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A reconnaissance of the late Tertiary and Quaternary geology geomorphology and contemporary surface hydrology of the Rattlesnake Creek watershed Missoula County Montana

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A RECONNAISSANCE OF THE LATE TERTIARY AND QUATERNARY GEOLOGY, GEOMORPHOLOGY AND CONTEMPORARY SURFACE HYDROLOGY OF THE RATTLESNAKE CREEK WATERSHED, MISSOULA COUNTY, MONTANA

by

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A Reconnaissance of the Late Tertiary and Quaternary Geology, Geomorphology and Contemporary Surface Hydrology of the Rattlesnake Creek Watershed, Missoula County, Montana (85 pp.)

Director: Robert R. Curry RRC

This study integrates information on the surficial geology, bedrock geology, geomorphology and hydrology of the Rattlesnake Creek watershed northwest of Missoula, Montana to provide reconnaissance-level land use planning base information.

The approximate distribution of geologic units was mapped by field traverses and air-photo interpretation. Their properties were obtained from field observation and detailed study of representative soil profiles. Laboratory testing by sieve and hydrometer established particle-size distributions for representative soil profiles. Microscope and x-ray diffraction study identified aspects of the mineralogy of the silt and clay fractions. Geomorphic data were generated from existing maps and plotted graphically. Stream discharge data were generated by surveying cross sections of the main stream channel and employing the slope-area method. These hydrologic data were compared to those from other watersheds and streams in western Montana.

The distribution of glacial till and erratics, as well as the presence of a buried argillic soil horizon, indicates that multiple Pleistocene glacial advances of variable extent have occurred in the watershed. One of these was probably 130 to 150,000 years old and more extensive than previously believed. Surface layers of some soils are partially wind-transported and include volcanic ash, probably from the Cascade Range. Hydrologic and morphologic data indicate that the watershed is a more effective precipitation catchment than are other regional watersheds. The upper portion of the watershed yields relatively large flood discharges.

Land use planners should consider the implications of interglacial and post-glacial landslides, low-permeability soil materials in the lower watershed, high erodability soils in the upper watershed and large flood discharges and shallow ground water in the canyon bottom. The combined factors indicate the watershed is particularly sensitive to disrupting activities. Further study of some sites is merited because of unique conditions of preservation of deposits within the watershed that can yield more information on the Pleistocene and Holocene geologic and climatic history of the area.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

Rattlesnake Creek drains a watershed of 205 km^2 (79.2 $mi.^2$) north of the City of Missoula, in western Montana. Historically valued as a water supply area, portions of the watershed are now or have been used for logging, grazing, framing, and mining. Presently the area is partially protected by access restrictions on motor vehicles and is increasingly used for recreation. Crucial management decisions concerning the future of this unique resource will be made in the next few years and the data available for making them are limited. Only ten years of discontinuous hydrologic record is available for estimating the watershed's hydrologic parameters, soil data are preliminary and geologic information relevant to the planning process is sparse. As a tributary of the Clark Fork River within the Missoula basin, Rattlesnake Creek's watershed is unique in having extensive and well developed glacial morphology in its upper reaches. The area provides information of academic and practical interest for the delineation of Quaternary stratigraphy and geologic history.

Scope of Study

The author intends this study to present some preliminary information on the late Tertiary and Quaternary geology, geomorphology and contemporary surficial hydrology of the Rattlesnake Creek watershed.

The lower portion of the Rattlesnake watershed is structurally, lithologically and morphologically similar to the lower portions of other watersheds along the northern margin of the Missoula basin. Where relevant for interpreting the geologic history of the Rattlesnake watershed, morphologic information about other portions of the basin is presented. This information is intended to supplement information on the primary study ara. Maps are not included. The reader should refer to the appropriate 7 1/2' topographic maps, produced by the U.S. Geological Survey.

The scope of the study has three parts:

1) To present a reconnaissance-level delineation of the nature and distribution of Tertiary and Quaternary deposits in the Rattlesnake watershed and to interpret aspects of the area's geologic history in the context of the local morphology, surficial stratigraphy and soil development
2) To provide a quantitative appraisal of the hydrodynamics of the watershed by comparing bankfull discharge estimates at different sites on the main stream and these, in turn, to discharge data from other streams in western Montana
3) To identify some considerations for land use planning in the area.

Methods of Study

The geologic information was obtained by traversing the major sub-drainages and their divides on foot, mapping till and till-like deposits, as well as apparent upper limits of glacial drift and striations. The boundaries of these deposits were further defined by mapping from false-color, infra-red aerial photography provided to the University of Montana by NASA. Soil profile samples were collected from Quaternary deposits at three sites in the watershed and analyzed for particle size distribution and type of clay minerals present. In the southern portion of the drainage, observations pertinent to the discussion of Tertiary sediments and their Quaternary reworking were made by field inspection of numerous construction excavations in the Rattlesnake Creek watershed and nearby portions of the Missoula basin.

Morphologic information was gathered through field observations and the study of aerial photographs and topographic maps. A point-count procedure was used on a topographic map base to produce a dimensionless hypsometric curve for depicting land area distribution and elevation.

Hydrologic field data were gathered by measuring channel cross sections at three sites along the trunk stream. Bankfull discharge was estimated by the slope-area method and this, in turn, was compared to gage data from Rattlesnake Creek and other gaged streams in western Montana.

Previous Work

Several authors have described or mapped portions of the Rattlesnake Creek watershed in the course of other studies and have thereby provided a base of information upon which this study elaborates.

Nelson and Dobell (1961) mapped the pre-Tertiary geology of the southern portion of the watershed in the course of mapping the geology of the Bonner 15 minute quadrangle. All Quaternary deposits were mapped as alluvium, colluvium or landslides. They recognized the largest landslide in the lower portion of the watershed and presented structural information on the Paleozoic and Precambrian rocks, which is herein compared with morphologic data generated for this study.

Konizeski, in McMurtney and others (1965), mapped the lower portion of the watershed in an overview fashion as a portion of a map of the Missoula basin. He delineated two deposits of Quaternary alluvium as well as glacial lake deposits, two Tertiary units and "basement rocks".

Alden (1953, p. 108-109) described the "Glacier of Rattlesnake Creek" and determined its terminus to have been at a prominent transverse moraine in the canyon bottom (SW 1/4, Sec. 19, T.13N, R.18W). In addition, he observed the relatively high gradient of the uppermost outwash terrace below the moraine and hypothesized it was the result of "torrential" transport or deposition from the wasting glacier front. Evidence gathered in the course of this study suggests both processes may have operated.

Published soil data is lacking though preliminary mapping has been completed by the Missoula Office of the Soil Conservation Service (Personal communication, Mr. Doug Harrison, 1976). This work provides a delineation of soil types though it does not primarily attend to the genetic interpretations pertinent to this study.

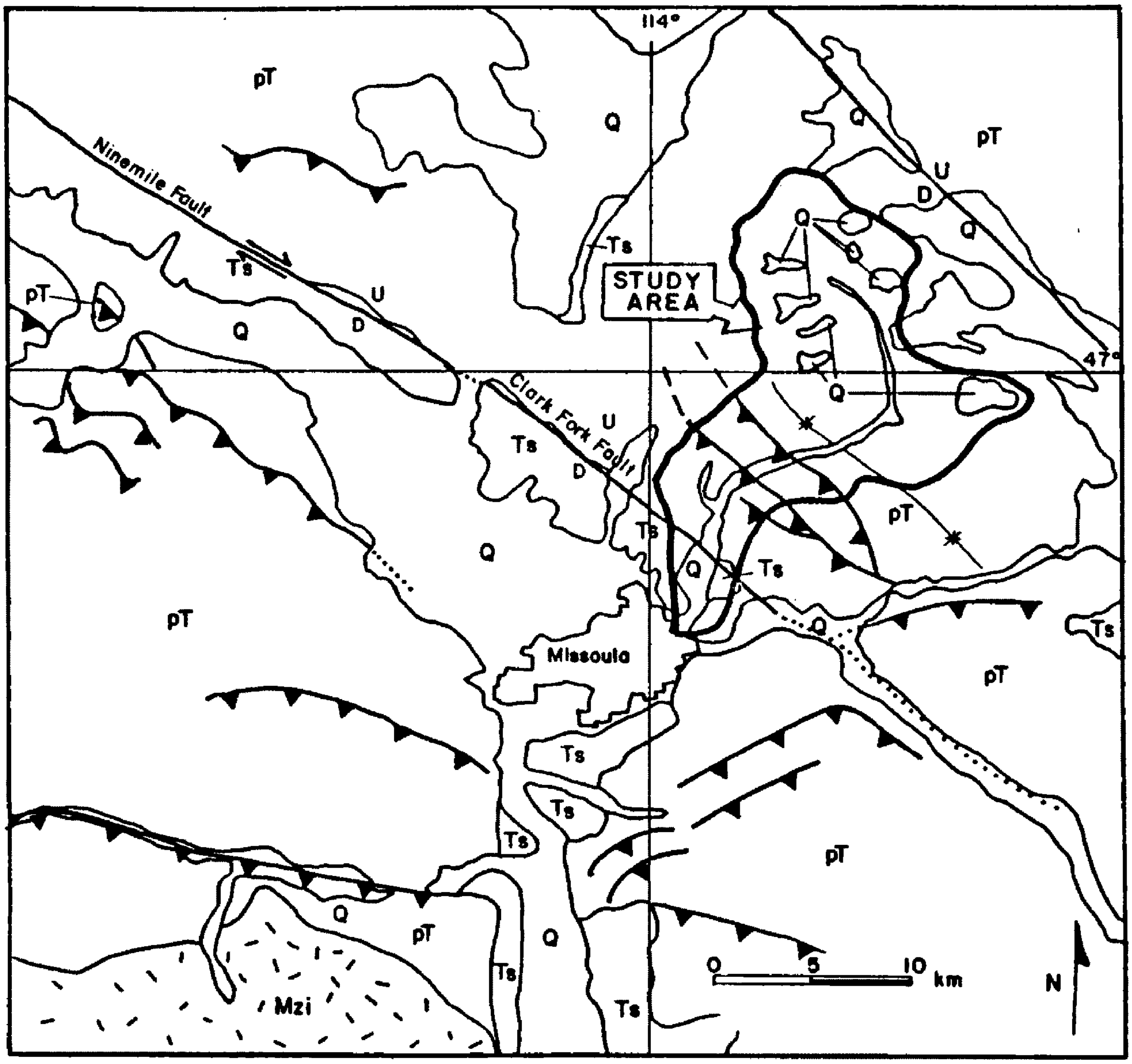
Ten years of discontinuous gage data were available from records of the U. S. Geological Survey. These data have been used in the hydrologic portion of this study.

CHAPTER II

GEOGRAPHY AND REGIONAL GEOLOGIC STRUCTURE

Within the Rattlesnake Creek watershed vegetative associations vary from grassland with a timbered watercourse, through pine and spruce forest to scrub timber in the sub-alpine zone, and moss and lichen in the alpine zone. Precipitation amounts increase with altitude, varying from 36 to 38 cm (14 to 15 in.) per year in the lower elevations to over 127 cm (50 in.) per year in the mountains (U.S.D.A., Soil Conservation Service, 1974).

Rattlesnake Creek drains two different geographic and structural areas. One, a block-like mass of Precambrian and Paleozoic rocks has been uplifted and tilted relative to the other, a downfaulted wedge of similar rocks, now partially covered by Tertiary and Quaternary basin deposits (Figure 1). In this paper the two areas will be referred to as the Rattlesnake Mountains and the Missoula basin. Though it appears the division between the two may actually be established by several sub-parallel faults (see map plate), the name "Clark Fork Fault" has precedence in the literature (Nelson and Dobell, 1961; McMurtney and others, 1965). It is here used to refer to the approximately linear zone of abrupt slope and lithologic transition between the mountains and the basin. Southwest of both the Rattlesnake Mountains and the Missoula basin are the Bitterroot Mountains. In the interior of the Bitterroots the rocks are dominantly quartz monzonite of the Idaho batholith, emplaced during late Cretaceous and early Tertiary time. Precambrian and Cambrian rocks on the southern margin of the Missoula Basin were generally thrust northward to their present location during the late Cretaceous or Tertiary (Hall, 1968); see Figure 1. Structure in the Precambrian and Cambrian rocks in the Rattlesnake watershed is dominated by northwest trending thrusts and fold axes. The equal area plot of poles-to-bedding in Figure 16 illustrates this well. The trend of the structural features suggest the dominant deformation was caused by local compressive stress from the southwest. Current theories for the origin of these stresses hypothesize tectonic transport to the north, away from the Idaho batholith (verbal communication, Dr. D. Alt, Univ. of Montana, 1978). The trend of the structural features suggests that compressive forces originated to the southwest, in the vicinity of the Idaho batholith. After thrust faulting, recurrent normal and strike-slip faulting displaced Precambrian, Cambrian and Tertiary sediments. As a result, at least one angular unconformity exists between tilted deposits of Tertiary sediments, rich in volcanics, and an overlying gravel cap of Pliocene-Pleistocene age. A generalized sequence of the geologic units is represented on the map plate and a generalized column of the Tertiary Units is presented in Figure 2. A generalized block diagram of the area, showing structural and lithologic relationship is presented as Figure 3.



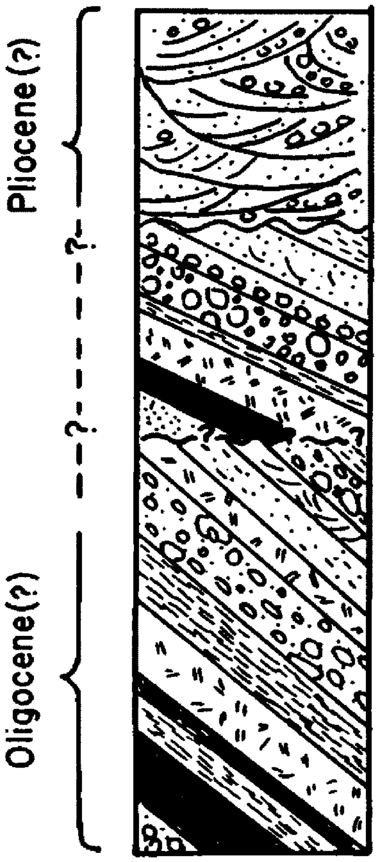
Explanation

D / U — faults: sawteeth on upper plate of thrust; arrows indicate relative movement

syncline

Q - Quaternary deposits
Ts - Tertiary sediments
pT - pre-Tertiary sediments
Mzi - Mesozoic intrusives

Figure 1. Regional structure and study area.



silty gravel and sand; brown, cross-bedded; permeable; unconsolidated.

conglomerate, shale, sandstone and volcanic ash; yellowish brown, gray, pale yellow and red; low permeability; semi-consolidated.

shale, sandstone, siltstone and conglomerate with some coal; gray, brown, greenish gray and tan; slightly permeable to impermeable; high-swelling clays in shales; fossils suggest Oligocene age.

Figure 2. Generalized column of Tertiary deposits, Northwest portion of Missoula Basin, thicknesses vary.

Pleistocene deposits occupy most of Rat 'esnake Creek's valley bottom, both upstream from the trace of the Clark Fork Fault, where they directly overlie Precambrian metasediments of the Belt Supergroup, and downstream from the fault where they overlap the Tertiary Units. Most of these Pleistocene deposits are moraine and outwash that were deposited during one or more intervals of glaciation. Recurrent alpine

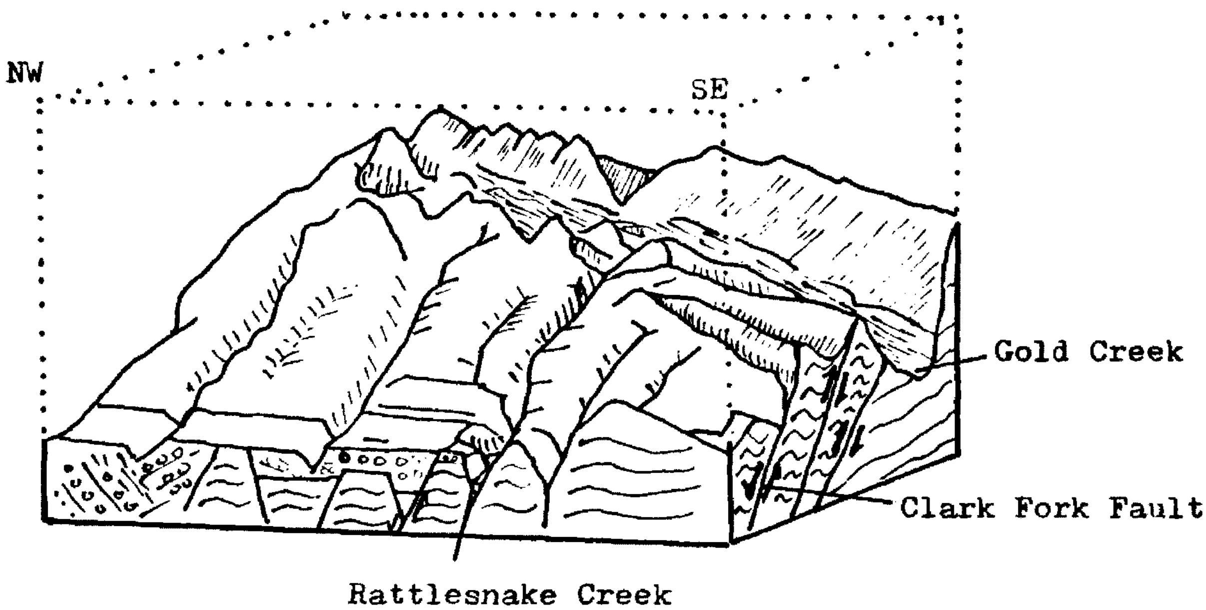


Figure 3. Generalized Block Diagram, Rattlesnake Mountains

glaciation in other mountain ranges in the region has been documented (Alden, 1953; Weber, 1972). This suggests that multiple glaciation occurred in the Rattlesnake Mountains as well. Evidence from the surrounding area indicates that on at least one occasion, the Rattlesnake Mountains lay at or near the southern terminus of the Clearwater-Swan Lobe of the Cordilleran Ice Sheet (Richmond and others, 1965). During several of its advances, Cordilleran ice dammed the Clark Fork River near the Montana-Idaho border and impounded vast quantities of water (Pardee, 1942; Alden, 1953). Strandlines from glacial Lake Missoula which formed as a result of this, are visible on the hillsides in the lower portion of the Rattlesnake watershed to an elevation of 1341 m (4400 ft.).

CHAPTER III

DISCUSSION OF MAP UNITS

A reconnaissance map of the Quaternary geology of the Rattlesnake Creek watershed is presented as a separate plate in an attached pouch. Selected features on the map are discussed below along with some information on erratics and littoral deposits.

Pre-Tertiary Rocks

Pre-Tertiary rocks are largely Precambrian and Cambrian sediments which have been subjected to low-to-intermediate grades of metamorphism. Argillites, siltites, quartzites and limestones predominate. Some of the rocks, particularly those in the southern half of the watershed, have been folded, fractured, faulted and intruded (Nelson and Dobell, 1961). During the Quaternary, large volumes of these rocks were eroded from the mountains and some of the material redistributed on the valley sides and bottoms as till, outwash, alluvium, talus, etc. Most of the drainage network of the watershed has been established in these rocks and appears to show a preferential development parallel and perpendicular to the strike of the bedding and fold axes (Figures 13 and 15). Different lithologies and formations have different weathering characteristics which affect outcrop morphology and soil development. In general, limestone and dolomite of the well-fractured Wallace

Formation (mapped as the Newland Formation by Nelson and Dobell, 1961) form deep colluvial mantles containing flat, angular fragments of parent rock. Pink, feldspathic quartzites of the Bonner Formation weathered mechanically to a blocky rubble. Clasts appear to become rounded by both chemical and mechanical processes often producing a sandy soil. Outcrops of the Bonner are relatively rare. Argillites and siltites of other formations as well as quartzites of the Pilcher Formation are more resistant to weathering and are therefore more commonly represented among striated erratics. Their outcrops are often prominant with planar, three dimensional jointing.

