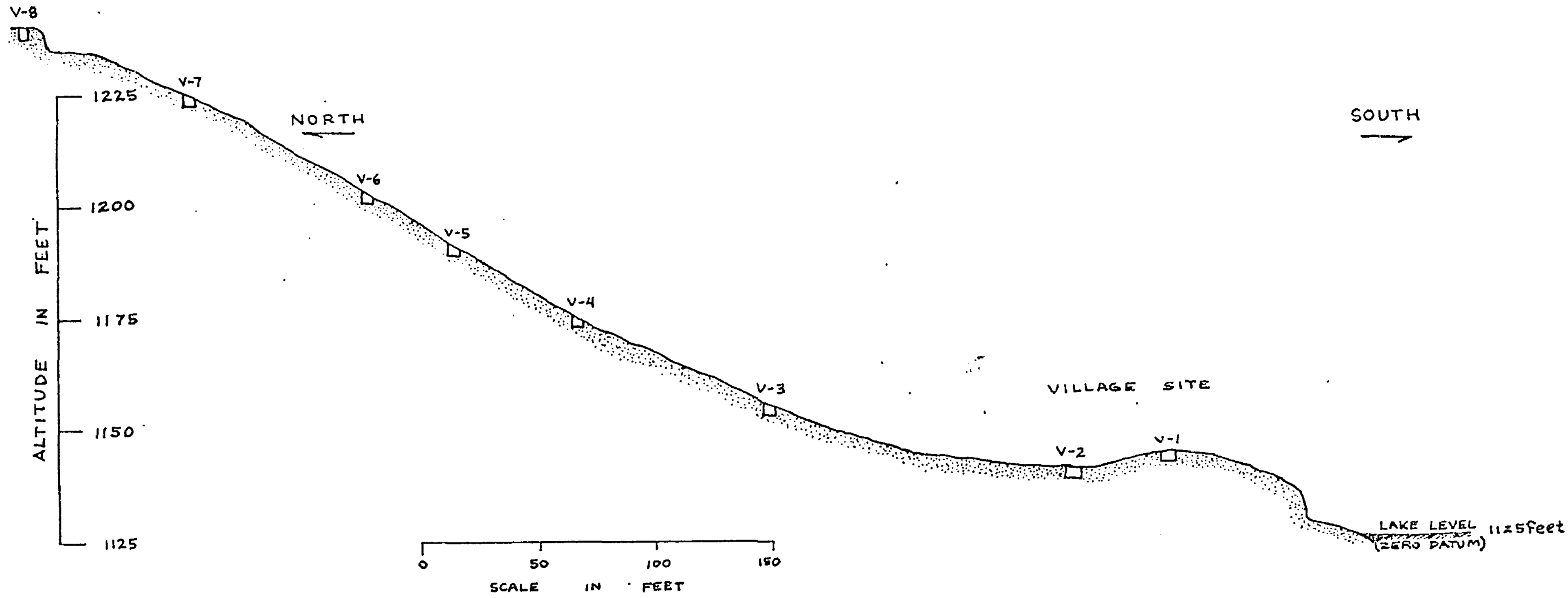


FIGURE 25: TOPOGRAPHIC PROFILE OF VILLAGE SITE AND ADJACENT BEDROCK RIDGE; WITH TEST PIT LOCALITIES (V-1 through V-8); VERTICAL EXAGGERATION 2X

Unit	Thickness (inches)	Lithology
Test Pit V-4: Altitude 1176 feet; Uphill from Test Pit V-3		
A	3	Organic mat
B	20	Silty loess, upper 7 inches oxidized
C	20+	Colluvial bedrock residiuum with ventifacted vein quartz on upper surface of unit
Test Pit V-5: Altitude 1190 feet; Uphill from Test Pit V-3		
A	2	Organic mat
B	23	Silty loess
C	7+	Colluvial residiuum derived from weathered bedrock
Test Pit V-6: Altitude 1205 feet		
A	2	Organic mat
B	16	Silty loess; upper 6 inches oxidized
C	6	Colluvial residiuum of grus and bedrock fragments.
Test Pit V-7: Altitude 1225 feet; Uphill from Test Pit V-3		
A	2	Organic mat
B	14	Silty loess, upper 6 inches of unit oxidized; clay skins at depths of 8, 10, 12, and 13 inches
C	4+	Bedrock (granodiorite) rubble with interspaces between stones partly filled with coarse eolian sand
Test Pit V-8: Altitude 1240; Crest of ridge, uphill from Test Pit V-3		
A	2	Organic mat
B	17	Silty loess, upper 7 inches oxidized
C	5+	Bedrock residuum of strongly oxidized fragments of diorite

Appendix II: Factor Analysis of Sediment Data

GEOFACT ON AGER SED SAMPLES 3-71 LOG TRANSFORMATION

CORRELATION MATRIX OF 60 SAMPLES

	MEAN	STD DEV	-3.5	-3.0	-2.5	-2.0	-1.5	-1.0	-0.5	0.	0.5	1.0	1.5	2.0
-3.5	0.100E-01	0.777E-01	1.000	1.000	0.975	0.425	0.230	0.166	0.127	0.070	0.077	0.083	-0.061	-0.104
-3.0	0.335E-01	0.259E 00	1.000	1.000	0.975	0.425	0.230	0.166	0.127	0.070	0.077	0.083	-0.061	-0.104
-2.5	0.868E-01	0.521E 00	0.975	0.975	1.000	0.545	0.295	0.207	0.157	0.097	0.072	0.111	-0.055	-0.146
-2.0	0.301E 00	0.953E 00	0.425	0.425	0.545	1.000	0.484	0.362	0.246	0.218	0.079	0.170	0.079	-0.320
-1.5	0.965E 00	0.157E 01	0.230	0.230	0.295	0.484	1.000	0.715	0.501	0.313	0.121	0.195	0.215	-0.218
-1.0	0.152E 01	0.176E 01	0.166	0.166	0.207	0.362	0.715	1.000	0.696	0.444	0.244	0.275	0.158	-0.305
-0.5	0.227E 01	0.166E 01	0.127	0.127	0.157	0.246	0.501	0.696	1.000	0.684	0.477	0.414	0.055	-0.132
0.	0.292E 01	0.136E 01	0.070	0.070	0.097	0.218	0.313	0.444	0.684	1.000	0.719	0.587	0.141	-0.092
0.5	0.314E 01	0.113E 01	0.077	0.077	0.072	0.079	0.121	0.244	0.477	0.719	1.000	0.642	0.103	0.003
1.0	0.335E 01	0.874E 00	0.083	0.083	0.111	0.170	0.195	0.275	0.414	0.587	0.642	1.000	0.259	0.152
1.5	0.345E 01	0.718E 00	-0.061	-0.061	-0.055	0.079	0.215	0.158	0.055	0.141	0.108	0.259	1.000	0.188
2.0	0.352E 01	0.433E 00	-0.104	-0.104	-0.146	-0.320	-0.218	-0.305	-0.132	-0.092	0.003	0.152	0.188	1.000
2.5	0.678E 00	0.508E 00	-0.156	-0.156	-0.248	-0.319	0.007	0.134	0.051	0.109	0.050	0.026	0.194	0.098
3.0	0.710E 00	0.480E 00	-0.187	-0.187	-0.215	-0.214	0.035	0.104	-0.030	-0.009	-0.091	-0.053	0.023	0.048
3.5	0.740E 00	0.573E 00	-0.164	-0.164	-0.183	-0.178	-0.056	-0.009	-0.141	-0.121	-0.148	-0.122	-0.100	0.060
4.0	0.736E 00	0.594E 00	-0.169	-0.169	-0.186	-0.181	-0.155	-0.161	-0.242	-0.229	-0.171	-0.135	-0.140	0.094
4.0+	0.970E 00	0.763E 00	-0.120	-0.120	-0.143	-0.194	-0.231	-0.286	-0.398	-0.425	-0.266	-0.188	-0.078	0.161

			2.5	3.0	3.5	4.0	4.0+
-3.5	0.100E-01	0.777E-01	-0.156	-0.187	-0.164	-0.169	-0.120
-3.0	0.335E-01	0.259E 00	-0.156	-0.187	-0.164	-0.169	-0.120
-2.5	0.868E-01	0.571E 00	-0.243	-0.215	-0.183	-0.186	-0.143
-2.0	0.301E 00	0.953E 00	-0.319	-0.214	-0.178	-0.181	-0.194
-1.5	0.965E 00	0.157E 01	0.007	0.035	-0.056	-0.155	-0.231
-1.0	0.152E 01	0.176E 01	0.134	0.104	-0.009	-0.161	-0.286
-0.5	0.227E 01	0.166E 01	0.051	-0.030	-0.141	-0.242	-0.398
0.	0.292E 01	0.136E 01	0.109	-0.009	-0.121	-0.229	-0.425
0.5	0.314E 01	0.113E 01	0.050	-0.091	-0.148	-0.171	-0.266
1.0	0.335E 01	0.874E 00	0.076	-0.063	-0.122	-0.135	-0.188
1.5	0.345E 01	0.718E 00	0.194	0.023	-0.100	-0.140	-0.078
2.0	0.352E 01	0.433E 00	0.098	0.048	0.060	0.094	0.161
2.5	0.678E 00	0.508E 00	1.000	0.758	0.448	0.227	0.054
3.0	0.710E 00	0.480E 00	0.758	1.000	0.887	0.682	0.487
3.5	0.740E 00	0.573E 00	0.448	0.887	1.000	0.888	0.736
4.0	0.736E 00	0.594E 00	0.227	0.682	0.888	1.000	0.921
4.0+	0.970E 00	0.763E 00	0.054	0.487	0.736	0.921	1.000

Appendix II

GEOFACT ON AGER SED SAMPLES 3-71 LOG TRANSFORMATION

UNROTATED FACTOR MATRIX

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
EIGENVALUE	4.95	3.03	2.75	1.56	1.20	1.07	0.71	0.46	0.37	0.31	0.22	0.17	0.12	0.03	0.02	0.01	-0.00
PERCENT	29.1	17.8	16.2	9.2	7.1	6.3	4.2	2.7	2.2	1.8	1.3	1.0	0.7	0.2	0.1	0.0	-0.0
MULATIVE PERCENT	29.1	46.9	63.1	72.3	79.4	85.7	89.8	92.5	94.7	96.6	97.9	98.9	99.6	99.8	100.0	100.0	100.0
-3.5	0.595	-0.305	-0.662	0.262	-0.102	-0.165	0.009	0.081	0.002	-0.001	-0.011	0.001	-0.014	0.024	-0.027	0.028	0.000
-3.0	0.595	-0.305	-0.662	0.262	-0.102	-0.165	0.009	0.081	0.002	-0.001	-0.011	0.001	-0.014	0.024	-0.027	0.028	-0.000
-2.5	0.646	-0.303	-0.658	0.195	-0.056	-0.054	-0.005	0.008	0.012	0.016	-0.030	-0.018	0.042	-0.051	0.065	-0.059	0.000
-2.0	0.600	-0.054	-0.345	-0.248	0.083	0.388	-0.221	-0.455	0.119	0.065	0.152	0.034	-0.030	0.006	-0.011	0.005	-0.000
-1.5	0.539	0.374	-0.239	-0.432	-0.198	0.266	0.212	-0.023	-0.149	-0.342	-0.148	0.097	-0.004	0.005	-0.005	-0.001	-0.000
-1.0	0.545	0.550	-0.160	-0.424	-0.077	0.040	0.201	0.165	-0.113	0.105	0.187	-0.243	-0.050	-0.004	0.007	0.002	0.000
-0.5	0.608	0.564	0.063	-0.117	0.153	-0.084	0.324	0.117	0.199	0.220	0.026	0.233	0.055	0.001	-0.005	-0.002	0.000
0.	0.563	0.612	0.181	0.194	0.237	-0.099	-0.082	-0.073	0.260	-0.033	-0.239	-0.138	-0.130	-0.019	-0.011	-0.000	0.000
0.5	0.455	0.487	0.215	0.456	0.331	-0.054	-0.179	0.100	0.027	-0.291	0.237	0.020	0.071	-0.002	0.005	-0.000	-0.000
1.0	0.436	0.480	0.152	0.499	0.128	0.242	-0.093	-0.077	-0.411	0.196	-0.095	0.030	0.011	0.006	-0.003	0.001	-0.000
1.5	0.129	0.271	0.156	0.145	-0.683	0.459	-0.315	0.231	0.172	0.052	-0.018	0.002	0.045	0.009	0.005	0.001	-0.000
2.0	-0.254	0.013	0.156	0.632	-0.330	0.192	0.546	-0.222	0.086	-0.047	0.069	-0.058	-0.010	-0.000	0.003	0.001	0.000
2.5	-0.307	0.597	-0.117	0.049	-0.456	-0.492	-0.142	-0.117	-0.073	-0.005	0.092	0.102	-0.156	0.026	-0.011	-0.024	0.000
3.0	-0.533	0.630	-0.450	-0.039	-0.145	-0.209	-0.065	-0.138	-0.003	0.011	-0.030	-0.010	0.122	-0.092	0.036	0.039	-0.000
3.5	-0.628	0.475	-0.561	0.002	0.110	0.018	-0.001	-0.050	0.051	0.010	-0.050	-0.091	0.164	0.062	-0.069	-0.030	0.000
4.0	-0.680	0.298	-0.543	0.082	0.263	0.218	0.016	0.074	0.052	0.000	-0.014	0.027	-0.084	0.082	0.092	0.012	-0.000
4.0+	-0.692	0.061	-0.510	0.139	0.200	0.359	0.023	0.181	-0.004	-0.003	0.055	0.065	-0.137	-0.087	-0.057	-0.008	0.000

