



A source study of the suspended solids in the Gallatin River
by Yuch Ping Hsieh

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
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Montana State University
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Abstract:

Water samples were taken from the Gallatin River and its tributaries. Dissolved and suspended material contents, mineralogy of the silts and clays were analyzed. The result shows that most streams in the Gallatin drainage were muddiest in the May-June period when rapid snowmelt occurred in the mountains and highlands. The minerals of silts and clays were used as indicators to trace the sources of the silt and clay carried in the Gallatin River. The results confirm the silt and clay content and turbidity measurements in showing that Taylor Fork was the main source of the silt and clay carried in the Gallatin River above the National Forest boundary in the May-June period.

The source of the silt and clay carried in Taylor Fork was traced to the upper Taylor Fork above Wapiti Creek. East Gallatin River contributed significant amounts of silt and clay to the Gallatin River in the broad valley floor during the sampling seasons, i.e., March-June, 1970 and 1971. Other tributaries of the Gallatin River were not found to be a dominant source of the suspended silt and clay in the Gallatin River, although some of them were very muddy on some sampling dates.

The clay minerals in most streams were smectite dominant. Beaver and Sage Creeks are two of the exceptions, they had smectite and kaolinite minerals. Minerals of silts in the sedimentary rock region were quartz dominant, while silts of the streams in the Tertiary volcanic rock region were quartz, feldspar, and vermiculite minerals. Minerals both in the clay and silt throughout the Gallatin River were similar to those of the streams in the sedimentary rock region.

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IN THE GALLATIN RIVER

by

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A thesis submitted to the Graduate Faculty in partial
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of

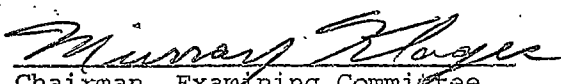
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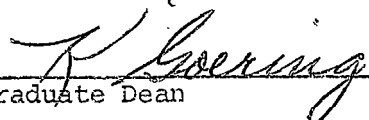
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ABSTRACT

Water samples were taken from the Gallatin River and its tributaries. Dissolved and suspended material contents, mineralogy of the silts and clays were analyzed. The result shows that most streams in the Gallatin drainage were muddiest in the May-June period when rapid snowmelt occurred in the mountains and highlands. The minerals of silts and clays were used as indicators to trace the sources of the silt and clay carried in the Gallatin River. The results confirm the silt and clay content and turbidity measurements in showing that Taylor Fork was the main source of the silt and clay carried in the Gallatin River above the National Forest boundary in the May-June period.

The source of the silt and clay carried in Taylor Fork was traced to the upper Taylor Fork above Wapiti Creek. East Gallatin River contributed significant amounts of silt and clay to the Gallatin River in the broad valley floor during the sampling seasons, i.e., March-June, 1970 and 1971. Other tributaries of the Gallatin River were not found to be a dominant source of the suspended silt and clay in the Gallatin River, although some of them were very muddy on some sampling dates. The clay minerals in most streams were smectite dominant. Beaver and Sage Creeks are two of the exceptions, they had smectite and kaolinite minerals. Minerals of silts in the sedimentary rock region were quartz dominant, while silts of the streams in the Tertiary volcanic rock region were quartz, feldspar, and vermiculite minerals. Minerals both in the clay and silt throughout the Gallatin River were similar to those of the streams in the sedimentary rock region.

INTRODUCTION

Sediment, the product of the earth surface erosion, is a major pollutant of our flowing streams, lakes, and reservoirs (Glymph & Storey 1967). Williams (1969) has pointed out that sediment transported by runoff water greatly exceeds in volume the combined total of other substances which pollute surface water. Although the problem of sediment has puzzled humans for thousands of years throughout history, our knowledge of the problem is still limited. One reason for this is there are many factors which affect sedimentation. Many of the factors associated with sedimentation, such as soil erodibility, character of storm, etc., are difficult to measure and to evaluate. Moreover, sedimentation is a characteristic of the individual watershed. In many cases, the knowledge obtained from a successful sedimentation study of one watershed is of little use to another watershed (Ackermann 1957).

The fine material of the stream sediment, i.e., silt and clay, is the most important and active entity that impairs water quality. Not only because it can be transported almost as fast and as far as the water, but it also acts as a carrier of many chemical wastes in water (Glymph & Storey 1967). It is necessary to know the source of this material before we can effect control over the erosion and sedimentation problems.

Predicting the source of sediment that is carried by streams in a watershed is one of the most difficult problems in a sedimentation study. A common method that has been used in several studies was analyzing the sedimentation data of many watersheds, and finding out the relation between sediment yield and its affecting factors, then using the relationships to estimate the source of sediment (Anderson 1957, Anderson & Wallis 1963). Although the method was successful in some studies, it is a laborious and expensive procedure. Ackermann (1957) has suggested using radioactive or tagged material to trace the source of sediment. This is probably a good idea, but we don't know how practical it is in a larger watershed.

Clay mineralogy of soil particles is a reflection of the geology, weathering condition, and other soil formation factors of the location where the soil particles were formed. If those factors are distinct among different parts of a watershed, we might expect that the clay mineralogy of the sediment from different parts of the watershed could reflect the source of the sediment distinctively.

The purpose of this study is to find out if the mineralogical measurement of the suspended solids in a stream can be used as an indicator in tracing the source of sediment. If so, it will greatly reduce the cost of determining the sources of sediment polluting the streams.

The river chosen, the Gallatin, is important locally, and also because of its contribution to the Missouri and the Mississippi River.

A limited number of studies on soil clay mineralogy in the area have shown differences within the area. The clay mineralogy of a chernozem soil developed on loess in the lower part of the Gallatin drainage was shown quite different from that of the subalpine soil developed on shale in the upper part of the drainage (Bourne & Whiteside 1962, and Klages & McConnell 1969). A geologic map of the area also showed several distinct geological units lying within the area (Ross et al 1955).

Literature Review

There are three fundamental processes of sedimentation before the sediment deposits on a river bed or a soil surface, i.e., weathering, erosion, and transportation (Trask 1950). It is recognized that not all of the material weathered and eroded contributes immediately to the downstream sediment problem. The sediment content of a stream is dependent on the limiting step among the three processes. The process with the slowest rate will determine the rate of sediment contributing to a stream. In general, erosion is the limiting process that determines the sediment content of a stream.

The gross erosion of a watershed includes gully erosion, channel erosion, and sheet erosion. Coarse particles larger than sand, i.e., gravel, mostly come from gully erosion and channel erosion, whereas, silt and clay were believed to come mostly from sheet erosion (Woodburn 1955). Sheet erosion also has been found as a most important source of

sediment found in streams. According to Glymph's study (1957), it accounts for 75% or more of the sediment in the 73 out of 113 watersheds in various parts of the United States. Silt and clay content in a stream more or less depends on how available it is from the watershed, and it has little relationship to the stream flow characteristics, because the stream flow would rarely be loaded to capacity with a suspended load (Woodburum 1955).

According to Musgrave (1947), there are at least four primary factors which influence the sediment load in a stream. They are:

- 1) Rainfall--particularly by intensity and amount in their determination of energy of impact.
- 2) Flow characteristics of the watershed surface--particularly affected by percent and length of the slope.
- 3) Soil characteristics--particularly those physical properties which affect erodibility of soil.
- 4) Vegetation cover and management.

Rainfall has a close relation to runoff if other factors remain constant. The raindrop provides the kinetic energy for the detachment of soil particles from the surface. The rainfall factor has a much greater effect on contributing silt and clay to the stream than it does the sand (Renard 1969).

Sheet erosion was found to be more important in more humid regions than drier regions of the United States (Glymph 1957).

Smith and Wischmeier (1957) found that the sheet erosion rate is proportional to the percent and length of the slope exponentially.

Percent slope has more effect than length of slope on the rate of soil loss. Their study also showed the significant difference on erodibilities of seven soils, the relative soil loss rates owing to the soil types only ranging from 1. to 1.5.

Anderson (1954) in his study of 29 watersheds in western Oregon showed that different geologic materials have different rates of erosion. Recent volcanic material has 8 times more relative erodibility than that of Jurassic and Triassic sediments.

Among the factors which influence the silt and clay content in streams, vegetation cover and soil management condition probably is the most important one. The effects of vegetation and management condition on the sediment load in the stream always overwhelm other factors such as soil character, rainfall character, etc.

The undisturbed forest and pasture cause few problems of sediment pollution of waters. Packer (1966) showed that the proper planned forest cutting only produces a limited amount of sediment to streams. Logging and skidding of logs from the forest without proper management will produce considerable sediment to stream water. Above all, roads that are inadequately drained or are located too close to streams are the main cause of sediment pollution in forest streams.

Smith and Wischmeier (1957), and Musgrave (1947) found that a row crop field has about one hundred times the soil loss rate of pasture or grassland by erosion.

Quantitative interpretation of the relationship between watershed variables and sediment yield was begun with Musgrave (1947). The principle of the method is assuming that the relationship between sediment and several independent variables is a multiple regression equation involving the product of those variables with different exponents. The basic equation is:

$$Y = a U^b V^c W^d \dots\dots$$

Where Y is the sediment yield or load, U, V, W, etc., are independent variables which affect Y. a, b, c, d, are constants which define the characteristics of sedimentation on a watershed. Many sedimentation studies based on the principle succeeded in estimating the individual effect of those variables on the sediment yield in a watershed

(Woodburum 1955, Anderson 1957, Anderson and Wallis 1963, Dragoun and Miller 1966, Renard 1969, and Spraberry and Bowie 1969). Results of those studies told us that the relative importance of those variables varies greatly from one watershed to another. This means watersheds have their own characteristic sedimentation problems.

People who are involved in sedimentation studies had largely devised their own equipment for sampling and measuring the sediment load in the stream according to their own ideas. This led to both inaccuracy and non-uniformity of results and with little basis for comparison or dependable utilization (Fry 1950). In order to remedy this situation, a set of standard sediment samplers and sampling technique has been

developed at the Iowa Institute of Hydrolic Research (1940-1948) for all U.S. Government agencies who are involved in sedimentation studies.

Other problems of sampling and measuring suspended sediment in a stream are the non-uniform vertical distributions of both suspended load and stream velocity (Benedict 1957).

Measurement by present sampling equipment does not accurately measure the total suspended sediment load, but difficulties also arise in measuring the sediment concentration close to the river bed. Estimation of the average suspended sediment load can be obtained by the flow duration sediment-rating curve method (Sheppard 1963) or by theoretical calculation using the hydrological relationships (Brook & Keck 1963).

Clay mineralogy of sediment has been well studied. Weaver (1958a) studied clay mineralogy of thousands of sediment samples by using x-ray analyses. He indicated that the great majority of clay minerals in sedimentary rocks were detrital in origin, strongly reflected the character of their source materials, and were only slightly modified in their depositional environments of sea water. A few other studies also confirmed Weaver's conclusion (Milne & Earley 1958, Griffin 1962, Mackintosh & Gardner 1966). On the other hand, clay mineral facies of sediments coincide with environmental facies of their formation place, although the clay mineral criteria for distinguishing any given type environment are extremely variable (Weaver 1959).

Keller (1956) reviewed many published references on the origin of clay minerals and concluded that clay minerals could be used as indicators of the environment of their formation. Griffin (1962) studied clay mineral facies of sediment in northeastern Gulf of Mexico and found that distinctive clay mineral facies were from different rivers which drain into the gulf. The Mississippi River contributes sediment with montmorillonite suite, the Apalachicola River contributes sediment with Kaolinite suite, and the Mobile River, which lies between the Mississippi and Apalachicola Rivers, contributes sediment with intermediate clay mineral suites to the Gulf of Mexico. Milne and Earley (1958) found that the clay mineralogy of sediment in the later stages of geological history appears to vary between two extremes in which either montmorillonite or Kaolinite predominates, and the climate of the source area may be the most important factor in determining the resultant clay mineral assemblage. Weaver (1958b) studied shales of upper Mississippian-lower Pennsylvanian age, and found different clay mineral assemblage for different shales. Jackson (1965) suggested Quaternary clays have, in part, been inherited as minerals from rocks of the entire geologic column and, in part, formed pedogenically. Jinks and Perkins (1968) correlated the soil minerals to the source of that soil by knowing the source. Mackintosh and Gardner (1966) noticed quantitative variations in the amounts of different clay minerals within and among the soils developed on the floodplain and deltaic deposits at the mouth of the Frazer River

in Canada. Skvortsov (1959) determined the source of sediment by knowing the geology of the watershed. Lund, et al (1970), used particle distribution curve of sediment in a reservoir to distinguish the recent mineral sediment from underlying material. They found clay mineralogy of the sediment was similar to the type of clay minerals identified in the corresponding watershed soils.

All the evidences showed that clay mineralogy could be a useful indicator for locating sediment sources.

DESCRIPTION OF THE STUDY AREA

Drainage and Topography

The Gallatin River is located in Gallatin County in southwestern Montana, where it is a part of a geologic structural entity, termed the Madison-Gallatin uplift (Hall 1961). The Gallatin River originates in the northwest part of Yellowstone National Park and flows through intermountain valleys between the Gallatin and Madison Ranges for about 80 miles before it enters the broad Gallatin Valley floor near the town of Gallatin Gateway. Then it flows northward and northwestward gently through the valley floor for a distance of about 28 miles, passes through a small gorge at Logan, and leaves the valley. Three miles downstream, it joins the Madison and Jefferson Rivers to form the Missouri River (Hackett et al 1960). The altitude of the whole Gallatin River basin ranges from about 6800 feet to about 4100 feet. The surface

gradient of the Gallatin drainage ranges from more than 100 feet per mile at the southern end of the valley to less than 40 feet per mile at the northern end of the valley (Hackett et al 1960). The area of the whole Gallatin drainage is about 1800 square miles (Stermitz et al 1963).

The upper part of the Gallatin Valley is the principal inlet of the surface water to the valley. Quite a few tributaries of the Gallatin River, most of them less than 15 miles in length, drain into the Gallatin River from high land on both sides of the river. Below Gallatin Gateway northward, the Gallatin River enters a broad valley floor and meets the East Gallatin River, which is the main tributary of the Gallatin River, north of Manhattan. The Gallatin Valley floor is shaped like a potato about 20 miles wide and 25 miles long. The west boundary of the valley floor is the Camp Hills. The south and east sides of the valley floor are bordered by coalescing alluvial fans that slope rather steeply from the Gallatin and Bridger Ranges. The Gallatin Range averages about 10,000 feet in crest altitude. The Bridger Range is located at the east side of the valley floor with an average crest altitude of 9,000 feet. On the north side of the valley floor is a sharp cliff of the Horseshoe Hills, cut by the East Gallatin River. Between the Horseshoe Hills and the Bridger Range there is the Dry Creek subarea. Dry Creek drains southward to the valley. The East Gallatin River enters the Gallatin Valley about 5 miles east of Bozeman near Bozeman Pass, and arcs northwestward to north of Manhattan and meets the Gallatin River.

The streams which come from the high land of the Gallatin and Bridger Ranges to the valley all contribute to the East Gallatin River. Those streams are Hyalite Creek, Bozeman Creek, Rocky Creek, Bridger Creek, and others (Data of Gallatin Valley floor after Hackett et al 1960).

Climate

The climate of the Gallatin River drainage is characterized by a long cold winter and a short cool summer. Daily and seasonal fluctuation in temperature is large. According to the data of the Weather Bureau from 1931 to 1952 (reviewed by Hall 1961), the highest recorded temperature in the area was 112° F; the lowest recorded temperature was -66° F. The mean annual temperature at the upper valley was 35° F, and 42° F at the lower part of the valley near Bozeman. The mean annual precipitation at the upper Gallatin Valley was 21.1 inches, and the mean annual snowfall was 155.2 inches. The freeze-free season at the upper part of the valley was 40 to 60 days, and at the lower part of the valley near Gateway was 90 to 100 days. In 1970-1971 the mean annual temperature at Gallatin Gateway was 36.1° F, and at Bozeman was 43.7° F. The mean annual precipitation at Gallatin Gateway was 25.1 inches, and at Bozeman was 17.8 inches.¹

¹ National Oceanic and Atmospheric Administration Environmental Data Service, U.S. Department of Commerce (1970-1971), Climatological Data, Montana, 73:13 and 74:13.

Precipitation is unevenly distributed throughout the area. The southeast part of the valley receives more precipitation than that of the north and northwest part of the area (Stermitz et al 1963). The mean annual runoff is also greater in the southwest part than that of the north or northeast part of the area. A great deal of snowfall accumulates in the mountain area of the Gallatin drainage during the long cold winter. Rapid snowmelt occurs around April-May-June when the temperature is high, and causes runoff.

The mean annual discharge is much larger in the downstream area of the Gallatin River than that of the upstream. The mean annual discharge ranges from 100 cubic feet per second in the upper part of the Gallatin Valley to 945 cubic feet per second at Logan, which is the only outlet of the Gallatin Valley. The mean annual discharge at Gallatin Gateway was 755 cubic feet per second (Data after Stermitz et al 1963).

Geology

The geology of the Gallatin drainage has been studied (Hackett et al 1960, Hall 1961, Mifflin 1963, Stermitz et al 1963, Glancy 1964, and McMannis & Chadwick 1964). From the geologic map of Montana (Ross et al 1955), the whole Gallatin drainage can be divided into four distinct geologic units as shown in Fig. 1 (after Ross et al 1955).

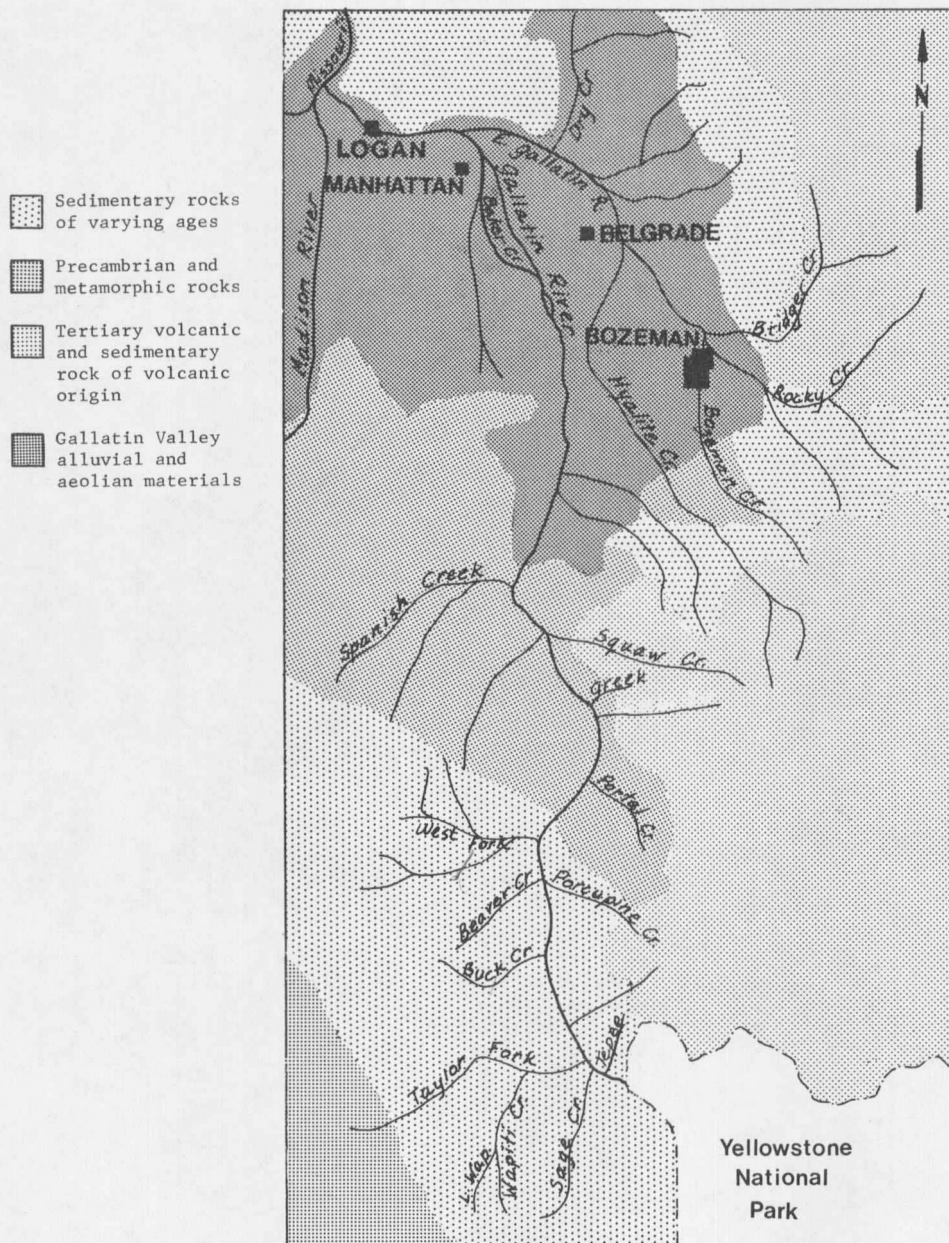


Fig. 1. Geology of the Gallatin drainage

The first unit is from Yellowstone Park to the mouth of West Fork. It has been described in detail by Hall (1961). In this region, the Gallatin River flows transverse to an intermontane area with basically sedimentary rocks of Cretaceous age (65 million to 135 million years ago). The upper part of this unit which is south of Buck Creek was mainly of late Cretaceous undifferential rocks. These rocks consist of siliceous shales, sandstone, and mudstones which are soft and highly erodible, and probably are the major sources of the sediment carried in the streams during the period of heavy rainfall or the rapid snowmelt. This soft material is unstable when it is wet and subject to earthflow and landslide. Hall found a very large landslide two miles north of Taylor Fork, and many other landslides at upper reaches of the streams in this area. Few older sedimentary rocks of limestone (Mississippian, 300 million to 330 million years ago), and sandstones of late Paleozoic or early Mesozoic age (200 million to 350 million years ago) were found along the courses of Sage Creek, Taylor Creek, and Buck Creek. The ancient Precambrian metamorphic rocks formed the higher mountain area near the Madison Range. These rocks are highly resistant and not likely to contribute much sediment or dissolved material to the streams.

