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Bedforms 4.0:
MATLAB Code for Simulating Bedforms and Cross-Bedding

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U.S. Department of the Interior
U.S. Geological Survey

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Introduction

This MATLAB (©1994-2005 The MathWorks, Inc.) code mathematically simulates bedforms and cross-bedding. The bedform program can be used experimentally to create cross-bedding produced by bedforms with a known morphology and behavior or can be used by trial and error to recreate the morphology and behavior of bedforms that produced specific deposits. Examples of the modeling, comparison with real structures, and results of computer experiments are discussed by Rubin (1987) in *Cross-Bedding, Bedforms, and Paleocurrents.*

This documentation describes the use of the bedform program but assumes that the user is familiar with MATLAB. Included are five script files (M-Files) and one data file (MAT-File) necessary to run the program: NewDunes.m, DuneInit.m, DuneTopo.m, sandsurface.m, moviemaker.m, and sandpic5.mat. The user only needs to run NewDunes.m for full program functionality, but the other files must be in the same working directory or on the same MATLAB path. Input files that can be used to reproduce the illustrations published by Rubin (1987) are included and also need to be in the same working directory as the files listed above.

The bedform program is written in MATLAB. The program generates bedform topography, computes the x-y-z coordinates of the surface, and converts the three-dimensional coordinates of the simulated structures to the corresponding two-dimensional coordinates on the page, and covers the topography with a sandy surface. The program uses sine curves to create surfaces that approximate the shape of bedforms. Displacement of the sine curves simulates bedform migration, changing amplitude simulates changing bedform height, and combining sets of sine curves simulates superpositioning of bedforms. The equations that generate these mathematical surfaces can be inspected in the program source code, but such inspection is not necessary to run the program.

The program can be used to produce block diagrams that display vertical sections through cross-bedding, sandy surfaces of bedform topography, horizontal sections through the bedforms, and horizontal sections through the underlying strata (Figure 1). Sequences of images can be animated with QuickTime (©1991-2004 Apple Computer, Inc.) to illustrate bedform behavior.

Software Requirements

This cross-platform program runs only in MATLAB. No extra toolboxes are needed. QuickTime Pro is recommended to create animations, but other movie or graphics software available may convert image sequences to movies.

Basic Usage

(1) Copy the Bedforms 4.0 folder and its contents to a local hard drive.

(2) Launch MATLAB.

(3) Set the MATLAB working directory to the Bedforms 4.0 folder.

(4) Open the file NewDunes.m in the Editor.

(5) Run NewDunes.m. The user will be prompted for selected inputs in the Command Window as follows:

(a) How many files do you want to run?

User: Enter the number of input figure files to calculate at one time and then hit Return (Enter on PC computers). This can be any value from 1- 62.

(b) Name of input parameter file?

User: Enter the name of the first figure to run and hit Return. If running more than one figure (as selected in (a)), a new prompt will appear for each figure. The figure names are the same as the names of the input M-files in the Bedforms 4.0 folder. For example, to run the input parameters listed in fig16.m, enter 'fig16.'

(c) Enter "color" for movies/tiffs or "bw" for single image postscripts :

User: Type "color" to create a full-color movie sequence or single image output in TIFF format. Type "bw" to create a single black and white figure output in postscript format (Adobe Illustrator). Black and white images are crisp and best for paper printing.