Most of the pre-Tertiary rocks are relatively impervious to fluids except where fractured. They show evidence of mass failure at one location described in the section of landslides.

Tertiary Deposits, Undifferentiated

Tertiary deposits outcrop primarily along the sides of the Rattlesnake valley, south of the trace of the Clark Fork Fault. A wide variety of lithologies include consolidated gray, buff and red shale, sandstone, conglomerate and volcanic ash, as well as unconsolidated clay, gravel and sand. Natural exposures of these units are rare and field observations have relied largely on information derived from construction excavations, landfill sites and gravel pits. It has not been possible to observe or construct a complete section. However, observations of the Tertiary sediments in the Rattlesnake watershed as well as those in nearby portions of the Missoula Basin, permit construction of a generalized column here presented as Figure 2. Seismic data prepared by this author in 1973 suggest that the east knoll of Waterworks Hill (NW 1/4, NE 1/4, NE 1/4, Sec. 15, T.13N, R.19W) is capped by 5 to 7m (15 to 20ft) of unconsolidated Tertiary and Quaternary sediments, which overlie bedrock of the Wallace formation. From the top of the knoll, the thickness of the deposit decreases in all directions. Across the Rattlesnake Creek valley, below the saddle of Mt. Jumbo (SE 1/4, Sec. 11, SW 1/4, Sec. 12, NE 1/4, Sec. 14, T.13N, R.19W) a brown gravel cap of variable thickness overlies light yellowish brown (2.5Y 6/4, dry) and red (2.5YR 5/6, dry) Tertiary clays. Unified Soil Classification field tests indicate the clays have high-to-low plastic properties. "Popcorn" weathering textures strongly suggest at least a moderate content of smectitic clays. Other investigators have demonstrated the presence of smectite clays in comparable materials in the Missoula Basin (verbal communication, Dr. Graham Thompson, Univ. of Montana, 1976).

Glacial Till

Distribution and General Properties

Deposits of unstratified and weakly stratified Pleistocene glacial drift cover portions of the floors of cirques, hanging valleys and of the main valley floor in the Rattlesnake Creek watershed. In addition, till and till-like deposits mantle consolidated rock in depressions and cols along the northeast and east drainage divide common to Rattlesnake

Creek and Gold Creek. Other deposits of till are found in small depressions in pre-Tertiary rocks which form the lower canyon walls. For purposes of this report, till is considered to exclude those deposits near cirque headwalls, presumed to be neoglacial by the lack of vegetation and the angularity of their boulders. Only the larger deposits of till are recognized on the map. These deposits generally have poorly defined boundaries and show considerable variation in thickness due to irregularities in bedrock topography. The operational criterion used to map the deposits was that they have a probable thickness equalling or exceeding 1 meter. This estimate was based on field data from natural and man-made exposures and inference about bedrock topography. The prevalence of dashed lines delineating the deposits indicates the uncertainties involved in these estimates.

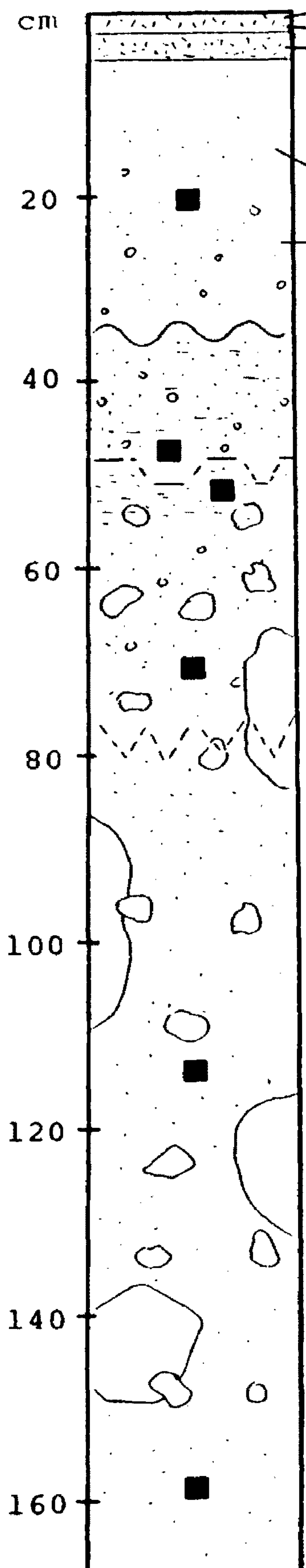
The composition of the tills varies with geomorphic position and parent rock. Northeast-facing cirques that lie below the western drainage divide contain detritus from the Garnet Range and McNamara formations of the Belt Supergroup. Till in Shoofly Meadows is dominated by detritus from the Bonner Quartzite and the Miller Peak argillite. Cirques on the north side of Sheep Mountain contain rocks from the Garnet Range and Pilcher formations. Till in a prominant moraine on the canyon bottom, near the trace of the Spring Gulch fault, comprises many lithologies. Near the surface of the moraine, gabbro and diabase from a nearby dike are common among the constituents. In general, the weathering characteristics of the rocks, varying distances from sources and the mechanics of deposition appear to cause large variations in particle size distributions in the till.

Soil Development on Till

In the past few decades increasing attention has been focused on distinguishing tills of different ages by comparing their weathering characteristics. Birkeland (1974) has summarized and explained some of the techniques involved. Comparative soil development has emerged as a useful though inexact tool for delineating Quaternary stratigraphy, when considered in the context of parent rock, elevation, geomorphic position, climate, drainage, etc.

Study Sites and Analyses

From information gathered in the course of field investigation, three sites, judged representative of nearby deposits, were chosen for detailed study hoping to establish differences which would permit relative age distinctions. The locations of these sites are noted on the descriptive soil profile columns presented as Figures 4, 6 and 8. Approximate locations are shown on the map in Figure 10. At each site a soil pit approximately 1.6 m in depth was excavated, the soil profile described and sampled at selected depths. Samples were analyzed for particle size distribution by wet sieve and hydrometer methods. The data, plotted as cumulative distributions, are presented as Figures 5, 7 and 9. Samples from upper horizons were examined under a polarizing microscope in an attempt to detect volcanic ash. Portions of seven samples were dispersed in distilled water with



O1 forest litter

O2 forest litter decomposed

A1 dark gray silty sand (10YR 4/1, moist), fine granular structure, many fine roots abrupt wavy boundary

Birh (?) brown to dark brown (7.5 YR 4/4 to 7.5 YR 5/6, moist); structureless

Bir silty and sandy pebble gravel with numerous random rootlets

Cn pinkish gray (5 YR 6/2, moist); silty and sandy pebble gravel; faint bedding; abrupt broken boundary

IIB_{2t} reddish yellow (7.5 YR 6/6); compact clayey cobble gravel; weak structure quartzites have 3-5 mm weathering rind; gradational boundary

II Cox light reddish brown (6 YR 6/5); sandy boulder gravel; moderately well compacted

Figure 4. Soil profile, Shoofly Meadows Site. NE 1/4, SE 1/4, Sec. 5, T14N, R17W, slope 6°

(colors pertain to dry state unless otherwise noted, black squares indicate sample locations).

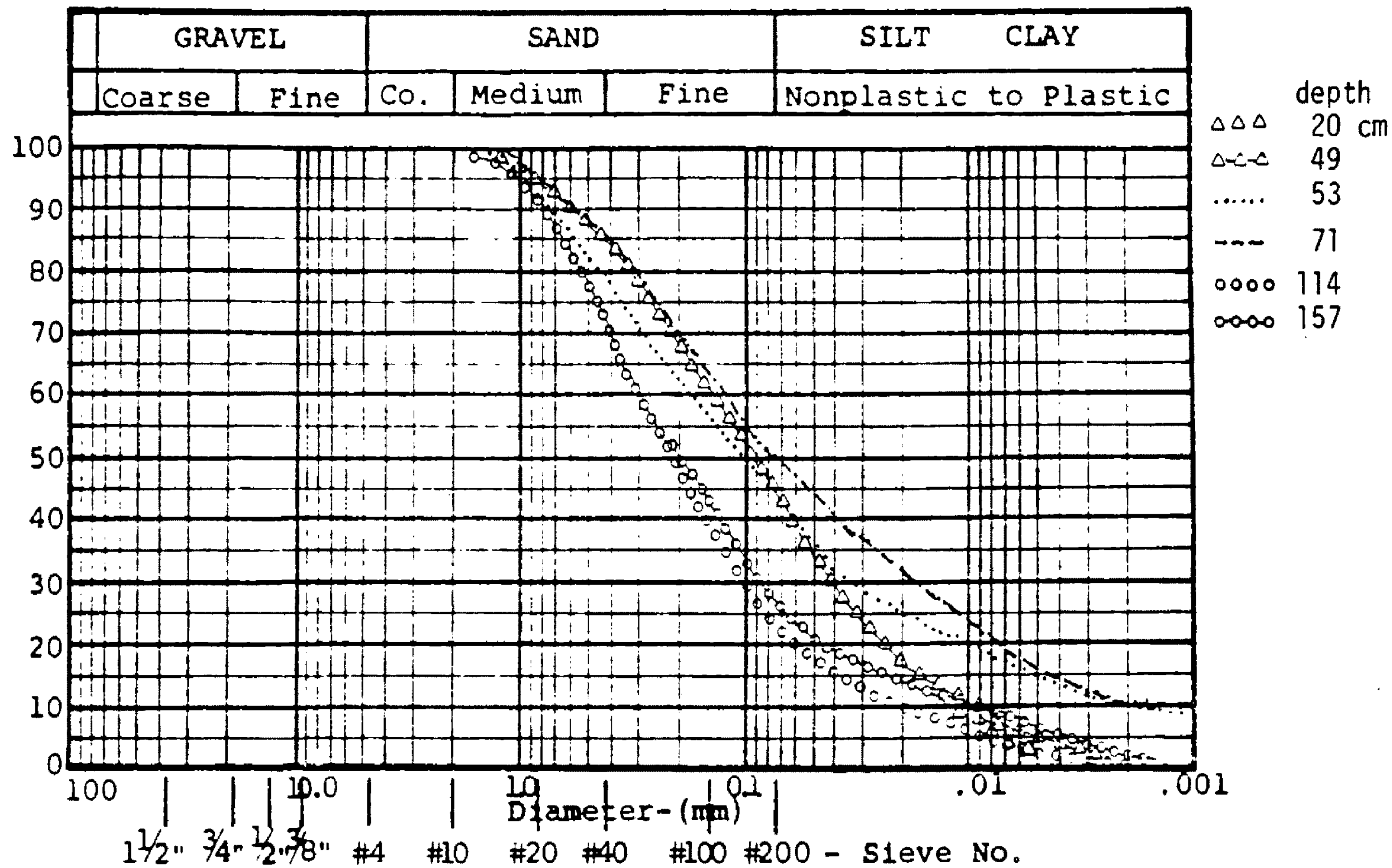
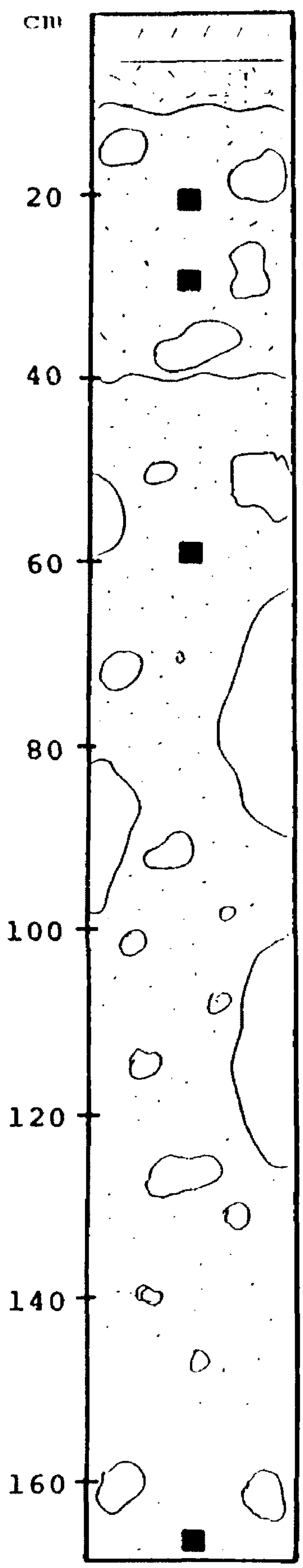


Figure 5. Particle size analyses, Shoofly Meadows Site



O_1 forest litter

O_2 forest litter decomposed

A_1 dark gray (10 YR 4/1, moist); sandy silt, fine granular structure, numerous rootlets; abrupt wavy boundary

Bir light yellowish brown (10 YR 6/4) silty gravel; weakly developed fine granular structure; numerous random rootlets; slightly sticky, non-plastic; abrupt wavy boundary

C_n pinkish gray (5 YR 7/2) sandy and silty gravel; structurless; no bedding, max. particle diam. 1 m.

Figure 6. Soil profile, Franklin Guard Station Site, NW 1/4, NE 1/4, Sec. 14, T14N, R18W.

(colors pretain to dry state unless otherwise noted, black squares indicate sample locations)

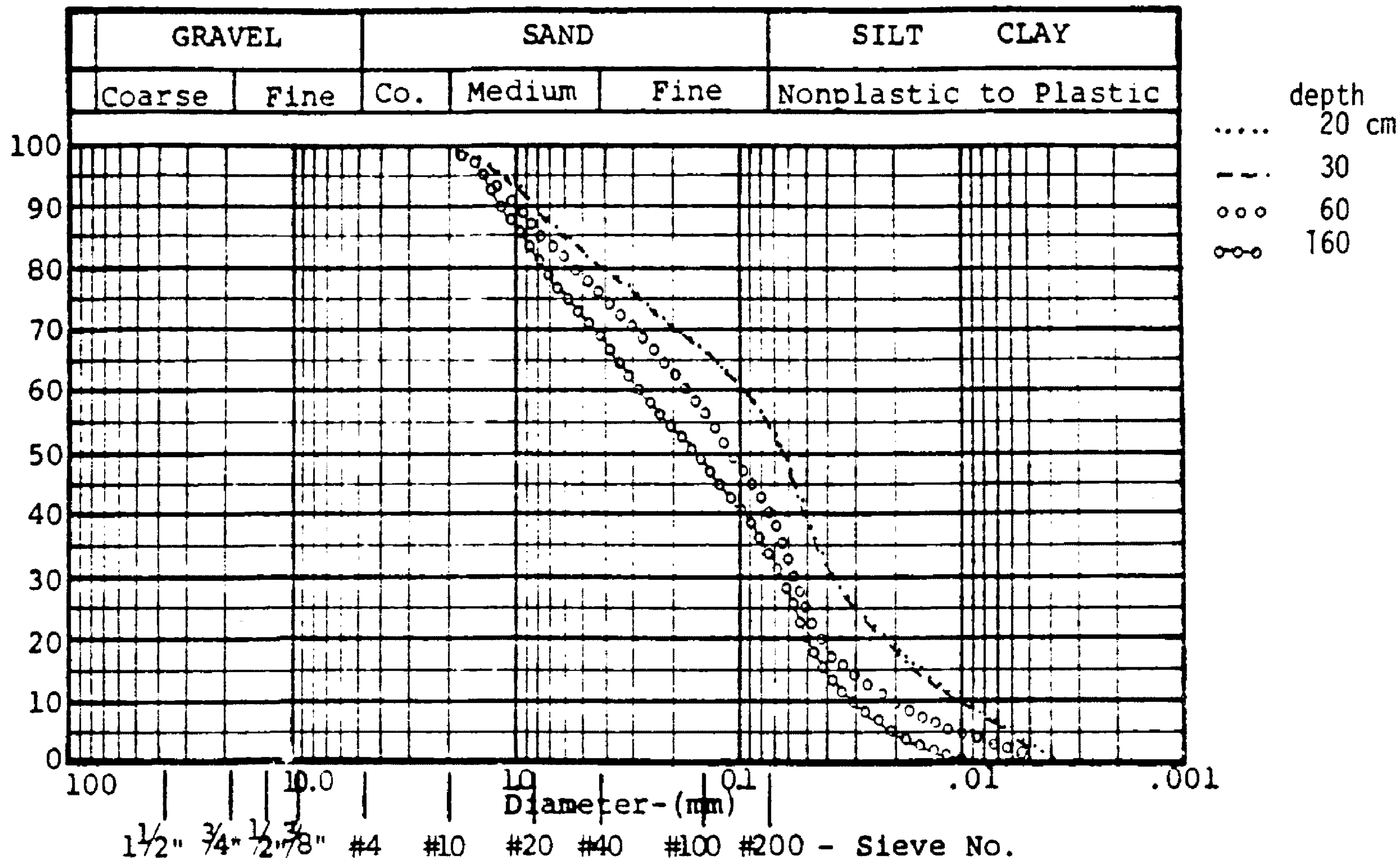
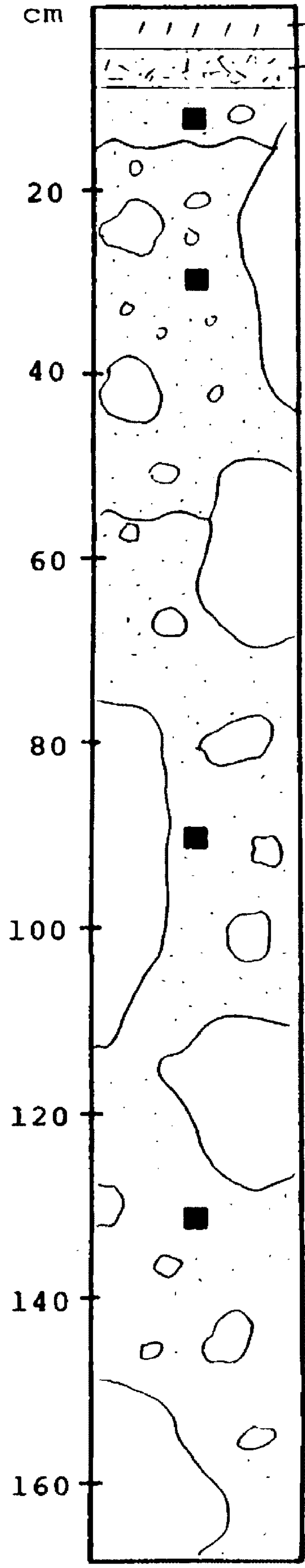


Figure 7. Particle size analyses, Franklin Guard Station Site



O_1 forest litter

O_2 forest litter, decomposed

$A_{2(?)}$ (E?) light brownish gray (10 YR 6/2); sandy silt; no structure; numerous rootlets; contains glass shards; abrupt boundary

Bir yellowish brown (10 YR 5/4); silty gravel, very fine granular structure, soft, finable, porous, numerous fine roots, slightly sticky, non-plastic; abrupt wavy boundary

C_n pale brown (10 YR 6.5/3); silty sandy boulder gravel, no structure, faint bedding; max. particle diam. 2 m

Figure 8. Soil profile, Lake Creek Site NW 1/4, NE 1/4, Sec. 29, T15N, R18W, Slope 9°

(colors pertain to dry state unless otherwise noted, black squares indicate sample locations)