Appendix II

GEOFACT ON AGER SED SAMPLES 3-71 LOG TRANSFORMATION

VARIMAX MATRIX ACCOUNTING FOR 85.7 PERCENT OF TOTAL PROBLEM VARIANCE

	FACTOR	1	2	3	4	5	6
SUM OF SQUARES		3.144	2.716	3.120	2.554	1.262	1.768
0.991	-3.5	0.078	0.036	-0.987	-0.083	0.034	0.035
0.991	-3.0	0.078	0.036	-0.987	-0.083	0.034	0.035
0.986	-2.5	0.070	0.042	-0.964	-0.174	0.033	0.138
0.701	-2.0	0.017	0.058	-0.407	-0.594	-0.026	0.427
0.784	-1.5	0.043	0.108	-0.157	-0.849	-0.161	0.003
0.812	-1.0	0.075	0.287	-0.073	-0.830	0.018	-0.170
0.736	-0.5	0.184	0.616	-0.035	-0.542	0.113	-0.116
0.826	0.	0.163	0.839	-0.008	-0.285	0.045	-0.110
0.811	0.5	0.095	0.895	-0.035	0.006	0.008	0.006
0.768	1.0	0.002	0.807	-0.064	-0.064	-0.312	0.107
0.813	1.5	0.103	0.047	0.074	-0.227	-0.857	-0.089
0.635	2.0	-0.090	0.117	0.023	0.503	-0.595	-0.069
0.917	2.5	-0.160	0.055	0.103	-0.027	-0.134	-0.927
0.950	3.0	-0.672	-0.017	0.105	-0.112	-0.005	-0.588
0.948	3.5	-0.892	-0.056	0.082	-0.030	0.068	-0.370
0.968	4.0	-0.966	-0.083	0.091	0.094	0.057	-0.084
0.930	4.0+	-0.908	-0.223	0.042	0.203	-0.060	0.100

Sample	Comm.	I	II	III	IV	V
A 105	0.9968	0.9427	0.0793	-0.1141	-0.1700	-0.2449
A 140	0.9928	-0.3428	-0.0321	0.8706	0.2389	-0.2432
A 141	0.9944	-0.1720	0.2203	-0.0766	0.0074	0.9541
A 26	0.9951	0.1092	-0.4671	0.6075	-0.1357	-0.6145
A 66	0.9997	0.7860	0.3051	0.0514	-0.5298	0.0736
A 59	0.9995	-0.3052	0.2003	0.4374	-0.4879	0.6609
A 88	0.9658	0.0436	-0.2605	-0.1217	0.9385	0.0206
A 106	1.0000	0.7296	-0.1038	-0.3128	-0.4797	0.3592
A 98	0.9774	0.3708	-0.0663	0.0234	0.9066	-0.1148
A 64	0.9995	0.0897	0.7942	0.1898	-0.5520	0.1413
A 107	0.0147	-0.0298	-0.0269	-0.0593	0.0932	0.0304
A 81	1.0000	0.6959	0.6961	0.0878	-0.0310	-0.1494
A 87	0.9863	0.6276	-0.0576	-0.3650	0.5155	-0.4361
A 89	0.9930	0.7901	-0.1567	-0.4369	-0.3916	0.0034
A 91	0.9797	0.7440	-0.1300	-0.3821	0.4941	0.1385
A 93	0.9970	0.6105	0.3284	-0.0459	0.5403	-0.4716
A 95	0.9948	0.7894	0.2867	-0.1147	0.2629	-0.4552
A 97	0.9905	0.3915	0.1531	0.0710	0.8234	-0.3614
A 99	0.9879	0.8653	-0.0069	-0.1405	0.4655	0.0516
A 96	0.9765	-0.1956	-0.0429	0.1721	0.8992	0.3133
A 101	0.9962	0.1737	-0.2885	-0.1637	-0.3177	0.8689
A 103	0.9966	0.9495	0.1303	-0.1929	-0.1884	0.0727
A 104	0.9980	0.9213	0.0554	-0.2208	-0.1017	-0.2950
A 4	0.9998	-0.2596	0.0607	0.8675	-0.3545	-0.2247
A 5	0.9994	-0.0640	0.5376	0.5371	-0.6222	-0.1748
A 6	0.9921	-0.4674	-0.3147	0.7645	-0.2008	0.2231
A 10	1.0013	-0.0556	-0.1007	-0.0467	-0.4359	0.8921
A 23	0.9957	0.3203	0.8422	0.2120	-0.3726	0.0077
A 24	0.9929	0.2014	0.1269	0.5210	-0.8013	0.1504
A 27	0.9963	0.0026	-0.2715	0.8553	-0.1730	-0.4014
A 28	0.9945	-0.1790	-0.0516	-0.0410	0.4544	0.8670
A 29	0.9864	0.4771	0.2672	0.2358	-0.6780	0.4149
A 39	0.9958	0.1108	0.3845	0.5855	-0.7020	-0.0040
A 58	0.9990	-0.2416	0.0498	0.8510	-0.4408	-0.1401
A 61	0.9911	-0.5606	-0.1625	0.8064	-0.0084	-0.0080
A 36	0.9849	-0.3157	-0.7330	-0.3614	-0.3256	-0.3337
A 38	0.9976	-0.7297	0.1237	-0.5800	-0.1413	-0.3058
A 47	0.9960	-0.3971	-0.0516	0.5049	-0.2911	-0.7043
A 51	1.0002	0.0508	-0.9754	-0.1113	-0.0263	-0.1822
A 55	0.9998	-0.8563	0.2117	-0.1560	-0.0842	-0.4362
A 56	0.9817	-0.7308	-0.1652	0.6312	-0.0729	0.1289
A 65	0.9918	-0.6294	0.1327	-0.6805	0.2283	-0.2507
A 74	0.9972	0.1739	0.2271	-0.3994	-0.7806	0.3828
A 75	1.0009	0.0609	0.9443	-0.0619	0.0669	-0.3117
A 80	1.0008	-0.0484	0.8601	-0.4294	-0.2113	0.1721
A 2	0.9904	-0.3442	0.0026	-0.8707	-0.1156	-0.3169
A 3	0.9903	0.1780	-0.6905	0.6371	0.0570	-0.2696
A 7	1.0006	-0.2575	0.2057	0.7917	0.0085	-0.5149
A 8	1.0003	-0.1114	0.8793	-0.1231	-0.4187	-0.1558
A 9	0.9969	-0.3149	-0.1147	0.7995	-0.4185	-0.2651
A 11	1.0006	-0.3810	0.6110	0.1226	0.6765	-0.0972
A 12	0.9756	-0.9738	0.0446	-0.0828	-0.1132	0.0745
A 18	0.9573	-0.5208	0.2115	0.0792	-0.7894	-0.1092
A 25	1.0002	-0.1547	0.8700	-0.1057	-0.3320	-0.3131
A 30	1.0003	-0.2976	0.7392	-0.2392	-0.2427	0.4992
A 31	0.9912	-0.3370	-0.9332	0.0576	-0.0001	-0.0581
A 34	0.9906	0.1861	-0.4470	-0.8342	-0.2309	0.0835
A 35	0.9917	-0.1706	-0.1281	-0.9181	-0.1641	-0.2764
A 76	1.0000	0.6300	0.7540	0.0704	0.0486	-0.1656
A 57	0.9965	0.1674	0.1098	0.6543	-0.6798	0.2572
	VARIANCE	23.653	18.996	21.813	19.602	13.619
	CUM VAR	23.653	42.649	64.462	84.064	97.683

APPENDIX III

Sample	Locality	Interpretation
A 7	Test Pit 11, saddle, Kidney Hill, 7 feet	Eolian sand, medium-fine grained
A 8	Village Site Excavation N50 E0, 48 inches deep	Eolian sand, coarse grained
A 9	Village Site Excavation N50 E0, 32 inches deep	Eolian sand, medium-coarse
A 11	Tanana River at locality (Trading Post), overbank deposit, 3 feet deep	Fluvial sand, medium-fine grained
A 12	Village Site Test Pit V-3 45 inches deep	Beach sand, late Pleistocene age probably transported somewhat by wind from beach
A 18	Test Pit 40, terrace, north side Healy River, 4 feet deep	Beach sand, late Pleistocene age well sorted, medium-coarse grained.
A 25	Test Pit 45, terrace, north side Healy River, 7 feet deep	Eolian sand, coarse, mixed or reworked
A 30	Test Pit 45, 42 inches deep	Eolian sand, coarse grained
A 31	Shore locality F, Healy Lake	Beach sand, very coarse, well sorted, modern
A 34	Shore locality C, Healy Lake	Beach sand, medium-coarse, well sorted, modern
A 35	Shore locality A, Healy Lake	Beach sand, medium grained, well sorted, modern
A 76	Test Pit 49, sand dune, north side Healy River, 9 feet deep	Eolian dune sand, mixture of adjacent lenses of coarse and fine sands
A 57	Test Pit 8, south slope of saddle, Kidney Hill, 28 inches deep	Eolian sands, poorly sorted dur to reworking
A 23	Test Pit 37, lower slope of ridge, north end of Healy Lake, 6 feet deep	Eolian sand, coarse grained
A 24	Test Pit 3, middle slope of ridge, northwest end, Healy Lake, 7 feet	Eolian sand, reworked or mixed layers of coarse and fine sands
A 27	Test Pit 34, lower slope of ridge, 42 inches depth	Eolian sand
A 28	Gerstle River, 3 miles north of bridge	Fluvial sand (overbank deposit)
A 29	Test Pit 36, lower slope of ridge, north end of Healy Lake, 9 feet	Eolian sand, mixed or reworked

Sample	Locality	Interpretation
A 39	Test Pit 37, middle slope of ridge, north end of Healy Lake, 8 feet	Eolian sand, mixed or reworked
A 58	Test Pit 7, saddle of Kidney Hill, 84 inches	Eolian sand
A 61	Test Pit 8, saddle of Kidney Hill, 7 feet	Eolian sand
A 36	Shore locality D, Healy Lake	Beach sand, modern, coarse grained, well sorted
A 38	Shore locality E, Healy Lake	Beach sand, modern, medium grained, well sorted
A 47	Test Pit 25, ridge crest, north of Healy Lake, 15 inches deep	Eolian and residual sand, poorly sorted, trapped between rock slabs
A 51	Shore locality E, north end Healy Lake	Beach sand, modern, coarse grained, well sorted
A 55	Shore locality C, north end Healy Lake	Beach sand, modern, fine grained, well sorted
A 56	Test Locality 32, north end Healy Lake	Beach sand, Pleistocene, somewhat mixed; ice wedge cast filling
A 65	Shore locality B, north end Healy Lake	Beach sand, modern, fine to medium grained
A 74	Test Pit 49, sand dune north side Healy River 7 feet deep	Beach/eolian sand, Pleistocene, coarse grained, well sorted
A 75	Test Pit 49, 14 feet deep	Eolian dune sand, medium-coarse
A 80	Test Pit 43, 66 inches deep, middle slope of ridge, north of Healy River	Eolian sand, coarse grained, in fill of fossil ice wedge cast, late Pleistocene in age
A 2	Test Pit 33, Kirsteatter's Well, 8 feet deep	Beach sand, Pleistocene, coarse, well sorted
A 3	Test Pit 34, upslope from Kirsteatter's cabin, 4 feet deep	Mixed sands, colluvium of eolian and possible eolian/beach origin, poorly sorted
A 105	Village Site Excavation N75 E0, depth 22-23 in.	Eolian sandy silt (loess)
A 140	Test Pit 45, terrace, north side Healy River Valley, depth 3 feet	Eolian sand
A 141	Test Pit 46, vegetated sand dune, north side Healy River Valley, depth 12 inches	Eolian sand
A 26	Test Pit 45, depth 4 feet	Eolian (?) sand, poorly sorted due to mixing or fluvial (?) influence

Sample	Locality	Interpretation
A 66	Test Pit 38, middle slope of bedrock ridge, north end Healy Lake, depth 7 feet	Eolian sandy silt
A 59	Test Pit 9, southwest slope of Kidney Hill, 5 feet deep	Eolian sand
A 88	Village Site Excavation N75 E0, 5-6 inches deep	Eolian silt (fine loess)
A 106	Village Site Excavation N75 E0, 23-24 inches deep	Eolian sandy silt (sandy loess)
A 98	Village Site Excavation N75 E0, 15-16 inches	Eolian silt
A 64	Test Pit 7, Kidney Hill saddle, 9 feet deep	Eolian sand, medium grained
A 107	Test Pit 70, Pruhs' Cabin area, 66 inches deep	Colluvium, coarse pebbly sediments, poorly sorted
A 81	Test Pit 44, Sand dune, north side Healy River, 9 feet deep	Eolian dune sand
A 87	Village Site Excavation N75 E0, 4-5 inches	Eolian silt (fine loess)
A 89	Village Site N75 E0, 6-7 in.	Eolian silt, slightly sandy
A 91	Village Site N75 E0, 8-9 in.	Eolian silt, slightly sandy
A 93	Village Site N75 E0, 10-11 in.	Eolian silt, slightly sandy
A 95	Village Site N75 E0, 12-13 in.	Eolian silt, slightly sandy
A 97	Village Site N75 E0, 14-15 in.	Eolian silt (fine loess)
A 99	Village Site N75 E0, 16-17 in.	Eolian sandy silt
A 96	Village Site N75 E0, 13-14 in.	Eolian silt, slightly sandy
A 101	Village Site N75 E0, 18-19 in.	Eolian sandy silt
A 103	Village Site N75 E0, 20-21 in.	Eolian sandy silt
A 104	Village Site N75 E0, 21-22 in.	Eolian sandy silt
A 4	Test Pit 6, Kidney Hill saddle, south slope, 3 ft.	Eolian sand, fine grained
A 5	Test Pit 6, 5 ft. deep	Eolian sand, mixed or reworked, mdeium grained
A 6	Test Pit 6, 4 ft. deep	Eolian sand, medium grained
A 10	Test Pit 43, middle slope, north side Healy River, 54 in.	Eolian sand, mixed or reworked

