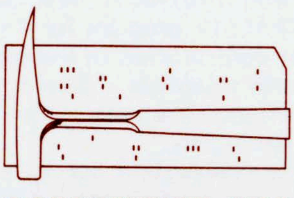
DANIEL F. MERRIAM, Editor

FORTRAN IV PROGRAM FOR SIMULATING GEOLOGIC DEVELOPMENT OF SEDIMENTARY BASINS

By

DENNIS R. OJAKANGAS
Information and Computing Centres Canada



COMPUTER CONTRIBUTION 49

State Geological Survey
The University of Kansas, Lawrence
1970

in cooperation with the
American Association of Petroleum Geologists
Tulsa, Oklahoma

Editor's Remarks

The U.S. Geological Survey has announced a new series of open-file publications dealing with computer contributions. These reports will include computer program descriptions and related material. The reports will be of interest to computer-oriented workers in the earth sciences, mathematics, computer science, engineering, administration, accounting, and other fields. To date four reports have been issued:

(1) Computer Contribution 1, Weighted triangulation adjustments, by W.L. Anderson, 1969

(2) Computer Contribution 2, Perspective center determination, by J.D. McLaurin, 1969

(3) Computer Contribution 3, Non-constant variance regression analysis, by M.S. Hellmann, 1970

(4) Computer Contribution 4, Hot pipe, by P.C. Doherty, 1970

Copies are available free on application to the Chief, Computer Center Division, U.S. Geological Survey, Washington, D.C. 20242. The U.S.G.S. is to be commended for initiating the new series which will be most welcome by all quantitative-oriented earth scientists.

The Water Resource Division (Kansas District) of the U.S. Geological Survey has been publishing computer programs in the Special Distribution Publications of the Kansas Survey for several years. These programs have been concerned, for the most part, with water problems. Other sections of the U.S.G.S., notably geochemistry, also have been involved in developing computer programs.

This program "FORTRAN IV program for simulating geologic development of sedimentary basins", by D.R. Ojakangas is another contribution in the area of simulation. Simulation is gaining a place in its own right in applications by earth scientists. Geology, long an observational and historical science, now has the opportunity of experimentation. The program will find use not only by teachers demonstrating geologic processes but by operational geologists.

For a limited time the Geological Survey will make available the program on magnetic tape for $25.00 (US). If punched cards are required an extra $10.00 (US) is necessary to cover the cost of handling and postage. A complete list of COMPUTER CONTRIBUTIONS can be obtained by writing Editor, COMPUTER CONTRIBUTIONS, Kansas Geological Survey, The University of Kansas, Lawrence, Kansas 66044.

---

* Active Member, ° Associate Member, + Junior Member, American Association of Petroleum Geologists

FORTRAN IV PROGRAM FOR SIMULATING GEOLOGIC DEVELOPMENT OF SEDIMENTARY BASINS

by

Dennis R. Ojakangas

ABSTRACT

A FORTRAN IV program is described for simulating geologic processes involved in the development of oil traps. Deposition, diastrophism, compaction and erosion can be defined mathematically and the structural highs within the three-dimensional model located.

The geology of the model area is gridded manually into a regular pattern and described in algebraic terms. Time is segmented by defining basement topography and then the geologic events as they are believed to have occurred. Experimentation with different hypotheses may be required to approximate the observed geology.

Visual displays can be specified at any time during the model development, permitting analysis of results before continuing with succeeding events. Displays include listings of geologic columns, structural elevations, and isopachous intervals and CALCOMP-plotted stratigraphic cross sections.

INTRODUCTION

It is possible to define and visualize individual geologic events by traditional field methods. The effects of combinations of events could produce results, however, that would be difficult to visualize if considering each event or geological process as an entity. A mathematical method is described for imitating or simulating some geologic processes and events which are important in the development of structural, erosional and sedimentary facies-type oil traps. The geologic processes are imitated by successive evaluations of equations and decision-making operations which are incorporated into computer programs. The computer programs can help reconstruct the geologic history of an area by allowing experimentation with different hypotheses. Several assumptions can be allowed and the variables embodied within the assumptions can be modified to make the results obtained with the simulation program agree with observed geology. The goal is not solely to match the observed geology, but also to explore the adjustments in the assumptions that are needed to obtain a reasonable match. This technique of simulation can give valuable insight into complex relationships of geologic processes. It might be possible to extrapolate knowledge gained from simulating an oil field into other areas of potential oil accumulations within the same basin.

The geologic processes which can be simulated by the computer program are: (1) deposition of lithologic units, (2) erosion, (3) diastrophism represented by the upward or downward movement of the basement rocks and overlying sedimentary strata, and (4) compaction of shale. Testing for structural highs as possible sites of oil accumulation also is possible. Geologic variables, such as permeability, are difficult to define over a wide area. However, the variables used in this simulation program are simple and obtained from direct observations of the geology or by experimentation. The parameters studied are: (1) structural elevation at various points in geologic time, (2) amount of erosion, (3) rock type, thickness and porosity of the rock units, and (4) amount of diastrophic movement of the basement rocks.

The simulation program described is a postdepositional model concerned with geological development of an area from the time a rock unit is deposited. The sedimentary factors of source, transportation and site of deposition are not involved in the modeling. The simulated process of erosion does not keep account of the eroded material. Assumptions are made in testing for structural highs as possible sites of oil accumulation. Porous sandstone and limestone are considered as the only possible reservoir rocks. Permeability parameters and pressures are not used in calculating the trap locations.

Figure 1 is a graphical representation of the procedure followed in modeling an area with the simulation program. The geological interpretation of the area is described in terms of mathematical variables and input as the basic data to the simulation computer program. Graphic displays in the form of cross sections and listings are output at specified points to check the geological development of the simulated model. If the geology of the simulated model does not agree satisfactorily with the observed geology, the basic data are modified until the observed geology has been simulated successfully.

Scale models have helped in the study of many hypotheses on folding, faulting and salt dome formation. The problem with scale modeling is the difficulty in finding substances to duplicate the behavior of rock materials and geologic time. A mathematical

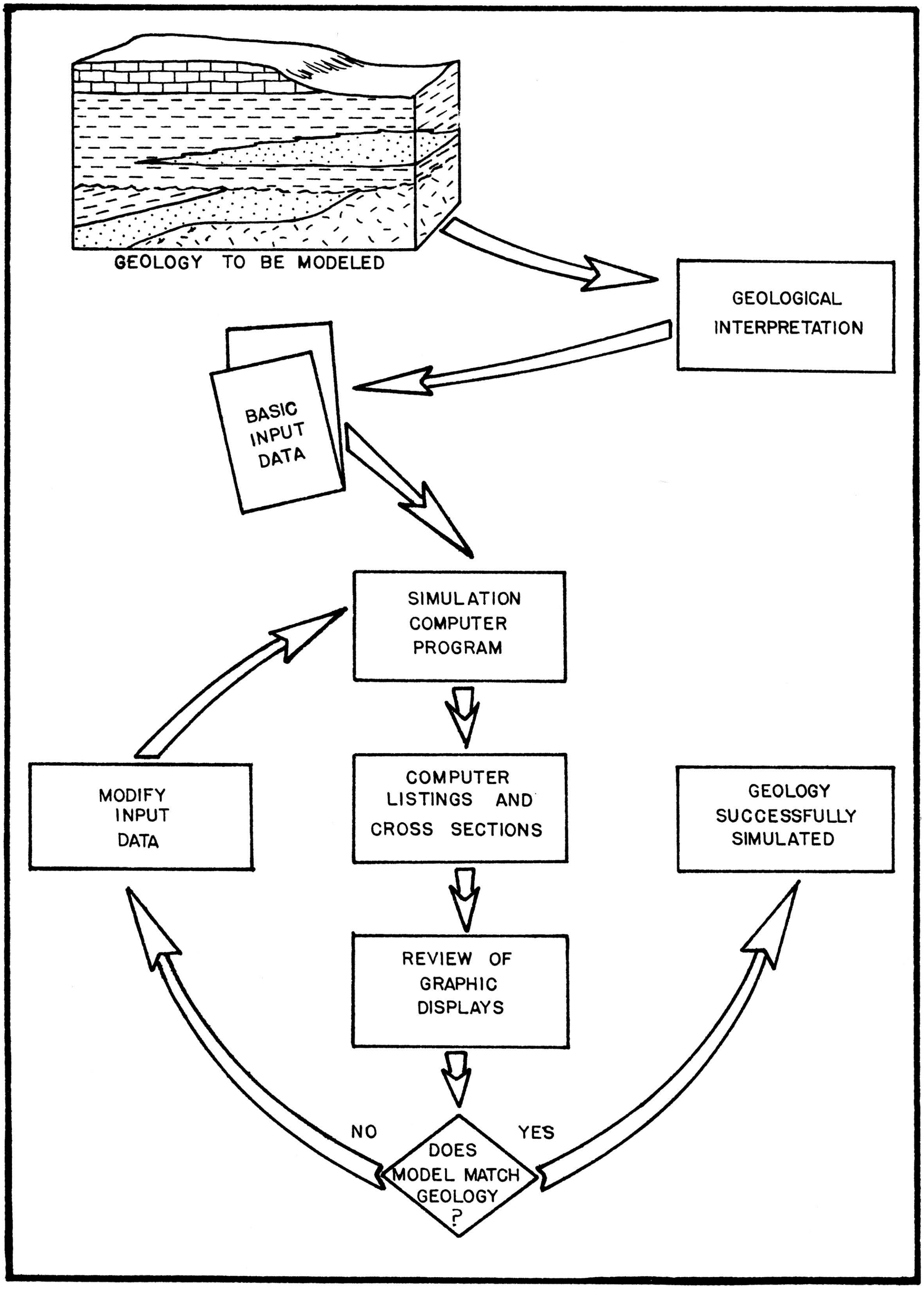


Figure 1.- Graphical representation of steps followed in modeling with computer program.

model is a representation of a physical model that uses mathematical variables, parameters and constants to define materials, forces and events. Mathematical simulation techniques overcome some problems inherent in scale modeling. It is possible to vary and define closely the parameters which simulate some natural processes and features.

Geologists only recently have begun to use digital computers for modeling. Harbaugh (1966) wrote a paper on the mathematical simulation of marine sedimentation with computers. He successfully duplicated the development of delta formation within a sedimentary basin by imitating the behavior of sediment as it is transported and deposited. Harbaugh and Merriam (1968) describe methods for simulating sedimentary processes with computer models.

Acknowledgments.- This report is condensed from a doctoral dissertation submitted to Stanford University (Ojakangas, 1967). I am indebted to John W. Harbaugh, Stanford University, who supervised the research and offered several suggestions to the original study. Valuable comments were received from Thomas D. Mueller, Standard Oil Company of California and Stanford University, Stanley N. Davis, University of Missouri, and Arvid M. Johnson of Stanford University. The writer was employed by Standard Oil Company of California during this research period and Standard Oil Company of California provided the computer and plotter time. Information and Computing Centres Canada Limited assisted in the preparation of this manuscript.

PROGRAM DESCRIPTION

The most convenient way to describe geology in mathematical terms is to lay a grid over the model area. This permits one value, such as the amount of erosion, to represent the average condition for each grid unit. Time is segmented by having the processes, such as deposition and erosion, cover a specified time interval. Figure 2 shows the method of gridding an area and the grid numbering scheme. The program as written requires each grid to be a square.

The system of programs has a main program and twelve subroutines. Table 1 contains the names and functions of the subroutines. The user controls the program by inserting data cards with certain geologic instructions as specified in Appendix B. The main program determines the action to be taken. The main program reads a TITLE card to start a job and a PARAMETER card which contains the job identification, the number of grid units in both the X and Y direction, and distance between grid centers. A BASEMENT card then is read followed by the basement elevations. The basement elevations are defined as those believed to represent the basement topography at the start of deposition. Then the thickness, rock type, and porosity for the first period of deposition are given as well as the parameters for periods of erosion and diastrophism.

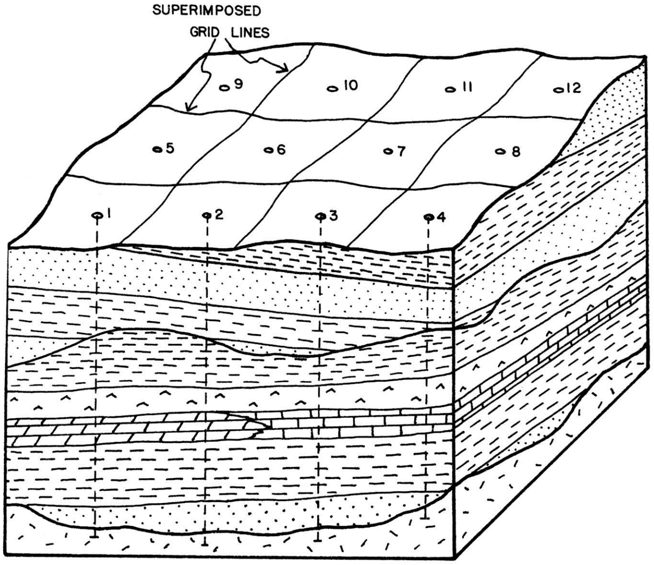


Figure 2.- Illustration of 4 by 3 grid model showing method of gridding geologic data. Numbers show grid numbering scheme.

Deposition

The subroutine is entered by a DEPOSITION control card. The thickness, rock type and porosity are read for each grid unit. The thickness of the shale units should be increased by the amount to be compacted. This is an experimental variable to establish the original thickness of mud at the time of deposition. An option is available to restrict deposition to below sea level.

If deposition below sea level only is desired, the elevation at the top of the stratigraphic column is calculated by

$$\mathrm{ELEV} = \mathrm{BASELV(I)} + \sum_{K=1}^{N} \mathrm{SAVE(K)},$$

where	BASELV(I)	is the basement elevation for grid (I), and
	SAVE(K)	is the thickness of each of the previous N rock units for grid (I).

Then, if ELEV $<$ 0, ELEV = ELEV + F(I),

where	F(I)	is the thickness of the rock unit currently being deposited,

or, if ELEV $>$ 0, F(I) = 0,

then, if ELEV $>$ 0, F(I) = F(I) - ELEV.

Five rock types are recognized by the subroutine.

Table 1.- List of subroutine and functions.

SUBROUTINE	FUNCTION
DEPOTS	Reads depositional variables of thickness, rock type and porosity.
COMPAC	Calculates compaction of the shales as a function of the depth of burial.
DIASTR	Reads amount of movement of the basement of the model.
ERODED	Reads amount of erosion and removes the specified amount of sediment or basement rock.
STHIGH	Calculates the location of the structural highs as possible sites of oil accumulation.
DYSNAP	Prepares listings for studying the dynamics of the model being developed.
PLANVU	Draws plan view map showing grid description and lines of cross sections.
SXPLOT	Draws stratigraphic cross sections at specified locations.
ENDING	Prepares summary listing of geologic events described during the simulation run. Ends the computer run.
ERRORS	Prepares comment describing detected error condition.
INTRPT	Stops simulation run and saves necessary information for a future continuation of the computer run.
RSTART	Continues a computer run that was interrupted at a previous time.

They are sandstone, shale, limestone, dolomite and evaporites. Except for shale, the input porosity of all rock types can differ. The porosity of shale should be input as 50 percent because the compaction subroutine assumes a near surface porosity of 50 percent when calculating compaction as a function of the depth of burial.

Compaction

Compaction is an automatic process not requiring input data other than a COMPACTION control card.

Compaction in clays and silts is considerable and continues as long as the pressure on them increases. It is assumed that only shales have a significant enough rate of compaction to be included in this program. Sandstone, limestone, dolomite and evaporites have different rates of compaction on a much less significant scale.

Figure 3 is a depth-versus-pressure curve from Maxwell (1960). Figure 4 is a modified form of the pressure-versus-porosity curve from Weller (1959). Values from the curves are used to calculate the amount of compaction the shales undergo with increased depths of burial. A direct relationship is used between decreased porosity and amount of compaction. If a shale with a thickness of 1000 feet is reduced to a porosity of 15 percent, it will have been compacted by 35 percent to a thickness of 650 feet.

Table 2 is a tabulation of porosity values obtained by different methods. The porosities are shown for certain depths of burial. The values of Weller (1959) agree closely with those calculated by the compaction subroutine. Proshlyakov's (1963) values were derived from actual field measurements. He stated that the shales contained more than 50 percent clay. Therefore the presence of sand and silt probably account for the lower beginning porosity. Athy's (1930) figures are from field observations and he stated that an unknown amount of overburden was removed by erosion, explaining the lower porosity at 5000 feet.

The following steps are taken to calculate the compaction of shale at each grid location. The average depth of burial is calculated by finding the depth to the base and top of the shale unit considered.

$$\text{BASE} = \sum_{L=M}^{N} \text{SAVE}(L),$$

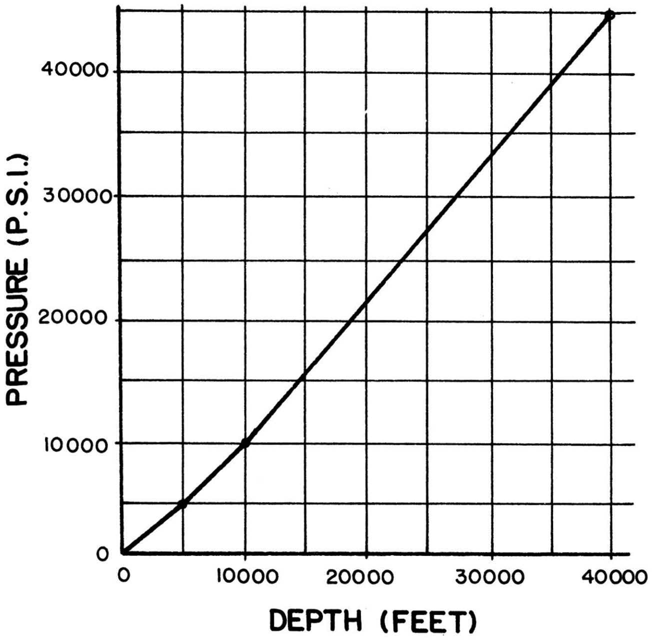


Figure 3.- Curve giving relationship of depth of burial versus pressure of overburden (after Maxwell, 1960).

where	SAVE(L)	is the thickness of each of the overlying rock units to the bottom of the shale unit,
	N	is the number of the uppermost rock unit, and
	M	is the number of the shale unit being considered.

