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 MASTER OF SCIENCE in Soil Science
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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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ABSTRACT

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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 determing 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 (Woodburum 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:

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

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 Apalochiola River contributes sediment with Kaolinite suite, and the Mobile River, which lies between the Mississippi and Apalochiola 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 predominents, and the climate of the source area may be the most important factor in determing the resultant clay mineral assemblage. Weaver (1958b) studied shales of upper Mississippian-lower Pennslyvanian 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 intermontain 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]

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[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 upperstream. 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).