DANIEL F. MERRIAM, Editor

MATHEMATICAL SIMULATION OF MARINE SEDIMENTATION WITH IBM 7090/7094 COMPUTERS

By

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Stanford University

COMPUTER CONTRIBUTION 1

State Geological Survey

The University of Kansas, Lawrence

1966

Editor's Remarks

It is appropriate that the first paper to appear in the Kansas Geological Survey's new series of Computer Contributions is one by John W. Harbaugh. Dr. Harbaugh was author of the first computer article, Special Distribution Publication 3, issued by the Survey in 1963. In the preface of that SDP it was stated:

> This special publication describes a computer program that will be useful to geologists in Kansas and elsewhere; it is the first of a series of publications of the Kansas Geological Survey in which the objective is to present details of computer programs that should be of general usefulness to geologists and petroleum engineers....

At the time it was unknown as to the extent this type of information would be used and by whom, and with this in mind, only a limited number of copies were printed. It was anticipated, however, and further stated that:

> ...the computer revolution is fast sweeping through the petroleum industry...It is the intention of the Kansas Geological Survey to provide some assistance in computer applications in solving geological and petroleum engineering problems.

Little did we realize how fast the computer revolution was sweeping! Demand for information in this new area of interest exceeded all expectations. Supply of many of the articles was soon exhausted, but they have now been reprinted, and the demand for both printed programs and examples of applications remains high (more than 14,500 copies have been distributed).

In response to the international acceptance and apparent wide use of this information, the Survey is proud to initiate a new series devoted exclusively to computer programs and examples of computer problem-solving applications in the earth sciences. The objectives of the new series, of course, remain the same as those of the Special Distribution Publications, but it is hoped they can be more adequately and fully developed.

In order to assure that material presented in the new series is of the highest quality, the board of editors has been enlarged to include people from industry as well as those from academic organizations. The willingness of these people to serve brings a breadth of scope and background of experience to the editorial board that is unequaled anywhere.

This contribution deals with the new and rapidly growing development of simulation in the earth sciences. It is exciting and challenging to say the least, and according to the author:

> Mathematical simulation makes an experimental approach possible in dealing with geologic problems in which experimental methods have been difficult or impossible to apply heretofore.

Although still in an infant stage of development, simulation, perhaps, offers the most promising area for future research in geology. New vistas are opened; new techniques will be developed; and new ideas will be formed, the results of which can only be guessed. As observed by J.N. Weber, "the enormous impact of ... (the computer)... on the nature of geological investigation is still to come."

The Survey will make available for a limited time the card decks pertaining to the simulation program for a cost of $20.00. The compiler system of BALGOL can be obtained from the Computation Center, Stanford University, Stanford, California, as per instructions given in the paper. Any comments or suggestions should be addressed to the editor.

MATHEMATICAL SIMULATION OF MARINE SEDIMENTATION WITH IBM 7090/7094 COMPUTERS

By

JOHN W. HARBAUGH

ABSTRACT

A mathematical model of marine sedimentation, using IBM 7090/7094 computers, imitates the behavior of sediments as they are transported and deposited within a marine sedimentary basin. By mathematical means, in symbolic three-dimensional space, the model imitates the processes of tectonic warping, winnowing of sediments along beaches, formation of deltas, and the growth and interaction of organism communities, including algal banks and coral reefs, that populate the sea floor. The model is operated by assuming a set of external controlling conditions and feeding these into the computer as numerical data. The model is then run forward, by increments, through geologic time. The effect of several million years geologic history can be studied in 15 minutes computing time.

Output from the computer program representing the model is in the form of lithofacies maps, structure maps, biofacies maps, sea-water depth maps, and geologic cross sections that show both structure and facies relationships. A series of maps and cross sections can be printed for each increment of geologic time making it possible to observe progressive geologic changes as they occur.

The model is used as an experimental tool by observing the response to a set of assumptions. When a change in the numbers used to control the program is made, the model responds dynamically in a few seconds computer time. Deltaic deposits, ancient beaches, algal reefs, and other sedimentary features develop progressively and undergo structural deformation with startling realism.

The objective in geological mathematical modeling is to produce symbolic geologic products (such as sedimentary strata) by imitating the principal geologic processes that produce the products. There is, however, uncertainty as to the mode of operation and relative importance of many processes. Consequently, assumptions must be made. These assumptions can be tested on a trial and error basis. If the results of a computer run with the model do not agree well with reality (i.e., the symbolic deposits do not accord well with real sedimentary deposits that are being imitated, etc.), the assumptions can be progressively changed, and new runs made until the model begins to perform realistically.

The mathematical model is embodied in a BALGOL computer language (version of ALGOL-58) program which may be used with any IBM 7090 or 7094 computer, provided the BALGOL system tapes are available. The principles of the program are outlined in the report, which also contains detailed operating instructions for the program's use.

INTRODUCTION

This report describes a program for IBM 7090 or 7094 computers for mathematically simulating marine sedimentation. It is believed to be one of the first programs of its type, in that it does not seek to analyze geological data, but instead, to create data. The program represents a dynamic mathematical model which imitates actual geologic processes and which produces symbolic geologic features that resemble real features.

The purposes of developing and describing this simulation program are twofold: (1) to provide a means of experimentation in dealing with problems of both modern and ancient marine sedimentation, a field where effective experimental approaches have been difficult heretofore, and (2) to demonstrate the power of mathematical simulation in geology in general.

Simulation has reached an advanced state in business (Forrester, 1961) and military applications, and has advanced notably in physiology and medicine, in some of the social sciences, and in city planning (Goldner and Graybeal, 1965). On the other hand, simulation has lagged in geology, perhaps because of the relative slowness of geologists to use computers as problem-solving tools.

The program described here is part of a long-range undertaking at Stanford University, in conjunction with the Kansas Geological Survey, to develop means of simulating the process of oil origin, migration and entrapment in sedimentary basins. The project is being undertaken in stages, the first stage dealing largely with processes of deposition. Subsequent stages will deal with tectonic processes in greater detail, and with oil origin, migration, and entrapment. The ultimate objective is to develop effective means of simulating geologic processes in sedimentary basins, beginning with initial deposition of sediment and extending forward through geologic time. It should be possible to imitate, in detail, the behavior of a sedimentary basin from the Cambrian to the present in several hours computing time, observing the development of geologic features and monitoring the underground behavior of water, gas, and oil.

The program is a mathematical model of a sedimentary basin in somewhat the sense that a model airplane is a replica of a real airplane. An important difference, however, is that the model airplane is a small-scale physical or material replica, whereas the mathematical model is entirely symbolic.

In considering the use of a simulation model, such as the one described in this paper, it is imperative to realize that a simulation model is intended to provide a means of testing assumptions. The validity of a simulation model is only as good as the assumptions that go into it. If some of the assumptions are poor, the performance of the model may be poor. The power of simulation, however, lies in the ability of simulation models to help discern between good and poor assumptions. Users of simulation models should keep in mind that, although initial assumptions incorporated in a model are likely to be poor, they can be improved experimentally.

In simulation it is generally possible to arrive at symbolic results that accord consistently well with real geologic features, even though a variety of different initial input data and process control parameters have been used to control the program. Moreover, the various combinations of assumptions for geologic processes and factors employed may be regarded as reasonable. This ambiguity is perhaps the biggest drawback to the usefulnes of simulation models. However, even if there is no guarantee of successfully achieving the "correct" set of assumptions used as input to the model, it is possible to test the general validity of the model by using it to make predictions and then checking to see how closely the predicted geologic features accord with those that actually exist. Finally, even if a simulation study fails to yield a valid model, it may provide the researcher with valuable new insight into the problem being investigated.

The program in its present form is not to be regarded as finished; instead, it should be regarded as an experimental tool that can be progressively modified. Indeed, prospective users should acquaint themselves with the essential elements of the programming language (which is a version of ALGOL-58, known as SUBALGOL or BALGOL) so that they can make changes in the program to adapt it to particular applications. Persons acquainted with FORTRAN IV should find most details of the language very familiar. A useful reference to the BALGOL language is entitled "Burroughs Algebraic Compiler, Revised Edition" (1963) which may be obtained from the Burroughs Corporation, Detroit 32, Michigan. A second manual entitled "SUBALGOL Reference Manual" by R. L. Smith (1965) may be obtained from the Stanford University Bookstore, Stanford, California, for $2.00. The Kansas Geological Survey will make card decks of the program available for a limited time for $20.00. The BALGOL compiler system can be obtained in magnetic tape form from Stanford University. Inquiries concerning the compiler should be directed to Computation Center, Stanford University, Stanford California.

Acknowledgments. - I am indebted to Daniel F. Merriam for long-continued encouragement, ranging from discussions in the early stages of this work to review of the final manuscript. I am also indebted to Perfecto Mary of Stanford University, for much of the drafting; to Mrs. Nan Cocke of the Kansas Geological Survey, for typing; and to R. W. Fetzner of Sun Oil Company, Ferruh Demirmen of Stanford University, J. M. Forgotson, Jr. and Harvey Meyer of Pan American Petroleum Corporation, and M. G. Pitcher of Continental Oil Company, for review of the manuscript. The Stanford University Computation Center furnished the computer used in developing the program. Partial financial support was provided by the Kansas Geological Survey, by the National Science Foundation through Grant GP-4514, by Shell Fund for Fundamental Research at Stanford University, and by the American Chemical Society through Petroleum Research Fund Grant PRF-1117-A2.

REPRESENTATION OF GEOLOGIC PROCESSES, FACTORS, AND FEATURES IN PROGRAM

Three-Dimensional Space

Geologic features in three-dimensional space may be readily represented in a digital computer by dividing the space into cells, which may be rectangular or cubic in shape. The qualities of the geologic features that occupy the cells may be represented by different numbers, which, in turn, may be stored as arrays in the computer and subjected to logic and arithmetic manipulations.

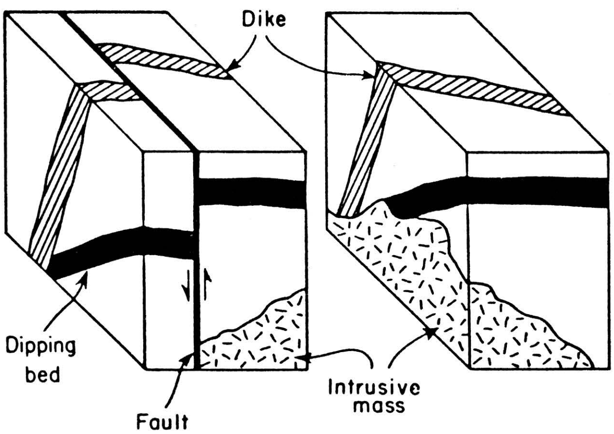

Figure 1.- Block diagram showing geologic features.

An example of numerical representation of geologic features is shown in Figures 1, 2, and 3. In Figure 1, several common geologic features are shown with conventional graphic symbols. In Figure 2, the same features are represented, but the block has been divided into cubes. There is a loss of detail in portraying the features in Figure 2, however, because of the relative coarseness of the cubes. If the cubes were smaller, the loss of detail would be less. In Figure 3, integers 1 to 4, which form a three-dimensional array, have been substituted for the graphic symbols. Information contained in the array is essentially equivalent to that represented in Figure 1. Knowing the key relating numbers and graphic symbols (Fig. 3), a person given only the numerical data in the array (Fig. 3) could reproduce Figure 1, provided that he did a bit of smoothing.

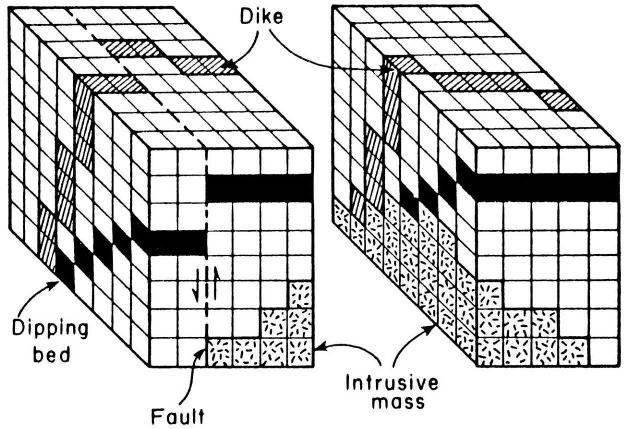

Figure 2.-Block diagram in which geologic features are represented by discrete cells (small cubes), each of which is marked by graphic symbol representing type of feature represented by that cell.

Units

All units in the simulation model are arbitrary, and may be assigned values that are convenient to the user. Four main classes of units are used: (1) units of geographic distance, (2) units that pertain to the vertical dimension (such as tectonic warping increments and sediment increments), (3) time increments, and (4) units that express relative intensity of various processes, such as "relative vitality" in organism communities, intensity of beach winnowing processes, etc. In the examples shown in Figures 13 to 22, the geographic units are in miles (each cell occupies one square mile geographically), the vertical dimensions are in feet, and the time increments are unspecified, but might be considered to be on the order of 5 to 10 thousand years each.

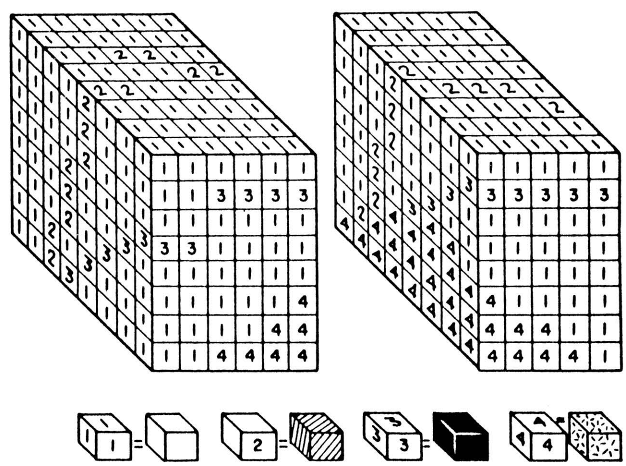

Figure 3.-Block diagram in which numbers (integers) are used instead of graphic symbols. Numbers form a three-dimensional array which may be stored and manipulated by computer.

Tectonic Warping, Deposition of Sediment, and Depth of Water

Tectonic warping is simulated by moving square "columns" upward or downward during each time increment (Fig. 4). The values of the warping increments are specified in an array (Table 2, Fig. 13). Vertical motion may take place at each time increment. Depending on the contrast between values in adjacent cells and their algebraic signs, conditions ranging from uniform downwarping or upwarping to complex folding and faulting can be simulated.

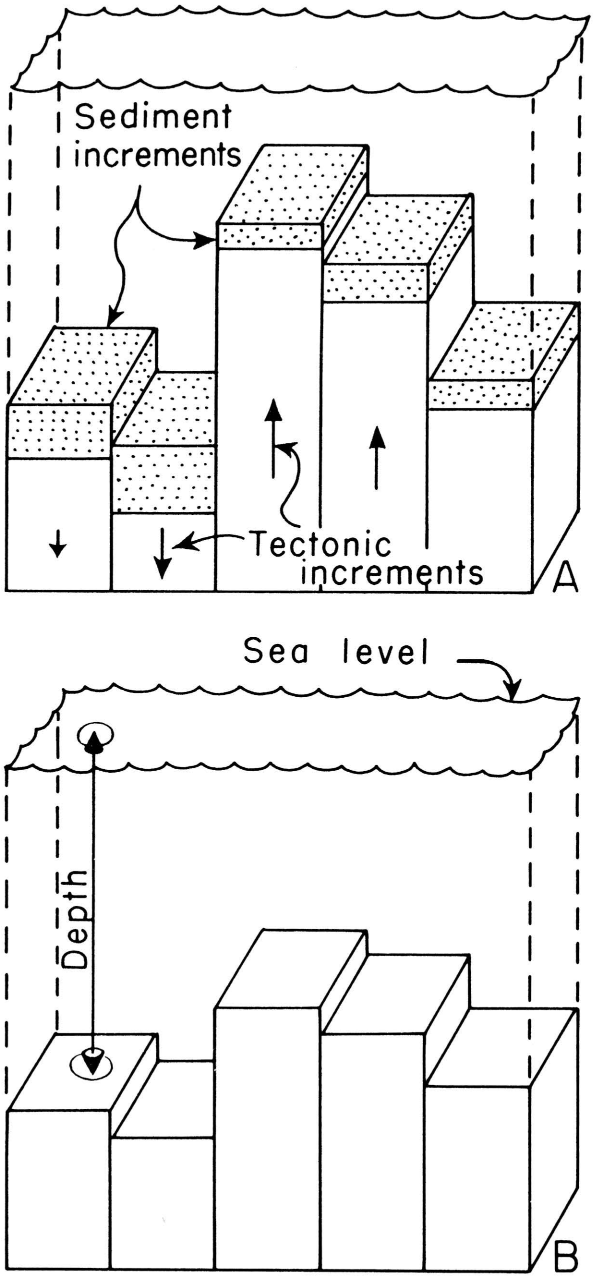

Figure 4.- Relationship between algebraically additive increments of tectonic warping and of sedimentation (A) with water depth as arithmetic complement (B).

Sediment deposition also takes place by increments. The factors and processes that control sedimentation rates are described subsequently, but sedimentation itself is simulated by adding the value of the sediment increment to the pre-existing sea floor (or land) elevation. Water depth is calculated as the difference between the sea floor and sea level. Elevations above sea level (i.e., on land) are denoted with negative signs.

Deltaic Sedimentation

The processes of deltaic sedimentation are simulated by varying the rate of supply of terrestrially derived sediment to mimic the effect of a river bringing sediment to the sea and spreading it out (Fig. 15). The rate of deposition of terrestrially derived sediment is not necessarily the same as the rate of supply, however. Where the depth of water is less than some specified value, the proportion of sediment deposited is proportionally less than the rate of supply. The proportion deposited declines to zero as a specified elevation (may be above or below sea level) is attained.

These controls over the rate of sedimentation are remarkably effective in simulating deltaic sequences composed of topset, foreset, and bottomset beds.

Winnowing of Fine Particles at Beaches

The effect of winnowing of fine particles at beaches is a function of both water depth and proportions of sand and mud. The relative intensity of the winnowing processes reaches a maximum at sea level and declines linearly to zero at some specified depth (Fig. 5). A nonlinear function might be more appropriate; however, a linear function was used for simplicity.

Representation of Organism Communities

The program provides for continuously populating, through time, the sea floor and adjacent

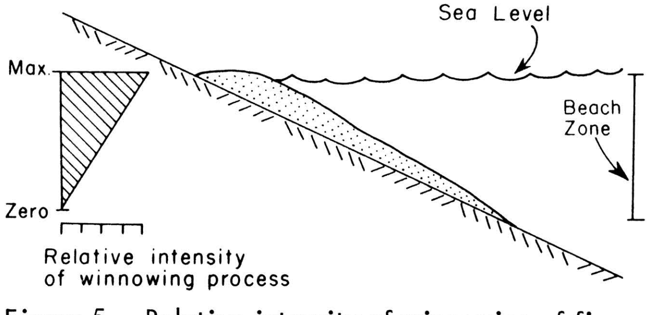

Figure 5.- Relative intensity of winnowing of fines to form beach deposits as function of depth.

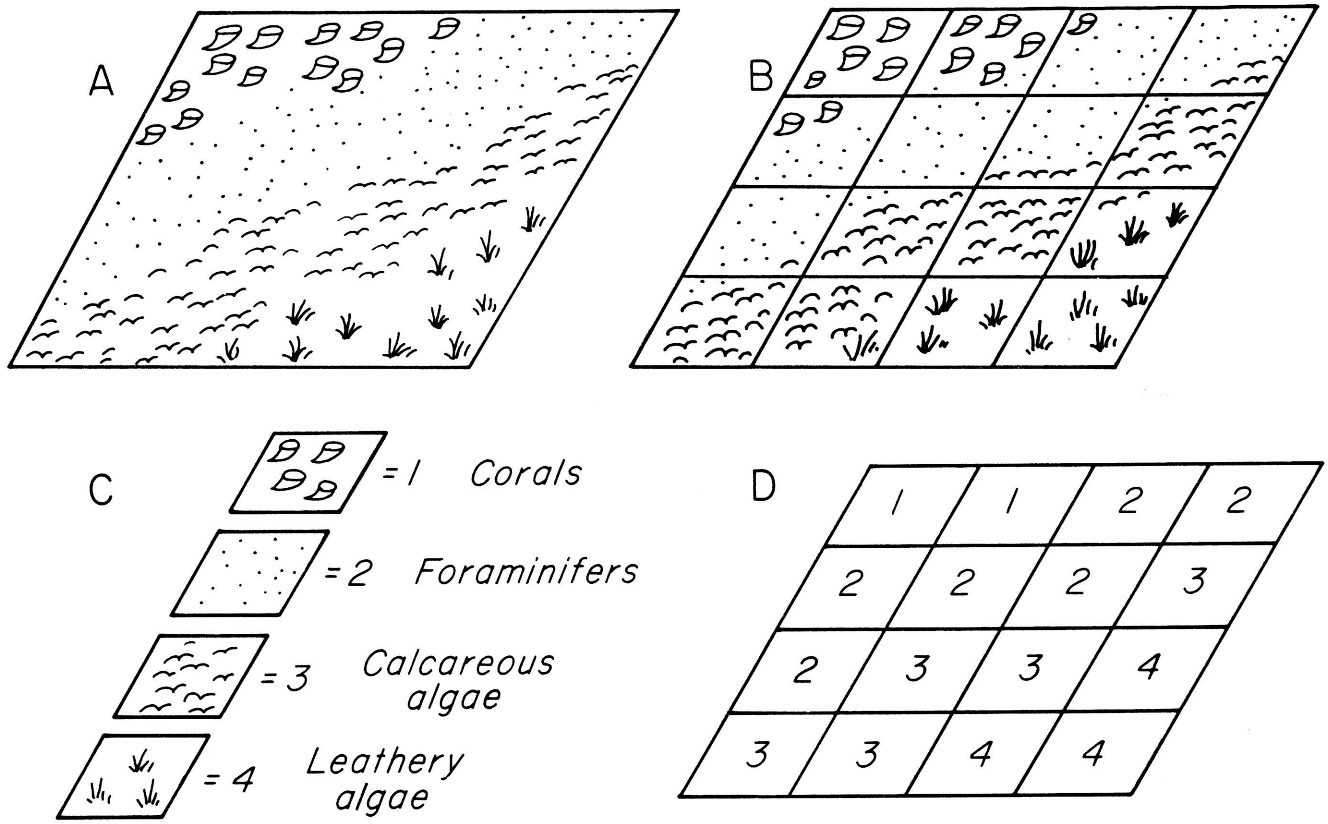

Figure 6.- Means of representing geographic distribution of organism communities: (A) sea floor is populated by different communities which are continuous and which are portrayed graphically; (B) sea floor has been discretized by division into square cells; (C) graphic symbols are assigned numerical equivalents; (D) two-dimensional array of integers contain essentially same information as graphic symbols in A, except for some loss of detail due to relative coarseness of discrete cells.

land areas (if present) with organism communities. Organism communities are defined as consisting of populations of organisms, although a community may be defined as consisting of a population formed by a single type of organism, depending on the assumptions of the user.

The means of representation of organism communities are shown in Figure 6. The sea floor (or land area) is divided into square cells. A single organism community occupies each cell, and is, in turn, represented by an integer.

Competition and Succession of Organism Communities

Organism communities represented in the program are endowed with properties that affect their ability to compete with other organism communities. The degree to which a series of different organism communities tends to form a specific ecologic succession can be specified.

The means by which these processes are imitated centers around selection of the communities that are to occupy the cells at each new increment of time. Selection involves the geographic distribution of organism communities for three preceding time increments, and the "relative vitality" of the organism communities involved. The relative vitality of an organism community is defined here as the degree of fitness of that community for its environment at a specific time and place, relative to other organism communities at the same time and place. Relative vitality, thus, is meaningful only in a comparative sense. Relative vitality is a means of expressing the competitive ability of different organism communities, and also by expressing their ability to contribute sediment (if they are capable of contributing sediment).

The means by which past events influence (but do not rigidly govern) succeeding events (i. e., selection of an organism community to occupy a particular cell) at subsequent time increments are illustrated in Figure 7. Moving forward through increments of short time duration, the most probable organism community to occupy a cell is the same community that occupied that cell immediately before. This assumes that other factors in the environment are relatively unchanged, and that adjacent cells do not harbor communities that would have a strong overpowering influence if present.

The occupation of the cell by a community, one that is next in an ideal ecologic succession, is the next most probable event. Of progressively lower probabilites are occupation of the cell by communities that are progressively further removed in an ideal ecologic succession.

The degree of "closeness" or "farness" in an ecologic succession can be expressed numerically (Fig. 8). For example, if there are 12 communities which are symbolized by numbers such that community 1 is a pioneer community and community 12 is the climax community (for a given set of environmental conditions), given sufficient time increments, the pioneer community (1) should gradually be replaced by communities symbolized by higher and higher numbers until the climax community (12) is reached. Thus, while there is a tendency for the succession to be unidirectional (i. e., toward the climax) momentary reversals can occur as a result of random fluctuations and major reversals can be produced by major changes in environmental factors (including catastrophic events). These reversals can be regarded as matters of probability.

In the program, the selection of the community to occupy each cell for the next time increment is treated as a probabilistic event in which the likelihood of selecting a particular community is proportional to a probability value assigned to each of the communities represented. The selection of the community is made with a pseudorandom number generated by a binary external procedure (RANDOM, line 813 of Table 1) which is used to select a single number from an array of integers (Fig. 8). In this array, the proportion of different integers reflects the probability that a specific integer will be chosen. Inasmuch as the integer array is a component in a loop which is cycled in each time increment, the proportions of integers may be regarded as a feedback influence (Fig. 8).