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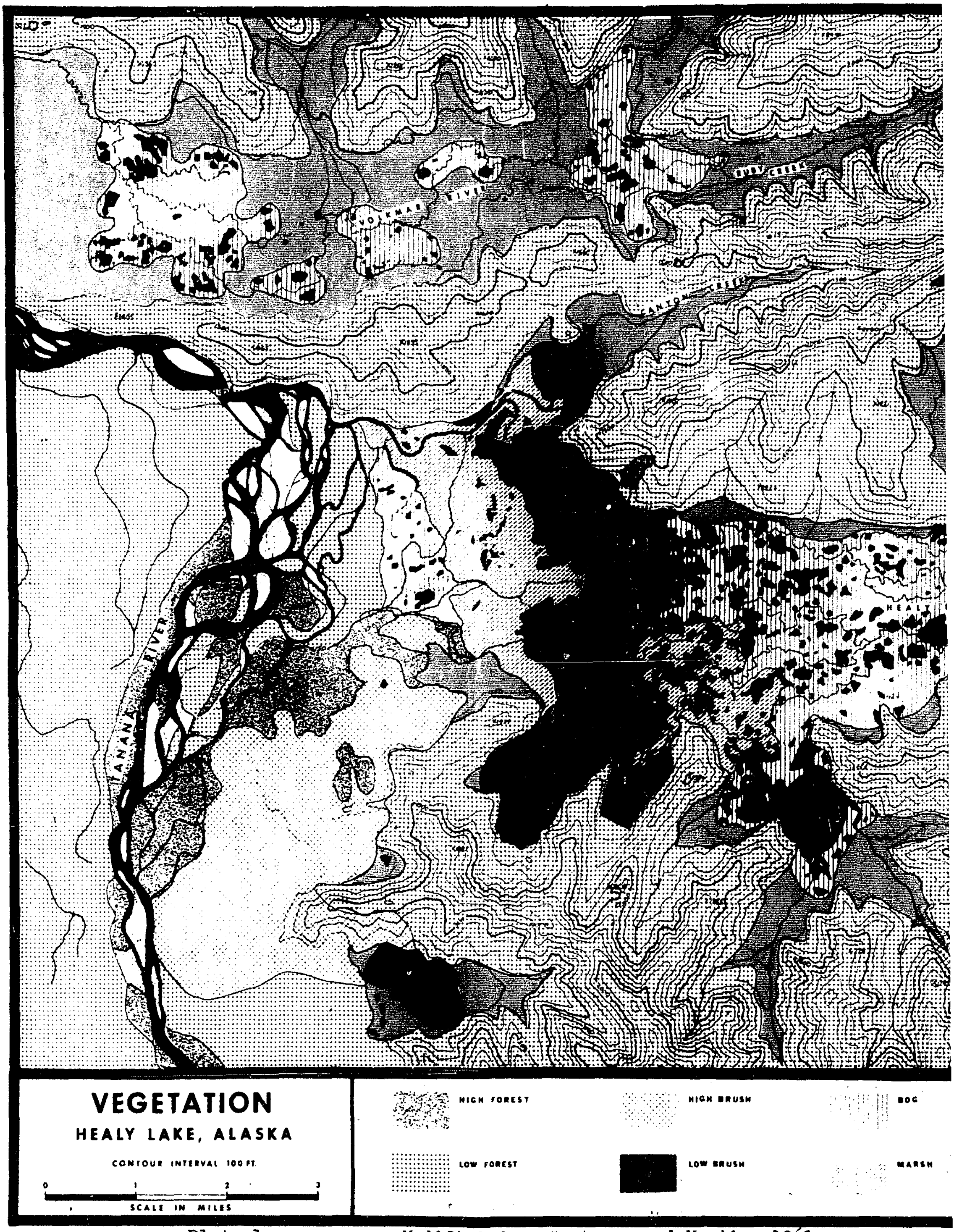
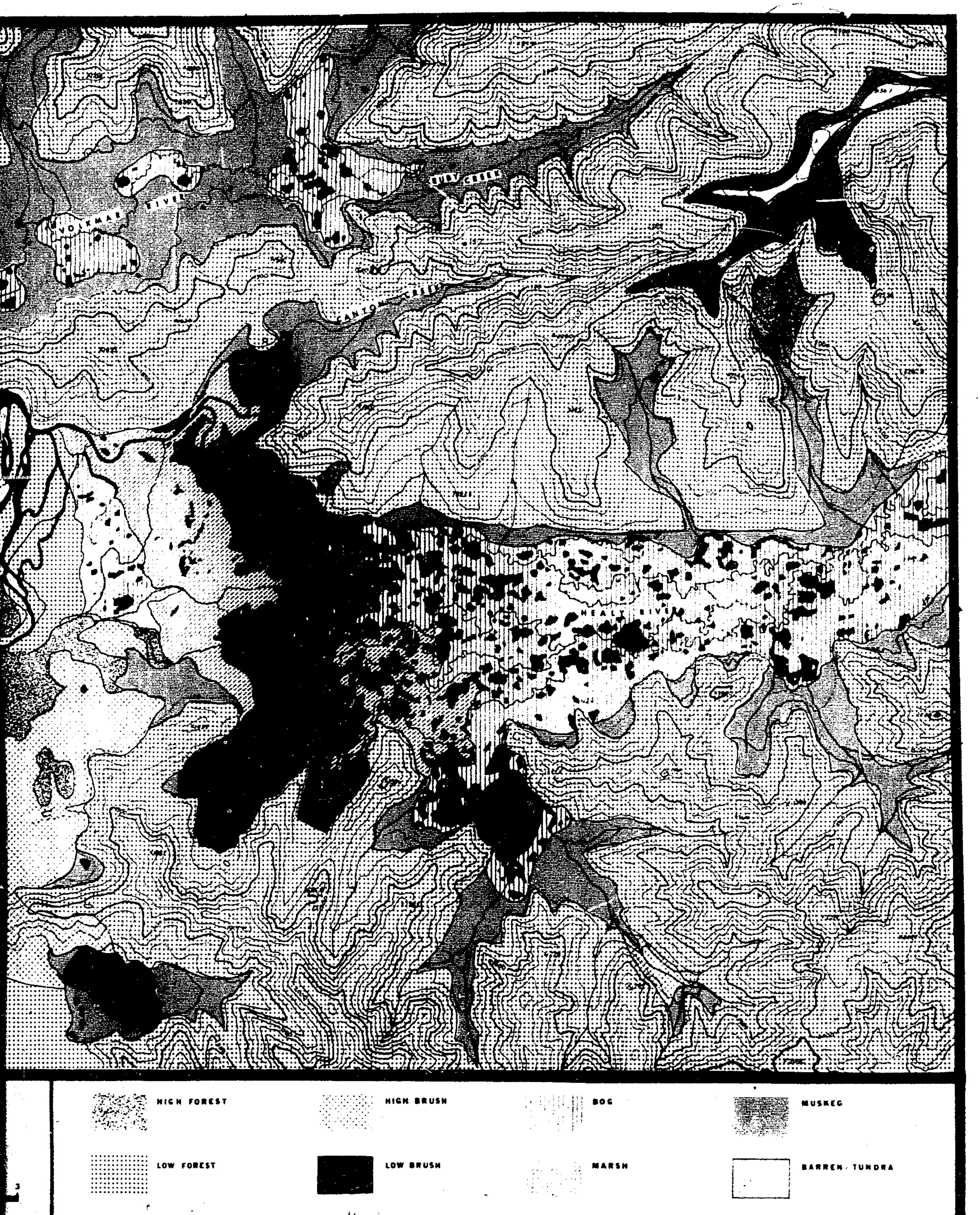


Plate 1 Modified from Spetzman and Martin, 1961



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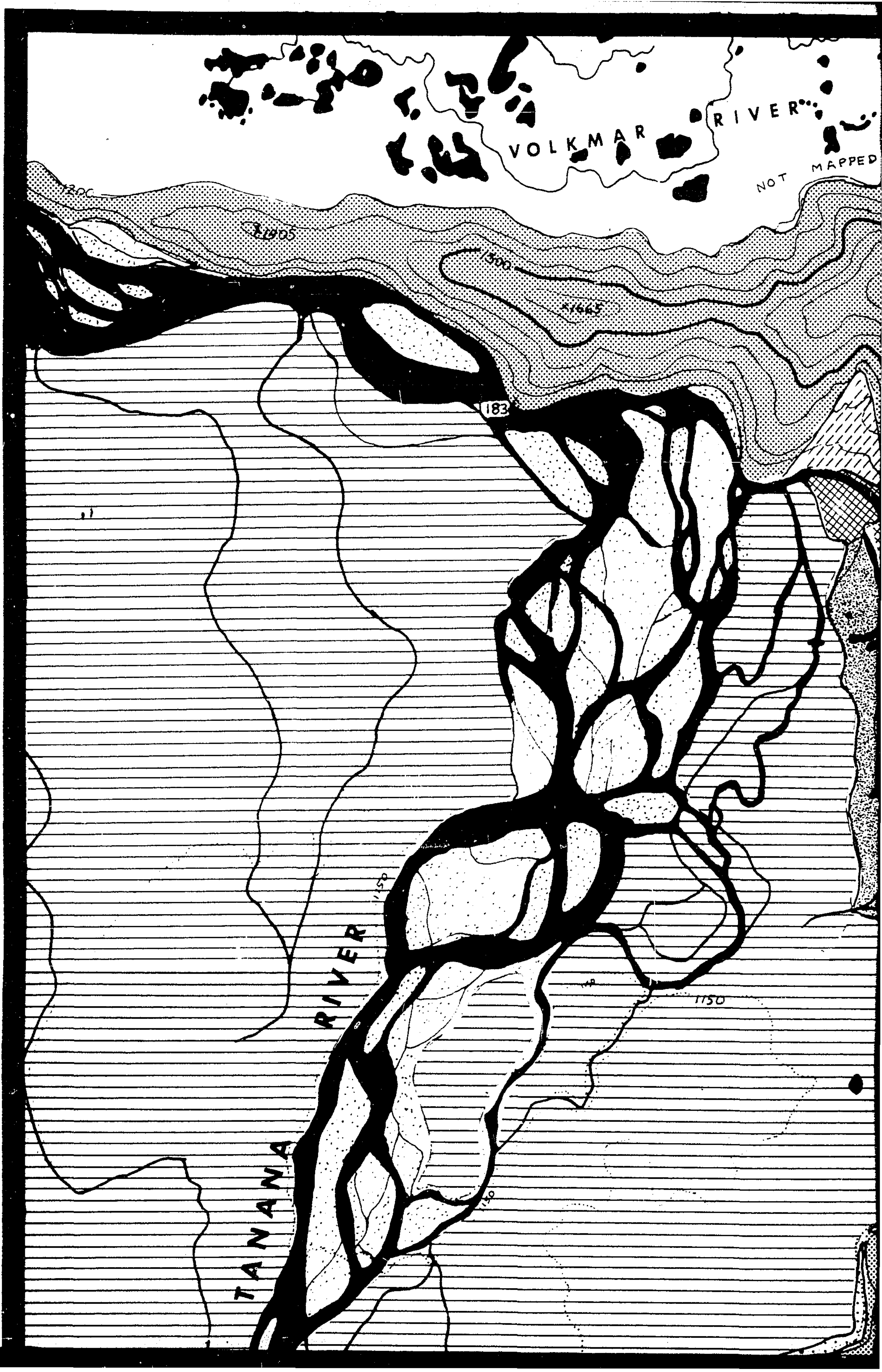
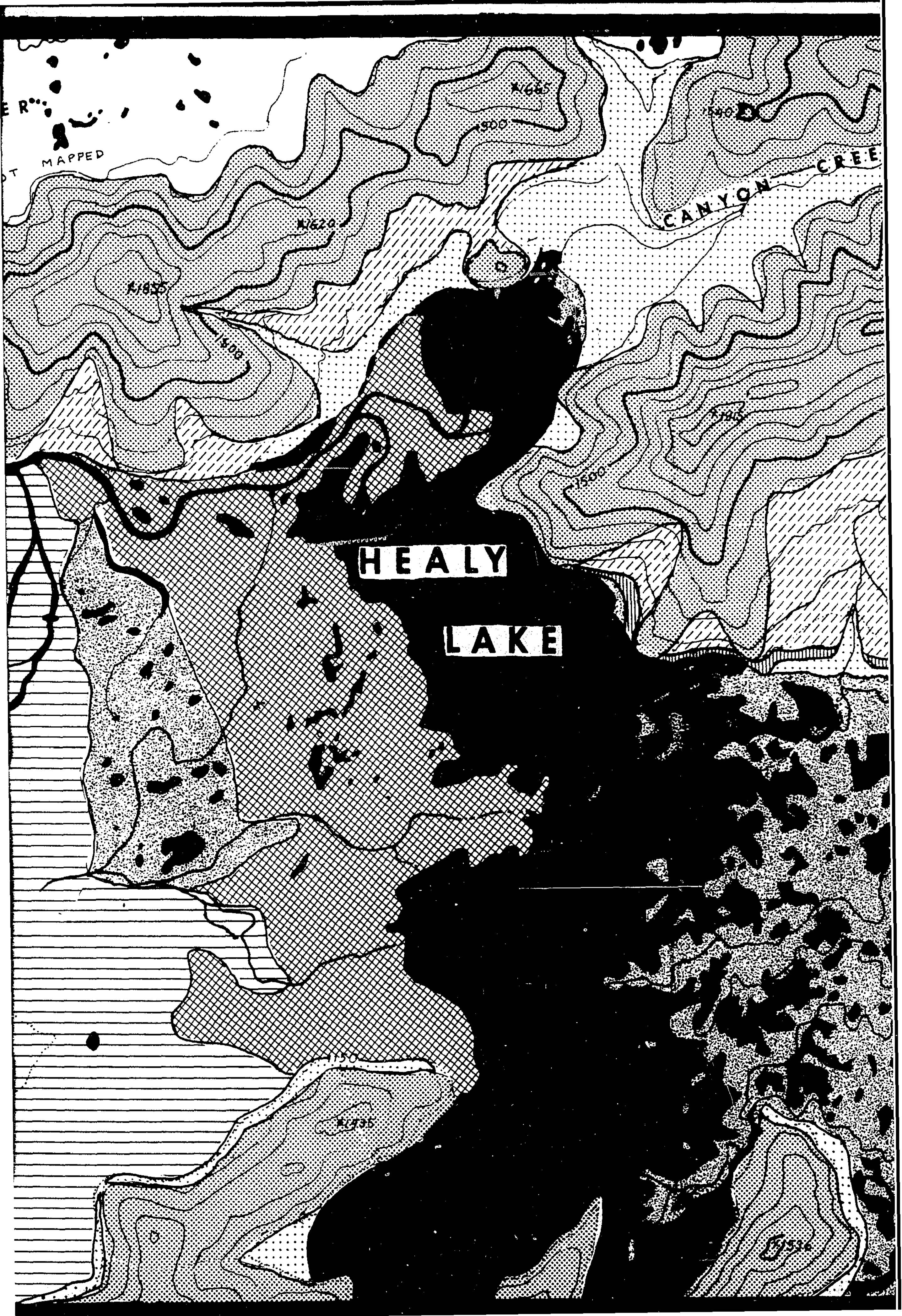
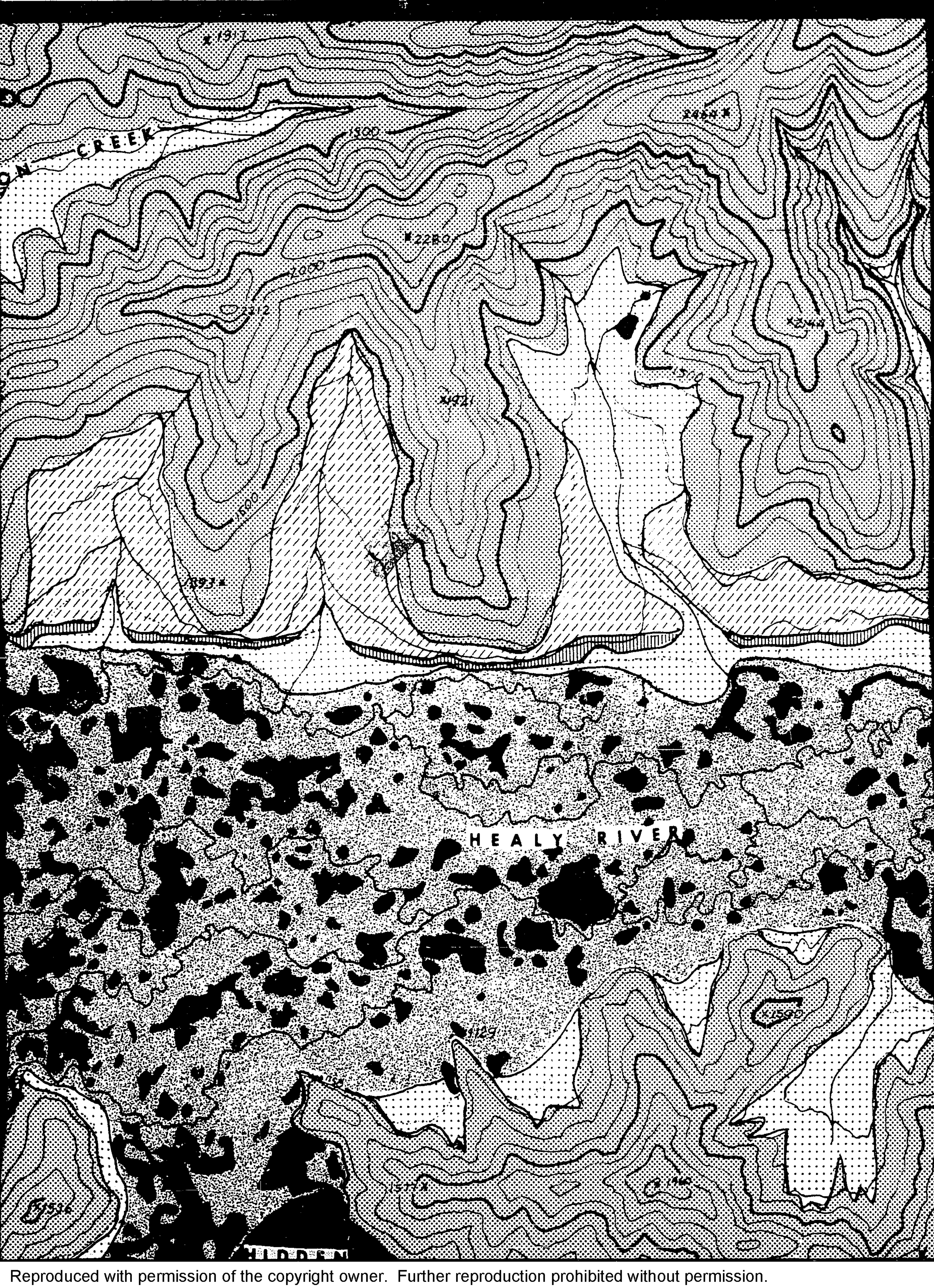