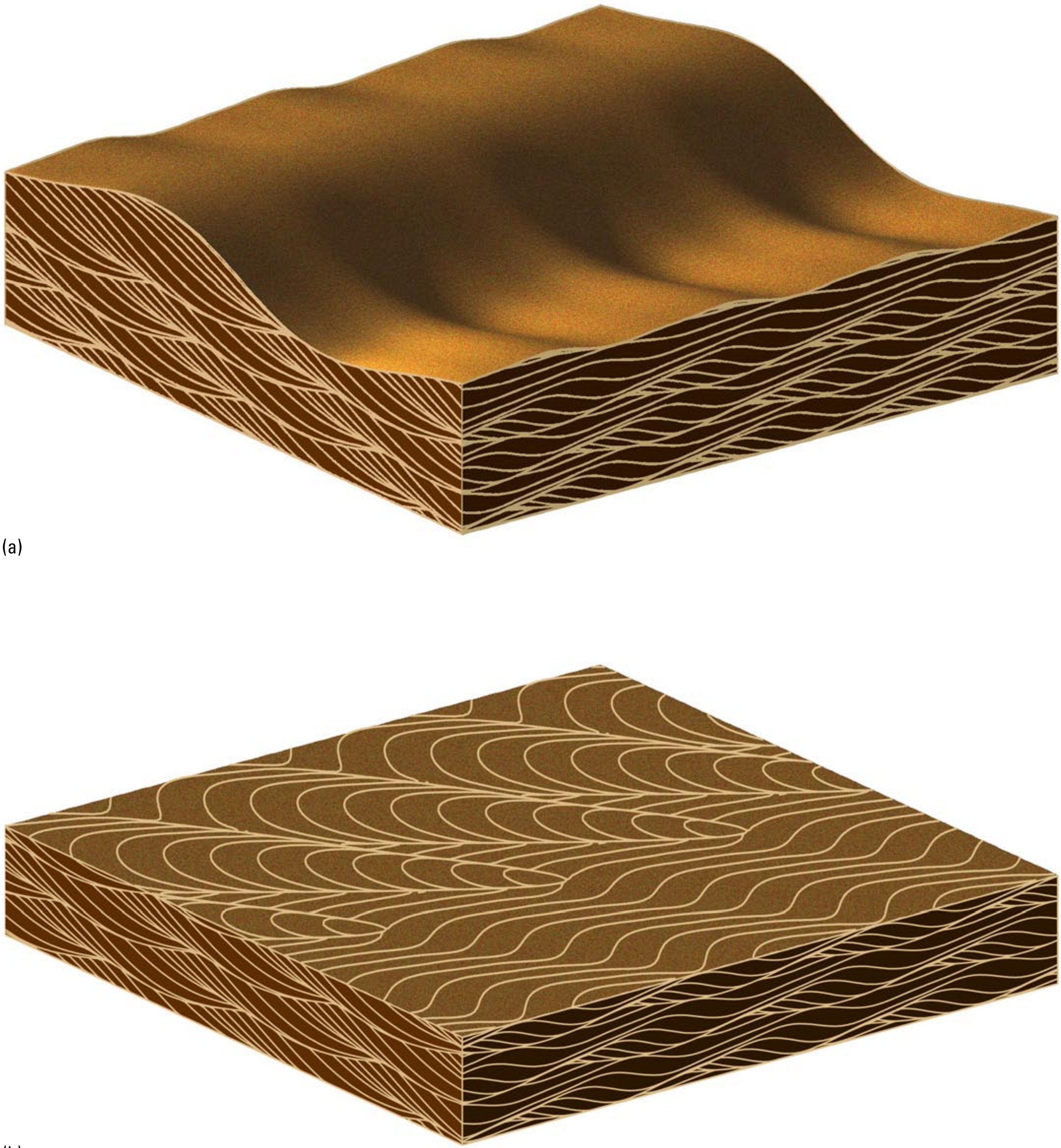
At this point, if the black and white postscript option is selected for figure output, the program will run and the selected files will be saved in the Bedforms 4.0 folder. If the color option is selected, the program proceeds as follows:

(d) How many frames showing deposition?

User: Enter an integer for the number of depositional frames and press Return. A value of 1 will produce a single still image. To create a movie, enter a higher number.

(e) How many pause frames after deposition?

User: When creating an animation, it is useful to have the movie pause in between deposition, rotation, and erosion. Enter an integer for the number of pause



(a)

(b)

Figure 1. Example figures produced by Bedforms 4.0. In (a), the figure depicts two sets of superimposed bedforms, and their corresponding cross-bedding structures. In (b), a horizontal section of the same figure is shown.

frames after deposition and hit Return. This value can be 0.

(f) How many frames showing rotation?

User: Each bedding structure can be rotated within the block diagram to illustrate how the same structure will appear in different outcrop orientations. Enter a value for the number of rotational frames to create and hit Return.

(g) How much total rotation in degrees?

User: Select the number of rotational degrees to rotate the block and press Return.

(h) How many pause frames after rotation?

User: See question (e).

(i) How many frames showing erosion?

User: Cross-bedding structures can be viewed from the top of the section by 'eroding' the figure. Enter the number of erosional frames and hit Return.

(j) How much erosion between frames?