From Buck Creek to the mouth of West Fork in this same unit is dominantly of Kootenai Formation sedimentary rocks (early Cretaceous age). Kootenai rocks in this area consist of three parts: upper and lower parts of this formation are resistant quartzitic sandstone, whereas the middle

part of the formation is non-resistant shales, silt- and clay-stones. The dark-gray Colorado shale and sandstone are also common in the drainage of West Fork.

Taylor Fork and West Fork are the two biggest tributaries of the Gallatin River in this unit. The upper course of Taylor Fork flows through a region of Precambrian metamorphic rocks, and through a large area of Quaternary glacial deposit or landslide material which consists of poorly sorted silt, sandstone, and gravel. The middle and lower parts of Taylor Fork are rocks of Cretaceous age to Mississippian age which are common in the whole unit.

The upper part of the West Fork drainage is Quaternary glacial deposit or landslide material. Then West Fork passes through a large area of Kootenai Formation rocks of conglomerates, claystones, sandstones, limestone, and Colorado shale. At its mouth, Tertiary sedimentary rocks were found.

Other important tributaries of the Gallatin River in the unit are Sage Creek, Buck Creek, Beaver Creek, which are located entirely in this unit, and Teepee Creek and Porcupine Creek in which only the downstream parts are in the unit.

Sage Creek and Buck Creek flow through similar sedimentary rocks which consist of conglomerates, sandstones, shales, and impure limestones of late Paleozoic to early Mesozoic ages (350 million to 63 million years ago), except Sage Creek passes through a region of Tertiary

volcanic material. The geology of the basin of Beaver Creek is similar to that of West Fork, except there is not much glacial material found at the upperstream.

Porcupine Creek and Tepee Creek drain into the Gallatin River from the eastern side, and only their downstreams are located in the unit.

The second geologic unit is from West Fork to the drainage basin of Spanish Creek (Detailed geology of the unit has been described by Mifflin 1963). A prominent Spanish peak fault is located in this unit. The material which had covered in this region has been removed by erosion. The old Precambrian metamorphic rocks of gneiss, schist, amphibolite, and metaquartzite outcrop throughout the unit. These exposed Precambrian rocks are deeply weathered, and become rock debris. Other rock outcrops in this unit are sedimentary rocks of Cambrian and Devonian ages (370 to 600 million years ago).

Spanish Creek and Portal Creek are entirely located in the unit. The upperstream and mouth of Spanish Creek cut through the Precambrian rocks, whereas a minor part of the middle stream of Spanish Creek flows through younger sedimentary rocks of Cambrian and Devonian ages. Portal Creek joins the Gallatin River from the eastern side. Squaw Creek and Swan Creeks flow through this unit before they enter the Gallatin River. The mouth of Squaw Creek is through complicated sedimentary rocks of

Cambrian, Mississippian, and Tertiary ages. The mouth of Swan Creek is through the Precambrian metamorphic rocks.

The third geologic unit is a vast area located to the east of the Gallatin River. This unit is basically of Tertiary volcanic rocks, which are, in general, younger than most of the sedimentary rocks in the area.

According to the study of McMannis and Chadwick (1964), the volcanic rocks in this unit unconformably overlie the Precambrian metamorphic rocks and the Paleozoic-Mesozoic sequence and cap most of the higher ridges including the backbone of the Gallatin Range.

Two lithologic types are dominant in these volcanic rocks. The first type is the crystallized lava flows of basic andesite composition. The second type is a stratified volcanic breccia of basic andesite to more acidic composition.

Some Tertiary intrusives also are found in this unit. The basalt intrusives located at the head of Porcupine Creek are very hard black basalt. Most of the intrusive bodies are porphyritic. In general, plagioclase is distinctive in the rocks of this unit.

The upper drainage basins of Tepee Creek, Greek Creek, Porcupine Creek, Swan Creek, and Squaw Creek are all in this unit. The headwaters of the streams which head from the Gallatin and Bridger Ranges are in this unit too. They are Hyalite Creek, Bozeman Creek, Rocky Creek, and Bridger Creek.

From Gallatin Gateway north to the Horseshoe Hills, which is the northern boundary of the Gallatin Valley, is the fourth geologic unit (Detail study of the geology has been made by Hackett et al 1960). Younger alluvium and fans cover most of the surface of this area. Tertiary strata only crop out at Camp Hills and Dry Creek subarea, but underlie Quaternary alluvium and fans throughout the valley.

Most of the Tertiary strata are poorly consolidated, moderately well cemented conglomerate, consisting of poorly sorted locally derived rock fragments in a matrix of clay or calcareous silt and sand.

Except for the Camp Hill area and Dry Creek subarea, most other places in the valley are covered by younger alluvium or fans of Quaternary age with thickness from 10 feet to 400 feet.

The stream-channel deposit alluvium lies between the Gallatin and East Gallatin Rivers and consists of cobbles and gravel intermixed with sand, silt, and clay which is believed derived from Gallatin and Bridger Ranges. The north part of this stream-channel deposit contains a higher proportion of silt and clay.

The alluvium along the streams which head from the Bridger Range is different from the alluvium along the streams which head from the Gallatin Range. The former consists of fragments of Precambrian gneiss, schist, and Paleozoic limestone and quartzite, whereas the latter is similar in composition to the alluvium underlying the plain between the

Gallatin and East Gallatin Rivers. In general, the ratio of fine- to coarse-grained material in all alluvium increases in a downstream direction.

Many hills and slopes in the Gallatin Valley are mantled with buff calcareous silt, probably of aeolian origin. The possible origin of this loess material is the Tertiary strata material.

Important streams in this unit are the Gallatin River, East Gallatin River, Bozeman Creek, Hyalite Creek, Rocky Creek, Bridger Creek, and Dry Creek.

Soils

The soil of the Gallatin River drainage can be roughly divided into two groups; those of the upper drainage which are in the canyon and mountainous areas, and those of the lower drainage, which are on the broad valley floor (Southard 1969).

The predominant soil series in the upper Gallatin River drainage are Loberg, Garlet, and Teton (Olsen et al 1971).

The Loberg soils are classified in the clayey-skeletal mixed mineralogy family of Cryoboralfs. They developed on clayey non-calcareous materials. They are well drained with slow permeability, and medium to rapid runoff. Loberg soils are extensive in many tributary drainages of the Gallatin Canyon area, especially in the West Fork, Beaver, Porcupine, Portal, and Squaw Creek drainages (Olsen et al 1971).

Garlet soils are classified in the loamy skeletal mixed mineralogy family of Cryochrepts. The soils are well drained, highly permeable, and with a low runoff rate.

The Teton soils are classified in the fine-loamy mixed mineralogy family of Typic Cryoborolls. They developed on sandstone bedrock uplands. They are well-drained with medium runoff and moderate permeability.

Representative soil series of the lower Gallatin drainage are the Bozeman, Bridger, Avalanche, and Burnt Fork series (Southard 1969).

Bozeman soils are classified in the fine-silty mixed mineralogy family of a Argic Pachic Cryoborolls. The parent materials are loess derived from mixed alluvial sources. The soil is well drained and moderately permeable. Runoff is slow to medium.

The Bridger series soils are classified in the fine mixed mineralogy family of Argic Cryoborolls. The underlying material is very gravelly. They developed in very thick loam or clay loam textured unconsolidated deposits from a variety of rocks. They are well drained and moderately permeable. Runoff is medium to slow.

The Avalanche and the Burnt Fork soils are on recent alluvium and older bench edges. These soils occur in the northwest edge of the Gallatin Valley floor. Avalanche and Burnt Fork soils have been classified as Calciorthid and Argiboroll soils respectively.

METHODS

Five-gallon water samples of the Gallatin River were taken at three locations, the National Forest boundary just below Spanish Creek, near Manhattan, and near Logan. The water was collected just beneath the surface using a sampler with a five foot handle. Care was taken not to disturb the soil of the stream bank or bed when sampling. The suspended solids measured represented the content near the surface instead of the whole vertical section of the sampling site. Two-gallon samples were taken on each of the creeks marked by names in Fig. 1, and on the Gallatin River at the Yellowstone National Park boundary. Samples were taken from Bridger, Rocky, Bozeman, and Hyalite Creeks where they leave the mountains and from the other creeks at or near their mouths. The East Gallatin River was sampled near Belgrade (below Dry Creek), and near Bozeman (below Bridger Creek).

In March and April of 1970 and 1971, the three locations of the Gallatin River below the National Forest boundary were sampled just after a shower or temperature was raising enough to cause snowmelt in low land of the valley. In May and June, the Gallatin River and its tributaries were sampled periodically. The period of May and June marked the time when runoff and erosion was most important in the mountains rather than the low lands.

Samples of the East Gallatin River were taken at Belgrade whenever the Gallatin River was sampled. The samples from tributaries of the East Gallatin River were sampled regularly from March to April in 1970, and less often in 1971.

Detailed studies of two of the major tributaries of the Gallatin River, i.e., Taylor and West Forks, were made on selected dates of 1971. Wapiti and Little Wapiti Creeks were sampled before their junction, and before joining Taylor Fork on June 17. Taylor Fork above Wapiti Creek was also sampled on the same date. Branches of the West Fork, i.e., North, Middle, and South Forks of West Fork, were sampled twice in May and once in June 1971.

Sediment was separated from these samples for further analysis. The sand was screened out using a 325 mesh sieve and discarded. The silt and clay were flocculated using calcium chloride. They were then concentrated by siphoning off the clear supernatant liquid. They were stored in small bottles using methanol as a preservative until the analysis.

At the same time when these samples were taken, a second sample of one liter was taken at each location for quantitative analysis. The sand was screened out, oven dried, and weighed. Dissolved salts (ppm) were estimated by multiplying electrical conductivity (micromhos) by 0.64 (U.S. Salinity Lab. Staff 1954). The entire liter of water was evaporated to dryness in a 250 ml beaker, and the gain in weight

measured. Dissolved salts then were subtracted from the total solids to estimate suspended silt and clay.

In the 1971 samples, turbidity was measured using a nephelometer at 650 m μ , and a Jackson turbidity meter.

Silt and clay were measured by the pipette method after destruction of organic matter with hydrogen peroxide, and dispersion with 2% calgon (Na_3PO_3).

After the mechanical analysis, the sample was separated into silt and clay fractions by the centrifuge method described by Jackson (1956).

Silts and clays were both saved for the x-ray mineralogical analysis. The silts were saturated with magnesium and excess salts washed out by centrifuging. Magnesium saturated silts were mounted on a glass slide, air dried, then x-rayed using a General Electric XRD-5 diffractometer. Copper K α radiation ($\lambda = 1.5405\text{\AA}$) was used. In some cases, the slides were heated at 350°C for two hours and x-rayed again in order to distinguish chlorite from vermiculite. X-ray diffraction patterns were run on the clays after each of the following treatments: magnesium saturated and air dried, magnesium saturated and glycerol solvated, and potassium saturated and heated 350°C for two hours. Smectite was recognized from the 18 $\text{\AA}$ peak on the magnesium saturated glycerol solvated diffraction pattern, while on the same pattern vermiculite and chlorite remain at 14 $\text{\AA}$. Highly interstratified smectite was

recognized by the magnesium saturated air dried samples giving a $14 \text{ \AA}$ peak which became a band of diffuse scattering at wider spacings when glycerol solvated. Chlorite was distinguished from vermiculite by the $14 \text{ \AA}$ peak remaining on the potassium saturated pattern after heating at 350°C . The preparation of glass-slide procedures followed that described by Kittrick (1961).

RESULTS AND DISCUSSION

A. Suspended Silt and Clay Content

In the March-April period, some streams in the Gallatin Valley floor were muddier owing to the rainfall and snowmelt. However, the Gallatin River above the National Forest boundary and its tributaries in the mountains were still too clean to study. In the May-June period, rapid snowmelt and rainfall caused runoff in the mountains, and most of the streams of the whole Gallatin drainage were muddy enough for study.

The suspended silt and clay contents of the lower Gallatin River and the streams in the lower Gallatin drainage, in the March-April sampling dates of 1970 and 1971, are given in Tables 1 and 2. The Gallatin River at the National Forest boundary, where the river leaves the mountains, and at Manhattan, before it meets the East Gallatin River, were both clean and had little difference in silt and clay content. However, the Gallatin River at Logan, near to the outlet of the Gallatin drainage, was much muddier on two of the sampling dates, i.e., April 11, 1970 and April 16, 1971. On these dates, the East Gallatin River was very muddy too. Examining the data in Tables 1 and 2, we can conclude that the increase in silt and clay of the Gallatin River between Manhattan and Logan on those two dates, as well as all other dates in March and April, was owing to the contribution of the East Gallatin River. Baker Creek, another tributary of the Gallatin

TABLE 1. The silt and clay content (ppm) of the Gallatin River and its tributaries in March and April, 1970

	Mar. 11	Mar. 19	Apr. 1	Apr. 11	Apr. 27	Ave.
Gallatin-Forest bdry.	9	14	17	21	16	15
Gallatin-Manhattan	11	11	21	51	15	22
Baker Creek		66	7	99	43	54
E. Gallatin-Belgrade	105	44	35	268	49	100
Gallatin-Logan		34	39	347	50	118

TABLE 2. The silt and clay content (ppm) of the Gallatin River and its tributaries in March and April, 1971

	Mar. 18	Apr. 1	Apr. 16	Ave.
Gallatin-Forest bdry.	2	33	23	19
Gallatin-Manhattan	6	14	21	14
E. Gallatin-Belgrade	18	57	239	105
Gallatin-Logan	17	36	170	74

River, was smaller and clearer than the East Gallatin River during this sampling period.

The suspended silt and clay contents of the Gallatin River and its tributaries, in May-June of 1970 and 1971, are given in Tables 3 and 4. Most of the streams were much muddier in this period than in the March-April period. This is because the rapid snowmelt occurred in the mountains and caused runoff and erosion. The silt and clay content of the upper Gallatin River at the Yellowstone National Park boundary was lower than those of the lower sampling sites on the river. The average silt and clay content at the Park boundary in the May-June period was 62 ppm for 1970 and 31 ppm for 1971. While at the Forest boundary, the content increased to 125 ppm for 1970 and 103 ppm for 1971. The increase was owing to the contributions of many tributaries in the mountains as well as the stream bank erosion of the river itself. There are at least twelve main tributaries of the Gallatin River between the Park and Forest boundaries---Taylor Fork and West Fork are the largest. Others are quite small except Squaw Creek which is medium size. In 1970, most of the tributaries had their highest measured silt and clay on June 8. Two exceptions were Tepee and Beaver Creeks; they were muddiest in early May, and suddenly the Tepee Creek became extremely clean in the rest of the sampling dates. In 1971, the peaks appeared in late May and early June.

TABLE 3. The silt and clay content (ppm) of the Gallatin River and its tributaries in May and June, 1970

	May 4	May 18	May 27	June 8	June 19	Ave.
Gallatin-Park bdry.	19	115	74	84	16	62
Tepee Creek	495	-	-	15	-	102
Sage Creek		215	114	616	24	242
Taylor Fork	87	174	154	639	39	219
Buck Creek		63	93	312	2	118
Porcupine Creek	155	250	238	413	42	219
Beaver Creek	64	487	124	223	-	179
West Fork	22	96	109	140	25	78
Portal Creek	15	13	43	59	29	31
Swan Creek				126		126
Greek Creek				437		437
Squaw Creek	15	121	364	626	21	229
Spanish Creek	29	23	24	32	16	25
Gallatin-Forest bdry.	29	103	184	277	30	125
Gallatin-Manhattan	29	264	212	448	39	198
E. Gallatin-Belgrade	269	363	394	127	87	248
Gallatin-Logan	171	798	390	267	72	320

TABLE 4. The silt and clay content (ppm) of the Gallatin River and its tributaries in May and June, 1971

	May 7-8	May 17-18	May 27-28-29	June 8-9	June 17-18	Ave.
Gallatin-Park bdry	25	11	69	34	14	31
Tepee Creek	52	26	-	-	-	16
Sage Creek		52	341	123	86	150
Taylor Fork	107	67	263	123	390	190
Buck Creek	37	42	130	70	43	64
Porcupine Creek	66	48	151	74	221	112
Beaver Creek	191	45	74	30	44	77
West Fork	80	37	123	57	51	70
Portal Creek		30	36	33	24	31
Greek Creek	1019	203	139	71	25	292
Squaw Creek	15	61	168	67	18	66
Spanish Creek		12	30	23	12	19
Gallatin-Forest bdry	89	54	153	126	96	103
Gallatin-Manhattan	146	23	161	203	139	134
Baker Creek	49	42				46
E. Gallatin-Belgrade	154	95	194	104	41	117
Gallatin-Logan	183	99	203	220	159	173

Taylor Fork was always muddier than the Gallatin River at the Forest boundary. The silt and clay content averaged 219 and 190 ppm in 1970 and 1971 respectively, compared with 125 and 104 ppm at the Forest boundary. It is large and muddy, and likely plays a significant role in contributing sediment to the Gallatin River. Other muddier tributaries in the mountains were Sage, Porcupine, Squaw, Greek, Beaver, and Tepee Creeks. They were on several sampling dates, but not all, muddier than the Gallatin River at the Forest boundary. Greek and Tepee Creeks, nevertheless, were the two muddiest streams of all on some dates. But since these two streams are very small, it is doubtful that they influenced the sediment content of the Gallatin River significantly. All of these, along with the West Fork, are located in the sedimentary rocks region and the Tertiary volcanic material region. The West Fork was not as muddy as the Gallatin River at the Forest boundary. The average silt and clay content of West Fork was 78 and 70 ppm in 1970 and 1971.

