DANIEL F. MERRIAM, Editor

MATHEMATICAL MODEL AND FORTRAN IV PROGRAM FOR COMPUTER SIMULATION OF DELTAIC SEDIMENTATION

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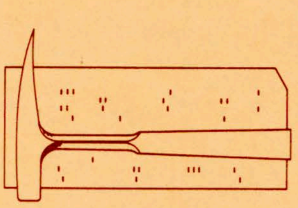

COMPUTER CONTRIBUTION 24
State Geological Survey
The University of Kansas, Lawrence
1968

Editor's Remarks

This publication, COMPUTER CONTRIBUTION 24, is concerned with a "Mathematical model and FORTRAN IV program for computer simulation of deltaic sedimentation". As stated by the authors, G.F. Bonham-Carter and A.J. Sutherland, the purpose of the paper is to "...describe a mathematical model of a simple fluvio-marine delta,...discuss a FORTRAN IV program..., and to illustrate the use of the program."

Although the delta model may seem complicated, it is relatively simple and represents conditions at only a single river mouth. Obviously, all the complexities of delta construction and destruction have not been considered. The program, however, is an excellent example of examining a geological process in depth, simulating its action, and experimenting with it to learn of its different ramifications.

This publication is an important step in geology, because we have not been overly concerned with simulation up to now. Other disciplines have been concerned, however, and simulation has reached an advanced state in business, physiology, medicine, social sciences, hydraulics, city planning, and military science. According to J.W. Harbaugh and D.F. Merriam (Computer applications in stratigraphic analysis, John Wiley & Sons, 1968, p. 212)

> In geological simulation the general approach is to imitate major geologic processes and to cause these processes to interact with each other through time, producing symbolic geologic "products". The objective is to create a mathematical or symbolic model that behaves realistically. We may regard such a model as an experimental tool because we can change the conditions under which it operates and observe its response.

As in many other applications of the computer to geologic problem solving, we can only guess the potential this approach offers. Undoubtedly the possibilities are many. Time may show that this approach is "the" one and that important problems which have faced geologists for many years are solvable after all. It is hoped that the Bonham-Carter--Sutherland paper presented here will stimulate interest and in some small way indicate to others the tremendous possibilities of the simulation approach.

For a limited time the Geological Survey will make the program available to those who would like to experiment. Charge for the program deck is $15.00; if a punched-card deck is required an extra charge of $10.00 is made to cover handling costs. A list of other programs and data decks available through the Geological Survey is available by writing the Editor, COMPUTER CONTRIBUTIONS, Kansas Geological Survey, The University of Kansas, Lawrence, Kansas 66044.

MATHEMATICAL MODEL AND FORTRAN IV PROGRAM FOR COMPUTER SIMULATION OF DELTAIC SEDIMENTATION

By

G. F. BONHAM-CARTER and **ALEX J. SUTHERLAND**

ABSTRACT

DELTASIM is a FORTRAN IV program for simulating deltaic sedimentation at a single river-channel mouth. A sediment-laden river flowing into a tideless, currentless marine basin is modeled as a plane jet discharging horizontally at the ocean surface. A velocity field is calculated using equations for open-channel and plane-jet flow. Sediment behavior is treated statistically; nominal sediment particles are traced along trajectories from the mouth as they spread laterally and settle vertically. The rate of sediment accumulation is calculated for each cell of a horizontal accounting grid. Input parameters include channel dimensions, water and sediment discharge, grain-size distribution and bottom topography. Experiments with a static simulation model illustrate the depositional variation produced by changes in grain size, river depth, and slope. The depositional area is narrow in plan view; in elevation, foreset slopes are a function of grain-size and hydraulic parameters, and are normally less than 1°. A dynamic model permits a delta platform to build forward during several time increments, nominal particle trajectories adjusting automatically to the position of the delta lip. Experiments illustrate the formation of bars building transversely across the river mouth and the development of submerged levees close to the mouth at the margins of the main flow.

The computer program runs on an IBM System/360 model 67. Graphic displays in the form of CALCOMP plots form an important part of the program output.

INTRODUCTION

The purpose of this paper is to describe a mathematical model of a simple fluvio-marine delta, to list and discuss a FORTRAN IV program that embodies the mathematical model in a computer simulation framework, and to illustrate the use of the program with sample computer runs.

Computer simulation only recently has been applied by geologists to sedimentation problems. Harbaugh (1966; Harbaugh and Wahlstedt, 1967) developed a generalized marine sedimentation model oriented toward the biological factors in sedimentation. Harbaugh's model is probabilistic in structure and makes extensive use of Markov processes. Briggs and Pollack (1966) simulated the circulation of water and deposition of evaporites in a restricted basin. Their approach was a deterministic one, with basic physical principles being used to determine a velocity field and to calculate brine concentration and thickness of salt deposits. The present delta model also is deterministic in structure. Transport and deposition of suspended sediment at river mouths is modeled by determining a velocity field and allowing sediment issuing from a river mouth to be sorted according to hydraulic principles. Bonham-Carter and Sutherland (1967) gave a preliminary account of the model.

As with the Harbaugh and Briggs-Pollack models, a grid mesh is used to subdivide the area into a number of discrete cells. Each cell is treated as a separate unit and contains values of attributes such as water depth and sediment thickness. The grid technique is useful for allowing complex surfaces to be described closely by an array of numbers stored in the computer. Most analytical mathematical models are unable to represent complex surfaces, and are restricted to those surfaces that may be described by polynomial or trigonometric functions. Furthermore, a cellular gridwork, coupled with the necessary programming steps, may be used as a massive bookkeeping device. Each cell has inputs and outputs for the materials in the system and all transactions must be recorded. Finally, the gridded nature of the stored information is in an ideal form for graphic display of maps and cross sections, using either the line printer or digital plotting devices. Graphic display is important for displaying geometric relationships that are difficult to describe mathematically, and for bringing the model to 'life' by illustrating it in an easily interpreted form. A map conveys information much more effectively than a table.

This model considers the hydraulic aspects of sediment deposition at river mouths, and thus is approaching the delta problem from the process point of view. Rather than starting with field data regarding the form and composition of a delta, from which statistical interrelationships are derived and inferences drawn regarding the processes, the processes themselves are used as the starting point. By formulating a model about the processes, simulation experiments are used to determine the composition and form of a 'delta' with different initial assumptions. This approach thus focuses strongly on the processes themselves.

Although the model does not have an immediate application to most real deltas, because few if any deltas are formed without modification by offshore energy factors, it does afford the geologist a technique to explore the interrelationships between the variables important in the constructive phase of delta building. This is an essential step in the development of more sophisticated and complex models. Sediments deposited in deltas comprise an important part of the sedimentary rock record, both quantitatively and economically, and may form stratigraphic traps for oil. Further insight into the formation of deltas is important to geology, and computer simulation is a technique that should be fruitful, particularly when executed in combination with field observations and flume experiments.

Acknowledgments.-We thank J.W. Harbaugh, R.L. Street, and C. Sonu for critically reading an early version of this manuscript. The work was supported by the Office of Naval Research under contract number N00014-67-A-0112-004 Task number NR 388-081. Reproduction is permitted for any purposes of the United States Government.

THE DELTA MODEL

Background Discussion

When a stream enters a large permanent body of water, its velocity is gradually reduced to zero. As a result, the sediment carried by the stream, either as bed load or as suspended load, is deposited largely near the channel mouth. These deposits accumulate to form deltas. To simulate deposition in this environment deterministically, it is necessary to develop a mathematical model for both the velocity field and sediment diffusion.

Existing knowledge of coastline hydrodynamics is confined essentially to conditions in estuaries (e.g., Ippen, 1966; Bowden, 1967), and to processes related to waves and wave-generated currents (Ippen, 1966). Although estuaries may be filled with deltaic sediments, tidal flushing action characteristic of estuaries is not ideal for studying delta formation. Furthermore, many major deltas in the world form coastline bulges, as opposed to coastline indentations typical of estuaries.

Diffusion of sediment from a river mouth is similar in some respects to the diffusion of sewage from an ocean outfall. The mixing phenomenon occurring at the point of sewage discharge occurs by the diffusing and mixing processes associated with a turbulent jet (Wiegel, 1964). Equations for velocities in a submerged turbulent jet discharging into a fluid of the same density are given by Albertson and others (1950). Both sewage outfall and river discharge, however, present special cases. In the former, the sewage ports are situated some distance beneath the water surface, and a turbulent plume rises toward the surface as a result of density difference. In the latter, river water, also of lower density than sea water, discharges horizontally into the ocean at the surface. Experiments by Horikawa (1958), reported by Wiegel (1964), show that velocity profiles for a submerged jet are almost the same as the lateral velocity distribution resulting from a jet discharging horizontally at the free surface.

Bates (1953) was the first to discuss the possible significance of jet mixing for delta formation. He pointed out that a river discharging into water of equal density, such as a lake, would mix both vertically and horizontally; this would be similar to an axial jet. River water entering the sea, however, would be buoyed up due to the density difference between fresh and saline water, vertical mixing between fresh and salt layers would be inhibited, and the system would be similar to a horizontal plane jet. Further, Bates (1953) suggested that the position of submerged levees and distributary mouth bars are governed by the structure of the jet velocity field. In the present model, Bates' plane jet hypothesis is modified to include the velocity variation with depth in an open channel; it is extended also by considering the diffusion of sediment in this velocity field.

Mathematical Model

A river of fresh water with depth D and width B discharges into a body of saline water as shown in Figure 1. The velocity profile in the river V(Z), river geometry and bottom topography of the salt water basin are assumed known. For a given mean velocity $\bar{V}$ in the river and a specified sediment discharge Q_s the depositional pattern in the basin is computed.

Although waves are an important factor in controlling delta formation (sufficient wave energy will completely inhibit delta building) the possibility of wave action in the basin is not considered. It is important to understand the constructive factors in delta building before including the destructive ones. The effect of longshore currents together with the influence of tidal and seasonal variations in river and sediment flow also are neglected. The latter effects could be added to the basic model as refinements.

The river, as it enters the basin, is compared to a jet discharging from a slot of width B. It is assumed to be composed of a series of plane jets (parallel to the XY-plane), placed one on top of another in the Z-direction with the initial velocity in each equal to that in the river at the same elevation. Thus the distribution of the X-component of velocity in the jet, U(X,Y,Z), at X = 0 is independent of Y and equal to V(Z).

In the river the shear velocity and the characteristics of turbulent mixing process combine to determine the velocity profile. In the basin, as the jet expands, both the shear velocity and turbulent mixing characteristics change. They do so in such a manner as to steepen the velocity profile and reduce the flow velocities near the interface, [Z=0, X>0]. However, it is assumed that the shear velocity and turbulent mixing characteristics are constant in the jet and equal to those in the river. This assumption is good for rivers where deposition occurs close to the mouth and is exact for the zone of no diffusion. It is less satisfactory for fast-flowing rivers containing fine-grained sediment that is carried far from the mouth before settling. With the above assumption, the velocity profiles U(X,Y,Z) in the Z-direction for each X and Y must be given by V(Z) multiplied by a function of X and Y only. This function depends on the jet spreading and is computed using the results of Albertson and others (1950) on the diffusion of submerged plane jets.

Another important assumption, necessary as a result of the plane jet assumption invoked above, is that mixing between the two fluids at the interface may be neglected. Two factors combine to insure that interfacial mixing is indeed minimal. As a result of the velocity profile in the river, velocities in the jet near the interface are small. In addition, the density difference at the interface tends to inhibit vertical mixing in this region. The model is not, therefore, realistic for rivers discharging into bodies of fresh water. Mixing occurring on the edges of the jet is not affected by the density difference because mixing takes place mainly in a horizontal plane.

Any sediment particle that reaches the interface is assumed to settle vertically to the bottom of the basin where it remains. Particles tend to settle vertically because their horizontal velocity, which is small at the interface, is rapidly reduced to zero by the viscous drag in the lower fluid. Thus no sediment entrainment can occur once the river enters the basin, and the sediment load in the jet must be continuously reduced. This assumption also places a restriction on the bottom topography of the basin; it cannot be so steep that the sediment will tend to slide and form a turbidity current.

The model will be formulated in terms of dimensionless variables using the slot width and the mean velocity in the river as reference quantities. Thus, let $x = X/B$, $y = Y/B$, $z = Z/B$, $d = D/B$, $u_* = U_*/\bar{V}$, and $u = U/\bar{V}$ where U_* is the shear velocity in the river.

Velocity Fields

In the river, the velocity profile is assumed to be that of flow in a two-dimensional channel

$$V(Z) = \bar{V} + U_*/k \ (1 + \ln Z/D),$$

where k is the von Karman constant and ln denotes logarithm to base e. Velocities near the river banks are thus overestimated. A value of 0.4 is used for k although some evidence for smaller values of k in sediment-laden streams has been presented (Vanoni, 1946). In dimensionless variables the profile is

$$V(Z)/\bar{V} = f_1(z) \equiv 1 + u_*/k \ (1 + \ln z/d). \tag{1}$$

In the basin the streamwise velocity can be predicted from the results of Albertson and others (1950) on plane jets. They distinguish three zones in the jet as shown in Figure 2. In the zone of no diffusion we have

$$u(x,y,z) = f_1(z).$$

In the region denoted by 2 in Figure 2, we have, for a constant value of z,

$$\begin{aligned} u(x,y,z) &= f_1(z) \exp\left\{-42.3[0.096 + (y-0.5)/x]^2\right\} \\ &\equiv f_1(z)\, f_2(x,y). \end{aligned} \tag{2}$$

In the zone of established flow Albertson and others (1950) show that for a fixed value of z,

$$\begin{aligned} u(x,y,z) &= f_1(z)\, x^{-1/2} \exp\left\{0.828 - 42.3\, y^2/x^2\right\} \\ &\equiv f_1(z)\, f_3(x,y) \end{aligned} \tag{3}$$

Sediment Discharge

For sediment used in experiments illustrated here, it is assumed that the grains are quartz with specific gravity 2.65. Nonuniform grain-size distributions can be treated by considering the different size fractions separately and superimposing the results. The program is designed to handle four size fractions simultaneously, but could be modified to handle more. The sediment normally is characterized by its settling velocity in still water, in which case neither the particle size nor its shape need be known. To use the model for a sediment of given size and shape, the settling velocity must be found by, for example, reference to charts published by the Task Committee (1962). If desired, a program option allows sediment to be characterized by its diameter and specific gravity, the settling velocity being automatically calculated by Rubey's formula (1933), which gives only approximate results and assumes that the grains are poorly rounded. For river-borne sediment, however, the settling velocity calculated by this method may be more representative than that obtained from tables which assume perfectly spherical grains. The most satisfactory course is to measure the settling velocity for each size fraction and thereby remove any uncertainty.

In the river the concentration c, of sediment

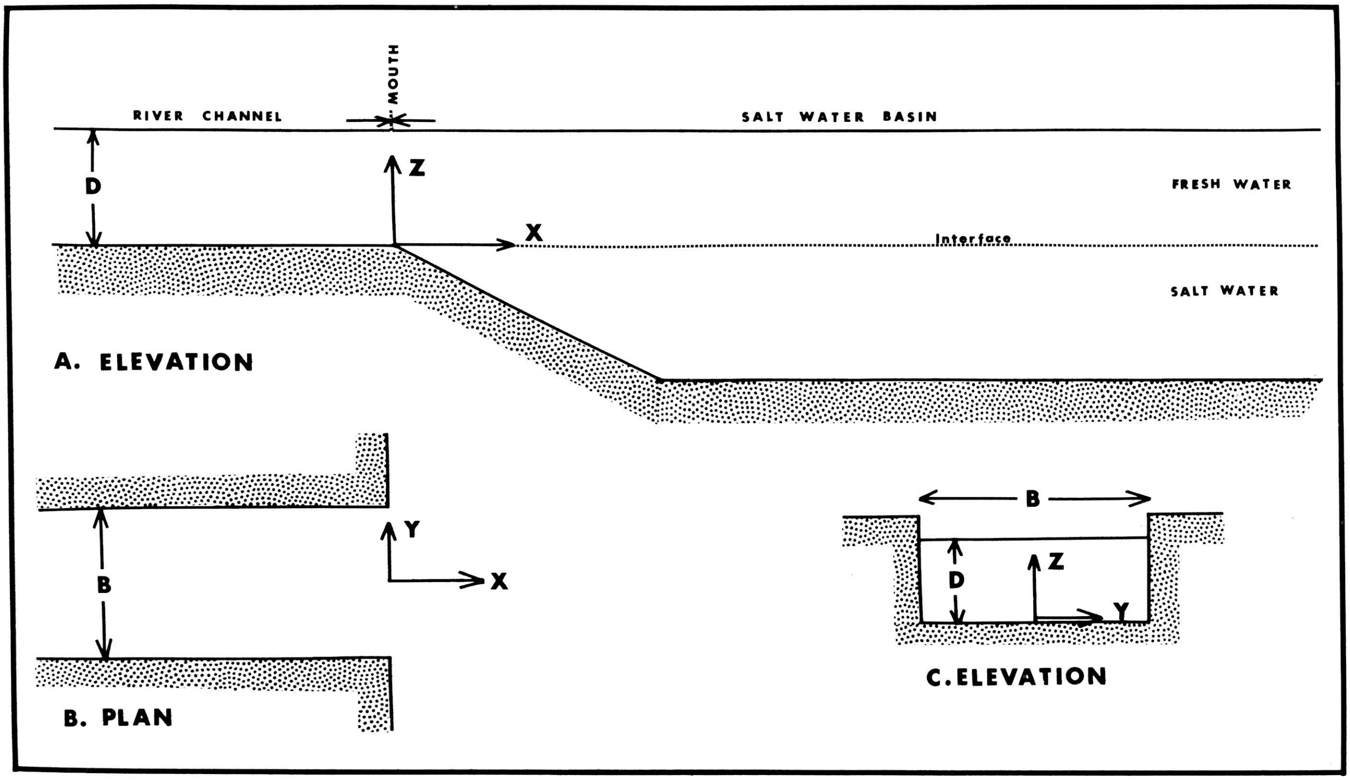

Figure 1.- Definition sketch.

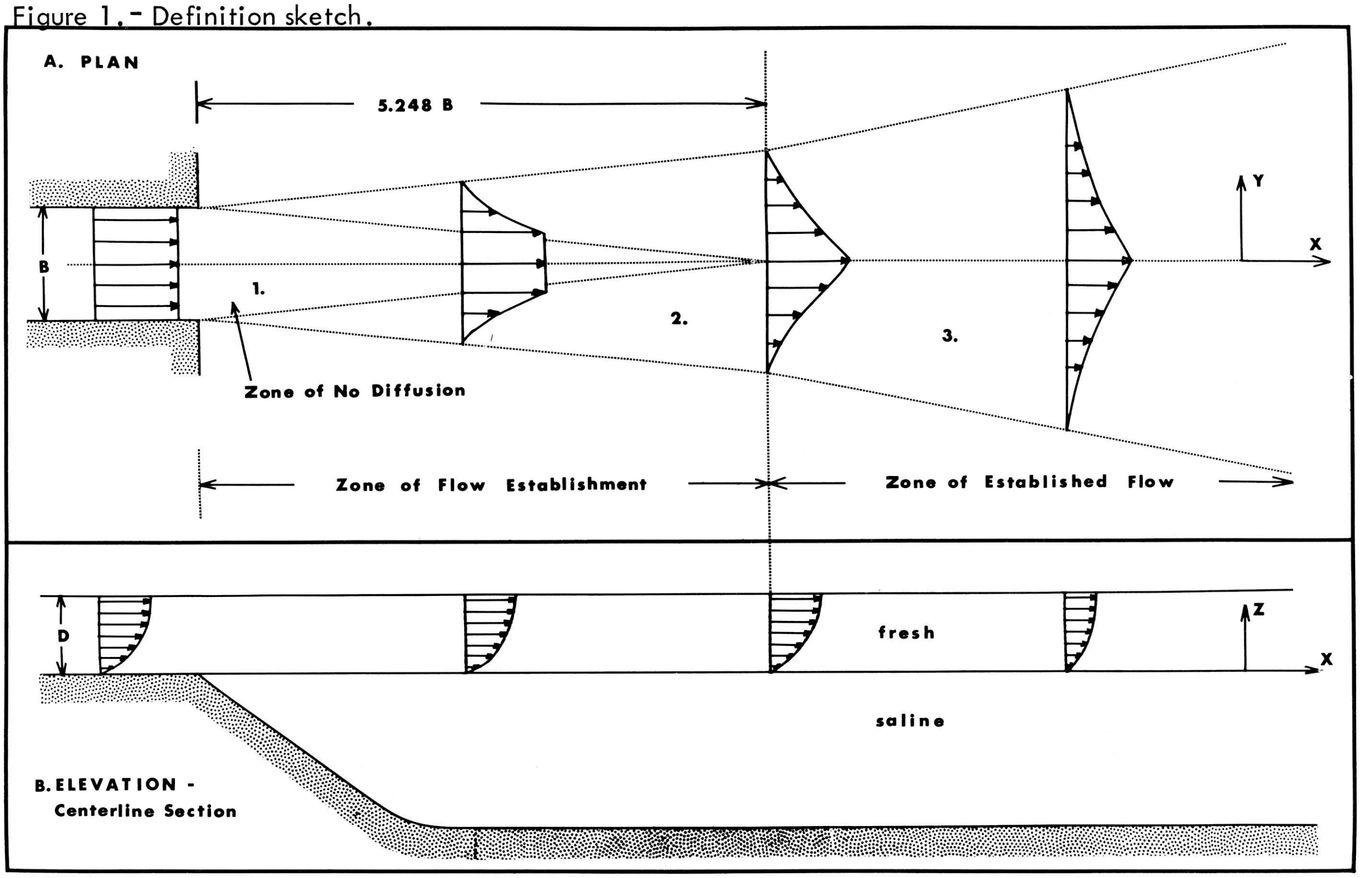

Figure 2.- Structure of velocity field. Plane-jet velocity field is based on results of, and uses the terminology from, Albertson and others (1950).

with settling velocity w_s, at any elevation z from the river bed in terms of the concentration c_a at elevation a is given by

$$\frac{c}{c_a} = \left[\frac{d-z}{z} \, \frac{a}{d-a} \right]^p , \qquad (4)$$

where $p = w_s/\beta k u_*$ (Vanoni, Brooks, and Kennedy, 1961). The quantity β is a numerical factor defined as the ratio between the diffusion coefficients of sediment and momentum, respectively. Its value has been determined by experiments in open channels by Vanoni (1946) and in a submerged jet by Singamsetti (1966). There is no firm agreement as to the value of β and indeed one would expect it to differ with the type of turbulence present in the particular situation. Studies have shown that β is close to 1.0 and has some dependence on grain size. Singamsetti (1966) reported values up to 1.4 for coarser sediments.

The suspended-sediment discharge/unit width in the river between elevations z_i and z_j is given by

$$s(z_i, z_j) = \int_{z_i}^{z_j} f_1(z) \, c_a \left[\frac{d-z}{z} \, \frac{a}{d-a} \right]^p dz .$$

Defining $F(z_i , z_j)$ as the fraction of the total sediment discharge passing between elevations z_i and z_j we have

$$F(z_i , z_j) = \frac{s(z_i, z_j)}{s(\epsilon, d)}$$

$$= \frac{\int_{z_i}^{z_j} f_1 (z) \left[(d-z)/z \right]^p \, dz}{\int_{\epsilon}^{d} f_1 (z) \left[(d-z)/z \right]^p \, dz} . \qquad (5)$$

The elevation $z = \epsilon$ is introduced because the velocity profile $f_1(z)$ is not valid to the boundary. The parameter ε then must be of the order of the sublayer thickness in the river and has been taken arbitrarily as four times the particle size. It is assumed that any sediment load below $z = \epsilon$ does not contribute significantly to the formation of the delta.