User: Select an erosional increment and press Return. This number describes the distance from the top of the highest bedform. A value of 1 will eliminate all surface topography.

(k) How many pause frames after erosion?

User: See question (e)

Example:

How many files do you want to run? : 2
Name of input parameter file? : fig5
Name of input parameter file? : fig42a
Enter "color" for movies/tiffs or "bw" for single image postscripts : color
How many frames showing deposition? : 100
How many pause frames after deposition? : 5
How many frames showing rotation? : 90
How many rotational degrees? : 45
How many pause frames after rotation? : 5
How many frames showing erosion? : 100
How much erosion between frames? : 0.025
How many pause frames after erosion? : 5

The example input parameters above will create 305 images each for Figure 5 and Figure 42a. Files are output as 250 dpi TIFF images and placed in the Bedforms 4.0 folder and can be opened with any image viewing software and reorganized or moved to a different folder.

To create an animation in QuickTime Pro continue with the following steps:

(6) Open QuickTime Pro

(7) Choose File > Open Image Sequence

(8) Navigate to the folder containing the output image files for a single figure, open the folder, highlight the first image in the sequence, and click 'Open.'

(9) Choose a frame rate (6 or 10 recommended).

(10) Adjust the movie size by choosing Movie > Half Size.

(11) While the movie is now viewable, it is advisable to make it self contained by choosing File > Export.

(12) Set a destination for the movie file and select 'Movie to QuickTime Movie.' Under 'Options' select 'Settings' and use the Sorenson Video 3 codec for compression at medium quality.

(13) Export the movie and then open it in QuickTime Pro for full screen viewing with Movie > Make Full Screen

Please Note: The above steps (6-13) are suggestions, and the user should be able to make beautiful movies with many combinations of frame rates, image sizes, codecs etc.

Advanced Usage

Experienced MATLAB users can change the code to suit their individual needs. Some options that advanced users may want to take advantage of are listed below.

Entering Names of Input Files

Rather than responding to input prompts, the user can manually enter the names of input files on line 21. In this case, lines 12-16 need to be commented out of the code.

Starting a Movie in the Middle

To start or restart the generation of movie files the user can specify the starting frame number. Two lines need to be uncommented from the code, 36 and 124. They are clearly identified in NewDunes.m.

Changing Line Width on Bedforms

To change the appearance of the cross-bedding and contours on a figure the user can customize their look as indicated on lines 70 and 85-89.

Changing File Output Format

By default, the file output format for colored movie frames is TIFF at 250 dpi. Black and white postscript images are output in Adobe Illustrator (ai) format. Both of these settings, as well as applicable image resolution, can be changed by the user in lines 112 and 119 of NewDunes.m, respectively. Consult the MATLAB documentation for the commands 'print' and 'saveas' for a complete list of file output format options.

Input Variables

Sixty-two input parameter files are included in Bedforms 4.0. These files, named fig15.m, fig46b.m etc., correspond to the figures in Rubin (1987).

The user of the bedform program can create an input parameter file that describes the shape and behavior of other bedforms. Warning: it is quite easy to create bedforms with a physically unreasonable behavior, such as dunes that migrate in the opposite direction from that indicated by their asymmetry. The following discussion describes, line by line, what variables must be specified in an input file. The easiest way to create an input file is to edit an existing one, replacing old values of the input variables with the desired ones. Unless otherwise specified, all of the input variables are real numbers; those that are integers, logical, or character variables are noted.

The following list describes the input variables that are contained in all input files.

(1) Name of the input file. This is a character variable with a maximum length of 31 characters. This variable is included in the input file so that the name of the file can be retained within the input file and plotted on the output figure.

(2) Caption to be printed on the output figure. This character variable should be contained in quotes.

The following group of variables describes the first set of bedforms to be generated, on which subsequent sets of bedforms can later be superimosed.

(3) Bedform wavelength. The sides of the block diagrams drawn by the dunes program are defined to have lengths equal to 100.0 units. All variables that specify length (or length components of variables that specify velocity) are expressed in the same arbitrary units.

(4) Bedform phase (in degrees). This variable specifies the position of the bedforms (at time=zero) within the block diagram. Where the spacing of the bedforms is equal to 100.0, phase of the bedforms has no effect on the actual structure that is produced; the variable merely controls the placement of the structure within the block. Where the spacing is greater than 100.0, the phase determines which part of the structure is included within the block.