In filling an array from which a selection will be made for the next time increment, the program considers the existing distribution of communities as well as the two preceding time increments. This provides positive feedback which affects the geographic stability of population through successive time increments. For example, if a given type of organism community has occupied a given cell for three successive time increments, the probability of the same community occupying the same cell in the forthcoming time increment is greater than it would be if different communities had occupied the cell during the three preceding time increments. The effect of this may be likened to inertia in that long-established communities may tend to resist subsequent change much more than communities whose occupation has been brief. Numbers fed in as data are used to control this inertia or feedback effect,

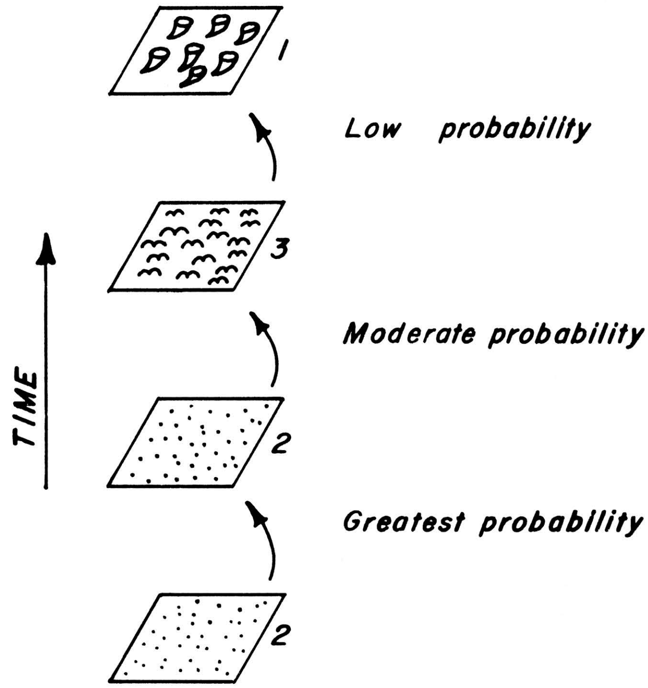

Figure 7.- Relative probabilities of succession of organism communities occupying same cell through time increments of short duration. Numbers adjacent to cells pertain to relative position in ideal ecologic sequence. Probability values pertain to probability of a particular community succeeding another in single time increment.

so that the degree of stability of communities can be finely regulated.

The selection of any particular community in any cell is influenced by communities in geographically proximate cells. This method is crudely analogous to the seeding effect of land plants, in that the influence of communities progressively declines with increasing distance. Figure 9 shows how this effect is approximated. The four cells (II) which lie immediately adjacent to the central cell (I) are given somewhat less weight than the central cell. The four cells (III) which touch the corners of the central cell are given somewhat less weight, since they lie at slightly greater distance. Finally, the twelve cells labeled IV are given still less weight.

Strong feedback effect — Moderate feedback effect — Weak feedback effect

77777777777777 8888888 999 10 11 12 1 2 2 3 4 5 6

Equal likelihood of choosing any single number

Figure 8.- Use of integer array within feedback loop. Strong positive feedback effect is provided by relatively high proportion of integers of particular value (such as 7's) and *vice versa* for those of low proportion.

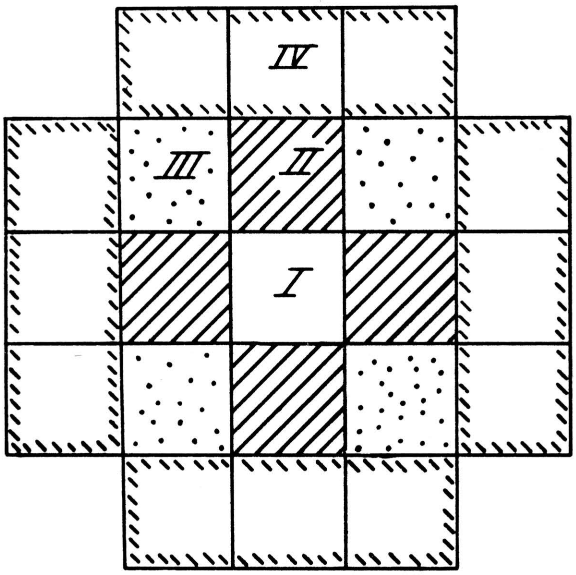

Figure 9.- Method by which communities occupying cells surrounding central cell (labeled I) influence selection of community to occupy cell in next time increment.

The weighting factors are fed in with data used to control operation of the program; consequently the seeding effect may be closely regulated. Cells lying at greater distances are considered to have negligible influence and are neglected. At the edges and corners of the map, special provision is made for the lack of symmetry about the central cell.

The seeding effect resulting from the operations described above provides a means by which communities can migrate geographically, competing for space and interacting with other communities. This causes a community which is better adapted for a given set of environmental conditions (i.e., has high "relative vitality") to gradually replace another community that has lower relative vitality (Fig. 10).

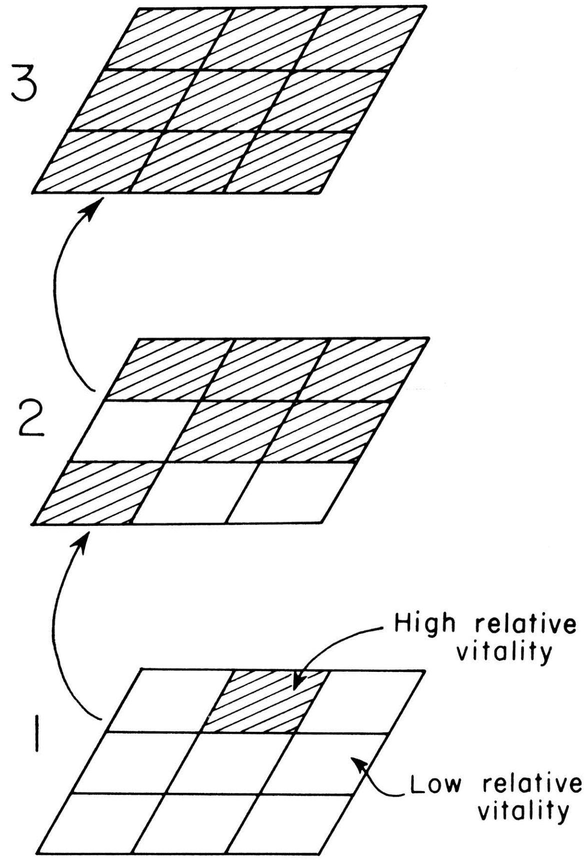

Figure 10.- Replacement of organism community of low relative vitality by one of high vitality through progressive time increments 1, 2, and 3.

Tolerance of Organism Communities for Depth and for Terrestrially Derived Sediment

The manner in which the relative vitality of organism communities is affected by variations in depth of water is shown in Figure 11. The influence of depth is assumed to vary linearly between three points (Fig. 11): (1) an upper depth limit, above which a particular organism community cannot survive, (2) a lower depth limit below which the community cannot survive, and (3) a most favorable depth, where the community is best able to compete (other conditions remaining equal) and produce the greatest amount of sediment. A nonlinear (Gaussian, for example) function could be used to link the three points.

The rate of supply of terrestrially derived sediment affects the vitality of an organism community in a slightly different manner. The rate of supply (in vertical units per time increment) is assumed to have no influence on the community until a specified threshold level is reached (Fig. 12). Above this level, increases in rate of supply cause the relative vitality of the community to decrease linearly until an intolerable sediment level is reached, where relative vitality reaches zero (or very nearly

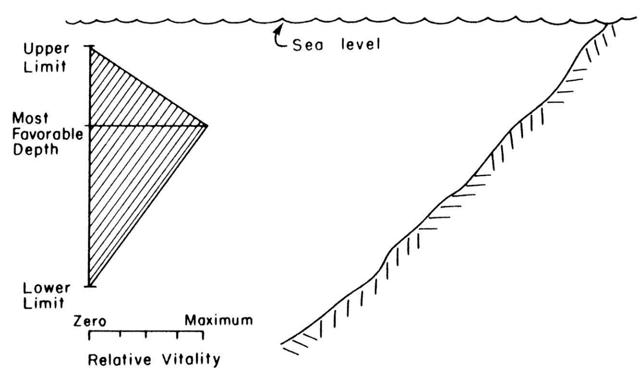

Figure 11.- Effect of variation in depth on relative vitality of organism community.

so). Production of sediment by the organism community is zero above the intolerable level, and the ability of the community to compete is reduced to a very low level. If, however, there is little or no competition from other organism communities, the community may survive even though the rate of supply of terrestrially derived sediment is above the intolerable level.

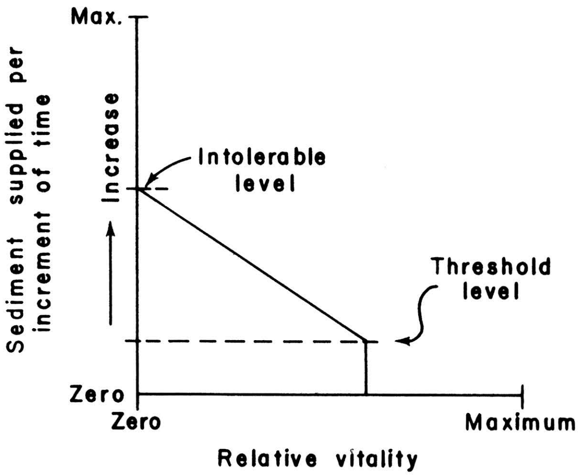

Figure 12.- Effect of variations in rate of supply of terrestrially derived sediment on relative vitality of organism community.

Cyclicity

An assumption of a sedimentary cycle of a prescribed number of time increments is incorporated in the program. The influence of parameters that control external environmental factors (such as supply of terrigenous sediment, etc.) are repeated from cycle to cycle. The cycle may be of any specified number of time increments, although it is currently limited to a maximum of 20 in the program (this limit could readily be increased by changing array dimensions).

The representation of rhythmic repetition of sedimentary cycles is suggested by cyclically bedded sediments of late Paleozoic age in many parts of the world. Presumably, these cyclic sediments reflect variations in ancient depositional environmental conditions that varied in more or less rhythmic fashions. Therefore, in the simulation program, provision is made for cyclic variation of external environmental factors. This does not imply, however, that the response of the model will be perfectly rhythmic from cycle to cycle. The model's response is affected by many factors, including its previous history with respect to organism communities. Because of the "inertia" effect of previous historical events, the model's response may be quite different from cycle to cycle.

VALIDITY OF SIMULATION MODEL

There are few, if any, rigorous means to determine the validity of assumptions incorporated in this simulation model. Instead, its validity must be established on a trial-and-error basis. The best that can be done is to incorporate assumptions concerning processes and factors in the model that seem reasonable from general scientific considerations, and to cause these processes to interact in an appropriate manner. If results (symbolic products) are obtained that accord consistently well with real geologic features, then the model may be judged to be reasonably valid.

PRINCIPAL COMPONENTS OF PROGRAM

Table 1 lists the statements of the simulation program. Each line (card) is numbered. The line numbers of principal components of the program are listed below:

(1) Type declaration for main program: 3-8, 11.
(2) Array declarations: 8-9, 12-19.
(3) Input and read statements of data used to control operation of program: 22-23, 26-28, 35-39.
(4) Input and output of values used as exponents in organism community feedback calculations: 35-47.
(5) Input and output of data used for external influence of organism community feedback values: 48-57.
(6) Procedure MAPLOT, for plotting of symbols in maps: 58-84.
(7) Procedure SHORT, for incremental filling of array KPF ( ) from which next generation organism community will be drawn at random: 85-93.
(8) Procedure FAVDEP, for calculation of relative degree of favorability of organism community at a specified depth: 94-117.
(9) Procedure FB3SHORT, used within other procedures for incremental filling of array KPF ( ): 118-131.
(10) Procedures utilized in incremental filling of array KPF ( ), from which organism community to occupy cell during next generation will be chosen at random. Procedures are listed as follows: CONPROB:132-142; LEFTINNEREDGE: 143-155; LEFTOUTEREDGE: 156-172; RITEINNEREDGE: 173-186; RITEOUTEREDGE: 187-205; UPPERINNEREDGE: 206-219; UPPEROUTEREDGE: 220-238; LOWERINNEREDGE: 239-252; LOWEROUTEREDGE: 253-271; UPPERLEFTCORNER: 272-284; LOWERLEFTCORNER: 285-309; UPPERRITECORNER: 310-333; LOWERRITECORNER: 357-380.

(11) Procedure VALSHORT, for selection of organism community from KPF ( ) array to occupy cell during next generation by use of pseduorandom number generator: 334-356.

(12) Filling of array containing "separateness" values which reflect degree of closeness between communities in three succeeding generations. Values initially supplied are replaced as the model moves forward through time: 381-386.

(13) If WEST equals 1, input data used to mimic influence of wind-driven currents: 387.

(14) Fill initial map array with numbers symbolizing organism communities: 388-394.

(15) If DELTAOP equals 1, information concerning geographic coordinate values of river mouth is input and output: 397-410.

(16) If TECTOP equals 1, information used to control tectonic warping, organism community tolerances, and parameters that control sediment deposition are both input and output: 413-477.

(17) Begin that part of program in which model is advanced through regular increments of time. This section extends from 480 to 811.

(18) If WEST equals 1, extend the geographic distribution of a favored organism community so as to mimic the effect of wind-driven currents in displacing organism communities: 486-498.

(19) If DELTAOP equals 1, perform calculations whose effect is to mimic the effect of a river in creating deltaic deposits flowing from left to right (on maps) bringing mud and/or sand to depositional basin: 499-531.

(20) Determine numerical separations between organism communities in each cell in the two preceding time increments: 532-541.

(21) Calculate feedback values to be stored in TEND ( ) array which regulate the "vitality" or competitive ability of organism communities: 542-563.

(22) Select new organism communities to fill each cell in succeeding time increment through use of procedure calls which accomodate interior, edges, and corners of map: 564-621.

(23) Test to make sure that each organism community assigned as input data is within its allowable depth range. If a community is out of its depth range, test successive communities until one is found that is suitable: 622-627.

(24) Calculate depth of water, while simultaneously considering previous depth, tectonic warping increment, sediment increment, and, if necessary, adjusting organism communities to insure that they are compatible with newly calculated depth: 640-679.

(25) If STRUCTOP equals 1, calculate and print out elevations of stratum (as a measure of its structural configuration), beginning with elevations at time of deposition and continuing as it undergoes subsequent tectonic deformation: 689-703.

(26) Print out organic increment values if called for by output option: 705-713.

(27) Calculate and print out facies maps, after first simulation effect of beach winnowing process, selecting appropriate symbol for type of sediment of greatest volumetric contribution per cell during time increment: 714-750. The values which control the winnowing process are set on line 704. The value assigned to LOWBEACH denotes the depth value at which the winnowing process reaches zero, and the value assigned to BEACHFACTOR pertains to the relative intensity of the winnowing process.

(28) Store and print out vertical geologic section whose horizontal trace lies along a specified map column: 751-783.

(29) Store and print out vertical geologic sections whose horizontal trace lies along a specified map row: 784-810.

(30) Binary external procedures for generating pseudorandom numbers: 813-814.