VOLKMAR RIVER
NOT MAPPED
1200
1405
1500
1665
183
1150
TANANA RIVER
1150
1150


HEALY
LAKE
CANYON CREE
MAPPED
1855
1620
1665
1500
1915
1535
1536


CREEK
HEALY RIVER
2280
2000
1500

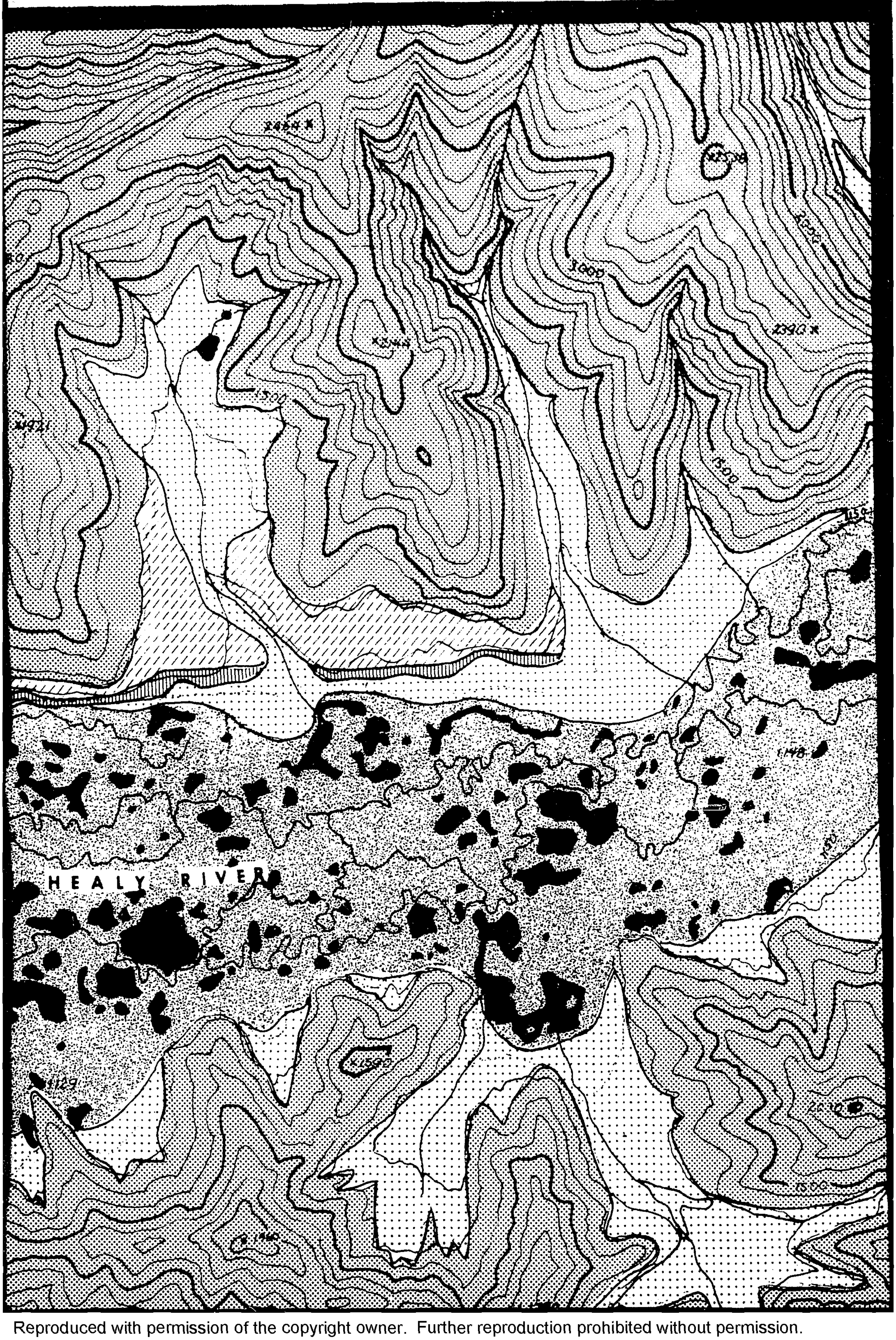

HEALY RIVER

PLATE 2

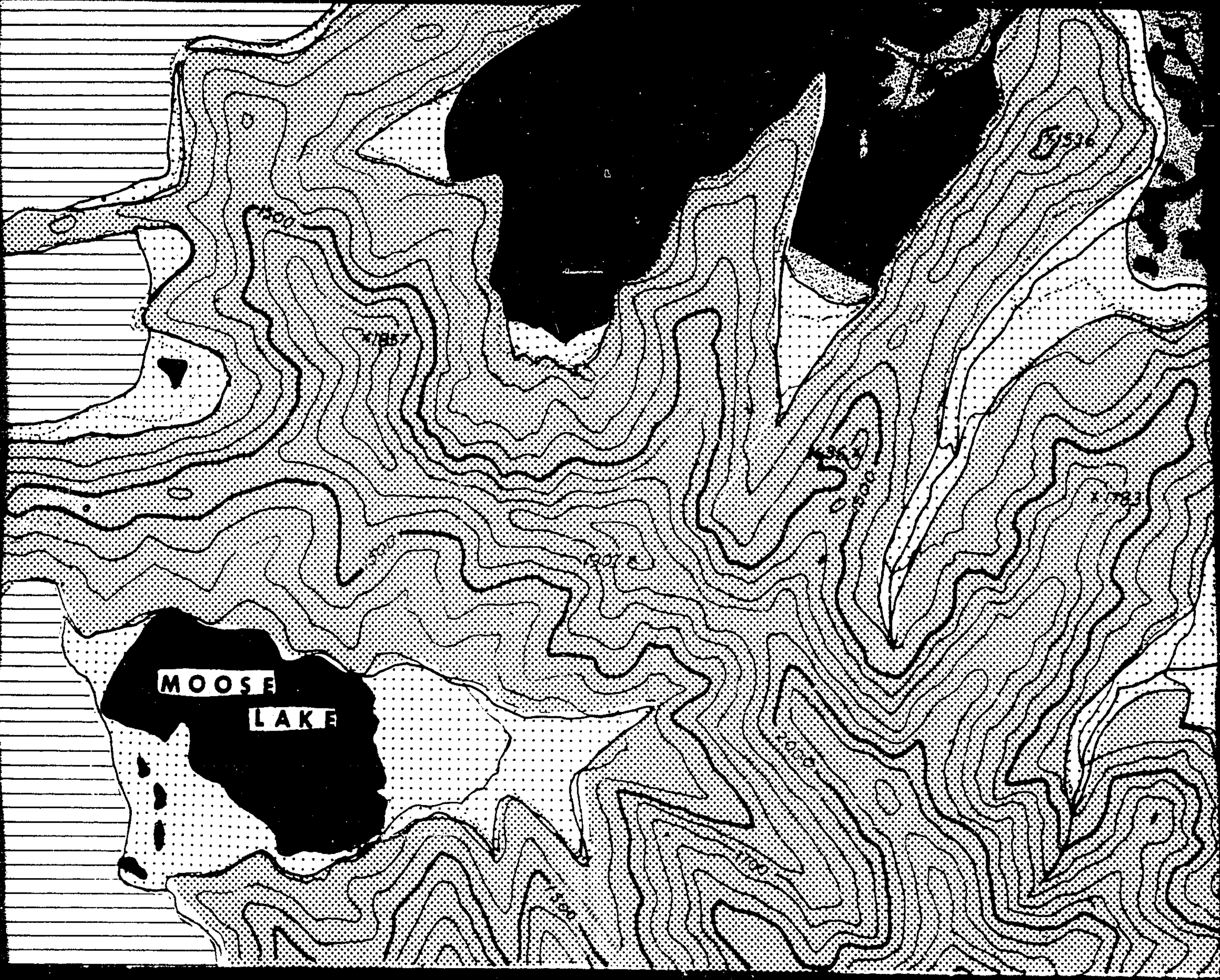
SURFICIAL GEOLOGY

HEALY LAKE AREA
ALASKA

CONTOUR INTERVAL 100 FT.

