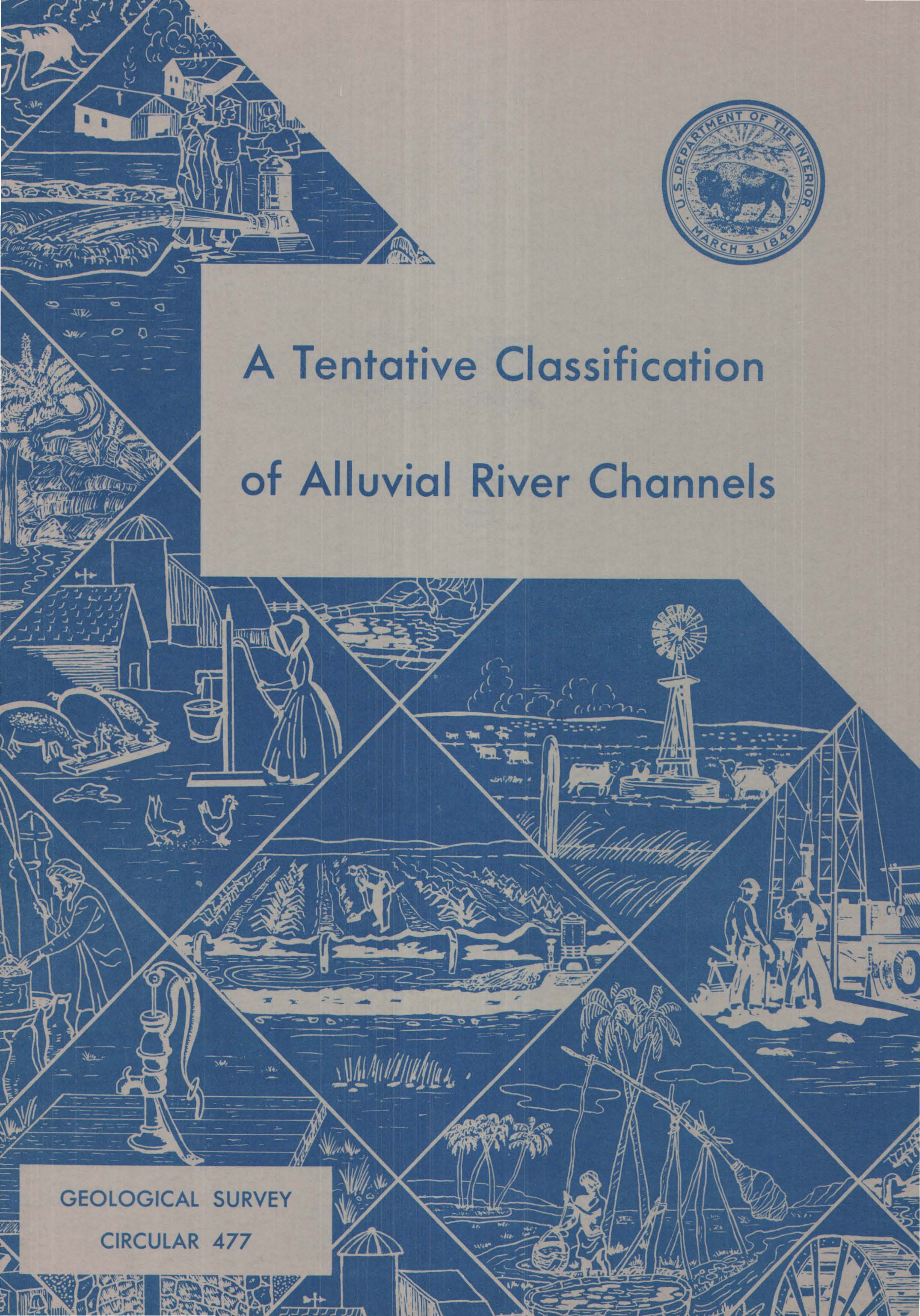

A Tentative Classification of Alluvial River Channels

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A Tentative Classification of Alluvial River Channels

By S. A. Schumm

An examination of similarities and differences among some Great Plains rivers

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ABSTRACT

A classification of river channels might be based on the independent variables, discharge and sediment load. Discharge, however, because it determines mainly the size of a channel, is not a critical factor for purposes of this study. Sediment load, because of its influence in determining channel stability, shape, and sinuosity, is used as the basis of this classification. Three classes of channels, stable, eroding, and depositing, are established with regard to channel stability or the relation of sediment load to transportability.