The Wapiti and Little Wapiti Creeks, of the Taylor Fork, were sampled on June 17, 1971. Both of these two branches were relatively clean. Little Wapiti Creek had 26 ppm in silt and clay; Wapiti Creek had 40 ppm before joining Little Wapiti and 30 ppm at Taylor Fork. The content was much higher in Taylor Fork above Wapiti (583 ppm). The mouth of Taylor Fork had 390 ppm silt and clay on the date. This showed

that the source of the silt and clay of Taylor Fork was from the upper stream itself instead of from the Little Wapiti or Wapiti Creeks.

Samples on May 28 and June 8, 1971 from the North Fork of West Fork were clean, averaging 11 ppm silt and clay. Middle Fork was higher, averaging 57 ppm, while South Fork of West Fork was highest having 105 ppm. The combined North and Middle Forks had an average content of 20 ppm just after they joined, and 43 ppm just before joining the South Fork. The silt and clay content of West Fork at the mouth before joining Gallatin River was averaged 90 ppm on those two dates. Thus, the contribution of silt and clay to the West Fork was more important from South Fork than from North or Middle Forks.

The two cleanest streams in the mountains are Spanish and Portal Creeks. They both lie in the Precambrian metamorphic rock region. The silt and clay content of Spanish Creek averaged 25 and 19 ppm in 1970 and 1971 respectively. Portal Creek was 31 ppm, both in 1970 and 1971.

The Gallatin River carried more silt and clay downstream at Manhattan than upstream at the Forest boundary, during the May-June period. It averaged 198 and 134 ppm in 1970 and 1971 respectively. The increase in suspended silt and clay content in this section of the Gallatin River may be attributed mostly to the streambank erosion.

The last sampling site, i.e., below Logan, was always the muddiest among the four locations on the river. The silt and clay content averaged 320 and 173 ppm in 1970 and 1971 respectively, for the May-June

period. In this period, the East Gallatin River was not as muddy as the Gallatin River at Logan. Its contribution thus was not as important as in the March-April period. However, its contribution was not negligible, because it was always muddier than the Gallatin River at Manhattan. Evidence of the local erosion of the Gallatin River between Manhattan and Logan was significant on some dates. For example, on May 8, 1970, the silt and clay content of the Gallatin River at Logan was 798 ppm. That was much higher than at Manhattan (264 ppm) or the East Gallatin River (363 ppm).

Bridger, Rocky, Bozeman, Hyalite, and Dry Creeks are branches of the East Gallatin River. Their suspended silt and clay contents are given in Tables 5 and 6. In the March-April period, Dry Creek was muddier than other branches in the mountains, because Dry Creek is not from the mountains and has snowmelt early in the season. In the May period, snow in the mountains was melting and Bridger and Rocky Creeks became muddier, while Dry Creek was clean. Bozeman and Hyalite Creeks were relatively clearer during both 1970 and 1971.

The upper East Gallatin River at Bozeman, below the junctions of the Bridger, Rocky, and Bozeman Creeks, was much lower in silt and clay content (averaging 36 and 44 ppm in the March-April of 1970 and 1971) than that further downstream below Belgrade (averaging 100 and 105 ppm in March-April of 1970 and 1971).

TABLE 5. Silt and clay content (ppm) of the East Gallatin River and its tributaries, 1970

	Mar. 11	Mar. 19	Apr. 1	Apr. 11	Apr. 27	May 18
Bridger	-	-	-	59		267
Rocky Cr.	-	-	1	87	12	268
Bozeman Cr.		-	5	4	6	94
E. Gallatin- Bozeman		37	6	91	12	
Hyalite Cr.		7	14	15	27	73
Dry Cr.		140	75	226	3	
E. Gallatin- Belgrade	103	44	35	268	49	363

TABLE 6. Silt and clay content (ppm) of the East Gallatin River and its tributaries of 1971

	Mar. 18	Apr. 1	Apr. 16	May 8	May 17
Bridger Cr.				195	
Rocky Cr.				137	
Bozeman Cr.				41	
E. Gallatin- Bozeman	-	25	109		
Hyalite Cr.				44	
Dry Cr.	102	62	2	60	30
E. Gallatin- Belgrade	18	57	239	154	95

B. The Dissolved Salt Content

Dissolved salt contents of the water are given in Appendix Tables 1 and 2. The fluctuation of the dissolved salt content was much smaller than the fluctuation of the suspended solid content in the same stream. Also, the dissolved salt content was quite close for the corresponding sampling dates in the two years.

Fig. 2 shows the dissolved salt content of the Gallatin River on selected dates of 1970. It was higher in the early season when the discharge was lower, and it was lower in the later season when the discharge was higher. The statistical analysis of the data showed an inverse correlation between dissolved salt content (DSC), and total suspended solid content (TSS) of the Gallatin River. The regression equations and the correlation coefficients of the Gallatin River at the different sampling sites are given as follows:

<u>Sampling site</u>	<u>Regression Equation</u>	<u>r</u>
The National Forest boundary	$\log \text{TSS (ppm)} = -2.9 \log \text{DSC (ppm)} + 7.88$	-0.93
Manhattan	$\log \text{TSS (ppm)} = -4.3 \log \text{DSC (ppm)} + 11.3$	-0.85
Logan	$\log \text{TSS (ppm)} = -2.8 \log \text{DSC (ppm)} + 8.53$	-0.73

The inverse relationship between the dissolved salt content and the total suspended solid is explained as follows: the suspended solid content of the river increased when the surface runoff and erosion increased owing to the rapid snowmelt and rainfall, while the dissolved

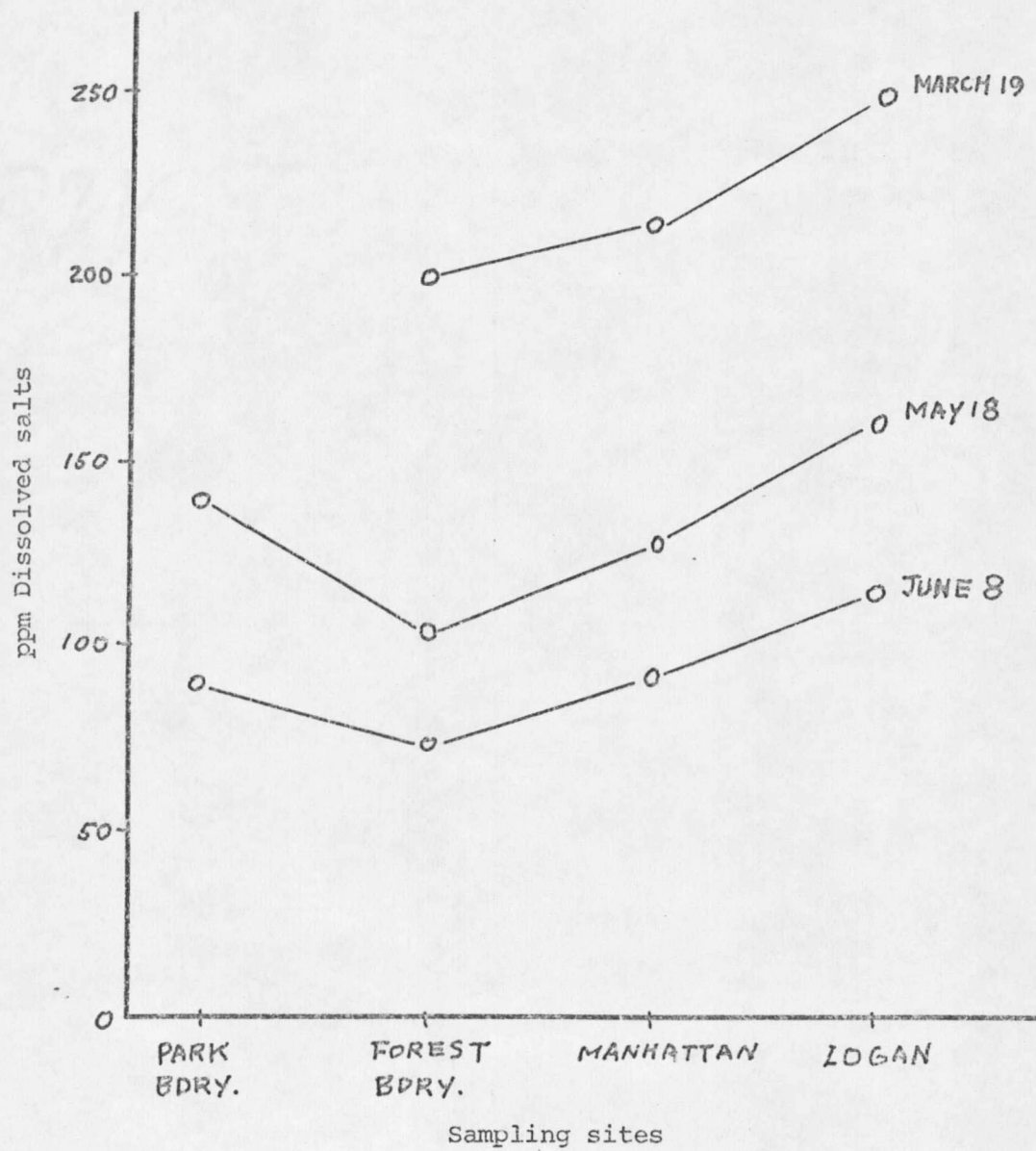


Fig. 2. Dissolved Salts in the Gallatin River on selected dates in 1970

salt content of the river was diluted by this extra surface water. In the drier season, water that entered the river was mostly groundwater and had a better chance to make contact with the salts in the soil and therefore had a higher dissolved salt content. The regression correlation coefficient between the dissolved salt content and the total suspended solid content was good in the Gallatin River at the Forest boundary. The dissolved salt content of the Gallatin River may be a good indicator of the turbidity of the river at that site.

The dissolved salt content of the streams from the sedimentary rocks region was, in general, higher than that of the streams from the volcanic or metamorphic rocks regions.

C. The Turbidity Measurement and the Suspended Solid Content

Turbidity of the 1971 water samples was measured using the Jackson turbidity meter (Jackson candle units) and the nephelometer (% Transmission). The results were compared to the suspended solids measured by the gravimetric method. The results are given in Appendix Table 2. A good correlation was found between the turbidity and the suspended solid content. The regression equations and the correlation coefficients of those measurements are given as follows:

The Nephelometer

TSS	(ppm) = 7.25 % Transmission - 6.18	$\frac{r}{0.88}$
Si+C	(ppm) = 4.8 % Transmission - 1.39	0.92

The Jackson turbidity meter

TSS	(ppm) = 1.94 JCU + 15.6	$\frac{r}{0.89}$
Si+C	(ppm) = 1.26 JCU + 10.4	0.95

where, TSS = Total suspended solids
 Si+C = Suspended silt and clay
 JCU = Jackson candle units

All the correlation coefficients are significant at the 1% level. Both the nephelometer and the Jackson turbidity meter are reasonably good in estimating the ppm suspended solids in the streams, especially in estimating the suspended silt and clay. The procedures of those two methods are simpler and quicker than the gravimetric method. The Jackson candle units can not be used to estimate less than 42 ppm silt and clay, or 63 ppm total solids by the equation, since a reading of less than 25 JCU cannot be measured. A nephelometer would be preferable for estimating suspended solids in a relatively clear stream. The upper limit of the regression equations of this study was 902 ppm total suspended solids, or 583 ppm suspended silt and clay.

D. X-ray Mineralogical Analysis of
 the Suspended Silts and Clays

X-ray mineralogical analysis was made on the silt and clay fractions separately. Silts and clays were separated as larger and smaller than 2 μ equivalent spherical diameter. The analysis was basically a qualitative one; the content of minerals can only be roughly estimated

from the relative peak heights of the diffraction patterns. The result of the analysis was expressed as the percent peak heights of the minerals. In the silts, the percent peak heights were calculated based on the x-ray diffraction patterns of magnesium saturated, air dried samples. In the clays, the percent peak heights were calculated based on the x-ray diffraction patterns of magnesium saturated, glycerol solvated, air dried samples. In the clays of the 1970 samples, quartz content was not included, while in 1971 samples quartz content was included. A summary of the mineralogical analysis of the samples will be given in the following section. Detail of the mineralogical analysis for every sample is given in Appendix Tables 3 and 4.

Table 7 shows the summary of the mineralogical analysis of the samples from the Gallatin River and its tributaries in March and April of 1970 and 1971. Clays of those streams were all high in smectite. The smectite was highly interstratified in these clays, except the samples of the Gallatin River at Logan and East Gallatin River below Belgrade in 1971. Silts of those samples were all high in quartz content.

In the May and June period, most of the streams of the Gallatin drainage were muddier than in March and April, because rapid snowmelt occurred in the mountains. Samples of the Gallatin River at the Yellowstone National Park boundary and streams above the National Forest

TABLE 7. Summary of x-ray mineralogical analysis of the Gallatin River and its tributaries in March and April, 1970 and 1971 (percent peak heights of minerals)

* Interstratified												
** Interstratified vermiculite-chlorite												
† Interstratified vermiculite-mica												
# Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar, Fe/Q=feldspar/ quartz												
		clay					silt					
1970	# Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/ Q	
Gallatin - Forest bdry.	46*	14	19	21		20	13	5	43	19	0.44	
Gallatin - Manhattan	68*	-	20	12		13	6	3	67	12	0.18	
Baker Cr.	52*	13	16	15		23	7	4	51	15	0.29	
E. Gallatin - Belgrade	50*	17	19	14		27	7	5	50	11	0.22	
Gallatin - Logan	59*	19	13	9		22	7	5	57	8	0.14	
<u>1971</u>												
Gallatin - Forest bdry.	61*	2**	14	12	12	13	6	5	61	14	0.23	
Gallatin - Manhattan	51*	3	16	13	16	15	5	4	60	14	0.23	
E. Gallatin - Belgrade	35	19	16	13	18	18	6	6	60	10	0.17	
Gallatin - Logan	44	15**	15	11	14	27	7	6	53	7	0.13	

boundary were taken in this period. The summary of the mineralogical analysis of the samples in May and June is given in Tables 8 and 9.

The Gallatin River at the Forest boundary, Manhattan, and Logan was still smectite dominant in clays, and quartz dominant in silts, but the evidence of the interstratified smectite, that appeared in the March and April samples, disappeared. This may distinguish the sources of the suspended solids of the Gallatin River from the well-weathered surface soils and the less-weathered subsoils, because the surface soils usually have poorer crystallinity of the minerals than that of the subsoils in this area. The Gallatin River at the Park boundary was smectite dominant in clay and quartz dominant in silt too, but content of smectite and quartz was not as high as the above three locations.

Among the tributaries of the Gallatin River in the sedimentary rock region, Taylor Fork and Buck Creek were smectite dominant in clays. Sage Creek had less smectite, and more mica and kaolinite in clays than those of Taylor Fork and Buck Creek. Moreover, evidence of interstratified vermiculite-mica was found in clays of Sage Creek. Clays of West Fork were similar to those of Sage Creek in mineralogy, except variation of mineral composition of West Fork was large during the sampling season (see Appendix Tables 3 and 4). This may imply that the sources of suspended solids in West Fork were more complicated than that of Sage Creek. Clays from the Beaver Creek were high in kaolinite, and also contained interstratified smectite. The mineralogy of silts from the streams

TABLE 8. Summary of x-ray mineralogical analysis of the Gallatin River and its tributaries in May and June, 1970 (percent peak heights of minerals)

* Interstratified ** Interstratified vermiculite-chlorite † Interstratified vermiculite-mica # Sm=smeectite, Ve=vermiculite, Ka=kaolinite, Q=quartz, Fe=feldspar, Mi=mica, Fe/Q=feldspar/quartz										
	clay				silt					
	# Sm	Ve	Mi	Ka	Ve	Mi	Ka	Q	Fe	Fe/Q
Gallatin - Park bdry.	63	4	22	10	22	4	5	56	13	0.23
Tepee Cr.	71	7	14	7	17	4	3	68	8	0.12
Sage Cr.	36	3†	27	34	10	7	10	69	4	0.06
Taylor Fork	68	1**	16	14	15	4	4	70	5	0.07
Buck Cr.	62	-	18	20	18	4	7	67	15	0.07
Porcupine Cr.	87	1	8	5	22	3	4	50	20	0.40
Beaver Cr.	24*	3†	21	53	6	5	13	73	3	0.41
West Fork	44	6**	24	26	15	5	7	68	5	0.07
Portal Cr.	87	9	4	-	33	5	3	31	28	0.90
Swan Cr.	67	7	17	10	44	-	-	23	33	1.44
Greek Cr.	93	-	7	-	56	9	2	18	15	0.80
Squaw Cr.	66	10	11	12	45	5	5	23	23	1.00
Spanish Cr.	67	-	17	17	16	15	4	55	9	0.16
Gallatin - Forest bdry.	64	6	14	17	27	3	6	55	8	0.14
Gallatin - Manhattan	62	10	15	14	29	6	7	49	10	0.20
E. Gallatin - Belgrade	47	18	17	19	30	4	6	52	8	0.15
Gallatin - Logan	59	12	15	14	31	7	7	46	9	0.20

TABLE 9. Summary of x-ray mineralogical analysis of the Gallatin River and its tributaries in May and June, 1971 (percent peak heights of minerals)

* Interstratified † Interstratified vermiculite-mica # Sm=smectite, Ve=vermiculite, Mi=Mica, Ka=kaolinite, Q=quartz, Fe=feldspar, Fe/Q=feldspar/quartz											
	clay					silt					
	# Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/Q
Gallatin - Park bdry.	48	13	13	11	15	17	3	4	62	13	0.21
Tepee Cr.	18	25	7	14	37	13	4	5	69	8	0.12
Sage Cr.	28	4†	22	22	26	9	7	9	72	4	0.06
Taylor Fk.	66	-	11	7	16	18	4	4	71	4	0.06
Buck Cr.	52	2	13	12	21	22	4	5	64	5	0.08
Porcupine Cr.	81	2	6	6	4	14	3	4	57	21	0.37
Beaver Cr.	10*	7	19	39	25	10	5	10	71	4	0.06
West Fk.	28	9	22	18	22	22	4	5	65	3	0.05
Portal Cr.	73	20	-	-	7	30	2	1	23	45	2.00
Greek Cr.	89	7	4	-	-	40	8	2	29	21	0.70
Squaw Cr.	72	10	5	7	5	40	7	3	23	25	1.10
Spanish Cr.	-	46	6	9	40	28	11	7	33	23	0.70
Gallatin - Forest bdry.	62	4	10	9	15	23	4	5	61	6	0.10
Gallatin - Manhattan	58	8	11	10	14	31	5	5	52	11	0.20
Baker Cr.	17	5	5	62	11	54	13	10	10	13	1.30
Gallatin - Belgrade	49	15	12	11	12	35	6	6	47	6	0.13
Gallatin - Logan	55	11	12	9	13	34	4	5	49	7	0.14

mentioned above were similar. Quartz was dominant, and feldspar appeared only in a small amount. The x-ray diffraction peak ratio of feldspar/quartz of those silts was less than 0.1. Vermiculite was the second important mineral in the silts.

The result of the mineralogical analysis of the branches of Taylor Fork and West Fork is given in Tables 10 and 11. Clays and silts of Wapiti and Little Wapiti Creeks had quite different mineral patterns from that in the upperstream of Taylor Fork. The minerals of the two creeks were higher in kaolinite and mica, and lower in smectite than that of Taylor Fork in upperstream. The branches of West Fork, i.e., North, Middle, and South Forks, also had different minerals from those of the lower part of West Fork. Even in different sampling dates, the minerals of suspended solids in the same stream of the West Fork basin were different. On May 28, 1971, smectite content was high in clays of North and Middle Forks, while it was low in clays of South Fork and West Fork at the mouth. On June 8, all the smectite peaks in x-ray diffraction patterns were smaller, broader, or even absent in these clays. It was not raining on May 28, but was raining on June 8. The difference of mineral pattern of the same stream between these two dates was probably due to the different sources of runoff caused by raining and snowmelt.