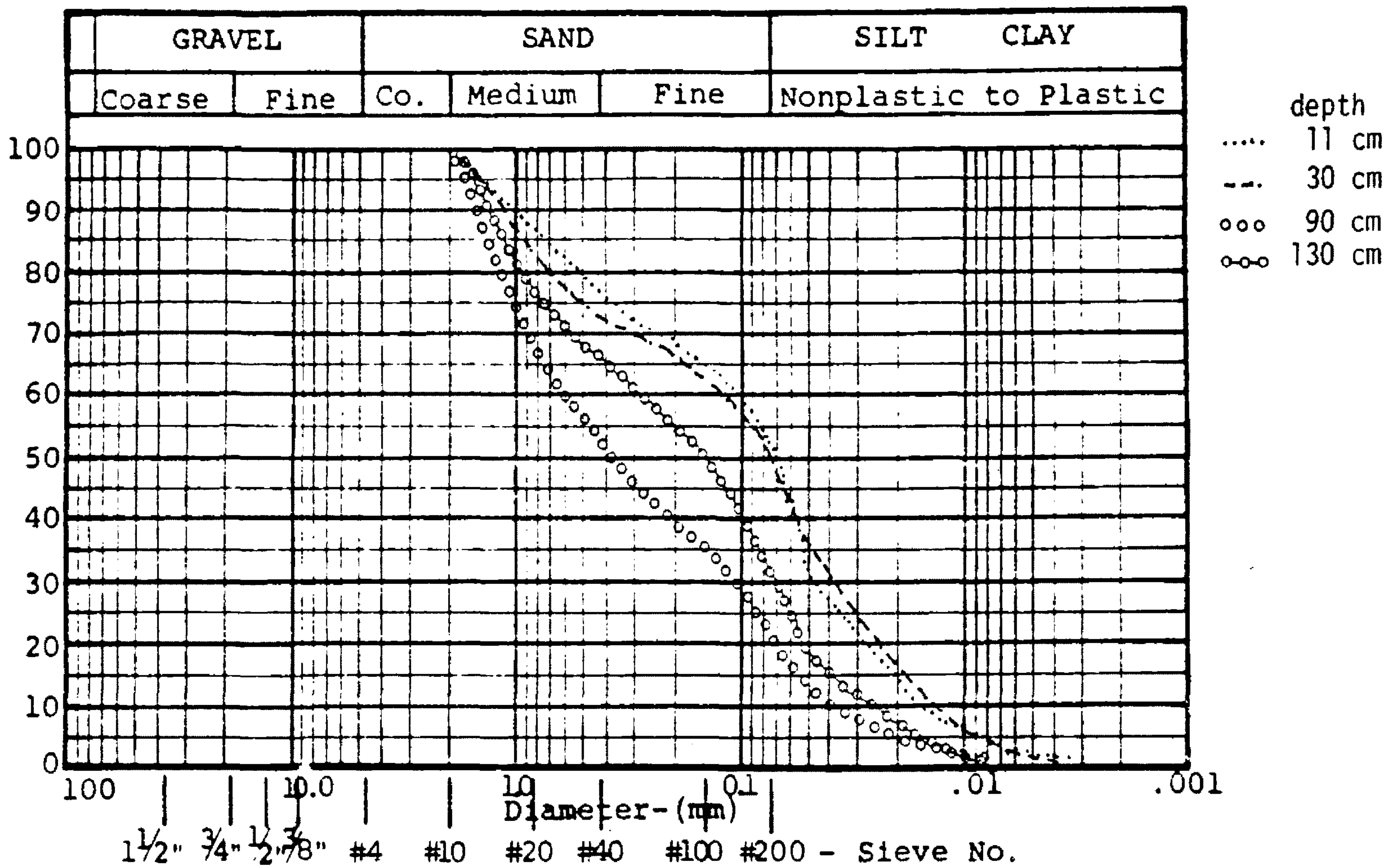


Figure 9. Particle size analyses, Lake Creek Site

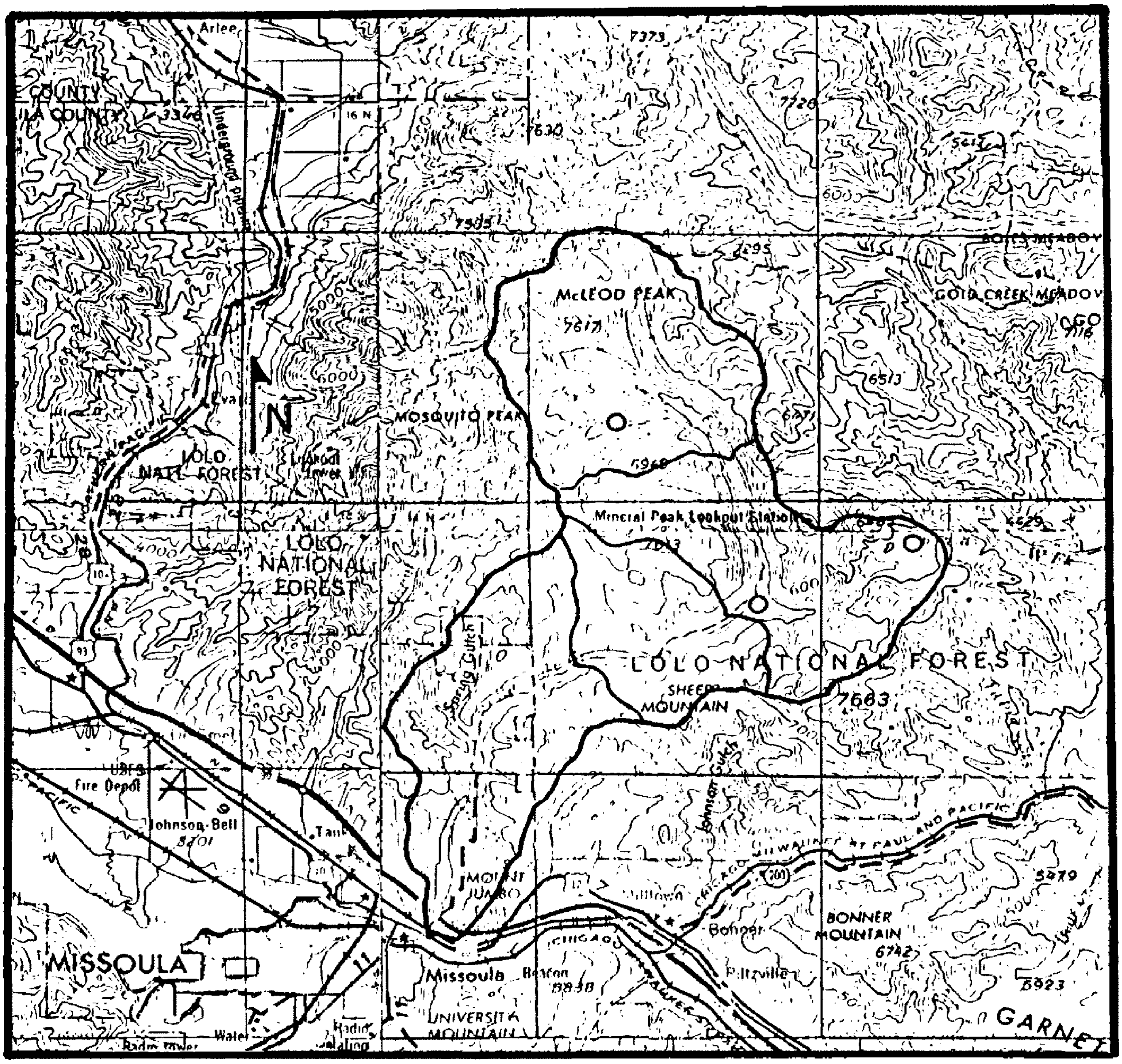


Figure 10. Rattlesnake Creek watershed; subdivisions show drainages of hydrologic study sites, circles show locations of soil study sites.

sodium hexametaphosphate, centifuged to obtain an equivalent particle size of less than 2 , and dried on glass slides to produce oriented mounts for x-ray diffraction study. Some of these slides were treated in a ethelyneglycol atmosphere for 24 hours. The diffraction patterns are presented in Appendix A, and interpretations of probable clay mineral constituents presented in Table 1.

Significant Features

The descriptive and analytical data show the existence of some distinct soil features which warrant discussion due to their significance in interpreting late Quaternary geologic history and the physical properties of the soils.

Bir Horizon. Soil profiles on all three tills have a common element represented as a near-surface accumulation of brown and yellowish-brown material rich in silt. On the basis of their physical properties, noted on the columns and attendant particle size curves, and descriptions of comparable materials by the Soil Conservation Service (1972), these horizons have been designated as "Bir". Ottersburg (1977) summarized data and opinions of soil scientists on the origins and physical properties of similar soil horizons in western Montana which he described as "andic" on the basis of their content of volcanic ash. Though a diversity of opinion was noteworthy, a consensus indicated the following:

Table 1. Clay mineralogu of soils on till

Location	Depth, CM	Horizon	Clay Minerals*
Shoofly Meadows site	19	Bir	Il., Ka.,Sm.
	53	IIB2t	Il.,Ka.,Il/Cl-Sm.
	114	IICox	Il.,Ka.,Il./Cl-Sm
Franklin Gd. Stn. site	30	Bir	Il.,Ka.,Cl./Vr.
	60	Cox	Il.,Ka.,Hl.,Cl/Vr.
Lake Creek site	11	A2	Cl./Vr.-Sm.
	30	Bir	Cl./Vr.-Sm.
	90	C	no clays identified

*Ka. = kaolinite, Il. = illite, Sm. = smectite, Cl. = chlorite, Vr. = vermiculite, Hl. = halloysite, "/" = either or both may be present, "-" = probable interlayering; constituents listed in order of relative intensity of diffraction peaks.

1) The Bir horizon is in part an accumulation of loess and volcanic ash in varying porportions;
2) Weathering of the latter tends to impart either an amorphous or smectite clay content to the suite of clay-size minerals present;
3) Physical properties tend to include low bulk density, high content of organic matter, high cation exchange capacity, high nitrogen and phosphorous content, high water holding capacity, high infiltration capacity, weak aggregation, characteristic brown or yellowish brown color;
4) Fertility is high when base saturation is adequate. Erosion hazard and potential for compaction are high.

Microscopic examination of the material from the Bir horizons at the sites studied, detected amorphous glass shards at only the Lake Fork site where they may account for as much as 10 percent of the volume of the particles. Interpretations of x-ray diffractograms suggest differences in clay mineralogy are greater between sites than between horizons at the same site. However, particle size data indicate the Bir horizons were deposited by different processes than were underlying horizons. Together these factors suggest wind deposition where sources within the watersheds of the study sites provided a substantial portion of the input. It should be noted that the accumulation of volcanic ash in the soil profile is at least somewhat stratified. At the Lake Fork site, samples from the horizon designated A_2 are approximately 30 percent glass shards. Other thin, gray ash-rich layers have been noted throughout the Rattlesnake watershed, particularly at timbered sites in the upper elevations. There were many possible sources for the ash, but some have been shown to have influenced soil in western Montana. Two of these were Glacier Peak, Washington, which erupted violently about 12,000 years B.P. (Fryxell, 1965) and Mount Mazama, Oregon, which erupted about 6,500 years B.P. (Powers and Wilcox, 1964).

Soils at all three study sites have an A/Bir/C profile. Since the Bir does not seem to have been strictly developed from the underlying parent material in situ, it is reasonable to consider it a distinct deposit. In this case the Bir of the complete soil profile could reasonably be designated the C horizon of the uppermost unit, but this is apparently contrary to convention established by soil scientists. The Bir horizon does not indicate relative age as would be the case for a B_t horizon. For geomorphic purposes it should be considered analogous to an A/C profile developed on a recent deposit. Soil development on deposits immediately beneath the Bir horizons were not detected.

IIB_{2t} horizon. At Shoofly Meadows the soil profile manifested a distinctly different feature in that another deposit was found to exist beneath the sequence of horizons common to all three sites in the upper 0.5 m. It is distinguished on the basis of position in the solum, color, an abrupt boundary, deeper weathering of quartzite cobbles and a higher degree of compaction than overlying materials. The upper 20 to 30 cm of lower deposit are enriched in clay content, have a massive to weak structural development, and have stronger colors than the till below (see Figures 7 and 8).

For these reasons the uppermost horizon of the lower deposit is classified IIB_{2t}. It should be noted however that ped structure in this horizon either was not strongly developed or has been partially destroyed. The till beneath has been designated as oxidized on the basis of color differences from younger materials of comparable compositions.

For purposes of this study the IIB_{2t} and IIC_{ox} horizons are interpreted as indicative of a paleosol in conformance with the criteria summarized by Birkeland (1974) and Yaalon (1971) and utilized by others such as Richmond (1962) and Ruhe (1968). Additional work with other soil profiles in the area will be needed to confirm or negate this interpretation. Field investigation has noted a comparable soil profile near the drainage divide between Rattlesnake Creek and Gold Creek (SW 1/4, SE 1/4, Sec. 11, T.15N, R.18W).

Age interpretation. Field work with, and air photo interpretation of, the Pleistocene tills in the Rattlesnake watershed has not yielded adequate criteria for distinguishing their relative ages on the basis of surficial morphology. For this reason ages of the tills have not been distinguished on the map. However, tentative evaluation of relative age is suggested on the basis of surface morphology at some locations and inference based on geomorphic position and the soil data generated for this study.

In general, recessional moraine ridge crests in the hanging valleys west of Rattlesnake Creek are better defined in being sharper in outline and having steeper sides than the possible morainal features in Shoofly Meadows and the depressions along the Rattlesnake Creek-Gold Creek divide (Sec. 11, 14, 15, 9, T.15N, R.18W). Since the hanging valleys west of Rattlesnake Creek are closer to the cirques late stands of ice probably persisted in those locations after retreat from the Gold Creek divide. The paleosol in Shoofly Meadows indicates it was last occupied by ice during a glaciation older than that which left till in the hanging valleys. An age interpretation of the Shoofly paleosol, based on comparable descriptions by Richmond (1965), could correlate the older deposit in Shoofly Meadows with the Bull Lake advances. Soils on till, as well as morphologic features in the hanging valleys west of the Creek match Richmond's description for tills on Pinedale age. Recent work by Pierce (1976) in the West Yellowstone area indicates that Pinedale tills may range in age from 20,000 to 35,000 years B.P., while Bull Lake tills range from 130,000 to 150,000 years B.P.

Holocene Mass-Wasting Deposits

Within the Rattlesnake Creek waterhsed, angular to sub-angular rock debris has accumulated on and below cliffs and other rocky slopes in a variety of forms. Talus is so common that it has not been distinguished as a map unit. However, there are mass-wasting deposits which are composed of the same types of materials which form talus, but which do not have simple, straight or concave slope forms. For purposes of this report, these deposits have been distinguished from talus on the basis of having ridges and or furrows in their surfaces. As does talus, they lack soil, grass or forest cover. Only those deposits which exceed approximately 50 m (150 ft.) in length or width, and which were visible from air photos were mapped. Morphology and geomorphic position indicate the following are present:

a) neoglacial moraines

b) apparently inactive rock glaciers

c) protalus ramparts.

Most were noted in glacial valleys and cirques at elevations above 2133 m (7000 ft.), where a sparseness of lichens on rock rubble indicates some mass-wasting deposits are still active.

The processes responsible for the formation of these deposits are difficult to identify. It is therefore difficult to assign genetic names with confidence. Rock glaciers differ from true glaciers in that they are mostly composed of rock debris. The mass derives fluid properties through the deformation of interstitial ice as opposed to the shearing and flow deformation of a mass composed primarily of ice. In the Alaska Range Wahrhaftig and Cox (1959) have noted that rock glaciers can become true glaciers with a depression of the local firn limit. Protalus ramparts may represent small, localized moraines or simply sites of debris accumulation at the toe of snowfields.

Moraines of neoglacial origin lie at or near cirque headwalls in the upper elevations of the watershed and generally have north aspects. In general they match the descriptions of neoglacial deposits presented by Richmond (1965). One of the best developed is found at the cirque head above Sanders Lake (NE 1/4, SE 1/4, Sec. 13, T.15N, R.19W). If a neoglacial age interpretation for these deposits is correct, according to Richmond they formed during the last 3100 years. Older neoglacial deposits may be present but are mapped as till since most have grass and/or forest cover and distinguishing features are not apparent.

Some deposits of talus-type material exhibit ridges and furrows in their surfaces, forming lobate structures in otherwise stabilized (lichen covered) slopes. Differential lichen cover indicates the ridges are relatively stable while the furrows are more active. In this respect they are comparable to rock glaciers as described by Wahrhaftig and Cox (1959). It is reasonable that some may have interstitial ice at their cores. Talus slopes at the toe of these deposits are generally lichen covered, suggesting they are inactive. An example of one of these features is found on the southwest flank of McCleod Peak in the NW 1/4, Sec. 7, T.15 N, R.18 W. At this location, the lobes of talus-type material are associated with stone stipes on slightly steeper slopes nearby. An apparently active rock glacier has been noted on the northwest flank of McCleod Peak, just outside the study area in the SW 1/4, SW 1/4, Sec. 31, T.16 N, R.18W.

Protalus ramparts stand as distinct ridges along the bases of talus deposits. Two of the most notable of these have southwest aspects, a condition which may favor a relatively high number of freeze-thaw cycles and an orientation parallel to the strike of the local bedding and structure. These features are found near the head of Pilcher Creek (secs. 5,6,8, T.14 N. R.18W), and on the side of an unnamed rocky knob approximately 2 km northeast of Sanders Lake (SW 1/4, Sec. 8, T.15N, R.18W).

Landslide Deposits

Low-Inclination Slumps

Landslide deposits in the Rattlesnake watershed are most conspicuously represented by a large area of slope failure along the trace of the Clark Fork Fault in portions of Secs. 2, 3, 10 and 11, T.13N, R.19W. The slide area has characteristic hommocky topography which includes transverse arcuate ridges and swales in the slide mass and an escarpment at its head, approximately 20 m high. Presently the slope across the slide, from the head of the escarpment to the toe of the slide mass is approximately 7° (12%). The low inclination suggests that materials with low angles of internal friction formed the failure surface and that it was relatively shallow. It is a reasonable speculation that Tertiary clays, softened by high water contents were a contributing element in the failure. At the toe of the large slide (NW 1/4, NW 1/4, Sec. 11, T.13N, R.19W) a portion of the slide material has been exposed in the excavation for a municipal aquaduct. Discrete blocks of pale-yellow, clay-rich Tertiary sediments, with vestiges of bedding intact, are preserved in a pinkish gray till-like matrix of silty, boulder gravel. The blocks, up to 3 m on a side, have sharp boundaries and angular corners which suggest transport and deposition attendant to mass failure. Field and laboratory tests on these and similar materials exposed along the northern and south-eastern boundaries of the Missoula Basin have established that some are high-to-low plastic clays (unpublished data by the author, 1977). With high water content, materials such as these typically possess cohesion but low angles of internal fraction (Spangler and Handy, 1973, p. 442-444).

Strandlines from Glacial Lake Missoula appear to have been erased by the upper portion of the slide while they are preserved on slopes nearby. Other strandlines are etched on the toe of the slide, indicating failure occurred between two stands of the Glacial Lake. It is a reasonable speculation that saturation by lake water may have been a factor in the sliding.

Across the Rattlesnake Creek valley below the saddle of Mount Jumbo (SE 1/4, SW 1/4, Sec. 17, T.13N, R.19W) similar materials, appear to have been displaced by sliding as suggested by at least one closed depression and a subdued ridge-swale morphology. (An alterlate hypothesis explains the morphology as a cavitation feature caused by lake draining currents flowing through the "saddle" of Mt. Jumbo.) High plastic clays underlie a surficial gravel cap in this area.

Blockfall Landslide

In the upper portion of Rattlesnake Creek's canyon, SW 1/4, NE 1/4, Sec. 11, T.14N, R.18W, another landslide occurred with a different mechanical style. Here the parent material was rock of the Belt Supergroup (Nelson and Dobell, 1961). Mechanically this failure was of the slab or blockfall type and appears to have been precipitated from the canyon walls too steep for the cohesion of the fractured rock. Field observation has noted that a significant component of the fractures in this area which strike NW-SE, tends to dip northward steeply, possibly predisposing northeast-facing slopes in the upper portion of Rattlesnake canyon, to mass failure of this type.

After the slab failure in Sec. 11 (above) alluvium filled the canyon immediately upstream, creating a boggy area with a braided channel pattern. Projecting the stream's profile through the obstruction, suggests that as much as 30 m (100 ft.) of unconsolidated fill exists behind this natural dam. The landslide obstruction is represented by the prominant nickpoint in the longitudinal profile between cross-section sites 1 and 2, see Figure 17. While no definite evidence can be found to date the occurrence of the failure, its rubbly, sparsely vegetated surface, combined with its prominance in the stream's longitudinal profile suggest it probably occurred in the Holocene.