A negative exponential correlation between silt-clay in the stream channel and the percent of total sediment load transported as bedload is proposed. From this relation the limits of three additional classes of channels, bedload, mixed-load, and suspended-load, are established, on the basis of the predominant mode of sediment transport or the proportions of suspended load and bedload transported through a channel. In all, nine subclasses of river channels are defined on the basis of channel stability and the dominant mode of sediment transport.

INTRODUCTION

Classifications of natural phenomena are of value because they focus attention on the key factors which distinguish the individual phenomena. Conversely, they may tend to restrict thoughtful consideration of a problem by categorizing things which are really members of a continuous series. When this disadvantage is recognized, they may become useful guides to further research.

This report classifies some relationships between river morphology and sediment type. The classification was prepared as a means of organizing these relationships as a guide and stimulus to further research on the influence of sediment load on fluvial morphology.

Drainage patterns have been defined by geologists with regard to the response of streams to geologic structure and lithology of an area—for example, dendritic, rectangular, and radial (Zernitz, 1932). Rivers have been classified according to their stage of development in the cycle of erosion, such as youthful, mature, and old (Davis, 1889), and also according to their origin on a land surface, such as antecedent, superposed, and consequent (Davis, 1890). These classifications relate the rivers to the geology of an area and are used in the geologic interpretation of aerial photographs (Miller, 1962, p. 90–97). The numerical classification of Horton (1945), whereby order numbers are assigned to the components of a drainage network, is extremely useful in the morphometric analysis of drainage systems. None of the above classifications, however, gives an indication of the character of the river channel with respect to the two independent variables, discharge and sediment load, upon which the morphology of alluvial river channels depends.

Melton (1936) related streams to the manner in which they build their flood plains, but discharge and sediment load of the streams did not determine Melton's classification—rather they were reflected in it. Owing to the complexity of the relationships and the lack of data, it is not surprising that a classification of river channels has not been attempted previously.

THE INDEPENDENT VARIABLES

RESTRICTIONS

The proposals must be restricted in application, first, because they are based on data obtained and observations made in the western United States, mainly on the Great Plains, though the writer is hopeful that the relationships may prove to be of a general nature; second, the rivers studies are alluvial, generally having a well formed flood plain and lacking regulation of course or gradient by rock outcrops except over short distances; third, the channels contain less than 20 percent coarse gravel and the sediment load is, therefore, relatively fine-grained.

The classification can only be applied locally or to segments of a river system, for the characteristics of a stream channel can change significantly within a short distance if it becomes unstable (Schumm, 1961) or receives sediment of a different type from a tributary (Schumm, 1960a). Therefore, it is a classification of channels rather than rivers.

The classification, as indicated in the title, is tentative, for the basic data necessary to prove its validity are lacking. Nevertheless, it is presented as a stimulus to the collection of the necessary data and perhaps as a new approach to the consideration of alluvial rivers.

DISCHARGE

Discharge is an independent variable that largely determines the size of stream channels (Leopold and Maddock, 1953) and the amplitude and wave length of meanders (Leopold and Wolman, 1957). Width and depth of the channels to be discussed herein are largely a function of discharge, although the sediment forming the channel may introduce important modifications (Schumm, 1962).

Discharge, however, is not a valid basis for a classification of stream channels unless size is considered most important, though a qualitative distinction among stream channels can be made on the basis of discharge characteristics, that is, ephemeral and perennial streams. This distinction is obvious but not fundamental. Downstream differences between ephemeral and perennial streams have been demonstrated by Leopold and Miller (1956), but the author has shown that some elements of the pattern and shape of both ephemeral and perennial stream channels are related to the type of sediment forming the perimeter of the channel (Schumm, 1960a, 1963) rather than to the amount or character of discharge.

TOTAL SEDIMENT LOAD

CHANNEL STABILITY

A major division of alluvial channels can be made on the basis of stream stability or lack of it. These differences can be thought of with respect to the total sediment load delivered to the channel. An excess of total load causes deposition, a deficiency causes erosion, and between the extremes lies the stable channel. Although often in the field a given river channel cannot be clearly identified as stable, eroding, or depositing, it is possible to think of all rivers as falling into one or another of these three classes.

