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THE EFFECT OF SEDIMENT TYPE ON THE SHAPE AND STRATIFICATION OF SOME MODERN FLUVIAL DEPOSITS—A REPLY*

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In his discussion of the subject paper, Melton's main contention is that a large part of the variation in M (weighted mean percent silt-clay) is due to variations in channel width and depth and that the correlation between M and width-depth ratio is fallacious (Melton, 1961). These assertions will be disproved. However, Melton is basically correct in stating that the equation

$$F = 255\ M^{-1.08} \tag{1}$$

contains width and depth in disguised form, for equation 1 is equivalent to

$$F = k \left(\frac{S_c W + 2 S_b D}{W + 2 D} \right)^a \tag{2}$$

or

$$F = k \left(\frac{F S_c + 2 S_b}{F + 2} \right)^a \tag{3}$$

where F is width-depth ratio, S_c is percent silt-clay in the channel bed, S_b is percent silt-clay in the banks, W is channel width, and D is channel maximum depth. The use of equation 1, however, seems justified, for it is the best expression of the situation in nature. In defense of this choice, it is necessary to demonstrate that the percentages of silt and clay in the bed and in the banks of a stream are independent variables strongly influencing stable alluvial channel shape, that M is a meaningful parameter, and that the calculation of M does not seriously bias the results.

A multiple regression analysis involving width-depth ratio, percent silt-clay in banks, and percent silt-clay in the streambed yields the following equation:

$$F = \frac{246}{S_b^{.50}\ S_c^{.34}} \tag{4}$$

The coefficient of multiple correlation is 0.73, and the coefficient of multiple determination is 0.53, indicating that 53 percent of the variation of width-depth ratio from the mean is explained by the use of S_b and S_c. In a simple correlation of F and S_b the coefficient of determination is 0.39; whereas it is 0.35 in a simple correlation of F and S_c. Thus, both bank and bed sediment are important in determining channel shape. When M is correlated with F, 83 percent of the variation is explained; therefore, even if it were possible to accept Melton's assertions, only about one-third of the variation of stable channel shapes can be explained in that way.

The significance of silt-clay in the bed and banks of an alluvial channel with respect to channel shape has been demonstrated. The decision to com-

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bine bed and bank material and to calculate a weighted mean value of percent silt-clay is based on both theoretical and practical grounds. If channel shape is dependent solely on the resistance of channel bed and banks to tractive force, then equation 4 above might be adequate, although the effects of bed and bank sediment probably may not be so readily separated in nature. However, if M is not only representative of the resistance of bed and banks to erosion but also reflects the predominate type of sediment transported through the channel, then the sediment in the bed and banks should not be treated separately. That is, if sediment larger than 0.074 mm can be considered to be transported generally as bed load or at least near the bed, the percent silt-clay in the perimeter of a channel (M) would indicate the percent of total load transported in suspension. Sundborg (1956, p. 219) suggests that the finest material transported as bed load is of the size 0.15 to 0.20 mm, or twice the size of percent silt-clay as used here (0.074 mm), and Hjulström's curves (1935, p. 274) suggest quite strongly that material larger than 0.074 mm will be transported near the streambed. Exception can be taken to these statements, for the size of sediment in suspension will vary from stream to stream and from day to day on the same stream, depending on fluctuations in velocity of flow and discharge. Nevertheless, it is known that stable channels having a low width-depth ratio carry a high proportion of total sediment load in suspension, whereas those having a high width-depth ratio are characterized by large amounts of bed load (Leopold and Maddock, 1953, p. 29).

Although S_b and S_c are significantly related to F (equation 4), they are of about equal importance as shown by partial correlation. However, if it is the silt-clay forming the perimeter of the channel which is most significant, then to treat the bed and bank sediment separately will give an incorrect representation of the sediment forming the perimeter of the channel. For this reason the weighting procedure was used.

The initial studies of the relation of sediment type to channel characteristics were made along five ephemeral streams. Four of these streams are used as examples of the differences in stratification developed during aggradation of channels in the subject paper (Schumm, 1960a, fig. 2, p. 181-183). At each channel cross section visited two composite sediment samples were taken, one composed of sediments from both banks, the other from the channel floor or bed. This sampling procedure was followed because initially it seemed advisable to collect information on the sediment forming the banks as well as the bed of the channel rather than a composite sample which included material from banks and bed combined. Later the need to combine the bank and bed data was recognized, and the weighted mean percent silt-clay (M) forming the channel perimeter was calculated. It remains to be shown that the weighting procedure does not introduce a serious bias.