Outwash

Alluvial deposits of presumed glacio-fluvial origin make up the majority of the near-surface material on the highest terrace surface in the Rattlesnake Creek valley, from the base of the prominant traverse moraine in Sec. 19, T.14N, R.18W, to the Creek's confluence with the Clark Fork River. Topographic expression of a braided-channel stream network remain on this terrace surface immediately down-valley from the moraine and in the N 1/2, Sec. 11, T.14N, R.19W. The composition of the material is unknown, but shallow test pits on the stream bank in the NE 1/4, NE 1/4, Sec. 25, T.14N, R.18W, revealed a sandy, boulder gravel (see Figure 4). Assuming there are no hidden bedrock irregularities, the maximum depth of this deposit should exceed the 37 m (125 ft.) entrenched to date. At its surface, this landform is locally covered by boulders, silt and poorly sorted sand and gravel. The gradient on the surface of the upper portion of the terrace is approximately 2.6 percent as contrasted with a 1.3 percent grade which now characterized the modern stream channel in the same area. Farther down-valley (S 1/2, Sec. 11, T.13N, R.19W) at a depth of approximately 1 m materials are dominantly weakly bedded, brown (7.5YR 5/2, dry), to pinkish gray (7.5YR 6/2, dry) sandy boulder gravel. The combination of relatively high gradient and bouldery composition led Alden (1953) to suggest that the outwash was in part deposited by glacier outburst (jokulhlaup) floods.

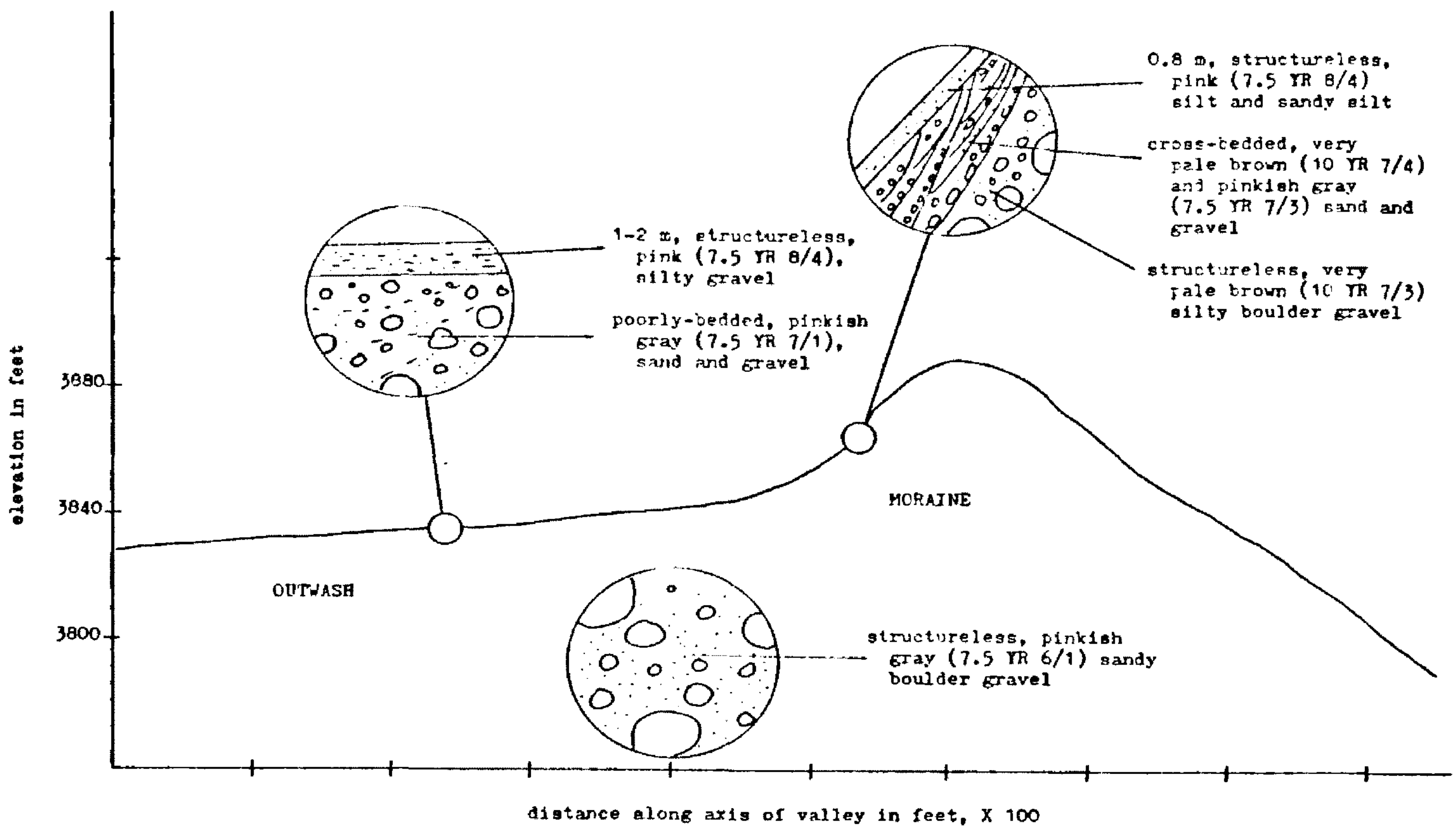


Figure 11. Moraine and outwash deposits, surficial stratigraphy.

Other outwash deposits exist upstream from the transverse moraine noted above, though they are not so continuous and cannot be adequately correlated with each other. These deposits are younger than the deposit below the moraine. They have been distinguished from terrace alluvium on the basis of surface morphology, geomorphic position, and direct association with deposits of till. Some outwash is intermixed with till deposits, particularly in hanging valleys in the upper drainage.

Colluvium

Colluvial deposits have accumulated in areas of relatively low slopes and are recognized by a dominantly angular and subangular shape of their clasts. They are most common in the lower portions of the drainage, particularly in areas underlain by the well-sheared Wallace limestone (see Nelson and Dobell, 1961). Spring gulch contains a deposit of this material on which two terraces have formed. Much of the colluvial material in Spring Gulch may have come from brecciated rock near the Spring Gulch Fault which has a trend northwest across the head of the Gulch (Nelson and Dobell, 1961). Evidence for this is provided by the abrupt increase in the slope of the surface deposits near the fault, and a commensurate increase in the percentage of angular clasts derived from the northern, upthrown side. The local morphology suggests, but does not demand, an interpretation of a landslide in the SW 1/4, Sec. 23, T.14N, R.19W.

In some locations, such as the forested slope on the east side of Rattlesnake canyon at the 1158 m (3800 ft.) elevation (SW 1/4, Sec. 36, T.14N, R.19W), an extremely well sorted layer of coarse, angular gravel suggests the action of littoral processes on material which is now covered by approximately 2 m of pale gray colluvium. At one location along the Creek (NW 1/4, SW 1/4, NE 1/4, Sec. 35, T.14N, R.19W) colluvial materials have covered a gravel-silt sequence represented in Figure 12. The pinkish cast of the silts combined with their near-surface stratigraphic position suggests their deposition in one of the

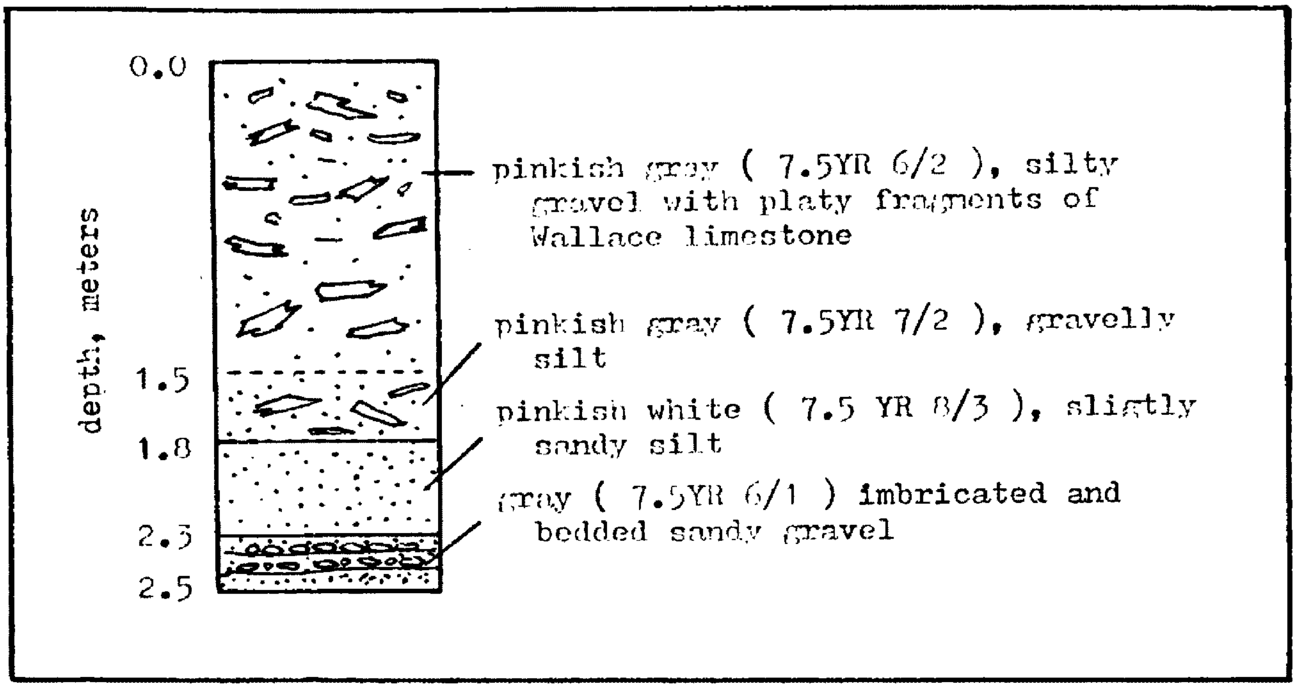


Figure 12. Profile of colluvial development on other Quaternary deposits.

stands of the Glacial Lake Missoula. It should be noted that most silt-size material indigenous to the upper Rattlesnake Creek watershed is gray in color while most lake silts are pinkish. Colluvial development subsequent to at least one lake stand is indicated by the inclusion of pink, varved lake silts at a discontinuity in colluvial gravel deposits exposed in a road cut and gravel pit on the south-side road, on the southern margin of the Missoula Basin (respectively, SE 1/4, SE 1/4, Sec. 26, T.14N, R.26W and NW 1/4, SE 1/4, Sec. 8, T.22W, R.14N).

Fan Deposits

Fan deposits, as mapped for this study, are of two different morphologic types and compositions. Both are similar in that they have general outlines that approximate conic sections. In the portion of the Rattlesnake Creek watershed north of the Spring Gulch Fault, fan deposits generally have steep surfaces, inclined between 25 and 40 degrees. Most of these steeper fans are composed of mixtures of material derived from drainages above them and include mixtures of reworked bouldery till in the form of alluvium and/or outwash, and grade laterally into talus and/or colluvium. On some, such as the fan of Beeskove Creek (SW 1/4, Sec. 16, T.14N, R.18W) constructional levees on the steep slopes of the fan suggest that alpine mudflows played a role in the fan's development.

South of the Spring Gulch Fault slopes on the surface of fans are typically in the range of 5 to 20 degrees. Materials of these fans are usually of sand, pebble and cobble size and are more aptly described as alluvium. The fan at the mouth of Danny O'Brien Gulch has aggraded onto the uppermost outwash surface in the lower portion of the drainage and contains at least one layer of water-laid volcanic glass shards.

Alluvium of the Terraces

Downstream from the prominent transverse moraine in the Rattlesnake Creek's canyon, at least two major and as many as four minor, discontinuous stream terraces have been formed below the level of the uppermost outwash surface. Though vertically separated from the outwash terrace by as much as 30 m (100 ft.), immediately downstream from the moraine, the vertical separation decreases toward the Creek's confluence with the Clark Fork River.

There are many theories relating terrace formation to climate as summarized by Frye (1961). Schumm (1965) evaluated terrace development by considering channel erosion or deposition at locations in different geographic regions and under different degrees of glacial influence. For basins partially occupied by ice he considered that the early glacial and glacial phases promote deposition. Late glacial and early interglacial phases promote erosion. Other interglacial times were considered to have fostered stable conditions for stream channels. The vertical convergence of the terraces downvalley indicates that aggradation was caused by increased sediment load from the upper drainage, probably during glacial advances.

Other terraces, preserved in tributary valleys on the south side of the Missoula Basin, seem to have been graded to a surface approximately 30 m (100 ft.) higher than the modern channel of the Clark Fork River. Some of the most continuously traceable of these are the terraces above Deep Creek, which are formed on a dominantly colluvial fill of possible Pleistocene age (see Fig. 13).

It is significant to note that in the downstream direction, the Deep Creek terraces are divergent vertically from the modern channel, suggesting that an elevated base level influenced their formation.

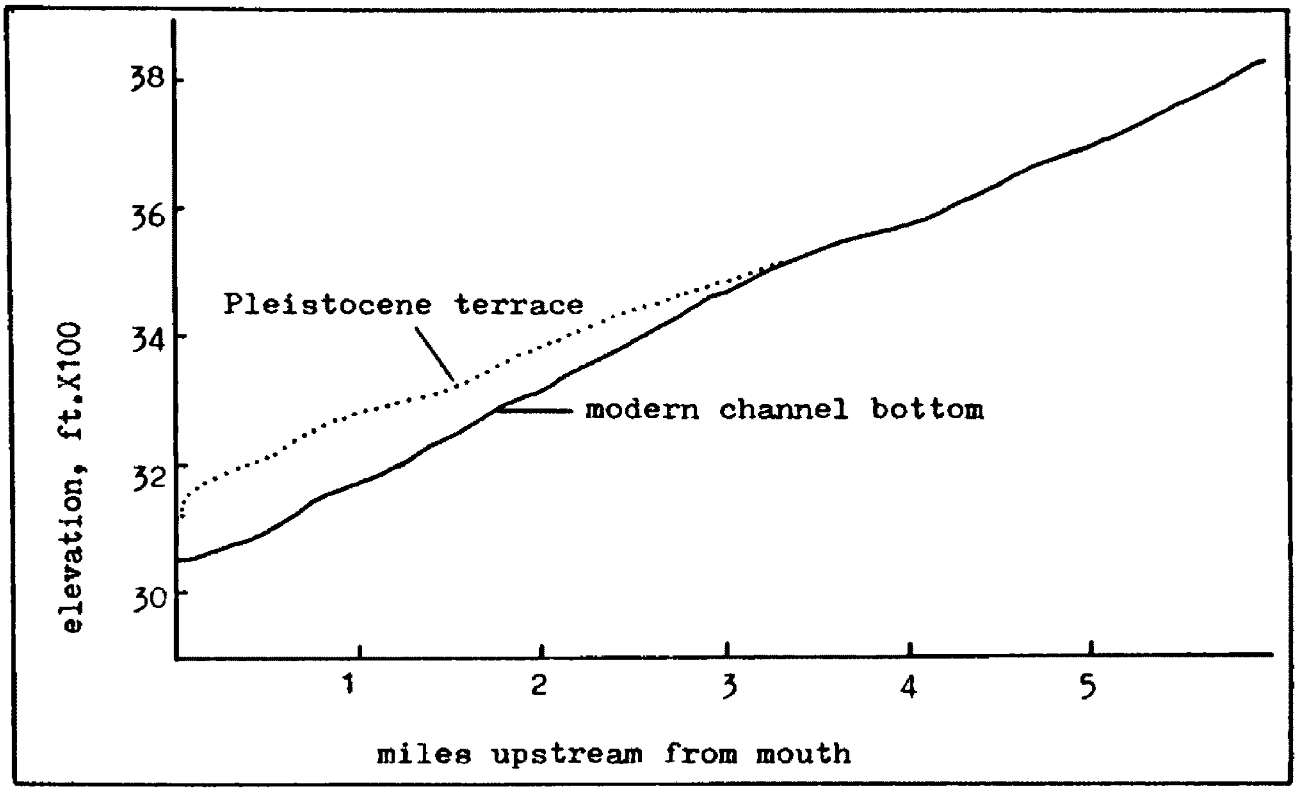


Figure 13. Stream terrace and channel profile, Deep Creek.

The difference in terrace morphology between Rattlesnake Creek and Deep Creek thus indicates differences in their watershed's dynamics during the Pleistocene. It should be noted that the distinction between outwash and alluvium shown on the map is somewhat arbitrary, since much of the terrace alluvium may actually be outwash from recessional glaciers or glaciations subsequent to that which left the transverse moraine. Terrace alluvium is, in general, better sorted than the outwash shown on the map, appears to have fewer large boulders and, in the lower portions of the drainage, is grayer.

Erratics and Littoral Deposits

Boulders of Belt rock, up to 1 meter in diameter litter the surface of almost every hillside in the lower portion of the Rattlesnake Drainage. Some of these boulders seem to be concentrated in bands that parallel preserved strandlines as on the west and east side of Waterworks Hill (E 1/2, Sec. 9, T.13N, R.19W; NE 1/4, NE 1/4, Sec. 1t, T.13N, R.19W). Their presence seems most easily explained by the mechanism of ice-rafting from a local glacial source. The lithologies of all these erratics are indiginous to the Rattlesnake Creek drainage and some, such as the distinctive Pilcher quartzite of the Belt Supergroup locally outcrop only in the upper portions of the drainage. From the relatively high concentration of these boulders in the lower portion of the drainage it seems probable that one or more of the Rattlesnake glaciers calved into a glacial lake. In addition, the prominent transverse moraine in Rattlesnake canyon lies at 1140 m (3740 ft.), well below the 1341 m (4400 ft.) elevation inferred for the highest strandlines. If the alpine glacial advance which left the prominent Rattlesnake moraine was synchronous with any of the Bull Lake or possibly all but the latest of the Pinedale advances of the Cordilleran ice, the conclusion that there was interaction of the Rattlesnake glaciers and Lake Missoula seems mandatory.

During their various stands, the waters of the glacial lakes slightly reworked pre-existing deposits, concentrating and sorting sands and gravels along the strandlines. An exposure of one of these deposits was observed in a construction trench, approximately 300 m west of the drainage divide in the "saddle" of Mount Jumbo, (SE 1/4, SW 1/4, Sec. 12, T.13N, R.19W), at an elevation of approximately 1158 m (3800 ft.). At this location 5-20 cm-thick beds of well sorted, light gray sand and pebble gravel were observed to lie unconformably on gray, light yellowish brown and red Tertiary units, discussed previously. The gravel and sand are bedded in thin sheets lying approximately parallel to the contemporary land surface, and contain dominantly subrounded to subangular clasts of Belt rocks. The sand and gravel deposit, where observed, was less than 1.5 m thick and incorporated beds stained a light red by silt and clay, apparently derived from similarly colored Tertiary deposits nearby. The deposit's geomorphic position, its unconformity with underlying materials, the high degree of sorting and the attitude of the bedding suggest that it is a Pleistocene shoreline deposit.

Sands and gravels, demonstrably littoral by their inclusion of and in varved lake silts, can be observed in low-inclination (less than 10°) deposits on the floor of the Missoula Basin and in gullies in its north-central interior (NW 1/4, Sec. 9, T. 13N, R19W and S 1/2, Sec. 6, T.13N, R.19W). Gravels immediately uphill from these deposits appear to interfinger with them, thereby indicating that they too are late Pleistocene in age. In some of these deposits such as that in Sec. 9, above, beds of moderately well sorted, reddish brown (5TY 5/3, moist) sand and gravel lie nearly parallel to the modern topography and include horizontally continuous, 5-10 cm thick, layers of slightly plastic reddish brown (5YR 5/4, moist) sandy silt. It is the author's belief that some of the gravels and sands were reworked from underlying Tertiary or earlier Pleistocene deposits by littoral processes associated with glacial Lake Missoula. The attitude and style of the bedding suggest the deposit was washed down the relatively steep (30°) hillside in successive sheets, separated by minor unconformities. The relatively poor sorting of the sandy and gravelly layers is to be expected on a steep slope where reworked gravels would have moved out of the zone of wave action quickly. The transience of individual lake stands would not have caused appreciable formation of beach ridges. The continuous sheets of sandy silt, though unvarved, may represent sublittoral accumulation in relatively calmer water during a transgressive interval in the lake's history. Repeated fluctuations of the lake levels are indicated by the numerous preserved shorelines (Pardee, 1910), and interpretations of the stratigraphy of benthic sediments (Chambers and Alt, 1971).