0 1 2 3

SCALE IN MILES



LATE 2

GY

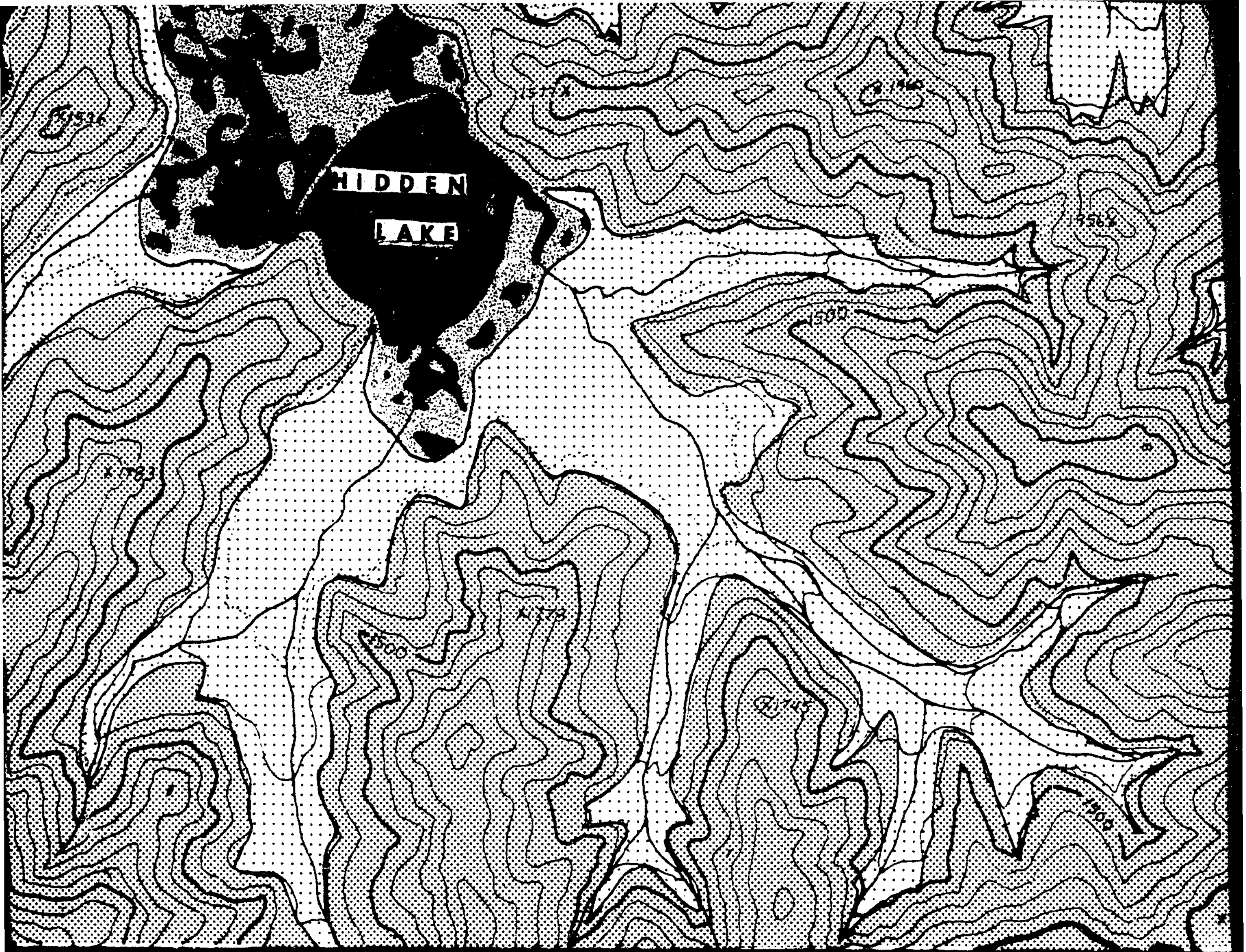
3

BEDROCK, UNDIFFERENTIATED
discontinuous loess mantle; late Pleistocene and Holocene

BOG
pe
sa

EOLIAN SAND
dunes and sheets; late Pleistocene

ALLUV
DEP
San
forn
Hol



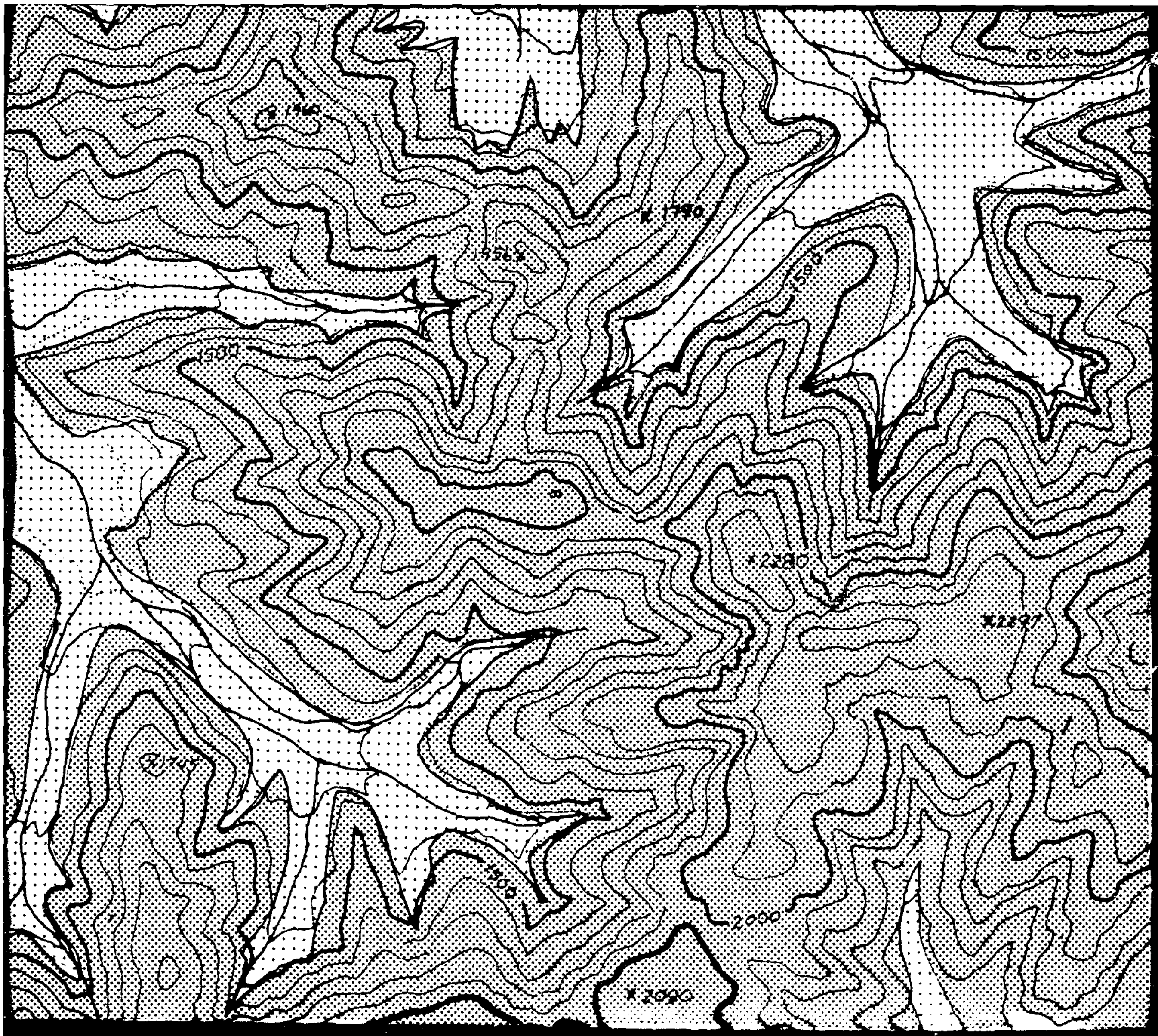
BOG DEPOSITS
peat, silt, and sandy silt; Holocene

TERRACE DEPOSITS (TANANA RIVER)
Gravel, sand, and silt; Holocene

ALLUVIAL - COLLUVIAL DEPOSITS
sand, silt, and muck; forms fans and aprons; Holocene

ALLUVIUM (TANANA RIVER)
Barren gravel and sand; late Holocene.

FIELD & PHOTOGEOLOGIC MAPPING



TERRACE DEPOSITS (TANANA RIVER)

Gravel, sand, and silt; Holocene

LACUSTRINE TERRACE DEPOSITS

Beach sand, eolian sand; late Pleistocene age; loess mantle of Holocene age

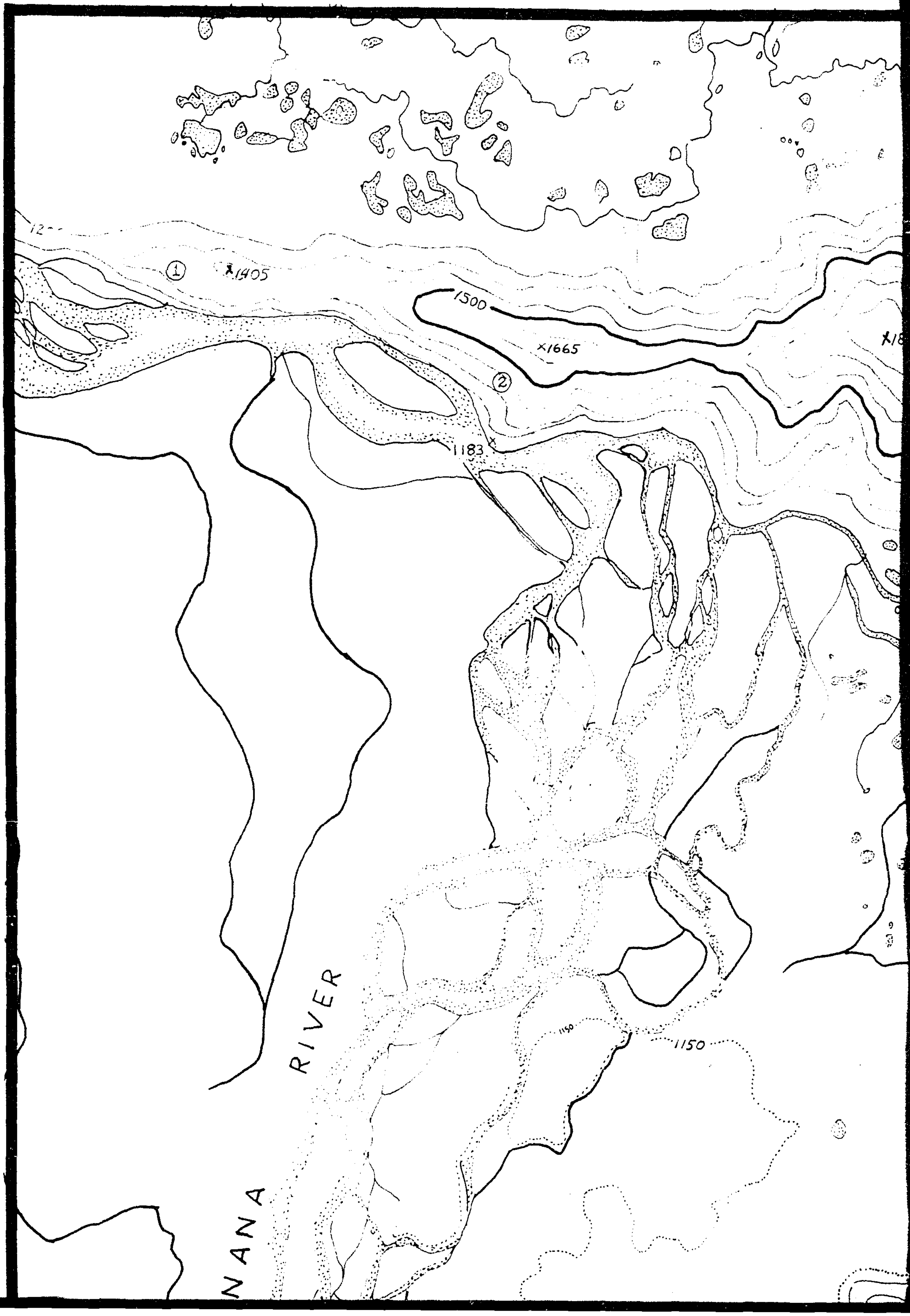
ALLUVIUM (TANANA RIVER)

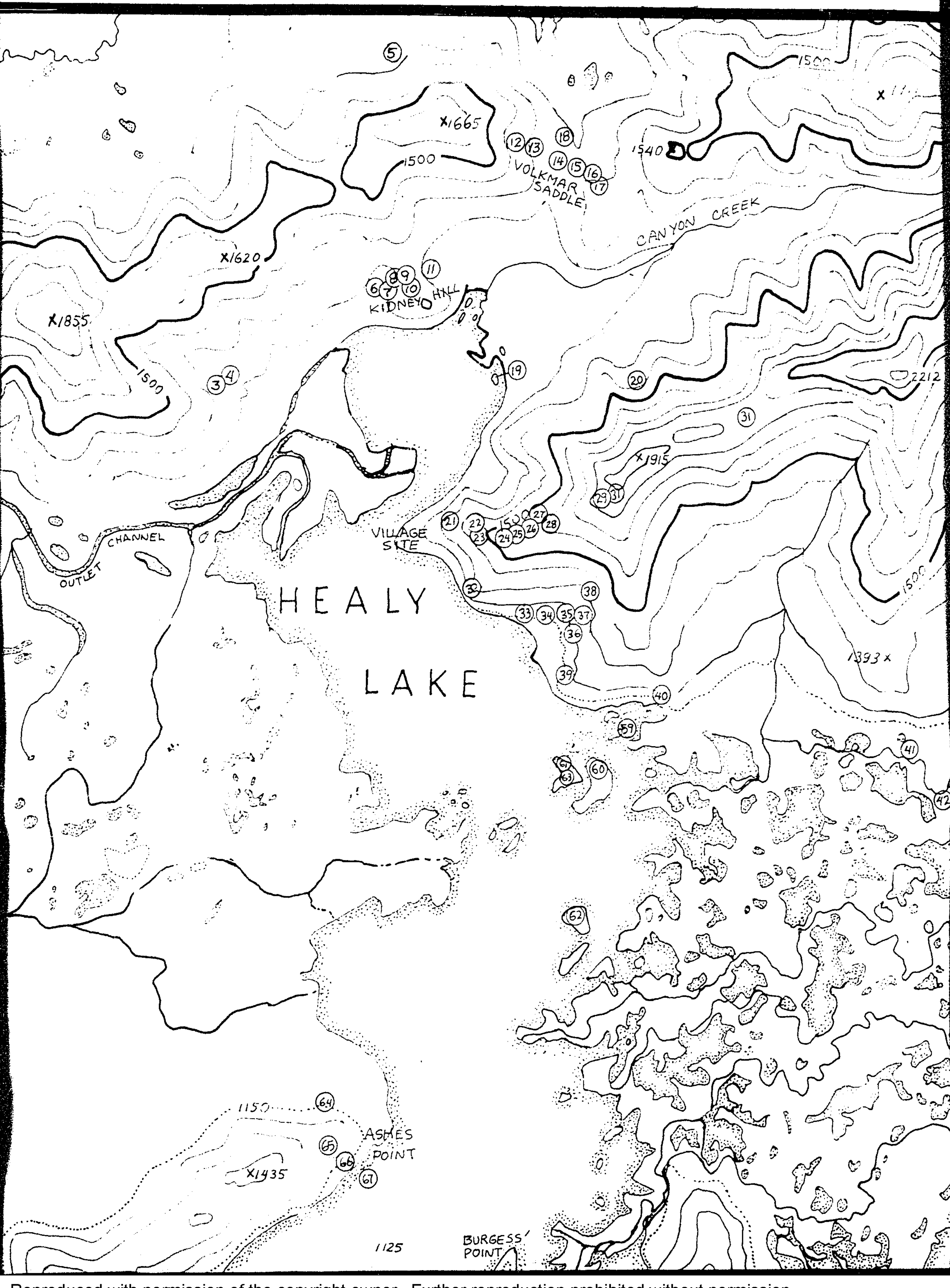
Barren gravel and sand; late Holocene.