TOP = BASE - SAVE(K),

where	SAVE(K)	is the thickness of the shale unit, and

AVEDEP = (BASE + TOP) / 2

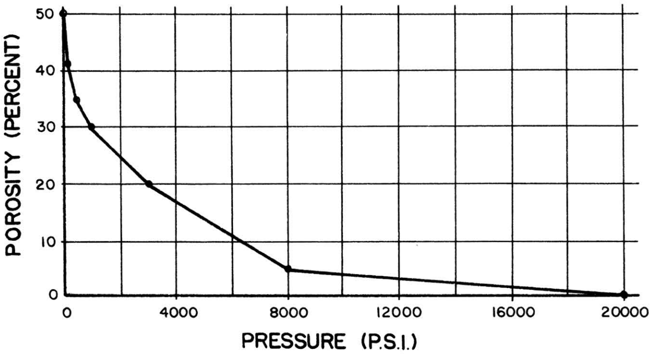


Figure 4.- Curve giving relationship of pressure of overburden versus porosity of shale (after Weller, 1959).

The pressure is obtained by using values from the curve in Figure 3.

If $\text{AVEDEP} < 5000$, $\text{PSI} = (\text{AVEDEP}/5000)(4950)$

If $5000 \leqslant \text{AVEDEP} < 10000$, $\text{PSI} = \left(\frac{\text{AVEDEP} - 5000}{5000}\right)$

$(5050) + 4950$

If $\text{AVEDEP} \geqslant 10000$, $\text{PSI} = \left(\frac{\text{AVEDEP} - 10000}{30000}\right)$

$(34500) + 100000$

The porosity for a shale unit is obtained by using

Table 2.- Table of percent porosity of shales versus depth of burial from different methods of calculations.

DEPTH TO CENTER OF UNIT (FEET)	PERCENT POROSITY			
	COMPUTED WITH PROGRAM	WELLER (1959)	PROSHLYAKOV (1963)	ATHY (1930)
0	50	80	27	50
500	33	33	25	37
1000	30	30	22	32
2500	23	22	16	17
5000	14	12	8	6
10000	4	3	5	-
20000	0	0	-	-

values from the curve in Figure 4.

$$\text{If PSI} < 100,\ \text{AVEPOR} = 50 - \frac{(\text{PSI})\ \ (8)}{100}$$

$$\text{If } 100 \leqslant \text{PSI} < 400,\ \text{AVEPOR} = 42 - \frac{(\text{PSI} - 100)(8)}{100}$$

$$\text{If } 400 \leqslant \text{PSI} < 1000,\ \text{AVEPOR} = 34 - \frac{(\text{PSI} - 400)(4)}{600}$$

$$\text{If } 1000 \leqslant \text{PSI} < 3000,\ \text{AVEPOR} = 30 - \frac{(\text{PSI} - 1000)(10)}{2000}$$

$$\text{If } 3000 \leqslant \text{PSI} < 8000,\ \text{AVEPOR} = 20 - \frac{(\text{PSI} - 3000)(15)}{5000}$$

$$\text{If } 8000 \leqslant \text{PSI} < 20000,\ \text{AVEPOR} = 5 - \frac{(\text{PSI} - 8000)(5)}{12000}$$

$$\text{If PSI} \geqslant 20000,\ \text{AVEPOR} = 0$$

If the average porosity is greater than the former porosity the former porosity is maintained and the shale unit is not compacted. This situation could arise if overlying sediment had been removed between cycles of compaction. Subsequent compaction occurs only if the previous depth of burial is exceeded.

The percentage of compaction is found by

$$\text{PERCOM} = 50 - \text{FORPOR},$$

where FORPOR is the former porosity of the shale unit before this cycle of compaction began, and

50 is the starting porosity for all shales.

The original thickness of the shale unit is calculated by

$$\text{ORIGIN} = \frac{\text{SAVE(K)}}{1 - (\frac{\text{PERCOM}}{100})},$$

where SAVE(K) is the thickness of the shale unit before this compaction cycle.

The new compacted thickness is found by

$$\text{SAVE(K)} = \text{ORIGIN} - \text{ORIGIN}\,(\frac{50 - \text{AVEPOR}}{100}).$$

This compaction process represents one particular function. Any other compaction process could be substituted for experimentation with different hypotheses.

Table 3 is a listing of a compacted element. The figures for the porosities show that the shales of earlier time units have a lower porosity than those of later times. Time unit 6 has a 23 percent porosity and time unit 9 has a 32 percent porosity.

Diastrophism

The diastrophism subroutine is used to change the elevations of the basement rocks and overlying strata of the model. Diastrophic movements are input as negative values for sinking areas and as positive values for rising areas. The new basement elevation is calculated by

$$\text{BASELV(I)} = \text{BASELV(I)} + \text{F(I)},$$

where F(I) is a signed value for the amount of movement at element (I).

An automatic adjustment to sea-level feature is available in this subroutine. If the option is used the routine calculates the elevation of the top of the uppermost time unit and adjusts the basement up or

Table 3.- Computer-prepared listing of grid element showing decreasing shale porosities with depth and locations of oil traps. Trap locations are shown by adding 100 percent to porosity of time units which contain traps.

```
ELEMENT NUMBER      1    BASEMENT ELEVATION    -2700

      TIME NO.     THICKNESS   ROCK TYPE   POROSITY

         1           900.      SANDSTONE      25.
         2          2800.      DOLOMITE       40.
         3             0.                     30.
         4          1900.      EVAPORITE       5.
         5           400.      LIMESTONE     110.
         6          1326.      SHALE          23.
         7            87.      SHALE          27.
         8           100.      LIMESTONE     105.
         9          1359.      SHALE          32.
```

down so that the top unit has an elevation of 0.

$$TOP = BASELV(I) + \sum_{J=1}^{N} SAVE(J),$$

where SAVE(J) are the thicknesses of all rock units in element (I), and

N is the total number of rock units deposited.

$$BASELV(I) = BASELV(I) - TOP.$$

Erosion

The erosion subroutine is used to remove sediment from the stratigraphic columns. The amount of erosion is given for each grid element and specified as a negative value. The basement elevation is lowered by the appropriate amount if all overlying sediment has been eroded away. Erosion is computed by

$$THICKN = SAVE(N) + F(I),$$

where SAVE(N) is the thickness of the present rock unit being eroded. It is always the uppermost rock unit at the start of the erosion.

If $THICKN < 0$, $SAVE(N) = 0$.

If all existing sediment has been eroded away and the total amount of erosion has not been satisfied, the basement elevation is lowered by the remaining amount of erosion,

$$BASELV(I) = BASELV(I) + THICKN.$$

Peneplanation is an automatic available feature. If desired, all sediment and basement rock above sea level is removed. The elevation of the top of the column is calculated by

$$ELEV = BASELV(I) + \sum_{J=1}^{N} SAVE(J),$$

where SAVE(J) are the thickness of all rock units at grid (I), and

N is the total number of rock units deposited.

The following steps are taken only if the elevation is greater than 0. ELEV is the amount of erosion which is to take place.

If $ELEV > SAVE(N)$, $ELEV = ELEV - SAVE(N)$,
and $SAVE(N) = 0$,

where SAVE(N) is the thickness of the present rock unit eroded. It is always the uppermost rock unit at the start of the erosion.

This removes all of the rock unit and ELEV is the amount of sediment yet to be removed. The next lower rock unit then is eroded.

If $ELEV < SAVE(N)$, $SAVE(N) = SAVE(N) - ELEV$.

If all sediment has been eroded and ELEV is greater than 0, the basement elevation is set to sea level by

$$BASELV(I) = 0.$$

Structure

The structural subroutine is an automatic process which does not require input data cards. All needed information has been saved on tape. Several assumptions are incorporated into this subroutine which identifies structural highs as possible sites of oil accumulation: (1) there was enough oil in the reservoir rock to accumulate in the structural highs; (2) porous sandstone and limestone were potential reservoirs, and (3) the oil had enough time to migrate to the highs at any time the subroutine is called.

Each porous sandstone and limestone unit is tested to determine the structural highs and whether the overlying rock is impervious. A test also is made to see that the highs are not at the surface due to erosion or nondeposition of overlying rock units.

The elevations at the top of each potential reservoir are calculated for each grid by

$$ELEV = BASELV + \sum_{M=1}^{N} THICK(M),$$

where BASELV is the basement elevation for the grid unit, and

THICK(M) are the thicknesses of all rock units (N) from the basement to the top of the rock unit tested.

Figure 5 is a plan view of a gridded potential reservoir showing the structural highs as oil-trap locations. The traps occur in grids 1, 8, 15, 17 and 25. The trap in grid 17 is a sedimentary facies trap and the others are structural traps.

The locations of oil traps are indicated on the plotted cross sections as shown on Figure 6. They are

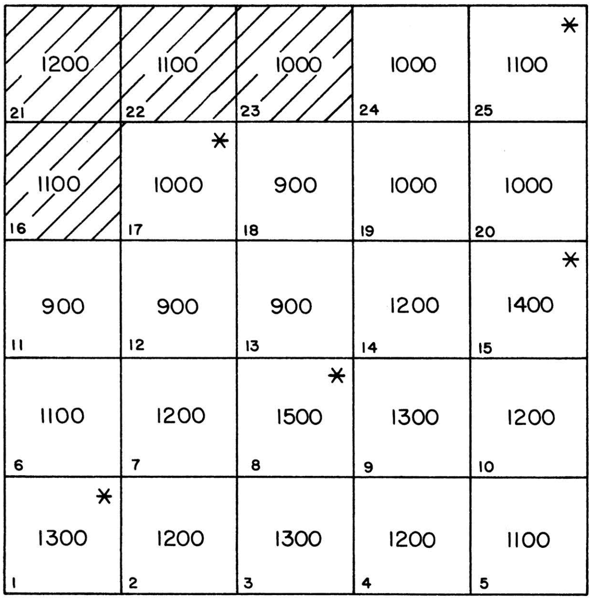


Figure 5.- Plan view map of gridded potential reservoir showing structural highs as trap location. Large numbers are elevations of reservoir top and small numbers are grid locations; traps are marked by asterisks; hatched area is shale facies and plain area is sandstone facies.

noted by an asterisk to the right of the porous sandstone and limestone. Element 1 has two limestone traps and element 9 has one sandstone trap. The listings for the stratigraphic columns or elements also denote the trap locations by adding 100 percent to the original porosity of the time unit. Table 3 shows traps located in rock units 5 and 8.

Dynamics

This subroutine prepares visual displays and listings for examining the development of the geologic model. The displays can be made at any time during the running of the program to enable a continuous examination of the dynamics of the physical processes simulated. The subroutine is entered by a DYNAMIC SNAPSHOT control card followed by a card with the words STRATIGRAPHIC SECTION, STRUCTURAL CONTOUR or ISOPACH INTERVAL. The routine makes tabulated listings of the stratigraphic sections at desired element locations. It prepares listings of structural tops at selected time unit tops and listings of intervals between specified time units.

The dynamic subroutine can instruct other subroutines to construct graphic stratigraphic cross sections and plan views of the sections. Table 3 is an example of a listing of an element of a model.

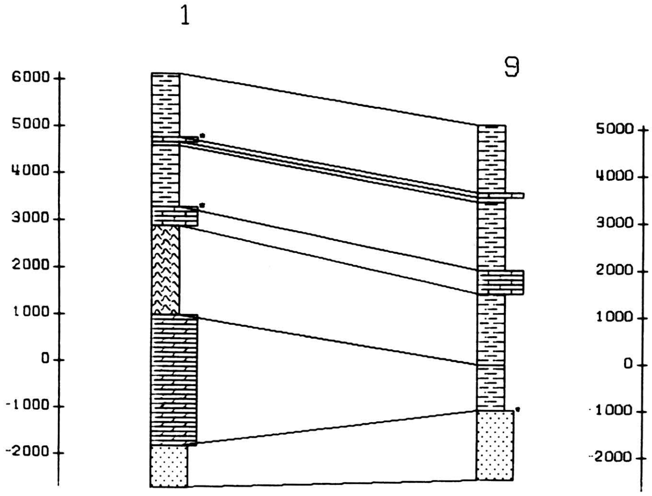


Figure 6.- Computer-plotter drawn stratigraphic cross section showing locations of oil traps and symbols used for five rock types. Trap locations are marked with asterisks. Left column shows rock type symbols. Starting at base and going up are sandstone, dolomite, evaporites, limestone and shale.

Plan

This subroutine shows the manner in which the model was defined. The grid elements and their numbering scheme are shown on a plotted map. A plan view is drawn each time a stratigraphic cross section is plotted. The line on the cross section is drawn on the plan view to give a visual method of locating the section within the model. Plan views showing the lines of section are included on the cross sections contained in Appendix D.

Section

Section is the subroutine that prepares the graphic cross sections. The line of cross section is defined by the element numbers of the columns along the section. The horizontal and vertical scales are specified. The distance between the columns is calculated so the true horizontal scale is always given. The sections can be lateral, longitudinal or any other specified direction across the model.

Cross sections prepared by this subroutine and plotted on an automatic plotter are included in Appendix D. The elevations are drawn at both ends of the section. The element or stratigraphic columns are numbered at the top of the section. Lines connect the time units between adjacent stratigraphic columns.

Ending

Ending is the subroutine that prepares the summary listing of the geologic events input during the development of the geologic model. It is entered when the END control card is read at the completion of a run. The summary listing can be used as a reference to see how the geology was described. A summary listing is shown in Appendix D.

Error

The error subroutine is called automatically by the program if a data input error is detected. The program checks many of the input parameters to test for conditions that would make the running of the model a waste of time because of some type of error. If such a condition is encountered, the subroutine writes a message describing the error condition and the computer run is terminated.

Interrupt

The interrupt subroutine provides for breaking a long computer simulation run into a series of shorter runs. The STOP control card is used for this purpose. If a stop card is encountered, the subroutine writes all necessary information onto a magnetic tape. This tape can be used for a continuation of the run at a later time. The subroutine calls the ending subroutine to prepare the summary listing of the geologic input events.

The interrupt subroutine is useful if a long computer run is made or after some dynamic snapshots have been taken. This gives the user a chance to examine the development of the model and make any adjustments before the run is continued. If a run is continued it is not necessary to develop the model to the point where it was interrupted.

Restart

The restart subroutine is used to continue a simulation run previously interrupted. It is entered by a RESTART control card. This subroutine reads the magnetic tape prepared by the interrupt subroutine during an earlier run of the model. The subsequent geologic processes then are defined for the continuation of the simulation.

FUTURE DEVELOPMENT

A mathematical model for simulating geological processes should be constantly revised throughout its use. The physical processes can be modified experimentally to test different hypotheses and new processes can be incorporated into the model. The simulation program described here is open-ended in that increased capabilities or modified functions can be added easily. This simulation program can be considered a basic foundation for future development of more refined and sophisticated models. Some additions that could be incorporated into future models are

(1) Fluid migration processes could be added to utilize certain hydrodynamic principles. Factors such as tilted water-oil surfaces and pressure gradients might be added to study the migration of fluids under assumed sets of conditions.

(2) The principles of faulting due to horizontal and vertical pressures could be included. If the pressure differences between adjacent grids exceed a given limit, a fault might be inferred.

(3) Automatic movement of the basement rocks could be defined to allow the basement to sink when receiving great quantities of sediment or to rise if the surface is rapidly eroded. This could be done by assigning an equilibrium factor to each grid element that would cause the basement to move depending upon the weight of the overburden.

(4) Salt tectonics could be included for studying salt-dome development. The physical processes by which a layer of salt moves to form a dome could be simulated in mathematical terms.

(5) Simulation of the diagenetic processes can be greatly expanded. Currently only shale compaction is included. The compaction of other sediments could be added. Removal by solution, cementation, recrystallization, dolomitization and gypsum-anhydrite transformation are other diagenic processes that could be simulated.

(6) The ability to input a few random data points and let the program compute the values to be used for each grid location would be a big asset. The basic input data for an area might be from randomly drilled wells. A routine could be added to compute the values for each of the grid elements using a technique such as interpolation between the random points.

REFERENCES

Athy, L.F., 1930, Density, porosity and compaction of sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 1, p. 1-24.

Blackstone, D.L., Jr., 1948, The structural pattern of the Wind RiverBasin, Wyoming: Wyoming Geol. Assoc. Field Conf. Guidebook, p. 69-78.

Harbaugh, J.W., 1966, Mathematical simulation of marine sedimentation with IBM 7090/7094 computers: Kansas Geol. Survey Computer Contr. 1, 52 p.

Harbaugh, J.W., and Merriam, D.F., 1968, Computer application in stratigraphic analysis: John Wiley & Sons, New York, 282 p.

Keefer, W.R., 1965, Geologic history of Wind River Basin, central Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1878-1892.

Maxwell, J.C., 1960, Experiments on compaction and cementation of sand, in Rock deformation: Geol. Soc. America Mem. 79, p. 105-107.

Ojakangas, D.R., 1967, Mathematical simulation of oil trap development: Unpubl. doctoral dissertation, Stanford Univ., 150 p.

Proshlyakov, B.K., 1963, Dependence of reservoir properties on depth of occurrence and lithologic composition of rocks: Geologiya Nefti i Gaza, v. 4, p. 693-697.

Weller, J.M., 1959, Compaction of sediments: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 2, p. 273-310.