Permissive evidence for assigning a Pleistocene age to the surface gravels mentioned above and, by inference, to the similar surficial gravels on Waterworks Hill, is provided by a fossil tooth, discovered in material excavated from a gravel pit in the NW 1/4, Sec. 9, T.13N, R.19W. Identification by Dr. R. W. Fields, University of Montana, (personal communication) established that the tooth (Left M_3) belonged to a mid-Pleistocene Equus.

CHAPTER IV

LATE TERTIARY AND QUATERNARY GEOMORPHOLOGY AND GEOLOGIC HISTORY

Relict Landforms

At the 1158 m (3800 ft.) elevation there is a distinct concavity in the slope profile of Mount Jumbo, a steep sided mass of Belt rock which forms the eastern drainage divide for Rattlesnake Creek south of the Clark Fork Fault. This same feature is somewhat better preserved on Mt. Sentinel, approximately 1.6 km (1 mile) to the south. Above the concavity, drainages are strongly incised in the topography, to a depth of 61 m (200 ft.) or more. Below the concavity the same drainages have formed only gullies, incised to a depth of 6 m (20 ft.). Such differential incision suggests that some form of sedimentary cover once existed to protect the lower portions of the slope while exposing the upper portions to erosion. Since the 1158 m (3800 ft.) elevation corresponds closely to the break-in-slope at the top of the Tertiary bench remnants on both the southeast and northern margins of the Missoula Basin, it seems a reasonable hypothesis that a similar bench once existed on the eastern margin of the Basin and the lower portion of the Rattlesnake drainage as well. The profile concavity might then be explained as relict of a basal slope concavity, developed at the head of a desert fan complex as described by Carson and Kirkby (1972). Konizeski (1958) has demonstrated the probable existence of a desert environment in the Bitterroot Valley during Pliocene time. Whatever the age of the covering materials, preserved strandlines indicate that they were removed before late Quaternary time. A Pliocene age interpretation for the mid-slope profile concavity demands that the old bench was eroded in the Pliocene or early-to-mid Quaternary.

Hypsometric analysis of the Rattlesnake Creek drainage (Figure 14) reveals a large land surface area between the 6000 and 7000 ft. (1829 and 2134 m) elevations. Reference to a 1:250,000 scale topographic map (Figure 10, p. 23) shows that much of this area is part of a low-inclination, ramp-like feature which includes both the Rattlesnake and neighboring Gold Creek drainages. The presence of other relatively low-inclination areas, at or near this elevation in the nearby mountains suggests that they and the Rattlesnake Creek-Gold Creek ramp may represent relicts of an ancient erosion surface. Some of the theories about the formation and significance of preserved erosion surfaces have been summarized by Thornbury (1965). Due to the highly speculative nature of such geomorphic interpretations, they will not be discussed here. It should be noted however that the steep-sided incision which Rattlesnake Creek has cut in the mountain mass contrasts markedly with the topography in the Gold Creek drainage and suggests that Rattlesnake Creek may have obtained its headwaters by piracy of part of the Gold Creek drainage. From the extent of subsequent incision, such an event would have probably taken place in the Tertiary or earliest Quaternary. This interpretation is also highly speculative. Causitive factors are not apparent.

Elevation	Rel. Ht.	Rel. Area
8000-9000'	1.00	0.00
7000-8000'	.85	.11
6000-7000'	.68	.43
5000-6000'	.51	.69
4000-5000'	.34	.89
3000-4000'	.17	1.00

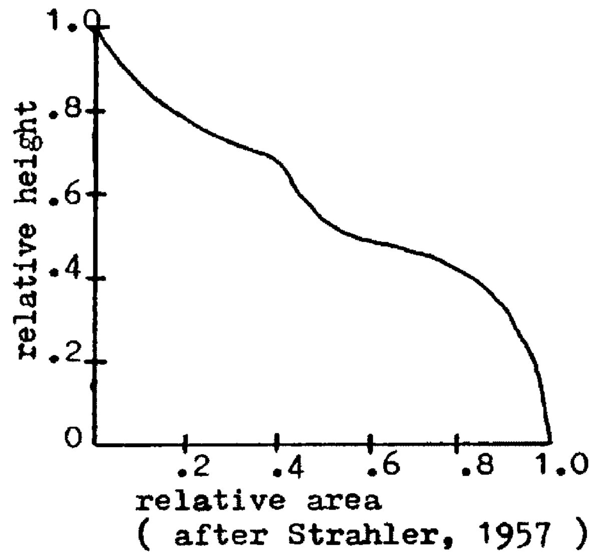


Figure 14. Land area elevation distribution, Rattlesnake Creek watershed.

Geologic History

From the geology and geomorphology of both the Rattlesnake Creek drainage and the Missoula Basin, the following sequence of events seem to have occurred in the area during the late Tertiary and Quaternary.

During an interval of time, tentatively dated as Oligocene (McMurtrey and others, 1965), deposits of sandy gravel, silt, clay, volcanic ash and organics (lignite) accumulated on top of older Tertiary sediments and an irregular bedrock topography in the Missoula Basin. Drainage into the basin from the granitic terranes of the Idaho or Boulder batholiths or associated intrusives is indicated by the presence of granite and gneiss detritus in these deposits.

Prior to the Pliocene or early Pleistocene, a period of faulting disturbed the earlier Tertiary rocks along the Basin margins, leaving some dipping as steeply as 70° (NE 1/4, SE 1/4, Sec. 10, T.14N, R.20W). Following the faulting, in the Pliocene (McMurtrey and others, 1965), a deposit of sandy and silty gravel was laid on top of the displaced Tertiary rocks, thereby forming a distinct angular unconformity. "Open-work" type deposition, graded bedding, cut-and-fill structures and cross bedding are common in some of the gravels and suggest they may have originated as alluvial fans of a now-eroded desert basin. Granite and gneiss detritus have not been detected in this material and its absence indicates either a local source for the gravel or its derivation from older, reworked deposits.

Evidence of late Tertiary and probably Pleistocene faulting is abundant in the Missoula Basin. Between Rattlesnake Creek and Grant Creek several gravel-capped ridges of Tertiary deposits (NW 1/4, Sec. 5, SW 1/4, Sec. 4, T.13N, R.19W, not shown on the map) show an abrupt right-lateral offset in their otherwise SSW-NNE trend. The distinctness of the fault zone, preserved in relatively soft material, suggests its youth. Further west, along the northern margins of the Missoula Basin, in the vicinity of Ninemile Creek (T.15 and 16N, R.22 and 23W), the topography shows that stream valleys, cut in Belt rocks north of the Clark Fork Fault, make an abrupt jog to the west and decline in gradient as they cross the fault zone. By comparing the alignment of well-developed valleys in the Tertiary basin rocks, with the upper portions of these valleys in the Belt rocks, it appears that 0.9 to 1.6 km (0.6 to 1.0 mi.) of right-lateral offset, combined with an undetermined normal component of fault movement has occurred since the end of Tertiary deposition.

During the Quaternary, incision of the Tertiary deposits removed at least 150 m (500 ft.) of material from the center of the Missoula Basin. Some of this material probably included deposits from earlier glaciations. Alden (1953), Richmond and others (1965) and Weber (1972) have recognized as many as four successive glacial deposits in northern Idaho and western Montana. Established by the presence of soils developed during interglacials or interstadials, the depsits are considered to be pre-Wisconsin (Illinoian) and Wisconsin in age. In chronological sequence the advances have been named early and late Bull Lake and early and late Pinedale by Richmond and others (1965). Weber (1972) working on the glaciations of the Bitterroot Mountains delineated three glacial deposits which are tentatively correlated with Richmond's Bull Lake, Pinedale and an earlier Sacajawea Ridge glaciation.

Recent studies in the West Yellowstone area have shown that the ages for Pinedale terminal moraines are about 20,000 to 35,000 years (Wisconsin) while those of the Bull Lake moraines are 130,000 to 150,000 years (late Illinoian) (Pierce and others, 1976).

Climatic Factors and the Extent of Glaciation

The presence of till at and near the Rattlesnake Creek-Gold Creek divide indicated that at one time glacial ice flowed between the two drainages. Till in the Gold Creek drainage appears to be of two different ages and indicates ice flowed to within 2 km of the Blackfoot River. The orientation of glaciated valleys which drain the Rattlesnake highland indicate that ice must have flowed in all directions from its area of maximum elevation. Because of this it seems reasonable to refer to the coalescent glaciers as a local ice cap, an arm of which constituted the Rattlesnake Glacier.

Richmond (1965, Figure 2) provides a graphical presentation of the average elevations of Pleistocene end moraines in the Rocky Mountains. From this one can note that the average elevation for early Bull Lake and Pinedale moraines at 47° latitude is approximately 1433 and 1524 m (4700 and 5000 ft.) respectively. Apparently the glacial advance which left the transverse Rattlesnake moraine was not average, since the moraine was deposited at approximately 1140 m (3740 ft.). The logical inference to be derived from this is that glaciation in this drainage was more intense than in other drainages at the same latitude. Some of the factors which might have contributed are listed below.

1) The Rattlesnake Mountains lay at or near the southernmost extension of Cordilleran ice sheet in the Rocky Mountain Trench. If one neglects some northward flow as a distinguishing feature, the Rattlesnake glacier was probably the

southernmost extension of that ice. The climatic influence of katabatic winds from the Cordilleran ice should have depressed the local orographic snowline and increased the area available for firn accumulation.

2. The presence of glacial Lake Missoula would have increased local precipitation by increasing the amount of atmospheric water vapor. Presumably this and the effect of proglacial climate would have affected the Bitterroot Mountains as well. Weber (1972) places Pinedale equivalent moraines in the 1189 to 1219 m (3900 to 4000 ft.) elevation range, seemingly corroborating this hypothesis.

3) Physiographically, Rattlesnake canyon has been incised into the dissected highland described previously. Using a conservative estimate of the elevation of the ice necessary for flow into the west fork of Gold Creek, the average gradient on the ice surface, when the transverse moraine was formed, would have been approximately 11%. In contrast, Roaring Lion and Lost Horse canyons in the Bitterroots would have only required a 4% ice gradient to produce their end moraines if one assumes the canyons were filled to the elevations of the mouths of the cirques closest to the Bitterroot Valley. Obviously factors such as differing aspect and valley configurations prohibit rigorous comparison between these drainages and the Rattlesnake. However, if one

considers that both the Bitterroot and Rattlesnake glaciers formed under comparable climatic regimes, in valleys with roughly similar cross sections, the steeper ice gradient and probably a greater flow velocity would require a more extensive wasting area for the Rattlesnake glacier to maintain its mass budget. This is particularly true since the Rattlesnake glacier's accumulation area was larger.

Inferential evidence exists to support the hypothesis that the transverse moraine in Rattlesnake canyon does not represent the furthest extent of the local glacial ice. The till and exotic erratics in the small, cirque-like feature on the north canyon wall, 2.4 km (1.5 mi.) upstream and 488 m (1600 ft.) above the moraine indicates the presence of glacial ice. If the canyon had been filled with ice to this elevation, the slope on the ice necessary for the glacier to have terminated in the vicinity of the moraine would have been 18 percent. In the absence of any substantial constriction in the canyon's cross-section that would have caused a compression-extension type of flow (Embleton and King, 1968), extensive calving into lake waters, or extension of the glacier, beyond the transverse moraine, seem most probable. Corroborative evidence for a greater extension is found in striated erratics included in colluvial material at the 1402 m (4600 ft.) elevation on Strawberry Ridge, SW 1/4, NW 1/4, Sec. 24, T.14N, R.19W. Both hypotheses can explain the presence of the large volume of material beneath the uppermost outwash terrace and its high gradient.

CHAPTER V

THE MODERN STREAM CHANNEL AND ITS HYDROLOGIC REGIMES

Structural Influence on the Drainage Pattern

As the Pleistocene geology and geomorphology reflect some of the past processes active in the Rattlesnake Creek drainage, so the modern stream channel reflects the watershed's contemporary dynamics. The modern drainage net is best described as a trellis, preferentially developed along two major trends, illustrated by the drainage net tracing and attendant rose diagram in Figure 15. To prepare the rose diagram, the downstream direction of all channels shown on a 1:24,000 scale map were measured as a series of discrete sections, 250 m in length. Each of these sections was assigned to a 10° class interval, and the total in each interval summed. This total was plotted radially from the center. Comparison with the equal area plot of poles-to-bedding of the Pre-cambrian and Cambrian rocks in the central part of the drainage, provided by Figure 16, suggests a structural relationship by trending at right angles to the dominant strike of the bedding in the pre-Tertiary rocks. Field observation on most traverses noted an apparent trend of jointing along strikes of 320-140° and 050-230°, parallel to the dominant alignment of the stream channels. An inspection of 1:250,000 scale topographic maps and ERTS immagery (not included in this report) suggests that stream valleys near the northeast margin of the Idaho

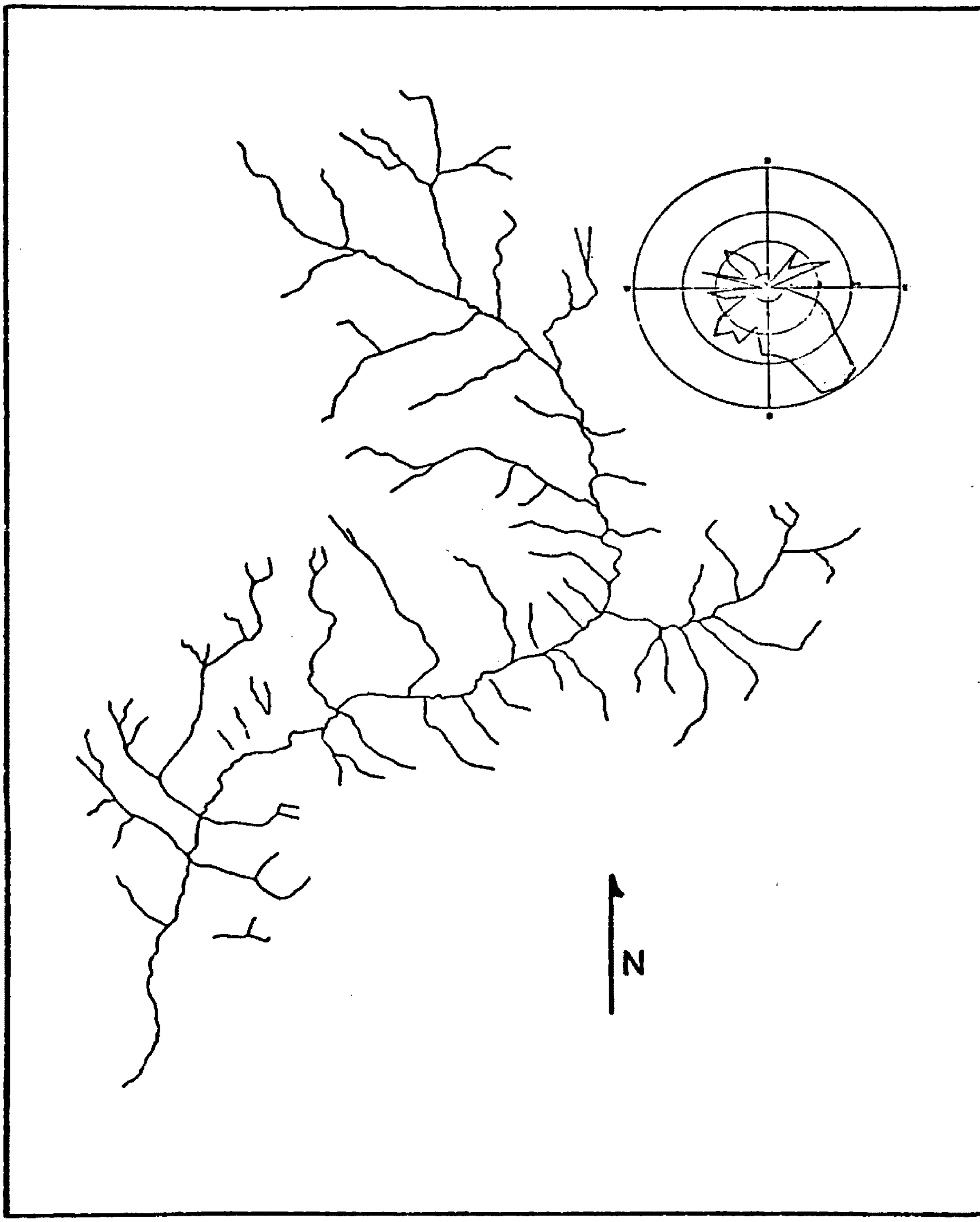


Figure 15. Drainage net and channel orientation diagram, Rattlesnake Creek watershed.

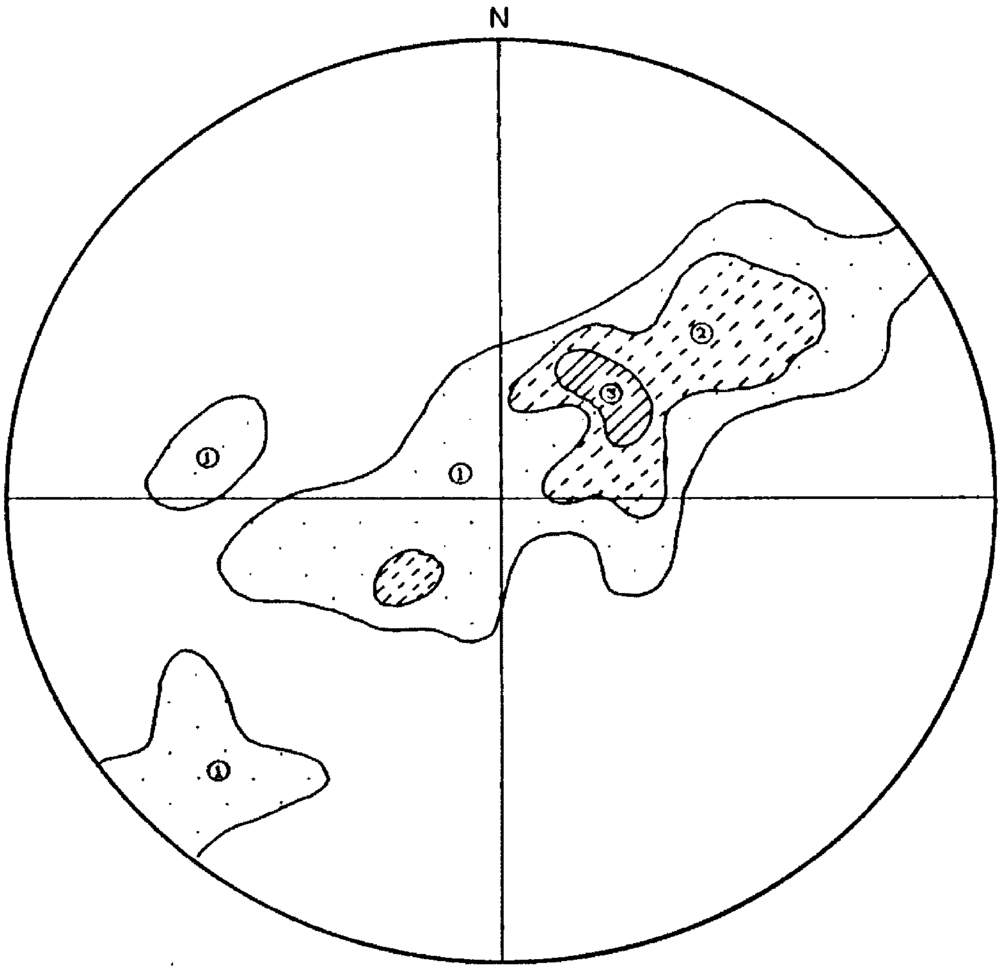


Figure 16. Equal-area plot of poles to bedding, (Secs. 22,23,24,25,25,T14N,R19W and Secs. 14,17,18,19,20,30,T14N,R18W) data from Nelson and Dobell (1961).

batholith, in the vicinity of Missoula, form a pattern that is generally radial and concentric to the batholith though obviously modified by subsequent structural events. The stream channel orientations in the Rattlesnake drainage also seem to manifest this pattern.