Table 1.- Listing of BALGOL statements in simulation program. Each line represents one punched card of program. Numbers in left column are for reference purposes in this report, and in practice may be placed within columns 73-80 on punched cards. Each program card should have 2 punched in column 1 (or column 1 left blank).

```
1 COMMENT THREE-DIMENSIONAL SEDIMENT/ORGANISM COMMUNITY SIMULATION
2 PROGRAM FOR 7090 OR 7094 COMPUTER. J.W. HARBAUGH, STANFORD UNIVERSITY $
3 INTEGER OTHERWISE  $
4 REAL  SLOPE, DX, DY, HPF(), VPF() ,FF , DTH,DEPTH,SCALE,THKFL1,THKFL2,
5  WATER, WTRFL ,HT, BTR ,SANDCON, LOWBEACH, BEACHFACTOR,COMCON ,TT    $
6 REAL  TCT(), DPL(,),SED(), DPT() ,BASE, PTH,LTH, WID,P,Q        $
```

```
 7 REAL UPBND, LOWBND, DIFF, FACTOR, RATIO, HV, SUMTER,TAMP,SANDFACTOR,
 7 MUDFACTOR, SF, MF ,TIMP                                               $
 8 REAL ARRAY MUD(20), SAND(20), TER(15,40), MUDINC(15,40),SANDINC(15,40),
 9 TERINC(15,40), ORGINC(15,40) ,STRUCT(15,40)                          $
10 REAL Y,V,LFL,TEND(,),          CPX(, ),FB1,FB2,FB3,FB4,SUMTFAC,TF()$
11    REAL ARRAY CFC(20,10),  SUB(6,10)    ,TEMP(15,40)               $
12 ARRAY  DLT( 1, 1), PTH(20,2), TCT(15,40),              DPT(15,40)   ,
13    SED(10,10), DPL(5,10), DPLOT(40), TCTFX(40), SEDFX(40), DPTFX(40) $
14 ARRAY  HPF( 1, 1), VPF( 1, 1)                        ,SECTOP(20)      $
15 ARRAY TF(5), PPP(40,20), THK(40,20), ROW(300) ,PVP(15,20)            $
16 ARRAY MAP(15,40,3),CV( 40),          TEND(15,40),SEP(15,40,2),
17    CPX( 5, 5    ),ALFA(12),CT(21),KPF( 1000),    TVK(15,20),
18    SMB(30)=('*','$','/','+','M','=','.','1','A','2','-','B','3','C',
19       '4','D','5','E','6','F','7','G','8','H','9','I','J','K','L','M')$
20 FORMAT FMTA(12A6,W3,W)$
21 START..
22 INPUT ALPH(FOR I=(1,1,12)$ ALFA(I))$
23 READ ($$ ALPH)$
24 OUTPUT ALPHA(FOR I =(1,1,12)$ ALFA(I)) $
25 WRITE ($$ ALPHA , FMTA) $
26 INPUT CONTROL(N,M,LIMIT, NC, TPL, LWL, DATOP, INVAL,FB1,FB2,FB3,FB4,
27       WEST , DELTAOP,    TECTOP, SCALE, KK, KD,BASE,STRUCTOP,HOR     )$
28 READ ($$ CONTROL) $
29 FOR J=(1,1,8 )$        CT(J) = 5.J$
30 REAL EXTERNAL PROCEDURE RANDOM() $
31 EXTERNAL PROCEDURE SETRANDOM() $
32 SETRANDOM(INVAL) $
33 COMMENT GENERATE AND PRINTOUT PROBABILITY EXPONENTS $
34 NP = 5$
35 INPUT CFAC(
36    FOR I=(1,1,NP)$
37       FOR J=(1,1,NP)$
38             CPX(I,J  ))$
39 READ ($$ CFAC)$
40 OUTPUT CPXARRAY(
41    FOR I=(1,1,NP)$
42       FOR J=(1,1,NP)$
43             CPX(I,J  ))$
44 FORMAT FMT6(*THE CPX ARRAY*,W2)$
45 WRITE ($$ FMT6)$
46 FORMAT FMTCPX(   5X 6.2,W,W)$
47 WRITE ($$ CPXARRAY,FMTCPX)$
48    INPUT CYFACTS(CLN,FOR I=(1,1,CLN)$ FOR J=(1,1,NC)$ CFC(I,J))$
49    READ($$ CYFACTS)$
50    FORMAT CF1(*ORGANISM COMMUNITY FACTORS FOR CYCLE*,W,W),
51    CF2(20X6.2,W,W)$
52    WRITE($$ CF1)$
53    FOR I=(1,1,CLN)$
54    BEGIN
55       OUTPUT CYDATA(FOR J=(1,1,  NC)$ CFC(I,J))$
56       WRITE($$ CYDATA, CF2)$
57    END$
58 PROCEDURE MAPLOT(L,M,N, MMP(,,), CV(), SMB(),  LL,CT(), LIMIT)$
59 BEGIN
60    COMMENT PROCEDURE MAPLOT PLOTS ALPHAMERIC SYMBOLS REPRESENTING
61       SEDIMENT/ORGANISM COMMUNITY ELEMENTS  $
62    INTEGER OTHERWISE $
63    FORMAT FT3(40I2,P)$
64    FORMAT FT4(     *MAP NUMBER*, I4,W )$          P = L         $
65    OUTPUT MAPNO(P)$   WRITE($$ MAPNO,FT4)$
66    OUTPUT COLHEAD(FOR J=(1,1, 8)$ CT(J))$
```

```
   FORMAT FT1(B3,   8I15,W4)$
   WRITE ($$ COLHEAD,FT1)$
   FORMAT FT2(I3,B2,42A3,W,W)$
   FOR I =(1,1,N) $
   BEGIN
      FOR J =(1,1,M) $ CV(J) = SMB(MMP(I,J,LL)) $
      OUTPUT LINE(I, FOR J =(1,1,M) $ CV(J)) $ WRITE($$ LINE, FT2) $
   END $
     IF LL GTR LIMIT         AND LL LEQ 2$
      BEGIN
      FOR I =(1,1,N)$
      BEGIN
      OUTPUT LINE1(FOR J=(1,1,M)$     MMP(I,J,LL)) $
WRITE ($$ LINE1,FT3)$
      END$
      END$
   RETURN
END MAPLOT()$
PROCEDURE SHORT(LX,FBX,I,J,TEND(,),MAP(,,)$SUM,KPF( ))$
BEGIN
   INTEGER OTHERWISE $
   REAL TEND(),FBX$
   SUM = SUM + 2 $
   KPF(SUM-1) = FBX.TEND(I,J)$
   KPF(SUM)   = MAP(I,J,LX)$
   RETURN
END SHORT()$
PROCEDURE FAVDEP(I,J,DTH,    DPL(,),SED(,),MAP(,,),CIND,LX2,SUB(,),
SF,MF$COMCON)$
BEGIN
INTEGER I,J,LX2, CIND ,MAP$
IF DTH        GEQ DPL(1,MAP(I,J,LX2)) AND DTH        LEQ
   DPL(3,MAP(I,J,LX2))$        BEGIN
   COMCON=((DTH        - DPL(1,MAP(I,J,LX2)))/ DPL(4,MAP(I,J,LX2))).
      SED(CIND,MAP(I,J,LX2))      $  GO LABL $ END$
IF DTH        GEQ DPL(3,MAP(I,J,LX2)) AND DTH        LEQ
   DPL(2,MAP(I,J,LX2))$        BEGIN
   COMCON=((-DTH       + DPL(2,MAP(I,J,LX2)))/ DPL(5,MAP(I,J,LX2))).
      SED(CIND,MAP(I,J,LX2))      $  GO LABL $ END$
COMCON= 0.0$                GO LABLL$
LABL..
IF SF GEQ SUB(2,MAP(I,J,LX2)) OR
   MF GEQ SUB(4,MAP(I,J,LX2))$(COMCON=0.0$ GO LABLL)$
IF SF GTR SUB(1,MAP(I,J,LX2)) OR
   MF GTR SUB(2,MAP(I,J,LX2))$   BEGIN
TAMP=COMCON-(COMCON.((SF-SUB(1,MAP(I,J,LX2)))/SUB(5,MAP(I,J,LX2))))$
TIMP=COMCON-(COMCON.((MF-SUB(3,MAP(I,J,LX2)))/SUB(6,MAP(I,J,LX2))))$
IF TAMP LSS 0.0$ TAMP= 0.0$
IF TIMP LSS 0.0$ TIMP= 0.0$
COMCON  =  MIN(TAMP,TIMP)$          END$
LABLL..
RETURN END FAVDEP()$
PROCEDURE FB3SHORT(LX,FB1,FB2,FB3,I,J,TEND(,),MAP(,,)$SUM,KPF())$
BEGIN
   INTEGER OTHERWISE $
   REAL TEND(), FB1,FB2,FB3,FB4 $
   FOR IFD=I-1,I+1$
      FOR JFD=J-1,J+1$
         SHORT(LX,FB3,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   FOR IFD=I-1,I+1$
         SHORT(LX,FB2,IFD,J  ,TEND(,),MAP(,,)$SUM,KPF())$
```

```
    FOR JFD=J-1,J+1$
            SHORT(LX,FB2,I   ,JFD,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB1,I   ,J   ,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END FB3SHORT()$
PROCEDURE CONPROB(LX,FB1,FB2,FB3,FB4,I,J,TEND(,),MAP(,,)$SUM,KPF())$
BEGIN
    INTEGER OTHERWISE $
    REAL  TEND(), FB1, FB2, FB3, FB4  $
    SUM = 0$
    FOR IFD = I-2,I+2 $ FOR JFD = J-1,J,J+1 $
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD = I-1,I,I+1 $   FOR JFD = J-2,J+2 $
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FB3SHORT(LX,FB1,FB2,FB3,I,J,TEND(,),MAP(,,)$SUM,KPF())$
RETURN END CONPROB() $
PROCEDURE LEFTINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX $
    SUM,KPF()) $
BEGIN
    INTEGER OTHERWISE $
    REAL TEND(), FB1,FB2,FB3,FB4 $
    SUM = 0 $
       FOR IFD=I-1,I,I+1$
            SHORT(LX,FB4,IFD,J+2,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-2,I+2$
       FOR JFD=J-1,J,J+1$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FB3SHORT(LX,FB1,FB2,FB3,I,J,TEND(,),MAP(,,)$SUM,KPF())$
RETURN END LEFTINNEREDGE() $
PROCEDURE LEFTOUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX $
    SUM,KPF()) $
BEGIN
    INTEGER OTHERWISE $ REAL TEND(), FB1,FB2,FB3,FB4 $
    SUM = 0  $
    FOR IFD=I-2,I+2$
       FOR JFD=J,J+1$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-1,I,I+1$
            SHORT(LX,FB4,IFD,J+2,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-1,I+1$
            SHORT(LX,FB3,IFD,J+1,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-1,I+1$
            SHORT(LX,FB2,IFD,J   ,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB2,I   ,J+1,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB1,I   ,J   ,TEND(,),MAP(,,)$SUM,KPF())$
RETURN END LEFTOUTEREDGE() $
PROCEDURE RITEINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
       FOR IFD=I-1,I,I+1$
            SHORT(LX,FB4,IFD,J-2,TEND(,),MAP(,,)$SUM,KPF())$
       FOR IFD=I-2,I+2$
          FOR JFD=(J-1,1,J+1)$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FB3SHORT(LX,FB1,FB2,FB3,I,J,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END RITEINNEREDGE()$
PROCEDURE RITEOUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
```

```
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
    FOR IFD=(I-1,1,I+1)$
            SHORT(LX,FB4,IFD,J-2,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-2,I+2$
        FOR JFD=J-1,J$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-1,I+1$
            SHORT(LX,FB3,IFD,J-1,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-1,I+1$
            SHORT(LX,FB2,IFD,J  ,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB2,I  ,J-1,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB1,I  ,J  ,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END RITEOUTEREDGE()$
PROCEDURE UPPERINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
        FOR JFD=(J-1,J,J+1)$
            SHORT(LX,FB4,I+2,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR IFD=I-1,I,I+1$
        FOR JFD=J-2,J+2$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   FB3SHORT(LX,FB1,FB2,FB3,I,J,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END UPPERINNEREDGE()$
PROCEDURE UPPEROUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
    FOR IFD=I,I+1$
        FOR JFD=J-2,J+2$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
        FOR JFD=J-1,J,J+1$
            SHORT(LX,FB4,I+2,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR JFD=J-1,J+1$
            SHORT(LX,FB3,I+1,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR JFD=J-1,J+1$
            SHORT(LX,FB2,I  ,JFD,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB2,I+1,J  ,TEND(,),MAP(,,)$SUM,KPF())$
            SHORT(LX,FB1,I  ,J  ,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END UPPEROUTEREDGE()$
PROCEDURE LOWERINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
    FOR IFD=I-1,I,I+1$
        FOR JFD=J-2,J+2$
            SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR JFD=J-1,J,J+1$
```

```
          SHORT(LX,FB4,I-2,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   FB3SHORT(LX,FB1,FB2,FB3,I,J,TEND(,),MAP(,,)$SUM,KPF())$
   RETURN
END LOWERINNEREDGE()$
PROCEDURE LOWEROUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,    I,J,LX$
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
    FOR IFD=I-1,I$
       FOR JFD=J-2,J+2$
          SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR JFD=J-1,J,J+1$
          SHORT(LX,FB4,I-2,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR JFD=J-1,J+1$
          SHORT(LX,FB3,I-1,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    FOR JFD=J-1,J+1$
          SHORT(LX,FB2,I   ,JFD,TEND(,),MAP(,,)$SUM,KPF())$
          SHORT(LX,FB2,I-1,J   ,TEND(,),MAP(,,)$SUM,KPF())$
          SHORT(LX,FB1,I   ,J   ,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END LOWEROUTEREDGE()$
PROCEDURE UPPERLEFTCORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX $
    SUM, KPF()) $
BEGIN
    INTEGER OTHERWISE $ REAL TEND(),FB1,FB2,FB3,FB4 $
    SUM = 0 $
    FOR     IFD =(1,1,4) $(JFD = 5 - IFD $
    SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$ SUM,KPF()))$
    FOR IFD =(1,1,3) $( JFD = 4- IFD  $
    SHORT(LX,FB3,IFD,JFD,TEND(,),MAP(,,)$ SUM,KPF()))$
    FOR IFD =1,2 $( JFD = 3-IFD$
    SHORT(LX,FB2,IFD,JFD,TEND(,),MAP(,,)$ SUM,KPF()))$
          SHORT(LX,FB1,I   ,J   ,TEND(,),MAP(,,)$SUM,KPF())$
RETURN END UPPERLEFTCORNER() $
PROCEDURE LOWERLEFTCORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
    SUM,KPF())$
BEGIN
    INTEGER OTHERWISE$
    REAL TEND(),FB1,FB2,FB3,FB4$
    SUM=0$
    FOR IFD=(I-3,1,I)$
    BEGIN
       JFD=IFD-I+4$
       SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    END$
    FOR IFD=(I-2,1,I)$
    BEGIN
       JFD=IFD-I+3$
       SHORT(LX,FB3,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    END$
    FOR IFD=I-1,I$
    BEGIN
       JFD=IFD-I+2$
       SHORT(LX,FB2,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
    END$
    FOR IFD=I$
          SHORT(LX,FB1,I   ,J   ,TEND(,),MAP(,,)$SUM,KPF())$
    RETURN
END LOWERLEFTCORNER()$
```

```
PROCEDURE UPPERRITECORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
   SUM,KPF())$
BEGIN
   INTEGER OTHERWISE$
   REAL TEND(),FB1,FB2    ,FB3,FB4$
   SUM=0$
   FOR IFD=(1,1,4)$
   BEGIN
      JFD=(J-4+IFD)$
      SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   END$
   FOR IFD=(1,1,3)$
      BEGIN
      JFD=J-3+IFD$
      SHORT(LX,FB3,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   END$
   FOR IFD=1,2$
   BEGIN
      JFD=J-2+IFD$
      SHORT(LX,FB2,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   END$
         SHORT(LX,FB1,I  ,J  ,TEND(,),MAP(,,)$SUM,KPF())$
   RETURN
END UPPERRITECORNER()$
PROCEDURE VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
BEGIN
   INTEGER OTHERWISE$
   REAL V,Y,VAL$
   REAL TF()$
   LX1 =  3 - LX2 $
   TOTAL = 0$
   FOR K =(1,2,SUM-1) $ TOTAL = TOTAL + KPF(K)$
   KPF(SUM+1) = TOTAL/10$
   KPF(SUM+2) = MOD(MAP(I,J,LX1),NC)   + 1 $
   TOTAL = TOTAL + KPF(SUM+1)$
   V=RANDOM(Y)$
   VAL = V.TOTAL $
   IF VAL LEQ 1.0 $ VAL = 1.0$  VLL = VAL $
   CHOICE = KPF(1) $      K = 1        $
UNTIL CHOICE GEQ VLL $
   BEGIN
      K = K+2$
      CHOICE = CHOICE + KPF(K)$
   END$
   MAP(I,J,LX2) = KPF(K+1)$
RETURN
END VALSHORT()$
PROCEDURE LOWERRITECORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
   SUM,KPF())$
BEGIN
   INTEGER OTHERWISE$
   REAL TEND(),FB1,FB2,FB3,FB4$
   SUM=0$
   FOR IFD=(I-3,1,I)$
      BEGIN
      JFD=J+IFD-I$
      SHORT(LX,FB4,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
   END$
   FOR IFD=(I-2,1,I)$
      BEGIN
      JFD=J-I+IFD$
```

```
         SHORT(LX,FB3,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
      END$
      FOR IFD=I-1,I$
      BEGIN
         JFD=J-I+IFD$
         SHORT(LX,FB2,IFD,JFD,TEND(,),MAP(,,)$SUM,KPF())$
      END$
            SHORT(LX,FB1,I   ,J   ,TEND(,),MAP(,,)$SUM,KPF())$
      RETURN
   END LOWERRITECORNER()$
   COMMENT FILL SEPARATION ARRAY FOR INITIAL OPERATION $
   FOR I =(1,1,N) $ FOR J =(1,1,M) $
   BEGIN
      SEP(I,J,1)= TPL $
      SEP(I,J,2)= LWL $
   END $
   IF WEST EQL 1 $ (INPUT WESTDATA(FAV, FF)$READ($$ WESTDATA))$
   COMMENT FILL INITIAL MAP ARRAY $
   IF DATOP EQL 1 $
   BEGIN
       INPUT MAPDATA(FOR I=(1,1,N)$ FOR J=(1,1,M)$ MAP(I,J,1))$
      READ ($$ MAPDATA) $
   FOR I=(1,1,N)$ FOR J=(1,1,M)$ MAP(I,J,2)=MAP(I,J,1)$
   END $
   COMMENT SECTION FOR INPUT OF ARRAY CONTAINING DELTA AND ARRAY CONTAIN-
   ING PATH OF DELTA AS GOES THROUGH CYCLE $
   IF DELTAOP EQL 1 $
   BEGIN
      COMMENT INPUT INFORMATION CONTROLLING GEOMETRY OF DELTA$
      INPUT DELCOM(BTR, HT, LTH, WID)$READ($$DELCOM)$
      COMMENT LEFT COLUMN OF PTH ARRAY CONTAINS ROW INDEX COORDINATE
         INCREMENT, RIGHT COLUMN CONTAINS COLUMN INDEX INCREMENT $
      INPUT PATH(      FOR I=(1,1,CLN) $ FOR J = 1,2 $ PTH(I,J)) $
      READ ($$ PATH) $
      FORMAT PATHMAT(*COORDINATE INDEX VALUES FOR PATH OF DELTA FOR EACH
   PHASE IN CYCLE, ROW COORD IN LEFT COL, COLUMN COORD IN RIGHT*,W,W)$
      WRITE($$        PATHMAT)$
      OUTPUT OUTPATH(FOR I=(1,1,CLN)$ FOR J=1,2 $ PTH(I,J))$
      FORMAT FMTPATH(2X6.2,W,W)$       WRITE($$OUTPATH,FMTPATH)$
   END $
   COMMENT SECTION FOR INPUT OF TECTONIC WARPING, INITIAL WATER DEPTH,
          SEDIMENT INCREMENT, AND DEPTH LIMIT ARRAYS $
   IF TECTOP EQL 1 $
   BEGIN
      FOR I =(1,1,N) $ BEGIN INPUT  TECTROW(FOR J =(1,1,M) $ TCTFX(J)) $
         READ($$ TECTROW) $  FOR J =(1,1,M) $(TCT(I,J)=TCTFX(J)     $
         TCT(I,J) = TCT(I,J).0.1 )$ END$
      FOR I =(1,1,N) $ BEGIN  INPUT  DPTHROW(FOR J =(1,1,M) $ DPTFX(J)) $
         READ($$ DPTHROW) $  FOR J =(1,1,M) $ DPT(I,J) = DPTFX(J)     $ END$
      COMMENT INPUT SEDIMENT INCREMENT VALUES FOR EACH COMMUNITY(IN
    COLUMN S    ) FOR EACH PHASE  IN CYCLE(IN )OWS      $
      INPUT SEDINC(FOR I =(1,1,CLN) $ FOR J =(1,1,NC) $ SED(I,J)) $
      READ ($$ SEDINC) $
      COMMENT INPUT UPPER AND LOWER DEPTH LIMITS FOR EACH SEDIMENT/
         ORGANISM COMMUNITY $
      INPUT DEPTHLIMITS(FOR I = 1,2,3$FOR J =(1,1,NC) $ DPL(I,J)) $
      READ ($$ DEPTHLIMITS) $
      FOR J=(1,1,NC)$ BEGIN  DPL(4,J)= DPL(3,J)-DPL(1,J)$
      DPL(5,J)= DPL(2,J)- DPL(3,J)$ END$
      FORMAT SEDFMT(*SEDIMENT INCREMENT VALUES FOR EACH COMMUNITY(IN COLS)
      FOR EACH PHASE IN CYCLE (IN  ROWS   )*,W,W)$ WRITE($$SEDFMT)$
```

```
432     FORMAT FMTSEDTAB(25X6.2,W,W)$
433     FOR I=(1,1,CLN)$ BEGIN OUTPUT SEDTAB(FOR J=(1,1,NC)$ SED(I,J))$
434     WRITE($$ SEDTAB, FMTSEDTAB)$ END$
435     FORMAT LIMFMT(*UPPER AND LOWER DEPTH LIMITS, AND MOST FAVORABLE DEPT
436  H, IN UNITS WITH RESPECT TO SEALEVEL*,W,
437    *(IN ROWS) FOR EACH SEDIMENT/ORGANISM COMMUNITY( IN COLUMNS)*,W,W)$
438     WRITE($$ LIMFMT)$
439     FORMAT LIMTABFMT( 17X7.1,W,W)$
440     FOR I = 1,2,3$BEGIN OUTPUT  DEPABLE(FOR J=(1,1,NC)$ DPL(I,J) )$
441     WRITE($$ DEPABLE, LIMTABFMT)$ END$
442     FORMAT DPTINCFMT(*WARPING INCREMENTS IN UNITS PER CYCLE MULTIPLIED
443  BY 10*,W,W)$
444     WRITE($$ DPTINCFMT)$
445     FOR I=  (1,1,N)$ BEGIN
446     FOR J=(1,1,M)$ TCTFX(J)=TCT(I,J).10.0$OUTPUT DTHINC(FOR J=(1,1,M)$
447     TCTFX(J))$   WRITE($$ DTHINC,    FMTDPTH   )$ END$
448     COMMENT INPUT DATA ON TERRESTRIALLY-DERIVED SEDIMENTS$
449     INPUT BOUNDS(UPBND, LOWBND)$ READ($$ BOUNDS)$
450     DIFF = LOWBND - UPBND$
451     FOR I=(1,1,CLN)$ (INPUT SDMD(SAND(I), MUD(I))$ READ($$ SDMD))$
452     IF DELTAOP NEQ 1$ BEGIN
453     INPUT RATEMAP(FOR I=(1,1,N)$ FOR J=(1,1,M)$ TER(I,J))$
454     READ($$ RATEMAP)$          END$
455     FORMAT SMTABFMT(I4,2X7.2,W,W)$
456     FORMAT SEDPHASE(*INCREMENT VALUES FOR TERRESTRIALLY-DERIVED SEDIMENT
457  *,W3,W,*PHASE   SAND     MUD*,W,W)$ WRITE($$ SEDPHASE)$
458     FOR I=(1,1,CLN )$ (OUTPUT SMTAB(I,SAND(I), MUD(I))$
459     WRITE($$ SMTAB, SMTABFMT))$
460     FORMAT DDHD(*RELATIVE RATES OF TERRESTRIALLY-DERIVED SEDIMENT, MAP*,
461     * NUMBER*,I4,W3,W,
462     *WITH TRANSITON DEPTH RANGE FROM UPPER LIMIT OF*, X6.1,*  AND LOWER*
463     ,* LIMIT  OF*,X7.1,*  UNITS*,W,W)$
464     FORMAT RMAPFMT(44I3,W,W)$
465     IF DELTAOP NEQ 1$ BEGIN
466     L=0$
467     OUTPUT BNDS(L,UPBND,LOWBND)$
468     WRITE($$ BNDS,DDHD)$
469     FOR I=(1,1,N )$ BEGIN
470        FOR J=(1,1,M)$ DPLOT(J)= TER(I,J).10.0$
471        OUTPUT RTMP(I, FOR J=(1,1,M)$ DPLOT(J))$
472     WRITE($$ RTMP, RMAPFMT)$ END$        END$
473      INPUT SUBVALS(FOR I=(1,1,4)$FOR J=(1,1,NC)$ SUB(I,J))$
474      READ($$ SUBVALS)$
474      FORMAT SUBFMT(*SEDIMENT TOLERANCE LIMITS  OF ORGANISM COMMUNITIES*,
474      * FOR MIN AND MAX SAND  VALUES (UPPER TWO ROWS) AND MUD (LOWER TWO *
474      ,* ROWS)*,W,W,W)$ WRITE($$SUBFMT)$
474      FOR J=(1,1,NC)$( SUB(5,J)=SUB(2,J)-SUB(1,J)$
474      SUB(6,J)= SUB(4,J)- SUB(3,J))$
474  FOR I=(1,1,6)$(OUTPUT SBBVALS(FOR J=(1,1,NC )$ SUB(I,J))$
474      WRITE($$ SBBVALS, FMTSEDTAB))$
474      INPUT SECTION(FOR I=(1,1,LIMIT)$ SECTOP(I))$ READ($$SECTION)$
474  END $
475  FORMAT INITIAL(    *INITIAL DISTRIBUTION OF ORGANISM COMMUNITIES*,W3)$
476  IF SECTOP(1) NEQ 2$ BEGIN
478  WRITE($$INITIAL)$
479             MAPLOT(0,M,N, MAP(,,), CV(), SMB(), 1,  CT(),LIMIT)$
477  END$
480  FOR L = (1,1,LIMIT)$
481  BEGIN
482      LX1 = MOD(L,2) + 1 $  LX2 = 3 - LX1 $
483      LX=LX1$
```

```
      CIND = MOD(L,CLN)$ IF CIND EQL 0 $ CIND = CLN$
   COMMENT SECTION FOR INFLUENCE OF WIND FROM NORTH  $
   IF ( WEST EQL 1 ) AND ( CFC(CIND,FAV) GEQ FF )$
   BEGIN
      FOR I =(1,1,N)$ FOR J =(5,1,M)$
      BEGIN
         IF MAP(I,J,LX1) EQL FAV $
         BEGIN
            IF    MAP(I+1,J-1,LX1) EQL FAV$
            MAP(I+4,J-3,LX1) = MAP(I+8,J-4,LX1)= FAV$
        IF MAP(I+1,J+1,LX1) EQL FAV$( MAP(I+4,J+3,LX1) = FAV$
            MAP(I+8,J+4,LX1) = FAV)$
         END$
      END$
   END$
IF DELTAOP EQL 1$
BEGIN
   BTR= SAND(CIND) + MUD(CIND)$      TT= HT+BTR$
   IF BTR NEQ 0.0$ (SANDFACTOR= SAND(CIND)/BTR$
      MUDFACTOR= MUD(CIND)/BTR)$
   FOR I =(1,1,N) $ FOR J =(1,1,M) $      TER(I,J) = BTR$
   FOR J=(1,1,M)$
   BEGIN
      IF J GTR PTH(CIND,2)  AND  J LSS (PTH(CIND,2)+ LTH)$
      BEGIN
         FOR I=(1,1,N)$
         BEGIN
            P=I$ Q=J$
            IF P GTR (PTH(CIND,1) - WID)  AND P LSS (PTH(CIND,1)+WID)$
            TER(I,J) =((HT -(((Q - PTH(CIND,2))/ LTH).HT)).
               (1.0 -(ABS(P - PTH(CIND,1))/ WID)))  + BTR $
         END$
      END$
   END$
FORMAT DELGEOM(*VALUES HAVE BEEN MULTIPLIED BY 10,          MAP NUMBER*
     ,I5,*   WHOSE BASE-RATE VALUE IS *,X5.2,*  ,WHOSE*,
     *   MAXIMUM VALUE IS *,X5.2,W ,W,*EAST/WEST  LENGTH OF DELTA IS*,
X6.2,* UNITS,  NORTH-SOUTH HALF-WIDTH IS*,X6.2,* UNITS,   E/W COORD*,
* VALUE IS*,X6.2,* ,  N/S COORD VALUE OF MOUTH IS*,X6.2,W,W)$
IF SECTOP(CIND) EQL 1$ BEGIN
   OUTPUT BDDD(L,UPBND,LOWBND)$
   WRITE($$BDDD, DDHD)$
OUTPUT DLTGM(L,BTR,TT,LTH,WID,PTH(CIND, 2), PTH(CIND,1))$
WRITE($$ DLTGM, DELGEOM)$
   WRITE ($$ COLHEAD,FT1)$
   FOR I=(1,1,N )$ BEGIN
      FOR J=(1,1,M)$ DPLOT(J)= TER(I,J).10.0$
      OUTPUT TTMP(I, FOR J=(1,1,M)$ DPLOT(J))$
   WRITE($$ TTMP, RMAPFMT)$ END$
END$      END$
   FOR I = (1,1,N) $
   BEGIN
      FOR J =(1,1,M) $
      BEGIN
         S1 = ABS( NC - MAP(I,J,LX1) + MAP(I,J,LX2)) $
         S2 = ABS(       MAP(I,J,LX1) - MAP(I,J,LX2)) $
         S3 = ABS( NC + MAP(I,J,LX1) - MAP(I,J,LX2)) $
      SEP(I,J,LX1)=ABS(MIN(S1,S2,S3)) + 1 $
       IF SEP(I,J,LX1) GTR 5$
         SEP(I,J,LX1)=5$
TEND(I,J)=(CFC(CIND, MAP(I,J,LX1))*(CPX(SEP(I,J,LX1), SEP(I,J,LX2))))$
```

```
COMCCN=TEND(I,J)$
IF DPT(I,J) GEQ DPL(1,MAP(I,J,LX1)) AND DPT(I,J) LEQ
   DPL(3, MAP(I,J,LX1))$ BEGIN
COMCON=COMCON.((DPT(I,J) - DPL(1,MAP(I,J,LX1)))/DPL(4,MAP(I,J,LX1))) $
       GO LAB9 $ END$
IF DPT(I,J) GEQ DPL(3,MAP(I,J,LX1)) AND DPT(I,J) LEQ
   DPL(2, MAP(I,J,LX1))$ BEGIN
COMCON=COMCON.((-DPT(I,J)+ DPL(2,MAP(I,J,LX1)))/DPL(5,MAP(I,J,LX1))) $
       GO LAB9 $ END$
TEND(I,J)=0.03$GO LAB15$ LAB9..
IF SF GEQ SUB(2,MAP(I,J,LX1)) OR
   MF GEQ SUB(4,MAP(I,J,LX1))$(TEND(I,J)=1.0$GO LAB15)$
IF SF GTR SUB(1,MAP(I,J,LX1)) OR
   MF GTR SUB(2,MAP(I,J,LX1))$   BEGIN
TAMP=COMCON-(COMCON.((SF-SUB(1,MAP(I,J,LX1)))/SUB(5,MAP(I,J,LX1))))$
TIMP=COMCON-(COMCON.((MF-SUB(3,MAP(I,J,LX1)))/SUB(6,MAP(I,J,LX1))))$
IF TAMP LSS 0.03$TAMP= 0.03$
IF TIMP LSS 0.03$TIMP= 0.03$
TEND(I,J)= MIN(TAMP,TIMP)$            END$              LAB15..
       END$
   END $
   COMMENT PICK NEW MAP ELEMENTS $
   FOR I =(3,1,N-2) $
   BEGIN
      FOR J =(3,1,M-2) $
      BEGIN
         CONPROB(LX,FB1,FB2,FB3,FB4,I,J,TEND(,),MAP(,,)$SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
END$
END$
   FOR I =(3,1,N-2) $
   BEGIN
J=2$
      LEFTINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,2,LX1$SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
      J=M-1$
         RITEINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
            SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
      J=M$
         RITEOUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
            SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
      J = 1 $
         LEFTOUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$
            SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
   END $
FOR I=1,2$ FOR J=1,2$ BEGIN
   UPPERLEFTCORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
END$
FOR I=N-1,N$ FOR J=1,2$ BEGIN
   LOWERLEFTCORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
END$
FOR I=N-1,N$ FOR J=M-1,M$ BEGIN
   LOWERRITECORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
          VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
END$
FOR I=1,2$ FOR J=M-1,M$ BEGIN
```

```
    UPPERRITECORNER(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
             VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
END$
FOR  J=(3,1,M-2)$
    BEGIN
        I=2$
        UPPERINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
             VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
        I=1$
        UPPEROUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
             VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
        I=N-1$
        LOWERINNEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
             VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
        I=N$
        LOWEROUTEREDGE(MAP(,,),TEND(,),FB1,FB2,FB3,FB4,I,J,LX$SUM,KPF())$
             VALSHORT(I,J,NC,SUM,LX2,TF(),KPF()$MAP(,,))$
    END$
FOR I=(1,1,N)$FOR J=(1,1,M)$ BEGIN
K=1$ LAB12..
IF DPT(I,J) GEQ DPL(1,MAP(I,J,LX2)) AND DPT(I,J) LEQ DPL(2,MAP(I,J,LX2
))$ GO LAB13$
MAP(I,J,LX2)= MOD(MAP(I,J,LX2),NC) +1$ K=K+1$ IF K EQL (NC+1)$GO LAB13$
GO LAB12$ LAB13..   END$
    IF TECTOP EQL 1 $
    BEGIN
        COMMENT CALCULATE DEPTH BY ALGEBRAIC ADDITION OF WARPING,
        SEDIMENT INCREMENT, AND PREVIOUS DEPTH, SELECTING, IF NECESSARY
        BY REPEATED ITERATIONS, A COMMUNITY SUITED FOR DEPTH RANGE $
        FORMAT DPTITLE(*DEPTH IN TENS OF UNITS, MAP NUMBER *,I3,W3,W)$
IF SECTOP(CIND) NEQ 2$ BEGIN
        OUTPUT DEPTHMAPNUMBER(L)$ WRITE($$DEPTHMAPNUMBER,DPTITLE)$
    OUTPUT COLHEAD(FOR J=(1,1, 8)$ CT(J))$
    FORMAT FT1(B3,   8I15,W4)$
    WRITE ($$ COLHEAD,FT1)$
END$
        FOR I =(1,1,N) $
        BEGIN
            FOR J =(1,1,M) $
            BEGIN
            DTH=TEMP(I,J)= DPT(I,J) + TCT(I,J)$
            K = 1 $
            IF DTH LSS UPBND$(TERINC(I,J)=0.0$ GO LAB4)$
            IF DTH GEQ UPBND AND DTH LEQ LOWBND$ (DTH=DTH -(TER(I,J).
                ((DTH- UPBND)/ DIFF))$  GO LAB11)$
            DTH= DTH - TER(I,J)$ LAB11..
            IF DTH LSS UPBND$ DTH= UPBND$
            TERINC(I,J)= TEMP(I,J) - DTH$ LAB4..
SF= SANDFACTOR.TER(I,J)$ MF= MUDFACTOR.TER(I,J)$
             FAVDEP(I,J,DTH    ,DPL(,),SED(,),MAP(,,),CIND,LX2,SUB(,),
SF,MF $COMCON)$
            DEPTH =  DTH - COMCON$
            EITHER IF
            DEPTH GEQ DPL(1,MAP(I,J,LX2)) AND DEPTH LEQ DPL(2,MAP(I,J,LX2)
                )$ GO LAB1$
            OR IF DEPTH LSS DPL(1,MAP(I,J,LX2)) AND DTH GEQ DPL(1,MAP(I,J
                ,LX2))$ ( DPT(I,J) = DPL(1,MAP(I,J,LX2))$ GO PAST)$
            OTHERWISE$
            UNTIL  DEPTH  GEQ  DPL(1,MAP(I,J,LX2)) AND DEPTH
                LEQ  DPL(2,MAP(I,J,LX2)) $
                BEGIN
```

```
              K = K+1 $
              IF K EQL (NC+1)$(DPT(I,J)=DTH  $  GO PAST) $
              MAP(I,J,LX2) = MOD(MAP(I,J,LX2),NC) + 1 $
             FAVDEP(I,J,DTH    ,DPL(,),SED(,),MAP(,,),CIND,LX2,SUB(,),
SF,MF $COMCON)$
              DEPTH = DTH - COMCON$
              IF DEPTH LSS DPL(1,MAP(I,J,LX2)) AND DTH GEQ DPL(1,MAP(I,J
              ,LX2))$ ( DPT(I,J) = DPL(1,MAP(I,J,LX2))$ GO PAST)$
              END $
            LAB1..
            DPT(I,J) = DEPTH $
            PAST..
            DPLOT(J) = DPT(I,J)      $
            ORGINC(I,J)=TEMP(I,J)-DPT(I, J) - TERINC(I,J) $
            END $
IF SECTCP(CIND) NEQ 2$ BEGIN
     OUTPUT DEPLINE(I,FOR K =(1,1,M) $ DPLOT(K)) $
       FORMAT FMTDPTH(44I3,W,W) $
       WRITE ($$ DEPLINE, FMTDPTH) $
       FORMAT DPTHPUNCH(20I4,P)$
       IF L GTR LIMIT$ (OUTPUT DPCH(FOR K=(1,1,M)$DPLOT(K))$
       WRITE($$DPCH,DPTHPUNCH))$
END$
       END $
    STRUCTOP EQL 1$
BEGIN
    IF L EQL HOR$(FOR I=(1,1,N)$FOR J=(1,1,M)$STRUCT(I,J)=DPT(I,J))$
    IF L GTR HOR$(FOR I=(1,1,N)$FOR J=(1,1,M)$STRUCT(I,J)=
       STRUCT(I,J)+ TCT(I,J))$
    FORMAT STRHED(*STRUCTURE MAP *,I3,W3,W)$
    IF SECTOP (CIND) EQL 1$ BEGIN
    WRITE ($$DEPTHMAPNUMBER, STRHED)$
    WRITE ($$COLHEAD,FT1)$
    FOR I=(1,1,N)$
    BEGIN
       FOR J=(1,1,M)$ DPLOT(J)= STRUCT(I,J)$
     OUTPUT STR(I,FOR J=(1,1,M)$ DPLOT(J))$ WRITE($$STR,FMTDPTH)$
    END$
END$     END$
LOWBEACH= 5.0$    BEACHFACTOR= 10.0$
IF SECTOP(CIND) NEQ 2$ BEGIN
FORMAT TEMORG(*ORGANIC INCREMENT VALUES MULTIPLIED BY 10, MAP NUMBER*,
I4,W3,W)$ WRITE($$DEPTHMAPNUMBER,TEMORG)$
WRITE($$COLHEAD,FT1)$
FOR I=(1,1,N)$ BEGIN
    FOR J=(1,1,M)$ DPLOT(J)= ORGINC(I,J).10.0$
    OUTPUT ORGOUT(I,FOR J=(1,1,M)$ DPLOT(J))$ WRITE($$ORGOUT,FMTDPTH)$
END$
END$
    FOR I=(1,1,N)$  FOR J=(1,1,M)$
    BEGIN
SANDCON= SAND(CIND)$
IF DPT(I,J) GEQ 0.0 AND DPT(I,J) LEQ LOWBEACH$
SANDCON = SANDCON + ((LOWBEACH - DPT(I,J)).BEACHFACTOR) $
       SUMTER= MUD(CIND) + SANDCON$
       IF SUMTER EQL 0.0$ (RATIO = 1.0$ GO LAB10)$
       RATIO=TERINC(I,J)/(MUD(CIND) + SANDCON)$      LAB10..
       MUDINC(I,J)=MUD(CIND).RATIO$
       SANDINC(I,J)=SANDCON    .RATIO$
       HV = MAX(ORGINC(I,J),MUDINC(I,J),SANDINC(I,J))$
       IF HV EQL ORGINC(I,J)$
```

```
      BEGIN
         MAP(I,J,3) = MAP(I,J,LX2)$
         IF J EQL KK$ PVP(I,L)= MAP(I,J,LX2)$
         IF I EQL KD$ PPP(J,L)= MAP(I,J,LX2)$
         GO LAB6 $
      END$
      IF HV EQL MUDINC(I,J)$
      BEGIN
         MAP(I,J,3) = 11$
         IF J EQL KK$ PVP(I,L)= 11$
         IF I EQL KD$ PPP(J,L)= 11$
         GO LAB6 $
      END$
      MAP(I,J,3) = 7$
      IF J EQL KK $ PVP(I,L) = 7 $
      IF I EQL KD $ PPP(J,L) = 7 $
      LAB6..
   END $
IF SECTOP(CIND) NEQ 2$ BEGIN
   FORMAT FACIESMAP(*FACIES MAP*,W3), ORGMAP(*ORGANISM COMMUNITY MAP*,
      W3)$  WRITE($$ FACIESMAP)$
           MAPLOT(L,M,N, MAP(,,), CV(), SMB(), 3,  CT(),LIMIT)$
   WRITE($$ ORGMAP)$
           MAPLOT(L,M,N, MAP(,,), CV(), SMB(),LX2, CT(),LIMIT)$
END$
   IF KK GTR 0$
   BEGIN
      FORMAT VPHED(*STRATIGRAPHIC SECTION*,I4,* ALONG COLUMN *,I2,
      *   SCALED SO THAT 1/10 INCH = *,X5.2,*   THICKNESS UNITS*,
      * AND BASE IS SET AT*,X5.2,* UNITS*,W3,W)$
      OUTPUT HEDATA(L,KK,SCALE,BASE)$
      FORMAT VPROFMAT(I3,B1,128A1,W,W)$
      IF SECTOP(CIND) GTR 0$ WRITE($$HEDATA,VPHED)$
      FOR I=(1,1,N)$
      BEGIN
         THKFL1 =(TEMP(I,KK)-DPT(I,KK)).SCALE $
         THKFX = THKFL1 $ THKFL2 = THKFX$
         IF (THKFL1 - THKFL2) LSS 0.5$(TVK(I,L)=THKFX $ GO LAB2)$
         TVK(I,L)=THKFX + 1 $ LAB2..
         IF DPT(I,KK) LEQ BASE$(KTR=0$ GO LAB3)$
         WATER =(DPT(I,KK)- BASE).SCALE$
         WTRFX = WATER$ WTRFL = WTRFX$
         IF (WATER - WTRFL) LSS 0.5$ WTRFX = WTRFX + 1$
         FOR J =(1,1,WTRFX)$ ROW(J) = 'I'$
         KTR = WTRFX $ LAB3..
         FOR JJ =(L,-1,1)$
         BEGIN
            FOR LL=(1,1,TVK(I,JJ))$
            BEGIN
               KTR = KTR + 1$
               ROW(KTR) = SMB(PVP(I,JJ)) $
            END$
         END$
         IF KTR GTR 128$ KTR = 128 $
            IF SECTOP(CIND) GTR 0$ BEGIN
         OUTPUT VPROFDATA(I,FOR J=(1,1,KTR)$ ROW(J))$
         WRITE($$ VPROFDATA, VPROFMAT)$       END$
      END$
   END$
   IF KD GTR 0$
   BEGIN
```

```
FORMAT HPHED(*STRATIGRAPHIC SECTION*,I4,* ALONG ROW    *,I2,
*   SCALED SO THAT 1/10 INCH = *,X5.2,*   THICKNESS UNITS*,
* AND BASE IS SET AT*,X5.2,* UNITS*,W3,W)$
OUTPUT HHDATA(L,KD,SCALE,BASE)$
IF SECTOP(CIND) GTR 0$ WRITE($$ HHDATA, HPHED)$
FOR J=(M,-1,1)$
BEGIN
   THKFL1 =(TEMP(KD,J)-DPT(KD,J)).SCALE    $
   THKFX = THKFL1 $ THKFL2 = THKFX$
   IF (THKFL1 - THKFL2) LSS 0.5$(THK(J,L)=THKFX $ GO LAB7)$
   THK(J,L)=THKFX + 1 $ LAB7..
   IF DPT(KD,J) LEQ BASE$(KTR=0$ GO LAB8)$
   WATER =(DPT(KD,J)- BASE).SCALE$
   WTRFX = WATER$ WTRFL = WTRFX$
   IF (WATER - WTRFL) LSS 0.5$ WTRFX = WTRFX + 1$
   FOR I =(1,1,WTRFX)$ ROW(I) = 'I'$
   KTR = WTRFX $ LAB8..
   FOR JJ =(L,-1,1)$
   BEGIN
      FOR LL=(1,1,THK(J,JJ))$
      BEGIN
         KTR = KTR + 1$
         ROW(KTR) = SMB(PPP(J,JJ)) $
         END$
      END$
      IF KTR GTR 128$ KTR = 128 $
         IF SECTOP(CIND) GTR 0$ BEGIN
      OUTPUT HPROFDATA(J,FOR I=(1,1,KTR)$ ROW(I))$
      WRITE($$ HPROFDATA, VPROFMAT)$       END$
   END$
END$
END $
END $
GO START $ FINISH $
RANDOM
SETRANDOM
FINISH$
```