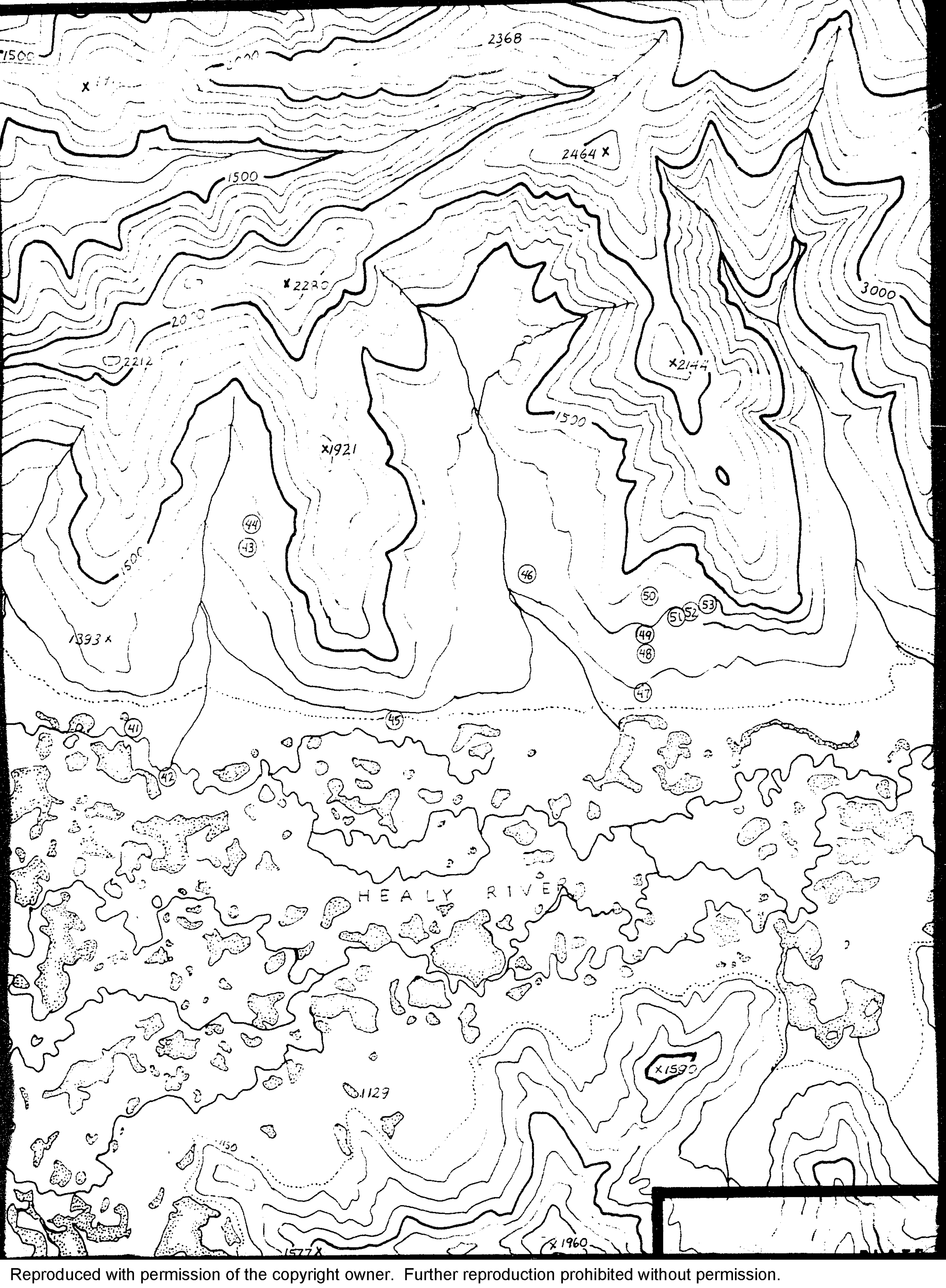
DELTA DEPOSITS

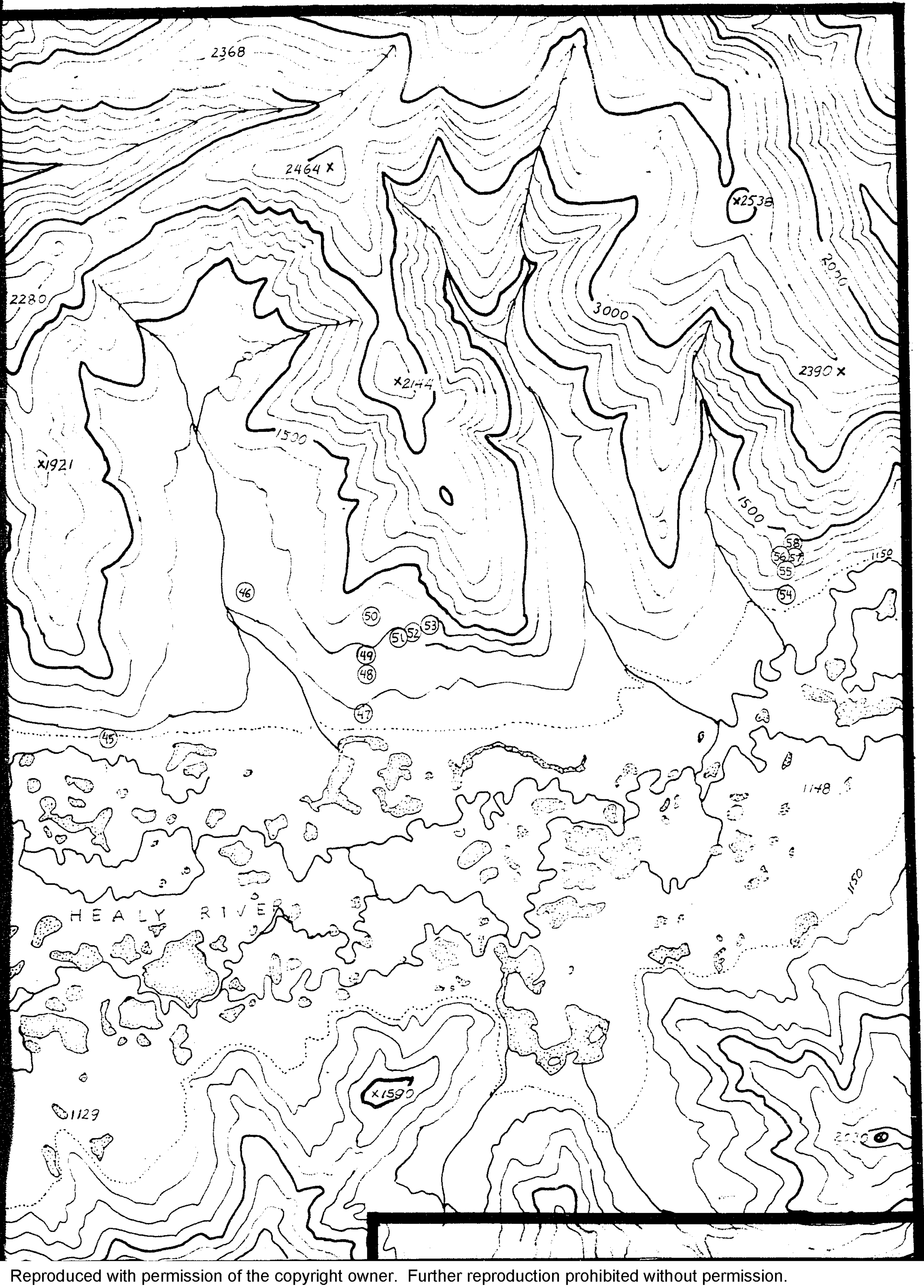
Silt and clay; late Holocene

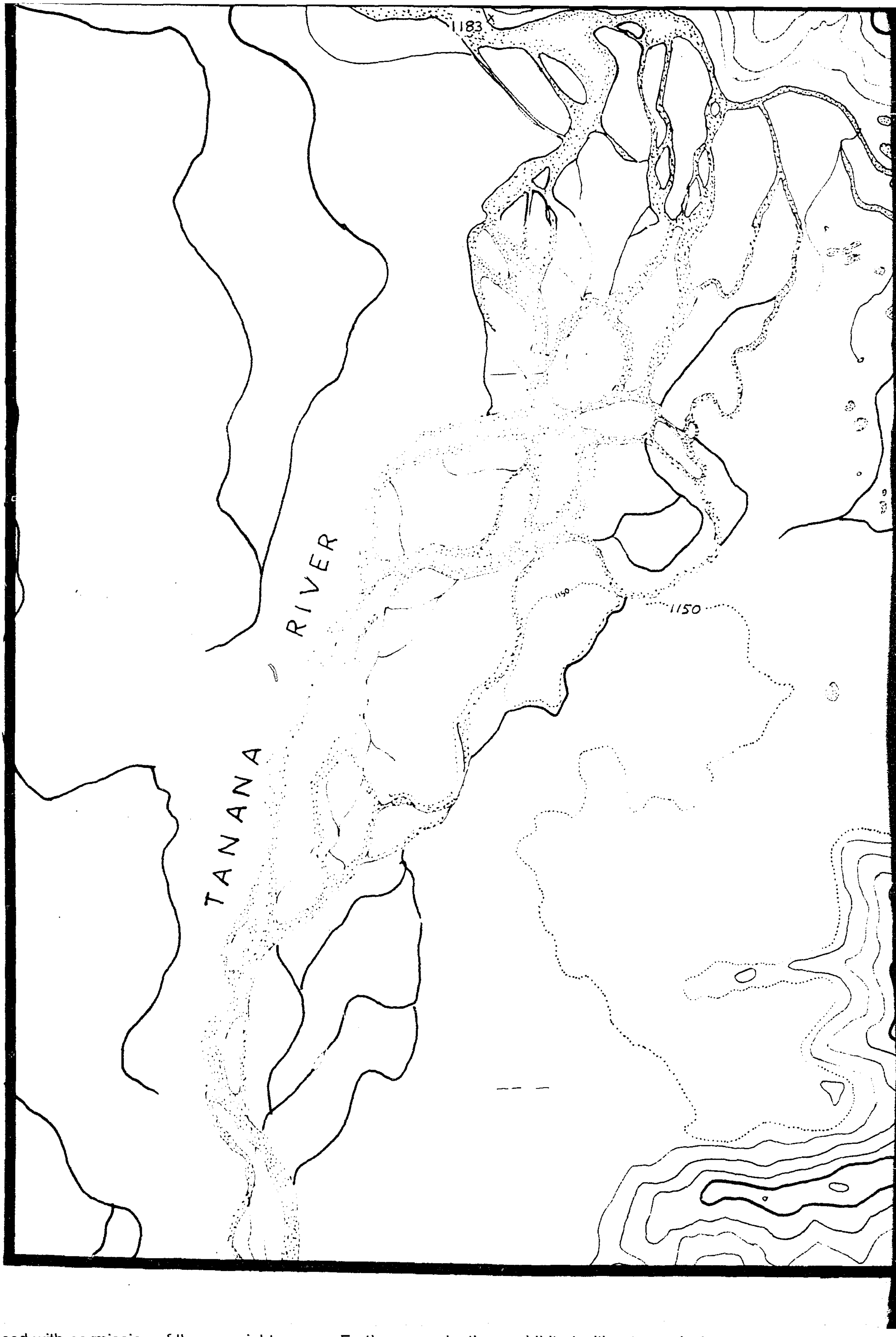
FIELD & PHOTOGEOLOGIC MAPPING BY THOMAS AGER, 1969