Squaw, Greek, Swan, Porcupine, and Tepee Creeks originate and flow through the Tertiary volcanic material region. They flow into the

TABLE 10. X-ray mineralogical analysis of Taylor Fork and its branches on June 17, 1971
(percent peak heights of minerals)

#	clay					silt				
	Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe
Wapiti Creek at Taylor Fork	33	-	21	21	26					
Wapiti Creek above L. Wapiti Creek	19	5	19	31	28	5	5	9	74	7
L. Wapiti Creek	28	-	21	24	28	7	5	10	75	3
Taylor Fork above Wapiti Creek	59	-	9	5	27	26	5	5	63	2
Taylor Fork - at the mouth	64	-	9	9	18	22	4	5	67	3

TABLE 11. X-ray mineralogical analysis of West Fork and its branches in 1971
(percent peak heights of minerals)

		# Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar * Interstratified									
		clay					silt				
		# Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe
North Fork	June 8	8*	42	13	17	21	15	3	4	66	12
Middle Fork	May 28	68	5	9	9	9	33	2	4	57	3
	June 8	-	41	-	-	59	26	3	4	62	5
N & M Fork (upper)	May 28	67	7	9	9	9	34	2	3	54	7
	June 8	-	35	15	21	29	23	2	5	60	10
N & M Fork (lower)	May 28	50	9	12	15	15	35	3	5	55	4
South Fork	May 28	14*	10	31	23	23	12	5	6	74	3
	June 8	9*	6	9	9	67	7	4	9	74	6
West Fork at the mouth	May 28	27	13	20	20	20	26	6	6	61	2
	June 8	10*	13	25	25	27	16	4	6	70	4

sedimentary rock region just before their junctions to the Gallatin River. Clays from these streams were very high in smectite, especially the clays from Porcupine and Greek Creeks. The mineralogy of the silts was quite different from that of the streams in the sedimentary rock region. The quartz content was not so high, and the feldspar became important in the silts. The x-ray diffraction peak ratio of feldspar/quartz in most of these silts was approaching or greater than one. The vermiculite content of these silts was higher than the silts of the streams in the sedimentary rock region. The silt of Tepee Creek was quite special. On June 8 and June 17, 1971, calcite was the only important mineral of the silt (not shown in Table 9).

The two cleanest streams, i.e., Portal and Spanish Creeks, are in the Precambrian metamorphic rock region. Clays of Portal Creek were extremely high in smectite with no evidence of kaolinite. The silts were similar to those of the streams in the volcanic material region, which are characterized by the feldspar/quartz peak ratio approaching one. Spanish Creek was different from Portal Creek in mineralogy of clays and silts. The sample of the Spanish Creek on May 4, 1970 showed smectite was dominant in clays, and quartz was dominant in silts. The feldspar/quartz peak ratio of silt was similar to the silts of the streams in the sedimentary rock region. But, the 1971 samples showed very different mineral patterns. In the clay fraction, the smectite peak disappeared, while the vermiculite peak was very high and sharp.

In the silt fraction, the feldspar/quartz peak ratio was close to one, which is the characteristic of the silts of streams in the volcanic material region. The variation in the mineralogy of clays and silts in the two years implies different sources of the suspended silt and clay of Spanish Creek. In 1970, the source might have been the sedimentary rocks included in the Spanish Creek basin, while in 1971 the source might be the igneous materials. For the same reason, the source of the silt and clay of Portal Creek might be the Tertiary volcanic materials that are in the east of the Portal drainage.

Baker Creek is in the lower Gallatin Valley. It flows through the region of alluvial material. Only one May sample was taken in 1971. Kaolinite dominated in clay and vermiculite in silt. Mineralogy of clay and silt from the East Gallatin River below Belgrade was similar to those of the Gallatin at Manhattan and Logan. Smectite dominated in clay and quartz dominated in silt, and no evidence of interstratified smectite was found in these May-June samples.

The result of the mineralogical analysis of the samples from the upper East Gallatin River (below Bozeman) and its branches is given in Table 12. Mineralogy of the East Gallatin River below Bozeman was similar to that of the river below Belgrade, that smectite dominated in clays and quartz dominated in silts. Evidences showed that smectite in the clay was highly interstratified. All the samples of the East Gallatin below Bozeman were taken before the snowmelt in the mountains.

TABLE 12. Summary of x-ray mineralogical analysis of the upper East Gallatin River and its branches, 1970 and 1971 (percent peak heights of minerals)

* Interstratified ** Interstratified vermiculite-chlorite # Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar, Fe/Q=feldspar/quartz												
		clay					silt					
		# Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/Q
1970												
Bridger Cr.	April	50	14	22	18		43	3	3	56	7	0.12
	May 18	62	13	13	13		45	5	7	38	5	0.12
Rocky Dr.	April	59	10	17	14		23	3	4	60	10	0.17
	May 18	58	8	17	17		31	4	7	52	6	0.11
Bozeman Cr.	May 18	36	21	21	21		40	8	8	38	6	0.17
E. Gallatin - Bozeman	Mar.-Apr.	41*	21	17	22		23	5	4	54	15	0.38
Hyalite Cr.	April 11	9	75	6	20		78	5	6	8	4	0.43
	May 18	54	12	15	20		27	8	7	46	12	0.25
Dry Cr.	Mar.-Apr.	43*	12	30	15		17	10	6	56	11	0.20
	June 19	27*	18	27	27		11	7	7	69	7	0.10
1971												
Bridger Cr.	May 8	55	18	12	6	9	42	-	3	48	8	0.15
Rocky Cr.	May 8	41	10	18	18	14	28	4	8	55	5	0.09
Bozeman Cr.	May 8	33	13	7	13	33	35	9	8	37	11	0.29
E. Gallatin - Bozeman	Mar.-Apr.	34*	18**	14	12	22	26	6	6	54	8	0.15
Hyalite Cr.	May 8	38	14	14	19	14	18	6	6	60	11	0.18
Dry Cr.	April 1	24*	15**	24	12	24	16	9	5	62	7	0.12
	May	12*	25	23	13	22	18	9	6	60	8	0.13

Bridger, Rocky, and Bozeman Creeks enter the East Gallatin River above the Bozeman sampling site. Clays of Bridger and Rocky Creeks were high in smectite both in March-April and May samples. Silts of these two creeks were high in quartz. The feldspar/quartz peak ratio of these silts lies between ratios of silts from the sedimentary rock region and volcanic material region. Only one May sample was taken for Bozeman Creek in 1970 and 1971. It shows that the smectite content in clay and quartz content in silt were not as high as those of Bridger and Rocky Creeks. The vermiculite became important in the silt. Some calcite was also found in the silt of Bozeman Creek.

Hyalite Creek flows through four distinct geologic units: the Tertiary volcanic materials, sedimentary rocks, metamorphic rocks, and recent alluvial materials, before it joins the East Gallatin River. Both clay and silt of the April sample had vermiculite as the dominant mineral. Mineral patterns of clay and silt of the May sample were quite different. The clay was smectite dominant, and the silt was quartz dominant. These were similar to the minerals found in the streams of the sedimentary rock region. Thus the sources of the clay and silt in Hyalite Creek were quite different before and after the snowmelt in the mountains.

Dry Creek joins the East Gallatin River from the north end of the Gallatin Valley floor. Almost the whole Dry Creek drainage is in the alluvial material region. However, the material found in the

drainage is older (Tertiary) than the material found in the East Gallatin River drainage (Quaternary) (Hackett et al 1960). In March-April samples, smectite and mica were important minerals in clays, while in May and June samples, smectite, vermiculite, mica, kaolinite, as well as quartz almost evenly distributed in the clays. The smectite was in a interstratified form. Quartz was dominant in silts both in March-April and May and June samples.

E. Tracing the Sources of the Silt and Clay in
the Main Stream by the Mineral Patterns

The mineral patterns of the main stream and its tributaries can be plotted on a diagram (% peak heights vs. minerals), and compared with one another. Clay particles can be well suspended in water for quite a long distance, while silt particles may precipitate and be picked up several times by turbulence. Thus the mineral pattern of clay is a more reliable indicator than the mineral pattern of silt. The interpretation of the mineral pattern diagram should be done carefully in order to distinguish that the similarity of the mineral patterns is due to the same source and not merely to coincidence. The possible tributaries that are likely to influence the silt and clay content of the main stream are those which had higher silt and clay content than that of the main stream on the same sampling date. So, only the mineral patterns of those tributaries need be compared with that of the main stream.

1. Sources of suspended silt and clay in the Gallatin River above the Forest boundary. From Table 4, we can see the sampling date on June 17-18, 1971 was one of the simpler cases. Only two tributaries were higher in silt and clay than the Gallatin River at the Forest boundary. Taylor Fork was 390 ppm, Porcupine Creek was 221 ppm, and the Gallatin River at the Forest boundary was only 96 ppm. The mineral patterns of these three samples were plotted in Fig. 3. It is obvious that the mineral patterns of the main stream are very similar to the patterns of Taylor Fork, and deviate from the patterns of Porcupine Creek. The silt and clay content data confirm that the silt and clay in the Gallatin River at the Forest boundary were basically from Taylor Fork on June 17-18. Porcupine Creek, although much muddier than the Gallatin River at the Forest boundary, was apparently not an important source of the silt and clay carried by the Gallatin River.

On June 8-9, 1971, the silt and clay content of the Gallatin River at the Forest boundary was 126 ppm. No tributaries above the Forest boundary were muddier than it. However, Taylor Fork and Sage Creek were the two muddiest streams in the area; both were 123 ppm in silt and clay. The mineral patterns of these three streams on the date are shown in Fig. 4. We can rule out the importance of Sage Creek immediately, because the patterns are quite different from the main stream. The patterns of the main stream were still similar to Taylor Fork, but

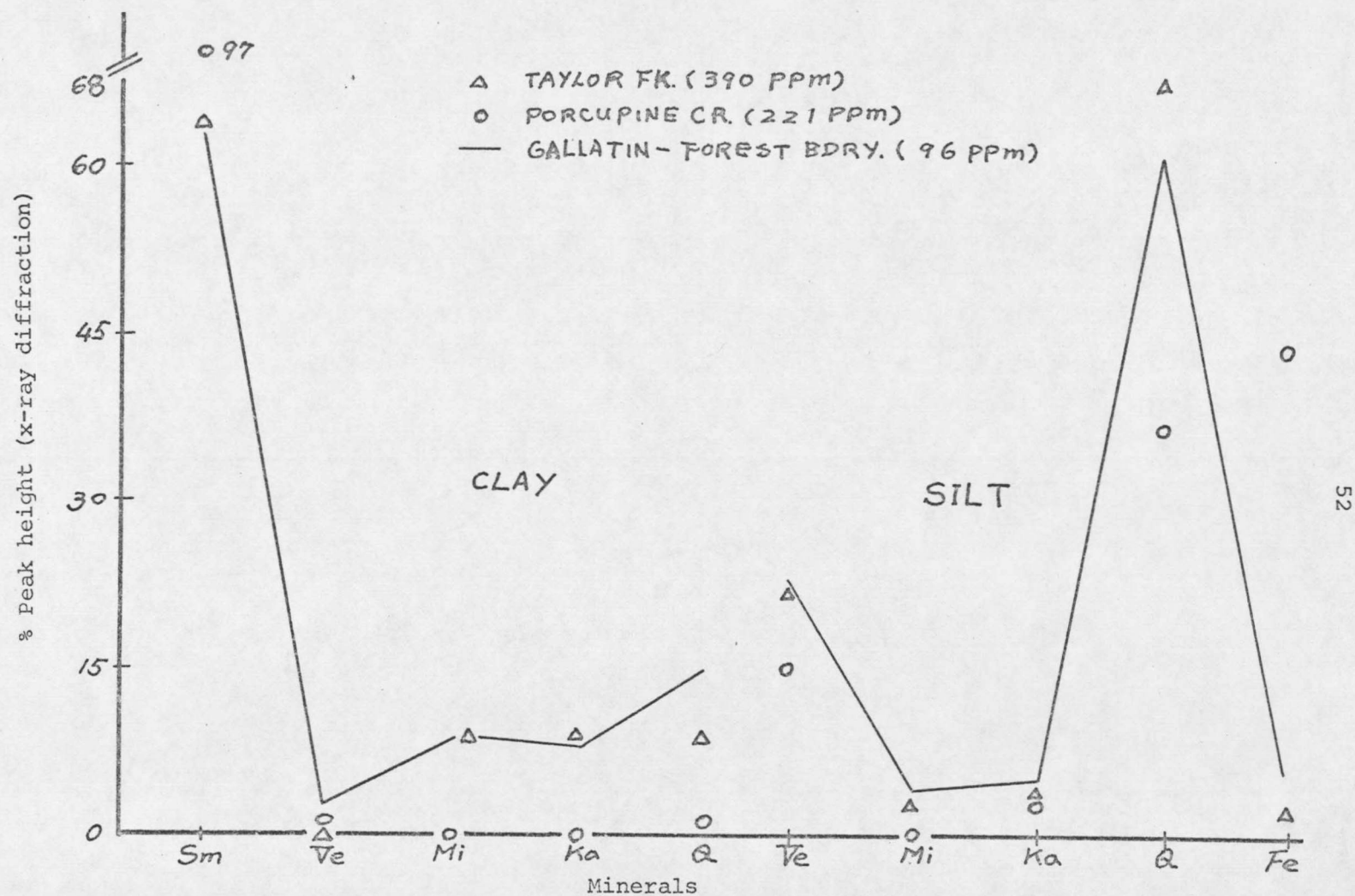


Fig. 3. Mineral patterns of the Gallatin River--Forest boundary, Taylor Fork, and Porcupine Creek on June 17-18, 1971.
(Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

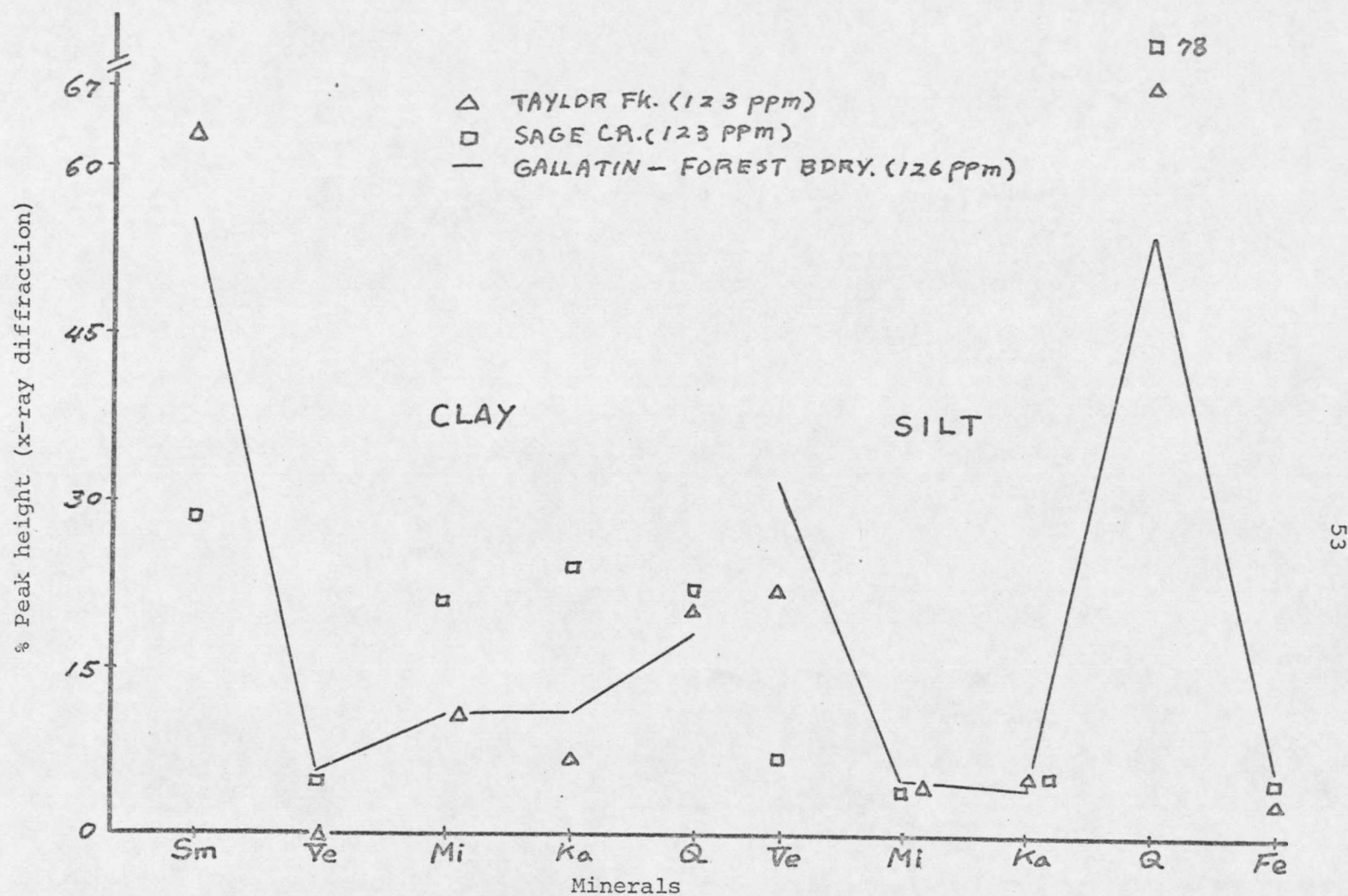


Fig. 4. Mineral patterns of the Gallatin River--Forest boundary, Taylor Fork, and Sage Creek on June 8-9, 1971.

(Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

they are not as similar as on June 17-18. On June 8-9, the stream bank erosion of the Gallatin River above the Forest boundary was more significant.

On May 28-29, 1971, most tributaries of the Gallatin River were muddy. Three streams were muddier than the river at the Forest boundary. Sage Creek was 341 ppm in silt and clay, Taylor Fork was 263 ppm, and Squaw Creek was 168 ppm, while the river at the Forest boundary was 153 ppm. The mineral patterns were plotted in Fig. 5. The patterns of the river at the Forest boundary are likely to be a "mixture" of other patterns. However, the mineral pattern of clays of the main stream is closer to the patterns of Taylor Fork and Squaw Creek than Sage Creek. While in the silts, the pattern of the main stream is only close to the pattern of Taylor Fork. This implies that although Squaw Creek is closer to the Forest boundary than Taylor Fork is, the contribution of Taylor Fork in suspended silt and clay still was more important than Squaw Creek in this date. Sage Creek, although still muddy on the date, again proved not as important as Taylor Fork or Squaw Creek, because the mineral patterns of the main stream had not been changed by the former. Again, Taylor Fork was still an important source of silt and clay on that day, but the contributions of other tributaries became evident, especially the Squaw Creek.