Computation of Particle Trajectories

For computational purposes, the transverse section of the river mouth is divided into a number of cells by means of a vertical grid (Fig. 3). All sediment which passes through a given river-mouth cell is assumed to follow the same path as would a nominal particle that had the coordinates of the cell center at x = 0. Hence, each cell is assumed to be the end of a streamtube, the axis of which is defined by motion of the nominal particle, and along which all sediment passing through the particular cell will travel. The tube for a cell with center coordinates $(x,y,z) = (0, y_0, z_0)$ is shown in Figure 4. Certainly turbulence in the jet will result in interchange of sediment from one tube to the next; thus the actual sediment grains that enter a particular tube may be replaced by other grains from adjacent tubes. In a statistical sense, however, one may consider that the net number of grains passing through a unit length of tube during a unit of time remains constant. The same assumption is made when computing sediment discharge in natural rivers; in this case the sediment discharge is constant along a reach although there is a continual interchange of particles between the flow and the bed. The trajectory of the nominal particle thus will be used to represent the average trajectory of all particles passing through the cell.

The y-coordinate of the particle trajectory is computed from the plan view. In the zone of no diffusion (zone 1), the nominal particle follows a straight path parallel to the jet centerline until it meets the boundary between zones 1 and 2 at point (x_d, y_0). From similar triangles (see. Fig. 4),

$$x_d = 5.248 \, (1 - 2y_0). \qquad (6)$$

Next, y_1 is computed in terms of y_0 by using an argument based on conservation considerations. At x = 0 the sediment discharge through a rectangular element, A, of thickness t_0, unit width and elevation z_0 is $q_{s_0} = f_1(z_0) \, c(z_0) \, t_0$ and the fraction η_0 of this total which passes between the planes $y = 0$ and $y = y_0$ is $\eta_0 = y_0$ (Fig. 5).

The velocity profile at x = 5.248 can be written in Gaussian form with standard deviation σ_m (Albertson and others, 1950). The sediment concentration is assumed to be Gaussian also, but with a standard deviation σ_s. This has been confirmed for an axisymmetric jet by Brush (1962) and Singamsetti (1966). At x = 5.248 the sediment concentration profile is assumed to be

$$c = c_{max} \exp \left\{ - y^2/2\sigma_s^{\,2} \right\},$$

where c_{max} is the sediment concentration on the jet centerline. Let t_1 and z_1 be the thickness and the centerline elevation at $x = 5.248 = x_1$ of the element formed by all streamtubes which started at x = 0 within element A. Total sediment discharge through these tubes at $x = x_1$ is thus

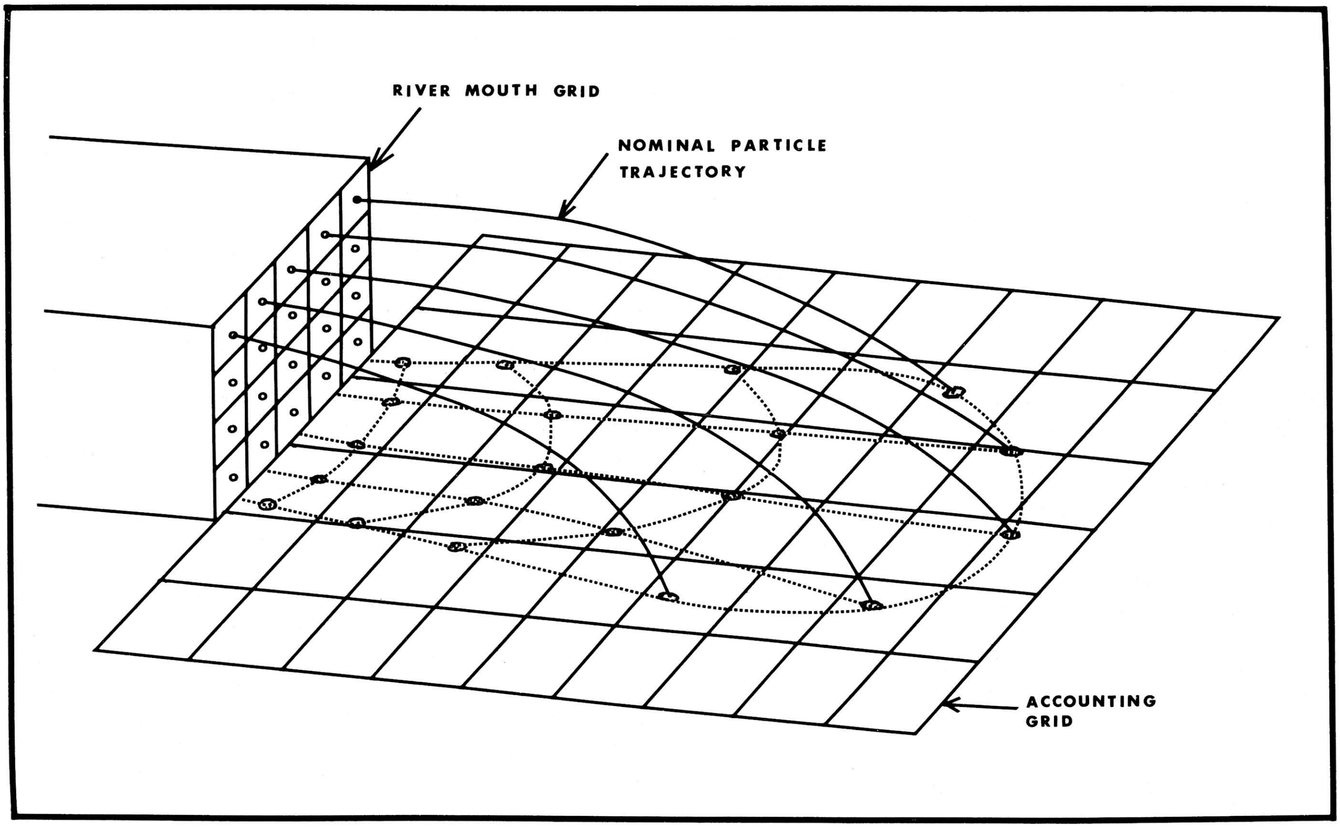

Figure 3.- Orientation of computational grids at river mouth. Nominal particle trajectories are shown for uppermost row of cells in river-mouth grid.

$$q_{s_1} = \int_{-\infty}^{+\infty} u(x_1, y, z_1)\, c_{max} \exp\left\{-y^2/2\sigma_s^2\right\} t_1 d_y .$$

The fraction of this total passing between $y = 0$ and $y = y_1$ therefore is

$$\eta_1 = \frac{\int_0^{y_1} u(x_1, y, z_1)\, c_{max} \exp\left\{-y^2/2\sigma_s^2\right\} t_1 d_y}{\int_{-\infty}^{+\infty} u(x_1, y, z_1)\, c_{max} \exp\left\{-y^2/2\sigma_s^2\right\} t_1 d_y} .$$

This can be simplified by using equation (3) and the Gaussian form of the velocity profile,

$$f_3(x_1, y) = f_3(x_1, 0) \exp\left\{-y^2/2\sigma_m^2\right\}.$$

The result is

$$\eta_1 = \frac{\int_0^{y_1} \exp\left\{-y^2/2\,(1/\sigma_m^2 + 1/\sigma_s^2)\right\} dy}{2\int_0^{+\infty} \exp\left\{-y^2/2\,(1/\sigma_m^2 + 1/\sigma_s^2)\right\} dy} .$$

Defining $r^2 = 1/2\,(1/\sigma_m^2 + 1/\sigma_s^2)$, we find that $\eta_1 = 1/2\,\mathrm{erf}(ry_1)$ where erf denotes the error function. Statistically, if $x_t > 5.248$, no sediment has been lost from the tube defined at $x = 0$ by the planes $y = 0$ and $y = y_0$ and at $x = 5.248$ by the planes $y = 0$ and $y = y_1$. If $x_d < x_t < 5.248$, it is assumed that spreading in zone 2 will occur at the same rate as the case where $x_t > 5.248$ (see Fig. 4). If $x_t < x_d$, it is not necessary to calculate y_1. Thus, for all $x_t > x_d$ the two fractions computed above, η_0 and η_1, must be equal. Therefore,

$$y_0 = 1/2\,\mathrm{erf}(ry_1), \qquad (7)$$

from which y_1 can be found if σ_m and σ_s are known. Albertson and others (1950) show that σ_m for $x = 5.248$ is equal to 0.572. Singamsetti's (1966) results show that $\sigma_s = \sqrt{\beta}\,\sigma_m$ in a submerged round jet. For the plane jet the authors assume $\sigma_s = \beta\,\sigma_m$. If $\beta = 1$, as for all experiments described herein, $\sigma_s = \sigma_m$ and the assumed relation is correct.

The y-coordinate for any value of x on the trajectory can now be written as (see Fig. 2),

in zone 1: $y = y_0$ where $x < x_d$, (8)

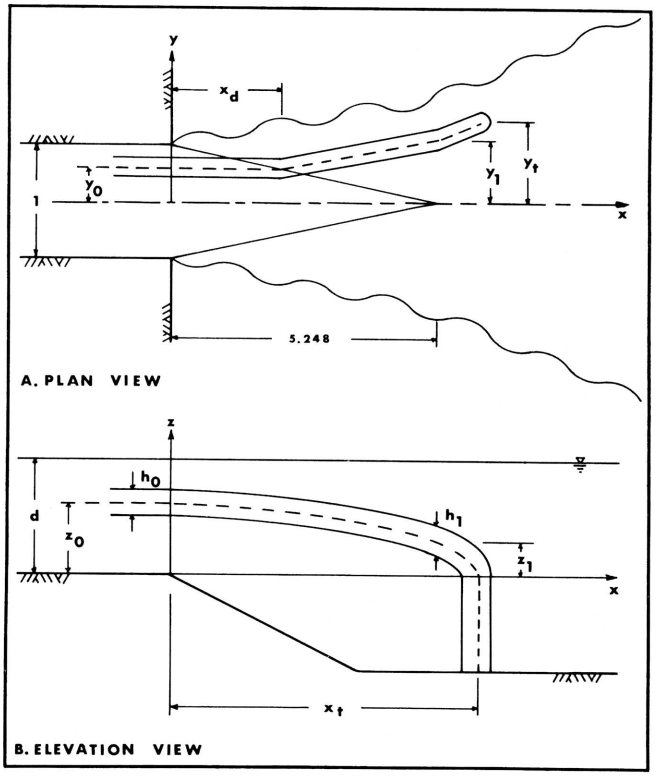

Figure 4.- Particle trajectory and streamtube geometry. Plan and elevation views show nominal particle trajectory (dashed line) at center of its streamtube.

in zone 2:

$$y = \frac{(y_1 - y_0)(x - x_d)}{5.248 - x_d} + y_0, \qquad (9)$$

where $x_d < x < 5.248$, and

in zone 3:

$$y = \frac{xy_1}{5.248}, \text{ where } x > 5.248. \qquad (10)$$

In deriving equation (9) it is assumed that the trajectory, in plan view, is straight throughout zone 2.

It remains to determine x_t, coordinate of the terminal point in the trajectory. Referring to the elevation view in Figure 4 the slope of the trajectory dz/dx is given by w/u where w is the instantaneous velocity component of the particle in the z-direction, and

$$u = f_1(z)\ [1, f_2(x,y), f_3(x,y)],$$

where the terms in the square brackets apply in zones 1, 2, and 3, respectively. Integrating along the trajectory, we obtain

$$\int_{z_0}^{\epsilon} f_1(z)\, dz = [\int_0^{x_d} w dx + \int_{x_d}^{5.248} wdx/f_2(x,y)$$

$$+ \int_{5.248}^{x_t} wdx/f_3(x,y)] ,$$

where ϵ is the small parameter introduced previously. Equations (9) and (10) are used to eliminate y from the integrands in the second and third integrals on the right.

The velocity w is composed of two portions, a mean value equal to the settling velocity and a fluctuating component caused by the action of turbulence. At each point on the trajectory, the probability that the particle will receive an upward impulse from the turbulence is equal to the probability that it will receive a downward impulse. Hence, if one averages over all particles passing through a particular point, the mean vertical velocity component will be equal to minus the settling velocity. This also must be the velocity of the nominal particle which defines the trajectory. Jopling (1964) presents some experimental evidence that justifies the use of the settling velocity as the mean vertical velocity of the nominal particle. Thus, x_t is given by the equation

$$\int_{\epsilon}^{z_0} f_1(z)\, dz = \int_0^{x_d} w_s dx + \int_{x_d}^{5.248} w_s dx/f_2(x,y)$$

$$+ \int_{5.248}^{x_t} w_s dx/ f_3(x,y) . \qquad (11)$$

Given the coordinates (y_0, z_0) of the starting point of the trajectory, equation (11) can be solved for x_t (see Appendix B). From x_t, y_t can be computed using equation (8), (9), or (10).

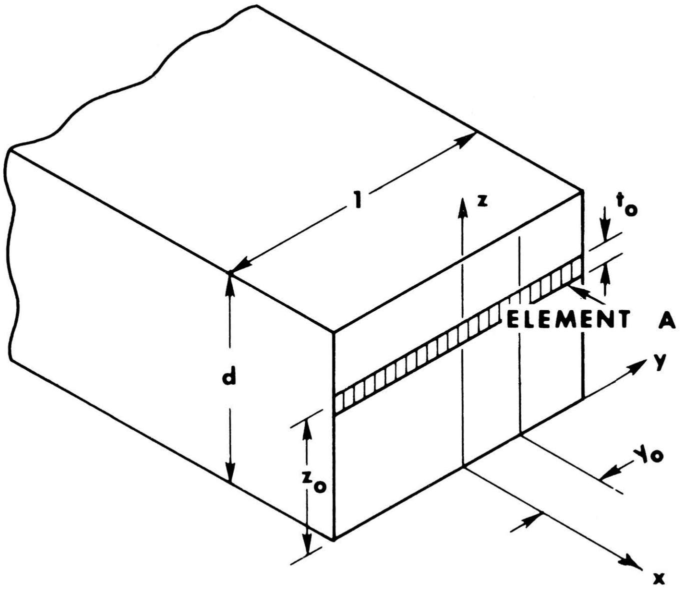

Figure 5.- Sketch to illustrate rectangular element, A, in vertical section at river mouth.

THE STATIC MODEL

Background Discussion

The simulation model can be described in two parts, static and dynamic. At a certain moment in time, all variables in the model have fixed states; under these conditions the model is static. If, however, more than one moment in time is considered, several model states are linked successively so that some of the output variables from one state become input variables to the next state and in this way the model becomes dynamic.

In the computer program described here, the static and dynamic components are inextricably interwoven. For illustrative purposes, however, it is useful to consider the two separately.

Basic to the structure of both static and dynamic components is the accounting system. All sediment entering the model travels through the cells of the vertical (y,z) river grid, is traced along settling trajectories using jet coordinates (x,y,z), and settles into the square cells of the horizontal (x,y) accounting grid, whose cells are labeled I for row number, J for column number. The relationships between these coordinate systems are illustrated in Figure 3.

It may be argued that many of the calculations performed in the model may be worked with a desk calculator, the few numerical integrations approximated by making some assumptions no less gross than those made for the model itself. Although this is true, and several such calculations have been made to check the program, the power of the computer is such that these calculations can be performed many times in a few seconds. By manipulating the input parameters, the configuration and composition of the resulting delta deposits can be calculated and repeated many times. Thus, the simulator can obtain an experimental 'feel' of this complex system in a manner that would be impossible even with a detailed knowledge of the governing equations.

Almost infinite numbers of simulation experiments are possible using this model, considering the large number of possible combinations of input parameters. The following experiments illustrate some aspects of the static model.

Experiments and Results

Three series of experiments, each consisting of three runs, are illustrated in Figures 6, 7 and 8, and Table 1. In each series a single variable has been altered. The first run in each series is identical to facilitate comparison. For every run, a map drawn on the CALCOMP plotter shows the positions of the terminal coordinates of the nominal particles.

The effect of changing grain size with the hydraulic parameters held constant is investigated in Series I (Fig. 6). Effect of higher stream velocities is shown by the results from Series II and III. The stream velocity is increased in Series II (Fig. 7) by increasing the river slope and in Series III (Fig. 8) by increasing the depth. In both cases, a grain diameter of 0.3 mm has been used. Although an increase in depth does not produce such high velocities as does an increase in slope, the depositional area is extended farther in the former instance because particles have to settle through a greater depth of water.

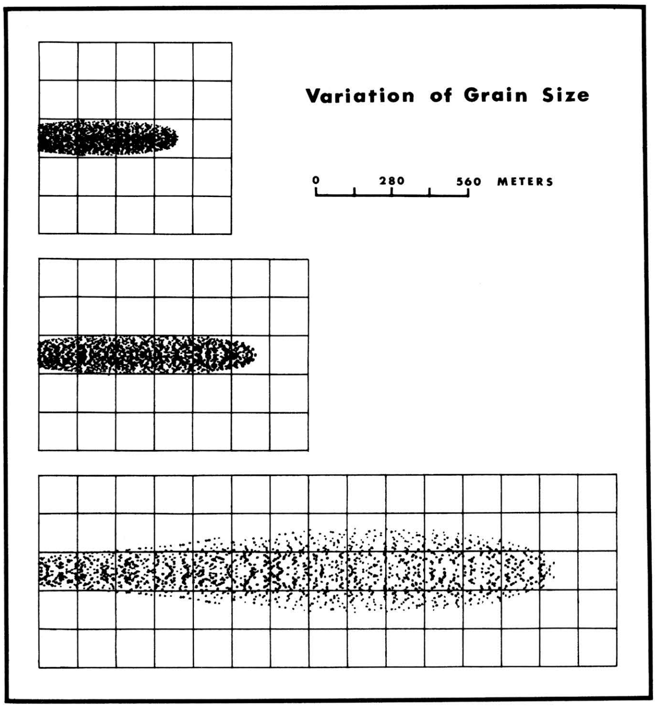

Figure 6.- Static model Series I, Run A (top), Run B (center), Run C (bottom), showing variation due to grain size; see Table 1 for details of parameter values. These maps, and similar ones that follow, show dots plotted at terminal coordinates of nominal particle trajectories. Maps are plotted automatically by a CALCOMP digital plotter.

Figure 6 illustrates the ability of the model to sort sediments according to size. Near the mouth, where both coarse and fine grains are deposited, the sorting is poor. Thickness of the resultant deposits indicates that in this region the coarse fraction is dominant. As distance from the mouth increases, the average grain size in the deposit is reduced and the sorting is improved. Far from the mouth only fine-grained sediments are found.

In elevation, not illustrated graphically, the sediment surface is essentially horizontal. If the original bottom slope of the depositional basin is discounted, the angle of the 'foreset' slope is about 1/2°. This slope steepens slightly with an increase in grain size or decrease in stream velocity,

Table 1.- Values of parameters for static model experiments.

Series	Run	Depth, D (meters)	Width, B (meters)	Slope	Average channel velocity, $\overline{V}$ (meters/sec)	Water discharge, Q (meters^3/sec)	Shear velocity, U_* (meters/sec)	von Karman constant, k	Darcy Weisbach friction factor	β	Length of cell side (meters)	Grain diameter (mm)	Fall velocity, W_s (mm/sec)	Sediment discharge, Q_s (tons x 10^6/year)	X_t max. (meters)	Y_t max (meters)
I	A	10.0	100.0	0.00010	2.00	2000.0	0.10	0.4	0.02	1.0	140.0	0.3	3.90	0.230	508.0	130
	B	10.0	100.0	0.00010	2.00	2000.0	0.10	0.4	0.02	1.0	140.0	0.2	2.40	0.239	794.2	140
	C	10.0	100.0	0.00010	2.00	2000.0	0.10	0.4	0.02	1.0	140.0	0.1	0.78	0.247	1890.0	300
II	A	10.0	100.0	0.00010	2.00	2000.0	0.10	0.4	0.02	1.0	140.0	0.3	3.90	0.230	508.0	130
	B	10.0	100.0	0.00023	3.00	3000.0	0.15	0.4	0.02	1.0	140.0	0.3	3.90	1.250	741.1	140
	C	10.0	100.0	0.00041	4.00	4000.0	0.20	0.4	0.02	1.0	140.0	0.3	3.90	4.030	941.8	150
III	A	10.0	100.0	0.00010	2.00	2000.0	0.10	0.4	0.02	1.0	140.0	0.3	3.90	0.230	508.0	130
	B	15.0	100.0	0.00010	2.43	3639.2	0.12	0.4	0.02	1.0	140.0	0.3	3.90	0.421	872.1	140
	C	20.0	100.0	0.00010	2.80	5602.9	0.14	0.4	0.02	1.0	140.0	0.3	3.90	0.660	1225.3	180

but is always less than 1° in these experiments. The original bottom slope is additive to this depositional slope, so foresets may be more steeply inclined, depending on the original basin geometry. Experimental values compare reasonably well with foreset slopes from the Grand Rhone distributary (2°), off the main passes of the Mississippi (about 1°), and off the Orinoco (1/4°), cited as typical of the range of foreset slopes of major deltas by van Straaten (1961). Along the jet centerline, thickness decreases evenly, without any tendency for a transverse mouth bar to form. Normal to the jet centerline, deposits are nearly flat-lying, except at the edges where thickness decreases rapidly. Near the mouth, these marginal slopes are much deeper than the angle of repose; sliding and slumping probably would occur in nature, but such processes have not been represented in the model. Using the static model, there is no tendency for marginal banks or levees to form.

In these experiments, the plan view of the depositional area is very narrow. This is a direct result of the slow rate of lateral spreading in a jet. The depositional area of most deltas is generally thought to expand more rapidly at the river mouth than does that of the model. At least two additional factors may be responsible for this difference: (1) In nature, a transverse bar forms across the mouth obstructing the main flow, thereby causing some of the current to diverge laterally, as discussed in the section below on the dynamic model; and (2) the main flow of real rivers probably oscillates from side to side due to minor shifts in the channel. To simulate such oscillation, a program option allows the jet to be rotated about the coordinate origin through a number of 'fan' positions on either side of the main channel axis. The angle of each fan position is determined by using a normally distributed random number, with zero mean and specified standard deviation.

Figure 9 illustrates a run in which the hydraulics and grain-size parameters are identical to those in Series III, Run C. In addition, the jet has been rotated through ten random positions which has produced a fan-shaped deposit. The uneven distribution of points could be overcome by increasing the number of random rotation positions.

THE DYNAMIC MODEL

Background Discussion

It is characteristic for delta-building rivers to bifurcate repeatedly in the downflow direction to form an anastomosing pattern of distributary channels. However, this delta model is restricted and considers depositional conditions at only a single channel mouth. Channel splitting sometimes is related to bank break-through (van Straaten, 1961) forming a crevasse in the natural levee. However, bifurcation is associated more commonly with the formation of a transverse bar across the channel mouth as described by Welder (1959) for the Cubits Gap crevasse on the Mississippi delta, by Axelsson (1967) for the Laitaure delta in Sweden, and by several other writers.