APPENDIX A.- Computer listings.

```
$IBFTC MAIN
CDYNAMO   DYNAMIC OIL TRAP DEVELOPMENT MODEL   D.R.OJAKANGAS
C         DRIVER ROUTINE.
C     NR=NO. OF ELEMENTS IN MODEL
C     NE=NO. OF GEOLOGIC INPUT EVENTS
C     NF=NO. OF GEOLOGIC FEATURES ON FILE TAPE--3/DEPOSITIONAL CYCLE.
C     NC=NO. OF CYCLES OF DEPOSITION.
C        LIMIT OF 50 BY 50 ELEMENTS IN MODEL.
C        LIMIT OF 100 CYCLES OF DEPOSITION.
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DATA REST,BASE,DEPO,COMP,DIAS,EROS,STRU,DYNA,STOP,END,TITL/
     X4HREST,4HBASE,4HDEPO,4HCOMP,4HDIAS,4HEROS,4HSTRU,4HDYNA,4HSTOP,
     X3HEND,4HTITL/
C
C     THE FOLLOWING ARE CALCOMP PLOTTER ROUTINES. CALCMP,EOFIL,PLTIN3,
C      DRWLNI, DRWCHR, AND YAXIS.
C
      NC=0
      NE=0
      NF=0
      ITAP=4
      IOUT=7
      CALL CALCMP(4,0,0,0,0,0,0)
      CALL EOFIL(-1)
      WRITE(6,4)
C     READ CONTROL CARD.
  100 READ(5,1)TE
      WRITE(6,5)TE
C     TEST TO SEE WHICH TYPE.
      IF(TE(1).NE.TITL)GO TO 200
C     TITLE CARD. READ IN PARAMETER CARD.
      READ(5,2)ID,IX,IY,DIST
      NR=IX*IY
      WRITE(6,3)ID
      IF(NR.LE.2500)GO TO 150
      KEYER=3
      GO TO 1200
  150 NUMA=0
      CALL PLANVU(NUMA)
      GO TO 300
  200 IF(TE(1).NE.REST)GO TO 400
C     RESTART CARD. CONTINUE WITH A PREVIOUS RUN.
      CALL RSTART
      GO TO 100
  300 READ(5,1)TE
      WRITE(6,5)TE
      IF(TE(1).EQ.BASE) GO TO 310
      KEYER=1
      GO TO 1200
C     DEFINITION OF BASEMENT CONFIGURATION.
C     READ THE DATA IN--STORE IN BASELV ARRAY.
  310 READ(5,6) (BASELV(I),I=1,NR)
      NE=NE+1
  350 WRITE(3)(TE(I),I=1,20)
      GO TO 100
  400 IF(TE(1).NE.DEPO)GO TO 500
```

```
      IF(NC.NE.100)GO TO 450
      KEYER=4
      GO TO 1200
  450 CALL DEPOTS
      NC=NC+1
      GO TO 350
  500 IF(TE(1).NE.COMP)GO TO 600
C     DIAGENETIC PROCESS OF COMPACTION.
      CALL COMPAC
      GO TO 350
  600 IF(TE(1).NE.DIAS)TO GO 700
C     DIASTROPHIC EVENT.
      CALL DIASTR
      GO TO 350
  700 IF(TE(1).NE.EROS)GO TO 800
C     EROSION PROCESS.
      CALL ERODED
      GO TO 350
  800 IF(TE(1).NE.STRU)GO TO 900
C     STRUCTURAL HIGH DETERMINATION.
      CALL STHIGH
      GO TO 350
  900 IF(TE(1).NE.DYNA)GO TO 1000
C     TAKE A PALEOGEOLOGIC SNAPSHOT.
      CALL DYSNAP
      GO TO 100
 1000 IF(TE(1).NE.END)GO TO 1100
C     END OF GEOLOGIC PROCESS.
 1050 CALL ENDING
      RETURN
 1100 IF(TE(1).NE.STOP)GO TO 1150
C     INTERRUPT RUN AT THIS POINT IN TIME.
      CALL INTRPT
      GO TO 1050
C     CARD NOT PROPERLY TYPED. PUNT OUT.
 1150 KEYER=5
 1200 CALL ERRORS(KEYER)
      RETURN
    1 FORMAT(20A4)
    2 FORMAT(10X,10A4,2I3,F6.0)
    3 FORMAT(20X,10A4)
    4 FORMAT(1H1,20X,42HDYNAMO--DYNAMIC OIL TRAP DEVELOPMENT MODEL//1X)
    5 FORMAT(1X,20A4)
    6 FORMAT(12F6.0)
      END
C
$IBFTC AA
C DEPOSITION.  READS AND STORES DEPOSITIONAL FACTORS.
C     DEPOSITION OF SEDIMENT.
      SUBROUTINE DEPOTS
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DATA SL/4HS.L./
C     READ IN THE THICKNESS AND SEDIMENT TYPE AND WRITE ON FILE TAPE.
C     ROCK TYPE 1= SANDSTONE
C               2= SHALE
C               3= LIMESTONE
```

```
C                   4= DOLOMITE
C                   5= EVAPORITE
      LI7=1
      READ(5,1)(F(I),V(I),I=1,NR)
      IF(NC.EQ.0)GO TO 450
      DO 100 I=1,NR
      READ(ITAP)(SAVE(J),J=1,NF)
      IF(TE(4).NE.SL)GO TO 90
C     NO DEPOSITION ABOVE SEA LEVEL.
      ELEV=BASELV(I)
      DO 50 K=1,NF,3
      ELEV=ELEV+SAVE(K)
   50 CONTINUE
      IF(ELEV.LE.0.0)TO GO 60
      F(I)=0.0
      GO TO 90
   60 ELEV=ELEV+F(I)
      IF(ELEV.LE.0.0)GO TO 90
      F(I)=F(I)-ELEV
   90 WRITE(IOUT)(SAVE(J),J=1,NF),F(I),V(I)
  100 CONTINUE
  105 NF=NF+2
  110 END FILE IOUT
      REWIND IOUT
      REWIND ITAP
      JSAV=IOUT
      IOUT=ITAP
      ITAP=JSAV
      GO TO (120,430),LIZ
C     READ IN POROSITY DATA AND WRITE ON FILE TAPE.
  120 READ(5,2)(F(I),I=1,NR)
      DO 200 I=1,NR
      READ(ITAP)(SAVE(J),J=1,NF)
      WRITE(IOUT)(SAVE(J),J=1,NF),F(I)
  200 CONTINUE
      NF=NF+1
      LIZ=2
      GO TO 110
  430 NE=NF+1
      RETURN
  450 DO 500 I=1,NR
      WRITE(IOUT)F(I),V(I)
  500 CONTINUE
      GO TO 105
    1 FORMAT(12(F5.0,F1.0))
    2 FORMAT(12F6.0)
      END
C
$IBFTC BB
CDIASTROPHISM.  CALCULATES NEW BASEMENT ELEVATION.
      SUBROUTINE DIASTR
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DATA SL/4HS.L./
      IF(TE(5).EQ.SL)GO TO 200
C     READ AMOUNT OF MOVEMENT
      READ(5,1)(F(I),I=1,NR)
```

```
C     CALCULATE NEW BASEMENT ELEVATION.
      DO 100 I=1,NR
      BASELV(I)=BASELV(I)+F(I)
  100 CONTINUE
  150 NE=NE+1
      RETURN
C     AUTOMATIC ADJUSTMENT TO SEA LEVEL.
  200 IF(NC.EQ.0)TO GO 400
      DO 300 I=1,NR
      TOP=BASELV(I)
      READ(ITAP)(SAVE(J),J=1,NF)
      DO 250 J=1,NF,3
      TOP=TOP+SAVE(J)
  250 CONTINUE
      BASELV(I)=BASELV(I)-TOP
  300 CONTINUE
      REWIND ITAP
      GO TO 150
  400 DO 450 I=1,NR
      BASELV(I)=0.0
  450 CONTINUE
      GO TO 150
    1 FORMAT(12F6.0)
      END
C
$IBFTC CC
CEROSION.  REMOVES GIVEN AMOUNT OF SEDIMENT OR BASEMENT.
      SUBROUTINE ERODED
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DATA SL/4S.L./
      IF(TE(3).EQ.SL)GO TO 400
C     READ AMOUNT OF EROSION--F-ARRAY.
      READ(5,1)(F(I),I=1,NR)
C     SUBTRACT APPROPRIATE THICKNESS FROM GEOLOGIC COLUMN.
      IF(NC.EQ.0)GO TO 290
  150 DO 200 I=1,NR
      N=NF+1
      READ(ITAP)(SAVE(J),J=1,NF)
  160 N=N-3
      IF(N.LE.0)GO TO 190
      THICKN=SAVE(N)+F(I)
      IF(THICKN.LE.0.0)GO TO 180
      SAVE(N)=THICKN
  170 WRITE(IOUT)(SAVE(J),J=1,NF)
      GO TO 200
  180 SAVE(N)=0.0
      F(I)=THICKN
      GO TO 160
  190 BASELV(I)=BASELV(I)+THICKN
      GO TO 170
  200 CONTINUE
  205 END FILE IOUT
      REWIND IOUT
      REWIND ITAP
      JSAV=IOUT
      IOUT=ITAP
```

```
      ITAP=JSAV
  210 NF=NF+1
      RETURN
  290 DO 300 I=1,NR
      BASELV(I)=BASELV(I)+F(I)
  300 CONTINUE
      GO TO 210
C     AUTOMATIC EROSION TO SEA LEVEL.
  400 DO 500 I=1,NR
      READ(ITAP)(SAVE(J),J=1,NF)
      ELEV=BASELV(I)
      DO 410 J=1,NF,3
      ELEV=ELEV+SAVE(J)
  410 CONTINUE
      IF(ELEV.LE.0.0)GO TO 490
C     SEDIMENT ABOVE SEA LEVEL--ERODE IT.
C     REMOVE ELEV FEET FROM THE TOP.
      N=NF+1
  420 N=N-3
      IF(N.LE.0)GO TO 480
      IF(ELEV.GT.SAVE(N))GO TO 450
      SAVE(N)=SAVE(N)-ELEV
      GO TO 490
  450 ELEV=ELEV-SAVE(N)
      SAVE(N)=0.0
      GO TO 420
  480 BASELV(I)=0.0
  490 WRITE(IOUT)(SAVE(J),J=1,NF)
  500 CONTINUE
      GO TO 205
    1 FORMAT(12F6.0)
      END
C
$IBFTC DD
CDYNAMIC SNAPSHOT.  MAKES VARIOUS PALEOGEOLOGIC MAPS AND SECTIONS.
      SUBROUTINE DYSNAP
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX.IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DIMENSION TYPE(6),IV(2500)
      DATA SC,ST,SO,OPT/
     X4HSTRA,4HSTRU,4HISOP,1HX/
      DIMEISION SA(3),DO(2),EV(2),TP(3)
      DATA SA(1),SA(2),SA(3),SH,CI,DO(1),DO(2),EV(1),EV(2),BL/
     X4HSAND,4HSTON,1HE,4HSHAL,4HLIME,4HDOLO,4HMITE,4HEVAP,4HGRIT,1H
      EQUIVALENCE(V,IV)
      READ(5,1)TYPE,NUMA,NUMB,XSC,ZSC,CNTOPT
      WRITE(6,2)TYPE,ID
      IF(TYPE(1).NE.SC)GO TO 200
C     STRAT COL. DISPLAY.
      READ(5,3)(IV(I),I=1,NUMA)
      N=0
      IFLAG=0
      DO 100 I=1,NUMA
   50 N=N+1
   55 READ(ITAP)(SAVE(J),J=1,NF)
      IF(N-IV(I))50,70,60
   60 NBS=N-IV(I)+1
```

```
      DO 65 L=1,NBS
      BACKSPACE ITAP
   65 CONTINUE
      N=N-NBS+1
      GO TO 55
C     LIST THIS ELEMENT.
   70 WRITE(6,4)N,BASELV(N)
      M=1
      DO 90 K=1,NF,3
      SE=SAVE(K+1)
      IF(SE.NE.1.0)GO TO 75
      TP(1)=SA(1)
      TP(2)=SA(2)
      TP(3)=SA(3)
      GO TO 80
   75 IF(SE.NE.2.0)GO TO 76
      TP(1)=SH
      TP(2)=SA(3)
      TP(3)=BL
      GO TO 80
   76 IF(SE.NE.3.0)GO TO 77
      TP(1)=CI
      TP(2)=SA(2)
      TP(3)=SA(3)
      GO TO 80
   77 IF(SE.NE.4.0)GO TO 78
      TP(1)=DO(1)
      TP(2)=DO(2)
      TP(3)=BL
      GO TO 80
   78 IF(SE.NE.5.0)GO TO 79
      TP(1)=EV(1)
      TP(2)=EV(2)
      TP(3)=SA(3)
      GO TO 80
   79 TP(1)=BL
      TP(2)=BL
      TP(3)=BL
   80 WRITE(6,5)M,SAVE(K),TP,SAVE(K+2)
      M=M+1
   90 CONTINUE
      IF(XSC.NE.0.0)CALL SXPLOT(IFLAG,N,NUMA)
  100 CONTINUE
      IF(XSC.NE.0.0)CALL PLANVU(NUMA)
      WRITE(6,12)
  110 REWIND ITAP
      RETURN
  200 IF(TYPE(1).NE.ST)GO TO 300
C     STRUCTURE TOP DISPLAY.  NUMA= TIME NO. OF TOP.
      WRITE(6,10)NUMA
      DO 250 I=1,NR
      IF(NUMA.EQ.0)GO TO 230
      READ(ITAP)(SAVE(J),J=1,NF)
      NUM=NUMA*3
      TOP=BASELV(I)
      DO 220 K=1,NUM,3
      TOP=TOP+SAVE(K)
  220 CONTINUE
```

```
      GO TO 240
  230 TOP=BASELV(I)
  240 WRITE(6,11)I,TOP
      IF(CNTOPT.NE.OPT)GO TO 250
C     WRITE POINT FOR CONTOURING PROGRAM.
      JY=1
      JX=1
  245 IF(JX.LE.IX)GO TO 246
      JY=JY+1
      JX=JX-IX
      GO TO 245
  246 X=JX
      Y=JY
      X=X*DIST
      Y=Y*DIST
      WRITE(2,14)X,Y,TOP
  250 CONTINUE
      IF(CNTOPT.EQ.OPT)WRITE(2,13)
      WRITE(6,12)
      GO TO 110
  300 IF(TYPE(1).NE.SO)GO TO 400
C     ISOPACH INTERVAL B/N NUMA(TOP) AND NUMB(BOTTOM).
      WRITE(6,20)NUMA,NUMB
      DO 350 I=1,NR
      READ(ITAP)(SAVE(J),J=1,NF)
      NA=NUMA*3-2
      NB=NUMB*3+1
      THICK=0.0
      DO 320 K=NB,NA,3
      THICK=THICK+SAVE(K)
  320 CONTINUE
      WRITE(6,11)I,THICK
      IF(CNTOPT.NE.OPT)GO TO 350
C     WRITE POINT FOR CONTOURING PROGRAM.
      JY=1
      JX=1
  330 IF(JX.LE.IX)GO TO 340
      JY=JY+1
      JX=JX-IX
      GO TO 330
  340 X=JX
      Y=JY
      X=X*DIST
      Y=Y*DIST
      WRITE(2,14)X,Y,THICK
  350 CONTINUE
      IF(CNTOPT.EQ.OPT)WRITE(2,13)
      WRITE(6,12)
      GO TO 110
C     CONTROL CARD NOT PROPERLY TYPED.
  400 KEYER=2
      CALL ERRORS(KEYER)
      RETURN
    1 FORMAT(6A4,2I4,2F6.0,2X,A1)
    2 FORMAT(1H1,1X,16A4,//1X)
    3 FORMAT(18I4)
    4 FORMAT(1X//16H ELEMENT NUMBER ,I4,21H   BASEMENT ELEVATION,F8.0,
     X//6X,44HTIME NO.     THICKNESS    ROCK TYPE    POROSITY/1X)
```

```
    5 FORMAT(9X,I2,9X,F5.0,5X,2A4,A1,5X,F4.0)
   10 FORMAT(1X//13H TIME NUMBER ,I2,//6X,22HELEMENT NO. ELEVATION/1X)
   11 FORMAT(9X,I4,7X,F7.0)
   12 FORMAT(1H1)
   13 FORMAT(3H777,77X)
   14 FORMAT(3X,3F10.0)
   20 FORMAT(1X//27H BETWEEN THE TOPS OF TIMES ,I2,5H AND ,I2,1H.//6X,
     X22HELEMENT NO.  THICKNESS/1X)
      END
C
$IBFTC EE
CENDING.  DOES FINAL TOTALS, TAPE REWINDS,ETC...
      SUBROUTINE ENDING
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      REWIND 3
      WRITE(6,3)
      DO 100 I=1,NE
      READ(3)(TE(J),J=1,20)
      WRITE(6,1)TE
  100 CONTINUE
      WRITE(6,2)NR,IX,IY,NE
      CALL EOFIL(1)
      END FILE 2
      RETURN
    1 FORMAT(1X,20A4)
    2 FORMAT(1X//,12H END OF JOB.,I4,18H ELEMENTS IN MODEL,I4,2H X,I4,1H
     X,/12X,I4,28H GEOLOGIC EVENTS WERE INPUT.)
    3 FORMAT(1H1,10X,26HSUMMARY OF GEOLOGIC EVENTS//1X)
      END
C
$IBFTC FF
CRESTART   SETS UP MODEL FOR A CONTINUATION RUN.
      SUBROUTINE RSTART
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      READ(9)NR,IX,IY,NE,NF,NC,DIST,ID
      DO 100 I=1,NE
      READ(9)(TE(J),J=1,20)
      WRITE(3)(TE(J),J=1,20)
  100 CONTINUE
      READ(9)(BASELV(J),J=1,NR)
      DO 200 I=1,NR
      READ(9)(SAVE(J),J=1,NF)
      WRITE(ITAP)(SAVE(J),J=1,NF)
  200 CONTINUE
      REWIND ITAP
      REWIND 9
      WRITE(6,1)ID
      NUMA=0
      CALL PLANVU(NUMA)
      RETURN
    1 FORMAT(16H RESTART RUN OF ,20A4)
      END
C
$IBFTC GG
CCOMPACTION.  CALCULATES COMPACTION OF SEDIMENTS AFTER DEPOSITION.
```

```
      SUBROUTINE COMPAC
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TF(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TF
      COMMON XSC,ZSC,DIST,XCOL
      IF(NC.EQ.0)GO TO 600
C     CALCULATE THE POROSITY FOR EACH SHALE UNIT.
  150 DO 500 I=1,NR
      READ(ITAP)(SAVE(J),J=1,NF)
      DO 400 K=1,NF,3
      IF(SAVE(K+1).NE.2.0)GO TO 400
C     CALCULATE DEPTH BY ADDING ALL OVERBURDEN TO BOTH BASE AND TOP
C         AND AVERAGE.
      BASE=0.0
      DO 155 L=K,NF,3
      BASE=BASE+SAVE(L)
  155 CONTINUE
      TOP=BASE-SAVE(K)
      AVEDEP=(BASE+TOP)/2.0
C     THE PRESSURE-DEPTH RELATIONSHIP IS FROM MAXWELL, FIG 1, P. 107.
C     FOUR POINTS DEFINE THE CURVE.  0 FT--0 PSI, 5000 FT--4950 PSI,
C     10000 FT--10000 PSI, AND 40000 FT--44500 PSI.
      IF(AVEDEP.LE.5000.0)GO TO 160
      IF(AVEDEP.LE.10000.0)GO TO 170
C     AVEDEP IS GREATER THAN 10000 FEET.
      PSI=((AVEDEP-10000.0)/30000.0)*34500.0+10000.0
      GO TO 180
C     AVEDEP IS LESS THAN 5000 FEET.
  160 PSI=(AVEDEP/5000.0)*4950.0
      GO TO 180
C     AVEDEP IS BETWEEEN 5000 AND 10000 FEET.
  170 PSI=((AVEDEP-5000.0)/5000.0)*5050.0+4950.0
C     COMPUTE AVERAGE POROSITY.  THE PRESSURE-POROSITY RELATIONSHIP
C     IS FROM WELLER, FIG 3, P. 287, WITH ONE EXCEPTION--THE INITIAL
C     POROSITY USED FOR MUD-SHALE IS 50 PERCENT INSTEAD OF 80.  SEVEN
C     POINTS DEFINE THE CURVE.  0 PSI--50 PERCENT, 100 PSI--42, 400 PSI--
C     34, 1000 PSI--30, 3000 PSI--20, 8000 PSI--5, AND 20000 PSI--0.
  180 IF(PSI.LE.100.0)GO TO 190
      IF(PSI.LE.400.0)GO TO 200
      IF(PSI.LE.1000.0)GO TO 210
      IF(PSI.LE.3000.0)GO TO 220
      IF(PSI.LE.8000.0)GO TO 230
      IF(PSI.LE.20000.0)GO TO 240
C     PSI GREATER THAN 20000 PSI.
      AVEPOR=0.0
      GO TO 250
  190 AVEPOR=50.0-(PSI*8.0/100.0)
      GO TO 250
  200 AVEPOR=42.0-((PSI-100.0)*8.0/300.0)
      GO TO 250
  210 AVEPOR=34.0-((PSI-400.0)*4.0/600.0)
      GO TO 250
  220 AVEPOR=30.0-((PSI-1000.0)*10.0/2000.0)
      GO TO 250
  230 AVEPOR=20.0-((PSI-3000.0)*15.0/5000.0)
      GO TO 250
  240 AVEPOR=5.0-((PSI-8000.0)*5.0/12000.0)
  250 IF(SAVE(K+2).LT.AVEPOR)GO TO 400
      FORPOR=SAVE(K+2)
```

```
      SAVE(K+2)=AVEPOR
C     CALCULATE COMPACTED THICKNESS OF SHALE UNIT.
      PERCOM=50.0-FORPOR
      ORIGIN=SAVE(K)/(1.0-(PERCOM/100.0))
      SAVE(K)=ORIGIN-ORIGIN*((50.0-AVEPOR)/100.0)
  400 CONTINUE
      WRITE(IOUT)(SAVE(J),J=1,NF)
  500 CONTINUE
      END FILE IOUT
      REWIND IOUT
      REWIND ITAP
      JSAV=IOUT
      IOUT=ITAP
      ITAP=JSAV
  600 NE=NE+1
      RETURN
      END
C
$IBFTC HH
CSTRUCTURAL HIGH.  CALCULATES POSITIONS OF STRUCTURAL HIGHS.
      SUBROUTINE STHIGH
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASFLV(2500),TF(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASFLV,TF
      COMMON XSC,ZSC,DIST,XCOL
      DIMENSION COL(300,9),KN(9),E(9),KB(4),ITN(2500),ITNS(9)
      IF(NC.LE.1)GO TO 1000
      IF(IX.LE.1)GO TO 1000
      IF(IY.LE.1)GO TO 1000
      DO 25 I=1,NR
      ITN(I)=0
   25 CONTINUE
      DO 950 NROW=2,IY,2
      DO 900 J=2,IX,2
      I=(NROW-1)*IX+J
      IF(I.EQ.NROW*IX.AND.NROW.EQ.IY)GO TO 50
      IF(I.EQ.NROW*IX)GO TO 40
      IF(NROW.EQ.IY)GO TO 30
      NU=9
      GO TO 90
   30 NU=5
      GO TO 90
   40 NU=6
      GO TO 90
   50 NU=4
C     COMPUTE COLUMNS TO BE READ IN.
   90 IF(NU.NE.9)GO TO 100
      KN(1)=I-IX-1
      KN(2)=I-IX
      KN(3)=I-IX+1
      KN(4)=I-1
      KN(5)=I
      KN(6)=I+1
      KN(7)=I+IX-1
      KN(8)=I+IX
      KN(9)=I+IX+1
      LIZ=3
      GO TO 200
  100 IF(NU.NE.6)GO TO 110
```

```