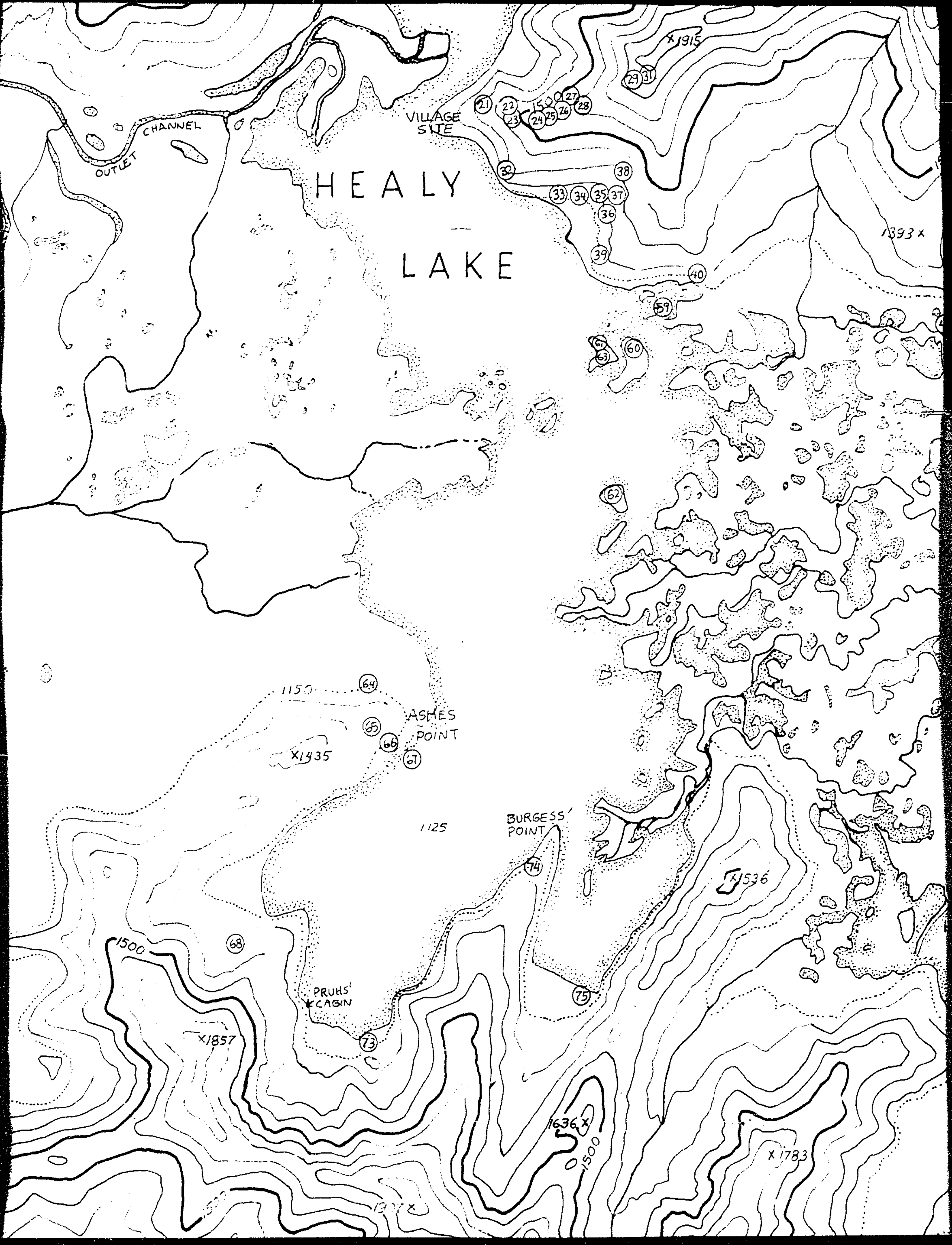

12
①
1405
1500
1665
②
1183
1150
1150
RIVER
NANA


HEALY
LAKE
VOLKMAR SADDLE
CANYON CREEK
KIDNEY HILL
VILLAGE SITE
OUTLET CHANNEL
ASHES POINT
BURGESS POINT
X1665
X1620
X1855
X1915
1540
1500
2212
1393 X
1150
X1435
1125

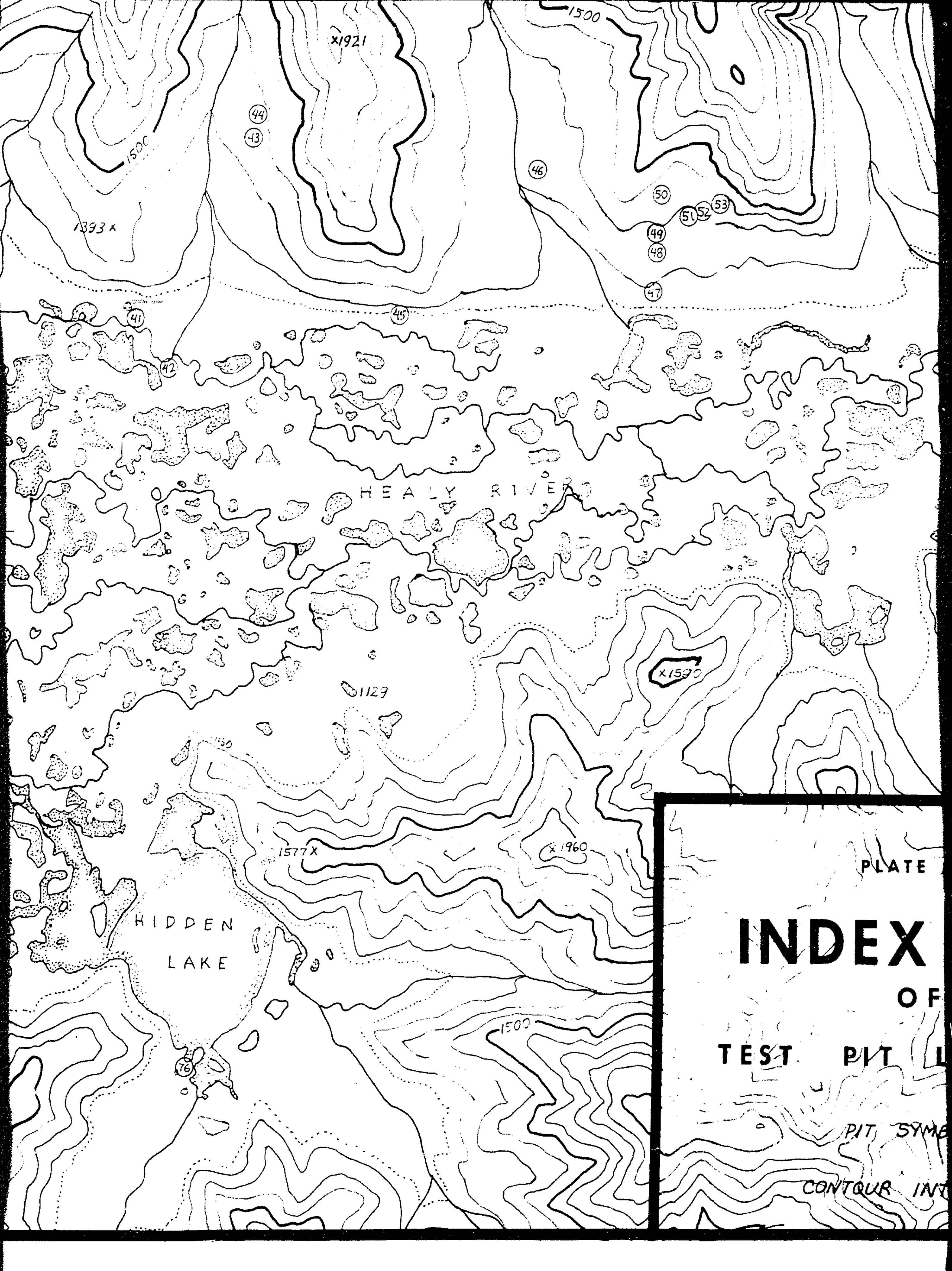

2368
1500
2464 x
1500
2000
2212
x2144
3000
1500
x1921
44
43
1500
1393 x
46
50
51
52
53
49
48
47
41
45
42
HEALY RIVER
x1590
1129
1150
x 1960


2368
2464 x
x2538
2280
3000
2000
x2144
2390 x
1500
x1921
1500
1150
1148
HEALY RIVER
1150
1129
x1590


1183
TANANA RIVER
1150
1150



x1915
29
31
21
22
23
1500
24
25
26
27
28
VILLAGE SITE
OUTLET CHANNEL
HEALY
LAKE
32
38
33
34
35
37
36
39
40
1393 x
59
61
63
60
62
1150
64
ASHES POINT
65
66
67
x1435
1125
BURGESS' POINT
74
x1536
1500
68
PRUHS' CABIN
75
73
x1857
1636 x
1500
x 1783


1500
x1921
44
43
1500
46
50
51
52
53
49
48
47
1393 x
41
45
42
HEALY RIVER
1129
1577 X
x 1960
HIDDEN LAKE
1500
76
PLATE
INDEX
OF
TEST PIT

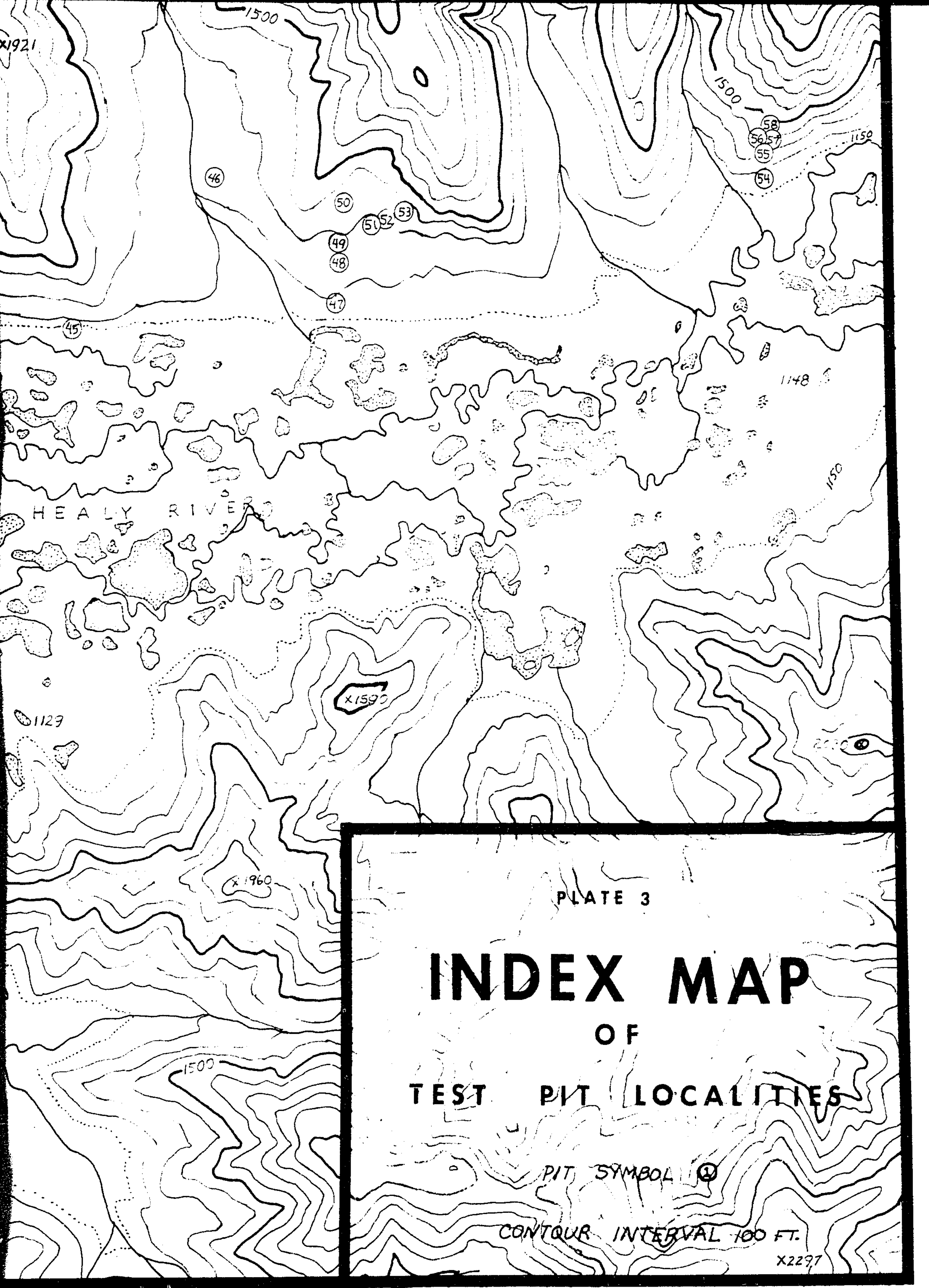
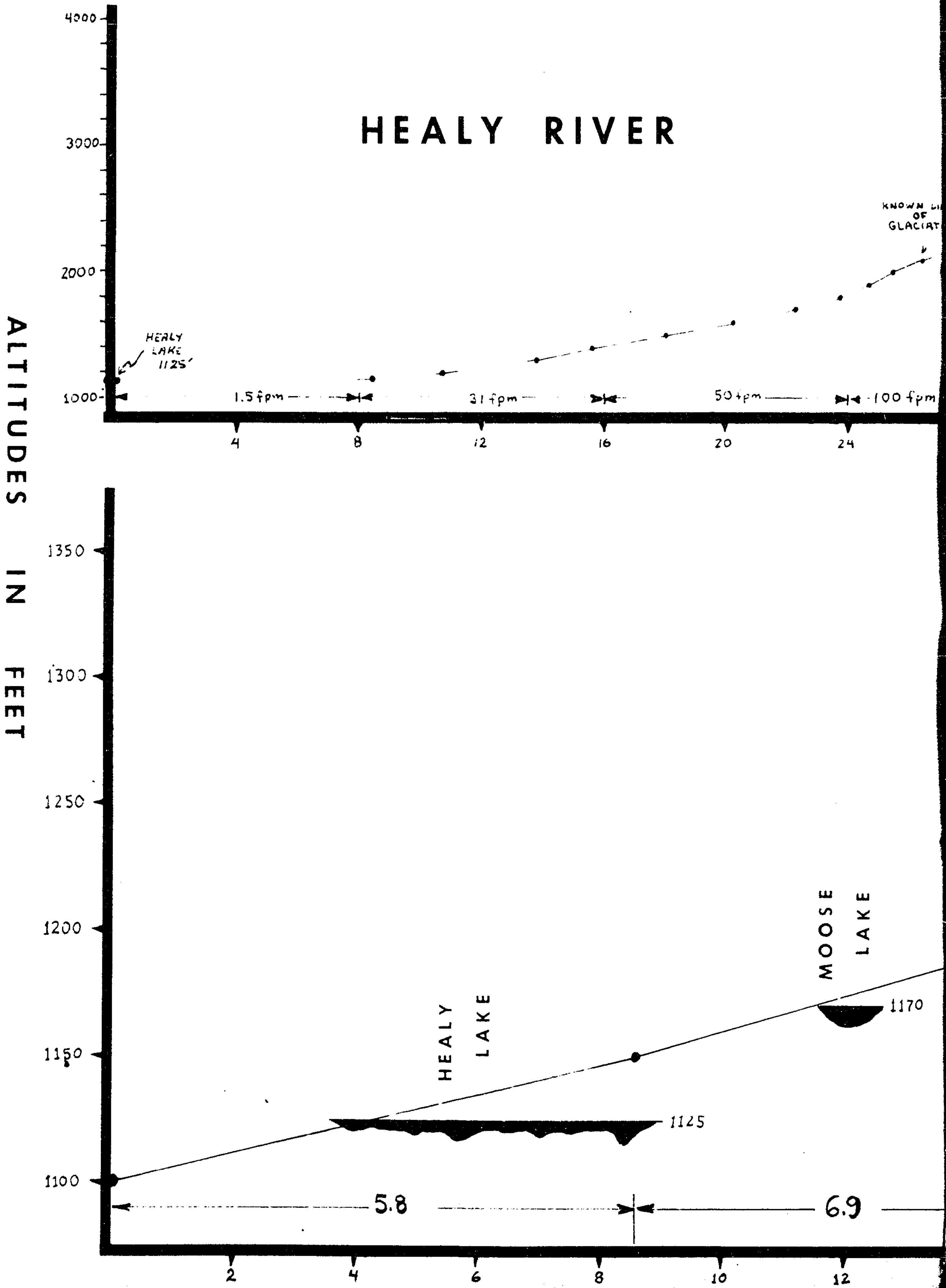
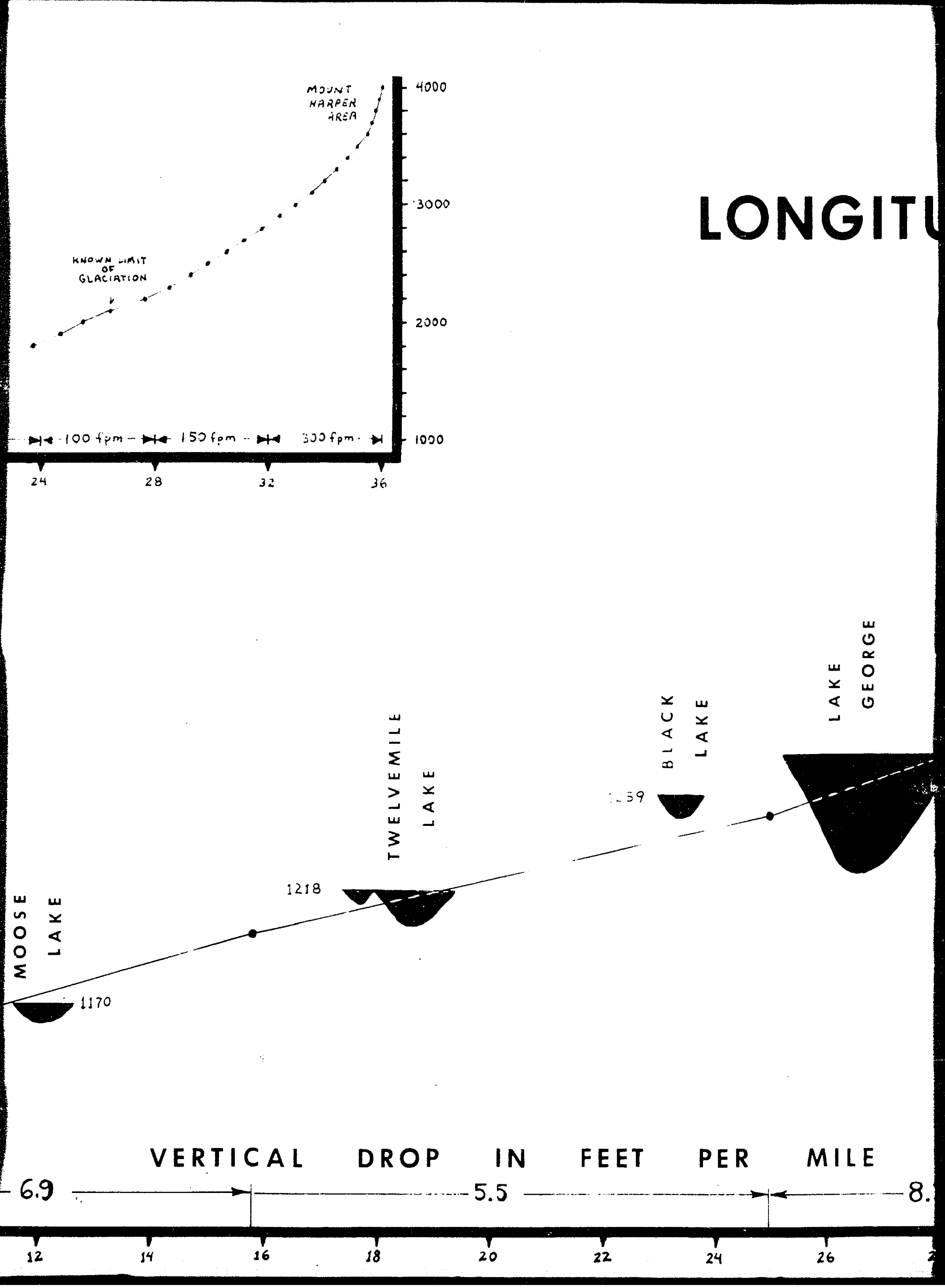