Typically, an undredged distributary mouth is characterized by a bottom that shoals gradually in the downstream direction, reaching its shallowest point over the 'distributary mouth bar'. Upstream from the mouth, river banks are higher than the surrounding surface due to the formation of subaerial levees during flood stage. Downstream from the mouth, subaerial levees seemingly continue as subaqueous levees that become less prominent with distance from the mouth and finally merge into the distributary mouth bar. Channel bifurcation may result if the mouth becomes sufficiently shallow to block the channel, causing it to divide; two new 'mouths' are scoured on either side of the bar. In

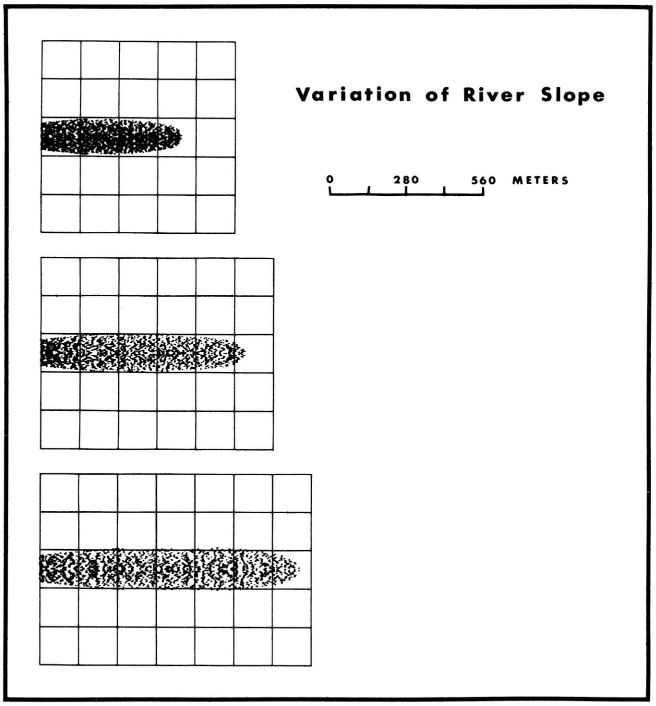

Figure 7.- Static model Series II, Run A (top), Run B (center), Run C (bottom), showing variation due to river slope.

time new distributary mouth bars may form, ultimately causing bifurcation once more. Mouth bar formation has been ascribed to a number of processes, as described by Welder (1959), Mikhailov (1966), and Axelsson (1967). Among other factors, clay flocculation and wave action seem to be important in some instances, but a reduction in the carrying capacity of the stream is probably the most significant factor involved. In proposing the jet theory Bates (1953) suggested that no deposition takes place in the zone of no diffusion and that subaqueous levees form at the margins of this zone. He further suggested that a bar will build at the end of the zone of flow establishment. Bates supported this argument by citing several rivers with bars that shoaled between four and eight slot widths from the mouth.

The static model experiments show no tendency for the formation of either bars or subaqueous levees. Levee growth might be expected if a large number of sediment particles were to reach the low velocity region at the margins of the jet. If the sediment diffuses at the same rate as momentum ($\beta = 1.0$), lateral spreading is slow, and sediment reaching the sides is insufficient for levee growth. By increasing β, the angle of spreading is increased, and there is a slight tendency for levees to build. This will be discussed further elsewhere.

Bars do not form in the static model because the rate of deposition along the jet centerline slowly decreases with distance from the mouth. This is due partly to the spreading of the jet and partly to the shape of the sediment discharge profile in an open channel. Sediment discharge normally increases as the elevation above the river bed is reduced. However, under certain conditions (very fine grained sediment and rapid channel velocities) the sediment discharge decreases toward the bed in which case the greater part of the sediment load is carried nearer the water surface. This factor might result in bar formation in rare situations. This also will be discussed further elsewhere. Both subaqueous levees and mouth bars can be built, however, by incorporating a dynamic response into the simulation model.

Contrary to Bates' (1953) statement, sediment can be deposited in the zone of no diffusion under certain conditions. Physically and also from static model experiments, sediment may be deposited if the basin floor onto which the river discharges slopes away from the river mouth. Contact between the sediment surface and turbulent stream is lost as the salt water interface is reached. Thus, sediment can no longer be entrained and particles will deposit causing the sediment surface to build upward, despite the fact that the current velocity is the same as that in the river. However, shoaling of the bottom is limited by the tendency for channel erosion. In the zone of no diffusion, where current velocities are the same as in the channel, water will not become shallower than the original channel depth. Upward limit of growth of the sediment surface will be referred to as the Limiting Depth Surface (LDS).

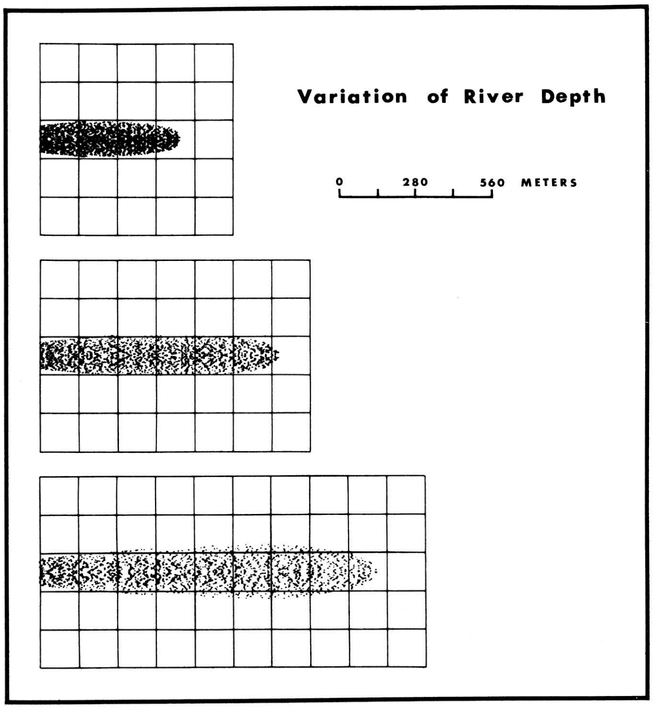

Figure 8.- Static model Series III, Run A (top), Run B (center), Run C (bottom), showing variation due to river depth.

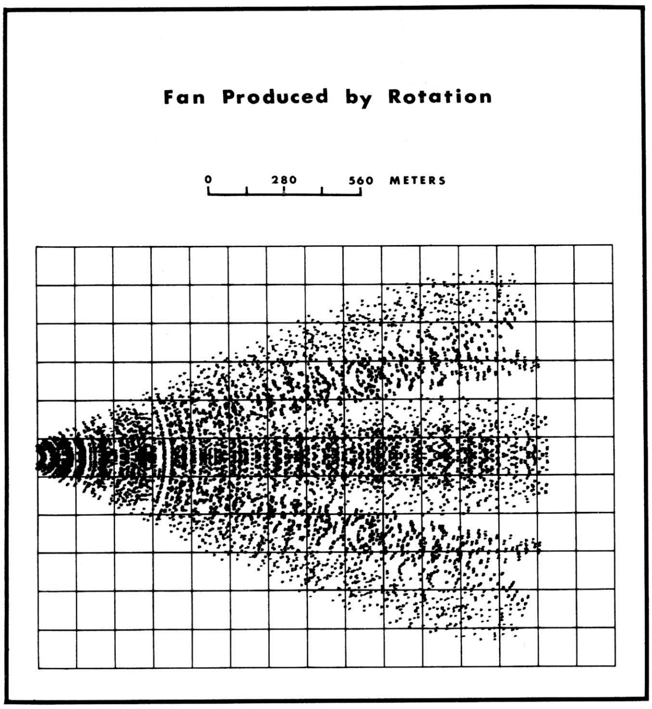

Figure 9.- Depositional fan produced by rotating axis of river jet in horizontal plane.

Outside the zone of no diffusion, current velocities drop below the initial river velocity and the bottom may become shallower than the channel depth. The LDS, being the result of an equilibrium between depositional and erosional tendencies, must be related to the velocity field. The form of this relation is unknown. For the purpose of this study, it is arbitrarily assumed that the LDS is related proportionately to the local plane-jet velocity. More precisely, the limiting depth in each cell is defined to be equal to $d\,[\,1,\ f_2(x,y),\ f_3(x,y)\,]$, where the terms in the square brackets are applicable in zones 1, 2, and 3 (see Fig. 2) respectively.

The rate at which the LDS will be reached by deposition will differ with position in the accounting grid, with grain size and with different hydraulic conditions. Normally, however, cells around the river mouth will fill most rapidly. As soon as a cell is full, it becomes part of the delta 'platform'. The outer edge of the platform, as defined by the boundaries of the full accounting cells, is referred to as the delta 'lip' (Fig. 10). Nominal particle trajectories must be horizontal as they pass over the delta platform and will begin to bend downward as they cross the lip.

When the delta platform has advanced beyond the margins of the zone of no diffusion, the sediment surface can build above the original river depth and will begin to obstruct the flow in the 'fresh water' layer. Current velocities will no longer be given correctly by the velocity field defined earlier. Presumably, the effect will be either to force a greater proportion of the flow laterally and increase the spread, or if spreading is inhibited by deposits along the margins, to channel the flow and increase the velocity over the bar. Thus, the differential rates of accumulation in front of and along the sides of the zone of no diffusion may be of considerable importance in controlling the tendency for bifurcation.

Because the velocity field is disrupted by the continued rise of the sediment surface, the velocity equations developed above are no longer reasonable. For the purpose of this study, it is assumed that the velocity field is unchanged so that the delta platform can be allowed to build outward for as many time increments as seem desirable.

Experiments and Results

Two experimental runs are illustrated (Fig. 11 and 12). In the first, the experimental conditions are identical to those for Series I, Run C of the static model. The accounting grid-cell size is set at one river width. In the second experiment, the grain diameter is increased to 0.4 mm, holding all other parameters constant, so that all deposition takes place in the zone of flow establishment. Resolution of the accounting grid is increased by decreasing the cell size to one-fourth the river width. In this way, deposition near the mouth can be more closely monitored.

The first experiment shows the formation of two transverse mouth bars, demonstrated on the

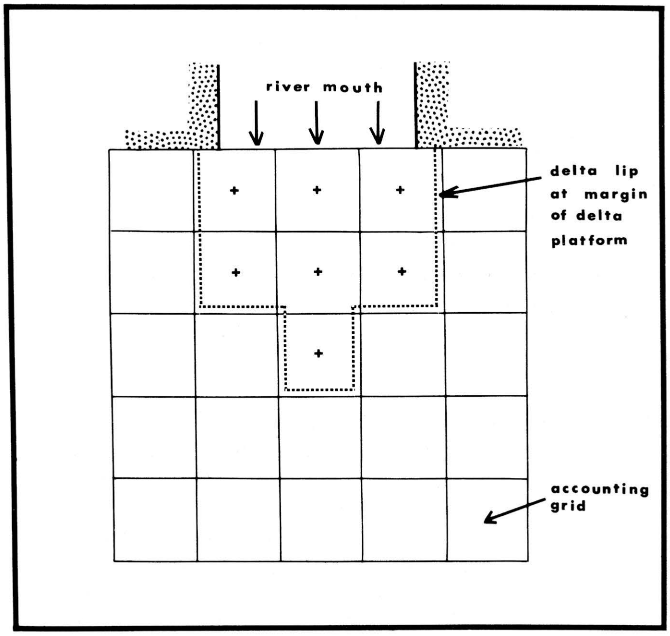

Figure 10.- Definition sketch of delta platform and lip in relation to river mouth and accounting grid; + indicates that cell is 'full', i.e., contains sediment up to its LDS value.

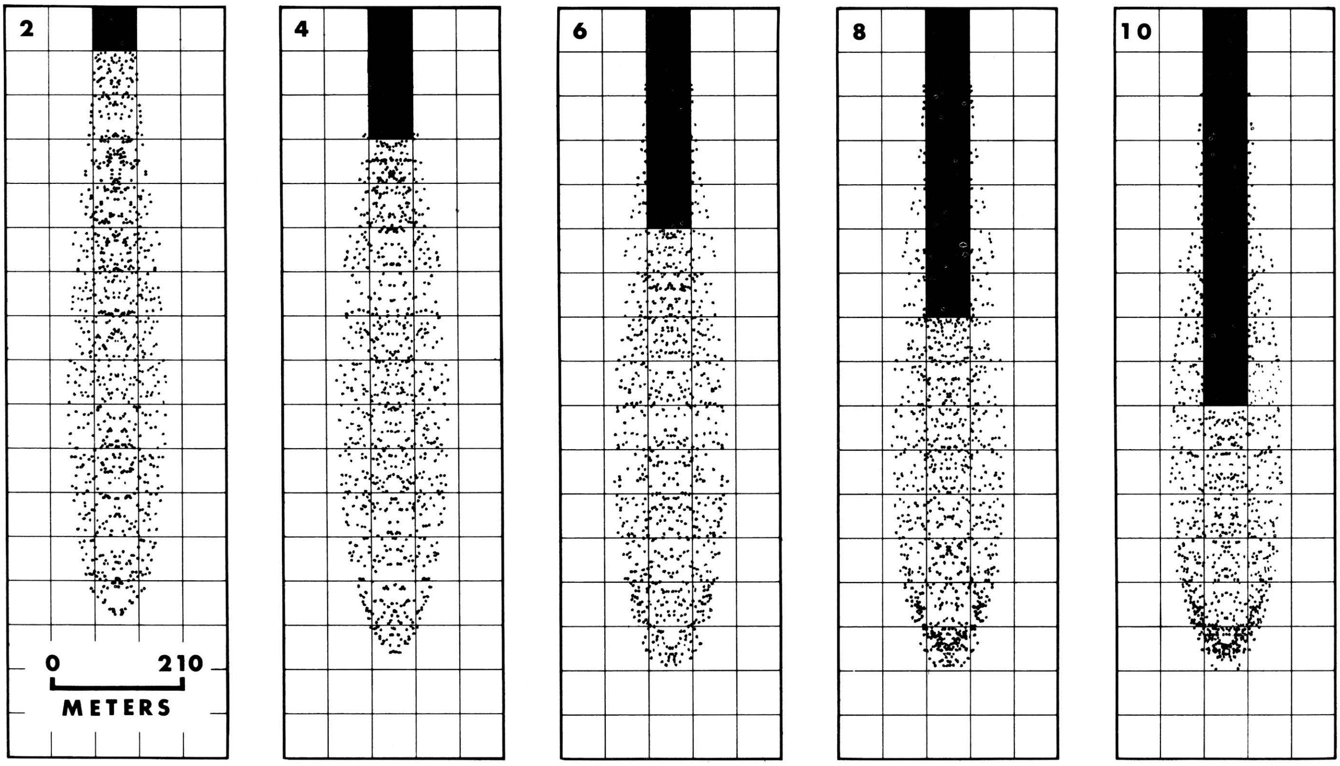

Figure 11a.- Dynamic model, first experiment. Particle maps from selected time increments show advance of delta platform (solid) and formation of transverse bar. This is indicated by high density of points round the nose of depositional area in later time increments.

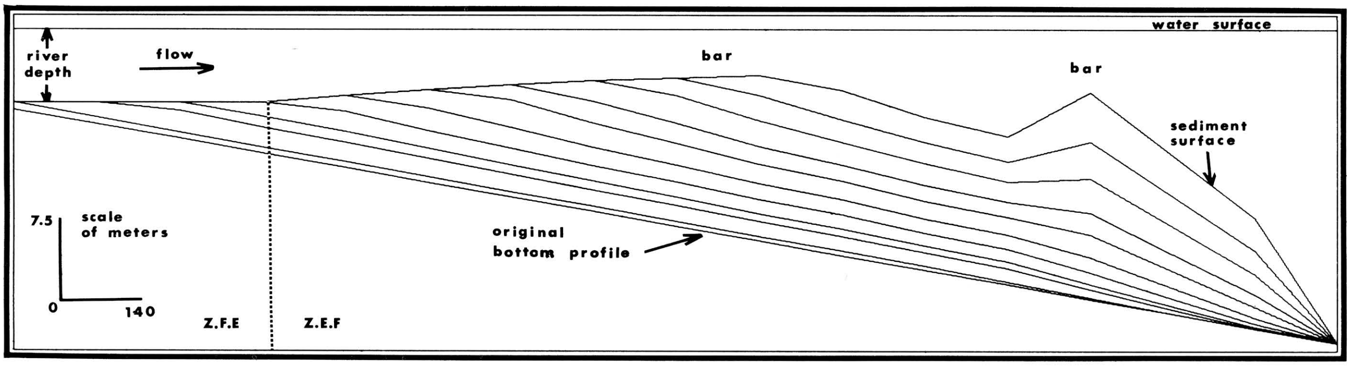

Figure 11b.- Dynamic model, first experiment. Vertical stratigraphic section along column 3 of accounting grid, facing right, after 10 time increments. Diagrams drawn automatically by CALCOMP digital plotter.

stratigraphic section in Figure 11b. The bar closest to the mouth is produced by a gradual shallowing of the LDS from the end of the zone of flow establishment. Limiting depth values have restricted the upward growth in this region. The second bar is formed by an increase in the rate of deposition near the distal end of the depositional area. Here current velocities have decreased significantly, steepening the trajectories for nominal particles from the upper part of the channel. As a result, the density of terminal points of nominal particles has increased around the 'nose' of the depositional area (Fig. 11a). This increase in density corresponds to the increased rate of deposition that has produced the secondary bar.

The accounting-grid resolution in this experiment is too coarse to determine whether submerged levees are forming. The delta platform is never more than one cell wide, so that depositional variation close to the mouth cannot be investigated in detail.

The second experiment permits a closer examination of deposition in the zone of flow establishment. Development of the delta platform can be followed from the particle maps (Fig. 12a). These maps show no increase in particle density at the flow margins that might indicate levee formation. Nevertheless, vertical stratigraphic sections trans-

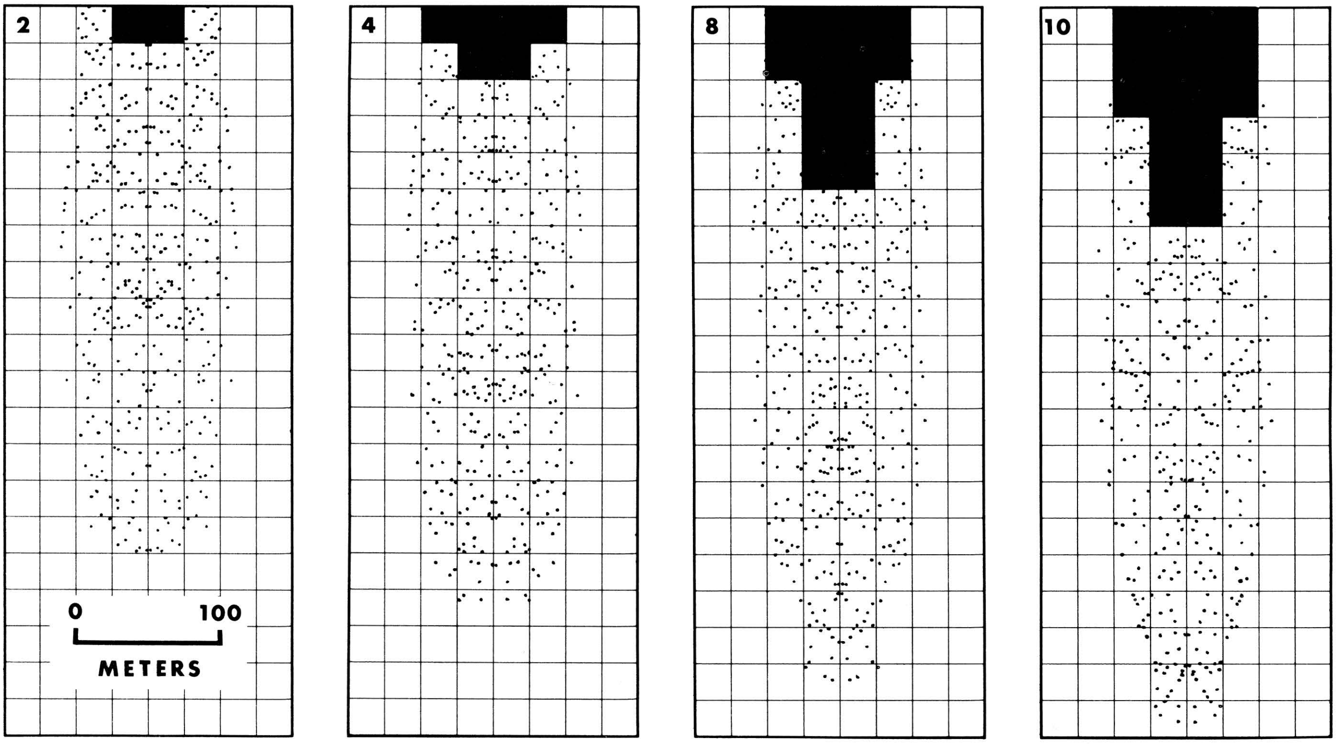

Figure 12a.- Dynamic model, second experiment. Particle maps for time increments 2, 4, 8, and 10.

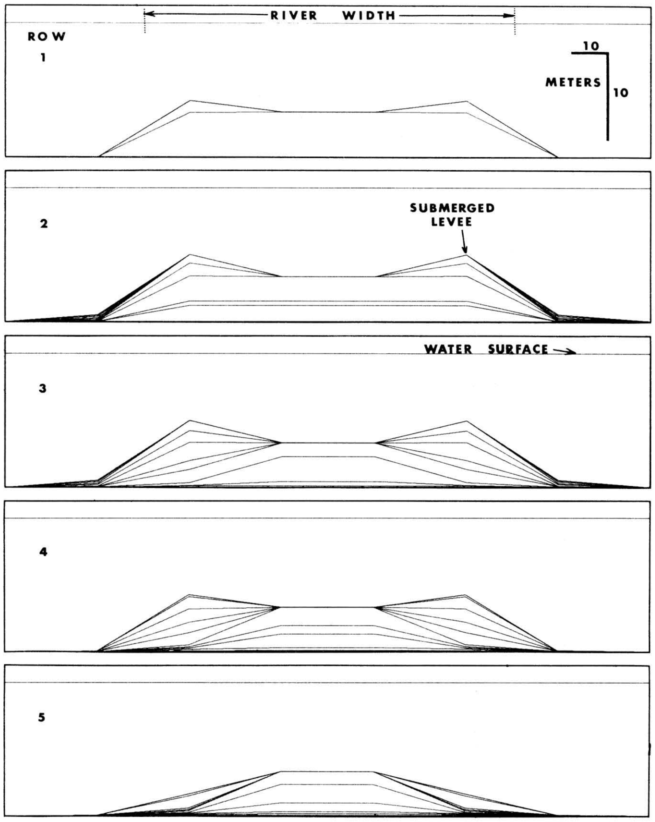

Figure 12b.- Dynamic model, second experiment. Vertical stratigraphic sections along rows 1, 2, 3, 4, and 5 of accounting grid after 12 time increments. Note formation of subaqueous levees.

verse to the principal flow axis show that levees are forming by the buildup of sediment in cells along the delta margins (Fig. 12b). The upward growth of levees is restricted by the LDS. In this experiment, no transverse bar can be formed because all deposition is in the zone of flow establishment where the LDS coincides with river depth.

COMPUTER PROGRAM DELTASIM

Introduction

This program initially was written in FORTRAN IV for an IBM 7090 at Stanford University, but subsequently modified to run on an IBM System 360/model 67. A CALCOMP plotter is used to plot particle maps and draw stratigraphic cross sections, but otherwise all output is printed. I/0 units 1, 2, 3, 4, and 13 are used for intermediate scratch storage. Flow and direction of control between subroutines are illustrated in Figure 13, and a section of short notes describes the function of each subroutine. The program is listed in Table 2.

Short Notes on Subroutines

This section is in conjunction with Figure 13 and the program listing.