On May 17-18, 1971, silt and clay content of the Gallatin River at the Forest boundary was only 54 ppm, while Greek Creek was 203 ppm,

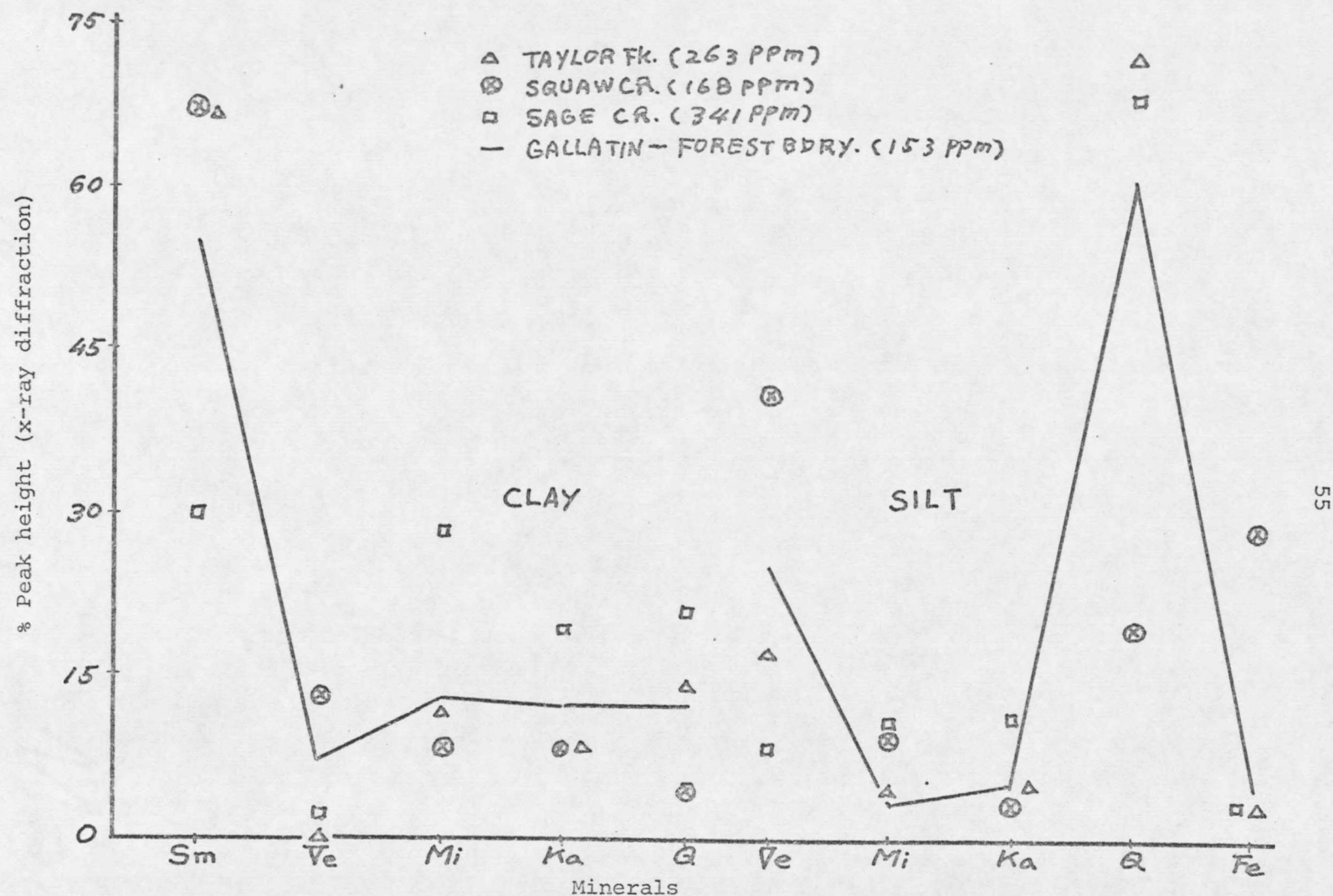


Fig. 5. Mineral patterns of the Gallatin River--Forest boundary, Taylor Fork, Squaw and Sage Creeks on May 28-29, 1971.

(Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

Taylor Fork was 67 ppm, and Squaw Creek was 61 ppm. The mineral patterns of Greek Creek were very different from those of the main stream. Thus, although Greek Creek was very muddy on the date, it was not the important source of the silt and clay of the Gallatin River, because it is too small. The mineral patterns of the main stream actually are very similar to the patterns of Taylor Fork in clay, but less similar in silt. The silt of the Gallatin River at the Forest boundary was likely dominated by a mixture of the silt from Taylor Fork and Squaw Creek on May 17-18.

On May 7-8, 1971, again three tributaries were higher in silt and clay content than the Gallatin River at the Forest boundary. Greek Creek was 1019 ppm, Beaver Creek was 191 ppm, Taylor was 107 ppm, and the main stream at the Forest boundary was 89 ppm. The mineral patterns of the main stream still deviate from the patterns of Greek and Beaver Creeks, and close to the patterns of Taylor Fork. So, Taylor Fork was more important than Greek and Beaver Creeks in contributing silt and clay to the Gallatin River on that day. Greek Creek is too small to contribute significant amounts of silt and clay to the Gallatin River even though it had silt and clay content as high as 1019 ppm.

On May 27, 1970, the Gallatin River at the Forest boundary was 184 ppm in silt and clay. Only two streams were higher in silt and clay than that, which were Squaw Creek (364 ppm) and Porcupine Creek (238 ppm). Taylor Fork was only 154 ppm in silt and clay. The

mineral pattern of the main stream is different from those of Porcupine Creek, and closer to Squaw Creek in clay (Fig. 6). In silts, the pattern of the main stream is closer to that of Porcupine Creek. The similarity of patterns between the main stream and Porcupine Creek could be a coincidence, because Porcupine Creek cannot only contribute silt portion without clay portion. However, mineral patterns of the main stream are still close to Taylor Fork both in clay and silt. This illustrates that even though Taylor Fork was not as muddy as the Gallatin River at the Forest boundary, it still contributes more clay and silt to the Gallatin River than Squaw or Porcupine Creek on May 27, 1970. Of course, Taylor Fork was not as important as on those days when it was muddier than the Gallatin River at the Forest boundary.

June 8, 1970 was a more complicated case. Six streams were higher in silt and clay content than that of the main stream. Sage Creek was 616 ppm, Taylor Fork was 639 ppm, Buck Creek was 312 ppm, Porcupine Creek was 413 ppm, Squaw Creek was 626 ppm, Greek Creek was 437 ppm, while the Gallatin River at the Forest boundary was 277 ppm. The mineral patterns of those streams (Fig. 7) shows that the patterns of the main stream was similar to those of Taylor Fork and Buck Creek. However, these three sets of patterns just lie in the midway of other patterns. We can not tell that the similarity of patterns is due to the same source of material or merely to the coincidence by one diagram. But from the size, silt and clay content of Taylor Fork and its

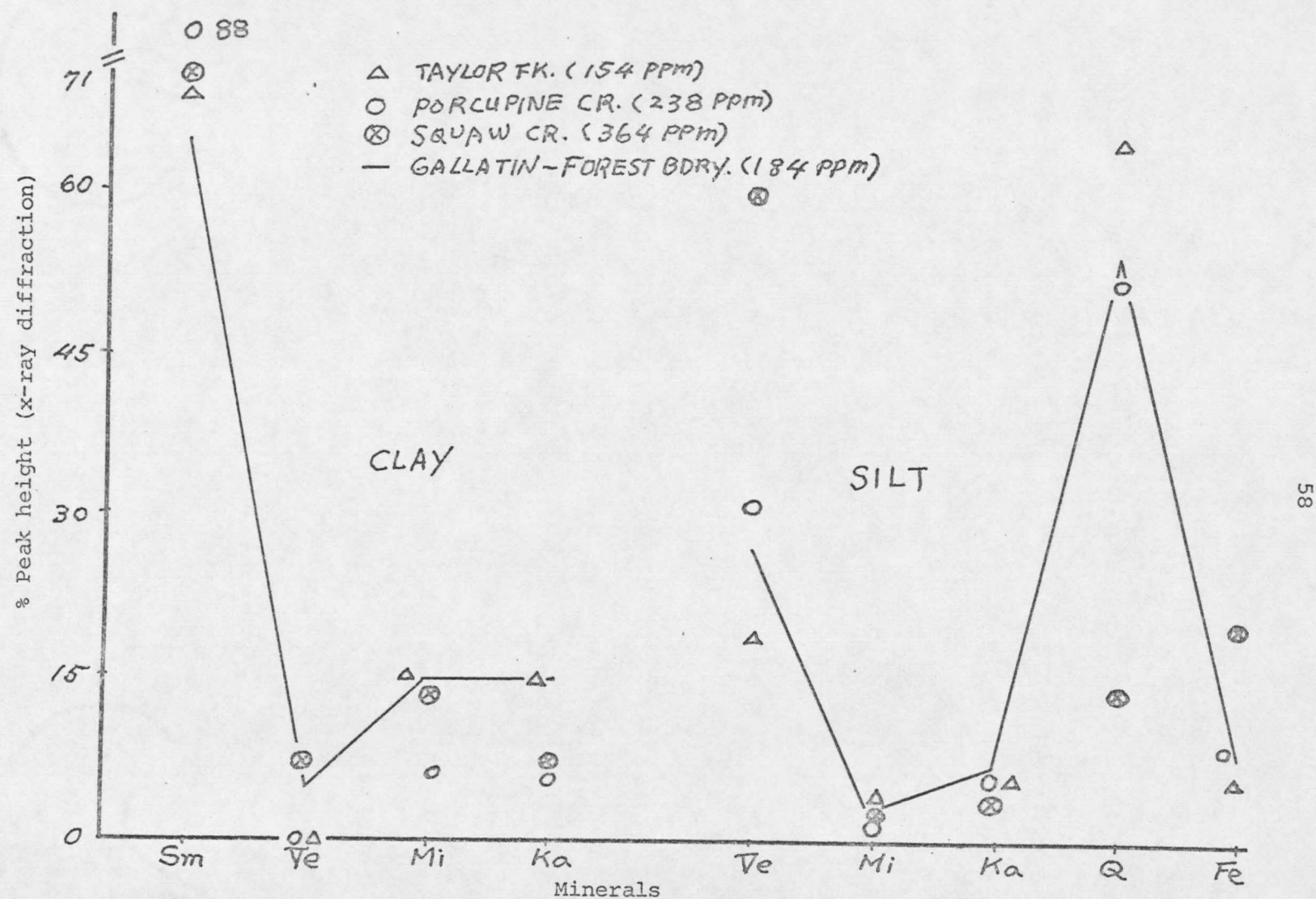


Fig. 6. Mineral patterns of the Gallatin River--Forest boundary, Taylor Fork, Squaw and Porcupine Creeks on May 27, 1970.
(Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

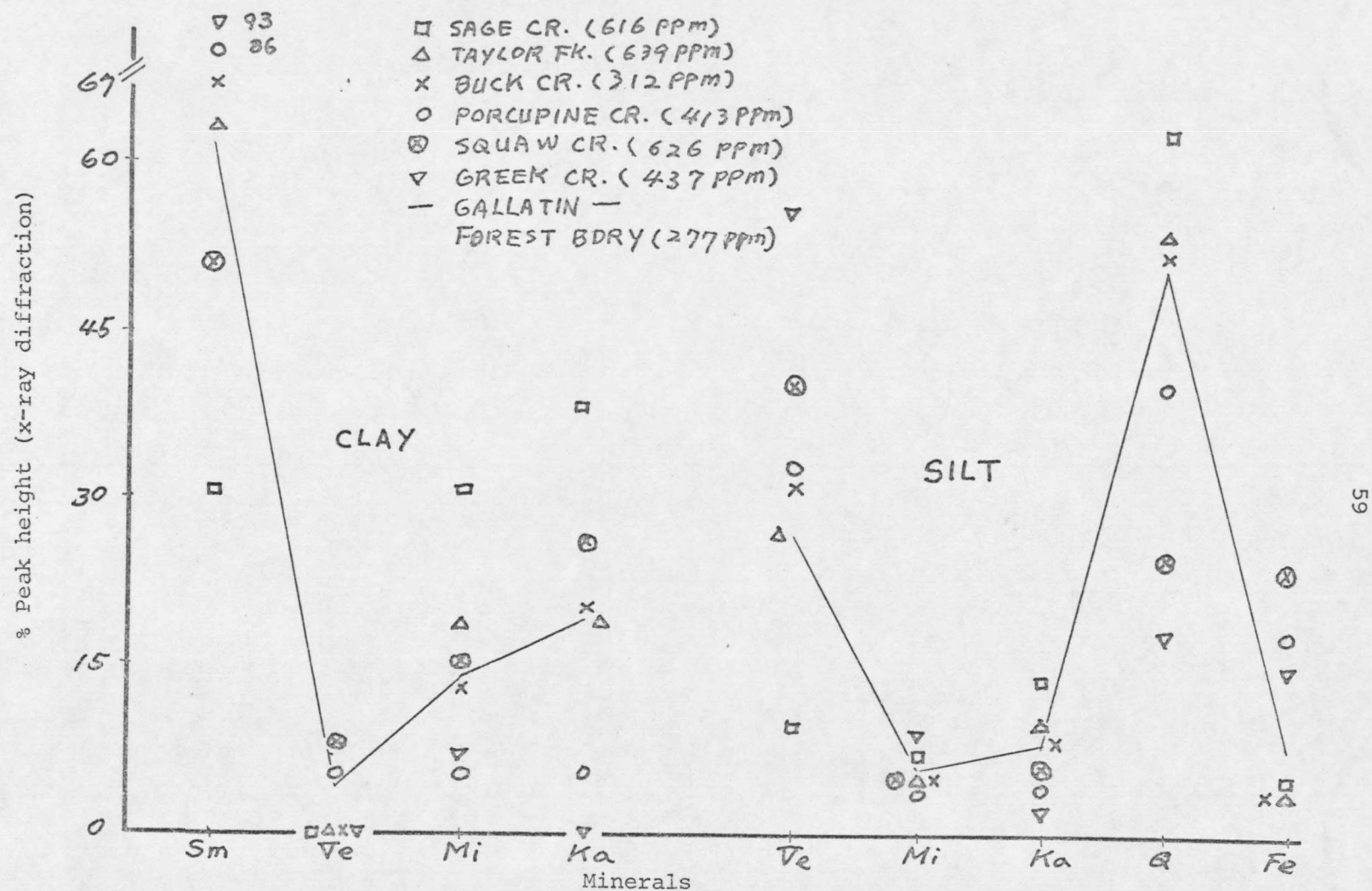


Fig. 7. Mineral patterns of the Gallatin River--Forest boundary, and its important tributaries on June 8, 1970.

(Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

importance on other days, we can say the similarity of the patterns between the main stream and Taylor Fork is due to the same source of silt and clay. While the similarity of the main stream and Buck Creek is a coincidence, because Buck Creek is not only small but was only half as muddy as Taylor Fork on that day.

May 18, 1970 was a five-sources case. On that day, streams were not as muddy as on June 8. The Gallatin River at the Park boundary was 115 ppm in silt and clay, Sage Creek was 215 ppm, Taylor Fork was 174 ppm, Porcupine Creek was 250 ppm, and Beaver Creek was 487 ppm, while the Gallatin River at the Forest boundary was 103 ppm. The mineral pattern of clay of the Gallatin River at the Forest boundary again is a "mixture" of the other patterns, and not similar enough to any one other pattern to prove it was a dominant source of clay (Fig. 8). In silt portion, the pattern of the main stream deviates from other patterns on one side. From Fig. 8, we only can conclude that the clay of the Gallatin River at the Forest boundary was a mixture of the five sources, and Taylor Fork and Porcupine Creek seemed contributing more weights of clay than other sources do, and the silt of the Gallatin River at the Forest boundary seemed not the "mixture" of those sources, it was picked up from banks or bed of the river itself.

This mineral pattern tracing technique seemed to work reasonably well in most cases of the upper Gallatin River. It indicated Taylor Fork as the main source, even when several smaller streams were also

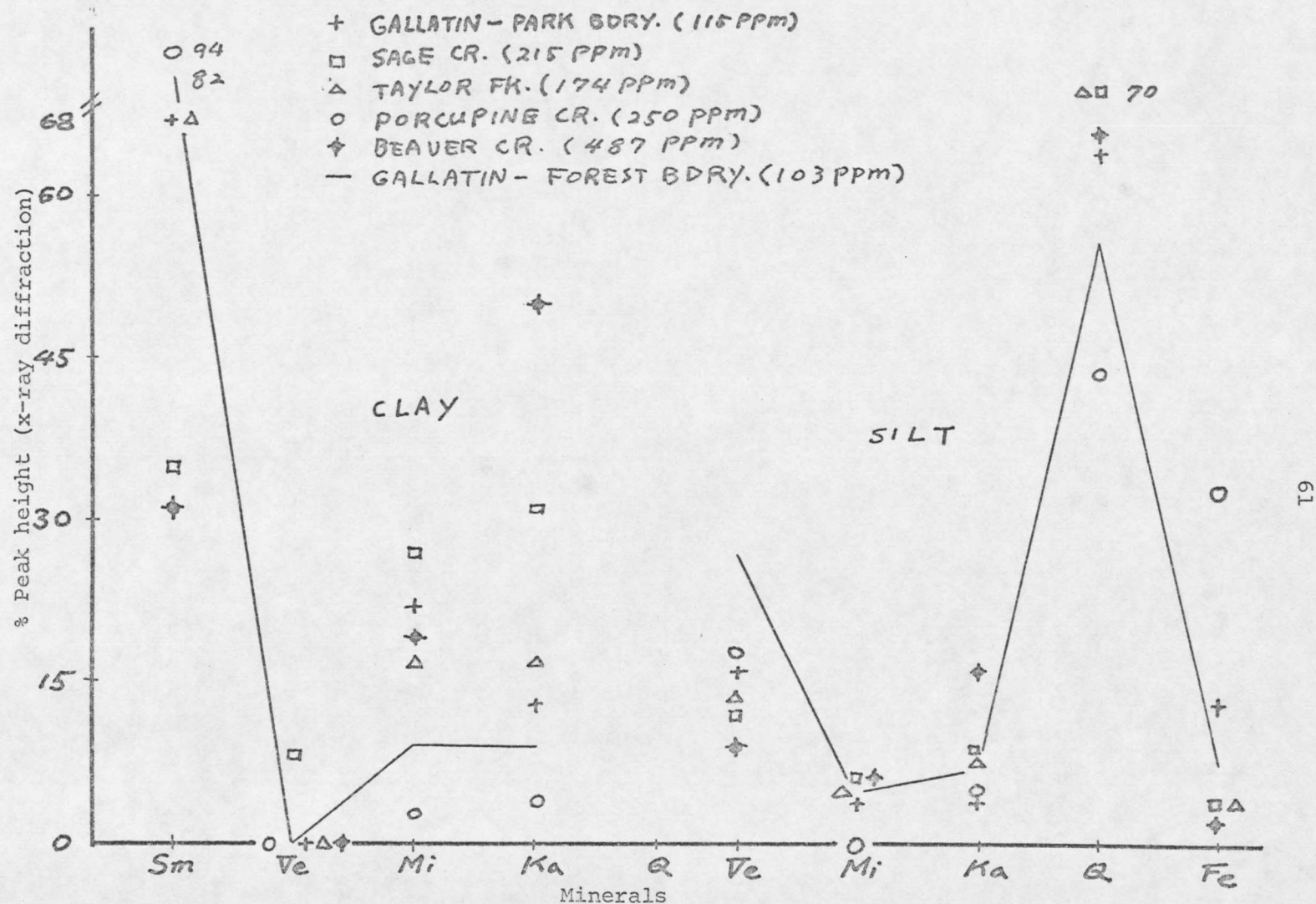


Fig. 8. Mineral patterns of the Gallatin River and its important tributaries on May 18, 1970.
 (Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

quite high in suspended silt and clay. There may be some reason to question the reliability of the method in the latter circumstances, since the final composition of silt and clay was a mixture of many sources, and it could be coincidence that it resembles that of Taylor Fork so closely. In these cases, additional samples of the main stream between the tributaries need to be taken in order to simplify the system and make the interpretation clearer.

The technique worked well in smaller watersheds in the study, i.e., the Taylor Fork and West Fork basins. A study of the Taylor Fork basin on June 17, 1971 showed that the mineral patterns of Taylor Fork at the mouth are similar to the patterns of the upper Taylor Fork, instead of those of Wapiti or Little Wapiti Creeks (Fig. 9). This agreed with the silt and clay content measurement in showing that the source of silt and clay in Taylor Fork was principally from the upper Taylor Fork instead of from these two creeks on that day.