Background for Channel Morphology-Discharge Relationship

It has been established that naturally equilibrated streams tend to have a recurrence interval for bankfull discharge that varies between 1 and 2 years, with an average close to 1.5 years (Leopold, Wolman and Miller, 1964). As a result, estimates of bankfull discharge are a reflection of the channel's response to a statistically definable runoff event. Therefore, in any one drainage, comparison of bankfull discharge at different locations, if corrected for size differences of the different sub-drainages, will reflect differences in the sub-drainage's runoff characteristics. Bankfull discharge is, however, difficult and expansive to measure by direct methods. A less precise though useful method is the indirect estimation of discharge by a careful survey of the channel's cross section and bankfull water surface gradient. By also estimating and employing a roughness coefficient, the bankfull discharge can be calculated using the slope-area method outlined by Boyer (1964). For metric units this method relies on the modified Manning equation shown below.

Eqn. 1

$$Q = \frac{A\ R^{2/3}\ S^{1/2}}{n}$$

in which:

Q = discharge in meters^3/second

R = hydraulic radius in meters (approximated by mean depth for shallow parabolic channels)

S = slope of bankfull water surface

n = Manning's roughness coefficient

A = cross-sectional area in meters^2

Field Data Collection and Development

To employ the contemporary channel morphology to differentiate the hydrologic properties of different sub-drainages of the Rattlesnake Creek watershed, a program of field data collection was undertaken in October of 1975. Equipment was provided by the University of Montana, and vehicular access authorized by the Missoula Ranger District of the Lolo National Forest. Three sites were chosen for survey at widely spaces intervals along the creek and numbered as shown in Figure 17 with areas represented in Figure 10. Sites were chosen which seemed representative of the surrounding reaches, had reasonably well defined channel boundaries, afforded reasonably easy access, and reasonably clear

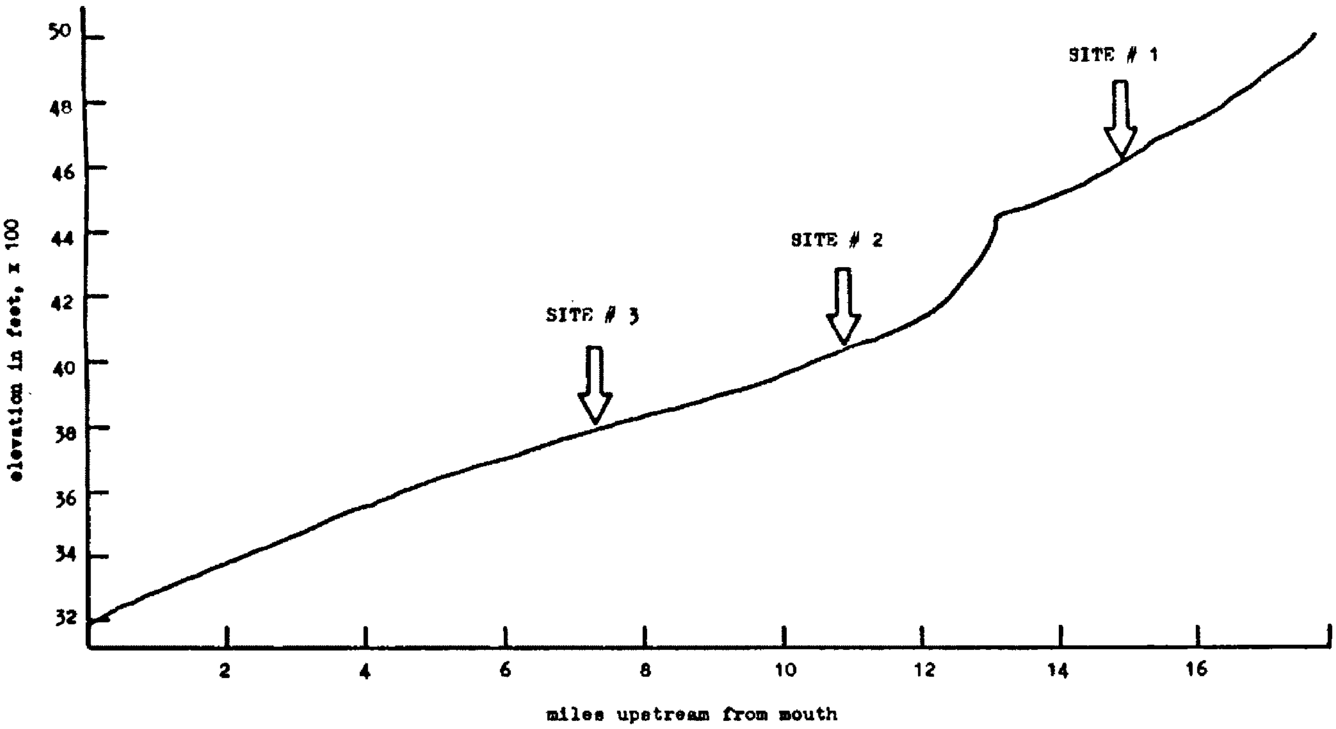


Figure 17. Longitudinal profile, Rattlesnake Creek.

sites for surveying instruments. A transit, rod and tape were the primary instruments used. Two cross-sectional surveys were performed at sites 1 and 3, at intervals slightly over 100 meters apart. Only one cross section was surveyed at site 2. Longitudinal profiles of the channel bottom and water surface were obtained at all three, along with estimates of the slope of the bankfull water surface. A steel tape was stretched across the stream to provide calibration for cross sections, while the stadia-intercept method was used to produce the longitudinal profiles. Bed armor size was sampled at all three sites to note any trends in its variation and to increase the accuracy of estimating Manning's n. Procedures for the method used are described in Leopold and Skibitzke (1967). The sizes of the drainages above each study site were determined from a map, using a compensating polar planimeter. The data are presented in Table 2. Channel profiles are presented in Appendix 2.

Using the field data, bankfull discharge estimates were produced for four cross-sections using the slope-area method. Manning's n was estimated for each cross-section by reference to U.S.G.S. Bulletin 1849. Corroboration for the estimates was provided by comparing the ratios of the 84th percentile (84% smaller) bed armor size, to bankfull depth, with those presented in Bull. 1849. To accommodate a range of error in estimating n, values ± .010 of the favored values were used to establish a range of possible discharges. When reviewing the data it should be noted that the number of apparently significant figures are a relict of the processes involved in modeling and do not imply similar precision in the estimates. The data and estimates are presented in Tables 2 and 3. Channel profiles and cross sections are in Appendix B.

Regional Data Acquisition and Development

In order to evaluate the hydrodynamic properties of the Rattlesnake Creek watershed in a regional context, data on 13 regional streams, including a limited amount of gaged data collected near the mouth of

Table 2. Hydrologic Data Summary

Type of data	Site 1	Site 2	Site 3	
bankfull water surface slope at x-sctn.	.0230 (1.31°)	.0359 (2.06°)	.0100 (.57°)	x-sctn 1
			.0081 (.46°)	x-sectn 2
cross section area at bankfull (m^2)	14.49	15.01	17.86	x-sectn 1
	22.1		19.75	x-sectn 2
bankfull depth (m)	.69	.38	.89	x-sectn 1
	.74		.91	x-sectn 2
width/depth ratio	41	103	23	x-sectn 1
	39		22	x-sectn 2
bed armor (cm)	12	10	10	D.50
	21	14	25	D.84
	14	10	16	Avg.
	9	5	18	Std. Dev.

Table 3. Discharge Estimates

Site	A area (m^2)	$\bar{D}$ (m) depth	S slope	n (est.)	Q (cfs.)	V (f.p.s.)
Site 1	14.49	.69	.023	.085	714	4.6
				.075	809	5.2
				.065	934	6.0
Site 2	15.01	.38	.0359	.070	757	4.7
				.060	883	5.5
				.050	.060	6.6
Site 3 x-sctn 1	17.86	.89	.010	.070	.834	4.3
				.060	.073	5.1
				.050	1168	6.1
Site 3 x-sctn 2	19.75	.91	.0081	.070	841	4.0
				.060	982	4.6
				.050	1179	5.5

$$Q = \frac{A\ \bar{D}^{2/3}\ S^{1/2}}{n}$$

Rattlesnake Creek, were obtained from records of the U. S. Geological Survey, stored on magnetic tape (see Appendix C). Utilizing the University of Montana's computer facility, yearly peak flow data were plotted as Log Pearson Type III probability distributions. By interpolating 1.5 year discharges from these plots as representative of bankfull discharge, the data, including those for Rattlesnake Creek, were plotted with basin size as shown in Figure 18. A regression line was fitted to the data by a logarithmically transfored, least squares method. Discharge estimates from the field data were plotted on this graph as well, with the average estimates for each n plotted as the upper, preferred, and lower values at each site.

Implications

Much of Rattlesnake Creek's channel, particularly in those reaches surrounding the study sites, is established in relatively poorly sorted glacio-fluvial debris. Due to the availability of unconsolidated rock materials of varied sizes, and an apparent lack of confinement by bedrock at the study sites, the channel's shape has probably been equilibrated to the component sub-drainage's hydrologic regime. The combination of field data and gaged data, shown in Figure 18, indicates that at bankfull stage at site 3, the creek discharges nearly twice the quantity of water that the regionally established trend suggests it would if its runoff characteristics were "average". The estimated bank-full discharges at sites 1 and 2 are proportionally higher still. The slope-area estimates for the three sites are reasonably consistent with each other, and with the gaged data, and thereby indicate confidence in the estimating technique.

From the unexpectedly high values for the bankfull discharge at site 1, it appears that it is the upper portion of the drainage, above that site, which contributes the largest portion of the flow in terms of discharge per unit area. While many factors undoubtedly contribute

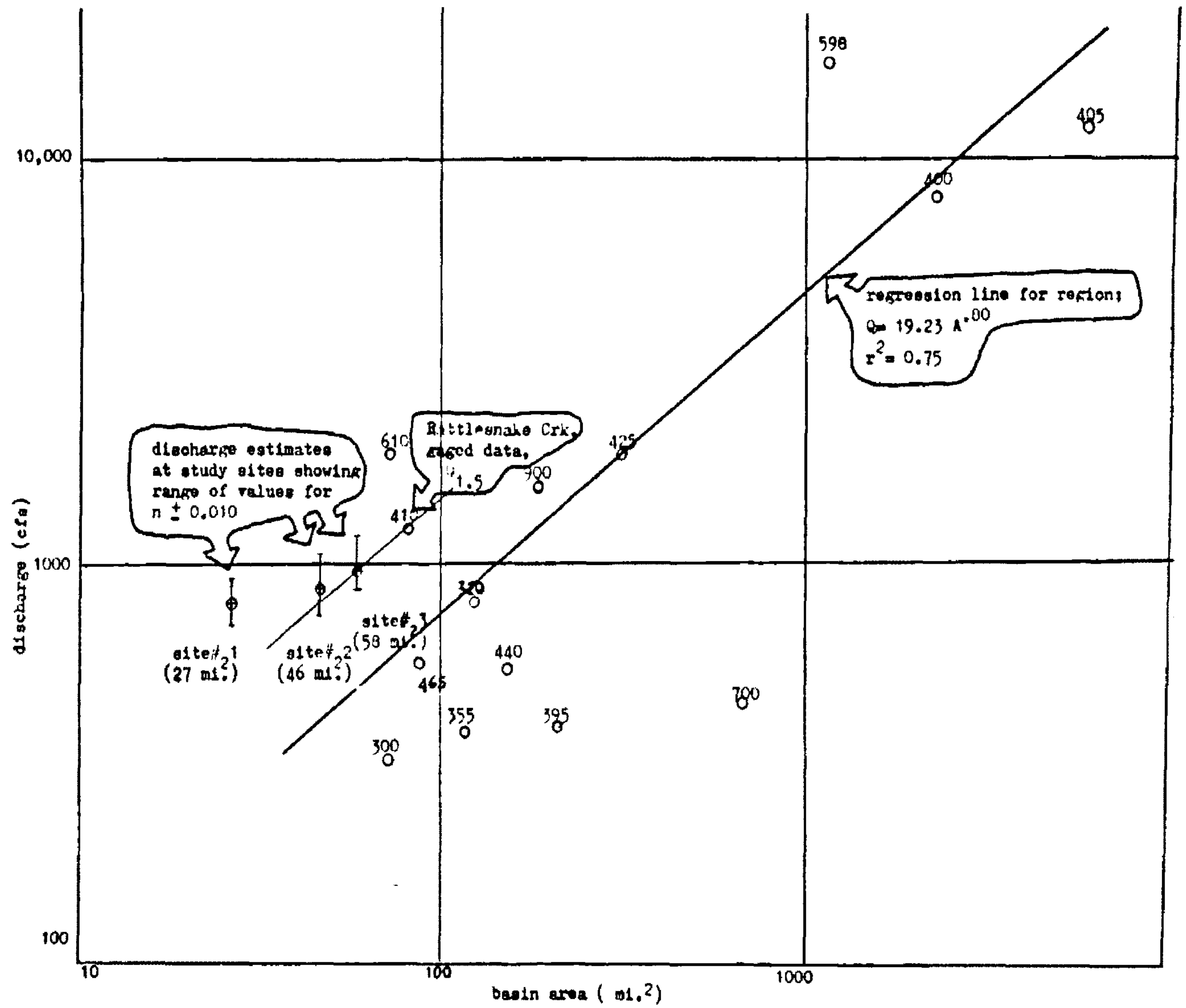


Figure 18. Relationship of $Q_{1.5}$ to basin area; numbers identify U.S.G.S. gage station sites (Appendix C)

to this condition, three important ones are listed below:

1) A large land surface area in the upper portion of the drainage as shown in Figure 14.
2) A tendency for precipitation quantity to be altitude stratified and greater at higher elevations (see Soil Conservation Service, 1974).
3) A steep, rocky, shallow-soil environment which allows rapid runoff.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The observations and data presented in this study have delineated certain aspects of the Rattlesnake Creek watershed's geology, morphology, and hydrology. Considered as a whole they reflect a set of conditions which are unique and therefore require special consideration from both academic and management perspectives.

Geologically the watershed comprises faulted and fractured metasediments which are covered to varying degrees by Tertiary and Quaternary deposits. Most of the Tertiary deposits are distinct in containing volcanic ash and plastic clays derived from them, and in having a discontinuous mantle of sand and gravel. Quaternary deposits vary considerably and include till, fans, outwash, alluvium, colluvium, landslides and other mass movement deposits. The geology and geomorphology indicate that Tertiary landscapes were dissected by faulting and subsequent erosion. Alpine glaciers during the Quaternary probably advanced and retreated at least three times. During at least one advance ice filled the highland of the Rattlesnake Creek watershed and flowed into Gold Creek. A tongue of this ice moved down the Rattlesnake canyon to a point below that which was considered its terminal moraine by previous workers. During the Holocene, aeolian materials, including volcanic ash, added a surficial layer to the soil profile.

Morphologically the watershed has a disporportionately large land area in its upper elevations. The drainage pattern appears to be partially controlled by the structure of the pre-Tertiary sediments. Remnants of former landscapes may exist; as the highland in the upper watershed, as slope profile concavities in the lower watershed, and as outwash and alluvial terraces in the valley bottom. Morphologic evidence indicates Tertiary basin deposits have a propensity for mass failure as do some steep bedrock slopes in Rattlesnake canyon.

Hydrologically, the watershed is characterized by relatively high peak discharge per unit area and a disproportionately large amount is contributed by the upper portion of the drainage. A pronounced nick point in the Creek's longitudinal profile indicates a contemporary disequilibrium of the stream's channel caused by a post-glacial landslide.

The study suggests some important considerations for anticipated land use within the watershed.

1) Tertiary sediments in the lower portion of the watershed are relatively unstable and should be evaluated for mass failure potential.
2) Clay-rich Tertiary units underlie gravelly and sandy deposits at some locations, and may cause hydrologic limitations to land use.
3) Glacial till in the upper watershed is unconsolidated and contains substantial quantities of silt. When disturbed

this material is eroded easily and will probably degrade water quality.

4) Some of the oldest tills and small sedimentary basins appear to manifest soil profiles which could provide significant information on the climatic and glacial history of the area.

5) The aeolian soil horizon which mantles portions of the drainage is particularly subject to erosion when disturbed and may be important to the fertility of the soil.

6) Local water tables usually lie at shallow depths in the alluvium on the valley bottom.

7) Comparison with regional data indicate the watershed has excellent properties as a precipitation catchment and a tendency to produce high flood discharges.

8) Jointing and steep slopes in the upper canyon may predispose this area to rockfall-type mass failure.