Subroutine MAIN

This subroutine is merely a program driver,

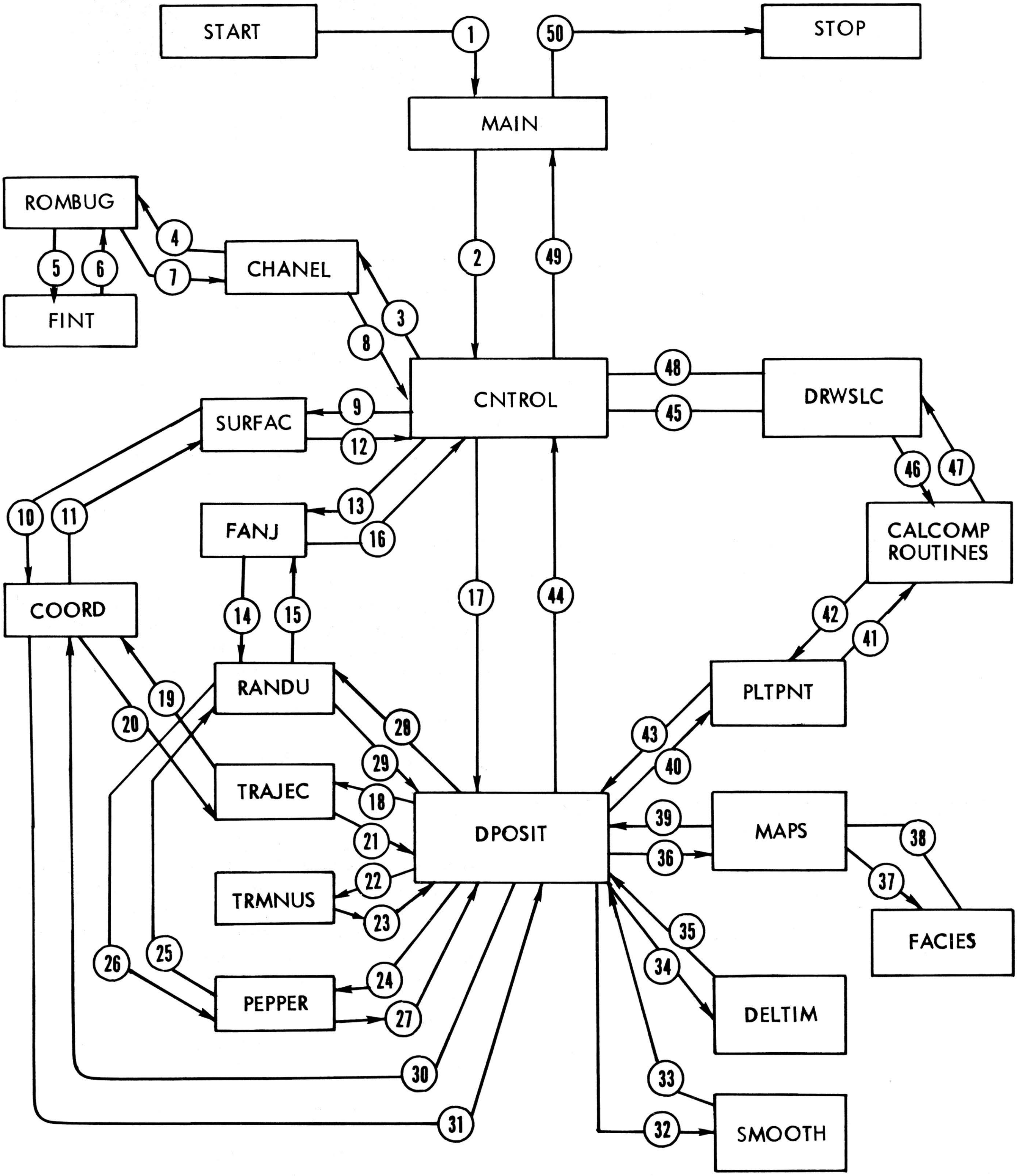

Figure 13.- Flow chart indicating structure and direction of flow between subroutines of DELTASIM.

and calls CNTROL.

Subroutine CNTROL

1. reads input parameters (see input instructions)
2. calls CHANEL
3. prints channel characteristics (see Table 4)
4. calls SURFAC
5. calls FANJ
6. calls DPOSIT
7. plots X-sections by calling DRWSLC

Subroutine CHANEL

1. computes channel parameters
2. finds maximum distances of travel along jet centerline for each particle size
3. scales a/c grid to fit depositional area if GRID.GT.0 (see input instructions)
4. calculates total sediment discharge for each grain size, if not already supplied as data, storing the result as (SEDLOD(L), where L is an index denoting grain size number)
5. calculates sediment discharge for each row of river grid for each grain size storing the result as (DISC(L,KK)), using ROMBUG and FINT
6. solves left-hand side of equation 11 for each row of river grid storing the result as HYT(KK)

Subroutine DPOSIT

1. sets up major DO-loop which is entered once per time increment
2. calls TRAJEC
3. sets up DO-loop which is entered once for each cell in river grid
4. calls TRMNUS
5. returns to (3) until all cells complete
6. sets up new loop which is again passed through for each cell in river grid
7. calls PEPPER
8. enters loop which is completed for each fan position
9. calls COORD
10. increments temporary a/c grid cell by appropriate quantity of sediment.
11. repeats 9 and 10 for the mirror image in the other half of river grid
12. returns to 8 until all fan positions complete
13. returns to 6 until all river grid cells complete
14. calls SMOOTH if NSM.GT.0 (where NSM is described in the input instructions)
15. calls DELTIM
16. updates water depth array, DEPTH (I,J)
17. writes out sediment budget (see Table 12)
18. calls MAPS
19. returns to (1) for each time increment
20. calls DELTIM

Subroutine TRAJEC

1. if this is the first time increment, calculates x_d (equation 6) y_d, y_0 (equation 7) for each column of the river mouth grid.
2. calculates position of delta lip for particles issuing from each column of river grid storing the results in (XLIP(K), YLIP(K))
3. calculates maximum values of the first two integrals on right side of equation 11; note that the lower bounds change as the delta lip advances; values for each column stored in SUMZND(K), SUMZFE(K)
4. writes out a table of trajectory constants, one row of constants for each column in the river mouth grid (see Table 11)

Subroutine SURFAC

1. calculates a value of LDS which is stored in (DEPLIM(I,J)) for each cell in the a/c grid
2. if KSRF.LT.1, the stream depth is set in each cell of the a/c grid
3. if KSRF.GE.1, the LDS value is made a function of the local velocity; a total of KSRF points are calculated (on a line normal to jet axis) and averaged for each a/c grid cell

Subroutine TRMNUS

1. calculates x_t, y_t, the terminal coordinates of a nominal particle, given the cell indices in the river grid (see Appendix B)

Subroutine COORD

1. if KON = 0, jet coordinates (x,y) are transformed to a/c grid coordinates (I,J)
2. if KON.GT.1, a/c grid coordinates are transformed to jet coordinates

Subroutine DELTIM

1. finds indices of a/c grid cell that will fill to its LDS value more rapidly than any other cell
2. calculates the length of time required to fill this cell which becomes the length of the time increment (DT)
3. stores indices of cell calculated in 1,(ISAVE ( ), JSAVE( ); this cell now is part of delta platform
4. if this is the last time increment, the history of delta growth is printed, using the ISAVE ( ) and JSAVE( ) values

Subroutine PLTPNT

The CALCOMP subroutines called by PLTPNT and DRWSLC are described in a Stanford Computation Center library program write-up, April 1967, obtainable by writing to the Systems Documentation office, Stanford Computation Center at a charge of 50 cents. The calls are similar to those in use at other computing centers.

1. if L = 1, labels and draws grid, and places an X in the delta platform cells
2. if L = 2 plots a point on this grid, given the coordinates (U,V); these are scaled automatically to floating point inches (see Fig. 6, 7, 8 and 9)
3. if L = 3, terminates this picture by moving plotting origin forward

Subroutine FACIES

If an accounting grid cell contains a sediment thickness comprising two or more size fractions, it is desirable to classify the sediment according to its composition. In order to do this, several standard facies may be set up, whose compositions are read in as data. Sediment in an a/c grid cell is then matched compositionally to the standard facies, classified according to which standard is 'closest' and assigned the appropriate alphameric symbol for plotting. Distance coefficients are used as measures of similarity (Fig. 15).

Subroutine SMOOTH

1. smooths by column or by row, whichever is parallel to the axis of jet flow
2. smoothing along a row or column is done by simple running averages, in groups whose size is specified by NSM (see input instructions)
3. cells containing zero sediment are treated as though they were the end of a row or column; thus the depositional area is not 'smeared' at the edges

Subroutine FANJ

1. enters loop; once through per fan position
2. calculates position of fan (FANANG) by drawing random number from Gaussian distribution, $\mu = 0^{\circ}$, σ = FANDEV$^{\circ}$; if FANANG.GT.FANLIM, draws another number
3. calculates duration spent in this fan position in years; made proportional to height of Gaussian curve - (EXP(FANANG/2.0*FANDEV))

Subroutine DRWSLC

1. determines scale factors, vertical exaggeration and size of plot, according to input options
2. plots headings and frame of X-section
3. plots sea level
4. plots original bottom profile
5. enters loop once for each time increment
6. calculates position of bottom profile for that time increment
7. plots bottom profile
8. returns to (5) until all time increments exhausted

Subroutine MAPS

1. prints sediment thickness maps for current time increment, for each size fraction (see Fig. 14a,b,c)
2. prints facies map (Fig. 15)
3. prints depth of water map (Fig. 16)

Subroutine PEPPER

The most lengthy calculations made by this program involve the solution of the equation describing each particle trajectory. However, unless a large number of particles are used, the resulting sediment 'surface' in the accounting grid becomes very uneven (subroutine SMOOTH helps to improve this). In order to minimize the number of calculated trajectories, yet maintain a large number of points, each nominal particle is used like a 'pepper pot' to generate a number (IEXTRA) of points that are positioned randomly in a rectangular area around the original point. The four margins of this rectangular area are placed midway between the original point and the four neighboring 'original' points, one on each side.

Subroutine ROMBUG

Romberg integration method translated from a Stanford ALGOL procedure by R.S. Dobson; uses an external function (DUMF), lower and upper limits and a tolerance.

Subroutine FINT

Function specifying a sediment concentration for any height above the bed of an alluvial channel. This function used by CHANEL and ROMBUG for calculating discharge between given channel elevations.

Subroutine RANDU

IBM 360 Scientific Subroutine Package routine for generating uniformly distributed random numbers between 0 and 1. Under OS/360 this routine is automatically available in the library.

Subroutines

STRTP1

```
MAP SHOWING THE DISTRIBUTION OF SIZE FRACTICN NUMBER    1 OF    1.00 MMS. DIAMETER
VALUES REPRESENT THICKNESS IN MTRS X 10
SCALE - 1 INCH =          41.96 MTRS
TIME INCREMENT    1
```

a

```
       1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

  1    0    0    0    0    0    0   11   62   11    0    0    0    0    0    0    0

  2    0    0    0    0    0    0    4   21    4    0    0    0    0    0    0    0

  3    0    0    0    0    0    0    0    1    0    0    0    0    0    0    0    0

  4    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

  5    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

  6    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

  7    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

  8    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

  9    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 10    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 11    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 12    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 13    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 14    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
```

```
MAP SHCWING THE DISTRIBUTICN CF SIZE FRACTICN NUMBER    2 OF    0.50 MMS. DIAMETER
VALUES REPRESENT THICKNESS IN MTRS X 10
SCALE - 1 INCH =          41.96 MTRS
TIME INCREMENT    1
```

b

```
       1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

  1    0    0    0    0    0    0   64  238   64    0    0    0    0    0    0    0

  2    0    0    0    0    0    0   32  105   32    0    0    0    0    0    0    0

  3    0    0    0    0    0    0   13   29   13    0    0    0    0    0    0    0

  4    0    0    0    0    0    0    8   13    8    0    0    0    0    0    0    0

  5    0    0    0    0    0    0    5    7    5    0    0    0    0    0    0    0

  6    0    0    0    0    0    0    3    4    3    0    0    0    0    0    0    0

  7    0    0    0    0    0    0    1    2    1    0    0    0    0    0    0    0

  8    0    0    0    0    0    0    0    1    0    0    0    0    0    0    0    0

  9    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 10    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 11    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 12    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 13    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

 14    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
```

```
MAP SHOWING THE DISTRIBUTION OF SIZE FRACTION NUMBER    3 OF     0.25 MMS. DIAMETER
VALUES REPRESENT THICKNESS IN MTRS X 10
SCALE - 1 INCH =           41.96 MTRS
TIME INCREMENT    1                                                          C

          1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

  1       0    0    0    0    0    0   44  170   44    0    0    0    0    0    0    0

  2       0    0    0    0    0    0   39  110   39    0    0    0    0    0    0    0

  3       0    0    0    0    0    1   35   67   35    1    0    0    0    0    0    0

  4       0    0    0    0    0    2   32   43   32    2    0    0    0    0    0    0

  5       0    0    0    0    0    5   27   32   27    5    0    0    0    0    0    0

  6       0    0    0    0    0    7   23   25   23    7    0    0    0    0    0    0

  7       0    0    0    0    0    8   19   20   19    8    0    0    0    0    0    0

  8       0    0    0    0    1    9   15   17   15    9    1    0    0    0    0    0

  9       0    0    0    0    2    8   11   13   11    8    2    0    0    0    0    0

 10       0    0    0    0    2    7    9   11    9    7    2    0    0    0    0    0

 11       0    0    0    0    3    5    7    8    7    5    3    0    0    0    0    0

 12       0    0    0    0    2    3    4    6    4    3    2    0    0    0    0    0

 13       0    0    0    0    1    2    2    4    2    2    1    0    0    0    0    0

 14       0    0    0    0    0    1    1    2    1    1    0    0    0    0    0    0
```

Figure 14.- Sediment thickness maps. (a) size fraction 1, (b) size fraction 2, and (c) size fraction 3.

ENDP1
SYMBL1
NUMBR1 CALCOMP subroutines
LINE1
PLOT1

Input Requirements

(i) Title Card

Columns		
1-60	TITLE	Alphameric title to be printed at head of each page (15A4).
66-69	UNITS	Alphameric name or abbreviation for distance units (e.g. FEET, MTRS) Any units may be used as long as they are consistent (A4).

(ii) Channel Card

Columns		
1-5	SLOT	Width of stream channel in UNITS as specified in title card (F5.0).
6-15	SLOTMM	Width of stream channel in mm. N.B. not in UNITS (F10.0).
16-20	STMDEP	Depth of stream (assumed uniform) in UNITS (F5.0).
21-30	STMSLP	Slope of channel (F10.0).*
31-35	DARWIB	D'Arcy Weisbach friction coefficient (F5.0).
36-40	VONKAR	Von Karman's constant (F5.0).
41-45	BETA	Ratio of diffusion coefficients for sediment and momentum (F5.0).
46-50	AVGVEL	Average channel velocity in UNITS/sec (F5.0).*
51-55	DSCHRG	Discharge of channel water in cubic UNITS/sec (F5.0).*

*only one of three starred parameters to be inserted; remaining two to be set to zero (not blank) and they will be calculated automatically.

(iii) Number of Size Fractions Card

Columns		
1-5	NFRACT	Number of size fractions. Maximum of 4. (I5). Size fractions must be listed according to size, starting with largest.

(iv) a. First size fraction card

Columns		
1-5	DIAM(1)	Diameter of grains in mm. N.B.

```
MAP SHOWING THE DISTRIBUTION OF FACIES

LEGEND -
       $ = V.COARSE      * =    COARSE      + =    MEDIUM      - =      FINE      = =    V.FINE

SCALE - 1 INCH =            41.96 MTRS

TIME INCREMENT    1


       1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

  1                                  $    $    $

  2                             +    $    $    $    +

  3                             -    *    *    *    -

  4                             -    +    +    +    -

  5                        =    -    +    +    +    -    =

  6                        =    -    -    -    -    -    =

  7                        =    =    -    -    -    =    =

  8                        =    =    =    =    =    =    =

  9                   =    =    =    =    =    =    =    =    =

 10                   =    =    =    =    =    =    =    =    =

 11                   =    =    =    =    =    =    =    =    =

 12                   =    =    =    =    =    =    =    =    =

 13                   =    =    =    =    =    =    =    =    =

 14                   =    =    =    =    =    =    =    =    =
```

Figure 15.- Facies map from line printer.

		<u>not</u> in UNITS (F5.0).
6-10	SETVEL(1)	Settling velocity (UNITS/sec) if this field is set to zero, Rubey's (1933) formula is used for calculating settling velocity (F5.0).
11-15	POROS(1)	Porosity of resulting sediment as ratio of pore volume/total volume (F5.0).
16-25	DENSIT(1)	Density in grams/cubic UNITS (F10.0).
26-35	SEDLOD(1)	Total sediment load as discharge in grams/year (F10.0).

b. <u>Second size fraction card</u> (if NFRACT.GT.1)

repeat as above, but for 2nd size fraction

Columns	
1-5	DIAM(2)
6-10	SETVEL(2)
11-15	POROS(2)
16-25	DENSIT(2)
26-35	SEDLOD(2)

```
DEPTH MAP

VALUES EXPRESSED AS MTRS

SCALE - 1 INCH =          41.96 MTRS

TIME INCREMENT    1


          1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

  1      50   50   50   50   50   50   38    3   38   50   50   50   50   50   50   50

  2      50   50   50   50   50   50   42   26   42   50   50   50   50   50   50   50

  3      50   50   50   50   50   50   45   40   45   50   50   50   50   50   50   50

  4      50   50   50   50   50   50   46   44   46   50   50   50   50   50   50   50

  5      50   50   50   50   50   49   47   46   47   49   50   50   50   50   50   50

  6      50   50   50   50   50   49   47   47   47   49   50   50   50   50   50   50

  7      50   50   50   50   50   49   48   48   48   49   50   50   50   50   50   50

  8      50   50   50   50   50   49   48   48   48   49   50   50   50   50   50   50

  9      50   50   50   50   50   49   49   49   49   49   50   50   50   50   50   50

 10      50   50   50   50   50   49   49   49   49   49   50   50   50   50   50   50

 11      50   50   50   50   50   49   49   49   49   49   50   50   50   50   50   50

 12      50   50   50   50   50   50   50   49   50   50   50   50   50   50   50   50

 13      50   50   50   50   50   50   50   50   50   50   50   50   50   50   50   50

 14      50   50   50   50   50   50   50   50   50   50   50   50   50   50   50   50
```

Figure 16.- Depth of water map.

c. <u>Third size fraction card</u> (if NFRACT.GT.2)

repeat as above

d. <u>Fourth size fraction card</u> (if NFRACT.GT.3)

repeat as above

Total number of size cards = NFRACT.

(v) <u>Number of Facies Card</u>

Columns		
1-5	NSTAND	Total number of standard 'facies' used for classifying sediment mixtures. Up to a maximum of 10 (15).

(vi) a. <u>First facies standard card</u>

Columns		
1-8	FACNAM(1)	Facies name, up to eight alpha-

		meric characters (2A4).
12	FACSYM(1)	Facies symbol - any alphameric symbol (A1).
13-22	STNDRD(1,1)	Weight factor ranging between 1.0 and 0.0 describing contribution of size fraction 1 to this standard (F10.0).
23-32	STNDRD(1,2)	Contribution of size fraction 2 (F10.0).
33-42	STNDRD(1,3)	(as above)
43-52	STNDRD(1,4)	(as above)

Total number of STNDRD entries = NFRACT

b. Second facies standard card (if NSTAND.GT.1)

Columns		
1-8	FACNAM(2)	(repeat as above)
12	FACSYM(2)	(repeat as above)
13-22	STNDRD(2,1)	(repeat as above)
23-32	STNDRD(2,2)	(repeat as above)
33-42	STNDRD(2,3)	(repeat as above)
43-52	STNDRD(2,4)	(repeat as above)

c. Third facies standard card (if NSTAND.GT.2)
(repeat as above)

d. Fourth facies standard card (if NSTAND.GT.3)
(repeat as above)

Total number of facies standard cards = NSTAND

(vii) Time Control Card

Columns		
1-5	NTIM	Number of time increments (I5).
6-10	LIP	Control on position of delta lip (I5). LIP = 1 - lip moves dynamically forward. LIP = 0 - lip not moved from channel mouth.
11-15	KBUG	Control on intermediate output regarding filling rates for each accounting grid cell. KBUG = 1 - print out = 0 - suppress

(viii) Accounting Grid Control Card

Columns		
1-5	NROWS	Number of rows (I5).
6-10	NCOLS	Number of columns (I5).
11-15	CELSIZ	Length of cell side in UNITS (F5.0).
16-20	GRDOPT	Optional fraction for scaling accounting grid to fit area of deposition; e.g., if GRDOPT = 0.5, accounting grid is scaled so that only 0.5 of grid is filled; if this fraction is greater than zero, either NROWS or NCOLS adjusted depending on DELANG, unless CELSIZ = 0.0, in which case CELSIZ is adjusted (F5.0).

(ix) River Grid Control Card

Columns		
1-5	NROWSG	Number of horizontal rows in river grid (I5).
6-10	NCOLSG	Number of vertical columns (I5).
11-15	DELTI	Accounting grid row-coordinate marking center of channel mouth (and origin of river grid) in margin of the accounting grid (F5.0).
16-20	DELTJ	Accounting grid column coordinate for above point (F5.0).
21-25	DELANG	Azimuth in degrees for direction of channel flow in relation to accounting grid, assuming direction 0°(N) parallel to a/c grid columns, pointing toward low-numbered rows, and increasing clockwise (F5.0).

(x) Miscellaneous Control Card

Columns		
1-5	KPLOT	If positive integer, CALCOMP particle maps are plotted in every KPLOT(th) time increment (I5).
6-10	RANPLT	Proportion of statistical particles to be plotted on particle maps expressed as a decimal fraction, e.g., if RANPLT = 0.8, 80% of all points plotted by CALCOMP (F5.0).
11-15	NBUG	Intermediate output control. If NBUG = 0, option suppressed. If a positive integer, every NBUG(th) particle is listed with details on terminal coordinates, sediment load, etc. (I5).
16-20	NSM	Optional smoothing of sediment thickness values. Running averages along rows or along columns in groups of NSM. See subroutine SMOOTH for details. Must be an odd integer (I5).
21-25	IX	Starting number for random number generator. Must be an odd integer (I5).
26-30	IEXTRA	Number of extra 'pepper pot' points, see description of subroutine PEPPER (I5).
31-35	PLTWID	Width of CALCOMP particle plot map in floating point inches (F5.0).

(xi) Depth Control Card

Columns		
1-5	KSRF	Control on limiting depth surface (LDS). If .GE. 1, LDS is a function of local velocity. If set = 0, all LDS values set to STMDEP. See description of subroutine SURFAC (I5).
6-10	KPOINT	Number of points to be used in calculating each LDS value (normally 6 is satisfactory) (I5).
11-15	KDEPTH	Input control for depth values. If set to 0, individual depth value must be entered for all positions of depth array (see below). If set = 1, the water depth is assumed to be uniform throughout the settling basin and only a single value is read in (I5).

(xii) Variable Format Card

Columns		
1-60	FMT	Variable format in parentheses for reading in depth array cards e.g. (10F5.0) (15A4).

(xiii) Depth Array Values

DEPTH(I,J)	Depth of water values for every cell in accounting grid, defining subaqueous topography of settling basin. If KDEPTH = 1, only a single value required. If KDEPTH = 0, values are read in row-wise, each row starting on a new card, according to variable format.

(xiv) Delta Fan Control Card

Columns		
1-5	FANDEV	Control for finding a random fan position. This is found by drawing a number randomly from a Gaussian distribution with $\mu = 0^{\circ}$, $\sigma = \text{FANDEV}^{\circ}$ (F5.0)
6-10	FANLIM	Limiting size of any fan position in degrees (F5.0).
11-15	NUMFAN	Number of random fan positions to be used each time increment (I5).

(xv) Plotting Control Card

Columns		
1-5	K1PLOT	Control for plotting stratigraphic cross sections with CALCOMP. If set = 1, plotter to be used; if set = 0, option suppressed (I5).
6-10	XLENG	Length of X-axis (long axis of CALCOMP paper) for cross-section diagram (F5.0).
11-15	YLENG	Length of Y-axis (not to exceed 10.0 inches) (F5.0).
16-20	EXAGVT	Vertical exaggeration. If set to 0.0 is automatically calculated according to XLENG and YLENG, so that full accounting grid is included in diagram. If set to some positive value, value of YLENG is scaled accordingly (F5.0).
21-25	SEELEV	Gap in inches to be left between upper margin of diagram and sea-level line (F5.0).