      KN(1)=I-IX-1
      KN(2)=I-IX
      KN(3)=I-1
      KN(4)=I
      KN(5)=I+IX-1
      KN(6)=I+IX
      LIZ=2
      GO TO 200
  110 IF(NU.NE.5)GO TO 120
      KN(1)=I-IX-1
      KN(2)=I-IX
      KN(3)=I-IX+1
      KN(4)=I-1
      KN(5)=I
      KN(6)=I+1
      LIZ=2
      NU=6
      GO TO 200
  120 KN(1)=I-IX-1
      KN(2)=I-IX
      KN(3)=I-1
      KN(4)=I
      LIZ=1
C     READ IN APPROPRIATE COLUMNS.
  200 N=0
      DO 300 II=1,NU
  210 N=N+1
      READ(ITAP)(COL(M,II),M=1,NF)
      IF(N.NE.KN(II))GO TO 210
  300 CONTINUE
      REWIND ITAP
      DO 310 I=1,NU
      JB=KN(I)
      ITNS(I)=ITN(JB)
  310 CONTINUE
      NFL=NF-3
      DO 700 JK=1,NFL,3
C     START TEST FOR HIGHEST ELEVATION.
      DO 320 MM=1,NU
      L=KN(MM)
      E(MM)=BASELV(L)
  320 CONTINUE
C     ASSIGN -99999.0 TO E(M) IF IT IS SHALE, DOLOMITE, EVAPORITE,
C         0 POROSITY OR 0 THICKNESS.
      DO 360 M=1,NU
      IF(COL(JK,M).EQ.0.)GO TO 355
      IF(COL(JK+1,M).EQ.2.0)GO TO 355
      IF(COL(JK+1,M).EQ.4.0)GO TO 355
      IF(COL(JK+1,M).EQ.5.0)GO TO 355
      IF(COL(JK+2,M).EQ.0.0)GO TO 355
      DO 350 N=1,JK,3
      E(M)=E(M)+COL(N,M)
  350 CONTINUE
      GO TO 360
  355 E(M)=-99999.0
  360 CONTINUE
      GO TO (380,390,390),LIZ
C     NU=4.
```

```
  380 K1=1
      K2=2
      K3=3
      K4=4
      NA=1
      GO TO 400
C     NU=6 OR 9.
  390 K1=1
      K2=2
      K3=4
      K4=5
      NA=2
C     SORT SUBSCRIPTS OF E-ARRAY INTO ASCENDING ORDER.
  400 IF(E(K1).GT.E(K2))GO TO 401
      KB(1)=K2
      KB(2)=K1
      GO TO 402
  401 KB(1)=K1
      KB(2)=K2
  402 I=KB(1)
      IF(E(K3).GT.E(I))GO TO 403
      I=KB(2)
      IF(E(K3).GT.E(I))GO TO 404
      KB(3)=K3
      GO TO 405
  403 KB(3)=KB(2)
      KB(2)=KB(1)
      KB(1)=K3
      GO TO 405
  404 KB(3)=KB(2)
      KB(2)=K3
  405 I=KB(1)
      IF(E(K4).GT.E(I))GO TO 406
      I=KB(2)
      IF(E(K4).GT.E(I))GO TO 407
      I=KB(3)
      IF(E(K4).GT.E(I))GO TO 408
      KB(4)=K4
      GO TO 440
  406 KB(4)=KB(3)
      KB(3)=KB(2)
      KB(2)=KB(1)
      KB(1)=K4
      GO TO 440
  407 KB(4)=KB(3)
      KB(3)=KB(2)
      KB(2)=K4
      GO TO 440
  408 KB(4)=KB(3)
      KB(3)=K4
  440 KAR=1
      DO 455 M=1,4
      I=KB(M)
      GO TO (442,444),KAR
  442 IF(E(I).EQ.-99999.0)GO TO 444
      IF(COL(JK+3,I).EQ.0.0)GO TO 445
      IF(COL(JK+4,I).EQ.2.0)GO TO 450
      IF(COL(JK+4,I).EQ.4.0)GO TO 450
```

```
      IF(COL(JK+4,I).EQ.5.0)GO TO 450
      IF(COL(JK+5,I).EQ.0.0)GO TO 450
  444 IF(COL(JK+2,I).GT.100.0)COL(JK+2,I)=COL(JK+2,I)-100.0
      GO TO 454
  445 NI=JK+6
  446 IF(NI.GT.NF)GO TO 444
      IF(COL(NI,I).EQ.0.0)GO TO 448
      IF(COL(NI+1,I).EQ.2.0)GO TO 450
      IF(COL(NI+1,I).EQ.4.0)GO TO 450
      IF(COL(NI+1,I).EQ.5.0)GO TO 450
      IF(COL(NI+2,I).EQ.0.0)GO TO 450
      GO TO 444
  448 NI=NI+3
      GO TO 446
  450 KC=KN(I)
      IF(ITN(KC).EQ.0)COL(JK+2,I)=COL(JK+2,I)+100.0
  454 KAR=2
  455 CONTINUE
  460 DO 465 M=1,4
      I=KB(M)
      KC=KN(I)
      ITN(KC)=1
  465 CONTINUE
      IF(NA.EQ.1)GO TO 600
      IF(NA.EQ.2)GO TO 470
      IF(NA.EQ.3)GO TO 480
      K1=5
      K2=6
      K3=8
      K4=9
      NA=1
      GO TO 400
  470 K1=2
      K2=3
      K3=5
      K4=6
      NA=1
      IF(NU.EQ.9)NA=3
      GO TO 400
  480 K1=4
      K2=5
      K3=7
      K4=8
      NA=4
      GO TO 400
  600 DO 650 I=1,NU
      JB=KN(I)
      ITN(JB)=ITNS(I)
  650 CONTINUE
  700 CONTINUE
      DO 710 I=1,NU
      JB=KN(I)
      ITN(JB)=1
  710 CONTINUE
C     WRITE THE COLUMNS BACK OUT.
      N=1
      DO 800 II=1,NR
      READ(ITAP)(SAVE(M),M=1,NF)
```

```
      IF(II.EQ.KN(N))GO TO 790
      WRITE(IOUT)(SAVE(M),M=1,NF)
      GO TO 800
  790 WRITE(IOUT)(COL(M,N),M=1,NF)
      N=N+1
      IF(N.GT.NU)N=NU
  800 CONTINUE
      END FILE IOUT
      REWIND IOUT
      REWIND ITAP
      ISAV=IOUT
      IOUT=ITAP
      ITAP=ISAV
  900 CONTINUE
  950 CONTINUE
 1000 NE=NE+1
      RETURN
      END
C
$IBFTC II
CINTERRUPT.  STOPS RUN--SAVES NECESSARY INFO FOR FUTURE RESTART.
      SUBROUTINE INTRPT
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      REWIND 3
      WRITE(9)NR,IX,IY,NE,NF,NC,DIST,ID
      DO 100 I=1,NE
      READ(3)(TE(J),J=1,20)
      WRITE(9)(TE(J),J=1,20)
  100 CONTINUE
      WRITE(9)(BASELV(J),J=1,NR)
      DO 200 I=1,NR
      READ(ITAP)(SAVE(J),J=1,NF)
      WRITE(9)(SAVE(J),J=1,NF)
  200 CONTINUE
      END FILE 9
      REWIND 9
      REWIND 3
      PRINT 1
      WRITE(6,2)
      RETURN
    1 FORMAT(39H OPERATOR--PLEASE SAVE A5 TAPE--THANKS.)
    2 FORMAT(1X,///52H RUN IS INTERRUPTED. USE A5 TAPE FOR FUTURE RESTAR
     XT.,///1X)
      END
C
$IBFTC JJ
CERRORS.  WRITE ERROR MESSAGES.
      SUBROUTINE ERRORS(KEYER)
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      GO TO (10,20,30,40,50),KEYER
   10 WRITE(6,1)
   15 RETURN
   20 WRITE(6,2)
      GO TO 15
```

```
   30 WRITE(6,3)
      GO TO 15
   40 WRITE(6,4)
      GO TO 15
   50 WRITE(6,5)
      GO TO 15
    1 FORMAT(37H BASEMENT ELEVATIONS NOT GIVEN--EXIT.)
    2 FORMAT(48H SNAPSHOT CONTROL CARD NOT PROPERLY TYPED--EXIT.)
    3 FORMAT(41H MODEL HAS MORE THAN 2500 ELEMENTS--EXIT.)
    4 FORMAT(42H MORE THAN 100 CYCLES OF DEPOSITION--EXIT.)
    5 FORMAT(39H CONTROL CARD NOT PROPERLY TYPED--EXIT.)
      END
C
$IBFTC KK
CPLANVU  DRAWS PLAN VIEW OF MODEL AND THE LINE OF X-SECTION.
      SUBROUTINE PLANVU(NUMA)
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DIMENSION XA(5),YA(5),ELEM(2),IV(2500)
      EQUIVALENCE (V,IV)
C
C     CALL BINCON CONVERTS BINARY NUMBERS TO BCD.
C        THE WRITE FOLLOWING CALL BINCON IS A DUMMY WRITE FOR BINCON.
      XI=IX
      YI=IY
      IF(IX.GT.IY)GO TO 50
      ISIZ=IY-1
      GO TO 60
   50 ISIZ=IX-1
   60 SB=(ISIZ/10)+1
      SIZ=1.0/SB
      CALL PLTIN3(1,0,0,0.,0.,30.,30.,3.,2.,0.,0.,1.,1.,XM,YM)
C     DRAW BOX AROUND PLAN VIEW.
      XA(1)=0.0
      XA(2)=XI*SIZ
      XA(3)=XA(2)
      XA(4)=XA(1)
      XA(5)=XA(1)
      YA(1)=0.0
      YA(2)=YA(1)
      YA(3)=YI*SIZ
      YA(4)=YA(3)
      YA(5)=YA(1)
      CALL DRWLN1(2,XA,YA,5,NOERR,0,0,0)
C     DRAW GRID LINES IN Y-DIRECTION.
      YA(2)=YA(3)
      IJ=IX-1
      DO 100 I=1,IJ
      XA(1)=FLOAT(I)*SIZ
      XA(2)=XA(1)
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      HOLD=YA(1)
      YA(1)=YA(2)
      YA(2)=HOLD
  100 CONTINUE
C     DRAW GRID LINES IN X-DIRECTION.
      IJ=IY-1
```

```
      XA(1)=0.0
      XA(2)=XI*SIZ
      DO 200 I=1,IJ
      YA(1)=FLOAT(I)*SIZ
      YA(2)=YA(1)
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      HOLD=XA(1)
      XA(1)=XA(2)
      XA(2)=HOLD
  200 CONTINUE
C     ANNOTATE THE ELEMENT NUMBERS ALONG THE MARGINS.
      CHA=SIZ*0.5
      SHA=CHA*10.0
      XL=-4.0*CHA-0.1
      YL=CHA*0.5
      NUM=1
      DO 300 I=1,IY
      CALL BINCON(ELEM)
      WRITE(3,1)NUM
      CALL DRWCHR(2,ELEM,4,NOERR,SHA,0,XL,YL)
      YL=YL+SIZ
      NUM=NUM+IX
  300 CONTINUE
      XL=XI*SIZ
      YL=YI*SIZ-0.75*SIZ
      NUM=NR
      DO 400 I=1,IY
      CALL BINCON(ELEM)
      WRITE(3,1)NUM
      CALL DRWCHR(2,ELEM,4,NOERR,SHA,0,XL,YL)
      YL=YL-SIZ
      NUM=NUM-IX
  400 CONTINUE
      IF(NUMA.NE.0)GO TO 500
C     SKIP PAPER FOR NEXT PLOT.
  450 CALL CALCMP(7,20.0,-2.0,0,NOERR,0,0)
      RETURN
C     DRAW THE LINE OF X-SECTION.
  500 DO 600 I=1,NUMA
      N=IV(I)
      NROW=1
  510 IF(N.LE.NROW*IX)GO TO 520
      NROW=NROW+1
      GO TO 510
  520 NCOL=N-(NROW-1)*IX
      XA(2)=FLOAT(NCOL)*SIZ-0.5*SIZ
      YA(2)=FLOAT(NROW)*SIZ-0.5*SIZ
      IF(I.EQ.1)GO TO 580
      CALL DRWLN1(12,XA,YA,2,NOERR,0,0,0)
  580 XA(1)=XA(2)
      YA(1)=YA(2)
  600 CONTINUE
      GO TO 450
    1 FORMAT(I4)
      END
C
$IBFTC LL
CSXPLOT  PLOTS STRATIGRAPHIC CROSS-SECTIONS.
```

```
      SUBROUTINE SXPLOT(IFLAG,N,NUMA)
      DIMENSION F(2500),V(2500),ID(10),SAVE(300),BASELV(2500),TE(20)
      COMMON F,V,NR,IX,IY,ID,NE,NF,NC,ITAP,IOUT,SAVE,BASELV,TE
      COMMON XSC,ZSC,DIST,XCOL
      DIMENSION SAVL(100),SAVP(100),XA(5),YA(5),NM(2)
      DIMENSION SCA(2),FE(3),HR(3),VR(3),XSCC(3),ZSCC(3)
      DIMENSION IV(2500),DI(10)
      EQUIVALENCE(V,IV)
      DATA SCA(1),SCA(2),FE(1),FE(2),HR(1),HR(2),VR(1),VR(2)/
     X6HSCALES,2H  ,6HFEET/I,3HNCH,6HHORIZO,6HNTAL--,6HVERTIC,6HAL----/
      DATA ASTR/1H*/
C
C     CALL BINCON CONVERTS BINARY NUMBERS TO BCD.
C        THE WRITE FOLLOWING CALL BINCON IS A DUMMY WRITE FOR BINCON.
      ATWF=0.25*XSC
      ATSF=0.375*XSC
      AFTN=0.5*XSC
      ATEN=0.1*ZSC
      ATWN=0.21*XSC
      ANNH=0.09*XSC
      ASXF=0.065*XSC
      ATWH=0.02*XSC
      AFVH=0.05*ZSC
      ATWL=0.12*XSC
      AETN=0.18*XSC
      ATHT=0.3*XSC
      ATFZ=0.025*ZSC
      AOTN=0.1*XSC
      ATFV=0.35*XSC
      ATTF=0.225*XSC
      ATSS=0.275*XSC
      AFTH=0.15*XSC
      AFRT=0.4*XSC
      IF(IFLAG.NE.0)GO TO 15
C     SET UP FOR THIS SECTION.  FIND LOWEST POINT IN SECTION.
      M=IV(1)
      BASMIN=BASELV(M)
      DO 10 I=2,NUMA
      M=IV(I)
      BASMIN=AMIN1(BASMIN,BASELV(M))
   10 CONTINUE
      XCOL=0.0
      CALL PLTIN3(1,0,0,0.,0.,100.,30.,2.,2.,0.,BASMIN,XSC,ZSC,XM,YM)
C     PRINT TITLE AND SCALES.
      CALL BINCON(DI)
      WRITE(3,1002)ID
      CALL DRWCHR(2,DI,40,NOERR,2.5,0,0.0,BASMIN-0.5*ZSC)
      CALL DRWCHR(2,SCA,8,NOERR,1.5,0,0.0,BASMIN-0.825*ZSC)
      CALL DRWCHR(2,HR,12,NOERR,1.5,0,1.2*XSC,BASMIN-0.72*ZSC)
      CALL DRWCHR(2,VR,12,NOERR,1.5,0,1.2*XSC,BASMIN-0.93*ZSC)
      CALL DRWCHR(2,FE,9,NOERR,1.5,0,3.9*XSC,BASMIN-0.825*ZSC)
      CALL BINCON(XSCC)
      WRITE(3,1001)XSC
      CALL BINCON(ZSCC)
      WRITE(3,1001)ZSC
      CALL DRWCHR(2,XSCC,6,NOERR,1.5,0,3.0*XSC,BASMIN-0.72*ZSC)
      CALL DRWCHR(2,ZSCC,6,NOERR,1.5,0,3.0*XSC,BASMIN-0.93*ZSC)
C     CALCULATE POSITION OF COLUMN(NROW,NCOL)
```

```
   15 NROW=1
   20 IF(N.LE.NROW*IX)GO TO 30
      NROW=NROW+1
      GO TO 20
   30 NCOL=N-(NROW-1)*IX
      SAVP(1)=BASELV(N)
      IF(IFLAG.EQ.0)GO TO 40
      RD=NRL-NROW
      CD=NCL-NCOL
      XCOL=XCOL+SQRT(RD*RD+CD*CD)*DIST
C     DRAW STRATIGRAPHIC COLUMN.
   40 YBOT=BASELV(N)
      YTOP=YBOT
      J=1
      DO 190 K=1,NF,3
      J=J+1
      IF(SAVE(K).EQ.0.0)GO TO 180
      YTOP=YBOT+SAVE(K)
C     DRAW BOX AROUND THIS LITHOLOGIC UNIT.
      IF(SAVE(K+1).NE.1.0)GO TO 60
C     SANDSTONE.
      XD=XCOL+0.4*XSC
      GO TO 80
   60 IF(SAVE(K+1).EQ.2.0.OR.SAVE(K+1).EQ.5.0)GO TO 65
      GO TO 70
C     SHALE OR EVAPORITE.
   65 XD=XCOL+0.3*XSC
      GO TO 80
C     LIMESTONE OR DOLOMITE.
   70 XD=XCOL+0.5*XSC
   80 XA(1)=XCOL
      XA(2)=XD
      XA(3)=XD
      XA(4)=XCOL
      XA(5)=XCOL
      YA(1)=YBOT
      YA(2)=YBOT
      YA(3)=YTOP
      YA(4)=YTOP
      YA(5)=YBOT
      CALL DRWLN1(2,XA,YA,5,NOERR,0,0,0)
      IF(SAVE(K+2).LT.100.0)GO TO 83
C     ANNOTATE LITHOLOGIC UNIT WITH AN *.  POSSIBLE POSITION OF OIL
C        ACCUMULATION.
      CALL DRWCHR(2,ASTR,1,NOERR,1.0,0,XD,YTOP-AFVH)
C     FILL BOX WITH THE PROPER LITHOLOGIC SYMBOL.
   83 IF(SAVE(K+1).NE.1.0)GO TO 100
C     SANDSTONE UNIT.
      YA(1)=YBOT-ATFZ
   84 YA(1)=YA(1)+AFVH
      IF(YA(1).GE.YTOP)GO TO 180
      XA(1)=XCOL+ATWH
      DO 85 L=2,5
      XA(L)=XA(L-1)+ANNH
   85 YA(L)=YA(1)
      CALL DRWLN1(15,XA,YA,5,NOERR,0,0,0)
      YA(1)=YA(1)+AFVH
      IF(YA(1).GE.YTOP)GO TO 180
```

```
      XA(1)=XCOL+ASXF
      DO 90 L=2,4
      XA(L)=XA(L-1)+ANNH
   90 YA(L)=YA(1)
      CALL DRWLN1(15,XA,YA,4,NOERR,0,0,0)
      GO TO 84
  100 IF(SAVE(K+1).NE.2.0)GO TO 120
C     SHALE UNIT.
      YA(1)=YBOT
  105 YA(1)=YA(1)+AFVH
      YA(2)=YA(1)
      IF(YA(1).GE.YTOP)GO TO 180
      XA(1)=XCOL
      XA(2)=XCOL+ATWL
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      XA(1)=XCOL+AETN
      XA(2)=XCOL+ATHT
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(1)=YA(1)+AFVH
      IF(YA(1).GE.YTOP)GO TO 180
      YA(2)=YA(1)
      XA(1)=XCOL+ANNH
      XA(2)=XCOL+ATWN
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      GO TO 105
  120 IF(SAVE(K+1).NE.3.0)GO TO 140
C     LIMESTONE UNIT.
      YA(1)=YBOT
  125 YA(2)=YA(1)+AFVH
      IF(YA(2).GT.YTOP)GO TO 180
      XA(1)=XCOL+ATWL
      XA(2)=XA(1)
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      XA(1)=XCOL+ATSF
      XA(2)=XA(1)
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(1)=YA(2)
      XA(1)=XCOL
      XA(2)=XCOL+AFTN
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(2)=YA(1)+AFVH
      IF(YA(2).GT.YTOP)GO TO 180
      XA(1)=XCOL+ATWF
      XA(2)=XA(1)
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(1)=YA(2)
      XA(1)=XCOL
      XA(2)=XCOL+AFTN
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      GO TO 125
  140 IF(SAVE(K+1).NE.4.0)GO TO 160
C     DOLOMITE UNIT.
      YA(1)=YBOT
  145 YA(2)=YA(1)+AFVH
      IF(YA(2).GT.YTOP)GO TO 180
      XA(1)=XCOL+AOTN
      XA(2)=XCOL+AFTH
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
```

```
      XA(1)=XCOL+ATFV
      XA(2)=XCOL+AFRT
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(1)=YA(2)
      XA(1)=XCOL
      XA(2)=XCOL+AFTN
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(2)=YA(1)+AFVH
      IF(YA(2).GT.YTOP)GO TO 180
      XA(1)=XCOL+ATTF
      XA(2)=XCOL+ATSS
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      YA(1)=YA(2)
      XA(1)=XCOL
      XA(2)=XCOL+AFTN
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
      GO TO 145
C     EVAPORITE UNIT.
  160 YA(1)=YBOT
  165 YA(2)=YA(1)+AFVH
      IF(YA(2).GT.YTOP)GO TO 180
      YA(3)=YA(1)
      XA(1)=XCOL+ATWH
      XA(2)=XCOL+ASXF
      XA(3)=XA(1)+ANNH
      CALL DRWLN1(2,XA,YA,3,NOERR,0,0,0)
      XA(1)=XA(3)+ANNH
      XA(2)=XA(2)+ANNH+ANNH
      XA(3)=XA(1)+ANNH
      CALL DRWLN1(2,XA,YA,3,NOERR,0,0,0)
      YA(1)=YA(2)
      YA(2)=YA(1)+AFVH
      IF(YA(2).GT.YTOP)GO TO 180
      YA(3)=YA(1)
      XA(1)=XCOL+ATWH+ANNH
      XA(2)=XCOL+ASXF+ANNH
      XA(3)=XA(1)+ANNH
      CALL DRWLN1(2,XA,YA,3,NOERR,0,0,0)
      YA(1)=YA(2)
      GO TO 165
  180 SAVP(J)=YTOP
      YBOT=YTOP
  190 CONTINUE
C     ANNOTATE COLUMN AT TOP WITH ELEMENT NUMBER (N).
      CALL BINCON(NM)
      WRITE(3,1000)N
      CALL DRWCHR(2,NM,4,NOERR,2.0,0,XCOL-ATHT,YTOP+0.5*ZSC)
      M=NC+1
      IF(IFLAG.EQ.0)GO TO 500
C     CONNECT TIME UNITS WITH THOSE OF LAST COLUMN.
      XA(1)=XCLL
      XA(2)=XCOL
      DO 300 I=1,M
      YA(1)=SAVL(I)
      YA(2)=SAVP(I)
      CALL DRWLN1(2,XA,YA,2,NOERR,0,0,0)
  300 CONTINUE
C     SAVE LAST STRAT. COLUMN VALUES.
```

```
  500 DO 510 I=1,M
      SAVL(I)=SAVP(I)
  510 CONTINUE
      IF(IFLAG.NE.0)GO TO 550
C     DRAW Y-AXIS AT LEFT OF PLOT.
      IBAS=BASMIN/1000.0
      BAS=IBAS*1000
      IBAS=BAS
      CALL YAXIS(BASMIN,YTOP,-1.0*XSC,1000.0,BAS,1000.0,IBAS,1000)
  550 NRL=NROW
      NCL=NCOL
      XCLL=XCOL+ATHT
      IFLAG=IFLAG+1
      IF(IFLAG.NE.NUMA)GO TO 600
C     DRAW Y-AXIS TO RIGHT OF PLOT.
      CALL YAXIS(BASMIN,YTOP,1.5*XSC+XCLL,1000.0,BAS,1000.0,IBAS,1000)
C     SKIP PAPER FOR NEXT PLOT.
      CALL CALCMP(7,XCOL+5.0*XSC,-2.0*ZSC+BASMIN,0,NOERR,0,0)
  600 RETURN
 1000 FORMAT(I4)
 1001 FORMAT(F6.0)
 1002 FORMAT(10A4)
      END
C
```