The stable channel is one that shows no progressive change in gradient, dimensions, or shape. Temporary changes occur during floods, but the stable channel, if the classification were not restricted to short segments of the river, would be identical to the graded stream as defined by Mackin (1948) in which, "over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin."

The eroding channel is one that is being progressively degraded or widened by bank erosion or both. Conversely, the depositing channel is one that is being aggraded or is having sediment deposited on its banks or both. Classification of river channels on the basis of stability as eroding, stable, or depositing, emphasizes the diversity among rivers and stream channels; each of the three classes can be considered to be distinct from the others.

MODE OF SEDIMENT TRANSPORT

The channels are further subdivided with reference to the predominant mode of sediment transport through the channel. Mode of transport is simplified here to mean the transportation of sediment as either suspended load or bedload.

It is necessary to clarify the definition of the terms bedload and suspended load as used herein. According to Einstein, Anderson and Johnson (1940, p. 632) "the bed-load consists of material moving as surface-creep and material moving in suspension, both of which can be expressed as a rate related to the stream discharge. ****Primarily the conception is that bed-load and suspended load do not supplement each other, as a certain grain may easily be in suspension and still be considered bed-load." The term bedload as used above is synonomous with the term bed-material load, which is defined as that part of the sediment load of a stream which consists of particle sizes represented significantly in the bed of the stream. The emphasis on significant representation excludes the small percentage of silt and clay usually found in most bed material (Einstein, 1950, p. 6, 7).

The term suspended lcad as used in this publication is synonomous with wash load, that part of the sediment load not significantly represented in the bed of the stream (Einstein, 1950, p. 7). Wash load moves almost entirely in suspension and bears no relation to discharge (Einstein et al., 1940, p. 632). As discharge increases in a stream channel the amount of bed-material transported by suspension increases. Nevertheless, bed-material load differs from wash load because at low flows bed-material load is stationary or moves on the bed; wash load, however, is always in suspension as it is washed through the channel. In the channels of the Great Plains rivers bed-material load is usually composed of sand, whereas wash load is composed of silt and clay.

In this report the terms bedload and suspended load will be used, for although for any short period of sediment discharge the terms bed-material load and wash load are meaningful, there is probably an average grain size which, over a period of years, forms the boundary between the sediment moved predominantly on the bed (bedload) and the sediment moved predominantly in suspension (suspended load).

The average grain size separating suspended load from bedload probably varies between rivers. Einstein, Anderson, and Johnson (1940) concluded from studies along the Enoree River in South Carolina that material larger than the 42-mesh sieve (0.351 mm) comprises the bedload when the river is in flood. The 0.351-mm size, because it reflects flood conditions, seems too high, for at low flows sediment particles 0.3 mm in diameter will certainly move on the stream bed. Sundborg (1956, p. 219) suggested that the finest material transported as bedload ranges from 0.15 to 0.20 mm, and Hjulstrom's curves (1935, p. 274) suggest strongly that sediment larger than the 200-mesh sieve (0.074 mm) will be transported near the streambed.

In brief, the proposed distinction among river channels is based on the predominant mode of sediment transport or the proportions of bedload and suspended load transported through a stream channel. Although a single grain size, which would form the boundary between suspended load and bedload, cannot be selected from available sediment-transport data, it is suggested that, in general, silt and clay are transported in suspension and that sand and coarser sediment are transported on or near the streambed.

THE IMPORTANCE OF SEDIMENT TYPE

Basic data on the proportions of bed and suspended load are available for only a few rivers. Therefore, it is necessary to retrace the steps whereby the writer has tentatively concluded that the proportions of suspended load and bedload in a stream may be the critical factor upon which many stream characteristics depend.

During a study of channel characteristics of some western streams, it was discovered that the shape of the channel of stable rivers expressed as a width-depth ratio (F) is related to the percentage of sediment finer than 0.074 mm in the perimeter of the channel (M) (fig. 1).