(xvi) Number of Cross Sections Card (skipped if K1PLOT = 0)

Columns		
1-5	IRNTOT	Total number of X-sections along a/c grid rows looking north. Max. 10 (I5).
6-10	IRSTOT	Total number of X-sections along rows looking south. Max. 10 (I5).
11-15	ICWTOT	Total number of X-sections down a/c grid columns looking west. Max. 10 (I5).
16-20	ICETOT	Total number of X-sections down columns looking east. Max. 10 (I5).

(xvii) Cross Section Cards (omit if K1PLOT = 0)

a. Rows looking north (omit if IRNTOT = 0)

Columns		
1-5	IRN(1)	First row number (I5).
6-10	IRN(2)	Second row number (I5). (repeat up to IRNTOT)

b. Rows looking south (omit if IRSTOT = 0)

1-5	IRS(1)	First row number (I5). (repeat up to IRSTOT)

c. Columns looking west (omit if ICWTOT = 0)

1-5	ICW(1)	First column number (I5). (repeat up to ICWTOT)

d. Columns looking east (omit if ICETOT = 0)

1-5	ICE(1)	First column number (I5). (repeat up to ICETOT)

(xviii) For Multiple Jobs

Repeat steps i through xvii and load decks consecutively, inserting one blank card between each deck.

(xix) Finish Card

Columns	
1-6	Insert word FINISH. First four letters are used to trigger return of control to monitor (A4).

SAMPLE RUN

Table 3 contains data input for a test run of the program. Tables 4 through 12 and Figures 14 and 15 illustrate some output from this run, and are described below.

Table 4. Channel Characteristics

The heading 'slots' refer to width of the channel at the mouth. Thus all distances are expressed in terms of slots or channel-mouth widths, as well as UNITS which in this case are MTRS (meters).

Table 5. Other Parameters

Some of these values have been supplied as data, others calculated. Note that in Table 3, GRID was set to 1.0 and CELSIZ to 0.0. CELSIZ has now been adjusted to 20.98 meters, which allows all sediment to settle within an accounting grid 14 rows x 16 columns.

Table 6. Total Sediment Load

For each size fraction the total sediment load is calculated using the Meyer-Peter discharge formula (Vanoni and others, 1961). If the given load totals less than 10,000 grams/year then the calculated load is used subsequently in calculations. Nonzero entries must be made in the given load input positions, however, as proportions of different size fractions in the total load are assumed to be those given as input. For example, in this instance the size fractions are in the ratio of 1:5:10.

Table 7. Sediment Characteristics

Characteristics are listed for each size fraction. Here the load in grams/year was that calculated by the Meyer-Peter formula. The 'load as cell-square thickness'...refers to the height to which a square column with cross section equal to CELSIZ x CELSIZ (dimensions of a/c grid cell) would fill if the entire sediment load was allowed to settle into it, assuming that the ratio of pore volume to total volume is given as the porosity. Here the settling velocity was calculated by Rubey's (1933) formula, which does not consider variation in grain shape and hence gives only an approximate settling velocity for poorly rounded grains. Alternatively by setting SETVEL to a nonzero value, this option could have been suppressed.

Table 8. Sediment Discharge Profiles

Each row of the vertically oriented river grid is listed with its height above the channel floor and the discharge values for each size fraction. Note that discharge is expressed in 'cell square thickness' ... as in Table 7. A small discrepancy exists between the total discharge for size fraction 1 in this table and that shown in the previous table. This results from rounding errors in the numerical integration procedure.

Table 9. Limiting Depth Surface

Because KSRF = 6, the LDS value for each a/c grid cell was calculated by averaging six individual values computed along a line at the cell center normal to the axis of jet flow.

Table 10. Fan Positions

Each angle was calculated by drawing a number randomly from a Gaussian distribution with $\mu = 0°$, $\sigma = 10°$, but excluding those greater than 20°. The aximuth is calculated simply by adding the original flow azimuth (180°) to the angle.

Table 11. Trajectory Constants

These refer to the plan view of the nominal particle trajectories, one for each column of the river grid. K refers to the column number, starting at the channel center and working outward. The opposite half of the channel is treated as a mirror image XD = x_d, YD = y_d, YF = y_0 used in the mathematical model. XLIP and YLIP refer to the coordinates of the delta lip on each trajectory. NLIP denotes the position of the delta lip (3 = zone of no diffusion, 2 = zone of flow establishment, 1 = zone of established flow). SUMZND and SUMZFE denote the values of the integrals for the zone of no diffusion and zone of flow establishment, multiplied by the fall velocity w, as given in equation 11. KLIST is set to 1 for the first time increment and is subsequently set to 0 for later time increments if the change in the position of the delta lip has been such that the trajectory constants are unaltered.

Table 12. Sediment Budget

Total sediment input to the system is tabulated for this increment, whose duration is given. For each size fraction, the input is expressed in 'cell-square thickness' as in Table 7. Due to rounding errors made by repeated arithmetic operations, small discrepancies may occur between these values and those obtained by multiplying the original sediment loads by the duration of the time increment.

Figure 14. Sediment Thickness Maps

A value of sediment thickness is printed for each cell in the accounting grid, one map for each sediment size fraction. Each value is multiplied by 10 and rounded to the nearest integer, so that summing these values will not give precisely the same quantities listed in Table 12.

Figure 15. Facies Map

Average composition of the sediment in each cell is matched with the composition of each standard facies, and classified according to which is 'closest'. The corresponding facies symbols have been plotted for each cell containing sediment deposited during this time interval; the remaining cells have been filled with alphameric blanks. Resulting maps display the sediment sorting produced by the hydraulic processes involved in delta formation.

Figure 16. Depth of Water Maps

Although unrealistic, the input for this test run specified that the depth of water in the basin before sedimentation started was 50 meters deep. The values for each cell shown on this map were obtained by subtracting the total sediment deposited from the original water depth, and rounding to the nearest meter.