APPENDIX B

Input Data Formats

This appendix contains instructions for filling in the input forms that contain the basic input data for the simulation of a geologic area. These data are supplied by the geologist. The column numbers refer to the column of the card into which the information is punched. Examples of these cards are included in Appendices C and D.

CARD	COLS.	CONTENTS/PURPOSE
TITLE	1-5	"TITLE" identifies the control card. It is used to start a new computer run. This card must be followed by a parameter card.
PARAMETER	1-9	"PARAMETER" identifies the control card.
	11-50	Job identification.
	51-53	Number of grids of model in X-direction.
	54-56	Number of grids of model in Y-direction.
	57-62	Distance between grid centers (feet).

This card must be followed by a basement card.

BASEMENT	1-8	"BASEMENT" identifies the control card.
	9-80	Any descriptive information.

This card is followed by the elevation cards.

Elevation	Each card has space for 12 values. Use as many cards as needed to provide an elevation for each grid element. Each card except the last must have 12 values (see Fig. 2 for grid numbering scheme).	
	1-6	1st, 13th, etc.. grid elevations.
	7-12	2nd, 14th, etc.. grid elevations.
	⋮	
	67-72	12th, 24th, etc.. grid elevations.

DEPOSITION	1-10	"DEPOSITION" identifies the control card.
	11-80	Any descriptive information.
	13-16	This is an option. If S.L. appears in these columns, deposition will not be allowed above sea level.

This card is followed by the rock cards and the porosity cards.

Rock	Each card has space for 12 sets of values. Use as many cards as needed to provide a thickness and rock type for each grid element. Each card except the last must have 12 sets of values.	
	1-5	1st, 13th, etc.. rock thickness.
	6	1st, 13th, etc.. rock type.
	7-11	2nd, 14th, etc.. rock thickness.
	⋮	
	72	12th, 24th, etc.. rock type

The codes for the rock types are: 1-sandstone, 2-shale, 3-limestone, 4-dolomite and 5-evaporites.

Porosity	Each card has space for 12 values. The format is the same as that of the ELEVATION card, except the porosity percent is substituted in the place of elevation.	
COMPACTION	1-10	"COMPACTION" identifies the control card.
	11-80	Any descriptive information.

This card alone causes all of the shales in the model to be compacted.

STRUCTURAL HIGH	1-15	"STRUCTURAL HIGH" identifies the control card.
	16-80	Any descriptive information.

This card alone causes the program to search out and note the structural highs as possible sites of oil accumulation.

DIASTROPHISM	1-12	"DIASTROPHISM" identifies the control card.

	13-80	Any descriptive information.
	17-20	This is an option. If S.L. appears in these columns, the basement elevation will be adjusted so the top of each column will be at sea level.

This card must be followed by elevation cards unless the option to adjust the tops to sea level is used.

The formats for specifying the amounts of movement are the same as that of the ELEVATION card.

EROSION	1-7	"EROSION" identifies the control card.
	8-80	Any descriptive information.
	9-12	This is an option. If S.L. appears in these columns, all rock above sea level will be eroded away.

This card must be followed by erosion amount cards unless the option for automatic erosion to sea level is used.

The formats for specifying the amounts of erosion are the same as that of the ELEVATION card, except the amount of erosion is substituted for the elevation value.

DYNAMIC SNAPSHOT	1-16	"DYNAMIC SNAPSHOT" identifies the control card.

This card must preceed each of the following types of snapshot cards.

STRATIGRAPHIC	1-13	"STRATIGRAPHIC" identifies the control card, as a type 1 snapshot to prepare a stratigraphic cross section.
	25-28	Number of grid elements along the cross section.
	33-38	Horizontal scale (ft/in).
	39-44	Vertical scale (ft/in).

The scales are given only if the cross sections are to be plotted on an automatic plotter.

This card must be followed by an element numbers card.

Element		This card gives the numbers of the grid elements along the line of the cross section. There is space for 18 numbers. Each card except the last must have 18 values.
	1-4	1st, 19th, etc.. element number.
	5-8 . .	2nd, 20th, etc.. element number.
	69-72	18th, 36th, etc. element number.
STRUCTURAL	1-10	"STRUCTURAL" identifies the control card as a type 2 snapshot to prepare a structural tops listing.
	25-28	The number of the time unit on which the structural top is to be calculated.
	47	In an "X" appears in this column, the values are written on a tape for further processing.
ISOPACH	1-7	"ISOPACH" identifies the control card as a type 3 snapshot to prepare an isopach interval listing.
	25-28	The number of the top of the time unit from which the interval is to be calculated.
	29-32	The number of the bottom of the time unit to which the interval is to be calculated.
	47	In an "X" appears in this column, the values are written on a tape for further processing.
END	1-3	"END" identifies the control card which terminates

		a simulation run on the computer.
STOP	1-4	"STOP" identifies the control card which interrupts a simulation run for a future restart.
RESTART	1-7	"RESTART" identifies the control card which continues a simulation run that was previously interrupted.

APPENDIX C

The Wind River Basin of central Wyoming is used as the sample case. The geology of the basin is well defined in a paper by Keefer (1965). Part of the geological input for the basin simulation is based on Keefer's discussion. The geological history is defined for each geologic period, starting with the description of the Precambrian surface before Cambrian deposition began. The geology as defined by Keefer (1965) is at a scale of about 90 miles per inch (58 km 1 cm). The geology was analyzed and reduced into a form suitable for modeling by the program. The thicknesses of the shales were increased to account for the compaction to present thicknesses. Diastrophic movements were defined periodically to make sure that the tops of the stratigraphic columns were at sea level at the end of an interval of marine deposition. Amounts of erosion and uplift were tested experimentally to provide a reasonable definition of the development of the surrounding mountains. Stratigraphic cross sections were prepared at the end of each geologic era to show the geology at these points in time.

The area is a large sedimentary and structural basin that formed during Laramide deformation. It is surrounded by broad belts of folded and faulted Paleozoic and Mesozoic rocks. The center of the basin is covered by nearly flat-lying lower Eocene rocks. Figure 7 is a simplified block diagram showing the geology as it is today.

Figure 8 shows the grid that was superposea on the area. The grids represent an area of 400 square miles (1024 sq km) or 20 miles (32 km) on a side. The entire basin and most of the surrounding mountains are covered with eleven grid elements in the east-west direction and seven in the north-south direction. This is an area of 220 by 140 miles (352 by 224 km). The locations of the lines of the stratigraphic cross sections are also shown on Figure 8. Figure 9 shows the manner in which the geologic history was described for the sample case. A partial listing of the input data cards used in the sample case follows.