PLATE 3
INDEX MAP
OF
TEST PIT LOCALITIES
PIT SYMBOL
CONTOUR INTERVAL 100 FT.
HEALY RIVER
x1921
1500
1500
1150
1148
1150
x1590
1129
x 1960
1500
X2297
45
46
47
48
49
50
51
52
53
54
55
56
57
58


HEALY RIVER
ALTITUDES IN FEET
4000
3000
2000
1000
HEALY LAKE 1125'
KNOWN LI OF GLACIAT
1.5 fpm
31 fpm
50 fpm
100 fpm
4
8
12
16
20
24
1350
1300
1250
1200
1150
1100
HEALY LAKE
MOOSE LAKE
1170
1125
5.8
6.9
2
4
6
8
10
12


LONGITU
MOUNT HARPER AREA
KNOWN LIMIT OF GLACIATION
4000
3000
2000
1000
100 fpm
150 fpm
300 fpm
24
28
32
36
MOOSE LAKE
1170
1218
TWELVEMILE LAKE
59
BLACK LAKE
LAKE GEORGE
VERTICAL DROP IN FEET PER MILE
6.9
5.5
8.
12
14
16
18
20
22
24
26

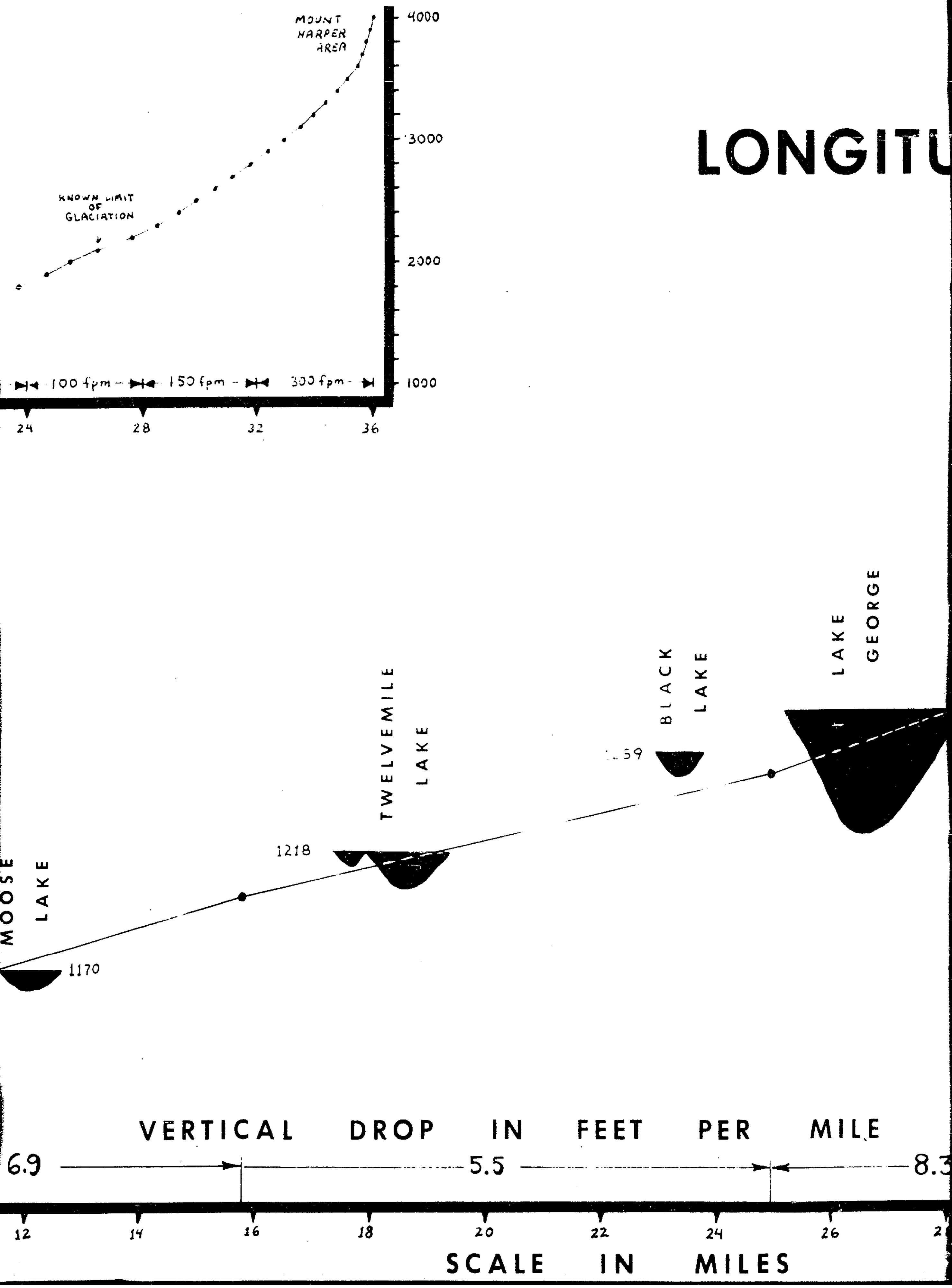
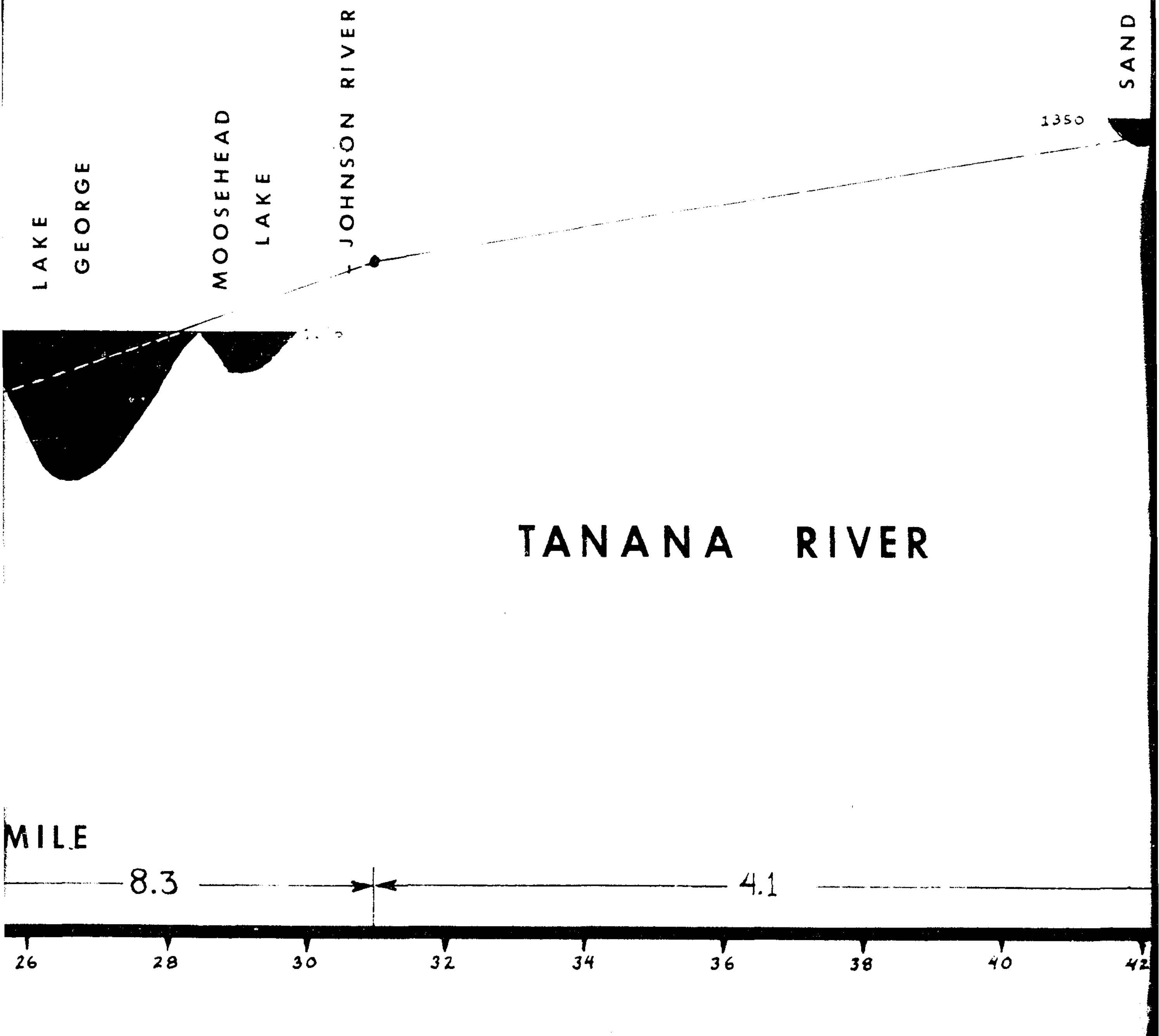

LONGITU
MOUNT HARPER AREA
KNOWN LIMIT OF GLACIATION
4000
3000
2000
1000
100 fpm
150 fpm
300 fpm
24
28
32
36
MOOSE LAKE
1170
TWELVEMILE LAKE
1218
BLACK LAKE
LAKE GEORGE
VERTICAL DROP IN FEET PER MILE
6.9
5.5
8.3
12
14
16
18
20
22
24
26
SCALE IN MILES

PLATE 4

IGITUDINAL PROFILES



LATE 4

AL PROFILES