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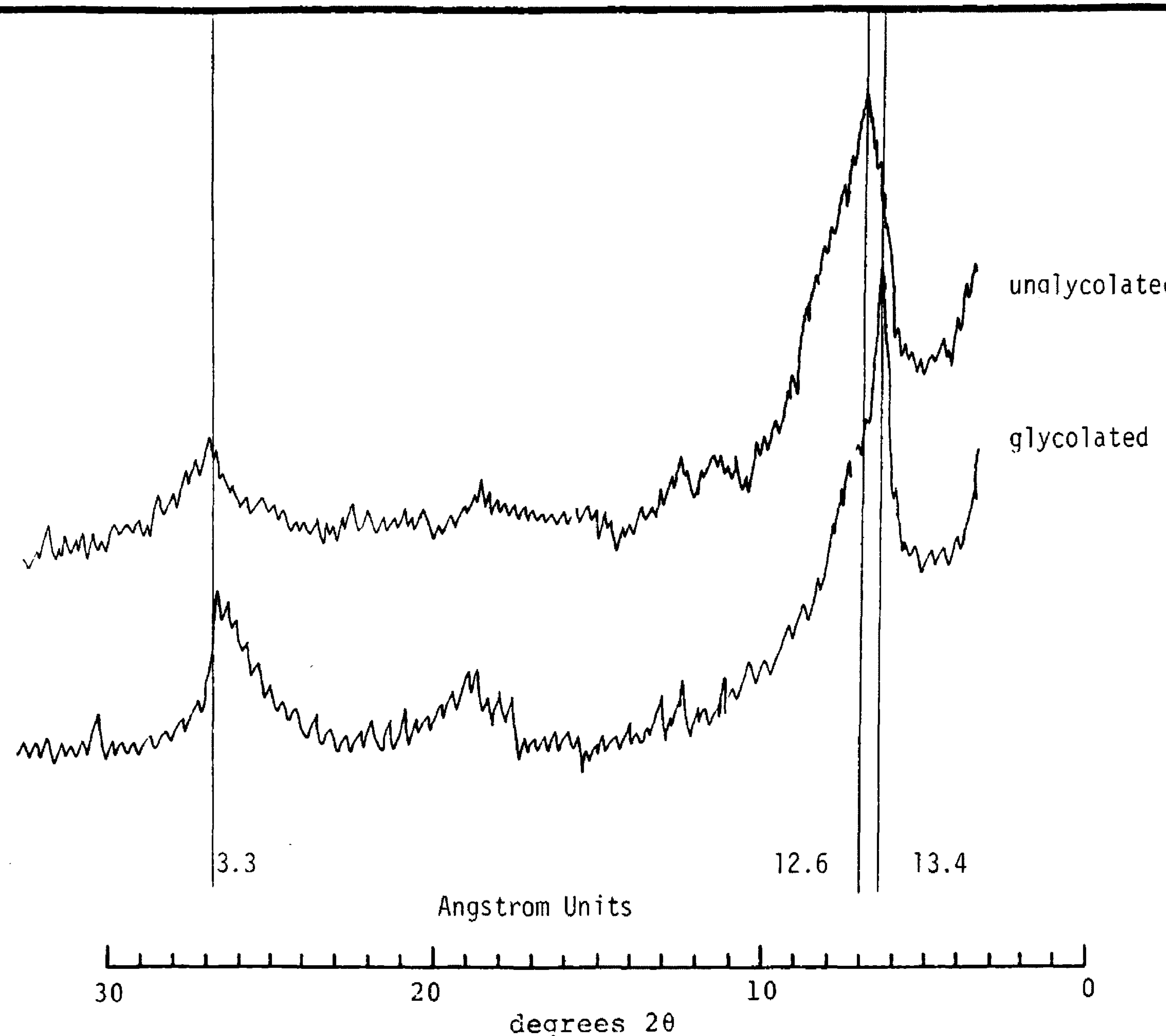
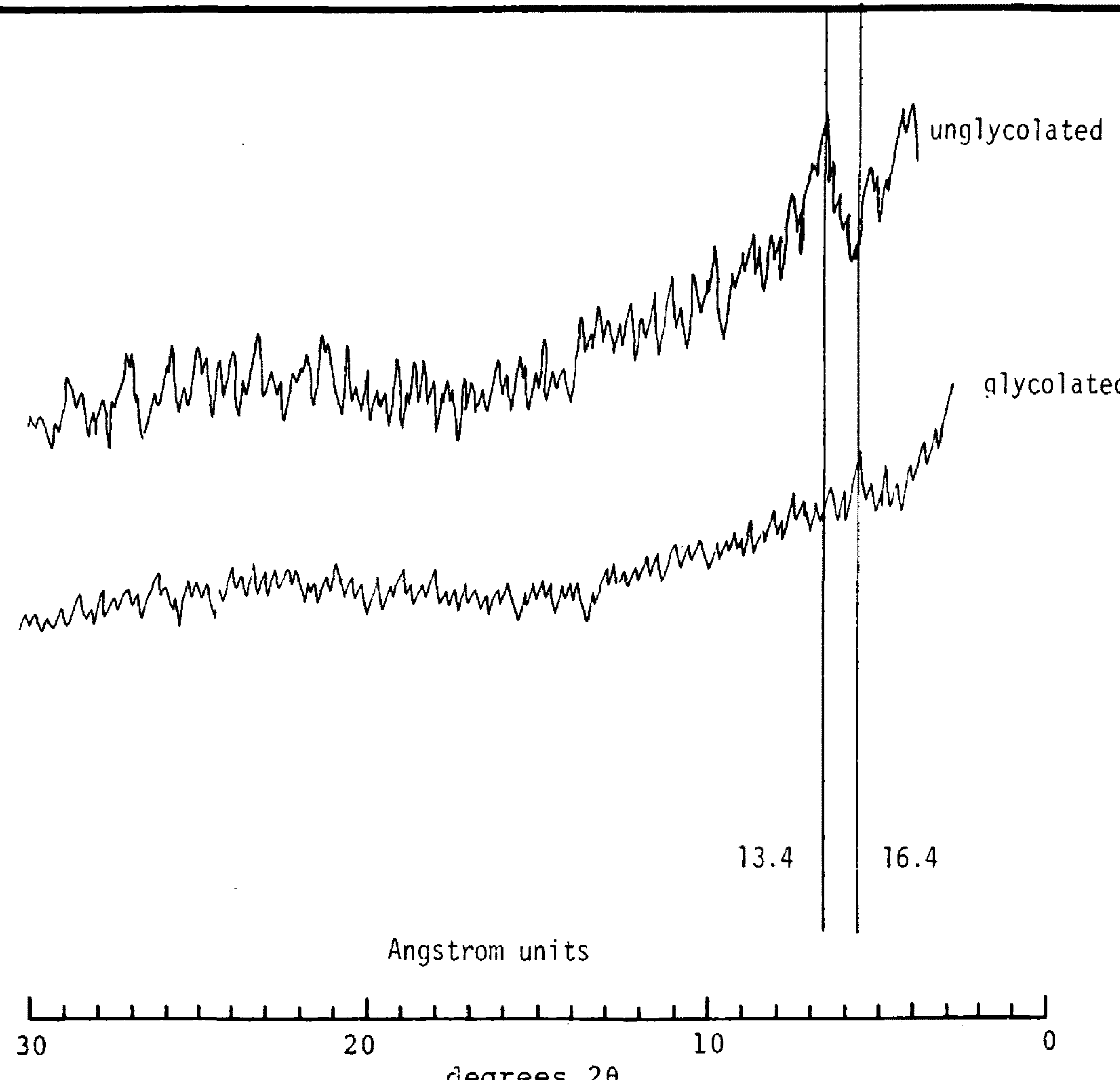
APPENDIX A

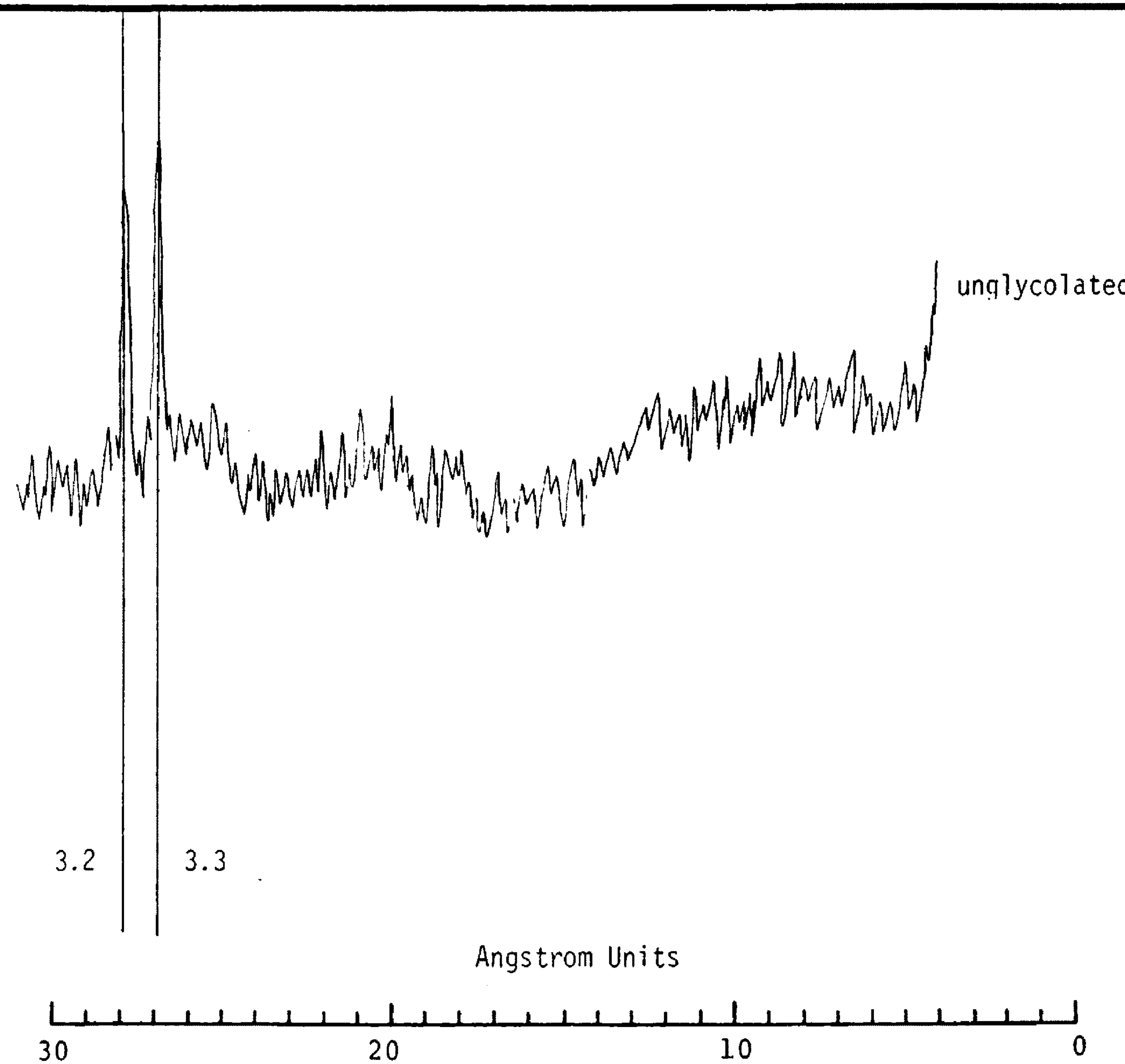
X-RAY DIFFRACTION PATTERNS



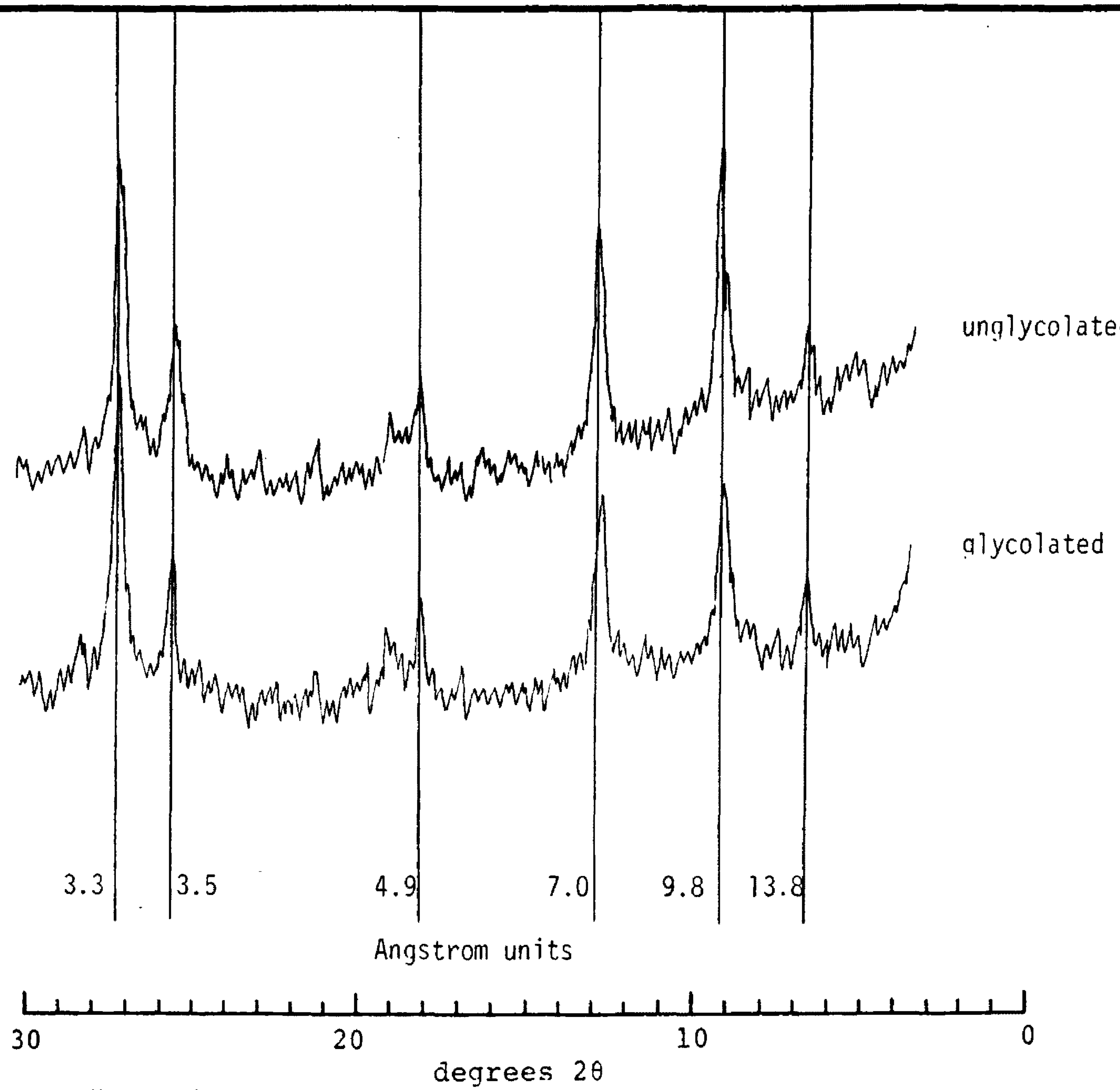
X-ray diffraction patterns, Lake Fork depth 11 cm



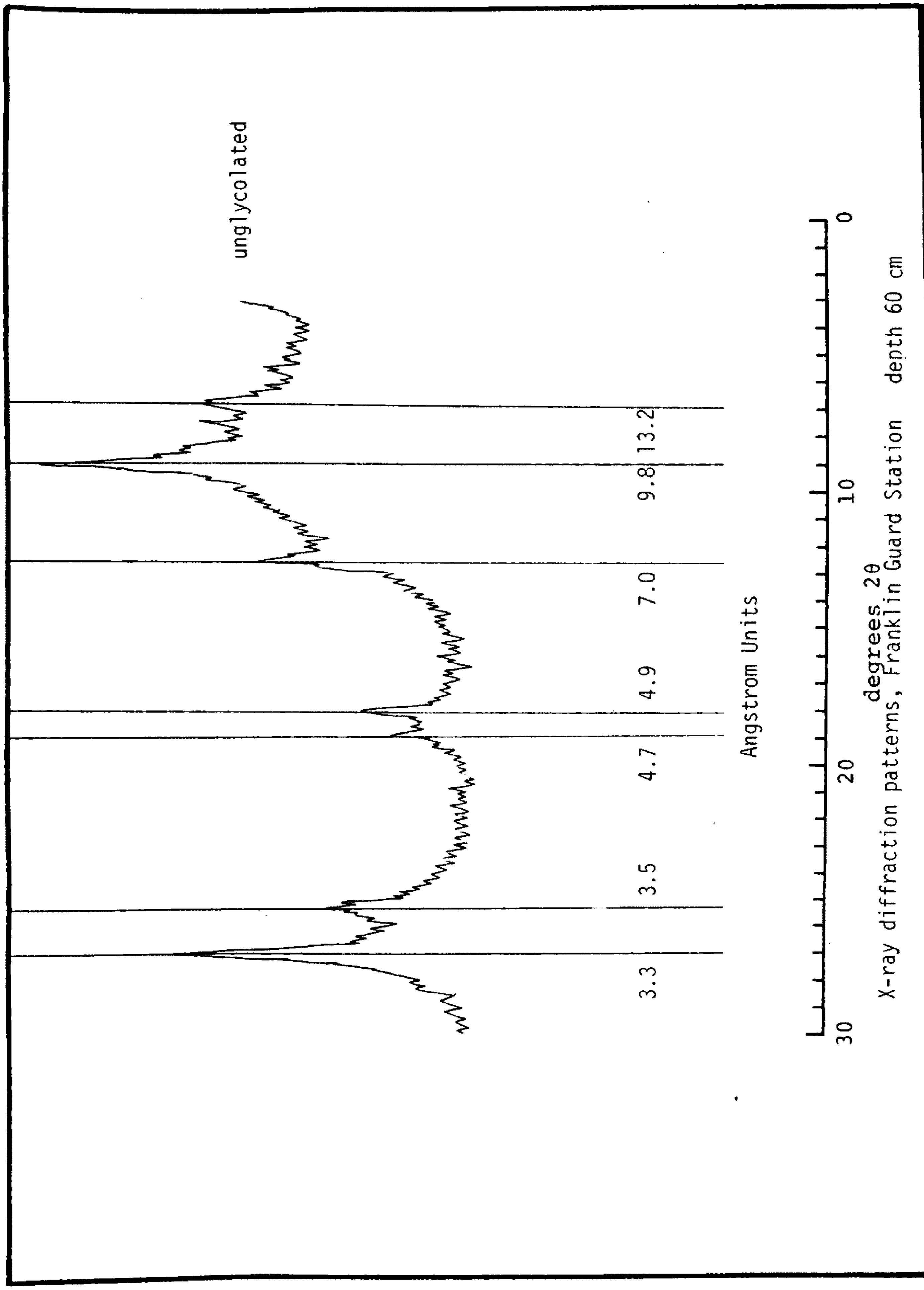
X-ray diffraction patterns, Lake Fork depth, 30 cm



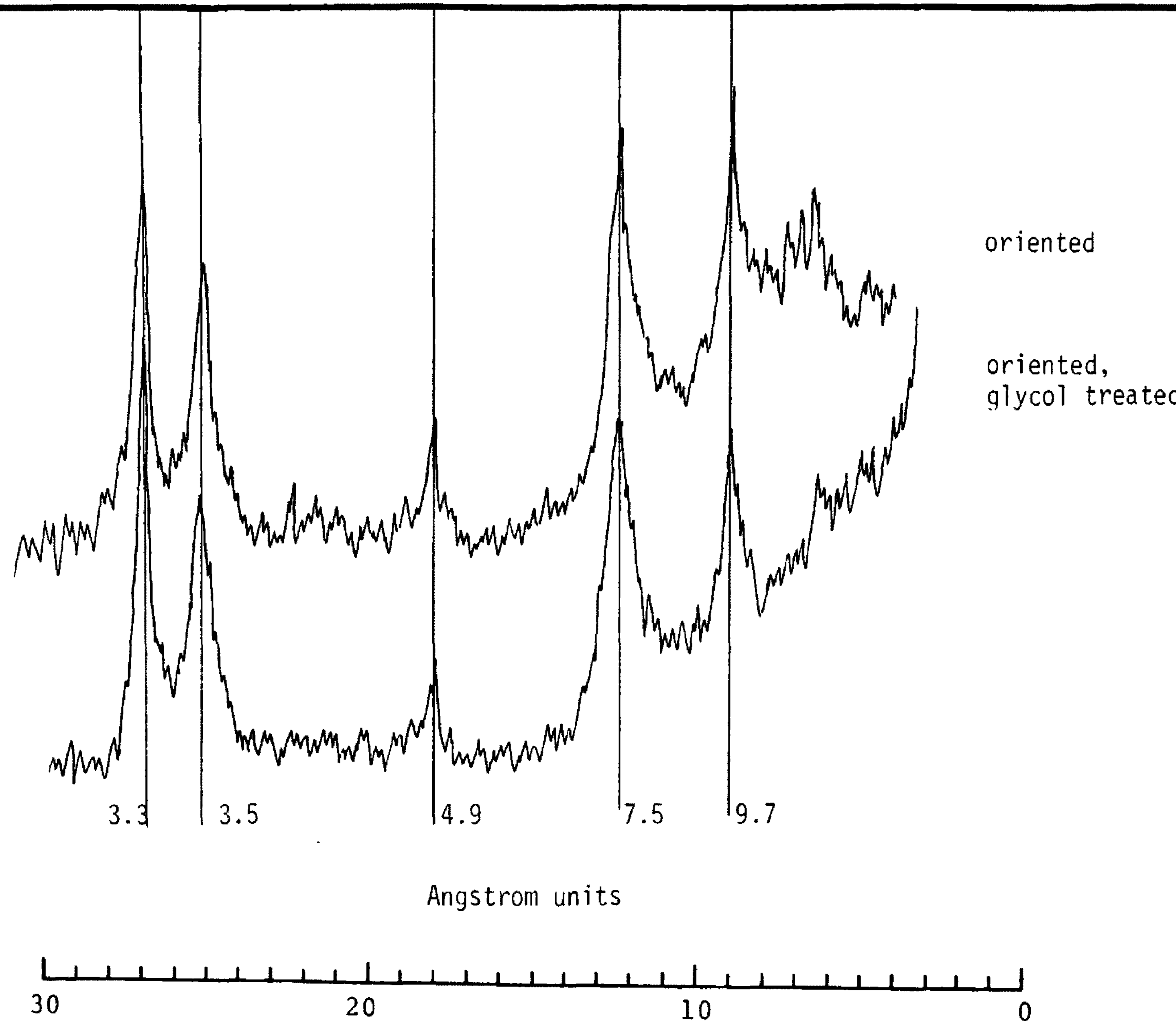
X-ray diffraction pattern, Lake Fork depth 90 cm