The silt and clay content and mineral patterns of the streams in the West Fork basin on May 28, 1971 are shown in Fig. 10. The mineral patterns of Middle Fork and the combined Middle and North Forks were similar to one another. The patterns of West Fork at the mouth lie between the patterns of South and Middle Forks, but a little closer to the patterns of South Fork. This confirms the result of the silt and clay content data of those streams which shows South Fork was muddier than North and Middle Forks. The June 8 samples show the same thing as

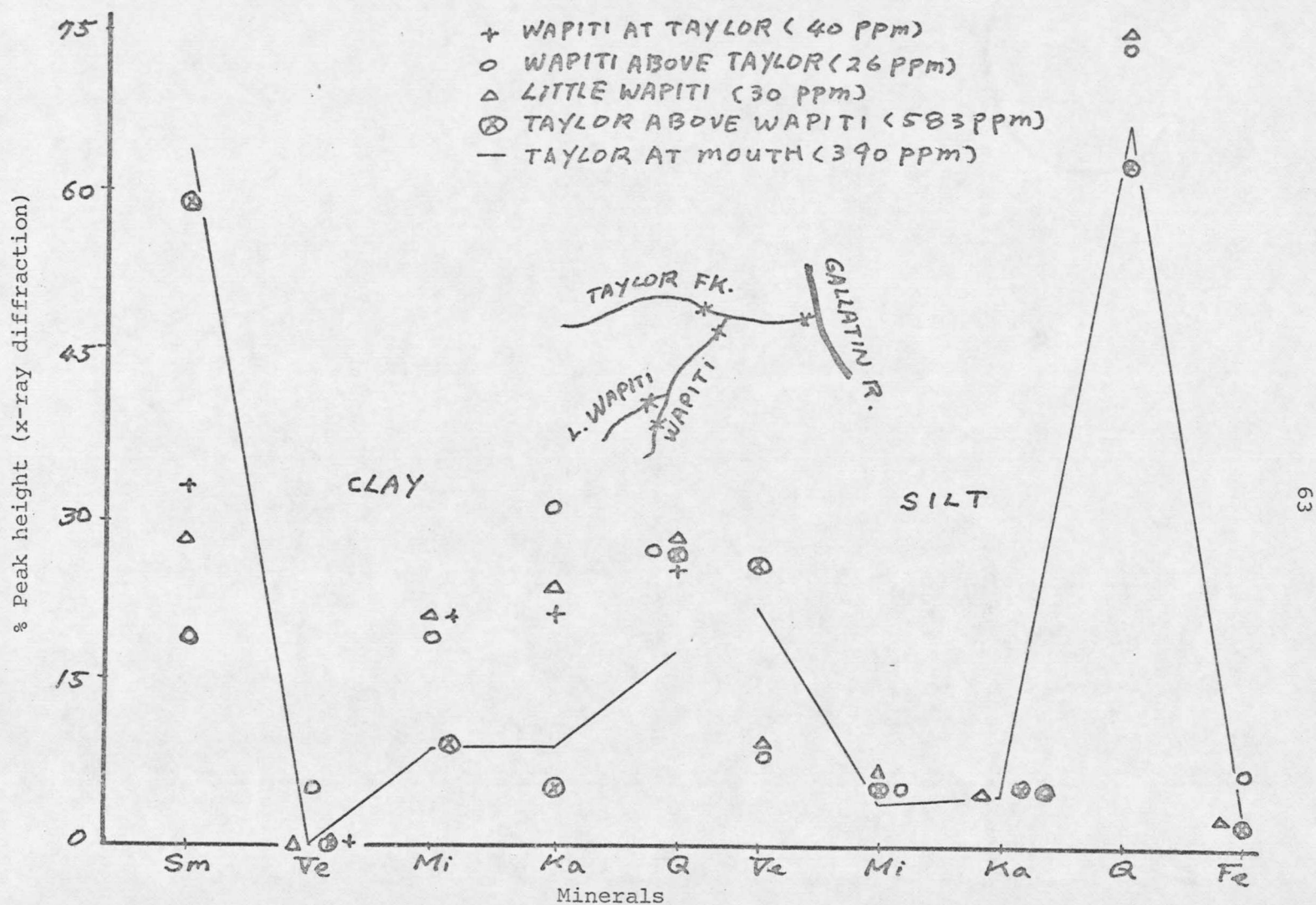


Fig. 9. Mineral patterns of Taylor Fork and its branches on June 17, 1971.
 (Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

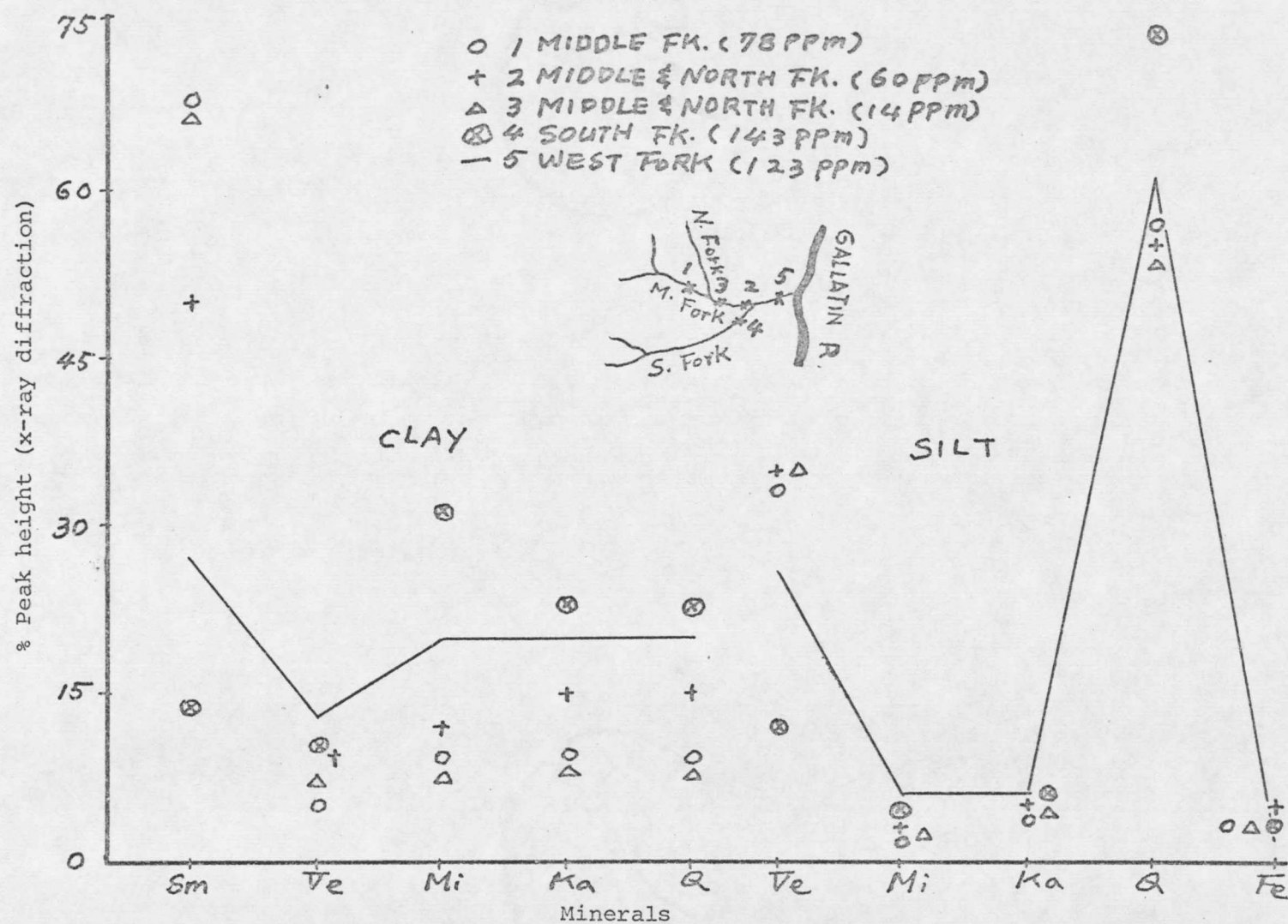


Fig. 10. Mineral patterns of West Fork and its branches on May 28, 1971.
 (Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

May 28 samples did, but the quartz content of the South Fork was unusually high in clay. This might be attributed to the experiment error, which is mostly due to the imperfect separation of silt and clay particles.

2. Sources of suspended silt and clay of the Gallatin River in the broad valley floor. The Gallatin River, in this section, was much muddier than in the mountains. Evidences of local erosion of the river in the valley floor can be seen from the relative silt and clay content at the different sampling sites on the river. The only important tributary of the river in the area is the East Gallatin River. The East Gallatin River is large and muddy. Unfortunately, the mineral patterns of the silt and clay of the East Gallatin River below Belgrade were quite similar to those of the Gallatin River at Manhattan and Logan. Thus, clear interpretation of the source of silt and clay in the lower Gallatin River by minerals was difficult.

As has been mentioned in the previous section, the mineralogy of the March-April samples of the Gallatin and East Gallatin Rivers was different from those of the May-June samples. The March-April samples were taken before the snowmelt of the mountains, and sediment is due to local erosion. While the May-June samples were taken when snow was melting quite rapidly in the mountains, and no erosion was taking place on the farmland of the lower valley. The average mineral patterns of

the rivers, in March-April and May-June respectively, can represent the minerals of the rivers in those two periods. Fig. 11 shows the mineral patterns of the Gallatin River and East Gallatin River before and after their junction using March-April 1970 averages. The patterns of the Gallatin River at Logan fell between those of the East Gallatin River below Belgrade and the Gallatin River at Manhattan, and a little closer to the Belgrade patterns. It does show that the silt and clay of the Gallatin River at Logan was a mixture of those of the East Gallatin River and the Gallatin River at Manhattan in March-April, 1970. The East Gallatin River had a heavier weight on the contribution of silt and clay to the Gallatin River than the river itself. The silt and clay content measurement also shows that the East Gallatin River was muddier than the Gallatin River at both the Manhattan and Logan sampling sites.

In May-June, 1970, the Logan patterns again fell in between the patterns of Manhattan and Belgrade (Fig. 12). However, the Logan patterns are a little closer to the patterns of Manhattan instead of Belgrade's. This implies that the importance of the East Gallatin River in the period was perhaps less than in the March-April period. In fact, the average silt and clay content of the rivers in May-June tells us that the East Gallatin River was clearer than the Gallatin River at Logan in the May-June period (see Table 3).

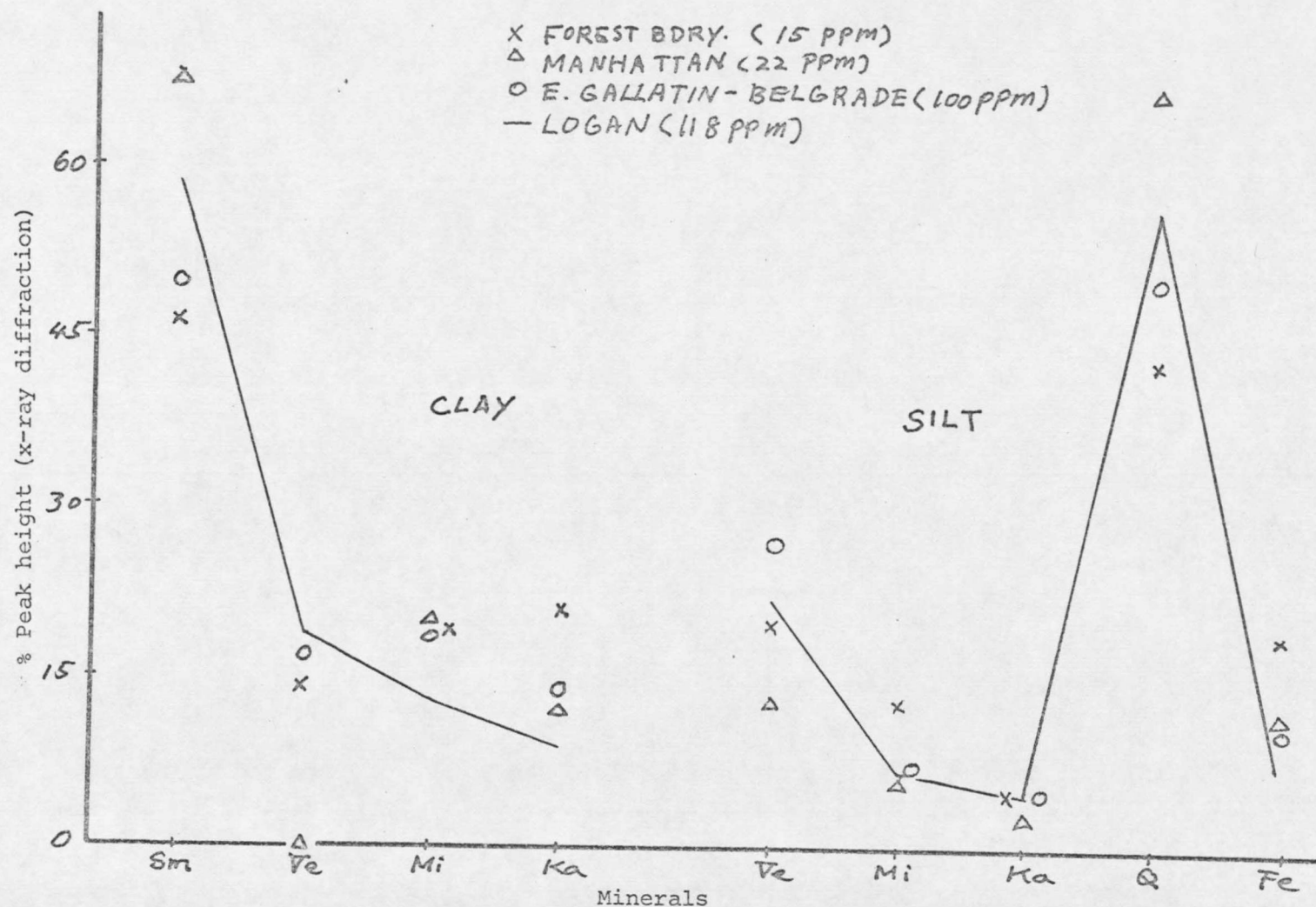


Fig. 11. Mineral patterns of the Gallatin River and East Gallatin River in March-April, 1970. (Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

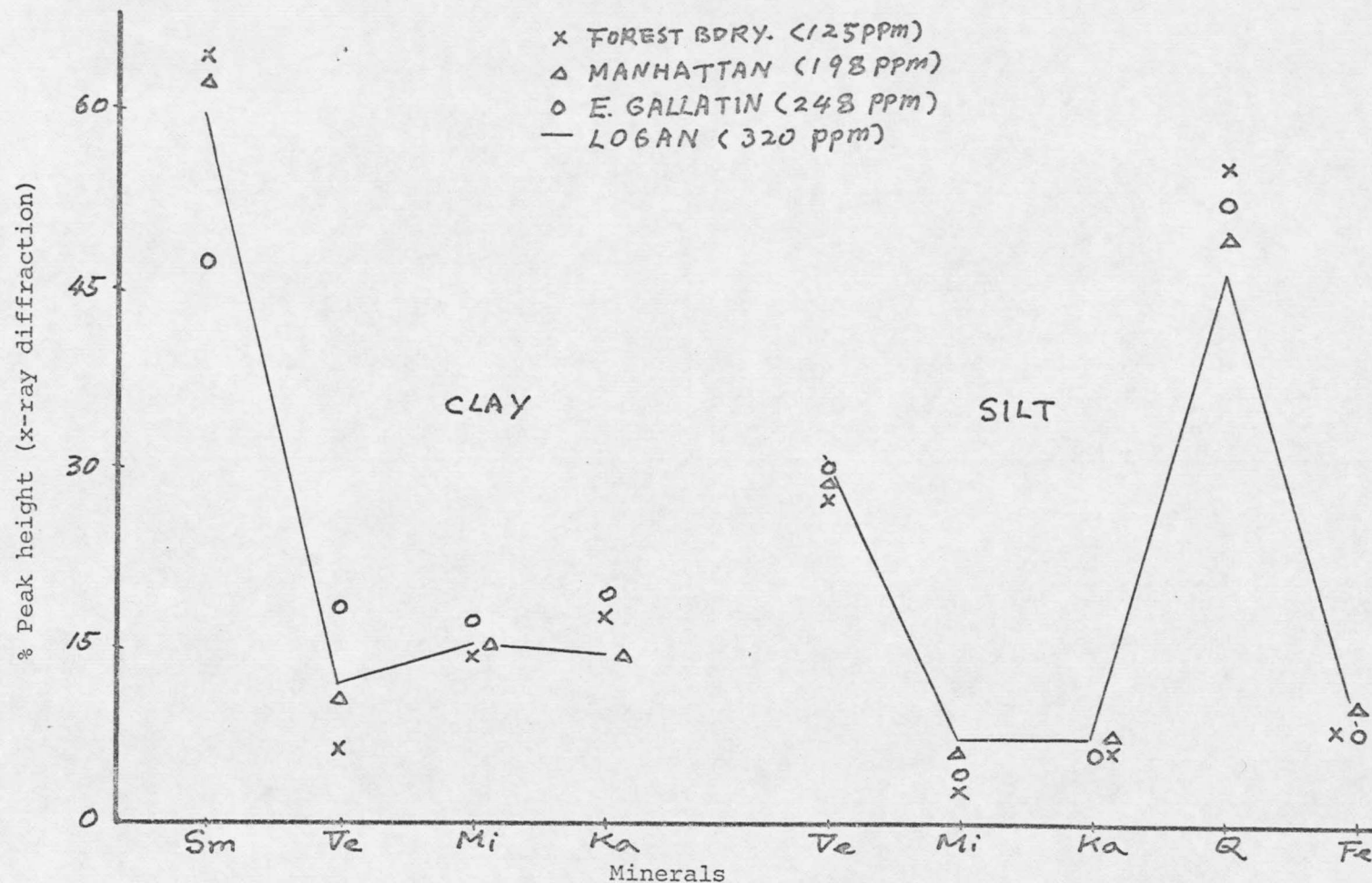


Fig. 12. Mineral patterns of the Gallatin River and East Gallatin River in May-June, 1970.
 (Sm=smeectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

The 1971 samples again showed that in the early season, i.e., March-April, the Logan patterns were a little closer to the Belgrade patterns than to the Manhattan patterns. But in the later season, i.e., May-June, the Logan patterns fell about midway between the patterns of Manhattan and Belgrade.

3. Sources of suspended silt and clay in the East Gallatin River. Among the tributaries of the East Gallatin River, Bridger, Rocky, and Dry Creeks were relatively muddier than Hyalite and Bozeman Creeks in both 1970 and 1971. In March-April, 1970, Dry Creek was the only tributary sampled which was muddy enough to consider as a significant contributor of sediment to the East Gallatin River. On April 11, the upper East Gallatin River below Bozeman was 91 ppm in silt and clay, the lower river at Belgrade (below Dry Creek) was 268 ppm, and Dry Creek was 226 ppm. The mineral pattern diagram (Fig. 13) of those streams shows that although Dry Creek was much muddier than the upper East Gallatin River at Bozeman, the mineral patterns of the river at Belgrade (below Dry Creek) were not influenced by the contribution of Dry Creek. Actually, the mineral patterns of the upper and lower East Gallatin River were similar to each other. This illustrates that the source of the suspended silt and clay in the lower East Gallatin River was not Dry Creek, it was from the local erosion or other tributaries which we did not sample. This point can be seen again on March 19, 1970.