INPUT TO PROGRAM

Data used to control operation of the program, and to establish the initial environmental conditions (such as depth) when a simulation run is begun, are read in on punched cards. The rules for data cards with BALGOL are very simple, and adherence to rigid input format specifications is not necessary, inasmuch as a free field is used. The following rules must be observed, however: (1) The first column of each data card is ignored. It may be convenient to punch 5 in column 1 of each data card for consistency's sake, since this was a requirement in earlier versions of BALGOL. (2) Numbers must be consistent as to type integer, or type real (decimal-point numbers). (3) At least one blank column must separate numbers. (4) The presence of an asterisk on a card causes all columns to the right of the asterisk on the card to be ignored. (5) Each new READ statement requires that reading begins with a new card.

The following data, in the prescribed sequence, are required by the program, with some omissions permissible, depending on options indicated on the control card (or cards). A new card in the sequence of data cards should be used for data items that are described in each of the sections that follow. Of course, more than one card may be used for the data in each section if needed. They are marked with the underlined headings. A listing of the data cards used to produce the output which is partially shown in Figures 13 to 20 is presented in Table 2. Any number of data sets may be used in succession.

<u>Alphameric</u> heading card. - The first card of each data set (example in line 1 of Table 2) consists of letters, numbers and other symbols for identification purposes (lines 22-23, Table 1). The card must be punched as follows:

(1) $ in columns 2 and 75.
(2) Any desired combination of symbols and blanks in columns 3 through 74. These will be reproduced as punched on the

card at various places in the program's output.

Control card (or cards). - The second data card must contain information used to control many of the operations of the program, as follows (lines 26-28, Table 1):

(1) An integer (N) specifying the number of rows in the map arrays (limited to a maximum of 25 unless the array dimensions are changed).

(2) An integer (M) specifying the number of columns in the map arrays (limited to a maximum of 40 unless the array dimensions are changed).

(3) An integer (LIMIT) specifying the number of increments of time through which the simulation model is to be run forward.

(4) An integer (NC) specifying the number of organism communities. The maximum number is 30 unless more symbols are added to the SMB ( ) array on lines 18 and 19 of Table 1.

(5) An integer (TPL) specifying the numerical separation between the set of organisms read in initially and a hypothetical preceding set that occupied the area prior to the first time increment is needed to get the simulation model started. A value of 1 is ordinarily appropriate.

(6) An integer (LWL) specifying the numerical separation between the first and second hypothetical sets of organism communities that occupied the map area prior to the set read in as data. A value of 2 seems appropriate.

(7) An integer (DATOP) specifying whether integers representing organism communities are to be read in as data, as follows:
   1 Read in data
   2 Generate the distribution of organism communities by a function, which would have to be written and inserted at an appropriate place, such as immediately following line 410.

(8) An integer (INVAL) used for starting the pseudorandom number generating system. Any positive integer may be used.

(9) Four decimal-point numbers (a decimal-point number will be called simply a "decimal" hereafter); FB1, FB2, FB3, FB4 which specify the relative weighting of the organism communities occupying individual cells in the center and surrounding cells (Fig. 9). Values of 50.0, 10.0, 3.0, and 1.0 (for weightings for cells labelled I, II, III, and IV respectively), have been used successfully, but different values may be used to adjust the competitive influence of adjacent communities. Increasing the latter values (FB4 and FB3) with respect to the former values (FB1 and FB2) would increase the distance over which organism communities influence their neighbors.

(10) An integer (WEST) specifying whether the effect of currents (possibly wind-driven) is to be simulated, as follows:
   0 do not simulate currents
   1 simulate currents.

(11) An integer (DELTAOP) specifying whether data controlling deltaic deposition is to be read in as data:
   0 do not read data (i.e., delta building will not be simulated)
   1 read in as data.

(12) An integer (TECTOP) specifying whether tectonic warping and accumulation of sediment are to be simulated:
   0 do not simulate
   1 simulate.

In general, (TECTOP) will be assigned a value of 1 when the program is used. If assigned a value of 0, the program could be used for experiments with hypothetical organism communities, ignoring such aspects as tectonic warping, water depth, etc.

(13) A decimal (SCALE) specifying the scaling factor to be used in printing of vertical geologic sections.

(14) An integer (KK) specifying the number of the map column along which column section will be calculated and printed. If no section is desired, punch zero.

(15) An integer (KD) specifying the number of the map row along which row section will be calculated and printed. If no section is desired, punch a zero.

(16) A decimal (BASE) specifying value of base of vertical sections (a value of 0.0, representing sea level, would ordinarily be used).

(17) An integer (STRUCTOP) specifying whether the structure of a specified horizon is to be calculated
   0 do not calculate
   1 calculate.

(18) An integer (HOR) specifying the number of the time increment at which the structure calculations are to begin. At the specified time increment, the structural configuration will be set equal to the "topographic" (marine and/or subaerial) configuration prevailing at that moment.

Values used as exponents in organism community selection. - Decimal values (CPX ( ) array) used as exponents in a function (line 542) that is a component of the method of selecting organism communities, are to be read in at this point. The values control the weighting influence that regulates the feedback effect, and in turn, affects the stability of succession of organism communities. The highest value in the array is assigned when identical communities (i.e.,zero separation) have occupied the same location for three time increments (i. e., greatest stability), and the lowest value where the organism communities occupying the same location for three successive time increments are separated from each other in an ideal ecologic sequence by four or more communities. Intermediate values of the array pertain to combinations of separation values ranging between zero and four, with higher values in the array pertaining to situations in which the numerical separation between the communities occupying a particular location in the immediate past, and the preceding time increment, is less than the separation between the preceding time increment and the time increment, in turn, that proceded it. In the present example, 25 values are required to fill the CPX array, and are read in in descending order (lines 4 to 8 in Table 2).

Values controlling cycle length and relative vitality of organism communities in each cycle. - Values are read in to control the number of time increments in a cycle, and the overall general external influence on relative vitality of each organism community during each time increment (lines 48-49, Table 1). If it is desired that there be no general external influence on relative vitality, the values read in can all be equal (set at 1.0 for example). The data must be read in as follows (example in lines 9 to 16, Table 2):

(1) An integer (CLN) specifying the number of time increments in a complete cycle.
(2) Decimal values of CFC (,) array which are read in as follows:
    (a) For each time increment, there must be values for each organism community in proper order (i.e., if there are organism communities whose sequence is 1 to 5, there must be five values).
    (b) There must be as many time increments as specified by CLN. Thus, if there are 8 time increments, and 5 organism communities, a total of 40 values must be read in.

Data pertaining to currents. - If WEST equals 1 on control card, the following data should be read in on a card placed at this point:

(1) An integer (FAV) to specify the organism community to be favored by lateral transport (as for example, transport in the larval stage by wind-driven currents).
(2) A decimal (FF) specifying the minimum value of the relative vitality (CFC array) before transport will be affected. The effect of transport is to cause the favored community to expand outward and downward with respect to the map.

Initial organism community population. - If DATOP equals 1 on the control card (or cards), cards should be placed at this point containing integers (MAP array) that specify the initial geographic distribution of organism communities. The values should be read in left to right within a row, and downward, row by row. An example is shown in lines 17 to 31 of Table 2.

Data to control delta geometry. - If DELTAOP equals 1 on the control card, two or more cards containing the following information should be placed in the sequence (lines 32 and 33 of Table 2):

(1) A decimal (BTR) specifying the base value, in arbitrary units, of terrestrially derived sediment to be deposited in each cell per time increment. A value of 0.0 may be convenient to use, because the supply of terrestrially derived sediment can be controlled externally and varied in each time increment.
(2) A decimal (HT) indicating the maximum rate of supply of terrestrially derived material at the mouth of the river (which creates the delta).
(3) A decimal (LTH) indicating the maximum east-west length of the delta (assuming map is oriented in customary manner) in terms of numbers of cells.
(4) A decimal (WID) indicating the north-south half width of the delta in terms of numbers of cells.
(5) Beginning on a new card and using one or more cards, place a sequence of pairs of decimal values (PTH array) which list, respectively, the vertical and horizontal geographic coordinate values of the river mouth producing the delta. The geographic coordinate origin is assumed to be in the upper left corner of the map. As many pairs of values should be read in as time increments in the cycle (CLN).

Tectonic warping increments. - If TECTOP equals 1, cards should be placed at this point in the sequence, to contain information controlling the amount of tectonic warping per time increment (example in lines 34 to 63 of Table 2). The amount of warping is uniform for each cell from time increment to time increment. The values should be integers (TCTFX array) which are ten times the intended values, and should be read in the order of their geographic position beginning with the cell in the upper left corner of the map, and continuing, left to right within each row, and then downward from row to row. Each new row should begin on a new card, but a row can occupy more than one card. Positive values signify downwarping, negative values upwarping. The values are in arbitrary units, and should correspond (except for the tenfold magnification) to the units used in dealing with sediment increments and water depths (in feet, meters, etc.) used elsewhere in the program.

Initial depth values. - If TECTOP equals 1, cards should be read in at this point in the data cards sequence to establish the initial water depth values (example in lines 64 to 93 in Table 2). The values should be integers (DPTFX array), should be in the desired units (feet, meters, etc.), and should be read in the same geographic order as the tectonic warping increment values.

Organic sediment increment values. - If TECTOP equals 1, decimal values should be read in at this point signifying, for each time increment in the cycle, the maximum increment of sediment to be contributed by each organism community (SED array). The values should be in the same units used for water depth and terrestrially derived sediment. The values should be read in in succession for the organism communities, beginning with community symbolized by 1, and continuing to the specified number of communities. In the example shown in lines 94 to 101 of Table 2, values (totalling 40) for five organism communities in eight time increments are given.

Organism community depth limits. - If TECTOP equals 1, decimal values (DPL array) specifying the upper depth limit, lower depth limit, and most favorable depth for each organism community, in the same units used to signify depth, should be read in as follows (example in lines 102-104 of Table 2):

(1) The upper depth limit for each organism community in numerical order of integers symbolizing the organism communities. Positive values denote values below sea level; negative above sea level.
(2) The lower depth limit for each organism community.
(3) The most favorable depth for each organism community.

Terrestrially derived sediment increment boundaries. - If TECTOP equals 1, a card containing two values to regulate accumulation of terrestrially derived sediment should be inserted at this point in the sequence. Positive values denote values below sea level; negative values above. The units should be in the same depth units used elsewhere with the program. An example is given on line 105 of Table 2:

(1) A decimal (UPBND) specifying the upper limit (elevation with respect to sea level), above which terrestrially derived sediment cannot accumulate.
(2) A decimal (LOWBND) specifying the limit, below which deposition of terrestrially derived sediment is not inhibited, but above which deposition is progressively inhibited, declining linearly to zero at the value assigned to UPBND.

Sand and mud increment values. - If TECTOP equals 1, a series of cards should be inserted at this point (number of cards equal to number of time increments in cycle), each card containing a pair of decimal values which signify the increment of sand and of mud, respectively, to be contributed during each time increment. The amounts supplied in a particular time increment are equal to all cells regardless of their geographic position. The units should be the same as used in a depth or vertical context elsewhere in the program. An example is shown in lines 106 to 113 of Table 2.

Terrestrially derived sediment. - If DELTAOP does not equal 1 (in other words, deltaic deposition is not to be simulated) but TECTOP does equal 1, a series of decimal values (TER array) should be read in at this point in the sequence. This will supply an amount of terrestrially derived sediment to each cell that is constant for each time increment but may vary from cell to cell. The values read in should be their appropriate geographic positions, beginning in the upper left corner of the map. The values should be in the same units (i.e., no tenfold exaggeration)as used for depth and other sediment values used with the program.

Sand and mud tolerance values. - If TECTOP equals 1, decimal values (SUB array), should be read in as follows (example given in lines 114 to 117, Table 2):

(1) The threshold value of tolerance to sand (in units available for deposition) of each organism community, in ascending order of the integers which symbolize the organism communities. The units should be the same as used elsewhere in specifying sediment increment (in feet, meters, etc.) per increment of time. Organism communities are not affected below the threshold level, but are progressively inhibited above it.
(2) Intolerable level of organism communities with respect to sand supply (organism communities are of low vitality above this level and do not contribute organic sediment).
(3) Threshold value with respect to mud.
(4) Intolerable value with respect to mud.

Output options. - If TECTOP equals 1, a series of integers (SECTOP array) should be read in on a separate card which contains a number of values equal to the number of time increments. Each integer specifies the choice of maps and vertical sections to be printed out for the corresponding time increment (example in line 118 of Table 2), as follows:

0 Output for each time increment, will include depth map, organic-increment map, organism-community map and facies map, but will not include map of rate of supply of terrestrially derived sediment, nor structure map, nor either of two vertical sections.
1 Output, for each time increment, will include all forms of output available from program.
2 Output, for each time increment, will

3 Output, for each time increment, will consist of depth map, organic-increment map, facies map, organism-community map, and the two vertical sections, but will not include map of rate of supply of terrestrially derived sediment nor the structure map.

If TECTOP does not equal 1, the program could be modified for experimental purposes with organism communities alone, ignoring tectonic warping, water depth and other aspects. Provision for appropriate output would have to be made in the modified program.