Table 2.- Program listing.

```
//DELTA JOB (WC62,203,4,5),'BONHAM-CARTER.G',MSGLEVEL=1
//STEP1 EXEC FORTHCLG
//FORT.SYSIN DD *
C.....DELTA SIMULATION PROGRAM BY G.BONHAM-CARTER. JAN. 25, 1967.
C.....MODIFIED AUGUST 17, 1967.
C.....TRANSLATED FOR 360/67 SYSTEM FEB. 1968 USING WYLBUR TEXT EDITING
C.....SYSTEM FROM AN IBM 2741 REMOTE TERMINAL
      DATA B/4HFINI/
      NPLOT=0
   10 CALL CNTROL(NPLOT)
      READ(5,1) A
      IF (A.NE.B) GO TO 10
      WRITE(6,2)
      IF (NPLOT.GT.0) CALL ENDPL
      RETURN
    1 FORMAT(A4)
    2 FORMAT(1H1, 20X, 20HTHIS JOB IS COMPLETE)
      END
C
C     ************************
      SUBROUTINE CNTROL(NPLOT)
C     ************************
C
C
C     INPUT/OUTPUT AND CONTROL OPERATIONS
      DIMENSION FMT(15), IRN(10), IRS(10),ICW(10),ICE(10)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG, UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IFXTRA,KDEL
      COMMON /COM3/ SEDLOD(5),SETVEL(5), FANANG(10), FANTIM(10), NUMFAN,
     1 FANDEV, FANLIM, NBUG, KPLOT, SHRVEL, BETA, VONKAR,TOTLOD(5),
     2 BWNDRY, NTIM
      COMMON /COM4/ NSTAND, FACSYM(10), FACNAM(10,2), STNDRD(10,5)
      COMMON /COM6/ POROS(5), DENSIT(5), CALCLD(5),DISTMX(5),DISC(5,50),
     1 DISK(5), DSCHRG, STMSLP, AVGVEL, DARWIB, SUMLOD, TOTCLD, VRTINC
      TIMFAC=1
C
C.....READ INPUT PARAMETERS
      READ (5,1) TITLE, UNITS
      READ(5,2) SLOT, SLOTMM, STMDEP, STMSLP, DARWIB, VONKAR, BETA,
     1 AVGVEL, DSCHRG, GACC
      READ(5,3) NFRACT
      DO 30 L=1, NFRACT
   30 READ(5,4) DIAM(L), SETVEL(L), POROS(L), DENSIT(L), SEDLOD(L)
      READ(5,3) NSTAND
      DO 31 N=1, NSTAND
   31 READ(5,5)(FACNAM(N,M), M=1,2),FACSYM(N), (STNDRD(N,L), L=1,NFRACT)
      READ(5,3) NTIM, LIP, KBUG
      READ(5,6) NROWS, NCOLS, CELSIZ, GRDOPT
      READ(5,6) NROWSG, NCOLSG, DELTI, DELTJ, DELANG
      READ(5,7) KPLOT, RANPLT, NBUG, NSM, IX, IEXTRA,PLTWID
      IF (IEXTRA.LT.1) IEXTRA=1
      READ(5,3) KSRF, KPOINT, KDEPTH
      READ(5,1) FMT
      IF (KDEPTH.EQ.1) GO TO 33
      DO 32 I=1, NROWS
   32 READ(5,FMT) (DEPTH(I,J), J=1,NCOLS)
      GO TO 35
   33 READ(5,FMT) DEPTH(1,1)
```

```
      DO 34 I=1, 50
      DO 34 J=1, 16
   34 DEPTH(I,J)=DEPTH(1,1)
   35 READ(5,8) FANDEV, FANLIM, NUMFAN
      IF (FANLIM.LT.FANDEV) FANLIM=FANDEV
      READ(5,9) K1PLOT, XLENG,YLENG,EXAGVT, SEELEV
      IF (K1PLOT.LT.1) GO TO 44
      READ(5,3) IRNTOT, IRSTOT, ICWTOT, ICETOT
      IF (IRNTOT.LT.1) GO TO 41
      READ(5,3) (IRN(I), I=1, IRNTOT)
   41 IF (IRSTOT.LT.1) GO TO 42
      READ(5,3) (IRS(I), I=1,IRSTOT)
   42 IF (ICWTOT.LT.1) GO TO 43
      READ(5,3) (ICW(I), I=1,ICWTOT)
   43 IF (ICETOT.LT.1) GO TO 44
      READ(5,3) (ICE(I), I=1, ICETOT)
C
C.....CALL PLOTTER IF NECCESSARY
   44 IF (NPLOT.EQ.1) GO TO 45
      IF (KPLOT.LT.1.AND.K1PLOT.LT.1) GO TO 45
      NPLOT=1
      CALL STRTP1(10)
   45 CALL CHANEL(GACC,SLOTMM,GRDOPT)
C
C
C.....PRINT OUT CHANNEL CHARACTERISTICS
      WRITE(6,10) TITLE, UNITS
      A=STMDEP*SLOT
      B=BWNDRY*SLOT
      C=SHRVEL*AVGVEL
      D=C*SLOT
      E=AVGVEL*SLOT
      F=DSCHRG*SLOT**3
      WRITE(6,11)STMDEP, A, STMSLP, DARWIB, VONKAR, BWNDRY, B, C, D,
     1  AVGVEL, E, DSCHRG, F
C
C.....PRINT OUT GRID PARAMETERS
      A=CELSIZ*SLOT
      B=FLOAT(NROWS*NCOLS)*CELSIZ**2
      C=B*SLOT**2
      WRITE(6,12)TITLE,  NTIM, NROWS, NCOLS, CELSIZ, A, UNITS, B,
     1  C, UNITS, NROWSG, NCOLSG
      A=1.0/CELSIZ
      WRITE(6,13)DELTI, DELTJ, DELANG, A, SLOT, UNITS
      DELANG=DELANG*0.017453312
C
C.....PRINT OUT MAX. DISTANCES OF PARTICLE TRAVEL ALONG JET CENTERLINE
      WRITE(6,14) UNITS
      DO 90 L=1, NFRACT
      B=DISTMX(L)*SLOT
   90 WRITE(6,15) L, DIAM(L), DISTMX(L), B
      WRITE(6,16) TITLE
      DO 100 L=1,NFRACT
  100 WRITE(6,17) L, DIAM(L), SEDLOD(L), CALCLD(L)
      WRITE(6,18) SUMLOD, TOTCLD
C
C.....PRINT OUT INFORMATION ON STREAM SEDIMENT LOADS
C.....IF THE TOTAL GIVEN LOAD LT 100 GRMS/YEAR, CALCULATED LOADS USED
      IF (SUMLOD.GT.10000.0) GO TO 110
      DO 105 L=1,NFRACT
  105 SEDLOD(L)=CALCLD(L)
```

```
C
  110 WRITE(6,19) TITLE, NFRACT
      B=(CELSIZ*SLOT)**2
      DO 120 L=1,NFRACT
      DA=SEDLOD(L)
      SEDLOD(L)=DA*TIMFAC/((1.0-POROS(L))*DENSIT(L)*B)
      A=SETVEL(L)*AVGVEL*SLOT
  120 WRITE(6,20)L, DA, UNITS, TIMFAC, SEDLOD(L), DIAM(L), A, UNITS,
     1  DENSIT(L), UNITS, POROS(L)
C
C.....PRINT OUT DISCHARGE PROFILES, ONE FOR EACH SIZE FRACTION
      WRITE(6,21) TITLE, UNITS, TIMFAC, UNITS, (L, L=1,NFRACT)
      DO 125 IG=1, NROWSG
      KKR=NROWSG-IG+1
      H=(FLOAT(KKR)*VRTINC-VRTINC/2.0+BWNDRY)*SLOT
  125 WRITE(6,22) KKR, H, (DISC(L,KKR), L=1,NFRACT)
      WRITE(6,23)     (TOTLOD(L), L=1,NFRACT)
      DO 130 L=1,NFRACT
  130 TOTLOD(L)=TOTLOD(L)*2.0*FLOAT(NCOLSG)
      WRITE(6,24) (TOTLOD(L), L=1,NFRACT)
C
C.....CALCULATE SURFACE DEFINING MINIMUMDEPTH TO WHICH A/C GRID MAY FILL
      CALL SURFAC(KSRF, KPOINT)
C
C.....FIND FAN ANGLES AND DURATION
      CALL FANJ
C
C.....WRITE ORIGINAL BOTTOM PROFILE ON OUTPUT UNIT 13
      IF (K1PLOT.LT.1) GO TO 200
      REWIND 13
      WRITE(13)  ((DEPTH(I,J), J=1,NCOLS), I=1,NROWS)
C
C.....INITIATE DEPOSITIONAL PHASE
  200 CALL DPOSIT(RANPLT)
C
C.....DRAW X-SECTIONS ON CALCOMP PLOTTER
      IF (K1PLOT.LT.1) GO TO 208
      IF (IRNTOT.LT.1) GO TO 202
      DO 201 KS=1,IRNTOT
  201 CALL DRWSLC(IRN(KS), 1,    SEELEV, EXAGVT, XLENG, YLENG)
  202 IF (IRSTOT.LT.1) GO TO 204
      DO 203 KS=1,IRSTOT
  203 CALL DRWSLC(IRS(KS), 0,    SEELEV, EXAGVT, XLENG, YLENG)
  204 IF (ICWTOT.LT.1) GO TO 206
      DO 205 KS=1,ICWTOT
  205 CALL DRWSLC(-ICW(KS), 0,   SEELEV, EXAGVT, XLENG, YLENG)
  206 IF (ICETOT.LT.1) GO TO 208
      DO 207 KS=1,ICETOT
  207 CALL DRWSLC(-ICE(KS), 1,   SEELEV, EXAGVT, XLENG, YLENG)
  208 CONTINUE
      RETURN
    1 FORMAT(15A4,  5X, A4)
    2 FORMAT(F5.0, F10.0, F5.0, F10.0, 6F5.0)
    3 FORMAT(4I5)
    4 FORMAT(3F5.0, 2F10.0)
    5 FORMAT(2A4, 3X, A1, 10F5.0)
    6 FORMAT(2I5, 3F5.0)
    7 FORMAT(I5, F5.0, 4I5, F5.0)
    8 FORMAT(2F5.0, I5)
    9 FORMAT(I5, 4F5.0)
   10 FORMAT(1H1, 15A4///// 3X, 23HCHANNEL CHARACTERISTICS, 34X,
```

```
     1 54SLOTS, 20X, A4)
   11 FORMAT(1H0, 7X, 5HDEPTH, 44X, F10.5, 15X, F10.5//8X, 5HSLOPE, 88X,
     1 F10.5// 8X, 35HDARCY WEISBACH FRICTION COEFFICIENT, 58X, F10.5//
     2  8X, 21HVON KARMAN'S CONSTANT, 72X, F10.5// 8X,
     3  22HNOMINAL LOWER BOUNDARY, 21X, E20.5, 10X, F15.5// 8X,
     4 14HSHEAR VELOCITY, 29X,  E20.5, 2X, 7HPER SEC, F12.5, 2X,
     5 7HPER SEC//8X, 16HAVERAGE VELOCITY, 27X,  E20.5, 2X, 7HPER SEC,
     6      F12.5, 2X, 7HPER SEC//8X,16HWATER DISCHARGE ,27X,E20.5,2X,
     7  7HPER SEC, F12.5, 2X, 7HPER SEC)
   12 FORMAT(1H1, 15A4///// 3X, 22HSIZE OF SIMULATION RUN//
     1                                                 8X, 25HNUMBER OF TIME IN
     2CREMENTS, 4X, I10// 8X, 17HSIZE OF MAIN GRID, 5X, I5, 2X, 4HROWS,
     3 5X, I5, 2X, 7HCOLUMNS//   8X, 19HLENGTH OF CELL SIDE, 2X, F10.5,
     4  2X, 5HSLOTS, 5X, F15.5, 2X, A4//  8X, 17HAREA OF MAIN GRID,
     5  5X, F15.5, 2X, 12HSQUARE SLOTS, 10X, F20.5, 2X, 7HSQUARE , A4//
     6   8X, 18HSIZE OF RIVER GRID, 5X, I5, 1X, 4HROWS, 5X, I5, 1X,
     7  4HCOLS)
   13 FORMAT(1H0//////3X,17HDELTA ORIENTATION//8X,'COORDINATES OF RIVER
     1MOUTH',10X,'ROW',F10.1, 5X, 6HCOLUMN, F10.1// 8X, 12HFLOW AZIMUTH,
     2 5X, F10.5, 3X, 7HDEGREES//  8X, 'RIVER WIDTH',    5X, F10.5, 3X,
     3  11HCELL WIDTHS, 5X, F15.5, 2X, A6)
   14 FORMAT(1H0/////////// 3X, 70HMAXIMUM DISTANCE OF TRAVEL ALONG JET C
     1ENTRELINE FOR EACH PARTICLE SIZE//    13X, 8HFRACTION, 20X,
     2 94DIAM(MMS), 19X, 17HDISTANCE IN SLOTS, 11X, 12HDISTANCE IN , A4)
   15 FORMAT(1H0, 13X, I4, 20X, F10.5,20X, F10.5,20X, F15.5)
   16 FORMAT(1H1, 15A4/// 5X, 32HLOAD EXPRESSED AS GRAMS PER YEAR//
     1  5X, 60HCALCULATED LOAD COMPUTED USING MEYER PETER DISCHARGE FORM
     2ULA// 5X, 13HSIZE FRACTION, 6X, 9HDIAM(MMS), 5X, 10HGIVEN LOAD,
     3  3X, 15HCALCULATED LOAD//)
   17 FORMAT(1H0, I11, 6X, 3E15.5)
   18 FORMAT(1H0, 5X, 6HTOTALS, 21X, 2E15.5)
   19 FORMAT(1H1, 15A4/////  3X,  24HSEDIMENT CHARACTERISTICS//8X,
     1 25HNUMBER OF SIZE FRACTIONS , I5)
   20 FORMAT(1H0//6X, 9HFRACTION , I3// 12X, 22HLOAD IN GRAMS PER YEAR,
     1  20X, E20.5// 12X, 33HLOAD AS CELL SQUARE THICKNESS IN , A4,
     2  18H ACCUMULATED OVER , F7.2, 6H YEARS, 5X, F20.5//12X,
     3  17HPARTICLE DIAMETER, 33X, F10.5, 2X, 3HMMS// 12X,
     4 17HSETTLING VELOCITY, 33X, E20.5, 2X, A4, 1X, 7HPER SEC// 12X,
     5 7HDENSITY, 43X, E20.5,17H GRAMS PER CUBIC , A4//12X, 8HPOROSITY,
     6  42X, F10.5)
   21 FORMAT(1H1, 15A4/////  8X,     45HSEDIMENT DISCHARGE PROFILE AT CH
     1ANNEL ORIFICE///   8X,'DISCHARGE EXPRESSED AS A/C GRID CELL THICKN
     2NESS IN ', A4, ' PER', F7.2, ' YEARS'// 8X, 'HEIGHT ABOVE BOTTOM E
     3XPRESSED IN ', A4// 30X,
     4  14HSIZE FRACTIONS/  6X, 3HROW, 3X,6HHEIGHT, 5I20//)
   22 FORMAT(1H , 4X, I3, 2X, F9.5, 4X, 5E20.5)
   23 FORMAT(1H0, 1X, 20HTOTAL FOR THE COLUMN, 1X, 5E20.5)
   24 FORMAT(1H0, 1X, 18HTOTAL FOR THE GRID, 3X, 5E20.5)
      END
C
C     **************************************
      SUBROUTINE CHANEL(GACC,SLOTMM,GRDOPT)
C     **************************************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM2/ XD(50), YD(50),YF(50),XLIP(50),KLIST(50),NLIP(50),
     1  HYT(50),SUMZND(50),SUMZFE(50)
      COMMON /COM3/ SEDLOD(5),SETVEL(5), FANANG(10), FANTIM(10), NUMFAN,
```

```
     1 FANDEV, FANLIM, NBUG, KPLOT, SHRVEL, BETA, VONKAR,TOTLOD(5),
     2 BWNDRY, NTIM
      COMMON /COM4/ NSTAND, FACSYM(10), FACNAM(10,2), STNDRD(10,5)
      COMMON /COM6/ POROS(5), DENSIT(5), CALCLD(5),DISTMX(5),DISC(5,50),
     1 DISK(5), DSCHRG, STMSLP, AVGVEL, DARWIB, SUMLOD, TOTCLD, VRTINC
      COMMON /COM7/   ZEXPON, A
      EXTERNAL FINT
C
C.....RUBEY'S FUNCTION FOR COMPUTING SETTLING VELOCITY (OPTIONAL)
      SETTLE(A,B,C)=(6.666667/A)*(SQRT(247.47*A**3+1.0)-1.0)/(B*C)
C.....SCALE ALL LINEAR QUANTITIES TO RATIOS OF SLOT
   45 STMDEP=STMDEP/SLOT
      GACC=GACC/SLOT
      CELSIZ=CELSIZ/SLOT
      DSCHRG=DSCHRG/SLOT**3
      AVGVEL=AVGVEL/SLOT
C
C.....COMPUTE CHANNEL PARAMETERS. VELOCITIES EXPRESSED AS RATIOS OF AVGVEL
C.....EITHER DISCHARGE, AVERAGE VELOCITY OR STREAM SLOPE IS SUPPLIED
C.....BUT NOT MORE THAN ONE OF THESE
      IF (DSCHRG.LT.0.000001) GO TO 46
      AVGVEL=DSCHRG/STMDEP
      GO TO 47
   46 IF (AVGVEL.LT.0.000000001)  GO TO 48
      DSCHRG=AVGVEL*STMDEP
   47 STMSLP=AVGVEL**2*DARWIB/(8.*GACC*STMDEP)
      GO TO 49
   48 AVGVEL=SQRT(8.0*GACC*STMDEP*STMSLP/DARWIB)
      DSCHRG=AVGVEL*STMDEP
   49 SHRVEL=SQRT(DARWIB/8.0)
      BWNDRY=4.0*DIAM(1)/SLOTMM
C
C.....TRANSFORM SETTLING VELOCITIES IF ALREADY SUPPLIED
      DO 55 L=1, NFRACT
   55 IF (SETVEL(L).GT.0.0) SETVEL(L)=SETVEL(L)/(SLOT*AVGVEL)
C
C.....FIND MAX. DISTANCES OF TRAVEL ALONG JET CENTRELINE, BY SETTING H=D
C.....AND SOLVING FOR XT
      HTC=STMDEP-BWNDRY+SHRVEL*BWNDRY*ALOG(STMDEP/BWNDRY)/VONKAR
      DO 70 L=1,NFRACT
      IF (SETVEL(L).LT.0.00000001) SETVEL(L)=SETTLE(DIAM(L), SLOTMM,
     1  AVGVEL)
      IF (HTC-SETVEL(L)*5.248) 60,60,65
   60 DISTMX(L)=HTC/SETVEL(L)
      GO TO 70
   65 DISTMX(L)=((HTC/SETVEL(L)-1.749)*3.436)**0.666667
   70 CONTINUE
C
C.....SCALE CELSIZ SO THAT GRID WILL FIT DEPOSITIONAL AREA
C.....GRDOPT SPECIFIES THAT FRACTION OF THE GRID OCCUPIED DURING INCR. 1
C.....IF (GRDOPT.GT.0.01) A/C GRID IS SCALED TO FIT DEPOSITIONAL AREA
C.....IF CELSIZ.GT.0.0 THEN CELSIZ IS SCALED, OTHERWISE NROWS OR
C.....NCOLS IS SCALED DEPENDING ON JET ORIENTATION
      IF (GRDOPT.LT.0.01) GO TO 85
      KDEL=DELANG/ 90.0 + 1.5
      IF (CELSIZ.LT.0.00000001) GO TO 82
      GO TO (75,76,75,76,75), KDEL
   75 NROWS=DISTMX(NFRACT)/(CELSIZ*GRDOPT)+0.5
      IF (NROWS.GT.50) NROWS=50
      GO TO 85
   76 NCOLS=DISTMX(NFRACT)/(CELSIZ*GRDOPT)
```

```
      IF (NCOLS.GT.16) NCOLS=16
      GO TO 85
   82 NNX=NROWS
      IF (MOD(KDEL,2).EQ.0) NNX=NCOLS
      CELSIZ=DISTMX(NFRACT)/(FLOAT(NNX   )*GRDOPT)
C
C.....EVALUATE SEDIMENT DISCHARGE FROM MEYER PETER FORMULA
C
   85 CSCTYR=3.1536E7
      CLBTGM=453.5923
      CMMTFT=0.003281
      SLOTFT=SLOTMM*CMMTFT
      SUMLOD=0.0
      DO 88 L=1,NFRACT
   88 SUMLOD=SUMLOD+SEDLOD(L)
C.....FIND AVERAGE (WEIGHTED) DIAMETER IN FEET
      AVDIAM=0.0
      DO 90 L=1,NFRACT
   90 AVDIAM=AVDIAM+DIAM(L)*CMMTFT*SEDLOD(L)/SUMLOD
C.....PETER MEYER FORMULA MODIFIED TO GIVE TOTAL DISCHARGE IN GRMS/YEAR
      TOTCLD=((39.25*(DSCHRG*SLOTFT**2)**0.66667*STMSLP-(9.95*AVDIAM))
     1    **1.5)*CLBTGM*CSCTYR*SLOTFT
      DO 95 L=1,NFRACT
   95 CALCLD(L)=TOTCLD*SEDLOD(L)/SUMLOD
C
C.....EVALUATE SEDIMENT DISCHARGE PROFILE AT EACH ROW OF RIVER GRID
C.....ORIGIN OF R.G. AT BWNDRY AND JET CENTRELINE
      VRTINC=(STMDEP-BWNDRY)/FLOAT(NROWSG)
      A=SHRVEL/VONKAR
      D=(CELSIZ*SLOT)**2
      DO 98 L=1,NFRACT
      C=TIMFAC/((1.-POROS(L))*DENSIT(L)*D)
      TOTLOD(L)=0.0
      ZEXPON=SETVEL(L)/(VONKAR*SHRVEL*BETA)
      DISK(L)=ROMBUG(FINT,Z,BWNDRY,STMDEP,0.0001)
      S=SEDLOD(L)
      IF (SUMLOD.LT.10000.) S=CALCLD(L)
      B=S*C/(DISK(L)*FLOAT(2*NCOLSG))
      H=BWNDRY
      DO 98 KK=1,NROWSG
      HP=H+VRTINC
      DISC(L,KK)=ROMBUG(FINT,Z,H,HP,0.0001) * B
      TOTLOD(L)=TOTLOD(L)+DISC(L,KK)
   98 H=HP
C
C.....SOLVE L.H.S. OF DIFFERENTIAL EQUATION FOR EACH ROW OF RIVER GRID
      H=BWNDRY+VRTINC/2.
      DO 100 KK=1, NROWSG
      HYT(KK)=H-BWNDRY+SHRVEL/VONKAR*(H*ALOG(H/STMDEP)+
     1 BWNDRY*ALOG(STMDEP/BWNDRY))
  100 H=H+VRTINC
      RETURN
      END
C
C     ************************
      SUBROUTINE DPOSIT(RANPLT)
C     ************************
C
C
C.....THIS SUBROUTINE CONTROLS THE DEPOSITIONAL PHASE OF DELTA BUILDING
      DIMENSION  SINA(10), COSA(10)
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```
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM2/ XD(50), YD(50),YF(50),XLIP(50),KLIST(50),NLIP(50),
     1  HYT(50),SUMZND(50),SUMZFE(50)
      COMMON /COM3/ SEDLOD(5),SETVEL(5), FANANG(10), FANTIM(10), NUMFAN,
     1 FANDEV, FANLIM, NBUG, KPLOT, SHRVEL, BETA, VONKAR,TOTLOD(5),
     2 BWNDRY, NTIM
      COMMON /COM6/ POROS(5), DENSIT(5), CALCLD(5),DISTMX(5),DISC(5,50),
     1 DISK(5), DSCHRG, STMSLP, AVGVEL, DARWIB, SUMLOD, TOTCLD, VRTINC
      COMMON /COM8/ XSTOR(50,50), YSTOR(50,50), XTX(100), YTY(100)
      FIEX=IEXTRA
      DO 110 L=1, NFRACT
      DO 110 KK=1, NROWSG
  110 DISC(L,KK)=DISC(L,KK)/FIEX
      DO 120 M=1,NUMFAN
      SINA(M)=SIN(FANANG(M))
  120 COSA(M)=COS(FANANG(M))
C
C.....ENTER MAJOR LOOP. ONCE THRU PER TIME INCREMENT
      DO 190 NT=1, NTIM
      NX=0
      MPLOT=0
      IF (KPLOT.LT.1) GO TO 130
      IF (MOD(NT,KPLOT).EQ.0) MPLOT=1
C
C.....FOR EACH COL OF O.G. FIND TRAJECTORY CONSTANTS
  130 CALL TRAJEC
      IF (NBUG.GT.0)  WRITE(6,1) TITLE, NT
C
C.....FOR EACH CELL IN ONE HALF OF O.G. FIND DESTINATION OF SEDIMENT AND
C.....INCREMENT ACCOUNTING ARRAY ACCORDINGLY
      GTOT=0.0
      DO 155 L=1,NFRACT
      IF (NT.EQ.1.OR.NFRACT.EQ.1) GO TO 131
      REWIND L
      READ(L) XSTOR, YSTOR
  131 TOTLOD(L)=0.0
C
C.....SET TEMP() TO ZERO
      DO 134 I=1,NROWS
      DO 134 J=1,NCOLS
  134 TEMP(I,J,L)=0.0
      DO 136 K=1, NCOLSG
      IF (KLIST(K).EQ.0) GO TO 136
      DO 135 KK=1, NROWSG
  135 CALL TRMNUS(XSTOR(KK,K), YSTOR(KK,K) ,K,KK,L,NZ)
  136 CONTINUE
      IF (MPLOT.EQ.1) CALL PLTPNT(0.0,0.0,1,L)
C
C.....DO 150 FOR EVERY NOMINAL PARTICLE IN RIVER GRID
      DO 150 KK=1,NROWSG
      DO 148 K=1,NCOLSG
      CALL PEPPER(K,KK)
      DO 145 IFX=1, IEXTRA
C
C.....FIND TERMINAL POINTS FOR EACH POSITION OF FAN AND DROP APPRPRIATE
C.....QUANTITY OF SEDIMENT
      DO 145 M=1,NUMFAN
      NX=NX+1
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```
      MMPLOT=0
      CALL RANDU(IX,IY,YFL)
      IX=IY
      IF (RANPLT.GT.YFL) MMPLOT=1
      XT=XTX(IEX)*COSA(M)-YTY(IEX)*SINA(M)
      YT=XTX(IEX)*SINA(M)+YTY(IEX)*COSA(M)
      CALL COORD(XT,YT,I,J,RI,RJ,1.0,0)
      IF (I.GT.NROWS.OR.I.LT.1.OR.J.GT.NCOLS.OR.J.LT.1) GO TO 140
      IF (MPLOT.EQ.1.AND.MMPLOT.EQ.1) CALL PLTPNT(RI, RJ, 2, L)
  138 AMOUNT=DISC(L,KK)*FANTIM(M)/TIMFAC
      TEMP(I,J,L)=TEMP(I,J,L)+AMOUNT
      TOTLOD(L)=TOTLOD(L)+AMOUNT
      IF (MOD(NX,NBUG).EQ.0)  WRITE(6,2) NX,  L, KK, K,
     1  FANANG(M), XT, YT, I, J, FANTIM(M), AMOUNT, NZ
C
C.....FOR MIRROR IMAGE
  140 CALL COORD(XT,YT,I,J,RI,RJ,-1.0,0)
      IF (I.GT.NROWS.OR.I.LT.1.OR.J.GT.NCOLS.OR.J.LT.1) GO TO 145
      IF (MPLOT.EQ.1.AND.MMPLOT.EQ.1) CALL PLTPNT(RI, RJ, 2, L)
  141 TEMP(I,J,L)=TEMP(I,J,L)+AMOUNT
      TOTLOD(L)=TOTLOD(L)+AMOUNT
  145 CONTINUE
  148 CONTINUE
  150 CONTINUE
      IF (MPLOT.EQ.1) CALL PLTPNT(0.0,0.0,3,L)
  152 GTOT=GTOT+TOTLOD(L)
      IF (NFRACT.EQ.1) GO TO 155
      REWIND L
      WRITE(L) XSTOR, YSTOR
  155 CONTINUE
C
      IF (NSM.GT.0) CALL SMOOTH(1)
C
C.....FIND DT, THE SMALLEST LENGTH OF TIME REQUIRED TO FILL ONE OF THE
C.....DELTA MARGIN CELLS.
      IF (LIP.GT.0) CALL DELTIM(DT, 0)
      DO 156 L=1,NFRACT
      DO 156 I=1,NROWS
      DO 156 J=1,NCOLS
  156 TEMP(I,J,L)=TEMP(I,J,L)*DT/TIMFAC
C.....UPDATE DEPTH ARRAY
      DO 170 I=1,NROWS
      DO 170 J=1,NCOLS
      THIK=0.0
      DO 157 L=1,NFRACT
  157 THIK=THIK+TEMP(I,J,L)
      DEPTH(I,J)=DEPTH(I,J)-THIK
C
C.....CHECK TO SEE IF NON-LIP CELLS ARE BEING OVERFILLED
      IF (DEPTH(I,J)+0.0001. GT. DEPLIM(I,J)) GO TO 170
      DIFF=DEPLIM(I,J)-DEPTH(I,J)
      DEPTH(I,J)=DEPLIM(I,J)
      IF (THIK.LT.0.00001) GO TO 170
      DO 160 L=1,NFRACT
  160 TEMP(I,J,L)=TEMP(I,J,L)-TEMP(I,J,L)*DIFF/THIK
  170 CONTINUE
C
C.....LOAD INFORMATION FROM THIS TIME INTERVAL ON TO DISK
      WRITE(13)  (((TEMP(I,J,L), L=1,NFRACT), J=1,NCOLS), I=1,NROWS)
C
C.....WRIT OUT SEDIMENT BUDGET FOR THIS TIME INCREMENT
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```
      WRITE(6,4)  TITLE, NT, DT, UNITS
      DO 180 L=1.NFRACT
      TOTLOD(L)=TOTLOD(L)*DT/TIMFAC
  180 WRITE(6,5)  L,  TOTLOD(L)
      GTOT=GTOT*DT/TIMFAC
      WRITE(6,6)   GTOT
      CALL MAPS
  190 CONTINUE
C
C.....PRINT HISTORY OF DELTA GROWTH
      CALL DELTIM(DT,1)
      RETURN
    1 FORMAT(1H1, 15A4// 10X, 'TABLE OF SEDIMENT DESTINATIONS AND LOADS'
     1 10X, 'TIME INCREMENT', I5//3X,'NX',5X,'SIZE', T20, 'VROW', T30,
     2 'VCOL',T40, 'FAN ANGLE', 5X, 'XT', 8X, 'YT', 7X, 'ROW', 7X,
     3 'COL', 5X, 'DURATION', 3X, 'AMOUNT', 4X, 'ZONE')
    2 FORMAT(1H ,I5,4X,3(I3,7X), 3(F7.2,3X), 2(I6,4X), 2(F7.2,3X), I6)
    4 FORMAT(1H1, 15A4// 10X, 'TIME INCREMENT', I5,10X,'DURATION',5X,
     1 F10.5,3X,'YEARS'//T20,'SIZE', T60,
     2 'THICKNESS (', A4, ')')
    5 FORMAT(1H0, T20, I5,  T55, F10.2)
    6 FORMAT(1H0,  T55, F10.2)
      END
C
C     ****************
      SUBROUTINE TRAJEC
C     ****************
C
C
C.....CALCULATES TRANSITION POINTS AND DELTA LIP COORDINATES FOR EACH
C.....PARTICLE TRAJECTORY
      DIMENSION YLIP(50)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM2/ XD(50), YD(50),YF(50),XLIP(50),KLIST(50),NLIP(50),
     1  HYT(50),SUMZND(50),SUMZFE(50)
      COMMON /COM3/ SEDLOD(5),SETVEL(5), FANANG(10), FANTIM(10), NUMFAN,
     1 FANDEV, FANLIM, NBUG, KPLOT, SHRVEL, BETA, VONKAR,TOTLOD(5),
     2 BWNDRY, NTIM
      IF (NT.GT.1) GO TO 5
      SDEP=STMDEP*SLOT
      ADD=0.005
      HRZINC=0.5/FLOAT(NCOLSG)
      SIGMAM=0.572032
      SIGMAS=BETA*0.572032
      R=SQRT(0.5*(1.0/SIGMAM**2+1.0/SIGMAS**2))
      STEP=CELSIZ/20.0
C
C.....KLIST(K)=1 MEANS THAT TERMINAL COORDINATES NEED TO BE
C.....RECALCULATED FOR THE KTH. COLUMN OF RIVER GRID
    5 DO 100 K=1,NCOLSG
      KLIST(K)=0
      IF (NT.EQ.1) KLIST(K)=1
C
C.....DO TO 25 ONCE ONLY PER SIMULATION RUN
      IF (NT.GT.1) GO TO 25
      YD(K)=FLOAT(K)*HRZINC-HRZINC/2.0
      XD(K)=5.248-YD(K) * 10.496
C
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```
C.....FIND YF(K) AT XF=5.248 BY ITERATION
C.....USING THE SEDIMENT DISCHARGE CURVE
      A=YD(K)
      IF (K.GT.1) A=YF(K-1)
      YDK2=YD(K)*2.0
      DO 10 I=1,100
      IF (ERF((A+ADD*FLOAT(I))*R    ).GE.YDK2) GO TO 20
   10 CONTINUE
   20 YF(K)= A    +ADD*FLOAT(I-1)
C
C.....FIND DELTA LIP ON EACH TRAJECTORY
      XLIP(K)=0.0
      YLIP(K)=YD(K)
      NLIP(K)=3
      GO TO 50
C
C.....IF DYNAMIC RESPONSE CONTROL (LIP) =0, SKIP TO 50
   25 IF (LIP.LT.1) GO TO 50
C
C..... ADVANCE ALONG TRAJECTORY IN INTERVALS OF STEP, TESTING FOR STMDEP
C.....WHEN DEPTH.GT.DEPLIM THIS POINT CONSTITUTES THE DELTA LIP
      A=(YF(K)-YD(K))/(5.248-XD(K))
      B=YF(K)/5.248
      GO TO 31
   28 XLIP(K)=XLIP(K)+STEP
      KLIST(K)=1
      IF (XLIP(K).LT.XD(K)) GO TO 29
      IF (XLIP(K).LT.5.248) GO TO 30
      YLIP(K)=XLIP(K)*B
      NLIP(K)=1
      GO TO 31
   29 YLIP(K)=YD(K)
      NLIP(K)=3
      GO TO 31
   30 YLIP(K)=YD(K)+(XLIP(K)-XD(K))*A
      NLIP(K)=2
   31 CALL COORD(XLIP(K), YLIP(K), I, J, RI, RJ, 1.0, 0)
      IF (DEPTH(I,J).LE.DEPLIM(I,J)) GO TO 28
C
C.....CALCULATE MAX. VALUES OF INTEGRALS FOR ZND AND ZFE FOR EACH TRAJEC
C.....RECALCULATION AFTER INITIAL CYCLE ONLY NECCESSARY IF DELTA LIP
C.....HAS BEEN EXTENDED
   50 IF (KLIST(K).LT.1) GO TO 95
      SUMZND(K)=0.0
      IF (NLIP(K).EQ.3) SUMZND(K)=AMAX1(0.0, XD(K)-XLIP(K))
      SUMZFE(K)=0.0
      IF (NLIP(K)-2)  95, 60, 70
   60 XLOW=XLIP(K)
      GO TO 80
   70 XLOW=XD(K)