(5) Bedform symmetry or asymmetry (an arbitrary, dimensionless, real variable). A value of 1.0 produces bedforms that are asymmetric, and a value of 0.0 produces symmetrical bedforms; values between 0.0 and 1.0 produce intermediate amounts of asymmetry. Note that if a positive value is specified, the steeper flank will face in the direction defined by positive bedform migration (as should normally be the situation); where a negative value is specified, the steeper flank will face in the opposite direction. In situations where asymmetry varies through time, the value specified here defines the mean asymmetry. Asymmetry at any one instant is the sum of this value and a cyclic component that is described by the following three variables. Asymmetry is simulated mathematically by summing two sinusoidal components. The first has a wavelength equal to the bedform wavelength; the second component has a wavelength of one-half the bedform wavelength. The relative phase of the two components determines bedform asymmetry.

(6) Amplitude of bedform-asymmetry cycle (same dimensionless units as in 5, above). During each complete cycle, asymmetry varies between (5) plus (6) and (5) minus (6). A value of 0.0, which produces no change in asymmetry, should be used to create bedforms that do not vary through time. Values greater than approximately 0.5 or 1.0 often produce peculiar results and should not be used without carefully inspecting the results.

(7) Period of bedform-asymmetry cycle. This variable (and all others that specify periods or velocities) can be based on any arbitrary units of time, provided that these units are consistent throughout the input file.

(8) Phase in the asymmetry cycle at time = zero. Values are in degrees; when this term is 90.0, asymmetry at time = zero is a maximum [equal to the mean asymmetry (5) plus the amplitude of asymmetry change (6)].

(9) Bedform steepness. Neglecting the effects of bedform superpositioning, a value of 1.0 causes bedform height to be approximately equal to 1/15 of the bedform wavelength. When other variables remain constant, bedform height is proportional to the value chosen. This variable defines the mean bedform steepness; where height varies through time, the instantaneous height also is a function of the next three variables.

(10) Amplitude of bedform-steepness cycles; units are the same as for mean height (9, above). During a complete height-fluctuation cycle, height varies between (9) plus (10) and (9) minus (10). To create bedforms

that do not change in height, this term should be equal to zero.

(11) Period of time during which bedform steepness changes.

(12) Phase at time = zero in the steepness-fluctuation cycle. Values are in degrees. A value of 0.0 produces bedforms with a steepness that is a minimum in the cycle.

(13) Wavelength of the first set of plan-form sinuosities. Values have the same units of length as all other lengths. Each set of bedforms can have as many as two sets of plan-form sinuosities. By specifying the appropriate values for the wavelength and amplitude of these sinuosities (as discussed in the descriptions in 17-19, below), it is possible to create sinuous, linguoid, or lunate plan forms. Note that if either this term or the following term is equal to zero, no sinuosities are created.

(14) Amplitude (measured in plan form) of the first set of sinuosities.

(15) Phase (along-crest placement) of first set of plan-form sinuosities. To create in-phase bedforms, this term should have the same value as (38), the analogous term for the second set of bedforms; to create out-of-phase bedforms, the two terms should differ by 180.0.

(16) Migration speed (along crest) of the first set of plan-form sinuosities; units are in length/time. For the most natural-looking results, this term should have a value less than approximately 3.0 to 4.0. Positive values cause the sinuosities to migrate toward a direction 90º clockwise of the migration direction specified for the bedform (21); negative values cause the sinuosities to migrate 90° counterclockwise.

(17) Wavelength of the second set of plan-form sinuosities. To create sine-shaped plan-form sinuosities, this term should have a value of 0.0. For lunate or linguoid bedforms this term should have a value equal to half of (13).

(18) Amplitude (plan form) of the second set of sinuosities. To create lunate or linguoid bedforms with a realistic curvature, a good value for this term is 1/4 of the value of (17).

(19) Phase (along-crest placement) of plan-form sinuosities. To create lunate bedforms, this term should have a value equal to (15)+270.0. To create linguoid bedforms, this term should have a value equal to (15)+90.0.

(20) Migration speed (along crest) of the second set of plan-form sinuosities. By specifying this value to differ from (16), bedform plan-form shape can be caused to vary through time.