Table 2.- Listing of data cards used as input to program to produce output shown in Figures 13 to 20.

```
5$* = SPNG/CRIN, DOL = SPNG, / = PHYLLOID ALG, + = OSAGIA,M=SWP, OSCIL DLT$
5  15  40  8    5   1  2  1  10    50.0    10.0   3.0  1.0    0 1 1  0.75 28  9 0.0
  1 1       *CONTROL B
5    5.0  4.8  4.6  4.4   4.2
5    4.0 3.8  3.6  3.4  3.2
5   3.0   2.8  2.6  2.4  2.2
5   2.0  1.8  1.6   1.4   1.2
5    1.0   .8   .6  .4   .2
5  8 1.0  1.0  4.0   1.0          1.          *1 CFC
5 1.   1.7  8.0  1.               1.           *2 CFC
5  1.0  1.4 16.0  1.            1.               *3 CFC
5  1.0  1.25 32.0  1.             1.          *4 CFC
5  1.   1.1  8.0  1.            1.
5 1.   1.0  5.0  1.                       1.
5 1.   1.0  2.4          1.       1.
5   1.0   0.5   0.1   1.0       1.
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 2 2 1
 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
   0.0     3(.0    33.0    10.0          *DELTA GEOM
  11.  -1.  11.  -1.   11.  -1.   11.  -1.   11. -1. 11. -1.  11. -1. 11. -1.
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 1
 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20                          * TCT   1
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 2
 20 20 20 20 20 19 19 19 19 19 20 20 20 20 20 20                          * TCT   2
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 3
 20 20 20 19 19 19 18 18 18 18 19 20 20 20 20 20                          * TCT   3
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 4
 20 20 19 19 19 18 17 17 17 18 18 19 20 20 20 20                          * TCT   4
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 5
 20 20 19 19 18 18 17 16 16 16 17 18 19 19 20 20                          * TCT   5
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 6
 20 20 19 18 18 17 16 15 15 16 17 18 20 20 20 20                          * TCT   6
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 7
 20 19 19 18 17 16 15 14 15 16 17 18 19 20 20 20                          * TCT   7
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 8
 20 19 19 18 17 16 15 14 14 15 16 18 19 19 19 20                          * TCT   8
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT 9
 20 19 19 18 17 16 15 14 15 16 16 17 18 19 19 19                          * TCT   9
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT10
 20 19 19 18 17 17 16 15 15 16 16 17 18 18 18 18                          * TCT  10
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT11
 20 20 19 18 18 17 17 16 16 16 16 16 15 16 17 17                          * TCT  11
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT12
 20 20 19 19 18 18 18 18 18 17 17 16 14 13 15 16                          * TCT  12
 10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20   *TCT13
```

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20 20 20 19 19 18 18 18 18 18 17 16 15 12 13 15                         * TCT  13
10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20  *TCT14
20 20 20 20 19 19 19 19 18 18 18 17 16 13 12 14                          * TCT  14
10 10 10 11 12 13 14 14 15 16 16 17 18 19 20 20 20 20 20 20 20 20 20 20  *TCT15
20 20 20 19 19 19 19 19 19 18 18 17 16 16 15 15                          * TCT  15
14 19 28 35 42 50 56 61 64 68 72 74 77 79 81 82 84 84 83 82 81 80 77 75 *DPT  1
73 70 68 65 64 62 61 61 63 65 67 69 70 71 72 74                          * DPT  1
15 20 28 36 43 52 57 61 65 69 72 75 77 80 81 82 83 83 82 81 80 78 75 72 *DPT  2
70 67 64 62 60 59 58 59 60 62 65 67 70 71 72 73                          * DPT  2
15 20 28 37 45 52 57 62 66 70 73 75 78 80 81 82 82 82 81 80 78 75 73 70 *DPT  3
67 64 61 59 57 57 57 58 59 61 64 68 70 71 72 72                          * DPT  3
16 20 28 37 44 52 57 62 66 70 73 75 78 80 81 81 81 81 80 78 76 73 71 68 *DPT  4
65 62 59 57 56 56 57 58 59 61 66 69 71 72 72 72                          * DPT  4
16 20 28 36 44 51 57 62 66 70 72 75 77 79 80 81 80 79 78 76 74 71 69 66 *DPT  5
63 60 58 56 54 54 55 58 59 62 67 71 72 72 71 71                          * DPT  5
16 20 27 35 43 51 56 61 65 70 72 74 76 78 79 79 78 77 76 74 72 70 67 64 *DPT  6
61 59 55 52 51 52 55 59 60 66 70 71 71 70 70 69                          * DPT  6
15 20 26 33 42 50 55 60 65 69 72 74 75 76 75 75 74 72 71 71 70 68 66 63 *DPT  7
61 57 52 49 49 52 56 60 66 70 71 70 70 68 66 65                          * DPT  7
15 19 25 32 40 48 53 59 63 68 71 73 74 73 72 71 70 69 68 67 66 66 65 63 *DPT  8
60 54 49 48 49 52 59 65 70 71 70 68 65 63 62 61                          * DPT  8
14 18 23 30 39 46 52 57 61 66 69 71 72 71 70 69 66 64 62 62 63 63 63 61 *DPT  9
59 52 49 48 50 57 62 70 70 70 66 62 60 58 57 56                          * DPT  9
13 17 22 28 36 42 50 55 60 63 67 70 71 70 67 63 61 59 59 59 60 60 61 60 *DPT 10
57 51 48 49 52 60 63 69 69 64 60 57 54 51 50 50                          * DPT 10
11 16 20 27 32 40 47 52 57 60 63 66 67 63 61 58 55 53 52 53 54 56 57 57 *DPT 11
53 50 47 49 54 61 64 66 62 59 55 51 48 45 43 44                          * DPT 11
10 14 19 24 30 37 42 50 53 58 60 61 61 58 55 52 48 47 47 48 50 52 53 53 *DPT 12
51 49 47 49 53 60 62 61 59 54 50 46 42 39 39 40                          * DPT 12
 9 12 17 21 27 32 40 46 51 53 56 57 56 53 50 43 40 39 40 42 45 47 50 49 *DPT 13
47 44 43 47 51 56 58 57 53 50 46 41 36 31 31 32                          * DPT 13
 7 11 15 20 25 30 35 40 46 50 51 51 50 48 42 38 36 36 37 38 41 43 44 43 *DPT 14
40 39 40 43 48 51 52 51 49 46 41 36 30 27 27 28                          * DPT 14
 6  9 13 19 22 27 31 36 40 43 45 45 44 41 39 36 34 33 34 36 38 39 40 39 *DPT 15
37 36 37 39 42 44 45 44 43 40 37 30 28 22 23 24                          * DPT 15
 3.  3.   6.   14.   4.
   4.  4.  15.  8.  4.           *2
  5.   5.   30.   6.   4.              *3
   6.   6.    45.   4.   4.          *4
   6.   5.    25.   2.  4.              *5
    5.  4.    8.  6.    4.                                  *6
4.  4.  4.  12.  4.
 3.  2.  2.    24.    2.                     *8
  40.0    25.0     3.0     2.0    -15.0    *UP DEP LIM
    200.0     85.0     68.0    10.0    5.0    *LOW DPT LIM
 80.0   55.0   30.0    5.0    0.0  *FAV DPT
5  -5.0     50.0  * LIMITS OF TERRESTRIALLY-DERIVED SED FADEOUT
  .6  .4
  .2   .3
   .02    .01   *3
   .02   .03            *4
     .50    .4   *5
    1.0     5.0    *6
          15.0     10.0    *7
   7.0     8.0    *8
   0.5    0.5     0.8    1.5     5.0     *SAND  MIN TOLERANCE
   2.0     2.0    3.0   3.0    25.0  *SAND MAX TOL
     0.4      1.0    0.4     1.0    5.0    *MUD MIN TOL
    1.0     1.5    2.0    2.0    15.0  * MUD MAX TOL
  1 1 1 1 1 1 1 1 * SECTOP
```

OUTPUT FROM PROGRAM

Types of output from the program depend on the options specified in the control cards, and on the number of time increments. Examples of output, based on data listed in Table 2, are given in Figures 13 to 20. The different arrays of numbers printed out in Figures 13 and 14 reiterate data that have been read in, and are part of the output for reference's sake, providing a record of the input controls used to obtain a particular set of results. The following information is part of the output, subject to variations which depend on options exercised in use of the program.

(1) Values used as exponents (CPX array) in selecting organism communities (Fig. 13).

(2) The relative vitalities (labeled "organism community factors for cycle") of organism

communities (in columns) for each time increment (in rows), are given (Fig. 13).

(3) The geographic coordinates of river mouth creating delta deposits (Fig. 13).

(4) The maximum increments of sediment contributed by each organism community (in columns) for each time increment (in rows), are given (Fig. 13).

(5) Depth limits for each organism community (in columns) upper depth limit (first row), lower depth limit (second row), and most favorable depth (third row), are given (Fig. 13).

(6) An array showing the geographic location of warping increment values (multiplied by ten) per time increment (Fig. 13).

(7) The increment values of sand and mud supplied per time increment (Fig. 14).

(8) Sediment tolerance limits of organism communities (Fig. 14).

(9) An array showing the geographic location of organism communities which initially populated the area. Symbols (Table 3) have been substituted for the integers which are used for actual representation of the organism communities (Fig. 14).

(10) Arrays showing the rate of supply of terrestrially derived sediment at each geographic cell per time increment (Fig. 15).

(11) Arrays which form structure maps showing elevations of a particular datum with respect to sea level at a time increment (Fig. 15).

(12) Arrays showing amount of organically derived sediment contributed during a time increment (Fig. 15).

(13) Arrays forming depth maps showing elevation of bottom with respect to sea level during successive time increments. Negative values denote elevations above sea level (Fig. 16).

(14) Arrays forming organism community maps or biofacies maps, during successive time increments (Fig. 17).

(15) Arrays forming facies maps showing predominant single lithologic type deposited in each geographic cell during successive time increments (Fig. 18). Dots represent sand, dashes mud, and the organism community symbols used elsewhere represent organically derived sediment.

(16) Vertical sections along one of the rows of the map showing structure and lithology at successive time increments (Fig. 19).

(17) Vertical sections along one of the columns of the map showing structure and lithology at successive time increments (Fig. 20).

Table 3. - List of symbols which are substituted for integers in printing out facies maps and organism-community maps. Substitutions can be made by changing cards 18 and 19 of program (Table 1).

Integer	Equivalent symbol	Integer	Equivalent symbol	Integer	Equivalent symbol
1	*	11	-	21	7
2	$	12	B	22	G
3	/	13	3	23	8
4	+	14	C	24	H
5	M	15	4	25	9
6	=	16	D	26	I
7	.	17	5	27	J
8	1	18	E	28	K
9	A	19	6	29	L
10	2	20	F	30	M

* = SPNG/CRIN, DOL = SPNG, / = PHYLLOID ALG, + = OSAGIA,M=SWP, OSCIL DLT

THE CPX ARRAY

5.00	4.80	4.60	4.40	4.20
4.00	3.80	3.60	3.40	3.20
3.00	2.80	2.60	2.40	2.20
2.00	1.80	1.60	1.40	1.20
1.00	.80	.60	.40	.20

ORGANISM COMMUNITY FACTORS FOR CYCLE

1.00	1.00	4.00	1.00	1.00
1.00	1.70	8.00	1.00	1.00
1.00	1.40	16.00	1.00	1.00
1.00	1.25	32.00	1.00	1.00
1.00	1.10	8.00	1.00	1.00
1.00	1.00	5.00	1.00	1.00
1.00	1.00	2.40	1.00	1.00
1.00	.50	.10	1.00	1.00

COORDINATE INDEX VALUES FOR PATH OF DELTA FOR EACH PHASE IN CYCLE, ROW COORD IN LEFT COL, COLUMN COORD IN RIGHT

11.00	-1.00	11.00	-1.00
11.00	-1.00	11.00	-1.00
11.00	-1.00	11.00	-1.00
11.00	-1.00	11.00	-1.00

SEDIMENT INCREMENT VALUES FOR EACH COMMUNITY(IN COLS) FOR EACH PHASE IN CYCLE (IN ROWS)

3.00	3.00	6.00	14.00	4.00
4.00	4.00	15.00	8.00	4.00
5.00	5.00	30.00	6.00	4.00
6.00	6.00	45.00	4.00	4.00
6.00	5.00	25.00	2.00	4.00
5.00	4.00	8.00	6.00	4.00
4.00	4.00	4.00	12.00	4.00
3.00	2.00	2.00	24.00	2.00

UPPER AND LOWER DEPTH LIMITS, AND MOST FAVORABLE DEPTH, IN UNITS WITH RESPECT TO SEALEVEL
(IN ROWS) FOR EACH SEDIMENT/ORGANISM COMMUNITY(IN COLUMNS)

40.0	25.0	3.0	2.0	-15.0
200.0	85.0	68.0	10.0	5.0
80.0	55.0	30.0	5.0	.0

WARPING INCREMENTS IN UNITS PER CYCLE MULTIPLIED BY 10

9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	18	18	18	19	19	19	19	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	18	17	17	17	17	18	19	19	19	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	18	17	16	16	16	17	17	18	19	19	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	17	16	15	15	15	16	17	18	18	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	17	17	16	15	14	14	15	16	17	19	19	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	16	15	14	13	14	15	16	17	18	19	19	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	16	15	14	13	13	14	15	17	18	18	18	19
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	16	15	14	13	14	15	15	16	17	18	18	18
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	16	16	15	14	14	15	15	16	17	17	17	17
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	17	17	16	16	15	15	15	15	15	14	15	16	16
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	17	17	17	17	16	16	15	13	12	14	15
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	17	17	17	17	17	16	15	14	11	12	14
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	18	18	17	17	17	16	15	12	11	13
9	9	9	10	11	12	13	13	14	15	15	16	17	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	18	18	18	18	18	18	17	17	16	15	15	14	14

Figure 13.- Output from program consisting of data in arrays that have been read as input data.

```
INCREMENT VALUES FOR TERRESTRIALLY-DERIVED SEDIMENT

PHASE  SAND    MUD

   1    .60    .40

   2    .20    .30

   3    .02    .01

   4    .02    .03

   5    .50    .40

   6   1.00   5.00

   7  15.00  10.00

   8   7.00   8.00

SEDIMENT TOLERANCE LIMITS  OF ORGANISM COMMUNITIES FOR MIN AND MAX SAND  VALUES (UPPER TWO ROWS) AND MUD (LOWER TWO  ROWS)