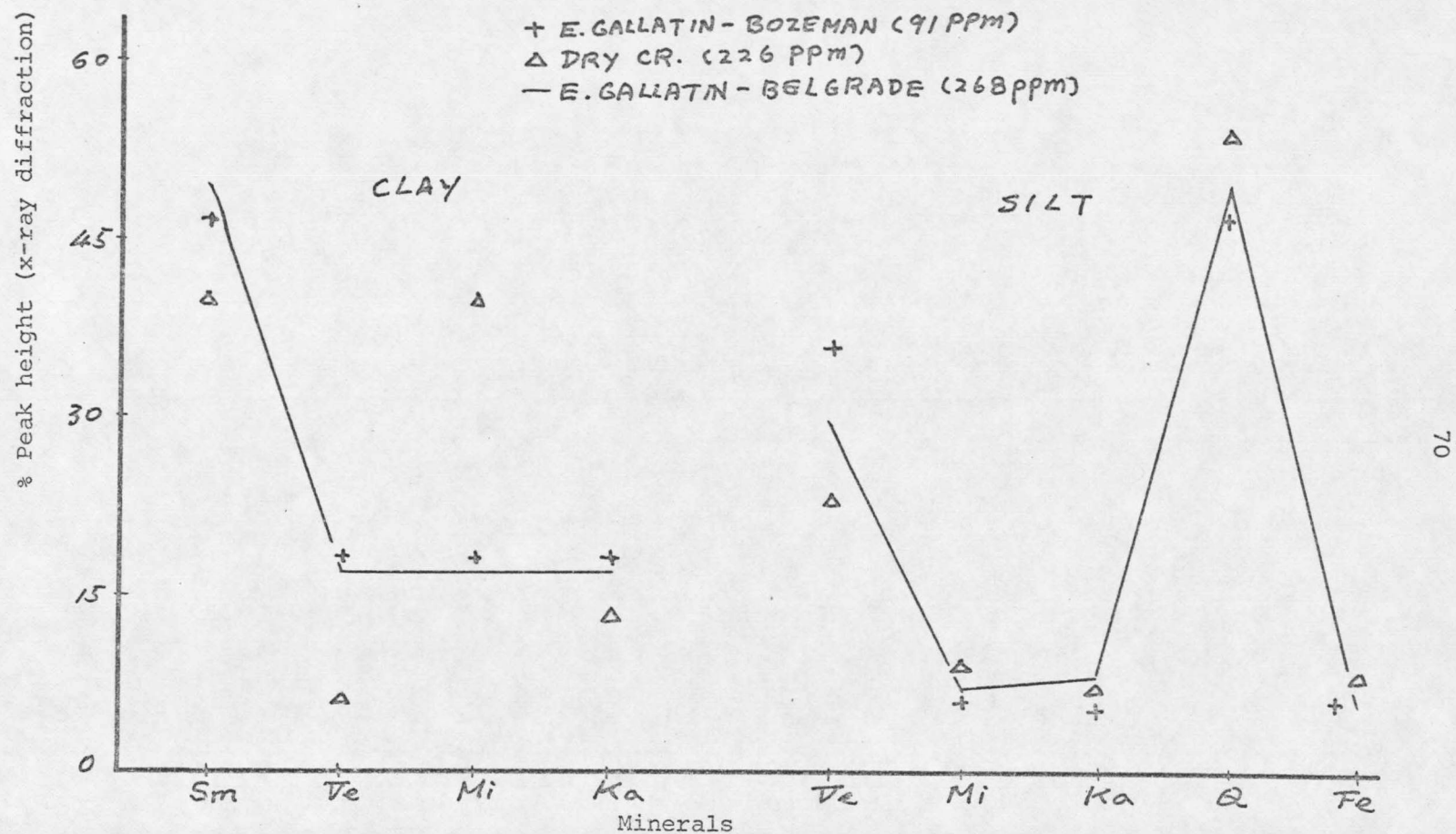


Fig. 13. Mineral patterns of the East Gallatin River and Dry Creek on April 11, 1970.
 (Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

On that date, Dry Creek was about three times (140 ppm) higher in silt and clay content than that of the East Gallatin River, both at Bozeman (37 ppm) and Belgrade (44 ppm). The mineral patterns of the East Gallatin River at Belgrade (below Dry Creek) were not more similar to those of Dry Creek than those of the upper East Gallatin River at Bozeman. Thus, Dry Creek still was too small to be a dominant contributor of silt and clay to the East Gallatin River on that day.

Bridger and Rocky Creeks drain East Gallatin River above Bozeman. They were clear in the March-April period, 1970. Then they became muddier in May, while Dry Creek turned clear in this period. On May 18, 1970, Bridger and Rocky Creeks both were muddy (267 and 268 ppm silt and clay content). The East Gallatin at Belgrade was 363 ppm on the date. The mineral patterns are shown in Fig. 14. The three sets of the mineral patterns were similar to one another in general, and the patterns of the East Gallatin River were a little closer to Rocky Creek. This agreed with the geology study of the area of Hackett et al (1960). They believed that the alluvial material in the middle East Gallatin drainage was similar to that of the Rocky Creek Basin. Thus, on that day, the silt and clay of the East Gallatin River was from Rocky and Bridger Creeks, or from the same materials that formed the Rocky and Bridger river basins.

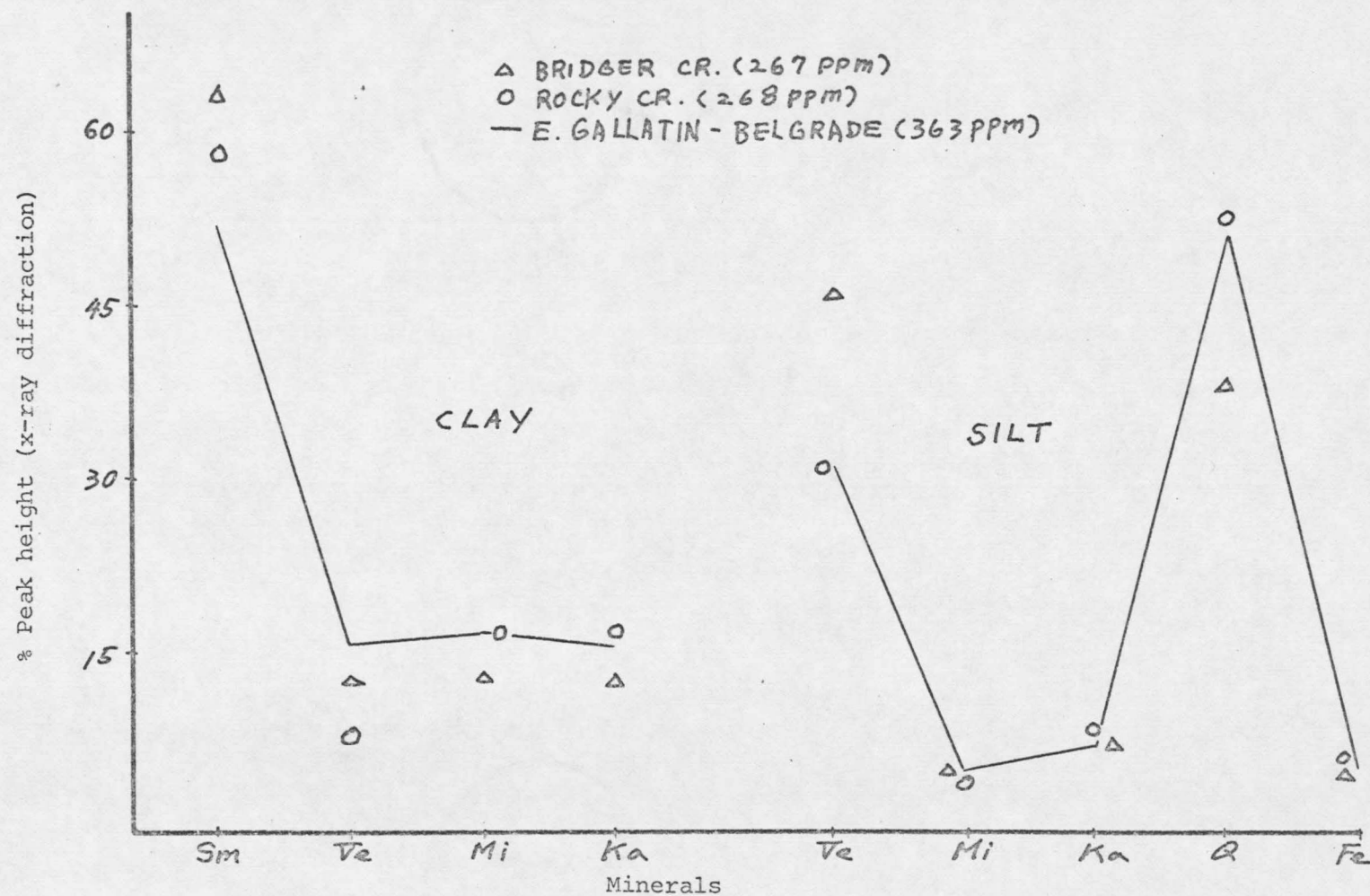


Fig. 14. Mineral patterns of the East Gallatin River, Bridger and Rocky Creeks on May 18, 1970.
 (Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar)

CONCLUSION

Measurement of the silt and clay content of the Gallatin River and its tributaries revealed that the river and most of its tributaries were muddiest during the May-June period when snow was melting rapidly in the mountains. Before this period, most streams, except the East Gallatin River and Dry Creek, were clean.

The suspended silt and clay of the Gallatin River increased in the downstream direction. Stream bank erosion of the Gallatin River above the National Forest boundary was not serious, and the suspended silt and clay was largely contributed from tributaries in the mountains. Geology is an important factor controlling the suspended load of the Gallatin River and its tributaries. Easily eroded soils, developed on the sedimentary rocks, provided more suspended load to the streams than soils developed on volcanic materials or the metamorphic rocks. The silt and clay measurement shows that Taylor Fork was the main source of the silt and clay found in the Gallatin River above the Forest boundary. The silt and clay of Taylor Fork was from the upper stream rather than Wapiti Creek on the muddiest day of Taylor Fork, 1971. The suspended silt and clay of the lower Gallatin River, which is in the broad valley floor, was increased by the local erosion and the contribution of the East Gallatin River. The high runoff in the Gallatin Valley floor might

be attributed to the poorer vegetative protection of the agricultural land than the forest and grass protected mountaineous.

There was an inverse relationship between dissolved salt content and suspended solid content of the stream. Dissolved salts were less concentrated during Spring runoff, because they were diluted with melted snow. Turbidity measurements, both the nephelometer and Jackson turbidity meter, can be used to estimate the suspended load. They are more accurate on the silt and clay than on the total suspended load.

Mineralogy of the suspended silt and clay of the streams was analyzed by the x-ray diffraction method. The suspended clay in the Gallatin River was dominated by smectite, while the suspended silt was highest in quartz. They are similar to the suspended clays and silts found in the tributaries of the sedimentary rock region. The suspended clays of the tributaries that come from the Tertiary volcanic material region were similar to those found in the sedimentary rock region, while the suspended silts were higher in feldspar/quartz ratio than those found in the sedimentary rock region.

The mineral patterns of the suspended clays and silts were used as indicators in tracing the source of the suspended silt and clay in the Gallatin River and East Gallatin River. They confirmed that Taylor Fork was the most important source of the suspended silt and clay found in the Gallatin River above the National Forest boundary in the May-June period. The source of the suspended load in Taylor Fork was traced to

the upper stream above Wapiti Creek. The East Gallatin River contributed more suspended silt and clay to the lower Gallatin River in the March-April period than in the May-June period of 1970 and 1971.

The mineral tracing shows that the source of suspended silt and clay in the East Gallatin River was basically from local erosion and the contributions of the Rocky and Bridger Creeks. Dry Creek mineral patterns show that although it was very muddy in the March-April period, it was too small to be an important contributor of the suspended silt and clay to the East Gallatin River.

The clay minerals of the Gallatin River in the March-April period, before rapid runoff from snowmelt had begun, were the interstratified forms similar to those found in the well-weathered surface soils.

The clay minerals were helpful indicators for determining the source of the silt and clay in a stream. The mineral tracing technique could not work well in a large or complex source system. In case of this complication, additional water samples of the main stream between the sources need to be taken, in order to simplify the system and make interpretation clearer.

APPENDIX

TABLE 1. Dissolved and suspended materials in the Gallatin River and its tributaries of 1970

	Dissolved ppm	Suspended Si+C, ppm	Suspended S, ppm	Total Suspended
<u>March 11, 1970</u>				
Rocky	306	--	3	3
Bridger		--	1	1
E. Gallatin - Belgrade		105	9	114
Baker	506	--	4	4
W. Gallatin - Manhattan	225	11	3	14
W. Gallatin-F.S. bdry.	217	9	1	10
<u>March 19, 1970</u>				
Rocky	290	--	3	3
Bridger	267	--	3	3
Sourdough	155	--	--	0
Hyalite	115	7	2	9
Dry	273	140	49	189
E. Gallatin - Bozeman	282	37	9	46
E. Gallatin - Belgrade	257	44	12	56
Baker	300	61	11	72
W. Gallatin - Manhattan	216	11	5	16
W. Gallatin-F.S. bdry.	201	14	--	14
Gallatin - Logan	250	34	3	37
<u>April 1, 1970</u>				
Rocky	236	1	2	3
Bridger	256	--	--	0
Sourdough	147	5	1	6
Hyalite	109	14	7	21
Dry	269	75	11	86
E. Gallatin - Bozeman	282	6	16	22
E. Gallatin - Belgrade	255	35	9	44
Baker	202	7	--	7
W. Gallatin - Manhattan	255	21	7	28
W. Gallatin-F.S. bdry.	204	17	2	19
Gallatin - Logan	244	39	5	44
<u>April 11, 1970</u>				
Rocky	141	87	30	117
Bridger	195	59	21	80
Sourdough	141	4	2	6
Hyalite	111	15	1	16

Table 1 continued

	Dissolved ppm	Suspended Si+C, ppm	Suspended S, ppm	Total Suspended
<u>April 11, 1970</u>				
Dry	249	226	32	258
E. Gallatin - Bozeman	205	91	40	131
E. Gallatin - Belgrade	211	268	32	300
Baker	288	99	19	118
W. Gallatin - Manhattan	185	51	5	56
W. Gallatin-F.S. bdry.	174	21	4	25
Gallatin - Logan	199	347	30	377
<u>April 27, 1970</u>				
Rocky	210	12	18	30
Bridger	237	--	1	1
Sourdough	153	6	2	8
Hyalite	90	26	1	27
Dry	268	3	4	7
E. Gallatin - Bozeman	259	12	12	24
E. Gallatin - Belgrade	236	49	15	64
Baker	280	43	11	54
W. Gallatin - Manhattan	209	15	3	18
W. Gallatin-F.S. bdry.	203	16	10	26
Gallatin - Logan	243	50	8	58
<u>May 4, 1970</u>				
Gallatin - Park bdry.	102	19	5	24
Tepee	147	495	501	996
Taylor Fork	179	87	31	118
Porcupine	142	155	38	193
Beaver	195	64	42	106
West Fork	156	22	10	32
Portal	65	15	0	15
Squaw	113	15	4	19
Spanish	78	29	21	50
W. Gallatin-F.S. bdry.	150	29	8	37
W. Gallatin - Manhattan	192	29	29	58
E. Gallatin - Belgrade	203	269	80	349
Gallatin - Logan	222	71	67	138
<u>May 18, 1970</u>				
Gallatin - Park bdry.	140	115	46	161
Tepee	262	--	13	13

Table 1 continued

	Dissolved ppm	Suspended Si+C, ppm	Suspended S, ppm	Total Suspended
<u>May 18, 1970</u>				
Sage	160	215	91	306
Taylor Fork	147	174	41	215
Buck	132	63	31	94
Porcupine	97	250	117	367
Beaver	116	487	117	604
West Fork	88	96	33	129
Portal	62	13	5	18
Squaw	79	121	146	267
Spanish	52	23	17	40
Gallatin-F.S. bdry.	104	103	28	131
Gallatin - Manhattan	129	264	207	471
E. Gallatin - Belgrade	171	363	63	426
Gallatin - Logan	162	798	194	992
Rocky	122	268	65	333
Bridger	146	267	62	329
Sourdough	121	94	87	181
Hyalite	65	73	55	128
<u>May 27, 1970</u>				
Gallatin - Park bdry.	112	74	38	112
Tepee	267	--	6	6
Sage	134	114	138	252
Taylor Fork	131	154	78	232
Buck	124	93	83	176
Porcupine	72	238	186	424
Beaver	102	124	85	209
West Fork	81	109	60	169
Portal	38	43	18	61
Squaw	64	364	448	812
Spanish	36	24	30	54
Gallatin-F.S. bdry.	87	184	63	247
Gallatin - Manhattan	108	212	257	469
E. Gallatin - Belgrade	164	394	20	414
Gallatin - Logan	133	390	93	483
<u>June 8, 1970</u>				
Gallatin - Park bdry	90	84	50	134
Tepee	292	15	11	226

Table 1 continued

	Dissolved ppm	Suspended Si+C, ppm	Suspended S, ppm	Total Suspended
<u>June 8, 1970</u>				
Sage	105	616	216	832
Taylor Fork	100	639	512	1151
Buck	109	312	75	387
Porcupine	62	413	673	1086
Beaver	91	223	141	364
West Fork	70	140	67	207
Portal	30	59	86	145
Swan	43	126	102	228
Greek	75	437	349	786
Squaw	63	626	685	1311
Spanish	27	32	43	75
Gallatin-F.S. bdry.	74	277	96	373
Gallatin - Manhattan	93	448	196	644
E. Gallatin - Belgrade	162	127	24	201
Gallatin - Logan	117	267	74	341
<u>June 18, 1970</u>				
Gallatin - Park bdry.	125	16	15	31
Tepee	318	--	4	4
Sage	190	24	29	53
Taylor Fork	147	39	51	90
Buck	154	2	13	15
Porcupine	77	42	14	56
Beaver	132	--	8	8
West Fork	90	25	13	38
Portal	42	29	3	32
Squaw	71	21	11	32
Spanish	37	16	10	26
Gallatin-F.S. bdry.	96	32	32	64
Gallatin - Manhattan	123	39	24	63
E. Gallatin - Belgrade	205	87	59	146
Gallatin - Logan	154	72	33	105
Dry	237	74	35	109

TABLE 2. Dissolved and suspended materials and turbidity in the Gallatin River and its tributaries of 1971

	Dissolved	Total Suspended*			Silt & Clay		
	ppm	ppm	%T	† JCU #	ppm	%T	JCU
<u>March 18</u>							
F.S. Boundary	204	6			2		
Manhattan	211	11			6		
E. Gallatin-Belgrade	251	29			18		
E. Gallatin-Bozeman	259	11			--		
Dry	254	113			102		
Logan	249	35			17		
<u>April 1</u>							
F.S. Boundary	193	39	6		33	6	
Manhattan	197	22	7		14	6	
E. Gallatin-Belgrade	237	69	22		57	17	
E. Gallatin-Bozeman	232	36	18		25	14	
Dry	266	71	31		62	26	
Logan	235	44	18		36	18	
<u>April 16</u>							
F.S. Boundary	170	24	4	<25	23	4	<25
Manhattan	191	22	4	<25	21	4	<25
E. Gallatin-Belgrade	218	305	58	225	239	54	210
E. Gallatin-Bozeman	191	153	33	105	109	27	100
Dry	245	5			2		
Logan	221	189	42	150	170	37	140
<u>May 7 & 8</u>							
Park Boundary	145	52	6	<25	25	6	
Tepee	262	65	7	<25	52	7	
Taylor	178	136	36	115	107	33	86
Buck	143	50	21	37	37	17	37
Beaver	127	276	55	170	191	59	150
Porcupine	128	102	17	44	66	17	44
W. Fork	97	113	25	56	80	22	55
Greek	65	1650	92	520	1019	80	450
Squaw	122	25	9	<25	15	15	
F.S. Boundary	128	107	20	57	89	21	58
Manhattan	147	194	31	90	146	23	75