The calculation of a weighted mean is a standard procedure for obtaining average percentages or means from two or more groups of different importance. Croxton (1959, p. 376) describes this simple procedure and concludes as follows: "If the groups being combined are of varying importance, weights should be used. . . ." Obviously to obtain a valid measure of silt-clay in a channel perimeter from two composite samples of bank and bed sediment, weights should be used. Thus, the weighting procedure is a standard one. If a single composite sample had been collected at each cross section, the silt-clay content of this single sample could have been used instead of M, and it would, in fact, be approximately equal to the weighted mean as calculated. Thus, if percent silt-clay forming the perimeter of a channel is measured directly by taking a composite sample along the perimeter of a channel, this measured value will be associated with a channel shape indicated by the regression line of figure 1. The calculation of M, therefore, does not affect the situation in nature that a stable channel of a given shape is found to contain a relatively constant amount of silt-clay in the channel perimeter. M simply expresses the proportion of material smaller than 0.074 mm in the channel perimeter, and as suggested above, M may be related to the proportion of silt-clay in the total sediment load moved through a channel.

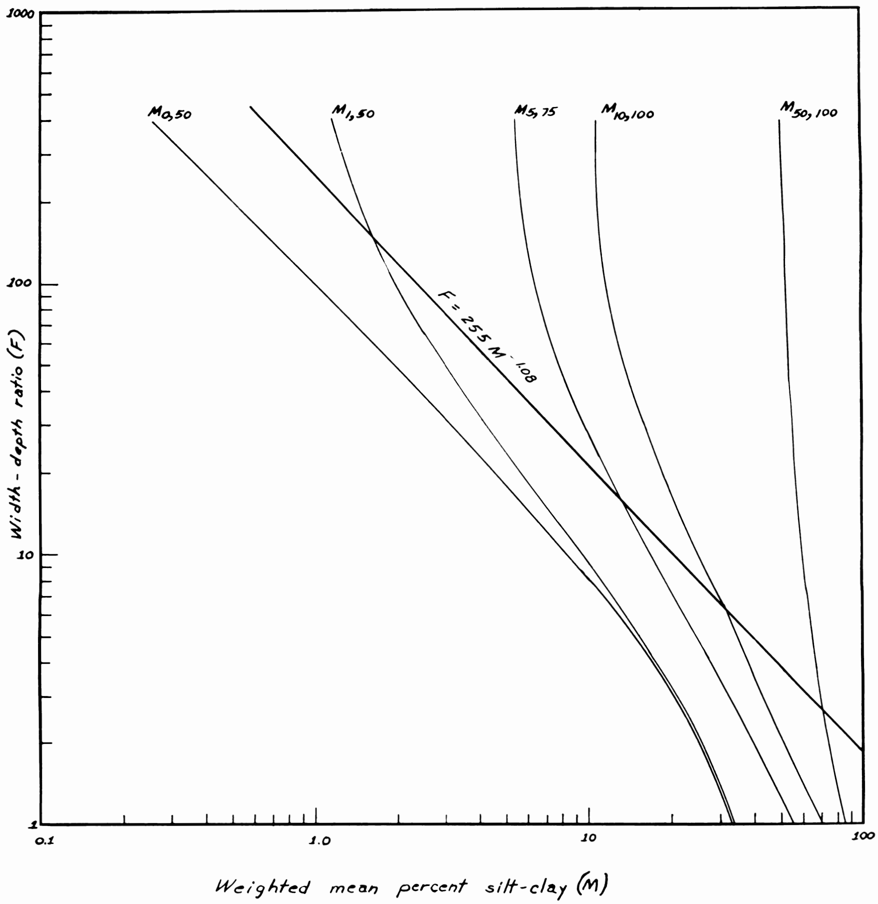

Fig. 1. Regression line illustrating relation between width-depth ratio and weighted mean percent silt-clay, $F = 255\ M^{-1.08}$, superimposed on a family of curves obtained by Melton's method.

The validity of equation 1 may be further demonstrated by refuting Melton's assertion that by holding S_c and S_b constant and by varying channel width and depth it is possible to calculate values of M which will duplicate the regression line of figure 1. Melton states that calculated values of $M_{5,\,75}$ "... can be plotted on Schumm's graph and will be found to fall mostly within the range of scatter of his data points, although with a steeper mean slope". However, when additional values of $M_{5,\,75}$ are calculated beyond the limits presented by Melton on his table 1 but within the limits of width-depth ratio of figure 1 ($w/d = 2$ to 400), it becomes apparent that the width-depth ratio—$M_{5,\,75}$ regression line—bears no relation to the line $F = 255\ M^{-1.08}$. The $M_{5,\,75}$ curve becomes asymptotic to the $M = 5$ ordinate, and it intersects the $M = 100$ ordinate at a width-depth ratio of 0.4, i.e., a channel four times deeper than wide. Other curves have been plotted on figure 1 for values of $M_{0,\,50}$; $M_{1,\,50}$; $M_{10,\,100}$; and $M_{50,\,100}$. All curves except that for $M_{0,\,50}$ cross the regression line, but none approximate it in shape and only $M_{0,\,50}$ in slope. Following Melton's reasoning it is possible to calculate values for a family of curves none of which, however, have any relation to reality.