  .50   .50   .80  1.50  5.00

 2.00  2.00  3.00  3.00 25.00

  .40  1.00   .40  1.00  5.00

 1.00  1.50  2.00  2.00 15.00
```

```
INITIAL DISTRIBUTION OF ORGANISM COMMUNITIES
MAP NUMBER    0

            5         10        15        20        25        30        35        40
  1 * * * * * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ * * * * *
  2 * * * * * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ * * * * *
  3 * * * * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ * * * * *
  4 * * * * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ * * * * *
  5 * * * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ * * * * * *
  6 * * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ * * * * * *
  7 * * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ * * * * * * *
  8 * * * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ * * * * * * *
  9 * * * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ * * * * * * * *
 10 * * * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ * * * * * * * *
 11 * * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ * * * * * * * *
 12 * * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ * * * * $ $ *
 13 * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $
 14 * * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $
 15 * * * * * * * * * * * $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $
```

Figure 14.- Output from program consisting of data in arrays that have been read as input data.

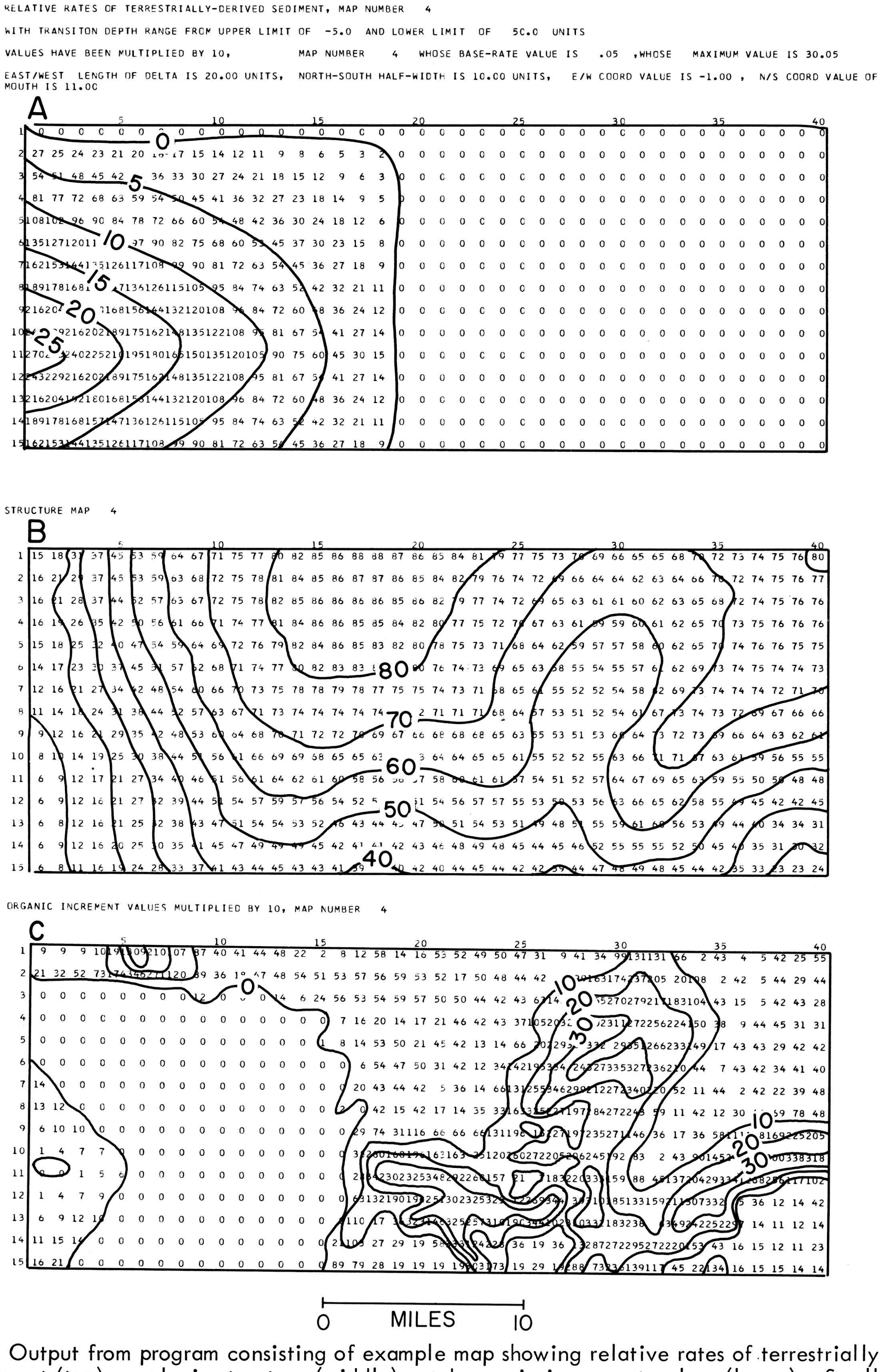
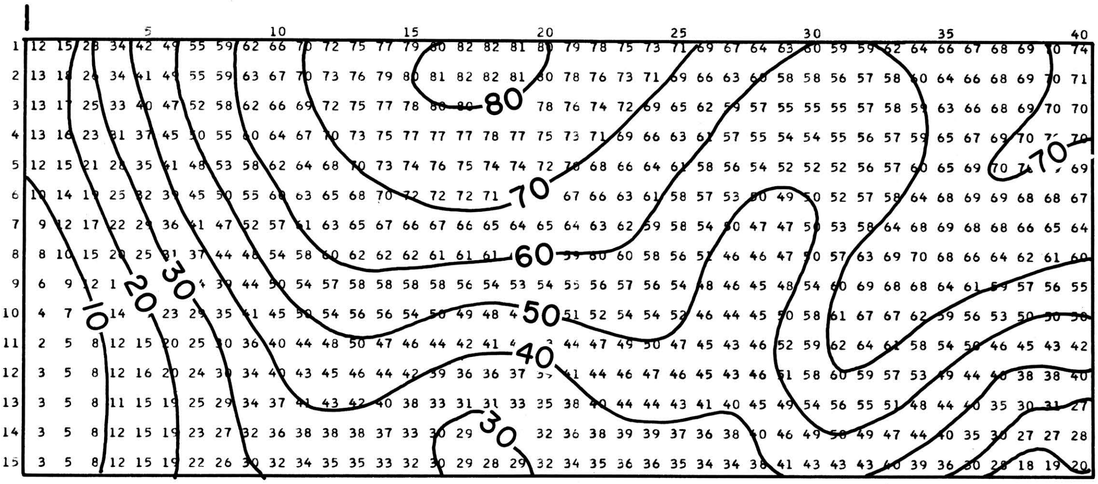
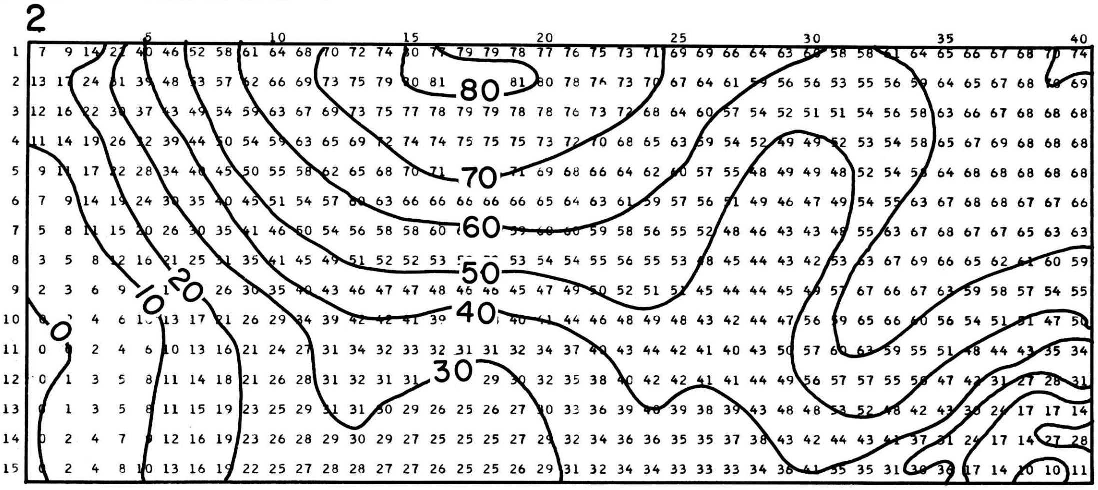


Figure 15.- Output from program consisting of example map showing relative rates of terrestrially derived sediment (top), geologic structure (middle), and organic increment values (lower). Small letters and numbers have been printed by computer's line printer; lines and large letters and numbers have been added by hand.

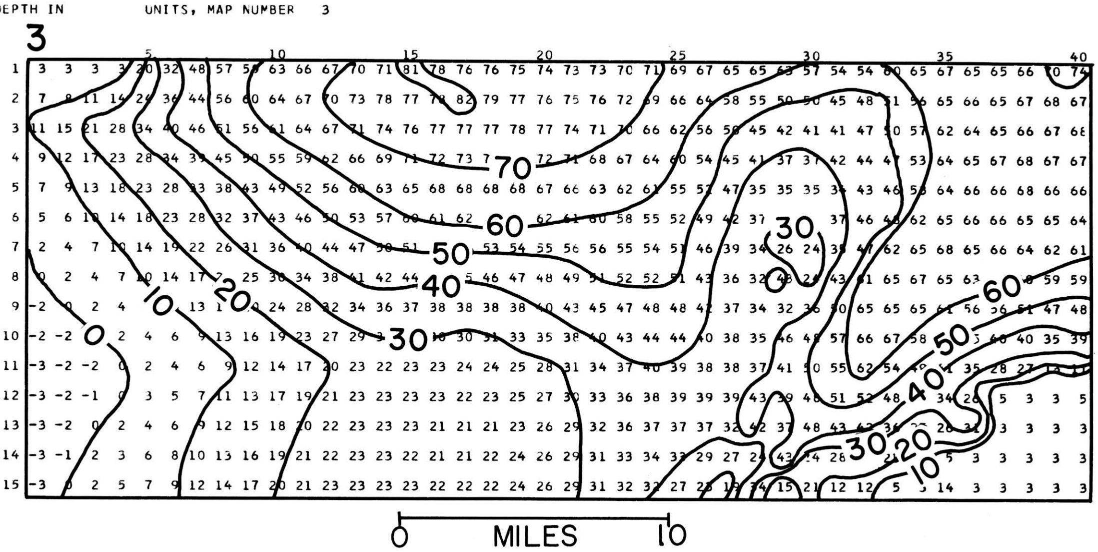
DEPTH IN UNITS, MAP NUMBER 1



DEPTH IN UNITS, MAP NUMBER 2

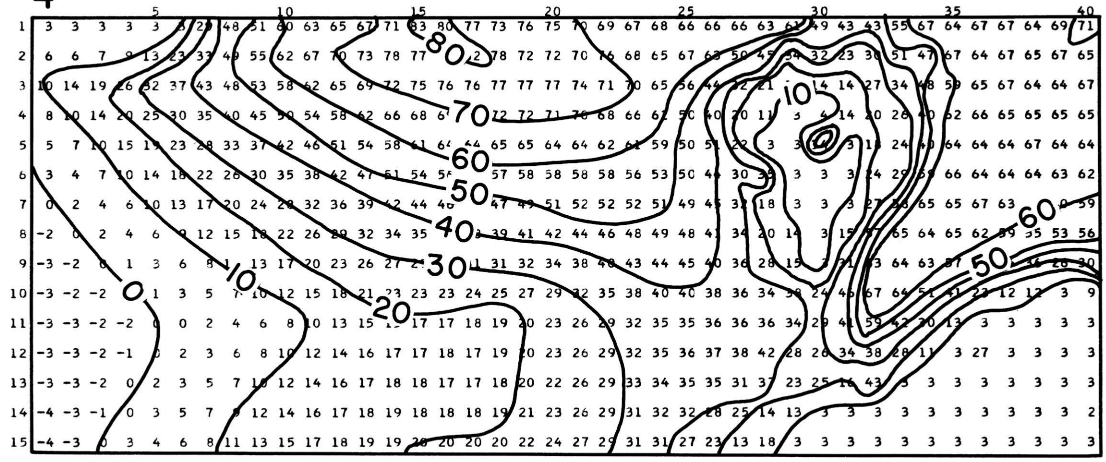


DEPTH IN UNITS, MAP NUMBER 3



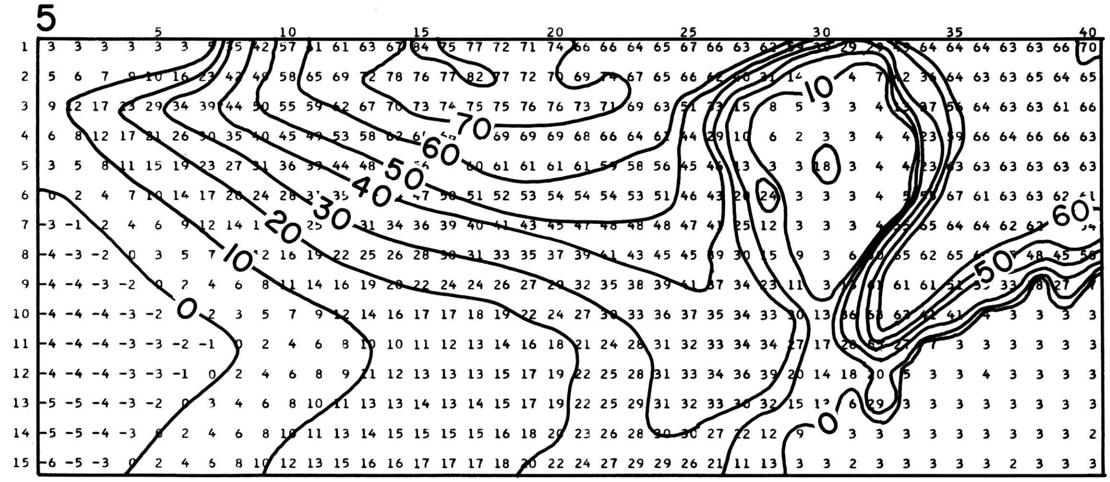
DEPTH IN UNITS, MAP NUMBER 4

4



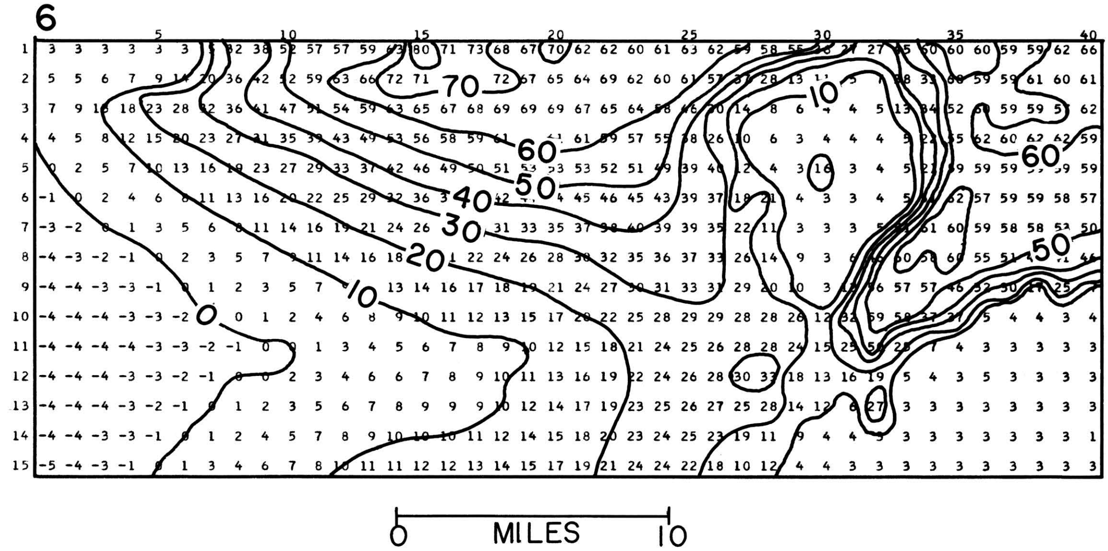
DEPTH IN UNITS, MAP NUMBER 5

5



DEPTH IN UNITS, MAP NUMBER 6

6



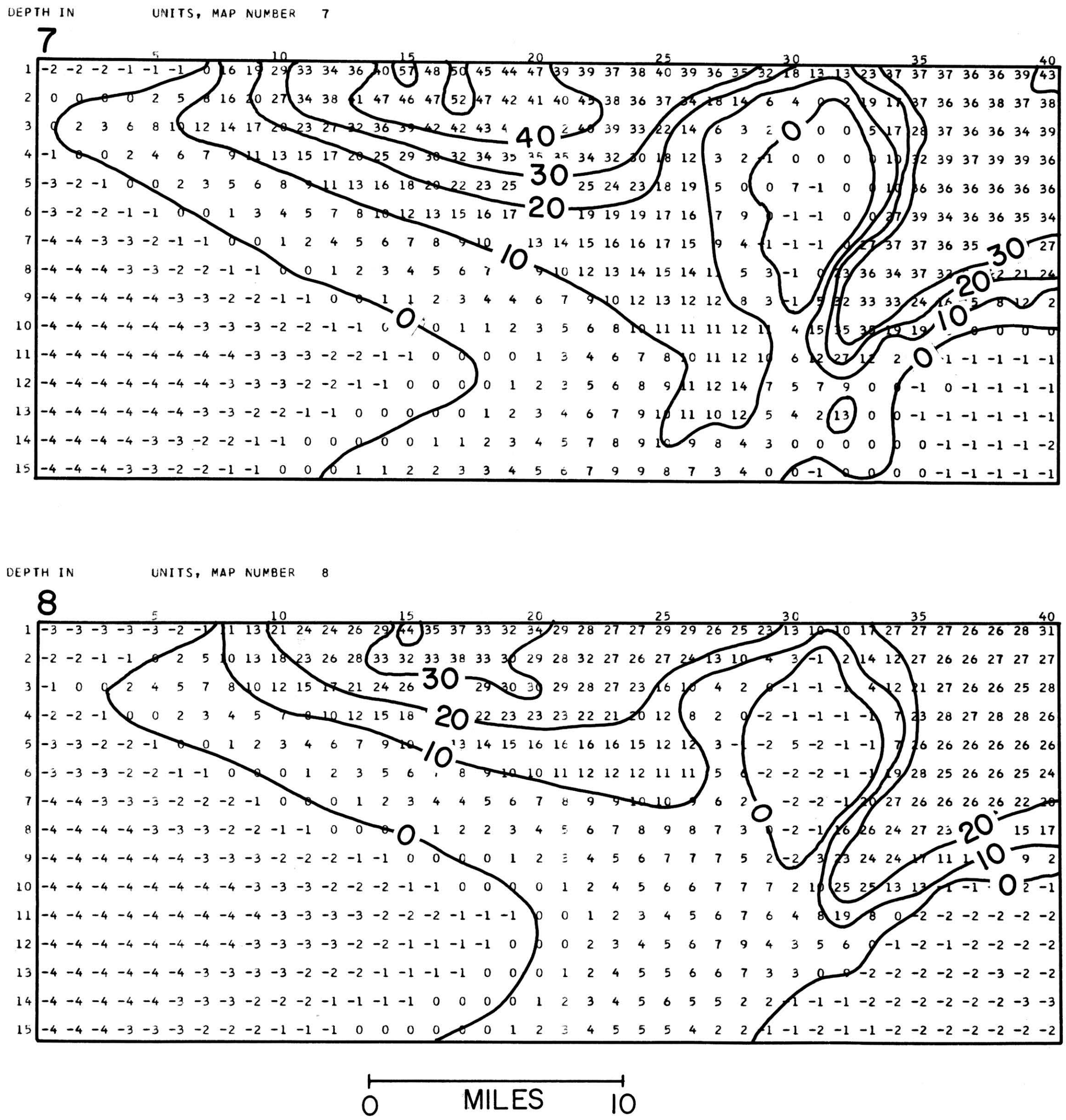
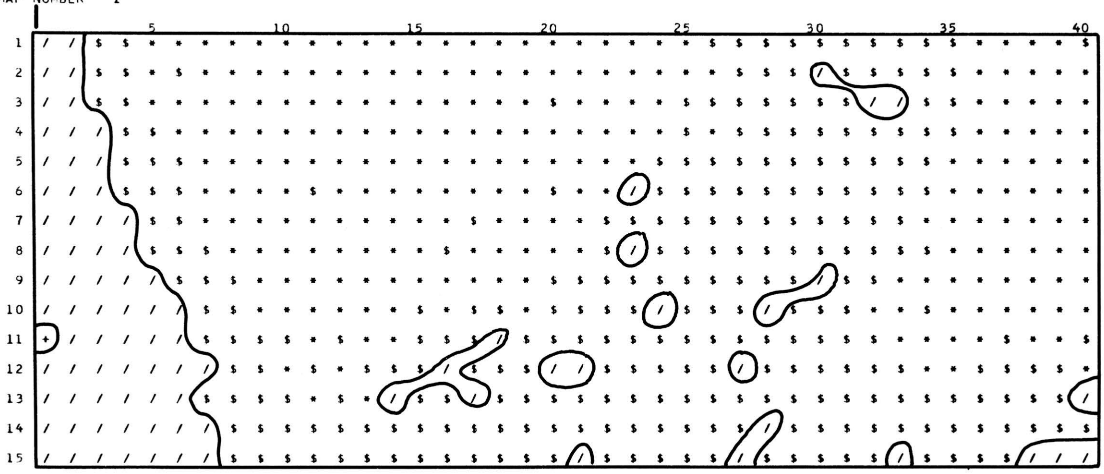
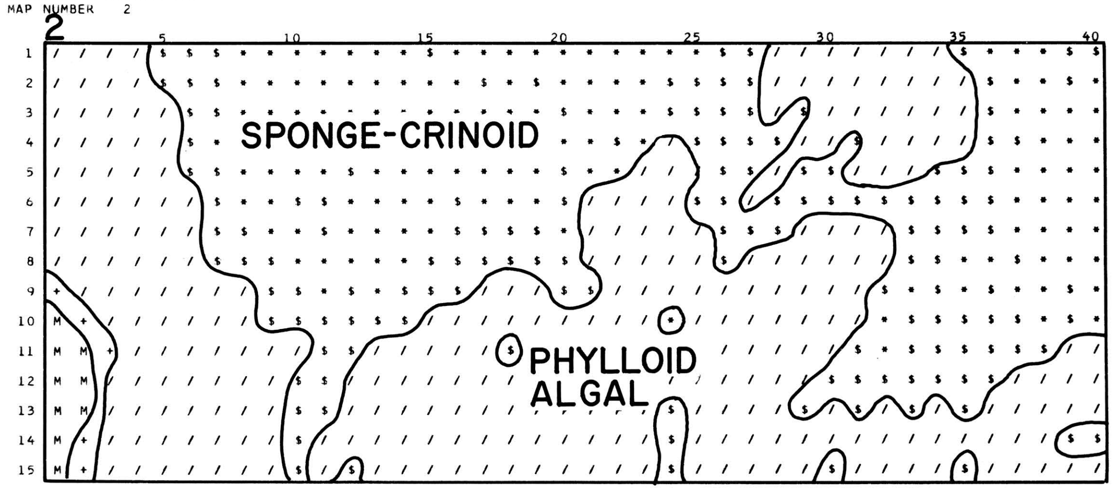


Figure 16.- Series of maps showing progressive changes in depth through eight increments of geologic time. Depth values are in feet. Positive values pertain to feet below sea level; negative values to feet above sea level. Letters and small numbers have been printed as output from program on computer's line printer; continuous lines have been drawn by hand.

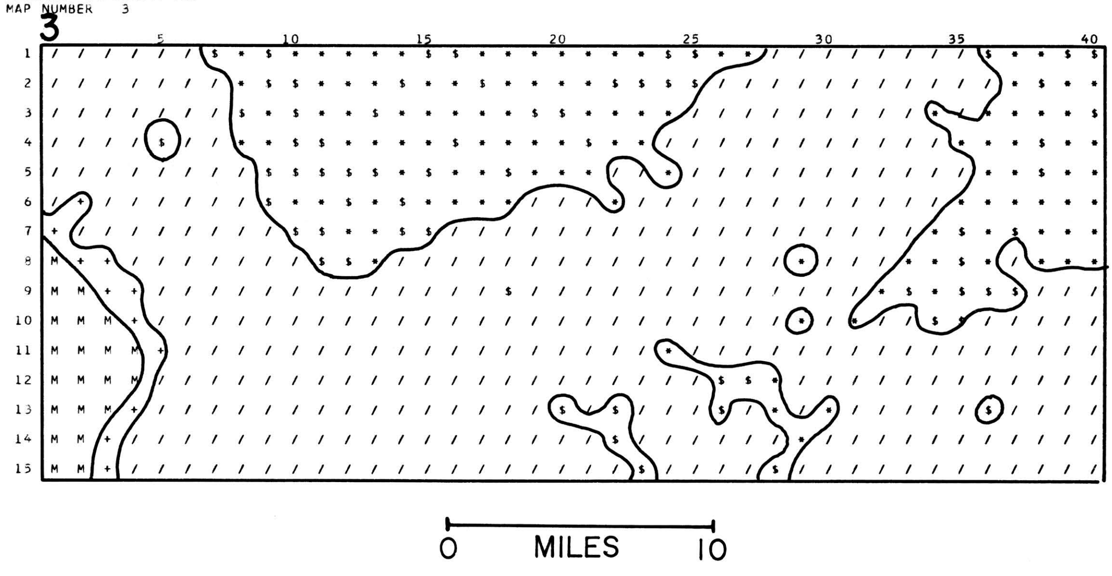
ORGANISM COMMUNITY MAP
MAP NUMBER 1



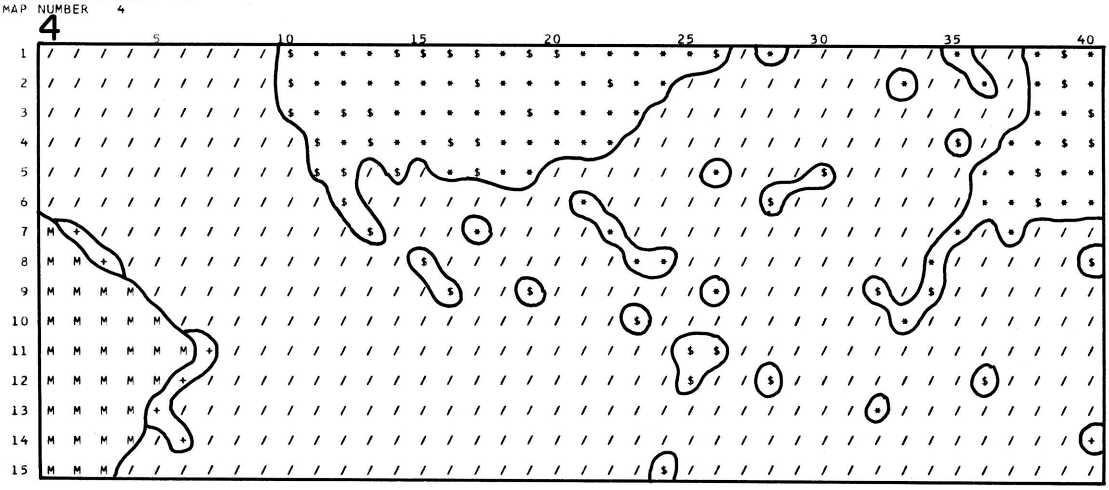
ORGANISM COMMUNITY MAP
MAP NUMBER 2



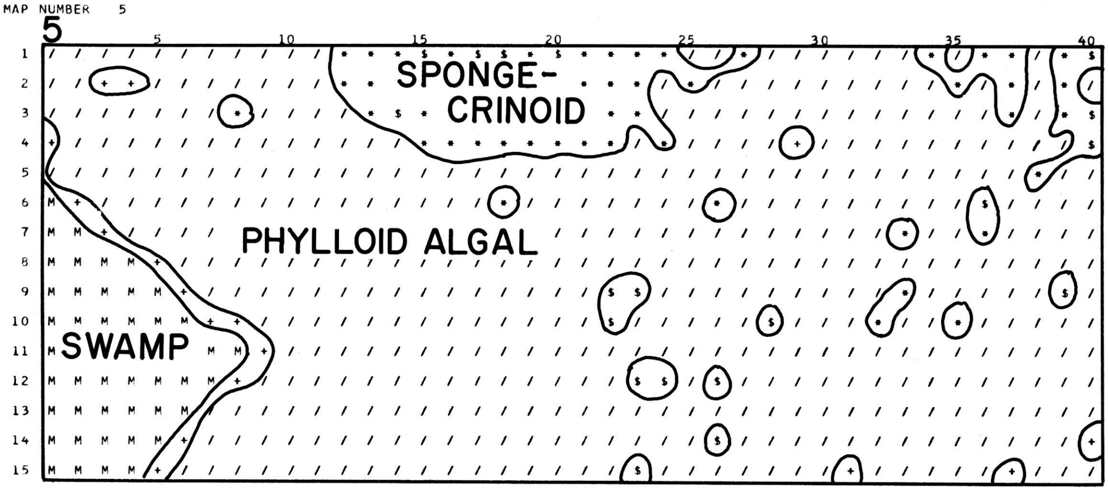
ORGANISM COMMUNITY MAP
MAP NUMBER 3



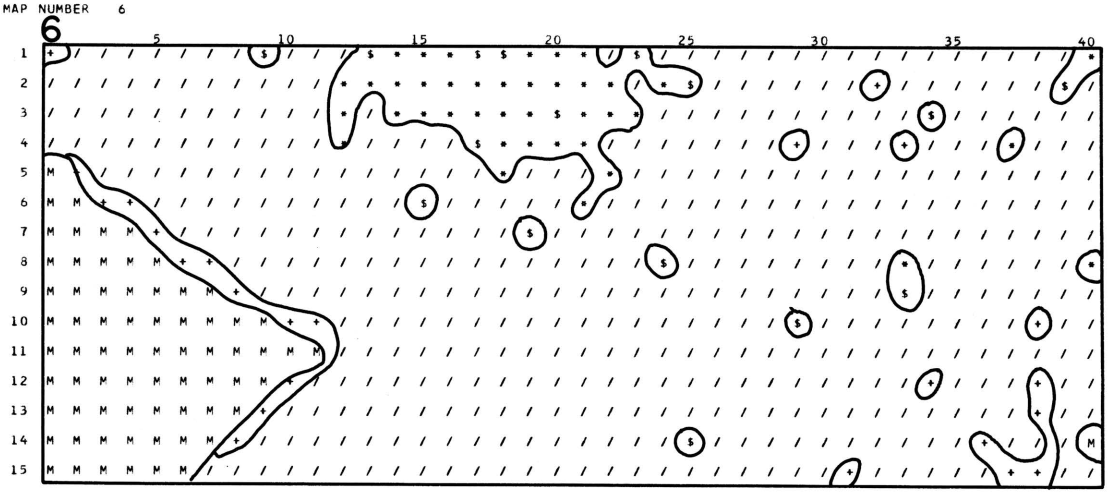
ORGANISM COMMUNITY MAP
MAP NUMBER 4



ORGANISM COMMUNITY MAP
MAP NUMBER 5



ORGANISM COMMUNITY MAP
MAP NUMBER 6



0 MILES 10

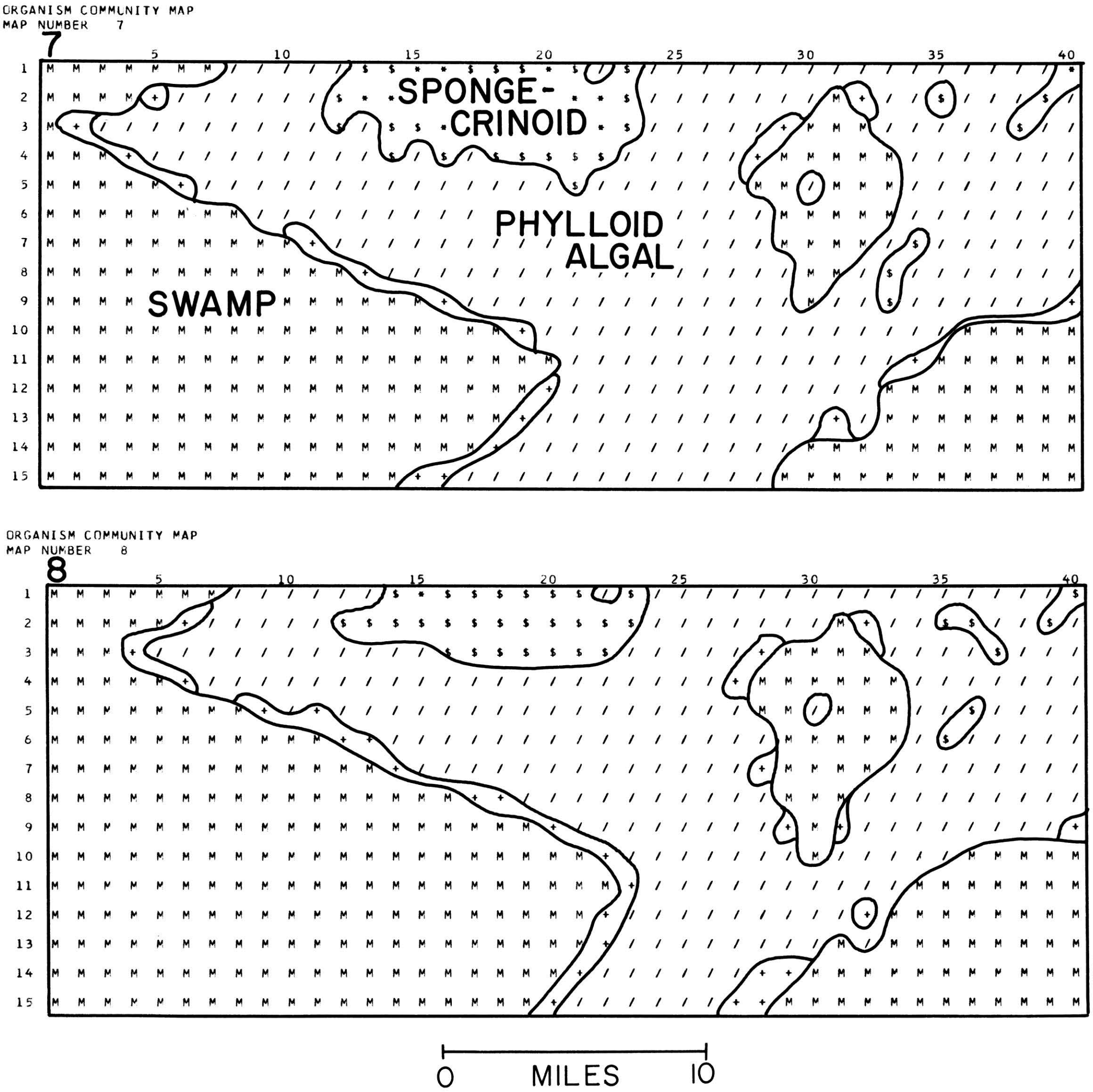
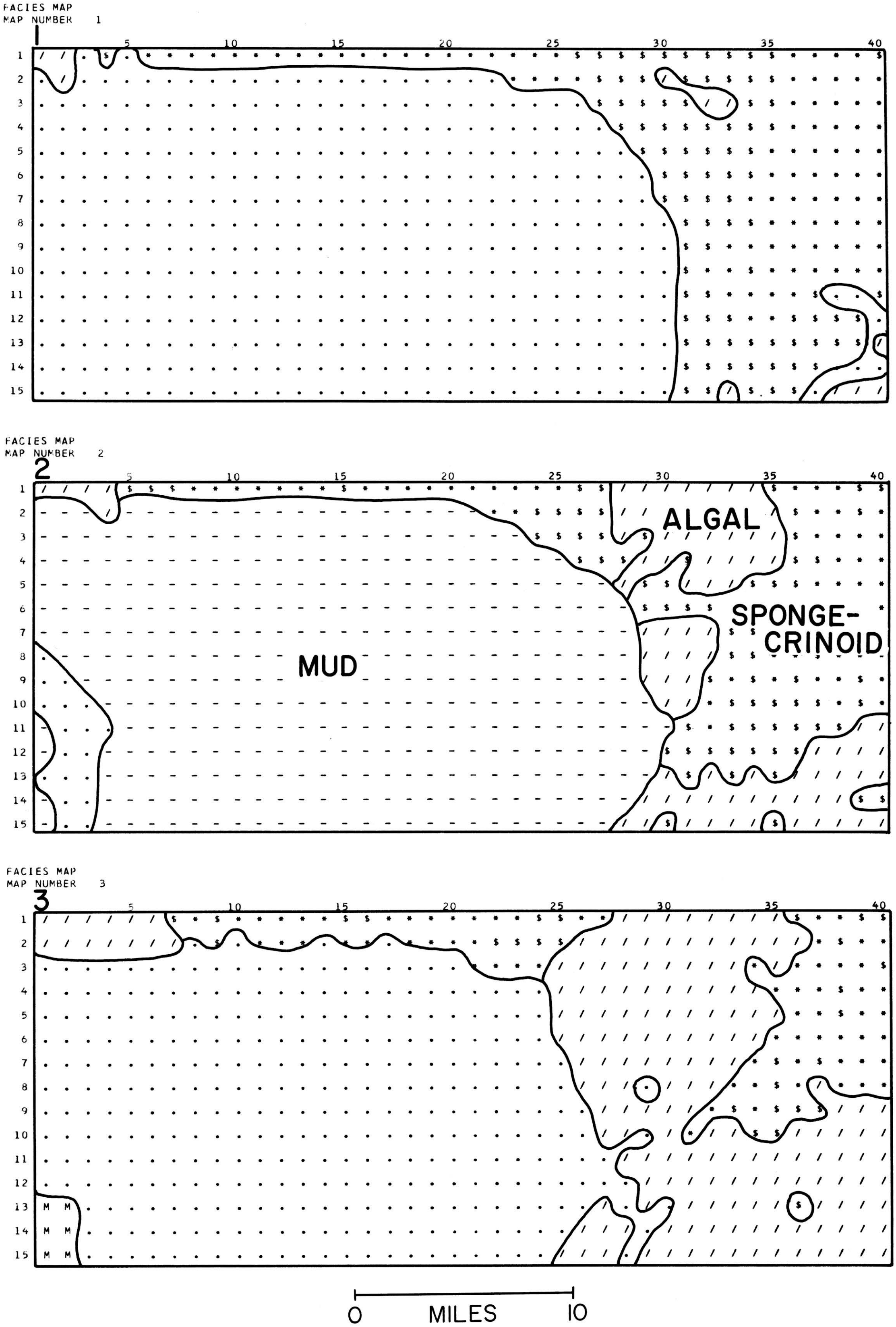
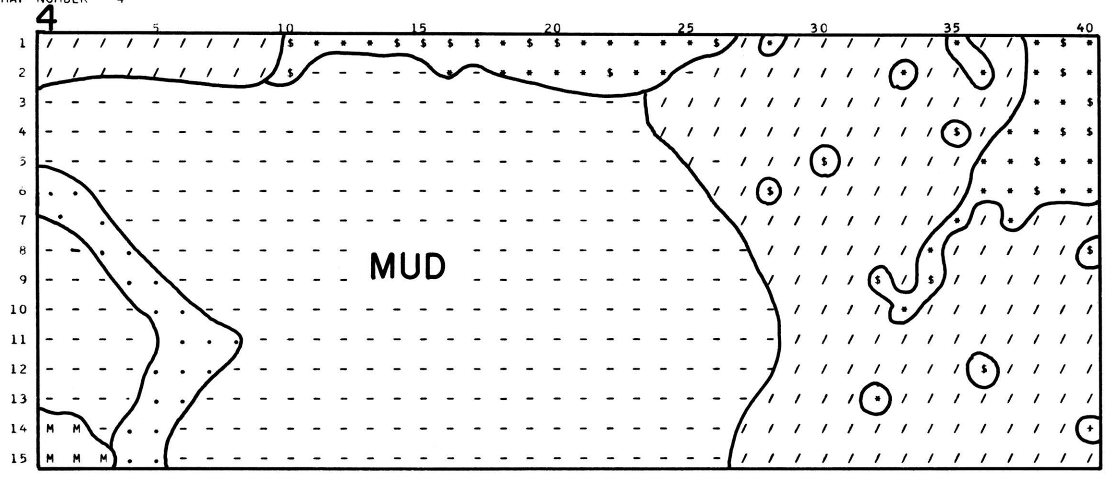


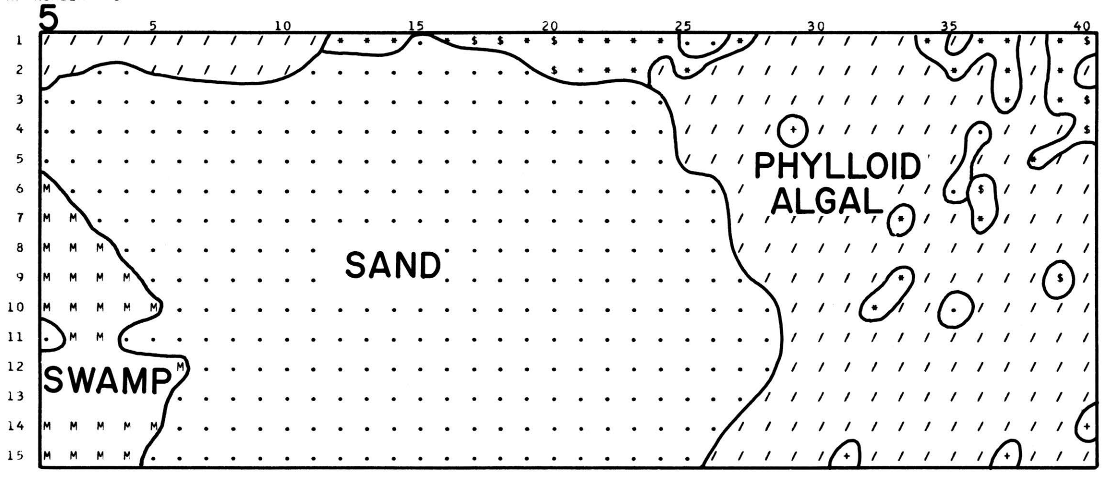
Figure 17.- Series of maps showing progressive changes in geographic distribution of organism communities through eight increments of geologic time. Symbols have been printed by computer's line printer; lines have been added by hand. Numbers at left and top edge of maps are row and column indexes. Asterisks pertain to community consisting predominantly of crinoids; dollar signs pertain to sponge community; slash symbols to phylloid algal community; plus signs to *Osagia* calcarenite; and M's to swamp community.


FACIES MAP
MAP NUMBER 1
FACIES MAP
MAP NUMBER 2
ALGAL
SPONGE-
CRINOID
MUD
FACIES MAP
MAP NUMBER 3
0 MILES 10

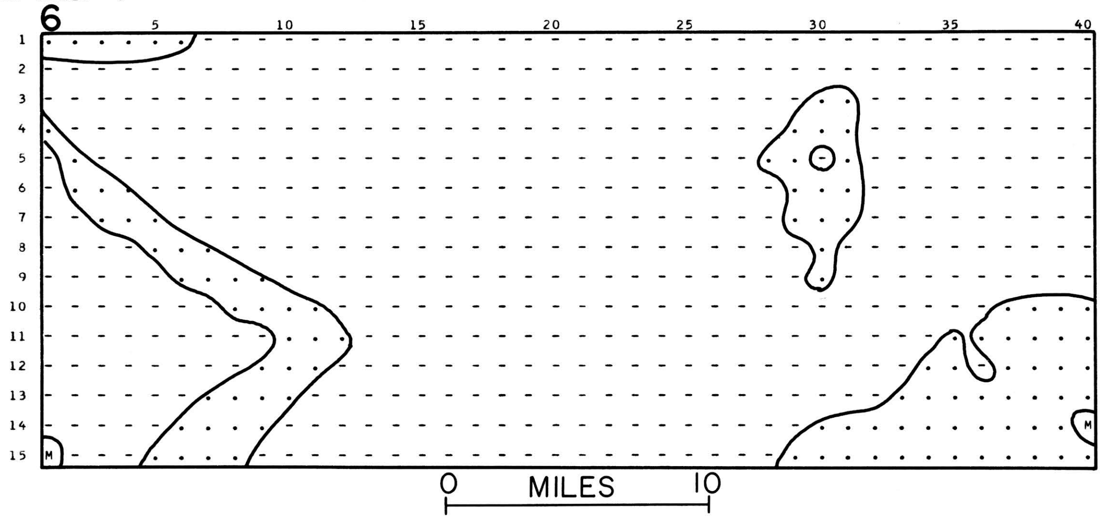
FACIES MAP
MAP NUMBER 4



FACIES MAP
MAP NUMBER 5



FACIES MAP
MAP NUMBER 6



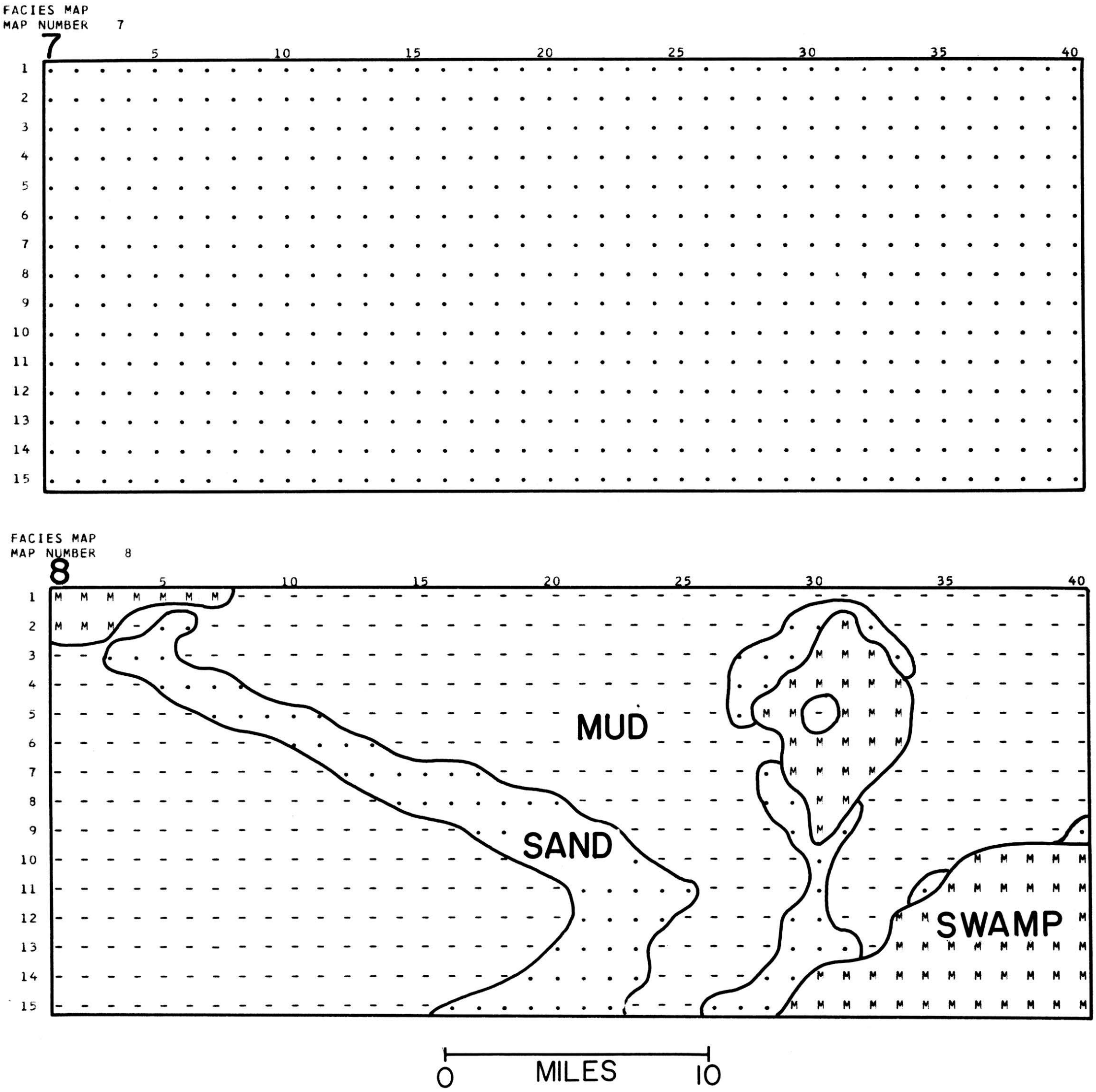
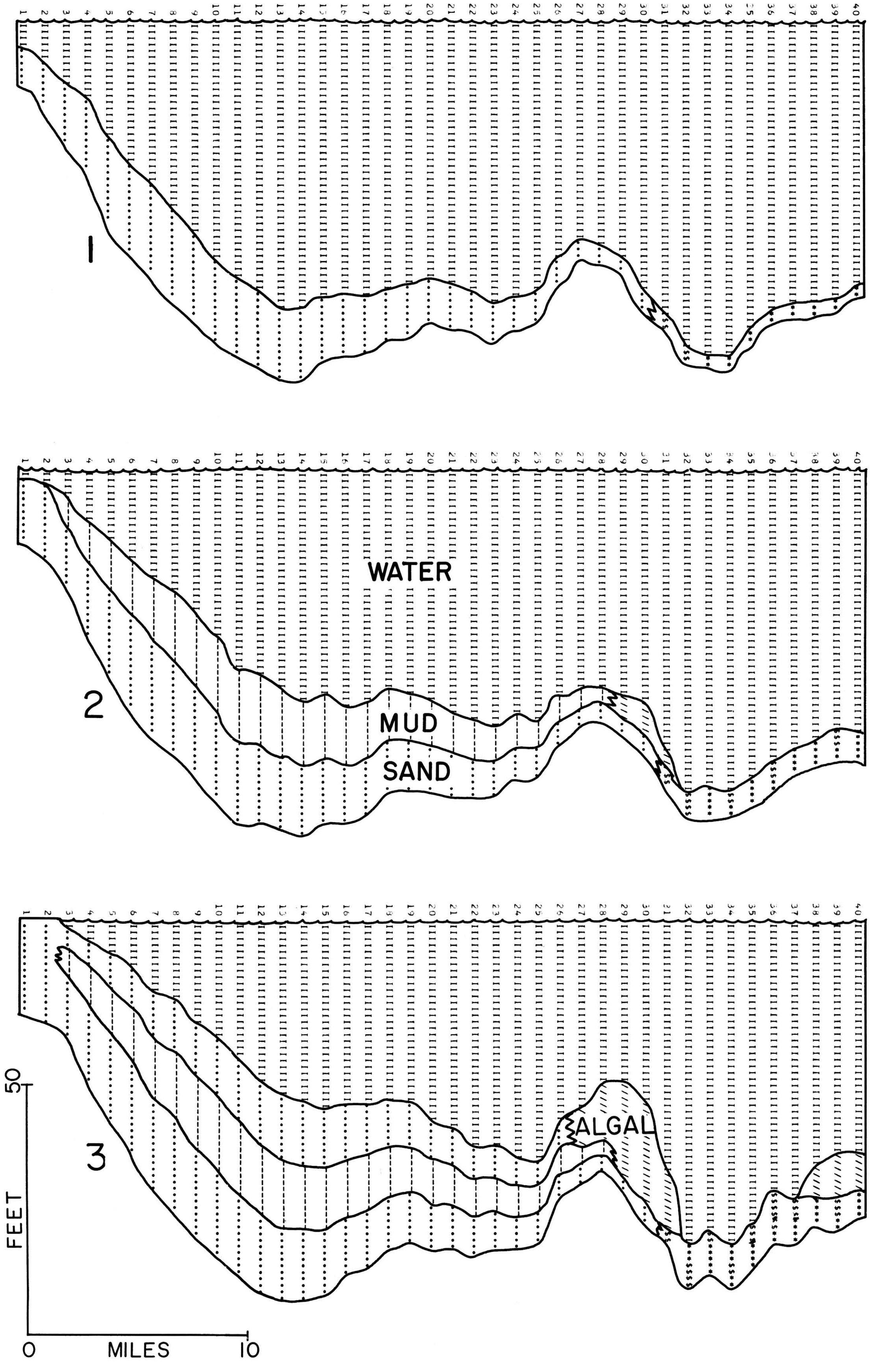
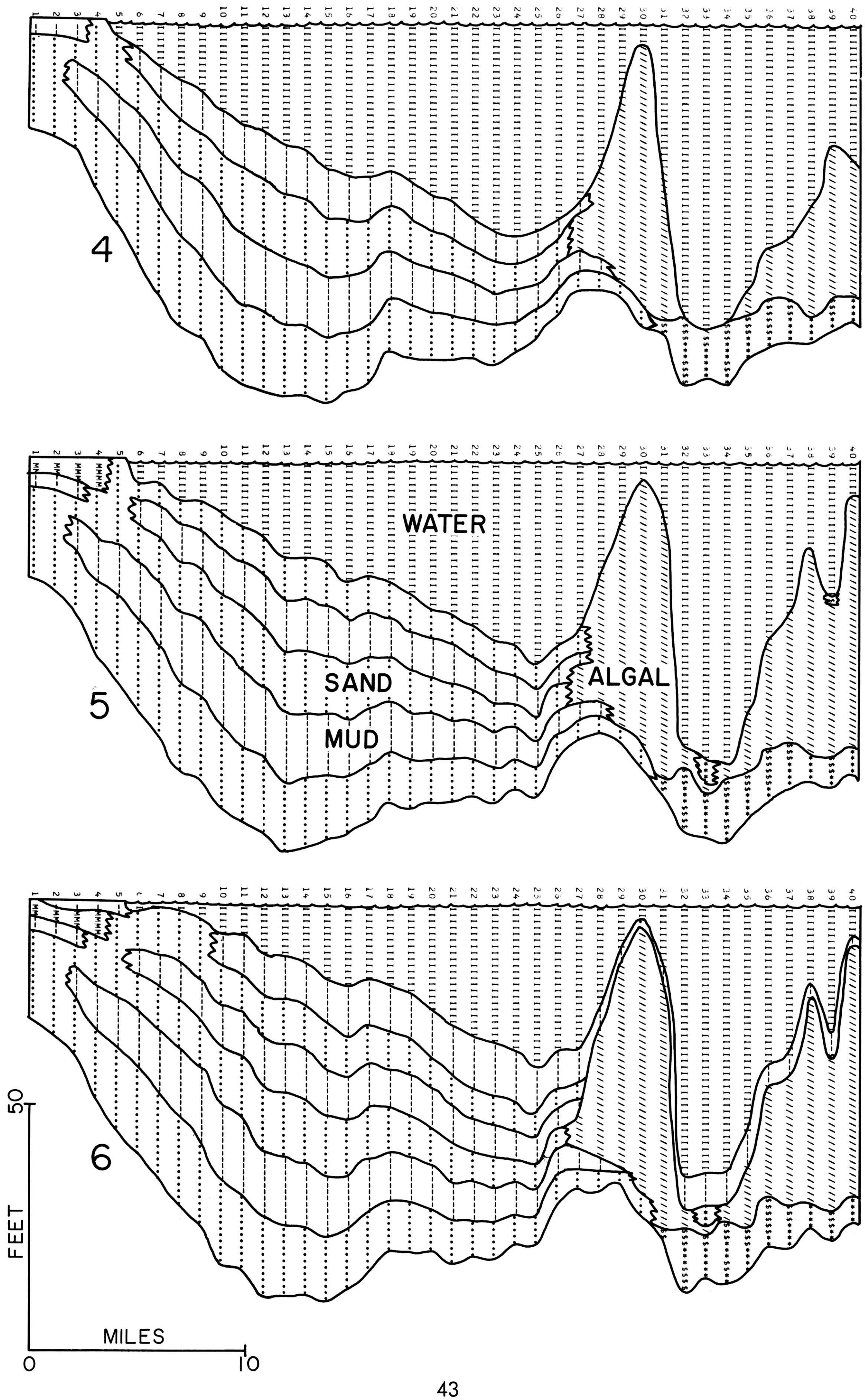


Figure 18.- Series of maps showing progressive changes in facies during eight increments of geologic time. Symbols have been printed by computer's line printer; lines and large letters have been added by hand. Numbers at left and top edges of maps are row and column indexes.


1
WATER
MUD
SAND
2
ALGAL
3
50
FEET
0
MILES
10



4
WATER
SAND
MUD
ALGAL
5
6
FEET
50
MILES
0
10

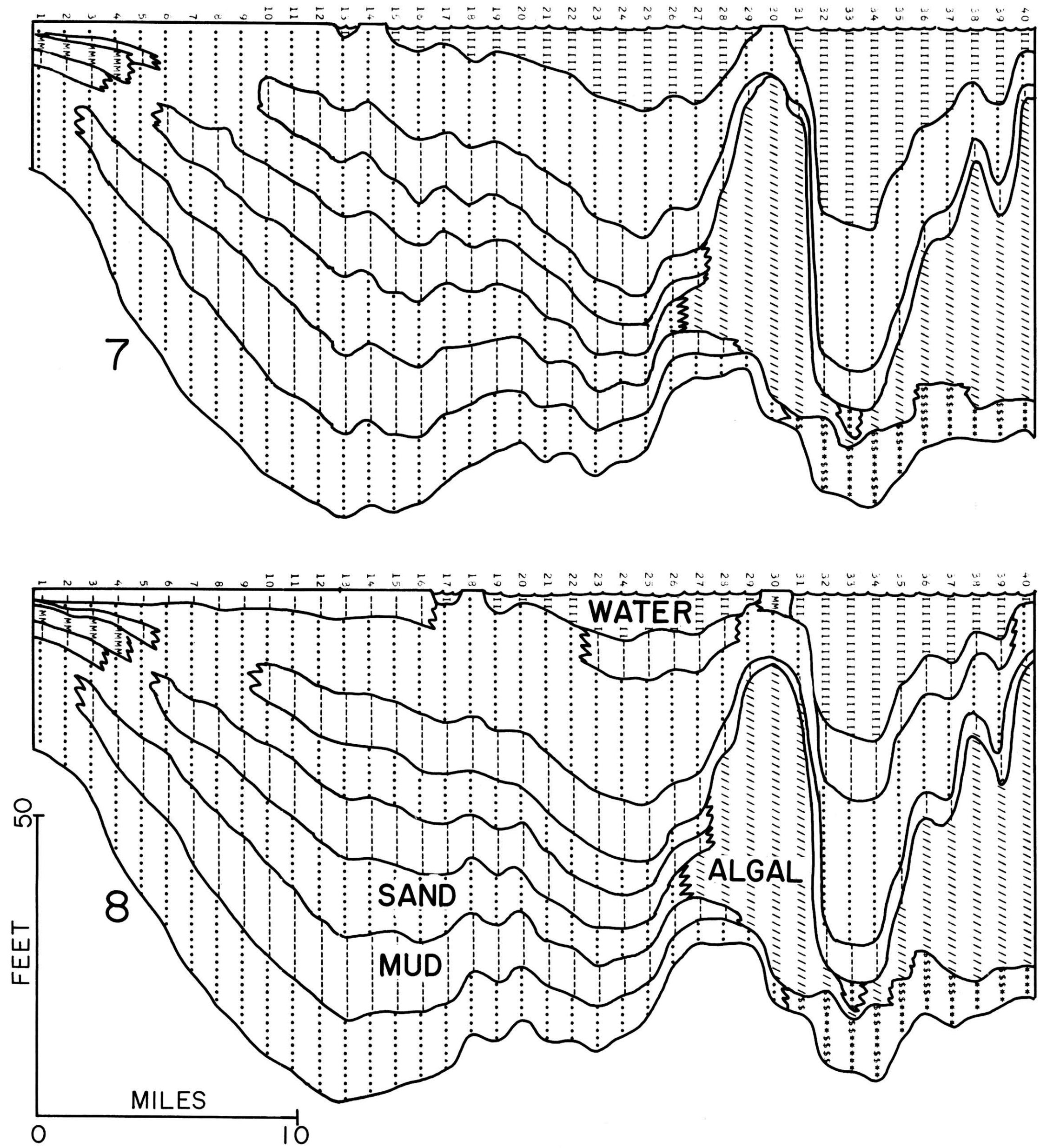


Figure 19.- Series of vertical sections along row 11 of area being simulated showing progressive deposition of sediment and structural warping through eight increments of geologic time. Numbers at top of sections are indexes of columns in maps (Fig. 16-18). Sections are 40 miles long. Except for lines and large letters, symbols have been printed by computer's line printer. Symbol representing sediment type of greatest volumetric importance per time increment is printed out. Asterisks and dollar signs pertain to sediment contributed by predominantly crinoids and sponges, respectively; slash symbols pertain to phylloid algae; plus signs to Osagia calcarenite; M's to swamp deposits; vertical dashes to mud; and prostrate I's to water.

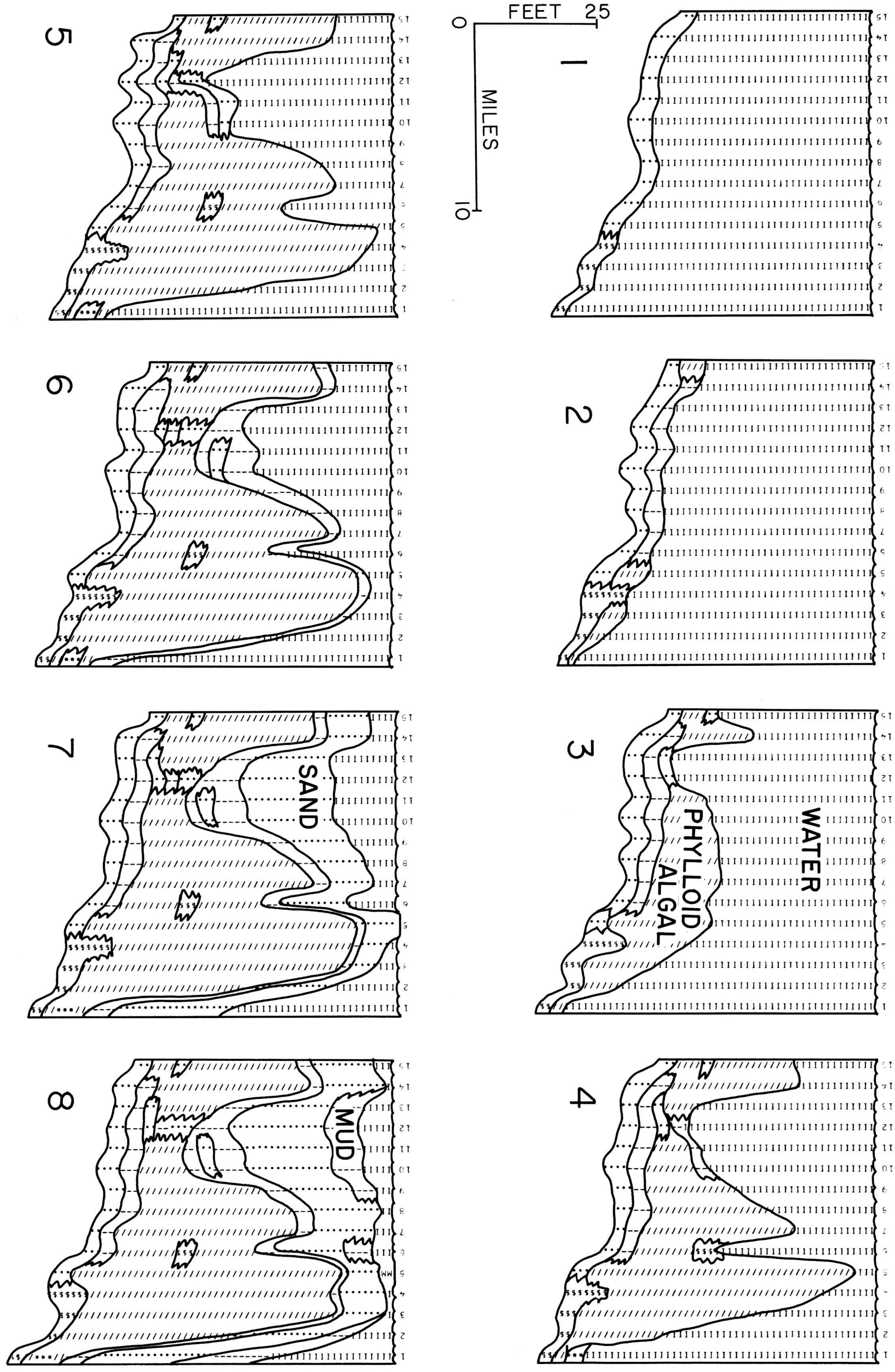


Figure 20.- Series of vertical sections along column 28 showing progressive changes through eight increments of time in simulation run (Fig. 16-19). Symbols have same significance as described in caption of Figure 19.