$$F = 255\, M^{-1.08} \qquad (1)$$

Further work revealed that the mechanics of deposition and erosion in ephemeral stream channels is related to M or silt-clay in the channel perimeter (Schumm, 1962). The sinuosity of Great Plains streams, expressed as a ratio of channel length to valley length (P), is related to M and width-depth ratio (F) as follows (Schumm, 1963):

$$P = 3.5\, F^{-.27} \quad \text{(fig. 2)} \qquad (2)$$

$$P = 0.94\, M^{.25} \quad \text{(fig. 3)} \qquad (3)$$

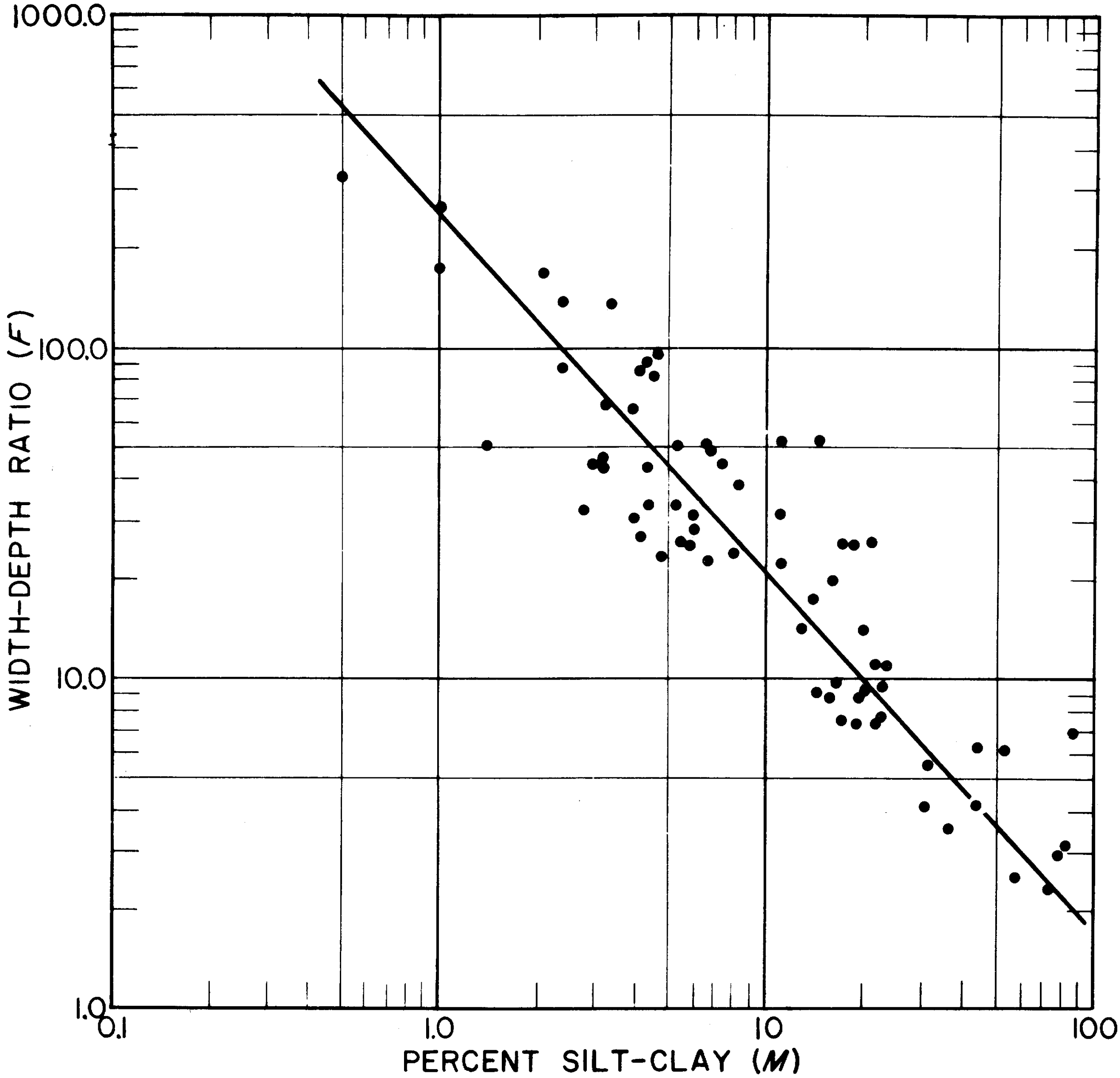

Figure 1.—Relation of width-depth ratio (*F*) to weighted mean percent silt-clay (*M*) (from Schumm, 1960).