(21) Migration direction of the first set of bedforms. Migration directions are normal to the bedform crestlines. Thus, specifying the migration direction also sets the bedform orientation.

(22) Mean migration speed of the first set of bedforms. For the most realistic results, this value should be less than approximately 3.0 or 4.0.

(23) Amplitude of migration-speed cycles; units are the same units of velocity as in (22). The value specified here should have a value of 0.0 if a constant migration speed is desired.

(24) Period of migration-speed cycle.

(25) Phase at time = zero in the migration-speed cycle. A value of 0.0 produces bedforms that at time = zero have a minimum speed.

The following group of variables describes the second set of bedforms that can be superimposed on the first. All terms are analogous to the corresponding terms defined above.

(26) Bedform wavelength.

(27) Bedform phase.

(28) Mean asymmetry.

(29) Amplitude of asymmetry cycle.

(30) Period of asymmetry cycle.

(31) Phase of asymmetry cycle.

(32) Mean steepness of second set of bedforms. The steepness specified is that of the bedforms before they are superimposed on the first set. Superpositioning can change the bedform steepness as discussed in the comments about the type of superpositioning (72).

(33) Amplitude of bedform-steepness cycle.

(34) Period of steepness cycle.

(35) Phase of steepness cycle.

(36) Wavelength of first set of plan-form sinuosities.

(37) Amplitude of first set of plan-form sinuosities.

(38) Phase of first set of plan-form sinuosities. To create in-phase bedforms, this term should have the same value as (15); to create out-of-phase bedforms, the two terms should differ by 180.0.

(39) Migration speed (along crest) of first set of plan-form sinuosities.

(40) Wavelength of second set of plan-form sinuosities.

(41) Amplitude of second set of plan-form sinuosities.

(42) Phase of second set of plan-form sinuosities.

(43) Migration speed (along crest) of second set of plan-form sinuosities.

(44) Migration direction of second set of bedforms.

(45) Mean migration speed.

(46) Amplitude of migration-speed cycles.

(47) Period of speed cycles.

(48) Phase of speed cycles.

The following group of variables describes the third set of bedforms that can be superimposed on the first and second sets. All terms are analogous to the corresponding terms defined in (3)-(25).

(49) Bedform wavelength.

(50) Bedform phase.

(51) Mean asymmetry.

(52) Amplitude of asymmetry cycle.

(53) Period of asymmetry cycle.

(54) Phase of asymmetry cycle.

(55) Mean steepness.

(56) Amplitude of steepness fluctuations.

(57) Period of steepness cycle.

(58) Phase of steepness cycle.

(59) Wavelength of first set of plan-form sinuosities.

(60) Amplitude of first set of plan-form sinuosities.

(61) Phase of first set of plan-form sinuosities.

(62) Migration speed (along crest) of first set of plan-form sinuosities.

(63) Wavelength of second set of plan-form sinuosities.

(64) Amplitude of second set of plan-form sinuosities.

(65) Phase of second set of plan-form sinuosities.

(66) Migration speed (along crest) of second set of plan-form sinuosities.

(67) Migration direction of third set of bedforms.

(68) Mean migration speed.

(69) Amplitude of migration-speed cycle.

(70) Period of speed cycle.

(71) Phase of speed cycle.

The following terms define characteristics that apply to the entire depositional situation that is being modeled.

(72) Integer variable that determines the geometric rules used to superimpose the second and third sets of bedforms on the first set. If this variable is equal to 1, superimposed bedforms are added to main bedforms by simple addition. If equal to 2, the local height of the superimposed bedforms is proportional to the local elevation of the main bedform. Steepnesses of superimposed bedforms thus vary from zero in the troughs of the main bedforms to a maximum at the crests of the main bedforms. The mean steepness of the superimposed bedforms is thus 1/2 of their steepness specified on lines (32) and (55). If the variable defined on line (72) of the input file is equal to 3, the elevations of all bedforms are calculated separately, and the elevation at any point on the surface is chosen to be that of whatever bedform is locally highest. This is the value to use to produce out-of-phase sinuous, lunate, or linguoid bedforms. Mean steepness of the resulting bedforms varies with the steepness, spacing, and phase relations of the various sets of bedforms. If the variable on line (72) is equal to 4, the height of the superimposed bedforms is inversely proportional to the local elevation of the main bedform. Steepnesses of superimposed bedforms vary from those specified on lines (32) and (55) in the troughs of the main bedforms to zero at the crests of the main bedforms. The mean steepness of the superimposed bedforms is thus 1/2 of the specified value. If the variable on line (72) is equal to 5, two sets of superimposed bedforms are created following the rules as if the variable were equal to 3; that assemblage is then added to the main bedforms as if the variable were equal to 1. If the variable on line (72) is equal to 6, the first set of superimposed bedforms is summed as if the variable were 2, and the second set is added as if the variable were 1.