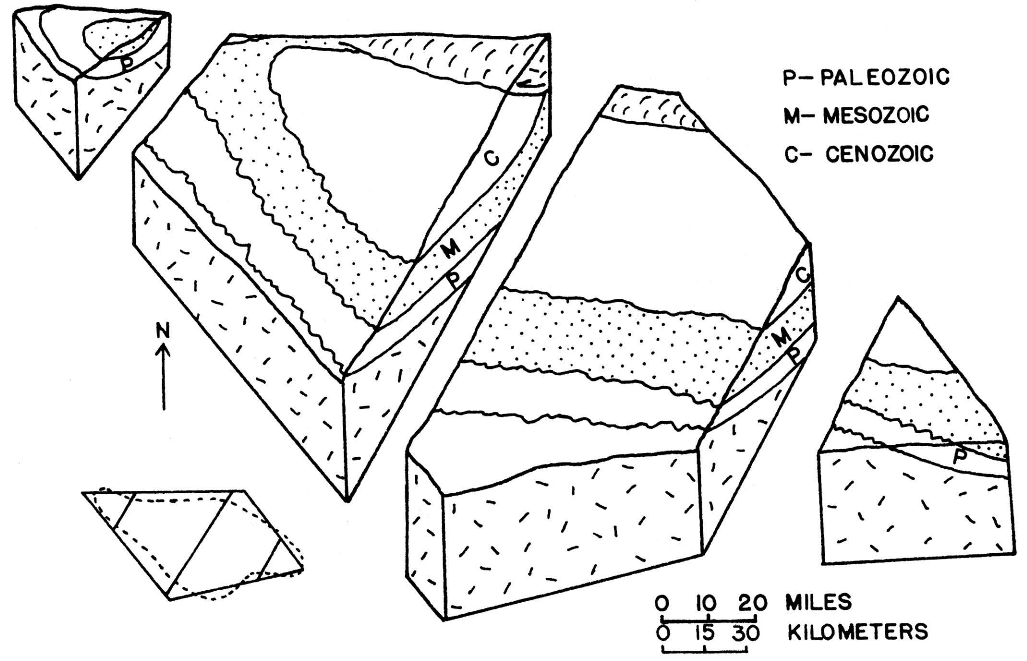


Figure 7. - Simplified block diagram of the Wind River Basin showing the general nature of the geology. In part after Keefer (1965) and Blackstone (1948).

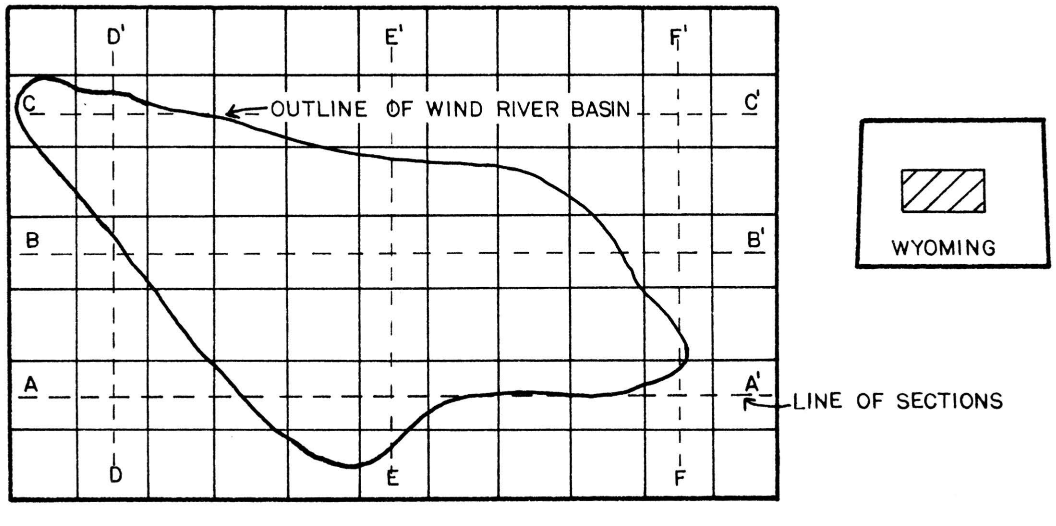
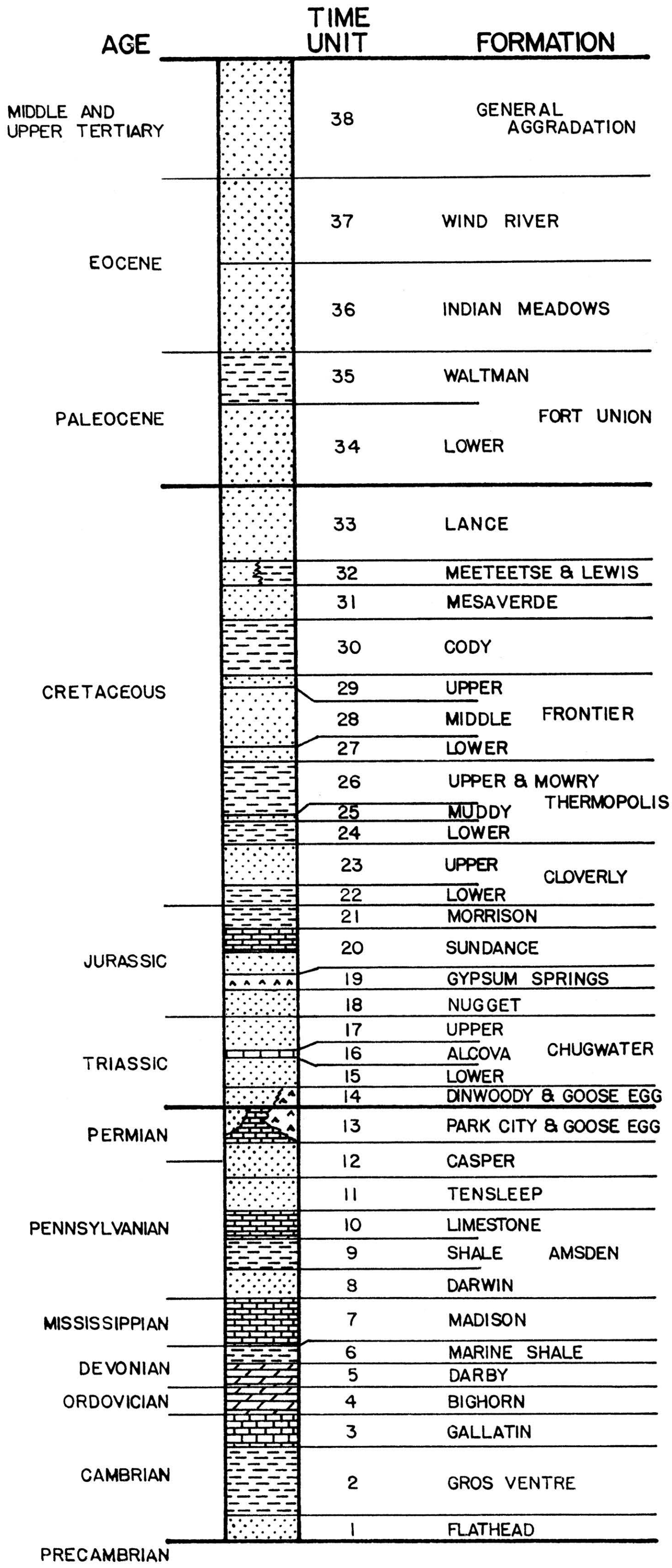


Figure 8. - Outline of the Wind River Basin showing the manner in which the region was gridded. The lines of the stratigraphic cross sections are shown also.



AGE	TIME UNIT	FORMATION	
MIDDLE AND UPPER TERTIARY	38	GENERAL AGGRADATION	
EOCENE	37	WIND RIVER	
	36	INDIAN MEADOWS	
PALEOCENE	35	WALTMAN	FORT UNION
	34	LOWER	
CRETACEOUS	33	LANCE	
	32	MEETEETSE & LEWIS	
	31	MESAVERDE	
	30	CODY	
	29	UPPER	FRONTIER
	28	MIDDLE	
	27	LOWER	
	26	UPPER & MOWRY	THERMOPOLIS
	25	MUDDY	
	24	LOWER	
	23	UPPER	CLOVERLY
	22	LOWER	
JURASSIC	21	MORRISON	
	20	SUNDANCE	
	19	GYPSUM SPRINGS	
	18	NUGGET	
TRIASSIC	17	UPPER	CHUGWATER
	16	ALCOVA	
	15	LOWER	
	14	DINWOODY & GOOSE EGG	
PERMIAN	13	PARK CITY & GOOSE EGG	
PENNSYLVANIAN	12	CASPER	
	11	TENSLEEP	
	10	LIMESTONE	AMSDEN
	9	SHALE	
	8	DARWIN	
MISSISSIPPIAN	7	MADISON	
DEVONIAN	6	MARINE SHALE	
	5	DARBY	
ORDOVICIAN	4	BIGHORN	
CAMBRIAN	3	GALLATIN	
	2	GROS VENTRE	
	1	FLATHEAD	
PRECAMBRIAN			

Figure 9.- Generalized stratigraphic column of the Wind River Basin. The units are not to scale. The deposition was described by 38 time units.

```
TITLE
PARAMETER WIND RIVER BASIN SIMULATION              11  7105600
BASEMENT  START OF PALEOZOIC ERA.
 -2200 -2100 -1995 -1800 -1785 -1590 -1300 -1140  -750   -75   -50 -2150
 -2060 -1925 -1700 -1625 -1465 -1340 -1130  -400  -100   -75 -2135 -2040
 -1860 -1680 -1655 -1545 -1380 -1210  -765  -300  -295 -2080 -2050 -1910
 -1855 -1790 -1670 -1405 -1000  -855  -535  -500 -1950 -1925 -1775 -1730
 -1680 -1595 -1330 -1240  -700  -650  -590 -1790 -1750 -1540 -1470 -1520
 -1590 -1515 -1470 -1000  -800  -705 -1730 -1745 -1500 -1460 -1540 -1540
 -1530 -1425 -1300 -1000  -900
DEPOSITION--TIME 1-CAMBRIAN FLATHEAD SS.
  2001  1901  1801  1651  1451  1251  1001   701   251    01    01  2301
  2201  2101  2001  1751  1501  1251   901   501    01    01  2551  2401
  2301  2201  2051  1801  1501  1051   701   201    01  2701  2601  2401
  2251  2051  1951  1551  1201   851   401    01  2601  2501  2301  2201
  2051  1751  1501  1001   751   501   151  2501  2301  2151  2001  1751
  1501  1201   901   651   501   251  2301  2201  2001  1751  1501  1251
  1001   801   551   401   301
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0
DEPOSITION--TIME 2-CAMBRIAN GROS VENTRE FM.
 19002 18002 16402 15002 13202 11802 10002  8802  7002  2201  1001 18002
 17002 16002 14002 12502 11302  9802  8602  3401  2101  1001 17202 16602
 15202 13802 12102 10902  9702  8202  6302  2001  1001 16402 16002 14102
 13002 11702 10402  9302  8002  6102  1801   801 15602 14502 13602 12202
 11002  9902  8802  7802  2901  1451   451 14802 14002 12802 11802 10402
  9402  8302  7002  2201  1001    01 14202 13202 12202 11202  9802  8802
  8802  6202  4002   801    01
    50    50    50    50    50    50    50    50    50     5     5    50
    50    50    50    50    50    50    50     5     5     5    50    50
    50    50    50    50    50    50    50     5     5    50    50    50
    50    50    50    50    50    50     5     5    50    50    50    50
    50    50    50    50     5     5     5    50    50    50    50    50
    50    50    50     5     5     5    50    50    50    50    50    50
    50    50    50     5     5
DEPOSITION--TIME 3-CAMBRIAN GALLATIN LS.
  4603  4303  4003  3903  3753  3603  3453  3303  3053  2903  2803  4803
  4503  4153  4003  3903  3703  3503  3303  3103  2953  2803  5003  4903
  4603  4353  4053  3903  3603  3403  3203  2953  2903  5103  5003  4753
  4503  4253  4003  3803  3653  3353  3103  2953  5153  5053  4803  4603
  4303  4053  3953  3703  3503  3253  3003  5103  5003  4753  4453  4203
  3953  3803  3603  3353  3203  3003  5053  4953  4603  4403  4053  3903
  3753  3453  3153  3003  2903
    15    15    15    20    15    15    15    15    10     5     0    15
    15    10    15    15    15    20    10     5     5     0    20    15
    15    15    20    15    15    10    10     5     5    10    15    15
    15    20    15    10    10     5    10     5     5    10    15    20
    15    20    15    15    15    10    15    10     5    10    15    10
    15    15    20    15    10     5     0     5     0     5    10    15
    15    10     5     5     0
COMPACTION
DIASTROPHISM-U.CAMB. DOWNWARPING WESTWARD. UPWARPING EASTWARD.
 -1100  -800  -700  -500  -350  -200     0    20    70   100   120  -825
```

```
   -600    -400    -300    -200    -100      20      50      95     130     170    -750    -500
   -300    -200    -100      10      40      90     115     160     200    -750    -490    -200
      0      15      50      70     100     130     200     210    -800    -500    -250       0
      5      40      70     100     135     200     205    -800    -600    -350    -200    -150
     10      60      85     115     150     190   -1000    -800    -600    -350    -250    -100
     15      50      80     110     150
EROSION S.L. PENEPLANATION OF EASTERN PART. U.CAMBRIAN.
DEPOSITION        TIME 4. ORDOVICIAN BIGHORN DOLOMITE.
   2104    1954    1704    1454    1154     804     204      04      04      04      04    2404
   2004    1854    1804    1454     854     504      04      04      04     104    2704    2304
   2004    3004    1704     704     504      04      04      54     354    3004    2754    2804
   3104    1804     804     504     304     204     504     604    3504    3304    3004    3204
   2504    1604    1004     704     704    1004    1004    3704    3704    3504    3304    3004
   2504    2004    1504    1004    1304    1504    4004    4054    4004    4004    4104    3504
   3504    3104    2004    1904    1804
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5
EROSION--IRREGULAR EROSION DURING SILURIAN TIME
    -60     -70     -95     -60     -70     -85     -90    -110    -150    -110    -100     -80
    -95     -80    -100    -100    -110    -100    -120     -95     -90     -80    -150    -130
   -190    -210    -220    -190    -175    -160     -95     -80     -40    -110    -150    -205
   -250    -200    -150    -170    -100    -140     -80     -50    -120    -195    -260    -200
   -180    -100     -90     -50    -150     -95     -60    -130    -180    -200    -180    -100
    -75     -50     -90    -160     -90      -0    -150    -190    -195    -150     -90     -40
    -20     -85    -120     -80     -20
DIASTROPHISM     S.L.
DEPOSITION     TIME 5. DEVONIAN DARBY FM.
   3104    2504    1804     804      04      04      04      04      04      04      04    3154
   2704    2004     304      04      04      04      04      04      04      04    3104    2704
   2004     404      04      04      04      04      04      04      04    3054    2604    2004
    604      04      04      04      04      04      04      04    3004    2104    1454     704
     04      04      04      04      04      04      04    3004    2004    1154     804     704
     04      04      04      04      04      04    3054    2404    1604    1304    1154     604
     04      04      04      04      04
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5       5       5       5       5       5       5       5
      5       5       5       5       5
EROSION  LATE DEVONIAN.
    -40     -45     -40     -50     -50     -55     -60     -75     -85    -100    -110     -50
    -55     -50     -50     -55     -55     -60     -85    -100    -165    -170     -50     -55
    -60     -60     -55     -60     -65     -80    -110    -155    -145     -50     -55     -60
    -70     -60     -60     -70     -70    -100    -115    -140     -55     -55     -65     -80
    -70     -85     -80     -95    -100    -130    -120     -60     -60     -75     -85     -90
   -105    -110    -150    -160    -170    -180     -65     -85    -100    -105    -110    -115
   -115    -140    -150    -150    -160
DIASTROPHISM     S.L.
DEPOSITION--TIME 6-LATE DEVONIAN MARINE SHALE
   1102    1002    1002     902     852     752     602     502     402     202      02     802
    852     802     702     602     552     502     302     102      02      02     602     602
```

```
   552   502   402   452   252   102    02    02    02   402   352   302
   302   252   202   102    02    02    02    02   202   202   152    52
    02    02    02    02    02    02    02    02    02    02    02    02
    02    02    02    02    02    02    02    02    02    02    02    02
    02    02    02    02    02
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50
DEPOSITION--TIME 7-MADISON LS. MISSISSIPPIAN.
  5303  4303  3803  3503  3203  2903  2953  4003  2903  1803  1603  6003
  5003  4103  4003  4003  3003  3003  4103  4003  2003  1603  6403  5803
  5003  4903  6003  4153  3703  3953  4003  3053  1903  6803  6053  6103
  6003  6003  4303  3803  3203  2903  3003  2103  7103  6953  7053  6003
  5353  4703  4053  3503  3003  2203  1953  7303  7153  6603  5003  4003
  3703  4003  2953  2503  2003  1603  7503  7103  6503  5503  4453  3603
  3003  2903  2503  2003  1553
    15    15    15    15    15    15    15    15    15    15    15    15
    15    15    15    15    15    15    15    15    15    15    15    15
    15    15    15    15    15    15    15    15    15    15    15    15
    15    15    15    15    15    15    15    15    15    15    15    15
    15    15    15    15    15    15    15    15    15    15    15    15
    15    15    15    15    15    15    15    15    15    15    15    15
    15    15    15    15    15
EROSION--LOWER PENNSYLVANIAN.
   -45   -45   -40   -40   -30   -40   -45   -45   -55   -40   -20   -55
   -70   -45   -45   -60   -50   -65   -70   -60   -40   -30   -80   -95
   -50   -50   -40   -55   -50   -95  -120   -75   -75   -90  -120  -100
   -45   -10   -30   -55   -50  -110  -105   -50   -75  -100  -130  -100
   -30     0     0   -50   -50   -70   -50   -60   -75  -105   -60   -50
     0     0     0   -10   -50   -65   -50   -60   -55   -50   -40   -50
   -40   -40   -50   -60   -65
DIASTROPHISM    S.L.
DEPOSITION--TIME 8-AMSDEN FM. DARWIN SS MEMBER. PENNSYLVANIAN
  2701  2801  2951  3401  4001  4201  3901  3301  2851  2301  1801  2601
  2751  2901  3351  4051  4301  3751  3051  2451  1901  1351  2301  2501
  2801  3301  3951  3801  3201  2701  2001  1501  1051  2001  2351  2701
  2951  2851  3001  2501  2001  1751  1901  1401  1901  2101  2101  2001
  2001  1701  1551  1901  2051  2051  1551  1501  1601  1801  1751  1601
  2001  2051  2301  2101  2001  1751  1001  1351  1651  1951  2051  2101
  2301  2601  2301  2101  1701
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20
DEPOSITION--TIME 9-AMSDEN FM. SHALE. PENNSYLVANIAN.
  3002  2752  2502  2302  2052  1852  1652  1452  1302  1102   902  3052
  2802  2602  2402  2102  1902  1752  1802  1602  1502  1102  3202  3102
  2802  2602  2302  2102  2152  2102  2052  1802  1302  3252  3052  2852
  2752  2502  2352  2152  2052  1902  1502  1052  3152  2902  2702  2502
  2352  2152  2002  1802  1502  1202   902  3052  2802  2552  2302  2102
  1902  1702  1502  1252  1002   852  2902  2852  2502  2302  2002  1802
```

```
  1502  1252  1002   902   802
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50    50    50    50    50    50    50    50
    50    50    50    50    50
DEPOSITION--TIME 10-AMSDEN FM. LS. PENNSYLVANIAN.
  3703  3503  3253  2953  2303  1903  1603  1403  1153   903   703  3503
  3303  3103  2803  2353  1853  1303   903   803   603   403  3303  3153
  3003  2653  2303  1903   953   703   503   353   253  3203  3103  3003
  2753  2203  1753  1003   803   453   203    03  3453  3203  3053  2803
  2303  1803  1153   753   403    03    03  3253  3103  3003  2703  2203
  1903  1303   803   453    03    03  3053  2753  2403  2003  1803  1453
  1103   753   403    53    03
    25    25    25    25    25    25    25    25    25    25    25    25
    25    25    25    25    25    25    25    25    25    25    25    25
    25    25    25    25    25    25    25    25    25    25    25    25
    25    25    25    25    25    25    25    25    25    25    25    25
    25    25    25    25    25    25    25    25    25    25    25    25
    25    25    25    25    25    25    25    25    25    25    25    25
    25    25    25    25    25
DIASTROPHISM    S.L.
DEPOSITION--TIME 11. TENSLEEP SS. U.PENNSYLVANIAN.
  4401  4151  3501  2551  1451   901   201    01    01    01    01  4201
  4051  3401  2501  1401   851    51    01    01    01    01  4101  3901
  3301  2501  1351   801   251    01    01    01    01  4051  3701  3201
  2401  1401   901   501   301   101    01    01  4001  3501  3001  2001
  1401   951   851   601   401   301   251  4051  3601  3151  2601  2051
  1651  1201   901   801   651   601  4151  4001  3651  3301  3001  2401
  1801  1401  1001   901   801
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20    20    20    20    20    20    20    20
    20    20    20    20    20
DIASTROPHISM    S.L.
DEPOSITION--TIME 12. CASPER FM. U.PENNSYLVANIAN-L.PERMIAN
    01    01    01   151   851  1701  2451  3201  3801  4551  5451    01
    01    01    01  1101  2001  2951  3701  4251  5051  6001    01    01
    01    01  1051  1801  2401  3201  4051  5101  6201    01    01    01
    01   401  1001  2001  3001  4001  5001  6101    01    01    01    01
    01   151  1301  2301  3601  4751  5601    01    01    01    01    01
    01   801  2001  3401  4301  4801    01    01    01    01    01    01
   201  1501  3201  3601  4001
    10    10    10    10    10    10    10    10    10    10    10    10
    10    10    10    10    10    10    10    10    10    10    10    10
    10    10    10    10    10    10    10    10    10    10    10    10
    10    10    10    10    10    10    10    10    10    10    10    10
    10    10    10    10    10    10    10    10    10    10    10    10
    10    10    10    10    10    10    10    10    10    10    10    10
    10    10    10    10    10
DEPOSITION--TIME 13. PARK CITY FM.-WEST. GOOSE EGG FM.EAST. PERMIAN.
  3051  3351  3603  3303  3203  3003  2805  2905  2855  2955  3205  2901
  3301  3503  3053  2903  4103  3505  3705  3805  3655  3505  2601  3103
```

```
    3203     2803     3003     3953     4155     3205     3205     3005     2955     2101     2603     3053
    3003     2003     2703     3155     3205     2805     3155     2905     1901     1903     2003     2003
    1803     1903     2205     2655     2705     2905     2755     1801     2201     1903     1803     2303
    2603     2905     3105     2805     2755     2805     1751     2301     2003     1953     2353     2803
    3105     3405     3105     3055     3105
       0        0       10       10       10       10        0        0        0        0        0        0
       0       10       10       10       10        0        0        0        0        0        0       10
      10       10       10       10        0        0        0        0        0        0       10       10
      10       10       10        0        0        0        0        0        0       10       10       10
      10       10        0        0        0        0        0       20       20       10       10       10
      10        0        0        0        0        0       20       20       10       10       10       10
       0        0        0        0        0
COMPACTION
DIASTROPHISM    S.L.
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION       11      50000    500
  12   13   14   15   16   17   18   19   20   21   22
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION       11      50000    500
  34   35   36   37   38   39   40   41   42   43   44
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION       11      50000    500
  56   57   58   59   60   61   62   63   64   65   66
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION        7      50000    500
   2   13   24   35   46   57   68
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION        7      50000    500
   6   17   28   39   50   61   72
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION        7      50000    500
  10   21   32   43   54   65   76
STOP
RESTART
DEPOSITION--TIME 14-DINWOODY FM-U.GOOSE EGG FM TO EAST. L.TRIASSIC.
    1001     1001     1001     1001     1001     1005     1005     1005     1005     1005     1005     1001
    1001     1001     1001     1001     1005     1005     1005     1005     1005     1005     1001     1001
    1001     1001     1001     1001     1005     1005     1005     1005     1005     1001     1001     1001
    1001     1001     1001     1001     1005     1005     1005     1005     1001     1001     1001     1001
    1001     1001     1001     1001     1005     1005     1005     1001     1001     1001     1001     1001
    1001     1001     1005     1005     1005     1005     1001     1001     1001     1001     1001     1001
    1005     1005     1005     1005     1005
       0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0
DEPOSITION--TIME 15. LOWER CHUGWATER FM. L.TRIASSIC.
                               .                               .                              .
                               .                               .                              .
                               .                               .                              .
COMPACTION
DIASTROPHISM--BOARD UPLIFT OF WHOLE REGION.
    6000     6000     5000     4500      300      400     4000     4000     4000     3500     3500     5500
    5000     4500      900     -200     -300      300     -500        0     -800     3000     5000     5000
     100     -400    -1600    -2400    -1700    -1650     -650    -2700     1000     4500     -800     -500
```

```
 -2400 -4100 -3500 -2400 -1600 -1000 -1000 -1000     0 -1100 -2600 -1600
 -5200 -5500 -1500  -900  1000  1000  3500 -4200  -900     0  4000  6350
  4900  2700  1400  3000  2000  1000  5700  4100  3000  2000  2500  2000
  2500  2000  2000  2500  1500
EROSION--DEGRADATION TO PRESENT TIME.
 -2100 -2700 -3500 -2370     0     0 -3400 -4100 -4100 -2700 -2000 -3000
 -1950 -1250     0     0     0     0     0     0     0 -3050 -2100  -700
     0     0     0     0     0     0     0     0 -2100 -2500     0     0
     0     0     0     0     0     0 -4000 -4200 -3400     0     0     0
     0     0     0     0     0 -2900 -4100     0     0 -2100  -750     0
     0     0     0 -1000 -2200 -2500 -2500 -1000 -1000 -1100 -1100 -1050
  -900 -1000 -1300 -2200 -2600
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION     11     50000  2000
  12  13  14  15  16  17  18  19  20  21  22
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION     11     50000  2000
  34  35  36  37  38  39  40  41  42  43  44
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION     11     50000  2000
  56  57  58  59  60  61  62  63  64  65  66
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION      7     50000  2000
   2  13  24  35  46  57  68
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION      7     50000  2000
   6  17  28  39  50  61  72
DYNAMIC SNAPSHOT
STRATIGRAPHIC SECTION      7     50000  2000
  10  21  32  43  54  65  76
END
```