   80 A=(YF(K)-YD(K))/(5.248-XD(K))
      DXX=0.05
      XHIGH=5.248-DXX/2.0
      C=XLOW-DXX/2.0
   90 C=C+DXX
      B=(A*(C-XD(K))+YD(K)-0.5)/C
      SUMZFE(K)=SUMZFE(K)+10.0**(AMIN1(18.4*(0.096+B)**2, 3.0))*DXX
      IF (C.LT.XHIGH) GO TO 90
   95 CONTINUE
  100 CONTINUE
      WRITE(6,1) TITLE, NT
```

```
      DO 110 K=1, NCOLSG
  110 WRITE(6,2) K, XD(K), YD(K), YF(K), XLIP(K), YLIP(K), NLIP(K),
     1  SUMZND(K), SUMZFE(K), KLIST(K)
      RETURN
    1 FORMAT(1H1, 15A4//// 10X, 14HTIME INCREMENT, 5X, I5/
     1////10X, 29HTABLE OF TRAJECTORY CONSTANTS/// 5X, 1HK, 9X, 2HXD,
     2 8X, 2HYD, 8X, 2HYF, 8X, 4HXLIP, 6X, 4HYLIP, 9X, 4HNLIP,  7X,
     3 6HSUMZND, 9X, 6HSUMZFE, T110, 'KLIST'//)
    2 FORMAT(1H , I5, 5X, 5F10.5, I10, 2F15.5, 5X, I5)
      END
C
C     ********************************
      SUBROUTINE SURFAC(KSRF, KPOINT)
C     ********************************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
C
C.....DETERMINE THE MINIMUM DEPTH TO WHICH EACH CELL CAN FILL
      SDEP=STMDEP*SLOT
      IF (KSRF.LT.1) GO TO 110
C.....SURFACE DESCRIBED BY INVERTED VELOCITY FUNCTION CURVE
      WRITE(6,1) TITLE, UNITS, (J, J=1,NCOLS)
      RINC=1.0/FLOAT(KPOINT-1)
    7 DO 100 I=1,NROWS
      RI=FLOAT(I)-0.5
      DO 90 J=1,NCOLS
      RJ=FLOAT(J)-0.5
C
C.....TAKE AVERAGE OK KPOINT POINTS ON LINE NORMAL TO JET AXIS
      DEPLIM(I,J)=0.0
      DO 80 K=1,KPOINT
      IF (KPOINT.EQ.1) GO TO 30
      GO TO (10,20,10,20,10) , KDEL
C
C.....FOR JET AXIS N-S
   10 RJ=FLOAT(J)-1.0+FLOAT(K-1)*RINC
      GO TO 30
C
C.....FOR JET E-W
   20 RI=FLOAT(I)-1.0+FLOAT(K-1)*RINC
   30 CALL COORD(X,Y,I,J,RI,RJ,1.0,2)
      IF (X.GE.5.248) GO TO 60
      Y=ABS(Y)
      IF (X.GE.(5.248-10.496*Y)) GO TO 40
C
C.....FOR ZONE OF NO DIFFUSION
      DEPLIM(I,J)=DEPLIM(I,J)+SDEP
      GO TO 80
C
C.....FOR ZONE OF FLOW ESTABLISHMENT
   40 IF (X.EQ.0.0.OR.Y.GE.0.5375*X) GO TO 80
      EX=18.4*(0.096+(Y-0.5)/X)**2
      IF (EX.GT.5.) EX=5.0
      DEPLIM(I,J)=DEPLIM(I,J)+SDEP/10.0**EX
      GO TO 80
C
C.....FOR ZONE OF ESTABLISHED FLOW
   60 IF (Y.GE.0.5375*X) GO TO 80
```

```
      DEPLIM(I,J)=DEPLIM(I,J)+SDEP*10.0**(0.36-18.4*Y**2/X**2)/SQRT(X)
   80 CONTINUE
   90 DEPLIM(I,J)=DEPLIM(I,J)/FLOAT(KPOINT)
  100 WRITE(6,2) I, (DEPLIM(I,J), J=1,NCOLS)
      RETURN
C.....PUT STREAM DEPTH AS LIMITING DEPTH ALL OVER
  110 DO 120 I=1,NROWS
      DO 120 J=1,NCOLS
  120 DEPLIM(I,J)=SDEP
      RETURN
    1 FORMAT(1H1, 15A4// 1X, 51HMAP SHOWING MINIMUM DEPTHS TO WHICH DELT
     1A CAN BUILD// 1X, 20HVALUES EXPRESSED AS , A4/// 4X, 16I7)
    2 FORMAT(1H //I5, 16F7.2)
      END
C
C     ******************************************
      SUBROUTINE TRMNUS(/XT/, /YT/, K, KK, L, NZ)
C     ******************************************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM2/ XD(50), YD(50),YF(50),XLIP(50),KLIST(50),NLIP(50),
     1  HYT(50),SUMZND(50),SUMZFE(50)
      COMMON /COM3/ SEDLOD(5),SETVEL(5), FANANG(10), FANTIM(10), NUMFAN,
     1 FANDEV, FANLIM, NBUG, KPLOT, SHRVEL, BETA, VONKAR,TOTLOD(5),
     2 BWNDRY, NTIM
C
C.....FIND TERMINAL COORDINATES
      A=HYT(KK)/SETVEL(L)
      IF (A.GT.SUMZFE(K)+SUMZND(K)) GO TO 30
      IF (A.GT.SUMZND(K)) GO TO 10
C
C.....ZONE OF NO DIFFUSION
      NZ=3
      XLOW=0.0
      IF (NLIP(K).EQ.3) XLOW=XLIP(K)
      XT=A+XLOW
      YT=YD(K)
      RETURN
C
C.....ZONE OF FLOW ESTABLISHMENT
   10 XLOW=XD(K)
      NZ=2
      IF (NLIP(K).EQ.2) XLOW=XLIP(K)
      DX=0.05
      XT=XLOW-DX/2.0
      S=0.0
      T=A-SUMZND(K)
      B=(YF(K)-YD(K))/(5.248-XD(K))
   20 XT=XT+DX
      C=(B*(XT-XD(K)) +  YD(K) - 0.5) /XT
      S=S + 10.0**(18.4*(0.096+C)**2)  *DX
      IF (S.LT.T) GO TO 20
   22 YT= (YF(K)-YD(K))*(XT-XD(K))/(5.248-XD(K))+YD(K)
      RETURN
C
C.....ZONE OF ESTABLISHED FLOW
   30 XLOW=12.02
      NZ=1
```

```
      IF (NLIP(K).EQ.1) XLOW=XLIP(K)**1.5
      B=10.**(0.36-18.4*YF(K)**2/27.5415)
      XT=(1.5*B*(A-SUMZND(K)-SUMZFE(K))+XLOW)**0.666667
      YT=XT*YF(K)/5.248
      RETURN
      END
C
C     ************************************************
      SUBROUTINE COORD(AX, AY, I, J, RI, RJ,/SIGN/, /KON/)
C     ************************************************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
C.....SIGN POSITIVE DENOTES CLOCKWISE SIDE OF JET AXIS
      IF (KON-1) 5,  50, 51
C
C.....OBTAIN GRID COORDINATES FROM JET COORDINATES
    5 X=AX/CELSIZ
      Y=AY/CELSIZ
      GO TO (10,20,30,40,10),KDEL
   10 RI=DELTI-X
      RJ=DELTJ+Y*SIGN
      GO TO 45
   20 RI=DELTI+Y*SIGN
      RJ=DELTJ+X
      GO TO 45
   30 RI=DELTI+X
      RJ=DELTJ-Y*SIGN
      GO TO 45
   40 RI=DELTI-Y*SIGN
      RJ=DELTJ-X
   45 I=RI+1.0
      J=RJ+1.0
      RETURN
C
C.....OBTAIN JET COORDINATES FROM GRID COORDINATES
   50 RI=FLOAT(I)-0.5
      RJ=FLOAT(J)-0.5
C
C.....ENTER HERE IF RI, RJ ALREADY SUPPLIED
   51 GO TO (110,120,130,140,110), KDEL
  110 AX=DELTI-RI
      AY=RJ-DELTJ
      GO TO 150
  120 AX=RJ-DELTJ
      AY=RI-DELTI
      GO TO 150
  130 AX=RI-DELTI
      AY=DELTJ-RJ
      GO TO 150
  140 AX=DELTJ-RJ
      AY=DELTI-RI
  150 AX=AX*CELSIZ
      AY=AY*CELSIZ
      RETURN
      END
C
C     **************************
      SUBROUTINE DELTIM(DT, KON)
```

```
C     **************************
C
      DIMENSION NUM(16)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM5/   ISAVE(50), JSAVE(50), NUMLIP
      IF (KON.EQ.1) GO TO 40
      IF (NT.EQ.1) NUMLIP=0
      WRITE(6,1) TITLE,NT
      IF (KBUG.EQ.1) WRITE(6,2)
C
C.....FIND SHORTEST LENGTH OF TIME REQUIRED TO FILL ANY CELL NOT
C.....ALREADY UP TO DEPLIM(I,J)
C.....MAKE 2 PASSES THRU LOOP, 1 TO FIND DT, 2 TO INCREMENT NUMLIP
      SWITCH=0.0
      HOLDT=100.
   10 DO 30 I=1,NROWS
      DO 30 J=1,NCOLS
      IF (NUMLIP.LT.1) GO TO 16
      DO 15 K=1,NUMLIP
      IF (ISAVE(K).EQ.I.AND.JSAVE(K).EQ.J) GO TO 30
   15 CONTINUE
   16 THIK=0.0
      DO 20 L=1,NFRACT
   20 THIK=THIK+TEMP(I,J,L)
      IF (THIK.LT.0.000001) GO TO 30
      DT=(DEPTH(I,J)-DEPLIM(I,J)+0.0001)*TIMFAC/THIK
      IF (SWITCH.LT.1.0) GO TO 29
      IF (DT.NE.HOLDT) GO TO 30
      NUMLIP=NUMLIP+1
      ISAVE(NUMLIP)=I
      JSAVE(NUMLIP)=J
      GO TO 30
   29 IF (KBUG.EQ.1) WRITE(6,4) I,J,DEPTH(I,J),DEPLIM(I,J),THIK,DT
      IF (DT.LT.HOLDT) HOLDT=DT
   30 CONTINUE
      SWITCH=SWITCH+1.0
      IF (SWITCH.EQ.1.0) GO TO 10
      DT=HOLDT
      WRITE(6,3) DT
      RETURN
C
C.....PRINT HISTORY OF DELTA GROWTH
   40 WRITE(6,5) TITLE, (J, J=1,NCOLS)
      DO 70 I=1,NROWS
      DO 60 J=1,NCOLS
      NUM(J)=0
      DO 50 K=1,NUMLIP
   50 IF (I.EQ.ISAVE(K).AND.J.EQ.JSAVE(K)) NUM(J)=K
   60 CONTINUE
   70 WRITE(6,6) I, (NUM(J), J=1,NCOLS)
      RETURN
    1 FORMAT(1H1, 15A4//// 1X, 27HTIME INCREMENT CALCULATIONS//
     1 1X, 'TIME INCREMENT    ', I5//)
    2 FORMAT(1H0, 3X, 3HROW, 2X, 3HCOL, 8X, 5HDEPTH, 7X, 11HDEPTH LIMIT,
     1  9X, 9HTHICKNESS, 7X, 26HTIME REQUIRED TO FILL CELL)
    3 FORMAT(1H0, 25HSHORTEST TIME INTERVAL = , F10.5, 2X, 5HYEARS)
    4 FORMAT(1H , 2I5, 2(5X, F10.5), 5X, F15.5, 10X, F15.5)
    5 FORMAT(1H1, 15A4/// 1X, 31HHISTORY OF DELTA GROWTH IN PLAN///
```

```
     1  5X, 25I5)
    6 FORMAT(1H // I3, 2X, 25I5)
      END
C
C     ***************************
      SUBROUTINE PLTPNT(U,V,L, M)
C     ***************************
C
      DIMENSION X(4), Y(4)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM5/   ISAVE(50), JSAVE(50), NUMLIP
      GO TO (1,2,3),L
    1 CALL PLOT1(3.0, 0.0, 23)
      SCF=PLTWID/FLOAT(NCOLS)
      DOTHYT=0.005*PLTWID
      A=CELSIZ*SLOT/SCF
C
C.....LABEL GRID
      CALL SYMBL1(0.0, 0.0, 0.15, TITLE, 90.0, 60)
      CALL SYMBL1(0.5, 0.0, 0.15, 17HSCALE - 1 INCH = , 90.0, 17)
      CALL NUMBR1(0.5, 3.0, 0.15, A, 90.0, 3)
      CALL SYMBL1(0.5, 5.0, 0.15, UNITS, 90.0, 4)
      CALL SYMBL1(1.0, 0.0, 0.15, 31HPARTICLE DIAMETER =        MMS.,
     1  90.0, 31)
      A=DIAM(M)
      CALL NUMBR1(1.0, 2.6, 0.15, A, 90.0, 3)
      CALL SYMBL1(1.5, 0.0, 0.15, 17HINCREMENT NUMBER , 90.0, 17)
      A=NT
      CALL NUMBR1(1.5, 2.5, 0.15, A,      90.0, -1)
      CALL PLOT1(3.0, 0.0, 23)
C
C.....DRAW GRID LINES - VERTICAL
      X(3)=0.
      Y(3)=0.
      X(4)=1.
      Y(4)=1.
      NCP1=NCOLS+1
      DO 50 J=1,NCP1, 2
      RJ=J
      Y(1)=(RJ-1.0)*SCF
      Y(2)=Y(1)
      X(1)=0.0
      X(2)=FLOAT(NROWS)*SCF
      CALL LINE1(X, Y, 2, 1, 0,LL)
      IF (J.EQ.NCP1) GO TO 50
      Y(1)=RJ*SCF
      Y(2)=Y(1)
      X(1)=FLOAT(NROWS)*SCF
      X(2)=0.0
      CALL LINE1(X, Y, 2, 1, 0,LL)
   50 CONTINUE
C
C.....      -  HORIZONTAL
      NRP1=NROWS+1
      DO 60 I=1,NRP1, 2
      RI=I
      X(1)=(RI-1.0)*SCF
      X(2)=X(1)
```

```
      Y(1)=0.0
      Y(2)=FLOAT(NCOLS)*SCF
      CALL LINE1(X, Y, 2, 1, 0, LL)
      IF (I.EQ.NRP1) GO TO 60
      X(1)=RI*SCF
      X(2)=X(1)
      Y(1)=FLOAT(NCOLS)*SCF
      Y(2)=0.0
      CALL LINE1(X, Y, 2, 1, 0, LL)
   60 CONTINUE
C.....PLACE X IN FILLED CELLS
      IF (NUMLIP.LT.1) GO TO 80
      DO 70 K=1,NUMLIP
      A=(FLOAT(ISAVE(K))-0.25)*SCF
      B=(FLOAT(JSAVE(K))-0.64286)*SCF
   70 CALL SYMBL1(A, B, SCF*0.5, 1HX, 90.0, 1)
   80 CONTINUE
      RETURN
    2 CALL SYMBL1(U*SCF, V*SCF, DOTHYT, 1HO, 90.0, 1)
      RETURN
    3 CALL PLOT1(FLOAT(NROWS)*SCF, 0.0, -3)
      RETURN
      END
C
C     ********************
      FUNCTION FACIES(I,J)
C     ********************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM4/ NSTAND, FACSYM(10), FACNAM(10,2), STNDRD(10,5)
C
C.....CLASSIFIES SAMPLES INTO FACIES USING DISTANCE COEFFICIENTS
      DATA BLANK /1H /
      A=0.0
      DO 5 L=1,NFRACT
    5 A=A+TEMP(I,J,L)
      IF (A.GT.0.001) GO TO 6
      FACIES=BLANK
      RETURN
    6 BIG=0.0
      NHOLD=0
      DO 20 N=1,NSTAND
      DIST=0.0
      DO 10 L=1,NFRACT
   10 DIST=DIST+(TEMP(I,J,L)/A-STNDRD(N,L))**2
      DIST=1.0-SQRT(DIST/FLOAT(NFRACT))
      IF (DIST.LT.BIG) GO TO 20
      BIG=DIST
      NHOLD=N
   20 CONTINUE
      FACIES=FACSYM(NHOLD)
      RETURN
      END
C
C     *********************
      SUBROUTINE SMOOTH(KB)
C     *********************
C
```

```
C
C.....SMOOTHE VALUES IN TEMP ARRAY
      DIMENSION DUM(50)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG, UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      NSTART=(NSM+1)/2
      IF (KB.EQ.2)   GO TO 5
      GO TO (5, 40, 5, 40, 5), KDEL
C
C.....BY COLUMN2
    5 DO 30 L=1,NFRACT
      NSTOP=NROWS-NSTART+1
      DO 30 J=1,NCOLS
      DO 20 I=NSTART, NSTOP
      DUM(I)=0.0
      DO 10 M=1,NSM
      INDEX=I+M-NSTART
   10 DUM(I)=DUM(I)+TEMP(INDEX,J,L)
   20 DUM(I)=DUM(I)/FLOAT(NSM)
      DO 30 I=NSTART, NSTOP
   30 TEMP(I,J,L)=DUM(I)
      IF (KB.EQ.2) GO TO 40
      RETURN
C
C.....BY ROWS
   40 DO 70 L=1,NFRACT
      NSTOP=NCOLS-NSTART+1
      DO 70 I=1,NROWS
      DO 60 J=NSTART, NSTOP
      DUM(J)=0.0
      DO 50 M=1,NSM
      INDEX=J+M-NSTART
   50 DUM(J)=DUM(J)+ TEMP(I,INDEX, L)
   60 DUM(J)=DUM(J)/FLOAT(NSM)
      DO 70 J=NSTART, NSTOP
   70 TEMP(I,J,L)=DUM(J)
      RETURN
      END
C
C     ***************
      SUBROUTINE FANJ
C     ***************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM3/ SEDLOD(5),SETVEL(5), FANANG(10), FANTIM(10), NUMFAN,
     1 FANDEV, FANLIM, NBUG, KPLOT, SHRVEL, BETA, VONKAR,TOTLOD(5),
     2 BWNDRY, NTIM
      RAD=0.017453312
      IF (NUMFAN.GT.1) GO TO 4
      NUMFAN=1
      FANANG(1)=0.0
      FANTIM(1)=TIMFAC
      RETURN
C.....FIND ANGLES OF FANNING, AND DURATION AT EACH POSITION
    4 FANTOT=0.
      DO 20 M=1,NUMFAN
```

```
C.....PICK RANDOM NUMBER, MEAN=0, ST.DEV= FANDEV
    5 SUM=0.
      DO 10 N=1,12
      CALL RANDU(IX,IY,YFL)
      IX=IY
   10 SUM=SUM+YFL
      FANANG(M)=(SUM-6.0)*FANDEV
      IF (ABS(FANANG(M)).GT.FANLIM) GO TO 5
C.....LET DURATION AT THIS ANGLE BE PROPORTIONAL TO HT. OF GAUSSUAN
C.....CURVE AT THIS DISTANCE FROM THE MEAN
      FANTIM(M)=EXP(-ABS(FANANG(M))/(2.*FANDEV))
      FANANG(M)=FANANG(M)*RAD
   20 FANTOT=FANTOT+FANTIM(M)
C.....SCALE FANTIM() SO THAT TOTAL TIME=TIMFAC
      DO 30 M=1,NUMFAN
   30 FANTIM(M)=FANTIM(M)*TIMFAC/FANTOT
C.....WRITE OUT THIS INFORMATION
   35 WRITE(6,1) TITLE, FANDEV, FANLIM
      DO 40 M=1,NUMFAN
      A=FANANG(M)/RAD
      B=(DELANG+FANANG(M))/RAD
   40 WRITE(6,2) M, A, B, FANTIM(M)
      RETURN
    1 FORMAT (1H1,15A4///1X,39HANGLE AND DURATION OF EACH FAN POSITION//
     1/ 5X, 21HSTANDARD DEVIATION = , F10.5, 9H  DEGREES//
     2  5X, 17HABSOLUTE LIMIT = , F10.5, 9H  DEGREES//
     3  5X, 6HNUMBER, 18X, 5HANGLE, 18X, 7HAZIMUTH,10X, 17HDURATION IN Y
     4EARS)
    2 FORMAT(1H0, I8, 3F25.3)
      END
C
C     ****************************************************************
      SUBROUTINE DRWSLC(NUM, IORIEN, SEELEV, EXAGVT, XLENG, YLENG)
C     ****************************************************************
C
      DIMENSION BOTPRF(50,16), X(50), Y(50), RC(2), ORIEN(4)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      DATA   RC, ORIEN    /4H ROW, 4H COL,
     1  4HNORT, 4HSOUT, 4HEAST, 4HWEST/
C
C.....READ ORIGINAL BOTTOM PROFILE
      REWIND 13
      READ(13)  ((BOTPRF(I,J), J=1,NCOLS), I=1,NROWS)
      NX=NROWS
      IF (NUM.GT.0) NX=NCOLS
C
C.....FIND LARGEST BOTTOM PROFILE VALUE
      BIG=BOTPRF(1,1)
      DO 5 I=1,NROWS
      DO 5 J=1,NCOLS
    5 IF (BOTPRF(I,J).GT.BIG) BIG=BOTPRF(I,J)
C
C.....DETERMINE SCALE FACTORS
      XMAX=CELSIZ*SLOT*FLOAT(NX-1)
      YMAX=BIG+SEELEV*1.5
      SCALEV=-YLENG/YMAX
      IF (EXAGVT.GT.0.001) GO TO 8
C
```

```
C.....XLENG IS SUPPLIED,  FIND EXAGVT
    6 SCALEH=XLENG/XMAX
      EXAGVT=-SCALEV/SCALEH
      GO TO 9
C
C.....EXAGVT SUPPLIED, FIND XLENG
    8 SCALEH=-SCALEV/EXAGVT
      XLENG=SCALEH*XMAX
      IF (XLENG.LT.60.0) GO TO 9
      XLENG=60.0
      GO TO 6
C
C.....PREPARE FOR PRINTING HEADINGS
    9 A=-SCALEV
      ND=IABS(NUM)
      E=1.0/A
      F=1.0/SCALEH
      D=ND
      IF (NUM.GT.0) GO TO 10
      B=RC(2)
      C=ORIEN(3)
      IF (IORIEN.LT.1)     C=ORIEN(4)
      GO TO 11
   10 B=RC(1)
      C=ORIEN(1)
      IF (IORIEN.LT.1) C=ORIEN(2)
   11 CONTINUE
      WRITE(6,3) B, ND, C, SCALEH, A, EXAGVT, XLENG, XMAX, YLENG, YMAX
C
C.....INITIALISE PLOTTING ROUTINES
      CALL PLOT1(3.0, 10.0, 23)
C
C.....DRAW HEADINGS
      CALL SYMBL1(0.0, 0.0, 0.15, TITLE, 0.0, 60)
      CALL SYMBL1(0.0, -0.5, 0.15, B, 0.0, 4)
      CALL NUMBR1(1.0, -0.5, 0.15, D, 0.0, -1)
      CALL SYMBL1(1.5, -0.5, 0.15, 6HFACING, 0.0, 6)
      CALL SYMBL1(2.3, -0.5, 0.15,  C,  0.0, 4)
      CALL SYMBL1(0.0,  -1.0,  0.15,  28HHORIZONTAL SCALE   1 INCH = ,
     1  0.0, 28)
      CALL NUMBR1(3.8,  -1.0,  0.15, F, 0.0, 3)
      CALL SYMBL1(4.8,  -1.0,  0.15, UNITS,  0.0,  4)
      CALL SYMBL1(0.0,  -1.5,  0.15,  26HVERTICAL SCALE   1 INCH = ,
     1  0.0, 26)
      CALL NUMBR1(3.8,  -1.5,  0.15,  E,  0.0, 3)
      CALL SYMBL1(4.8,  -1.5,  0.15,  UNITS,  0.0, 4)
      CALL SYMBL1(0.0,  -2.0,  0.15,  26HVERTICAL EXAGGERATION = X ,
     1  0.0,  26)
      CALL NUMBR1(3.8, -2.0, 0.15, EXAGVT, 0.0, 3)
      CALL PLOT1(10.0,  -10.0,  23)
C
C.....DRAW MARGINS
      X(1)=0.0
      Y(1)=0.0
      X(2)=0.0
      Y(2)=YLENG
      X(3)=XLENG
      Y(3)=YLENG
      X(4)=XLENG
      Y(4)=0.0
      X(5)=X(1)
```

```
      Y(5)=Y(1)
      X(6)=0.
      Y(6)=0.
      X(7)=1.
      Y(7)=1.
      CALL LINE1(X, Y, 5, 1, 0, LL)
C
C.....MOVE PLOTTING ORIGIN TO SEA LEVEL
      CALL PLOT1(0.0,YLENG+SEELEV*SCALEV, 23)
C
C.....DRAW SEA LEVEL
      X(1)=0.0
      Y(1)=0.0
      X(2)=XLENG
      Y(2)=0.0
      X(3)=0.
      Y(3)=0.
      X(4)=1.
      Y(4)=1.
      CALL LINE1(X, Y, 2, 1, 0, LL)
C
C.....FOR EACH TIME INCREMENT PLOT BOTTOM PROFILE
      A=CELSIZ*SLOT*SCALEH
      N=1
      X(NX+1)=0.
      Y(NX+1)=0.
      X(NX+2)=1.
      Y(NX+2)=1.
      NTIMP1=NT+1
      DO 130 NT1=1, NTIMP1
      IF (NT.EQ.1) GO TO 30
      N=N+1
   30 J=-NUM
      IF (NUM.GT.0) I=NUM
      DO 110 INDEX=1,NX
      IF (NUM) 40,40,70
   40 I=INDEX
      IF (IORIEN.LT.1) I=NROWS-INDEX+1
      GO TO 100
   70 J=INDEX
      IF (IORIEN.LT.1) J=NCOLS-INDEX+1
  100 CONTINUE
      X(INDEX)=FLOAT(INDEX-1)*A
      Y(INDEX)=BOTPRF(I,J)*SCALEV
  110 CONTINUE
      CALL LINE1(X, Y, NX, 1, 0, LL)
C
C.....UPDATE BOTTOM PROFILE
  115 IF (NT1.EQ.NTIMP1) GO TO 130
      READ(13)  (((TEMP(I,J,L), L=1,NFRACT), J=1,NCOLS), I=1,NROWS)
      DO 120 I=1,NROWS
      DO 120 J=1,NCOLS
      DO 120 L=1,NFRACT
  120 BOTPRF(I,J)=BOTPRF(I,J)-TEMP(I,J,L)
  130 CONTINUE
C
C.....MOVE PLOTTING ORIGIN FORWARD TO NEW POSITION
      CALL PLOT1(XLENG+10.0, -(YLENG+SEELEV*SCALEV), -3)
      RETURN
    3 FORMAT(1H1, 40HSTRATIGRAPHIC SECTION PLOTTED ON CALCOMP///
     1 1X, A4, I5, 2X, 6HFACING, A4//  1X, 19HHORIZONTAL SCALE = , F7.2
```

```
     2  // 1X, 17HVERTICAL SCALE = , F7.2//  1X, 24HVERTICAL EXAGGERATIO
     3N = , F7.2//  1X, 8HXLENG = , F7.2,  5X, 7HXMAX = , F7.2//
     4  1X, 8HYLENG = , F7.2, 5X, 7HYMAX = , F7.2)
      END
C
C     ***************
      SUBROUTINE MAPS
C     ***************
C
      DIMENSION NUM(25), DUM(25)
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COM4/ NSTAND, FACSYM(10), FACNAM(10,2), STNDRD(10,5)
      SCALE=CELSIZ*SLOT*2.0
C
C.....PRINT THICKNESS MAPS
      DO 20 L=1,NFRACT
      WRITE(6,1) TITLE, L, DIAM(L), UNITS
      WRITE(6,2) SCALE, UNITS, NT,         (J, J=1,NCOLS)
      DO 20 I=1,NROWS
      DO 10 J=1,NCOLS
   10 NUM(J)=TEMP(I,J,L)*10.0+0.5
   20 WRITE(6,3) I, (NUM(J), J=1,NCOLS)
C
C.....PRINT FACIES MAPS
      WRITE(6,4) TITLE, (FACSYM(N), (FACNAM(N,M), M=1,2), N=1,NSTAND)
      WRITE(6,2) SCALE, UNITS, NT,         (J, J=1,NCOLS)
      DO 40 I=1,NROWS
      DO 30 J=1,NCOLS
   30 DUM(J)=FACIES(I,J)
   40 WRITE(6,5) I, (DUM(J), J=1,NCOLS)
C
C.....PRINT DEPTH MAP
      WRITE(6,6) TITLE, UNITS
      WRITE(6,2) SCALE, UNITS, NT,         (J, J=1,NCOLS)
      DO 60 I=1,NROWS
      DO 50 J=1,NCOLS
   50 NUM(J)=DEPTH(I,J)+0.5
   60 WRITE(6,3) I, (NUM(J), J=1,NCOLS)
      RETURN
    1 FORMAT(1H1, 15A4// 1X, 52HMAP SHOWING THE DISTRIBUTION OF SIZE FRA
     1CTION NUMBER, I5, 4H OF , F7.2, 14H MMS. DIAMETER// 1X, 30HVALUES
     2REPRESENT THICKNESS IN , A4, 5H X 10)
    2 FORMAT(1H0, 17HSCALE - 1 INCH = ,F15.2,1X,A4//1X,14HTIME INCREMENT
     1,I5,5X                        //// 7X, 25I5)
    3 FORMAT(1H // I4, 3X, 25I5)
    4 FORMAT(1H1, 15A4// 1X, 38HMAP SHOWING THE DISTRIBUTION OF FACIES//
     1  1X, 9HLEGEND - , ( /10X, 5(A1, 3H = , 2A4, 5X)))
    5 FORMAT(1H // I4, 3X, 25(4X, A1))
    6 FORMAT(1H1, 15A4// 1X, 9HDEPTH MAP// 1X, 20HVALUES EXPRESSED AS ,
     1  A4)
      END
C
C     **********************
      SUBROUTINE PEPPER(K,KK)
C     **********************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
```

```
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA,KDEL
      COMMON /COMB/ XSTOR(50,50), YSTOR(50,50), XTX(100), YTY(100)
C
C.....FOR EACH MAIN POINT COMPUTE IEXTRA RANDOM 'PEPPER POT' POINTS
C.....WITHIN THE RANGE BOUNDED BY HALF THE DISTANCE TO NEIGHBOURING
C.....MAIN POINTS
C.....TAKING THE X-COORDINATE
      IF (KK.GT.1) GO TO 5
      XRANGE=XSTOR(KK+1,K)-XSTOR(KK,K)
      GO TO 15
    5 IF (KK.LT.NROWSG) GO TO 10
      XRANGE=XSTOR(KK,K)-XSTOR(KK-1,K)
      GO TO 15
   10 XRANGE=(XSTOR(KK+1,K)-XSTOR(KK-1,K))/2.0
   15 DO 16 IEX=1, IEXTRA
      CALL RANDU(IX,IY,YFL)
      IX=IY
   16 XTX(IEX)=(YFL-0.5)*XRANGE+XSTOR(KK,K)
C
C.....TAKING THE Y-COORDINATE
      IF (K.GT.1) GO TO 20
      YRANGE=YSTOR(KK,K+1)-YSTOR(KK,K)
      GO TO 30
   20 IF (K.LT.NCOLSG) GO TO 25
      YRANGE=YSTOR(KK,K)-YSTOR(KK,K-1)
      GO TO 30
   25 YRANGE=(YSTOR(KK,K+1)-YSTOR(KK,K-1))/2.0
   30 DO 35 IEX=1, IEXTRA
      CALL RANDU(IX,IY,YFL)
      IX=IY
   35 YTY(IEX)=(YFL-0.5)*YRANGE+YSTOR(KK,K)
      RETURN
      END
C
C     **********************************
      FUNCTION ROMBUG(DUMF, X, A, B, EPS)
C     **********************************
C
C.....ROMBERG INTEGRATION METHOD TRANSLATED FROM STANFORD ALGOL
C.....PROCEDURE BY R.DOBSON
C.....DUMF MUST BE FUNCTION SUBROUTINE  FOR SOLVING F(X)- EXTERNAL
C.....A=LOWER LIMIT, B=UPPER LIMIT, EPS=TOLERANCE
      DIMENSION T(15)
      R = B-A
      X = A
      VAL = DUMF(X)
      X = B
      VAL = (VAL+DUMF(X))*0.5
      T(1) = VAL
      N = 1
      DO 111 I = 1,14
      U = 0.0
      N2 = N+N
      FN2 = N2
      S = R/FN2
      N21 = N2-1
      DO 112 J = 1,N21,2
      FJ = J
      X = A+FJ*S
  112 U = U+DUMF(X)
```

```
      FN = N
      T(I+1) = (U/FN+T(I))/2.
      K = 1
      L = I+1
      DO 113 J = 1,I
      L = L-1
      FK = K*4
  113 T(L) = T(L+1)+(T(L+1)-T(L))/(FK-1.)
      N = N2
      IF (ABS(VAL-T(1)) .LE. EPS*ABS(T(1)) .AND. N .NE. 1) GO TO 110
  111 VAL = T(1)
      Z = T(1)*R
  110 ROMBUG = T(1)*R
      RETURN
      END
C
C     ****************
      FUNCTION FINT(Z)
C     ****************
C
      COMMON /COM1/ TEMP(50,16,5), DEPTH(50,16), DEPLIM(50,16),
     1 DIAM(5), TITLE(15), STMDEP, CELSIZ, NROWS, NCOLS, NFRACT, SLOT,
     2 NCOLSG,NROWSG,UNITS, DELANG, NT, IX, LIP, TIMFAC, NSM, DELTI,
     3 DELTJ, PLTWID, KBUG, IEXTRA, KDEL
      COMMON /COM7/   ZEXPON, A
C.....CALCULATES VALUE OF CONCENTRATION FUNCTION FOR ANY HT, ABOVE BED
      FINT=1.0+A*(1.0+ALOG(Z/STMDEP))
      B=0.0
      IF (STMDEP.GT.Z) B=(STMDEP/Z-1.0)**ZEXPON
      FINT=FINT*B
      RETURN
      END
/*
```