The range of width-depth ratios and the range of percent silt-clay in banks and channel floor is considerable at the river cross sections studied (Schumm, 1960b). Therefore, according to Melton's reasoning it is surprising that the correlation between width-depth ratio and M is significant, for with the possibilities of scatter as great as indicated by the curves plotted on figure 1, no correlation should exist unless there are limits to the extent of these imposed by alluvial characteristics. That is, the physical properties of the alluvium forming the perimeter of a channel prevent the development of stable channel shapes markedly different from that indicated by the width-depth ratio—M regression line.

Data from 69 stable cross sections were the basis of the disputed regression line (fig. 1); however, data are also available for 10 additional stations which were found to be unstable, i.e., actively aggrading or degrading. The channels found to be degrading plotted below the regression line, whereas those found to be aggrading plotted above the regression line (Schumm, 1960b). Thus, the position of the points which deviate markedly from the regression line can be explained by channel instability. Since unstable sections plot away from the line, it might be assumed that they would deviate from the line in a manner similar to that suggested by the curves of figure 1. However, studies of actively degrading and aggrading channels show that as the channels become unstable the sediment forming the perimeter of the channel also changes. The percentage of silt and clay in the streambed generally increases with aggradation and decreases with degradation (Schumm, in press).

In spite of the wide scatter of points that should be produced if the points fell along a family of curves (fig. 1), a significant correlation between width-depth and M exists. An explanation as suggested by Melton is that the sample is inadequate. Although the data were collected in only seven Western States, the channel sediment and hydrologic conditions vary as follows:

Silt-clay in bank ....0.5 percent to 97 percent
Silt-clay in channel ....0.5 percent to 89 percent

Channel width ....15 feet to 820 feet
Channel depth ....1.5 feet to 18 feet
Drainage area above section ....1.7 to 56,710 square miles
Mean annual flood ....$<$450 to 48,000 cfs
Mean discharge ....$<$30 to 5,155 cfs

Admittedly the writer has no information concerning streams with significantly greater amounts of silt-clay in the channel floor than in the banks, such as the hypothetical channel mentioned by Melton with no silt-clay in the banks and with 50 percent silt-clay in the channel. In fact, since it has been demonstrated by Hjulström (1935) that the size of sediment transported decreases inversely as the distance from the floor of the channel, it would not be expected that stable alluvial channels would contain larger sediment in the banks than in the bed or more silt-clay in the bed than in the banks.

It still remains to be demonstrated that equation 1 is valid. If equation 4 is substituted as an approximation for F into equation 3, the following is the result

$$F = k \left\{ \frac{246 \dfrac{S_c^{.66}}{S_b^{.50}} + 2\,S_b}{\dfrac{246}{S_b^{.50}\,S_c^{.34}} + 2} \right\}^{a} \qquad (5)$$

Substituting values of S_c and S_b into this equation results in an approximation of M determined, however, without the use of values for width and depth. When equation 5 is solved graphically for k and a the results are as follows:

$$k = 255$$
$$a = 1.1 \quad .$$

Thus the coefficient and exponent of the original equation $F = 255\ M^{-1.08}$ are substantially the same when the relation between width-depth ratio and the sediment forming the perimeter of a channel is determined either by using a weighting procedure involving channel width and depth or by using equation 5 above. It may be well to repeat here that M is a measure of the silt-clay exposed in the perimeter of a stream channel and that M could be obtained directly in the field by collecting a composite sediment sample along the perimeter of the channel.

Melton has also objected to the use of the silt-clay content of the alluvium rather than some measure of grain size in this paper. An analysis of variance indicates that no correlation exists between median grain size and width-depth ratio. This is not surprising considering that grain size alone is not the most important factor determining the physical properties of sediments. One need only refer to papers by Bouyoucos (1935), Trask (1959) and Dunn (1960) to be convinced of this.

Unquestionably much remains to be done before a full understanding of the effects of sediment on stream character can be obtained, but there is no question that an exchange such as this is helpful in stimulating ideas and doubts about field techniques and the problem in general.

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