Initially these relationships were explained by the higher cohesion of the bed and bank sediments, which contain large amounts of silt and clay. This assumption was reasonable for bank material, but in most channels the bed material doesn't contain enough silt and clay to be cohesive. Yet, it was not the percent silt-clay in the banks alone that showed the best correlation with channel shape and sinuosity but rather the percent silt-clay in the entire perimeter of the channel. After many attempts to explain the significance of M in terms of the physical properties of the sediments, it occurred to the writer that, in addition to being an indication of the cohesiveness of the sediment, M may be related to the average percent of total load transported in suspension. Conversely, the percent of sediment coarser than 0.074 mm exposed in the channel may be related to the average percent of total sediment load transported as bedload. The data presented by Hjulstrom (1935) and Sundborg (1956) on the size of sediment transported on or near the streambed lend support to this hypothesis.

Supporting evidence for the suggestion that, as the percentage of sand and coarser sediment in the perimeter of a channel increases, the proportion of total load transported as

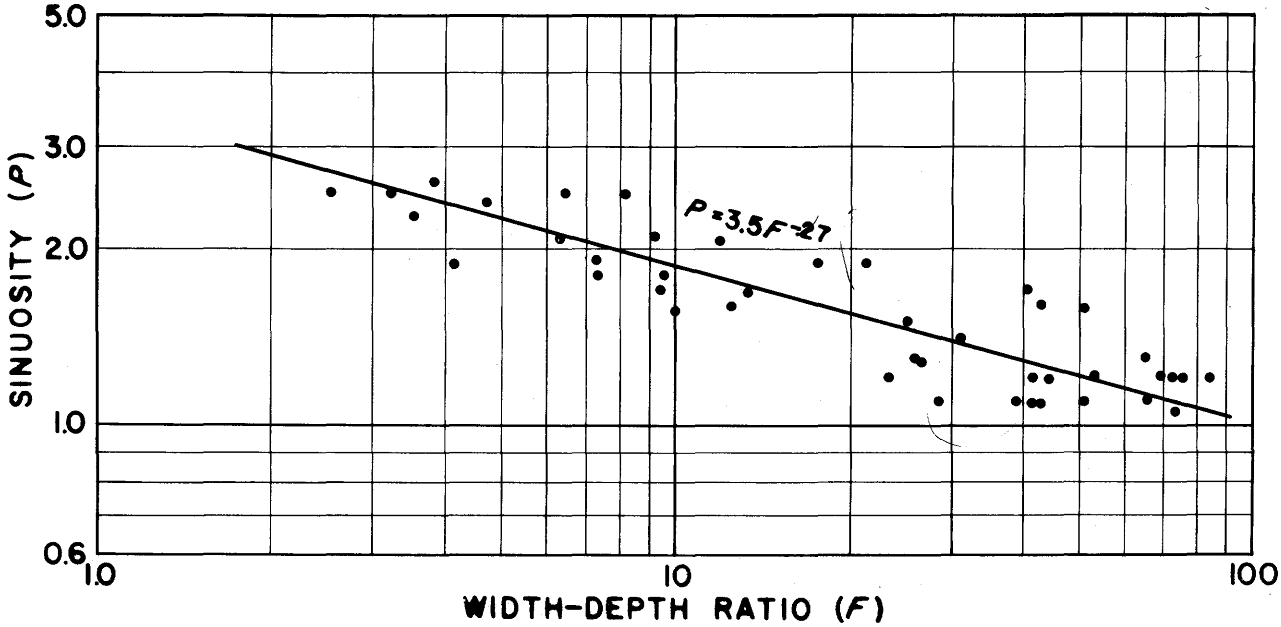

Figure 2.—Relation of sinuosity (P) to width-depth ratio (F) (from Schumm, 1963).