Table 3.- Data for test run.

```
1376.      TEST DECK FOR DELTA SIMULATION                                    MTRS
1377.         30   30000.0     3       .001 0.02    .4   1.0   0.0   0.0 9.81
1378.          3
1379.       1.00  0.0  0.2   2660000       1.0
1380.       0.50  0.0  0.2   2660000       5.0
1381.       0.25  0.0  0.2   2660000      10.0
1382.          5
1383.      V.COARSE    $  0.1 0.45 0.45
1384.        COARSE    *  0.0  0.3  0.7
1385.        MEDIUM    +  0.0  0.2  0.8
1386.          FINE    -  0.0  0.1  0.9
1387.        V.FINE    =  0.0  0.0  1.0
1388.          1    1    1
1389.         14   16  0.0  1.0
1390.         10   10  0.0  7.5  180
1391.          0    0  500    3   99   10
1392.          1    6    1
1393.      (10F5.0)
1394.         50
1395.         10   20   10
1396.          0    0    0    0    0
1397.      FINISH
1398.      /*
COMMAND ?
```

Table 4.- Channel characteristics.

```
TEST DECK FOR DELTA SIMULATION


  CHANNEL CHARACTERISTICS                              SLOTS                   MTRS

      DEPTH                                            0.10000                 3.00000

      SLOPE                                                                                    0.00100

      DARCY WEISBACH FRICTION COEFFICIENT                                                      0.02000

      VON KARMAN'S CONSTANT                                                                    0.40000

      NOMINAL LOWER BOUNDARY                           0.13333E-03             0.40000E-02

      SHEAR VELOCITY                                   0.57184E-02  PER SEC    0.17155   PER SEC

      AVERAGE VELOCITY                                 0.11437E 00  PER SEC    3.43103   PER SEC

      WATER DISCHARGE                                  0.11437E-01  PER SEC  308.79272   PER SEC
```

Table 5.- Other parameters.

```
SIZE OF SIMULATION RUN

     NUMBER OF TIME INCREMENTS            1

     SIZE OF MAIN GRID        14  ROWS        16  COLUMNS

     LENGTH OF CELL SIDE     0.69937  SLOTS            20.98112  MTRS

     AREA OF MAIN GRID           109.56288  SQUARE SLOTS                 98606.56250  SQUARE MTRS

     SIZE OF RIVER GRID       10 ROWS        10 COLS




DELTA ORIENTATION

     COORDINATES OF RIVER MOUTH          ROW       0.0      COLUMN       7.5

     FLOW AZIMUTH      180.00000   DEGREES

     RIVER WIDTH        1.42986   CELL WIDTHS           30.00000    MTRS




MAXIMUM DISTANCE OF TRAVEL ALONG JET CENTRELINE FOR EACH PARTICLE SIZE

          FRACTION                    DIAM(MMS)                    DISTANCE IN SLOTS           DISTANCE IN MTRS

              1                       1.00000                         3.48532                       104.55974

              2                       0.50000                         5.52780                       165.83389

              3                       0.25000                         9.79120                       293.73584
```

Table 6.- Total sediment load.

```
   TEST DECK FOR DELTA SIMULATION

        LOAD EXPRESSED AS GRAMS PER YEAR

        CALCULATED LOAD COMPUTED USING MEYER PETER DISCHARGE FORMULA

        SIZE FRACTION      DIAM(MMS)     GIVEN LOAD   CALCULATED LOAD


               1         0.10000E 01    0.10000E 01    0.74291E 11

               2         0.50000E 00    0.50000E 01    0.37146E 12

               3         0.25000E 00    0.10000E 02    0.74291E 12

         TOTALS                         0.16000E 02    0.11887E 13
```

Table 7.- Sediment characteristics.

```
SEDIMENT CHARACTERISTICS

    NUMBER OF SIZE FRACTIONS      3


  FRACTION    1

       LOAD IN GRAMS PER YEAR                                    0.74291E 11

       LOAD AS CELL SQUARE THICKNESS IN MTRS ACCUMULATED OVER     1.00 YEARS                  79.30663

       PARTICLE DIAMETER                                           1.00000  MMS

       SETTLING VELOCITY                                                0.98419E-01  MTRS PER SEC

       DENSITY                                                          0.26600E 07 GRAMS PER CUBIC MTRS

       POROSITY                                                    0.20000


  FRACTION    2

       LOAD IN GRAMS PER YEAR                                    0.37146E 12

       LOAD AS CELL SQUARE THICKNESS IN MTRS ACCUMULATED OVER     1.00 YEARS                 396.53296

       PARTICLE DIAMETER                                           0.50000  MMS

       SETTLING VELOCITY                                                0.62013E-01  MTRS PER SEC

       DENSITY                                                          0.26600E 07 GRAMS PER CUBIC MTRS

       POROSITY                                                    0.20000


  FRACTION    3

       LOAD IN GRAMS PER YEAR                                    0.74291E 12

       LOAD AS CELL SQUARE THICKNESS IN MTRS ACCUMULATED OVER     1.00 YEARS                 793.06616

       PARTICLE DIAMETER                                           0.25000  MMS

       SETTLING VELOCITY                                                0.32162E-01  MTRS PER SEC

       DENSITY                                                          0.26600E 07 GRAMS PER CUBIC MTRS

       POROSITY                                                    0.20000
```

Table 8.- Sediment discharge profiles.

```
TEST DECK FOR DELTA SIMULATION

      SEDIMENT DISCHARGE PROFILE AT CHANNEL ORIFICE


      DISCHARGE EXPRESSED AS A/C GRID CELL THICKNNESS IN MTRS PER    1.00 YEARS

      HEIGHT ABOVE BOTTOM EXPRESSED IN MTRS

                              SIZE FRACTIONS
   ROW    HEIGHT                    1                 2                  3
    10    2.85019             0.36952E-03       0.54491E-01        0.84473E 00
     9    2.55059             0.18546E-02       0.16182E 00        0.15498E 01
     8    2.25100             0.45024E-02       0.28331E 00        0.20639E 01
     7    1.95139             0.87826E-02       0.42976E 00        0.25435E 01
     6    1.65180             0.15681E-01       0.61509E 00        0.30351E 01
     5    1.35220             0.27243E-01       0.86338E 00        0.35768E 01
     4    1.05260             0.48277E-01       0.12232E 01        0.42201E 01
     3    0.75300             0.92821E-01       0.18138E 01        0.50655E 01
     2    0.45340             0.22345E 00       0.30517E 01        0.63935E 01
     1    0.15380             0.30484E 01       0.11351E 02        0.10359E 02

 TOTAL FOR THE COLUMN         0.34714E 01       0.19848E 02        0.39652E 02

 TOTAL FOR THE GRID           0.69427E 02       0.39695E 03        0.79303E 03
```

Table 9.- Limiting depth surface.

```
MAP SHOWING MINIMUM DEPTHS TO WHICH DELTA CAN BUILD

VALUES EXPRESSED AS MTRS

        1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16

  1   0.0   0.0   0.0   0.0   0.0   0.0   0.50  3.00  0.50  0.0   0.0   0.0   0.0   0.0   0.0   0.0

  2   0.0   0.0   0.0   0.0   0.0   0.0   0.87  3.00  0.87  0.0   0.0   0.0   0.0   0.0   0.0   0.0

  3   0.0   0.0   0.0   0.0   0.0   0.0   1.04  3.00  1.04  0.0   0.0   0.0   0.0   0.0   0.0   0.0

  4   0.0   0.0   0.0   0.0   0.0   0.01  1.14  2.95  1.14  0.01  0.0   0.0   0.0   0.0   0.0   0.0

  5   0.0   0.0   0.0   0.0   0.0   0.03  1.23  2.91  1.23  0.03  0.0   0.0   0.0   0.0   0.0   0.0

  6   0.0   0.0   0.0   0.0   0.00  0.08  1.32  2.85  1.32  0.08  0.00  0.0   0.0   0.0   0.0   0.0

  7   0.0   0.0   0.0   0.0   0.00  0.14  1.39  2.80  1.39  0.14  0.00  0.0   0.0   0.0   0.0   0.0

  8   0.0   0.0   0.0   0.00  0.01  0.21  1.45  2.75  1.45  0.21  0.01  0.00  0.0   0.0   0.0   0.0

  9   0.0   0.0   0.00  0.00  0.02  0.34  1.58  2.64  1.58  0.34  0.02  0.00  0.00  0.00  0.00  0.00

 10   0.0   0.0   0.00  0.00  0.06  0.47  1.66  2.53  1.66  0.47  0.06  0.00  0.00  0.00  0.00  0.00

 11   0.0   0.00  0.00  0.01  0.10  0.59  1.71  2.43  1.71  0.59  0.10  0.01  0.00  0.00  0.00  0.00

 12   0.0   0.00  0.00  0.02  0.16  0.71  1.74  2.34  1.74  0.71  0.16  0.02  0.00  0.00  0.00  0.00

 13   0.00  0.00  0.00  0.04  0.23  0.81  1.75  2.25  1.75  0.81  0.23  0.04  0.00  0.00  0.00  0.00

 14   0.00  0.00  0.01  0.06  0.30  0.90  1.75  2.18  1.75  0.90  0.30  0.06  0.01  0.00  0.00  0.00
```

Table 10.- Fan positions.

```
TEST DECK FOR DELTA SIMULATION

ANGLE AND DURATION OF EACH FAN POSITION

    STANDARD DEVIATION =   10.00000  DEGREES
    ABSOLUTE LIMIT =   20.00000  DEGREES
    NUMBER              ANGLE            AZIMUTH        DURATION IN YEARS
       1              -16.996            163.004                 0.061
       2                0.601            180.601                 0.138
       3               15.167            195.167                 0.067
       4                4.286            184.286                 0.115
       5               -0.966            179.034                 0.135
       6               10.587            190.587                 0.084
       7                1.188            181.188                 0.134
       8                9.506            189.506                 0.088
       9               -9.641            170.359                 0.088
      10                8.818            188.818                 0.091
```

Table 11.- Trajectory constants.

```
TEST DECK FOR DELTA SIMULATION


      TIME INCREMENT          1


      TABLE OF TRAJECTORY CONSTANTS

   K          XD        YD        YF       XLIP      YLIP        NLIP      SUMZND      SUMZFE       KLIST

   1       4.98560   0.02500   0.02500   0.0       0.02500      3      4.98560      0.30018        1
   2       4.46080   0.07500   0.07500   0.0       0.07500      3      4.46080      0.80297        1
   3       3.93600   0.12500   0.12500   0.0       0.12500      3      3.93600      1.36425        1
   4       3.41120   0.17500   0.18000   0.0       0.17500      3      3.41120      1.89095        1
   5       2.88640   0.22500   0.24000   0.0       0.22500      3      2.88640      2.50225        1
   6       2.36160   0.27500   0.30500   0.0       0.27500      3      2.36160      3.11495        1
   7       1.83680   0.32500   0.37500   0.0       0.32500      3      1.83680      3.88554        1
   8       1.31200   0.37500   0.46500   0.0       0.37500      3      1.31200      4.83597        1
   9       0.78720   0.42500   0.58000   0.0       0.42500      3      0.78720      6.46253        1
  10       0.26240   0.47500   0.79000   0.0       0.47500      3      0.26240     11.25587        1
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Table 12.- Sediment budget. Total thickness of deposit.

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TEST DECK FOR DELTA SIMULATION

          TIME INCREMENT    1           DURATION          0.15531    YEARS

                     SIZE                                     THICKNESS (MTRS)

                        1                                         8.84

                        2                                        56.48

                        3                                       118.15

                                                                183.46
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APPENDIX A: Mathematical Notation

Where two symbols are given, the capital letter denotes a dimensional quantity and the lower case letter the corresponding dimensionless quantity.

B, b	river width
c	sediment concentration
c_a	sediment concentration at elevation $z = a$
c_{max}	sediment concentration at $y = 0$ for a given x and z
D, d	river depth
$F(z_i, z_j)$	fraction of total sediment discharge in river passing between elevations z_i and z_j
k	von Karman constant
Q_s, q_s	sediment discharge (weight/unit time)
r	$1/2(1/\sigma_m^2 + 1/\sigma_s^2)^{1/2}$
$s(z_i, z_j)$	sediment discharge/unit width in the river passing between elevations z_i and z_j
t	vertical thickness
U, u	streamwise velocity in jet
U_*, u_*	shear velocity in river
V	velocity in river
$\bar{V}$	mean velocity in river
w	vertical velocity in jet
W_s, w_s	settling velocity of sediment
X, x	streamwise coordinate
x_d	x-coordinate of the point on the boundary between zones 1 and 2 on a particle trajectory
x_t	x-coordinate of terminal point of particle trajectory
Y, y	transverse coordinate
y_t	y-coordinate of terminal point of particle trajectory
Z, z	vertical coordinate
β	ratio between the diffusion coefficients of sediment and momentum
ϵ	small length (equal to four grain diameters in this study)
σ_m	standard deviation of streamwise velocity profile in the jet for $x > 5.248$
σ_s	standard deviation of sediment concentration profile in the jet for $x > 5.248$
——_0	denotes quantity taken at $x = 0$
——_1	denotes quantity taken at $x = 5.248 = x_1$

APPENDIX B: Solution of Equation 11

In solving equation (11) for x_t the following quantities are known: y_0, z_0, u_*, d, w_s, k and ϵ. First the left-hand side is evaluated as

$$I_1 = \int_{\epsilon}^{z_0} f_1(z)\,dz = z_0 - \epsilon + u_*/k\,(z_0 \ln z_0/d + \epsilon \ln d/\epsilon).$$

The second integral

$$I_2 = \int_0^{x_d} w_s dx$$

is computed using equation (6) to determine x_d. If $I_2 > I_1$, the trajectory terminates in zone 1 and x_t is found from

$$I_1 = \int_0^{x_t} w_s dx = w_s x_t \ .$$

If $I_2 < I_1$, the third integral

$$I_3 = \int_{x_d}^{5.248} w_s dx/f_2(x,y)$$

is computed. This was done numerically. If $I_2 < I_1 < I_2 + I_3$ the trajectory terminates in zone 2 and x_t is found from

$$I_1 = I_2 + \int_{x_d}^{x_t} w_s dx/f_2(x,y)$$

using a numerical step-by-step method.

If $I_1 > I_2 + I_3$ the particle enters zone 3. The fourth integral

$$I_4 = \int_{5.248}^{x_t} w_s dx/f_3(x,y)$$

is evaluated by substitution from equations (10) and (3). After integration we find

$$I_4 = 0.29\, w_s \, [\, x_t^{3/2} - 12.02\,] \ \exp\left\{ 1.55 y_1^2 \right\}$$

and y_1 is known from equation (7). The terminal coordinate x_t is now found from $I_1 = I_2 + I_3 + I_4$.

KANSAS GEOLOGICAL SURVEY COMPUTER PROGRAM
THE UNIVERSITY OF KANSAS, LAWRENCE

PROGRAM ABSTRACT

Title (If subroutine state in title):

Mathematical model and FORTRAN IV program for computer simulation of deltaic sedimentation.

Date: April 1968

Author, organization: G.F. Bonham-Carter and Alex J. Sutherland
Department of Geology, Stanford University

Direct inquiries to:

Name: G.F. Bonham-Carter

Address: Department of Geology
Stanford University

Purpose/description: Simulate the deposition of sediments from a river as it debouches into the sea

Mathematical method: Fully described in paper

Restrictions, range:

Computer manufacturer: IBM

Model: System/360 model 67

Programming language: FORTRAN IV, level H

Memory required: K

Approximate running time:

Special peripheral equipment required: Calcomp plotter

Remarks (special compilers or operating systems, required word lengths, number of successful runs, other machine versions, additional information useful for operation or modification of program)

Program has been run successfully many times at Stanford University.

COMPUTER CONTRIBUTIONS

Kansas Geological Survey
University of Kansas
Lawrence, Kansas

Computer Contribution

1.	Mathematical simulation of marine sedimentation with IBM 7090/7094 computers, by J.W. Harbaugh, 1966	$1.00
2.	A generalized two-dimensional regression procedure, by J.R. Dempsey, 1966	$0.50
3.	FORTRAN IV and MAP program for computation and plotting of trend surfaces for degrees 1 through 6, by Mont O'Leary, R.H. Lippert, and O.T. Spitz, 1966	$0.75
4.	FORTRAN II program for multivariate discriminant analysis using an IBM 1620 computer, by J.C. Davis and R.J. Sampson, 1966	$0.50
5.	FORTRAN IV program using double Fourier series for surface fitting of irregularly spaced data, by W.R. James, 1966	$0.75
6.	FORTRAN IV program for estimation of cladistic relationships using the IBM 7040, by R.L. Bartcher, 1966	$1.00
7.	Computer applications in the earth sciences: Colloquium on classification procedures, edited by D.F. Merriam, 1966	$1.00
8.	Prediction of the performance of a solution gas drive reservoir by Muskat's Equation, by Apolonio Baca, 1967	$1.00
9.	FORTRAN IV program for mathematical simulation of marine sedimentation with IBM 7040 or 7094 computers, by J.W. Harbaugh and W.J. Wahlstedt, 1967	$1.00
10.	Three-dimensional response surface program in FORTRAN II for the IBM 1620 computer, by R.J. Sampson and J.C. Davis, 1967	$0.75
11.	FORTRAN IV program for vector trend analyses of directional data, by W.T. Fox, 1967	$1.00
12.	Computer applications in the earth sciences: Colloquium on trend analysis, edited by D.F. Merriam and N.C. Cocke, 1967	$1.00
13.	FORTRAN IV computer programs for Markov chain experiments in geology, by W.C. Krumbein, 1967	$1.00
14.	FORTRAN IV programs to determine surface roughness in topography for the CDC 3400 computer, by R.D. Hobson, 1967	$1.00
15.	FORTRAN II program for progressive linear fit of surfaces on a quadratic base using an IBM 1620 computer, by A.J. Cole, C. Jordan, and D.F. Merriam, 1967	$1.00
16.	FORTRAN IV program for the GE 625 to compute the power spectrum of geological surfaces, by J.E. Esler and F.W. Preston, 1967	$0.75
17.	FORTRAN IV program for Q-mode cluster analysis of nonquantitative data using IBM 7090/7094 computers, by G.F. Bonham-Carter, 1967	$1.00
18.	Computer applications in the earth sciences: Colloquium on time-series analysis, D.F. Merriam, editor, 1967	$1.00
19.	FORTRAN II time-trend package for the IBM 1620 computer, by J.C. Davis and R.J. Sampson, 1967	$1.00
20.	Computer programs for multivariate analysis in geology, D.F. Merriam, editor, 1968	$1.00
21.	FORTRAN IV program for computation and display of principal components, by W.J. Wahlstedt and J.C. Davis, 1968	$1.00
22.	Computer applications in the earth sciences: Colloquium on simulation, edited by D.F. Merriam and N.C. Cocke, 1968	$1.00
23.	Computer programs for automatic contouring, by D.B. McIntyre, D.D. Pollard, and R. Smith, 1968	$1.50
24.	Mathematical model and FORTRAN IV program for computer simulation of deltaic sedimentation, by G.F. Bonham-Carter and A.J. Sutherland, 1968	$1.00