(73) Integer variable that can be used to rotate all bedforms and migration directions such that trough axes are normal or parallel to the sides of the block diagrams. If equal to 0, no rotation is performed. Values of 1, 2, 3, or 4 can be selected to cause scour pits to migrate out of any of the four vertical sides of the block (1 for the back right, 2 for the front right, 3 for the front left, and 4 for the back left).

(74) Elevation of interdune flats. A value of less than -1.0 will generally produce no interdune flats. A value of 0.0 will cause approximately half of the surface area to be occupied by interdune flats.

(75) Mean rate of deposition; same units of length/time as migration rates.

(76) Amplitude of cycle in the rate of deposition; same

units of length/time as migration rates.

(77) Period of cycle in the rate of deposition; same units as all other time periods.

(78) Phase of cycle in the rate of deposition (in degrees). If equal to 0.0, the rate of deposition is at a minimum at time = zero.

(79) Integer number of steps backward through time to the beginning of the depositional event that is being simulated.

(80) Integer interval between the plotting of foresets. This term is normally equal to 1 for detailed line drawings, but can be in increased to 4 or higher for drawing on the screen or if bedforms move so slowly that the resulting foresets are too close to each other. Larger numbers require less computing time but produce less detailed images.

(81) Integer that specifies the time of the end of the depositional episode (i.e., the time when the surface is illustrated). Changing this number causes a change in location of the bedforms within the block diagram. For making single images, this term need not differ from 0. In animation sequences, this number is automatically incremented from frame to frame.

(82) Logical variable that, if true, causes the figure caption (2) to be plotted.

(83) Logical variable that, if true, causes the name of the input file (1) to be plotted.

(84) Logical variable that has been discontinued but was kept so that input files will remain compatible with older versions of Bedforms. Can be either ".true." or ".false." .

(85) Integer variable that chooses between long computation times (with high precision of plots) and shorter computation times (accompanied by lower precision); the value of this variable must equal 1, 2, 4, 5, or 10. In the bedform-drawing program, this variable specifies the spacing of the grid used to compute bedform topography and used to create the surface mesh or shading. Small values create more natural-looking images (smoother curves, particularly in horizontal sections) but take longer to run and require more disk space for each image. The high precision (and longer computation times) specified by a value of 1 is probably necessary only for publication-quality images of bedforms and bedding or for statistical studies of bounding-surface distribution.

(86) Elevation of the horizontal section, expressed in non-dimensional units (relative to 0.0 at the lowest point on the bedform surface and 1.0 at the highest point). A value of 1.0 will cause the horizontal section to be equal to the highest point on the bedform surface; the entire bedform surface will be shown. A value of 0.0 will cause the elevation of the horizontal section to coincide with the lowest elevation of the bedform surface; the top of the block diagram will consist entirely of a horizontal section. Intermediate values will produce block diagrams that are capped by a horizontal section at the specified elevation.

Processing Time and File Sizes

The time required to create figures and movie frames will vary depending on computer processing speed. For comparison, a machine with a dual 2GHz processor can produce up to six figures per minute for images with bedform surfaces. Horizontal sections have a longer processing time. These rates also depend on the complexity of the input parameter file being run.

The file size of each output TIFF image ranges from approximately 3 - 5 MB. Creating a number of movie frames at this size can add up to large amounts of hard drive space quickly. However, if the directions for creating a QuickTime movie are followed (see pg. 2) the movie should compress into a 30 MB file and the TIFF images can be deleted. File sizes for the postscript figures are approximately 2 MB.

References

Rubin, David M., 1987, "Cross-Bedding, Bedforms, and Paleocurrents." Society of Economic Paleontologists and Mineralolgists, Concepts in Sedimentology and Paleontology, v.1: Tulsa, 187 p.

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