EXPERIMENTS WITH PROGRAM

Two related experimental runs with the model are shown in Figures 16 to 22. In both experiments, the objective has been to see what assumptions are needed, expressed as input to the model, to produce results that generally resemble marine deposits of Pennsylvanian age in southeastern Kansas (Harbaugh, 1959, 1962; Harbaugh and others, 1965). A forthcoming paper will describe the results in more detail. It is to be emphasized, however, that the results shown here are hypothetical. The following assumptions (expressed as data which were input to the model) were made in both experiments:

(1) That a large river brought substantial quantities of sand and mud into a marine depositional basin. The river flowed in a northerly direction (assuming that the maps are geographically oriented such that south is to the left)

(2) That the river debouched to supply sand and mud at rates which tapered off progressively moving away from the river mouth in all directions.

(3) That five organism communities were available for colonization within the area:
   - (a) crinoid community
   - (b) sponge community
   - (c) phylloid algal community
   - (d) Osagia-calcarenite community
   - (e) swamp community

(4) That depth varied from place to place initially (Fig. 16-1).

(5) That each of the organism communities was depth dependent, and each was assigned an assumed minimum depth, maximum depth, and most favorable depth (Fig. 13).

(6) That each of the organism communities was sensitive to terrestrially derived sediment (sand and mud), and each was assigned a threshold and intolerable value for sand, and for mud, (Fig. 14).

(7) That terrestrially derived sediment was supplied to the basin at rates which varied from one increment of time to the next (Fig. 14). The rate during a given time increment was the same to all cells that lie outside the site of deltaic deposition.

(8) That rate of tectonic warping varied from cell to cell but was constant within a given cell during each time increment.

First Example of Simulation Run

The output from the program, illustrating the first of two simulation runs shown here, appears in Figures 16 to 20. Both have been moved forward through eight time increments.

Depth changes.- Changes in depth during the eight increments are shown in Figures 16, 19, and 20. The initial depth values, fed in as input data, are very close to those shown in Figure 16-1. Progressive variations in depth occur, and are due mostly to gradual filling in of the basin, although some tectonic downwarping occurs during the run (compare Fig. 19-1 with 19-8). During the simulation run, variations in depth had strong influence on localization of organism communities (Fig. 17) as well as strongly influencing the development of beaches (Fig. 18).

One of the notable influences of depth is localization of carbonate banks (produced mostly by phylloid algae) in the eastern part of the area. These banks, stimulated by initial shallow places (Fig. 16-1), rapidly built up into shallow water (Fig. 19, 20). In the southern part of the area, where shallow water conditions also prevailed initially, prominent carbonate banks did not form because of the inhibiting influence of sand and mud, which was poured into the basin by the river flowing in a south to north direction.

At the end of the run, much of the basin area being simulated had been filled in, so that depths in most places lay close to sea level (Fig. 16-8). In the southern part of the area, swamps, which lay slightly above sea level (indicated by negative values here), had formed by progressive spreading over areas that previously lay slightly below sea level (Fig. 16-4 to 16-8).

Organism communities. - Changes in organism communities during the run are shown in Figure 17. The area was initially populated (by reading in as input data, Table 2) by crinoids (symbolized by asterisks, Fig. 14) and sponges (symbolized by dollar signs). The distribution of organism communities after the first increment of time is shown in Figure 17-1, where the geographic location of each community is compatible with depth limits, established as input data. The changes in distribution of organism communities that may be observed in the remaining runs (Fig. 17-2 to 17-8) reflect adaptation to (a) changing depths (Fig. 16), as much of the area was gradually filled with sediment, (b) externally imposed changes in vitality of each of the organism communities, (c) the natural succession of organism communities, and (d) variations in proportions of terrestrially derived sediment available for deposition at each time increment. The externally imposed changes in vitality form a crude (but forceful) way of mimicking environmental changes where the overall effect is to stimulate the relative geographic spread of certain communities, and inhibit the spread of others. The tendency of one community to replace another, as time progresses, is relatively weak in the example shown here, but does have some influence.

The following general changes in distribution of organism communities can be observed:

(1) Due to continued strong vitality, the phylloid algal community (symbolized by a /) tended to spread into areas where depths range from about 5 to 60 feet.

(2) At depths greater than 60 feet, the crinoids (*) and sponges ($) continued to dominate.

(3) At depths ranging from sea level to about 5 feet, the Osagia community (+) dominated, whereas above sea level (negative values for depth), the swamp community (M) dominated.