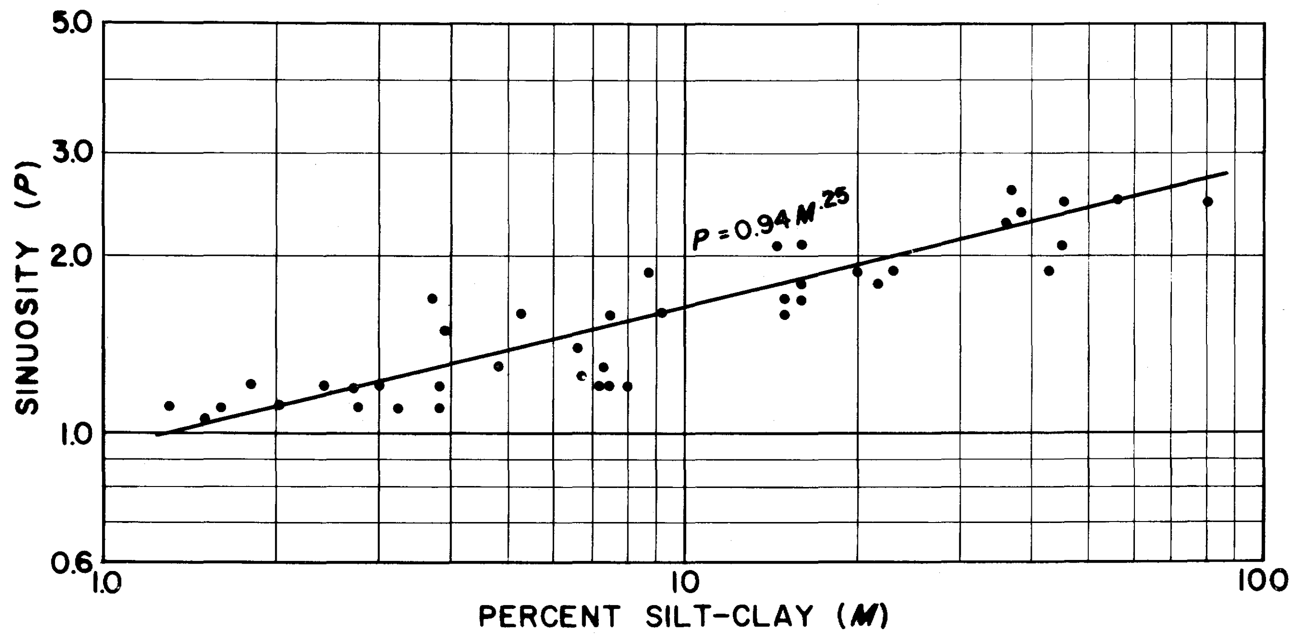

Figure 3.—Relation of sinuosity (P) to silt-clay (M) in perimeter of channel (from Schumm, 1963).

bedload increases is given by the relation of percent silt-clay in the channel perimeter to width-depth ratio (equation 1), for others have noted that wide shallow rivers are characterized by high-bedload transport. Leopold and Maddock (1953, p. 29) state, "At constant velocity and discharge, an increase in width is associated with a decrease of suspended load and an increase in bedload transport." They quote from Lane (1937, p. 138), Griffith (1927, p. 246), and Mackin (1948, p. 484) to support the view that to be stable an alluvial channel transporting a large proportion of bedload must have a relatively wide and shallow cross section. In addition, high sinuosity is not conducive to efficient bedload transport, for Shulits (1959) observed that flume experiments indicate that bedload is one-third less in a 180° bend than in a straight channel and that in a meandering channel the bedload per unit width is 20 percent less than in a straight channel. This observation is in agreement with that of Dryden and others (1956, p. 483) that the frictional resistance to flow increases as sinuosity increases. When the relation of sinuosity to width-depth ratio and to M (equations 2 and 3) are considered with regard to the above statements, the case for the significance of the proportions of suspended load and bedload in determining channel characteristics is strengthened. Sundborg (1956, p. 203–204) suggested that as bedload decreases the channel becomes narrow and deeper and tends to meander; the writer concurs in this opinion.

An opportunity to examine the effect of changes in the proportions of suspended load and bedload in a channel is afforded by the Smoky Hill-Kansas River system. In western Kansas the sinuosity of the Smoky Hill River is about 1.2, the percent silt-clay (M) is about 5 percent, and width-depth ratio is about 85. Near the junctions of the Saline and Solomon Rivers with the Smoky Hill, the sinuosity increase to about 2.5, percent silt-clay (M) is 20, and width-depth ratio decreases to about 10. The Saline and Solomon Rivers appear to introduce a large amount of suspended load into the Smoky Hill channel. Below the junction of the Republican River with the Smoky Hill River, sinuosity decreases progressively to 1.1 at Topeka, percent silt-clay (M) decreases to about 3, and width-depth ratio increases to about 45. The Republican River has only about 4 percent silt-clay (M) in its channel above the junction, and it undoubtedly introduces a large amount of bedload into the Kansas River. If, as suggested, the major part of the change in the sinuosity and channel shape of the Smoky Hill and Kansas Rivers is the result of the type of sediment load introduced by its major tributaries, the importance of the proportions of bedload and suspended load to river morphology has been demonstrated.