APPENDIX D

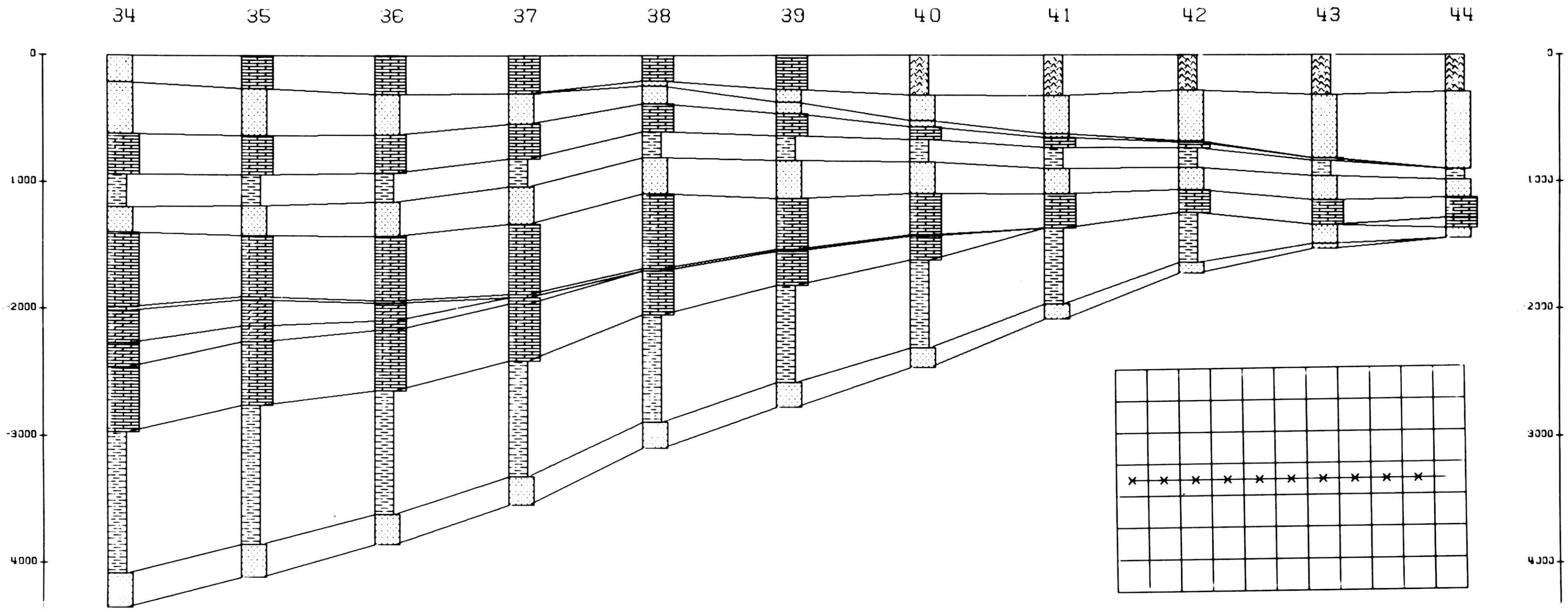


Figure 10. - Stratigraphic cross section B - B ' showing the simulated geology of the Wind River Basin at the end of the Paleozoic Era. The section is 200 miles long. Vertical scale is in feet.

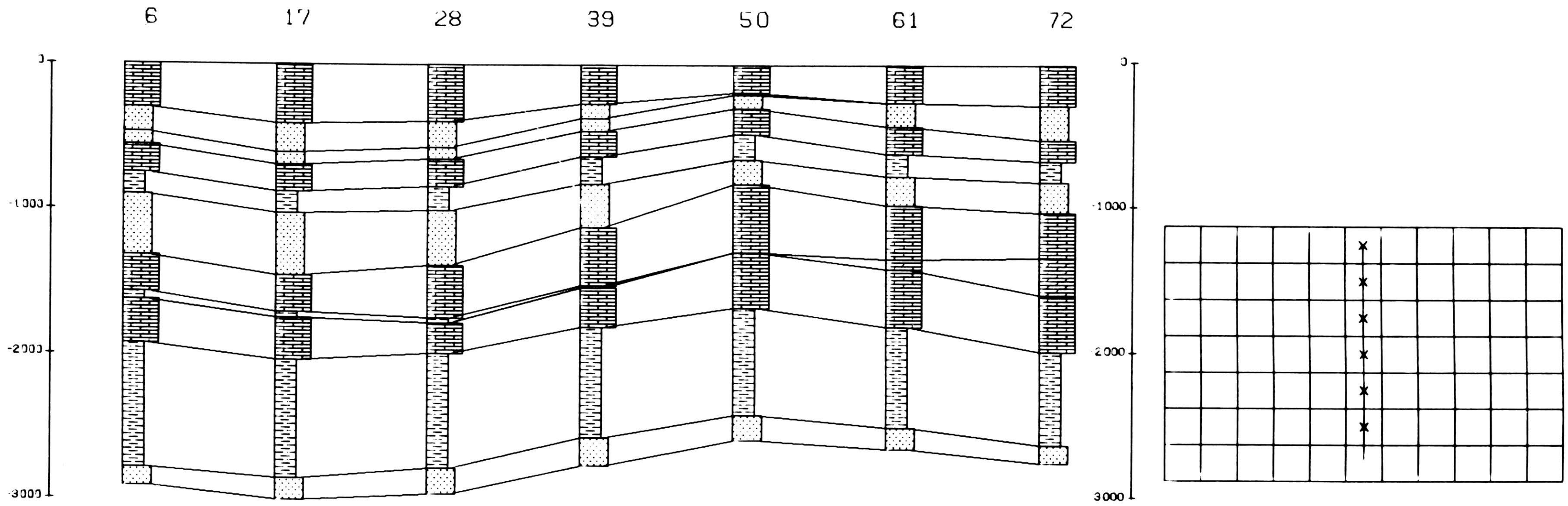


Figure 11.- Stratigraphic cross section E - E' showing the simulated geology of the Wind River Basin at the end of the Paleozoic Era. The section is 120 miles long. Vertical scale is in feet.

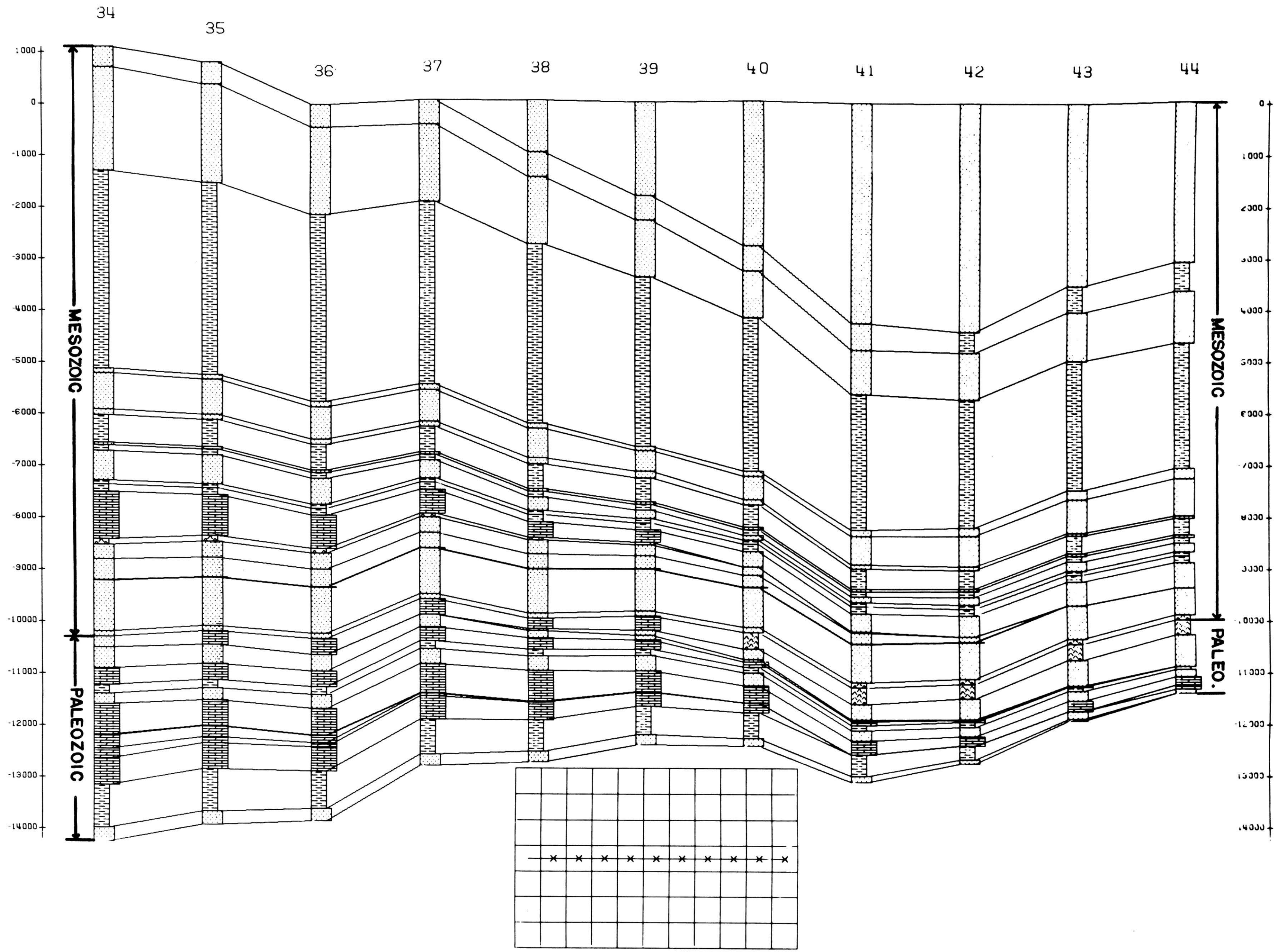


Figure 12. - Stratigraphic cross section B - B ' showing the simulated geology of the Wind River Basin at the end of the Mesozoic Era. The section is 200 miles long. Vertical scale is in feet.