Facies. - The symbols in Figures 18 to 20 portray the lithology of the most quantitatively important sediment type. If one of the sediment types contributed by an organism community predominates in a particular cell, then the same symbol is printed as on the organism community map for that cell. Where sand predominates, a dot is printed, and where mud predominates, a dash is printed.

The variations in the facies maps (Fig. 18) and the sections (Fig. 19, 20) reflect the following principal influences:

(1) Variations in the relative proportions of mud and sand supplied from terrestrial sources.

(2) The presence of the river mouth near the western edge of the area, resulting in development of a delta complex, the inability of the phylloid algal community to contribute much sediment in those parts of the area where mud and sand are supplied in abundance, and the beach processes by which mud is winnowed from the sand.

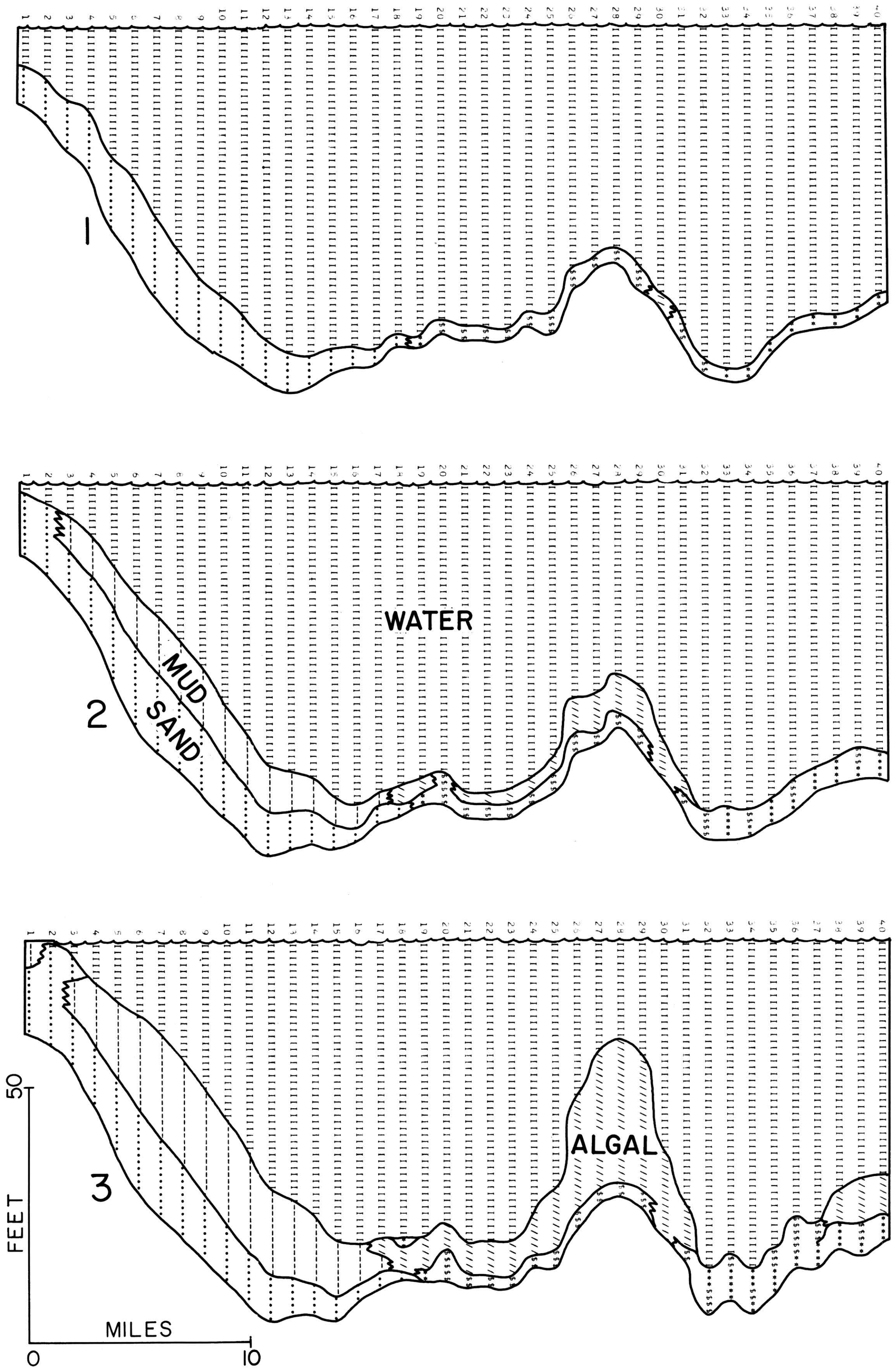
Note the bands of dots in Figure 19 and in Figure 18-2, 18-4, 18-6, and 18-8 that represent beach deposits. Note also the development of topset, foreset, and bottomset beds (Fig. 19) that form a realistic delta complex that interfingers, at its eastern edge, with a phylloid algal bank.

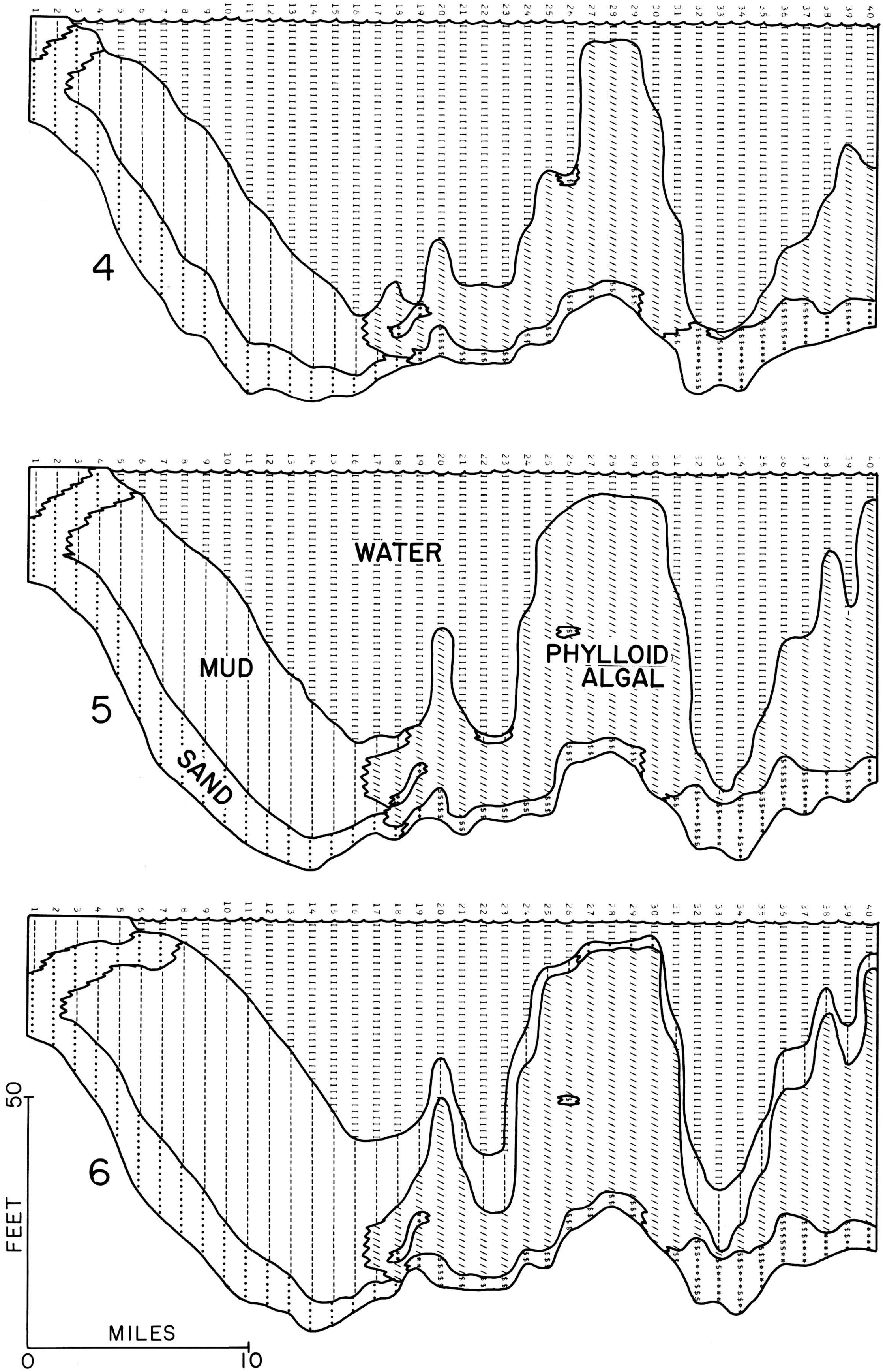
Second Example of Simulation Run

The results from another simulation run, in which changes in external influences listed below were made, are shown in a series of sections in Figures 21 and 22 (the corresponding maps of water depth, organism community distribution and facies distribution are not reproduced here). The principal differences in external conditions are (a) that the influence of the river in supplying terrestrially derived sediment does not extend as far to the east as in the first simulation example (Fig. 19, 20) and (b) that the terrestrially derived deposits consist predominantly of mud, except in time increments 1 and 8, where sand predominates.

The response of the model indicates that it is quite sensitive to these changes. The most obvious difference is the lack of alternating beds of mud and sand in the deltaic deposits in the southern (to left) part of the area. On the other hand, the importance of beach processes in producing sandy deposits in shallow water is evident. Note how the beach deposits in the southern part of the area progressively migrated toward the east (Fig. 21-3 to 21-6) as basin filling continued. Another important difference is marked by the greater area covered by phylloid algal banks in the second example. Due to the shorter south-to-north influence of the delta deposits in the second example, the phylloid algal community was capable of extending farther north than in the first example (compare Figure 19-3 to 19-6 with Figure 21-3 to 21-6). The differences in geographic expanse of the algal banks reflect the inability of the algal community to contribute sediment in quantity due to the inhibiting influence of mud or sand. Thus, the algal banks formed principally at or beyond the delta margin in places where depth conditions were appropriate.

The two examples of simulation runs shown here are relatively crude in that they incorporate only a few of the processes that could ultimately be incorporated in a dynamic model to simulate shallow water marine environments. Furthermore, the models are divided into cells on a relatively coarse scale, there being only 600 (15 by 40) cells to represent the geographic expanse of the area. In spite of these simplifications, the model performs with suprising realism, adapting to differences in conditions imposed on it, and demonstrating the power of simulation as a means of experimentation.


1
WATER
MUD
SAND
2
ALGAL
3
50
FEET
MILES
0
10


4
WATER
MUD
SAND
PHYLLOID
ALGAL
5
6
50
FEET
MILES
0
10

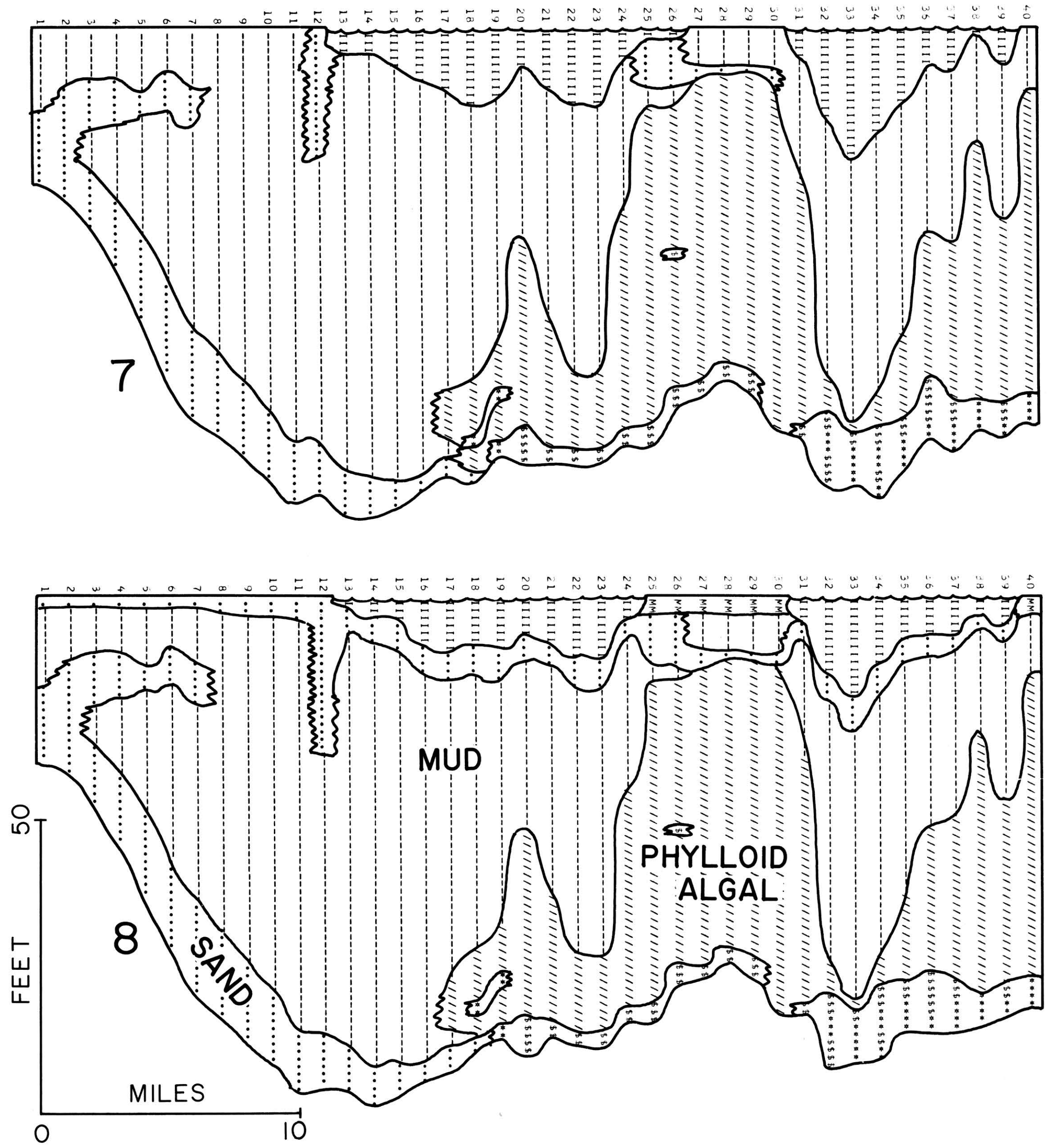


Figure 21.- Series of vertical sections along row 11 of area being simulated showing progressive deposition of sediment and structural warping through eight increments of geologic time. Some external conditions in simulation run have been changed with respect to those of Figure 19, illustrating differences in response of simulation model to different conditions.

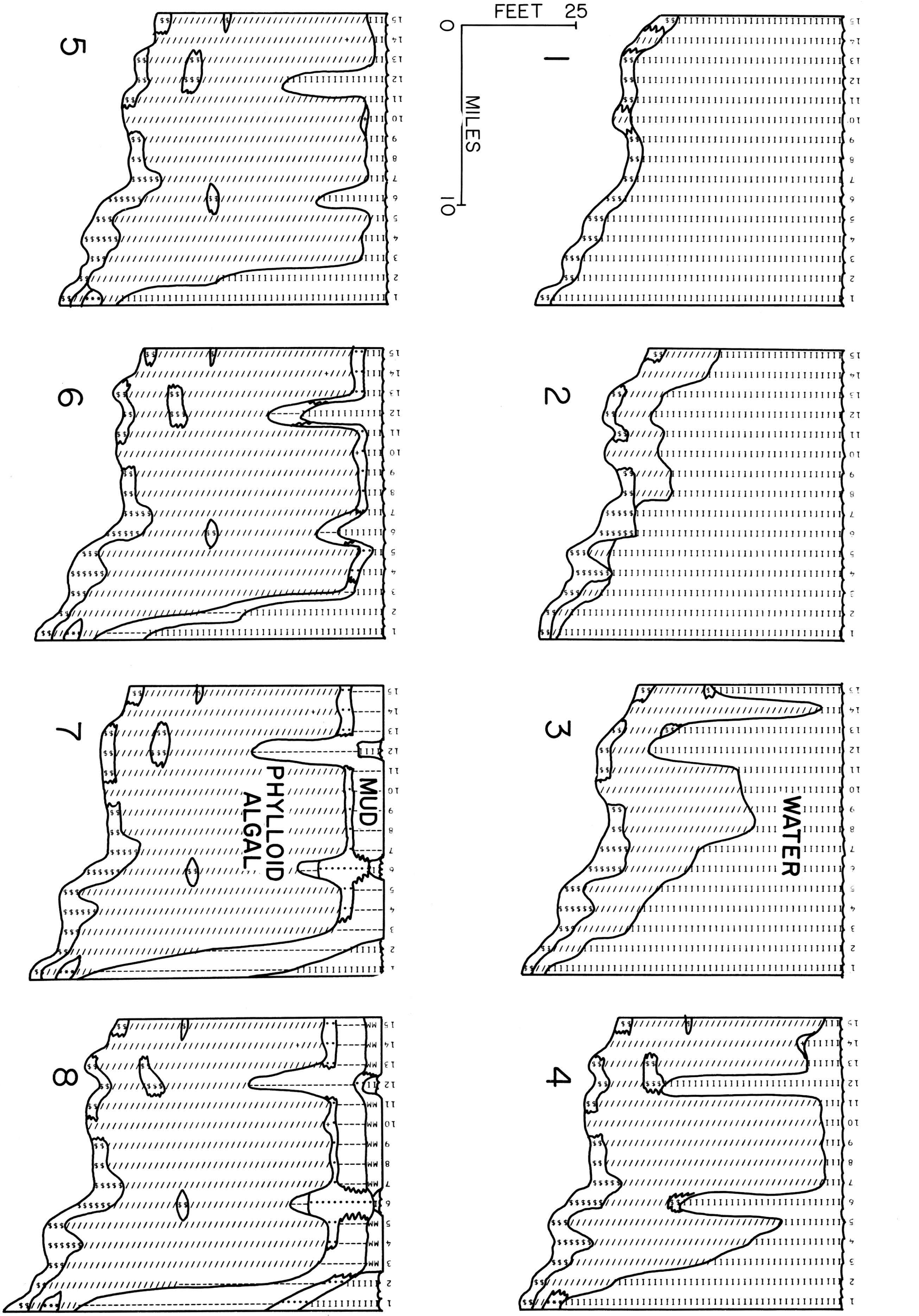


Figure 22.- Series of vertical sections along column 28 of simulation runs shown in Figure 21. Sections portray progressive development through eight increments of geologic time. Numbers at top of sections are row indexes. Use of symbols is identical with use described in caption of Figure 19.

REFERENCES

Forrester, J.W., 1961, Industrial dynamics: John Wiley and Sons, San Francisco, 464 p.

Goldner, W., and Graybeal, R.S., 1965, The Bay Area simulation study: Pilot model of Santa Clara county and some applications: Unpub. report, Center for Real Estate and Urban Economics, Univ. California, Berkeley, 29 p.

Harbaugh, J.W., 1959, Marine bank development in Plattsburg Limestone (Pennsylvanian), Neodesha-Fredonia area, Kansas: Kansas Geol. Survey Bull. 134, pt. 8, p. 291-331.

Harbaugh, J.W., 1962, Geologic guide to Pennsylvanian marine banks, southeast Kansas, in Geoeconomics of the Pennsylvanian marine banks in southeast Kansas: Kansas Geol. Soc. 27th Field Conf. Guidebook, p. 13-67.

Harbaugh, J.W., Merriam, D.F., Wray, J.L., and Jacques, T.E., 1965, Pennsylvanian marine banks in southeastern Kansas: Geol. Soc. America 1965 Ann. Meeting Field Conf. Guidebook, 54 p.

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