* Sand + Silt + Clay

† % Transmission

Jackson candle unit

Table 2 continued

	Dissolved	Total Suspended*			Silt & Clay		
	ppm	ppm	%T	† JCU #	ppm	%T	JCU
E. Gallatin-Belgrade	168	166	53	190	154	49	173
Baker	180	56	13	42	49	9	32
Dry	236	67	14	42	60	11	41
Hyalite	68	50	10	<25	44	9	
Sourdough	116	71		<25	41	9	
Rocky	130	271	16	51	137	18	38
Bridger	145	306		130	195	39	115
Logan	172	239	41	150	183	44	148
<u>May 17 & 18</u>							
Park Boundary	128	22	3		11	1	
Tepee	262	29	2		26	2	
Sage	196	71	13	25	52	13	29
Taylor	170	97	21	58	67	19	56
Buck	145	52	10		42	9	
Beaver	118	59	12		45	11	
Porcupine	89	75	8		48	7	
W. Fork	96	61	13	<25	37	11	
NF of W. Fork	91	18	2		15	0	
N & MF of WF lower	76	46	0		25	9	
SF of W. Fork	103	44	14	<25	35	13	
Portal	45	34	2		30	1	
Greek	64	407	54	220	203	53	220
Squaw	66	79	4		61	3	
Spanish	44	22	1		12	1	
F.S. Boundary	105	72	7		54	3	
Manhattan	130	42	9		23	8	
E. Gallatin	179	113	29	78	95	25	73
Baker	154	46	6		42	6	
Dry	224	77	14	36	30	13	38
Logan	150	126	21	60	99	18	43
<u>May 27, 28, & 29</u>							
Park Boundary	104	129	11		69	10	
Tepee	290	3	1		---	1	
Sage	145	551	82	300	341	78	280
Taylor	129	521	55	200	257	52	200
Buck	123	189	27	86	130	25	86
Beaver	102	125	25	58	74	23	59
Porcupine	70	274	28	100	151	25	108

Table 2 continued

	Dissolved	Total Suspended*			Silt & Clay		
	ppm	ppm	%T	JCU #	ppm	%T	JCU
<u>May 27, 28, & 29</u>							
W. Fork	80	191	26	67	123	23	69
NF of W. Fork	73	29	4		12	4	
MF of W. Fork	51	135	16	42	78	16	40
N & MF of W. F., upper	58	79	14	36	14	13	34
N & MF of W. F., lower	64	90	14	35	60	15	36
SF of W. Fork	87	207	25	80	143	29	89
Portal	35	46	3		36	3	
Greek	71	208	18	81	139	18	89
Squaw	58	435	29	100	168	27	102
Spanish	30	58	1		30	2	
F.S. Boundary	95	213	28	98	153	26	101
Manhattan	122	243	25	102	161	26	106
E. Gallatin	165	253	39	150	194	39	170
Logan	148	303	32	135	203	31	143
<u>June 8 & 9</u>							
Park Boundary	106	75	6		34	2	
Tepee	307	3	1		----	1	
Sage	144	256	28		123	26	70
Taylor	130	226	27		123	25	83
Buck	128	124	16		70	15	45
Beaver	109	47	12		30	12	27
Porcupine	67	141	13		74	11	39
W. Fork	81	89	14		57	13	32
NF of W. Fork	75	22	2		10	2	
MF of W. Fork	56	58	5		39	4	
N & MF of W.F., upper	63	50	6		27	6	<25
N & MF of W.F., lower	66	42	5		26	5	
SF of W. Fork	85	106	18		68	17	42
Portal	32	42	2		33	2	
<u>June 8 & 9</u>							
Greek	81	84	7		71	7	<25
Squaw	62	96	5		67	5	
Spanish	31	38	2		23	1	
F.S. Boundary	84	164	28		126	26	90
Manhattan	147	395	49		203	47	177
E. Gallatin	168	156	17		104	16	58
Logan	141	355	41		220	41	170

Table 2. continued

	<u>Dissolved</u>	<u>Total Suspended*</u>			<u>Silt & Clay</u>		
	ppm	ppm	%T	† JCU #	ppm	%T	JCU
June 17 & 18							
Park Boundary	112	41	8	<25	14	7	
Tepee	344	0	2		---	1	
Sage	145	205	30	82	86	28	84
Taylor-gaging station	121	593	75	265	390	70	270
Wapiti above L. Wapiti	109	58	11	25	26	10	<25
Little Wapiti	104	61	13	31	30	12	25
Wapiti at Taylor	107	77	12	26	40	11	<25
Taylor above Wapiti	121	902	90	370	583	84	370
Buck	131	86	12	29	43	10	28
Beaver	115	23	11	<25	44	9	
Porcupine	70	537	43	190	221	39	195
W. Fork	82	89	14	34	51	13	32
Portal	32	30	2		24	2	
Greek	96	30	4		25	4	
Squaw	63	28	3		18	2	
Spanish	31	29	2		12	1	
F.S. Boundary	90	135	25	77	96	22	69
Manhattan	108	300	36	117	139	33	114
E. Gallatin	211	83	17	50	41	13	44
Logan	130	236	36	125	159	34	113

TABLE 3. X-ray mineralogical analysis of the Gallatin River and its tributaries in 1970
(percent peak heights of minerals)

		clay					silt					
		#	Sm	Ve	Mi	Ka	Ve	Mi	Ka	Q	Fe	Fe/Q
* Interstratified ** Interstratified vermiculite-chlorite † Interstratified vermiculite-mica # Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar, Fe/Q=feldspar/quartz												
Gallatin - Park bdry.	May	18	67	-	22	11	16	4	4	64	13	0.20
	May	27	64	6	24	6	28	5	5	49	13	0.26
	June	8	57	7	21	14	22	3	6	55	14	0.26
Tepee Cr.	May	4	71	7	14	7	17	4	3	68	8	0.11
Sage Cr.	May	18	35	8†	27	31	11	6	9	70	3	0.04
	May	27	35	5†	30	30	8	5	7	76	4	0.06
	June	8	31	-	31	38	10	7	14	64	5	0.08
	June	19	42	-	21	36	10	9	11	66	4	0.06
Taylor Fork	May	4	71	7**	14	7	7	3	4	82	5	0.06
	May	18	67	-	17	17	14	5	8	70	3	0.05
	May	27	69	-	15	15	19	4	6	65	6	0.09
	June	8	63	-	19	19	27	5	10	54	4	0.07
	June	19	70	-	17	13	10	3	4	78	5	0.06
Buck Cr.	May	18	67	-	17	17	17	5	8	66	5	0.07
	May	27	47	-	27	27	16	3	7	71	3	0.05
	June	8	67	-	13	20	31	5	8	52	4	0.07
	June	19	67	-	17	17	8	3	5	78	6	0.08
Porcupine Cr.	May	4	73	-	20	7	14	4	4	67	10	0.15
	May	18	94	-	3	4	18	-	5	44	32	0.73
	May	27	88	-	6	6	31	2	6	52	9	0.18
	June	8	86	5	5	5	33	4	4	41	18	0.45

Table 3 continued

			clay				silt					
		#	Sm	Ve	Mi	Ka	Ve	Mi	Ka	Q	Fe	Fe/Q
Porcupine Cr.	June 19	92	-		4	4	14	4	2	48	31	0.65
Beaver Cr.	May 4	42*	5		21	32	3	4	6	84	3	0.04
	May 18	31*	-		19	50	9	6	16	66	2	0.03
	May 27	13*	8		17	63	5	5	14	74	2	0.03
	June 8	8*	-		31	62	7	5	18	68	1	0.02
	June 19	25*	-		15	60	7	5	10	74	5	0.07
West Fork	May 4	54	-		18	27	8	4	8	72	8	0.10
	May 18	63	-		25	13	21	5	5	65	4	0.06
	May 27	38	11		26	26	22	5	8	63	3	0.04
	June 8	42	10**		22	26	18	8	8	63	4	0.06
	June 19	23	8**		31	38	8	3	6	78	4	0.05
Portal Cr.	May 27	92	8	-	-	-	27	3	2	41	27	0.66
	June 8	82	10		8	-	39	6	4	22	30	1.33
Swan Cr.	June 8	67	7		17	10	44	-	-	23	33	1.44
Greek Cr.	June 8	93	-		7	-	56	9	2	18	15	0.83
Squaw Cr.	May 4	67	17		8	8	44	5	5	21	26	1.21
	May 27	71	7		14	7	60	3	4	14	19	1.36
	June 8	51	8		15	26	40	5	6	25	24	0.95
	June 19	75	8		8	8	35	5	5	31	24	0.76
Spanish Cr.	May 4	67	-		17	17	16	15	4	55	9	0.16
Gallatin - Forest bdry.	April 1	47*	7**		20	27	15	22	7	37	19	0.50
	April 11	45*	18		18	18	36	11	5	31	17	0.55
	April 27	45	18		18	18	9	6	2	60	22	0.37
	May 4	70	0		13	18	17	-	5	67	10	0.15
	May 18	82	0		9	9	27	4	7	56	7	0.12
	May 27	65	5		15	15	27	3	7	54	9	0.16
	June 8	62	5		14	19	27	6	8	51	8	0.15

Table 3 continued

		clay					silt					
		#	Sm	Ve	Mi	Ka	Ve	Mi	Ka	Q	Fe	Fe/Q
Gallatin - Forest bdry.	June	19	68	7	15	10	35	3	5	49	7	0.16
Gallatin - Manhattan	April	11	69*	-	21	10	19	8	3	61	9	0.15
	April	27	67*	-	20	13	8	7	3	69	13	0.19
	May	4	67	9	13	11	26	4	6	53	12	0.22
	May	18	69	9	11	11	30	5	8	50	7	0.13
	May	27	59	12	15	15	28	5	9	50	8	0.16
	June	8	63	8	16	14	26	6	6	49	14	0.28
	June	19	53	12	18	18	37	8	6	41	8	0.19
Baker Cr.	March	19	45*	18	18	18	32	7	4	48	9	0.20
	April	1	67*	-	19	15	24	8	3	54	11	0.20
	April	11	44*	22	22	11	12	6	4	52	25	0.48
E. Gallatin - Belgrade	March	11	60	10	17	13	29	8	5	39	19	0.50
	March	19	44*	22	22	11	35	7	6	44	8	0.19
	April	1	44*	22	22	11	28	5	5	51	11	0.22
	April	11	50	17	17	17	30	7	8	50	6	0.12
	April	27	50*	17	17	17	15	6	3	63	13	0.20
	May	4	50	17	17	17	26	4	7	56	7	0.13
	May	18	52	16	17	16	31	5	7	50	7	0.13
	June	8	41	18	12	29	35	4	5	47	9	0.19
	June	19	43	21	21	21	27	5	4	56	8	0.14
Gallatin - Logan	March	19	56*	31	6	6	17	7	6	61	9	0.15
	April	1	89*	11**	6	6	27	8	6	52	6	0.12
	April	11	45*	9**	27	18	19	7	4	63	8	0.12
	April	27	47*	27	13	13	27	6	4	52	11	0.20
	May	4	58	13	16	13	38	9	7	37	9	0.24
	May	18	65	10	15	10	31	7	9	45	8	0.17
	May	27	64	11	13	13	27	5	6	52	9	0.18

Table 3 continued

			clay				silt					
		#	Sm	Ve	Mi	Ka	Ve	Mi	Ka	Q	Fe	Fe/Q
Gallatin - Logan	June 8	58	17	13	13	27	3	6	53	11	0.20	
	June 19	50	11	17	22	30	9	7	45	9	0.21	
Bridger Cr.	April 11	59	18	18	12	27	3	3	56	11	0.20	
	April 27	40	10	25	25	59	3	4	56	3	0.54	
	May 18	62	13	13	13	45	5	7	38	5	0.12	
Rocky Cr.	April 11	50	20	20	10	33	2	4	54	7	0.12	
	April 27	68*	-	14	18	13	3	4	67	13	0.20	
	May 18	58	8	17	17	31	4	7	52	6	0.11	
Bozeman Cr.	May 18	36	21	21	21	40	8	8	38	6	0.17	
E. Gallatin - Bozeman	March 19	42*	17**	17	25	18	4	4	57	17	0.30	∞
	April 1	36**	23	18	23	18	3	3	54	23	0.41	
	April 11	47	18**	18	18	36	6	5	47	6	0.13	
	April 27	38*	25	16	22	20	5	5	58	12	0.21	
Hyalite Cr.	April 11	9	75	6	20	78	5	6	8	4	0.43	
	May 18	54	12	15	20	27	8	7	46	12	0.25	
Dry Cr.	March 19	44*	11	28	17	22	10	9	52	6	0.13	
	April 1	40*	20	27	13	20	15	6	52	9	0.17	
	April 11	40*	7	40	13	22	9	7	53	8	0.14	
	April 27	50*	12	23	15	4	5	3	68	20	0.28	
	June 19	27*	18	27	27	11	7	7	69	7	0.10	

TABLE 4. X-ray mineralogical analysis of the Gallatin River and its tributaries in 1971
(percent peak heights of minerals)

		clay						silt					
		#	Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/Q
* Interstratified													
** Interstratified vermiculite-chlorite													
† Interstratified vermiculite-mica													
# Sm=smectite, Ve=vermiculite, Mi=mica, Ka=kaolinite, Q=quartz, Fe=feldspar, Fe/Q=feldspar/quartz													
Gallatin - Park bdry.	May	28	54	13	13	10	10	15	3	3	67	11	0.16
	June	8	46	14	11	11	17	10	3	4	70	12	0.17
	June	17	44	11	15	13	18	25	3	5	49	17	0.36
Tepee Cr.	June	8	-	38	-	13	50	13	4	4	68	11	0.17
	June	17	37	13	13	15	23	14	5	5	70	5	0.08
Sage Cr.	May	7	31	4†	22	24	20	7	7	9	73	4	0.05
	May	29	30	2	28	19	21	8	10	11	68	3	0.05
	June	8	28*	5†	21	24	22	7	4	5	78	5	0.07
	June	17	22	3	16	19	41	12	7	9	69	3	0.05
Taylor Fork	May	7	73	-	11	5	11	16	3	4	72	5	0.07
	May	17	66	-	9	6	19	13	4	4	75	4	0.05
	May	29	66	-	12	8	14	17	4	4	72	3	0.04
	June	8	63	-	11	7	20	22	4	5	67	3	0.04
	June	17	64	-	9	9	18	22	3	4	68	3	0.04
Buck Cr.	May	7	53	4	16	13	13	13	5	7	71	4	0.06
	May	17	62	-	14	13	11	15	5	5	69	6	0.09
	May	28	50	5	14	14	18	23	4	5	65	4	0.06
	June	8	54	-	14	14	18	26	3	4	62	5	0.08
	June	19	40	2	6	6	46	32	3	6	54	4	0.08
Porcupine Cr.	May	7	81	-	11	7	-	11	3	3	68	14	0.20
	May	17	70	-	9	11	11	8	3	6	71	12	0.17

Table 4 continued

		clay						silt					
		#	Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/Q
Porcupine Cr.	May	29	72	6	8	8	6	17	3	5	59	16	0.27
	June	8	85	2	4	4	4	21	5	2	51	21	0.41
	June	17	97	1	-	-	2	15	0	3	37	44	1.18
Beaver Cr.	May	7	16*	4†	20	32	28	29	6	6	54	6	0.1
	May	17	18*	6†	20	35	20	6	5	10	74	4	0.06
	May	29	10*	5†	22	45	18	5	5	12	75	3	0.05
	June	8	-	13†	18	36	33	5	3	11	78	3	0.04
	June	17	5*	7†	16	45	27	5	5	13	74	2	0.03
West Fork	May	7	32	9	27	14	18	13	4	4	74	4	0.06
	May	17	50	8	17	13	12	42	5	5	45	3	0.07
	May	28	27	13	20	20	20	26	6	6	61	2	0.04
	June	8	10*	13	25	25	27	12	4	6	75	4	0.05
	June	17	21	4	22	19	35	15	4	6	70	4	0.06
Portal Cr.	June	9	73	18	-	-	9	28	3	1	27	41	1.52
	June	17	73	23	-	-	4	31	2	0	20	48	2.38
Greek Cr.	May	7	90	6	4	-	-	54	9	-	20	17	0.80
	May	17	91	5	5	-	-	58	12	3	15	12	0.80
	May	28	91	6	2	-	-	19	5	3	47	27	0.60
	June	9	84	10	6	-	-	28	6	2	35	28	0.80
Squaw Cr.	May	7	63	16	5	11	5	45	9	4	26	30	0.67
	May	17	78	6	8	4	4	33	6	3	27	28	1.11
	May	29	67	13	8	8	4	41	9	3	20	30	1.45
	June	9	82	5	-	5	9	42	5	3	20	11	1.46
Spanish Cr.	June	9	-	40	7	7	47	27	5	6	39	23	0.59
	June	18	-	52	5	11	32	29	6	8	26	32	1.26
Gallatin - Forest bdry.	March	18	63*	-	13	13	13	13	6	5	52	24	0.47
	April	1	63*	-	16	13	9	16	7	4	61	12	0.19

Table 4 continued

		clay						silt					
		#	Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/Q
Gallatin - Forest bdry.	April 16	57		7	13	10	13	11	6	5	71	7	0.10
	May 7	65		-	9	7	19	18	3	3	69	6	0.08
	May 18	68		5	8	8	11	25	4	6	59	7	0.11
	May 28	55		7	13	12	12	25	3	5	61	5	0.08
	June 9	55		5	11	11	18	32	4	4	54	6	0.11
	June 18	65		3	9	8	15	23	4	5	62	6	0.10
Gallatin - Manhattan	March 18	60*		-	13	13	13	14	7	4	60	13	0.26
	April 1	50*		-	20	15	15	20	3	3	57	15	0.26
	April 16	43		10	14	12	21	12	6	6	64	21	0.20
	May 7	54		11	11	11	14	27	6	6	53	14	0.14
	May 17	63		19	11	7	11	29	5	5	54	11	0.13
	May 27	60		7	12	9	12	31	4	4	53	12	0.14
	June 9	51		6	10	12	21	36	4	6	48	21	0.11
	June 18	63		6	9	9	12	32	4	5	52	12	0.15
Baker Cr.	May 7	17		5	5	62	11	54	13	10	10	13	1.30
E. Gallatin - Belgrade	March 18	20*		30**	15	15	20	18	7	5	56	13	0.23
	April 1	38		17**	17	12	17	18	4	4	64	10	0.16
	April 16	47		9**	15	12	18	18	6	8	59	8	0.14
	May 7	45		20	12	10	12	24	6	7	59	6	0.10
	May 18	54		14	11	11	11	46	6	6	37	6	0.15
	May 27	55		10	12	12	10	31	6	7	49	8	0.16
	June 8	48		15	14	10	14	36	6	7	45	6	0.13
	June 18	45		18	10	10	16	36	5	5	48	6	0.13
Gallatin - Logan	March 18	40		7**	14	10	19	16	9	7	59	9	0.15
	April 1	44		16**	16	12	12	34	5	6	49	6	0.13
	April 16	52		11	15	11	11	31	6	6	50	6	0.13
	May 7	50		17	13	8	13	36	4	5	49	5	0.11
	May 17	54		13	13	10	10	31	4	6	51	8	0.16

Table 4 continued

		clay						silt					
		#	Sm	Ve	Mi	Ka	Q	Ve	Mi	Ka	Q	Fe	Fe/Q
Gallatin - Logan	May	27	53	11	13	13	10	34	5	4	50	6	0.12
	June	9	56	7	11	7	19	40	4	4	44	8	0.18
	June	18	61	8	10	8	13	31	5	6	51	8	0.16
Bridger Cr.	May	8	55	18	12	6	9	42	-	3	48	8	0.15
Rocky Cr.	May	8	41	10	18	18	14	28	4	8	55	5	0.09
Bozeman Cr.	May	8	33	13	7	13	33	35	9	8	37	11	0.29
E. Gallatin - Bozeman	March	18	23*	23**	12	12	31	30	8	8	48	8	0.16
	April	1	33*	19**	15	11	22	23	5	5	59	7	0.11
	April	16	47	13**	16	13	13	25	5	5	55	10	0.17
Hyalite Cr.	May	8	38	14	14	19	14	18	6	6	60	11	0.18
Dry Cr.	April	1	24*	15**	24	12	24	16	9	5	62	7	0.12
	May	7	10*	30	25	10	25	14	9	6	64	7	0.11
	May	17	15*	20	22	15	19	22	9	6	55	9	0.16

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