A RELATION OF PERCENT SILT-CLAY TO BEDLOAD TRANSPORT

As indicated previously, there are practically no data to support the hypothesis that the percent silt-clay in the perimeter of a channel is related to the components of total load. Some recent measurements along two rivers show that the average percent of total load transported on or near the bed of the Niobrara and Middle Loup Rivers is about 50 percent (Hubbell and Matejka, 1959, p. 1; Colby and Hembree, 1955, p. 111). The percentage of material coarser than silt-clay in the perimeter of the Niobrara River, upstream from the points of sediment measurement, is about 98 percent. It can be expected that the proportion of bedload on the average would be less than the percent of sand in the perimeter of the channel, for during floods large amounts of fine sediment would be carried through the channel in suspension. In any event, it seems reasonable to suppose that as the proportion of bedload increases the percent silt-clay forming the perimeter of the channel decreases.

It may be possible to suggest the type of relationship that exists between the percent silt-clay in the channel perimeter and the average percent of total load transported as bedload. For two localities it is known that about 50 percent of total load is transported on the bed when percent silt-clay (M) is about 2. Bedload probably is never greater than about 60 to 70 percent of total load because fine sediments are present in every stream and generally are transported at a maximum rate when bedload transport is high. Therefore, a curve relating percent silt-clay (M) to percent bedload might intersect the bedload axis at about 60 to 70 percent (fig. 4).

On the other hand, percent silt-clay (M) will approach 100 percent when bedload transport is zero. Probably bedload transport is low when percent silt-clay (M) is about 30 percent because above this value sinuosity is

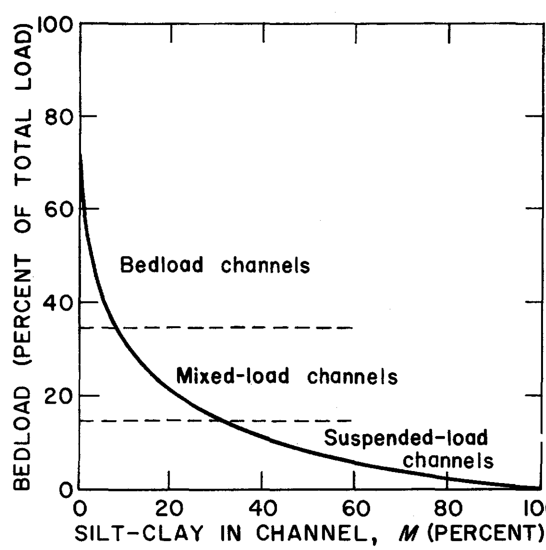

Figure 4.—Hypothetical relation of bedload, as percent of total load, to silt-clay in perimeter of channel (*M*).

high (>2.1) and width-depth ratio is low (<7.0). This type of channel theoretically is not capable of transporting large bed loads. Therefore, the curve should intersect the M axis at an acute angle at 100 percent (fig. 4). If the curve shown on figure 4 is correct, then a negative exponential relationship exists between M and the percent of total load transported as bedload. If it does, width-depth ratio is a positive exponential function of the percentage of total sediment load transported on or near the stream bed, and stream sinuosity is a negative exponential function of the percentage of total sediment load transported on or near the stream bed.

THE CLASSIFICATION

The classification of alluvial channels based on data from rivers transporting materials finer than coarse gravel is given on table 1. Nine subclasses of channels are shown, based on channel stability and on the predominant mode of sediment transport. Although variations in the proportions of bed and suspended load are transitional, it is possible to think in terms of a suspended load channel transporting perhaps 0 to 15 percent bedload or 100 to 85 percent suspended load, a bedload channel transporting 35 to 70 percent bedload and 65 to 30 percent suspended load, and a third category, the mixed load channel, transporting from 15 to 35 percent bedload and 85 to 65 percent suspended load. The boundaries between these groups are based on the assumed relation between M and percentage of bedload (fig. 4) and on the known characteristics of streams having varying amounts of silt and clay in their channels (figs. 1 and 2). The range of channel shape and sinuosity are established for each subclass, but gradient can be suggested only qualitatively, for the absolute value of gradient for these alluvial channels depends to a large extent on discharge, which varies greatly.