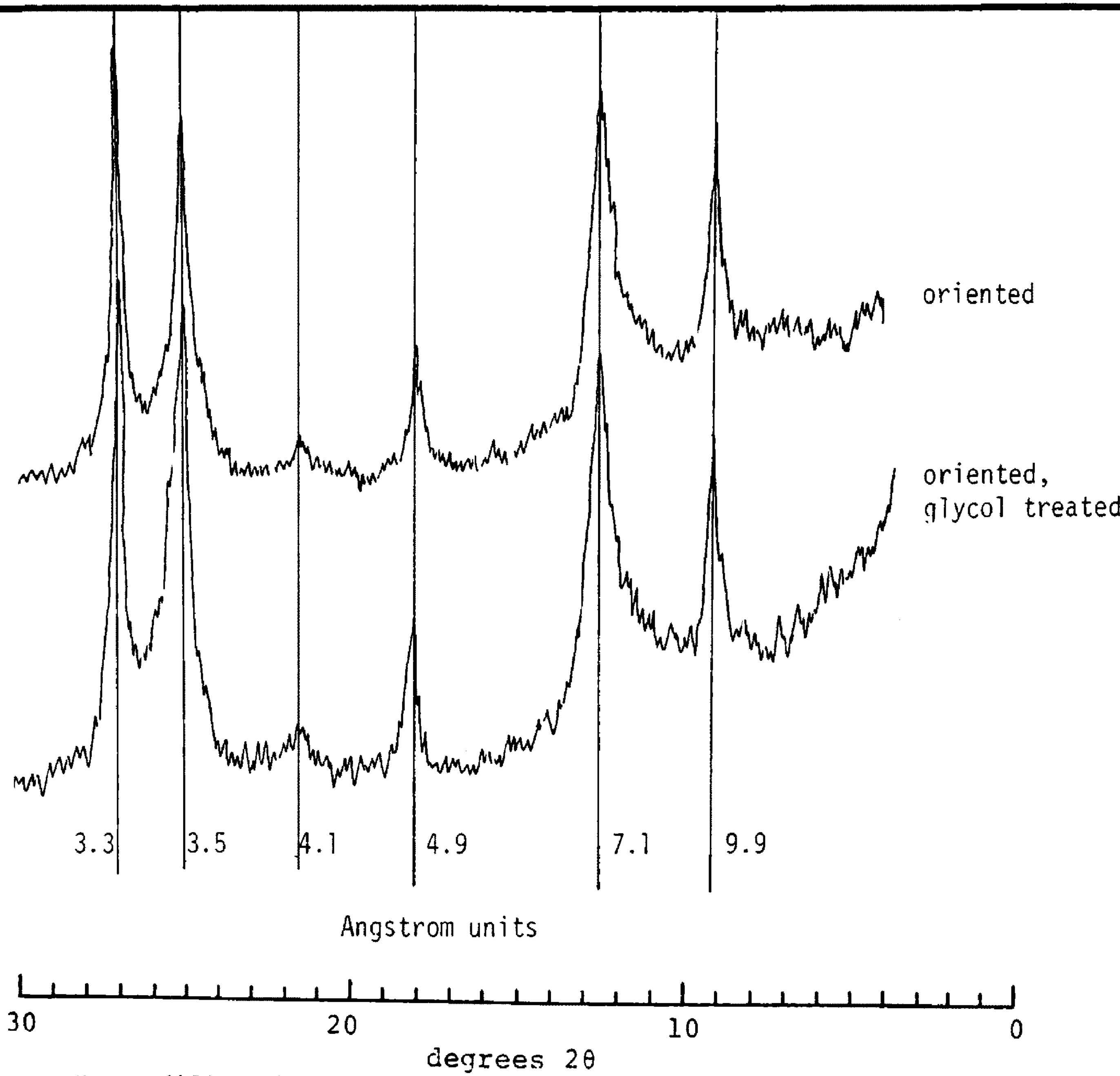
X-ray diffraction patterns, Franklin Guard Station depth 30 cm



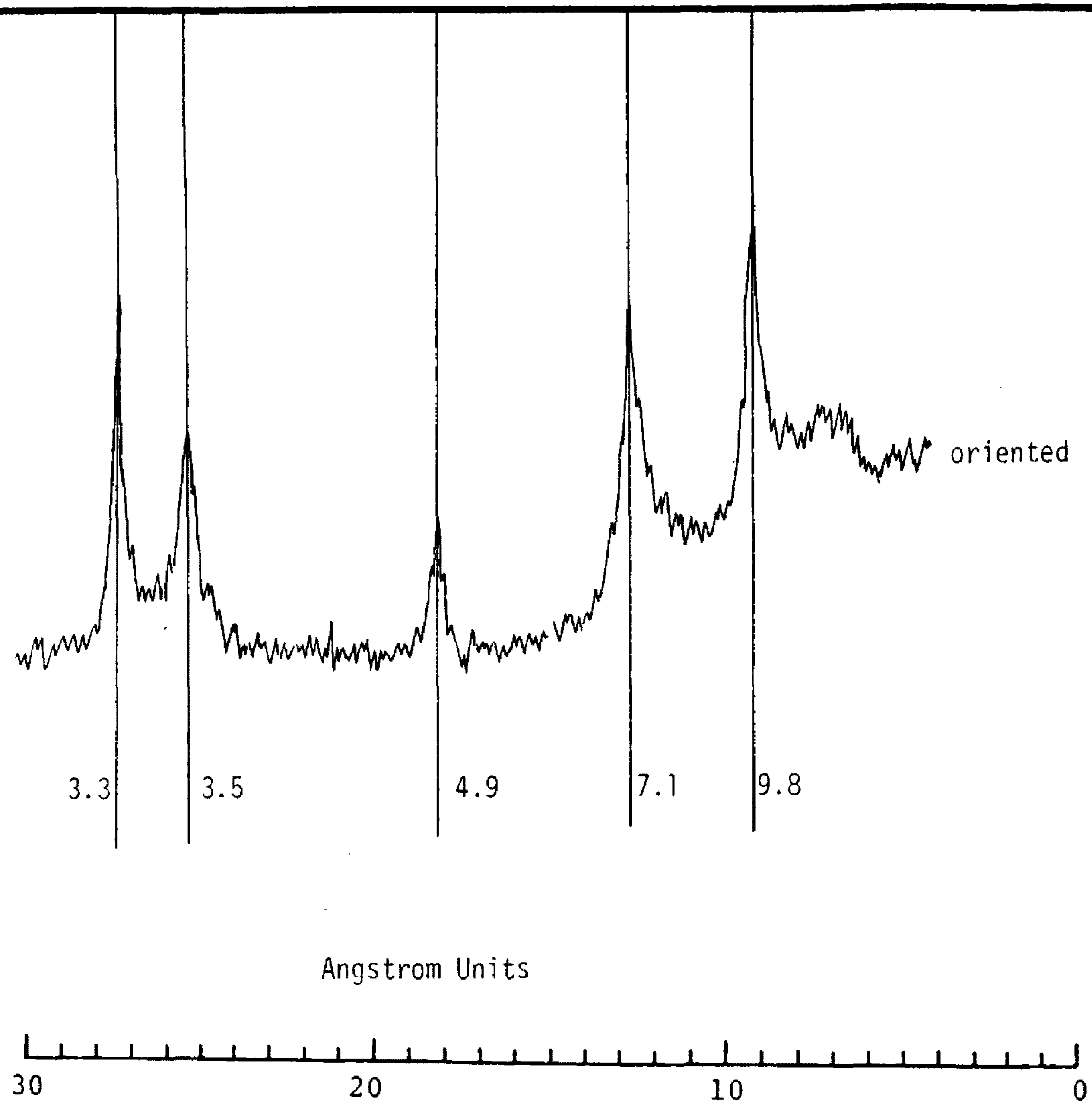
X-ray diffraction patterns, Franklin Guard Station depth 60 cm



X-ray diffraction patterns, Shoofly Meadows depth 19 cm



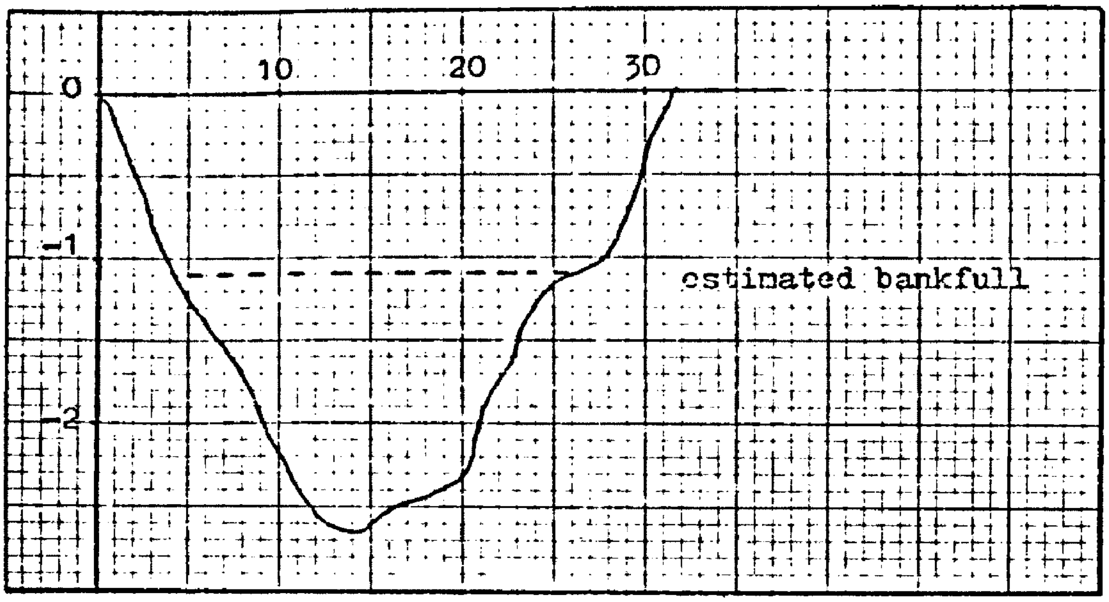
X-ray diffraction patterns, Shoofly Meadows depth 21 cm



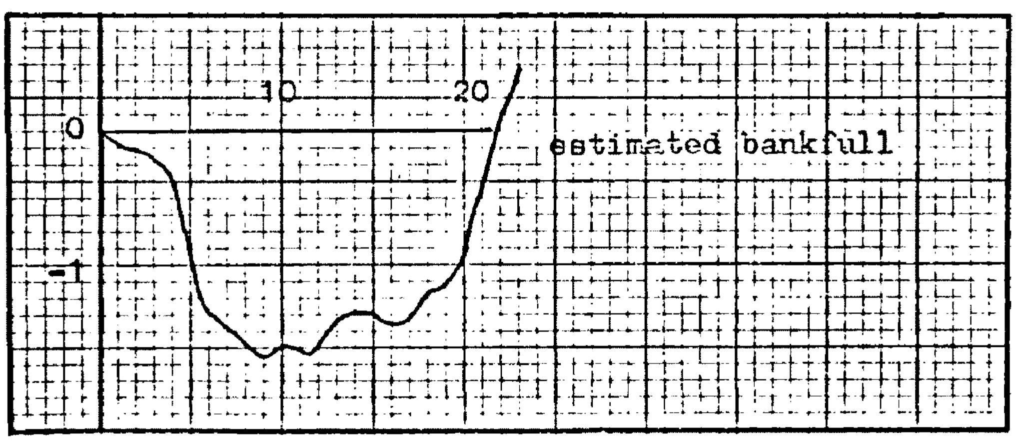
X-ray diffraction pattern, Shoofly Meadows, depth 114 cm

APPENDIX B

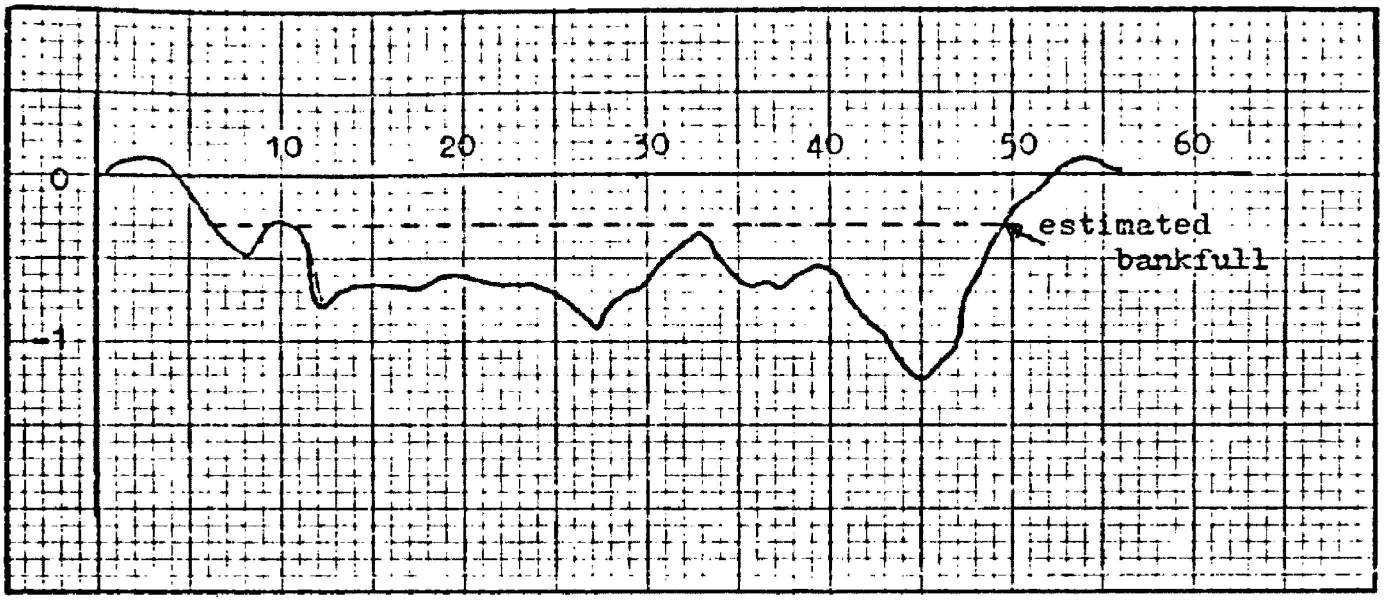
STREAM CHANNEL CROSS SECTIONS



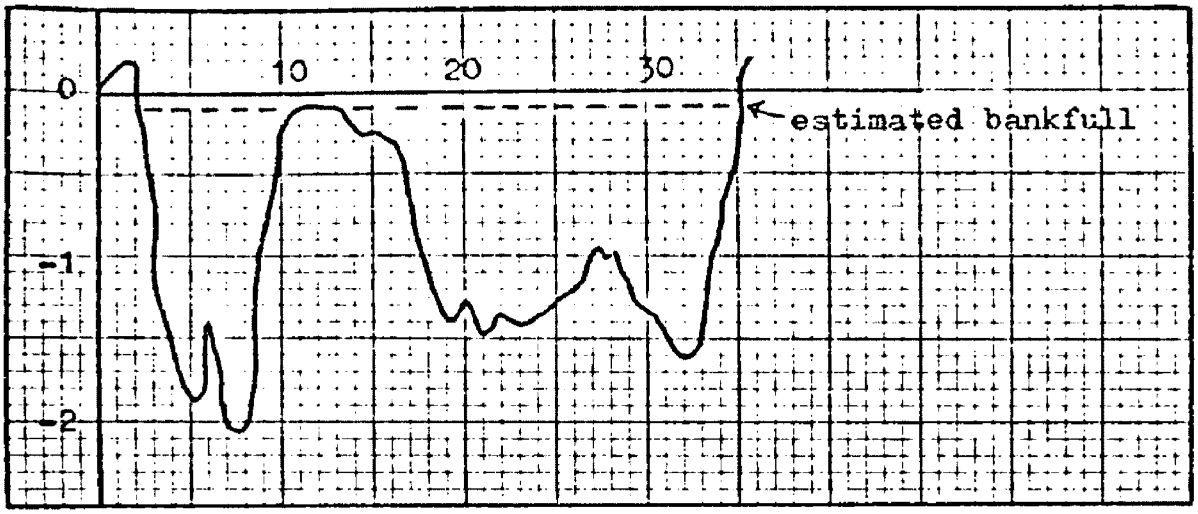
Cross-section #1, Site #3, view upstream, units
are meters; SW 1/4, SE 1/4, Sec. 19, T.14N, R18W



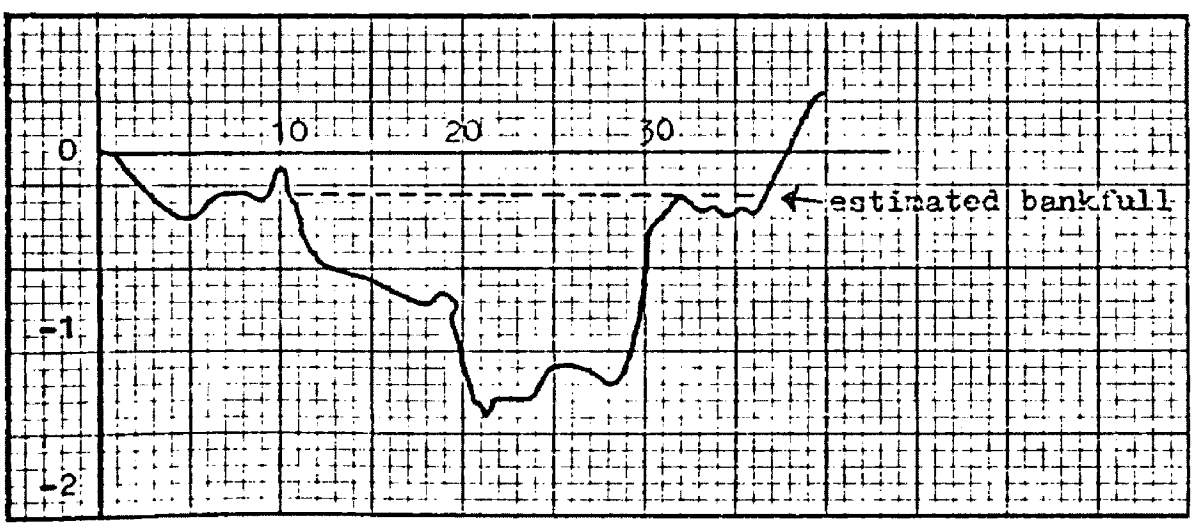
Cross-section #2, Site #3, view upstream



Cross-section, Site #2, view upstream, units are meters, SW 1/4, NW 1/4, T14N., R18W



Cross-section #1, Site #1, view upstream, units are meters; SE 1/4, SE 1/4, Sec. 27, T15N, R18W.



Cross-section #2, Site #1, view upstream

APPENDIX C

LIST OF GAGE SITES USED

Stations Used

Gage Location	U.S.G.S. Station No. I.D. used	Basin Area (mi^2)
Flint Creek at Maxville, MT	12329500	208
Boulder Creek at Maxville, MT	12330000	71
Mid. Fork Rock Creek near Phillipsburg, MT	12332000	123
Nevada Creek near Finn, MT	12335500	116
Blackfoot River near Bonner	12340000	2290
Clark Fork at Missoula, MT	12340500	5999
West Fork of Bitterroot River	12342500	317
Bitterroot River near Darby, MT	12344000	1049
Skalkaho Creek near Hamilton, MT	12346500	878
South Fork of Flathead River near Hungry Horse, MT	12359800	1160
Sullivan Creek near near Hungry Horse, MT	12361000	71
Swan River near Bigfork, MT	12370000	671
Prospect Creek at Thompson Falls, MT	12390700	182
Rattlesnake Creek at Missoula, MT	12341000	80 77