The ways in which channels of each of the nine classes modify their gradients and shapes by erosion and deposition have been fairly well established for ephemeral streams in the West and perennial streams elsewhere, and this information is given on table 1. In high suspended-load channels deposition begins along the banks of the channel (Schumm, 1960b). This type of deposition is common along regime canals in India (Blench, 1957). In mixed-load channels deposition occurs initially along the banks, but as deposition continues the bedload fills the channel (Schumm, 1960b). In bedload channels, deposition occurs directly on the floor of the channel, which is raised until the channel is filled (Schumm, 1960b); in some bedload channels islands form and a new flood-plain is constructed (Schumm and Lichty, 1963).

Erosion occurs differently for each class, for the suspended-load channels have deposited fine material and their banks are cohesive and resistant to erosion. Streambed erosion is dominant, and later widening of the channel may be minor. Arroyo cutting of western valleys is of this type. The mixed-load channel is lowered by degradation but, because the banks are less cohesive, channel widening may be important. The bedload channel may change shape with only minor degradation; for example, Cimarron River in southwestern Kansas widened greatly after 1914, but it may not have degraded significantly (Schumm and Lichty, 1963).

Some alluvial channels that do not seem to fit the above classification are those of relatively narrow and deep meandering streams of mountain meadows. Their form suggests that they are suspended-load channels, but the channel floor is composed of cobbles and boulders. The presence of such coarse material seems anomalous, but a logical explanation is that the coarse bed material does not move under the present stream regimen. Observations in South Park, Colo., seem to substantiate this hypothesis, for the cobbles are stained and some are moss covered on their upper surfaces, whereas the under surface of the rock is not stained, a fact that suggests lack of movement for long periods. These are suspended- or mixed-load channels, for the large part of the sediment found on their floors may be relicts of a period of higher discharge. It is doubtful that during erosion or deposition they will behave similarly to the eroding or depositing channels transporting finer sediments. Stream channels, which contain coarse bed material that moves are, of course, bedload channels. As noted above, absolute size of sediment load may be less important than the manner in which it moves through the stream channel.

CONCLUSIONS

On the basis of data limited to fine-grained alluvial rivers, alluvial stream channels have

Table 1.—*Classification of Alluvial Channels*

Mode of sediment transport	Channel sediment (M) percent	Proportion of total sediment load		Channel stability		
		Suspended load percent	Bedload percent	Stable (graded stream)	Depositing (excess load)	Eroding (deficiency of load)
Suspended load	30–100	85–100	0–15	Stable suspended-load channel. Width-depth ratio less than 7; sinuosity greater than 2.1; gradient relatively gentle.	Depositing suspended load channel. Major deposition on banks cause narrowing of channel; streambed deposition minor.	Eroding suspended-load channel. Streambed erosion predominant; channel widening minor.
Mixed load	8–30	65–85	15–35	Stable mixed-load channel. Width-depth ratio greater than 7 less than 25; sinuosity, less than 2.1 greater than 1.5; gradient moderate.	Depositing mixed-load channel. Initial major deposition on banks followed by streambed deposition.	Eroding mixed-load channel. Initial streambed erosion followed by channel widening.
Bedload	0–8	30–65	35–70	Stable bedload channel. Width-depth ratio greater than 25; sinuosity, less than 1.5; gradient relatively steep.	Depositing bedload channel. Streambed deposition and island formation.	Eroding bedload channel. Little streambed erosion; channel widening predominant.

been classified on the basis of one of the two independent variables influencing stream morphology. Discharge is not used as a basis for the classification because it controls mainly the size of the channels. The dimensionless properties of the channels depend mainly on the sediment load moved into the channel. Channel stability depends on the balance, or lack of it, between sediment load and transportability, and three classes of channels result: stable, eroding, and depositing. The type of material transported or the mode of its transport as bedload or suspended load appears to be a major factor determining the character of a stream channel, and a final subdivision of channels is based on this relation.

This classification of stream channels can only afford a basis for discussion until more data become available on the components of total sediment load in a stream channel. Perhaps the quickest way in which the suggestions advanced here can be evaluated is through model studies of stream channels. The experiments would have to be performed in flumes wide enough to permit formation of miniature channels. The sinuosity and shape of these channels could then be related to varying mixtures of silt-clay and sand introduced into the channel. If slope and discharge were constant, the variations in the proportions of bed and suspended sediment introduced into the miniature channels should determine the type of channel produced.

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