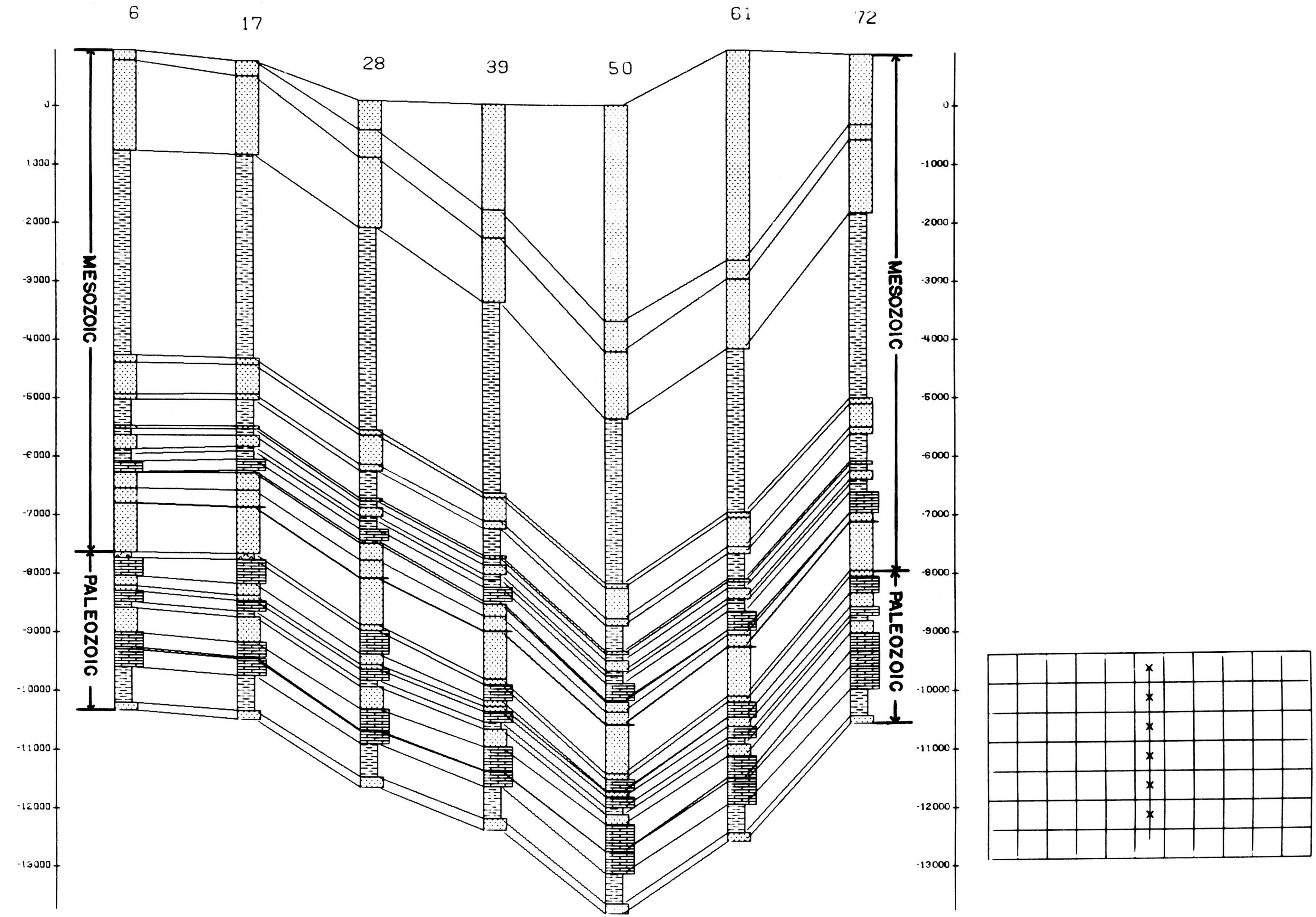


Figure 13. - Stratigraphic cross section E - E ' showing the simulated geology of the Wind River Basin at the end of the Mesozoic Era. The section is 120 miles long. Vertical scale is in feet.

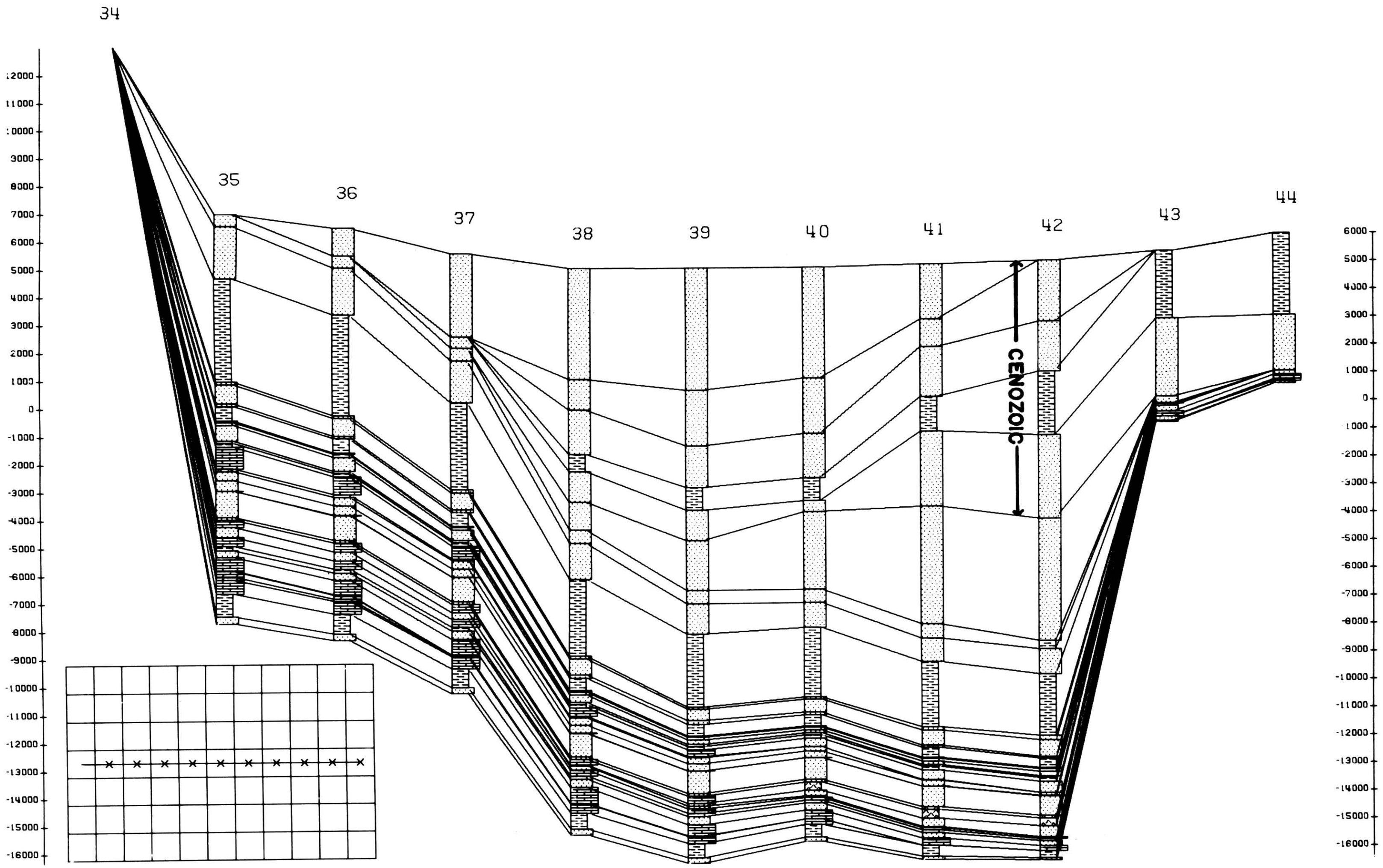


Figure 14. - Stratigraphic cross section B - B' showing the simulated geology of the Wind River Basin at the end of the Cenozoic Era. The section is 200 miles long. Vertical scale is in feet.

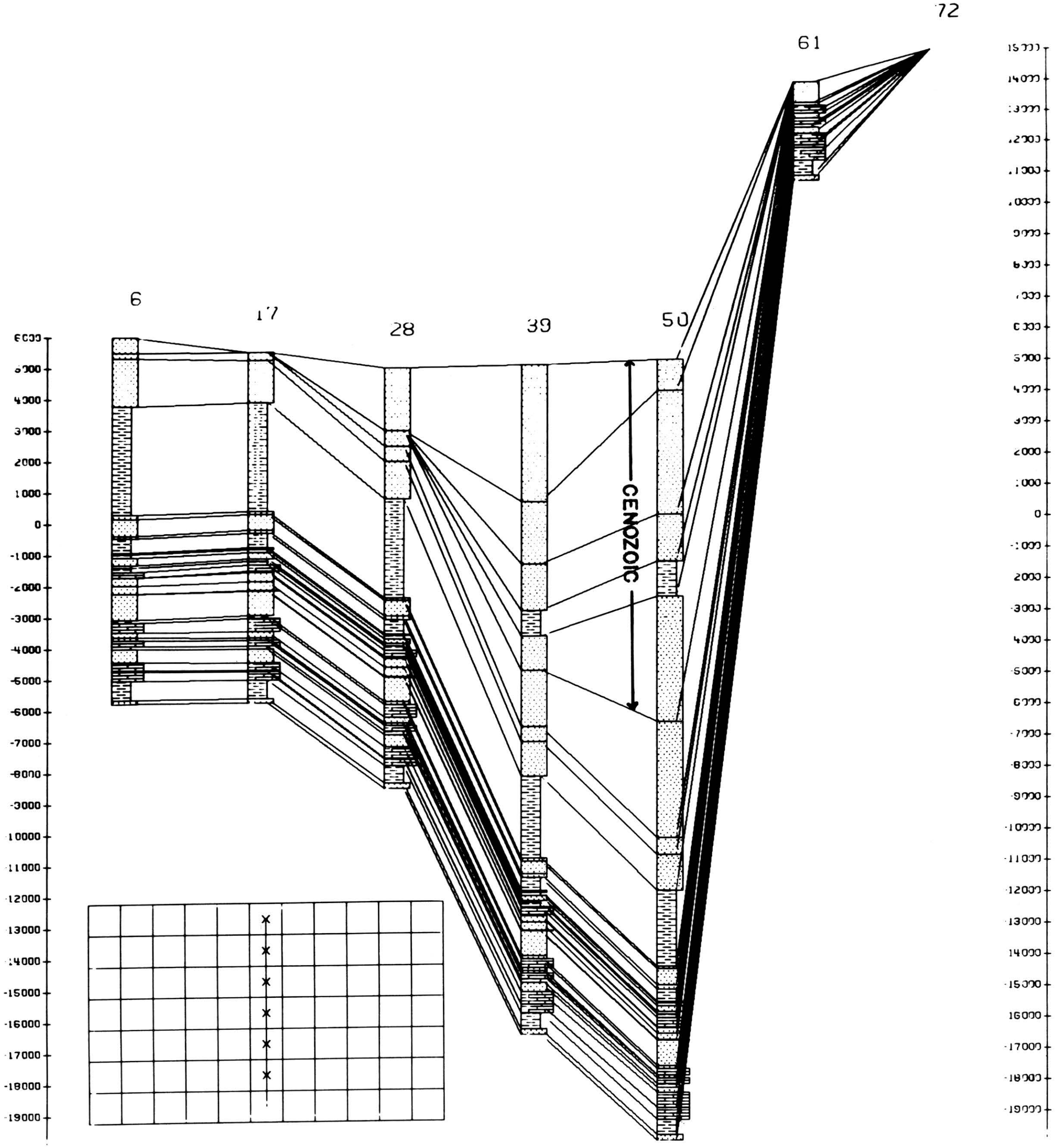


Figure 15. - Stratigraphic cross section E - E' showing the simulated geology of the Wind River Basin at the end of the Cenozoic Era. The section is 120 miles long. Vertical scale is in feet.

Table 4. - Listing of the geologic computer language control cards used to describe the geologic history of the Wind River Basin.

```
              SUMMARY OF GEOLOGIC EVENTS


BASEMENT  START OF PALEOZOIC ERA.
DEPOSITION--TIME 1-CAMBRIAN FLATHEAD SS.
DEPOSITION--TIME 2-CAMBRIAN GROS VENTRE FM.
DEPOSITION--TIME 3-CAMBRIAN GALLATIN LS.
COMPACTION
DIASTROPHISM-U.CAMB. DOWNWARPING WESTWARD. UPWARPING EASTWARD.
EROSION S.L.  PENEPLANATION OF EASTERN PART. U.CAMBRIAN.
DEPOSITION           TIME 4. ORDOVICIAN BIGHORN DOLOMITE.
EROSION--IRREGULAR EROSION DURING SILURIAN TIME
DIASTROPHISM     S.L.
DEPOSITION  TIME 5. DEVONIAN DARBY FM.
EROSION  LATE DEVONIAN.
DIASTROPHISM     S.L.
DEPOSITION--TIME 6-LATE DEVONIAN MARINE SHALE
DEPOSITION--TIME 7-MADISON LS. MISSISSIPPIAN.
EROSION--LOWER PENNSYLVANIAN.
DIASTROPHISM     S.L.
DEPOSITION--TIME 8-AMSDEN FM. DARWIN SS MEMBER. PENNSYLVANIAN
DEPOSITION--TIME 9-AMSDEN FM. SHALE. PENNSYLVANIAN.
DEPOSITION--TIME 10-AMSDEN FM. LS. PENNSYLVANIAN.
DIASTROPHISM     S.L.
DEPOSITION--TIME 11. TENSLEEP SS. U.PENNSYLVANIAN.
DIASTROPHISM     S.L.
DEPOSITION--TIME 12. CASPER FM. U.PENNSYLVANIAN-L.PERMIAN
DEPOSITION--TIME 13. PARK CITY FM.-WEST.GOOSE EGG FM.EAST. PERMIAN.
COMPACTION
DIASTROPHISM     S.L.
DEPOSITION--TIME 14-DINWOODY FM-U.GOOSE EGG FM TO EAST. L.TRIASSIC.
DEPOSITION--TIME 15. LOWER CHUGWATER FM. L.TRIASSIC.
DIASTROPHISM     S.L.
DEPOSITION--TIME 16. ALCOVA LS MEMBER-CHUGWATER FM. M.TRIASSIC.
DEPOSITION--TIME 17. UPPER CHUGWATER FM. U.TRIASSIC.
DEPOSITION--TIME 18. NUGGET SANDSTONE. L.JURASSIC
DIASTROPHISM     S.L.
DEPOSITION--TIME 19. GYPSUM SPRINGS FM. M.JURASSIC.
EROSION  TRUNCATION OF NUGGET AND GYPSUM SPRINGS FMS.
DEPOSITION--TIME 20. SUNDANCE FM. U.JURASSIC
DEPOSITION--TIME 21. MORRISON FM. U.JURASSIC
DEPOSITION--TIME 22. L.CLOVERLY FM. L.CRETACEOUS.
DIASTROPHSIM     S.L.
DEPOSITION--TIME 23. U.CLOVERLY FM. L.CRETACEOUS.
DEPOSITION--TIME 24. L.THERMOPOLIS FM. L.CRETACEOUS
DEPOSITION--TIME 25. MUDDY (DAKOTA) SS MEMBER-THERMOPOLIS FM.
DEPOSITION--TIME 26. U.THERMOPOLIS FM--MOWRY SHALE. L.CRETACEOUS.
DEPOSITION--TIME 27. L.FRONTIER FM. U.CRETACEOUS.
DEPOSITION--TIME 28. M.FRONTIER FM. U.CRETACEOUS.
DIASTROPHISM     S.L.
DEPOSITION--TIME 29. U.FRONTIER FM. U.CRETACEOUS.
DEPOSITION--TIME 30. CODY SHALE. U.CRETACEOUS.
DEPOSITION--TIME 31. MESAVERDE FM. U.CRETACEOUS
DEPOSITION--TIME 32. MEETEETSE FM-WEST. LEWIS SHALE-EAST. U.CRETACEOUS
COMPACTION
DIASTROPHISM     S.L.
DIASTROPHISM--START OF LARAMIDE TECTONICS.
```

```
EROSION--CUTTING OF UPWARPED REGIONS.
DEPOSITION--TIME 33. LANCE FM. U.CRETACEOUS.
COMPACTION
DIASTROPHISM AT END OF MESOZOIC.
EROSION--PALEOCENE EROSION OF RISING MOUNTAIN RANGES.
DEPOSITION--TIME 34. L.FORT UNION FM. U.PALEOCENE.
DEPOSITION--TIME 35. WALTMAN SHALE MEMBER-FORT UNION FM.
DIASTROPHISM--CONTINUED FOLDING AND SINKING. L.EOCENE.
DEPOSITION--TIME 36. INDIAN MEADOWS FM. L.EOCENE.
DIASTROPHISM--STRONG FOLDING AND UPLIFT OF MOUNTAINS. L.EOCENE
EROSION--CUTTING TO CORES OF ALL BORDERING MOUNTAINS RANGES.
DEPOSITION--TIME 37. WIND RIVER FM. L.EOCENE.
DEPOSITION--TIME 38. M.AND U.TERTIARY AGGRADATION.
COMPACTION
DIASTROPHISM--BROAD UPLIFT OF WHOLE REGION.
EROSION--DEGRADATION TO PRESENT TIME.
END

END OF JOB.  77 ELEMENTS IN MODEL  11 X    7.
             71 GEOLOGIC EVENTS WERE INPUT.
```

KANSAS GEOLOGICAL SURVEY COMPUTER PROGRAM
THE UNIVERSITY OF KANSAS, LAWRENCE

PROGRAM ABSTRACT

Title (If subroutine state in title):

FORTRAN IV PROGRAM FOR SIMULATING GEOLOGIC DEVELOPMENT
OF SEDIMENTARY BASINS

Date: January 1970

Author, organization: D.R. Ojakangas, Information and Computing Centres Canada, Limited
600-6th Ave., Calgary 1, Alberta, Canada

Direct inquiries to: Author or

Name: D.F. Merriam

Address: Kansas Geological Survey, University
of Kansas, Lawrence, Kansas 66044

Purpose/description: Simulation of some geologic processes involved in the development of some oil traps.

Mathematical method: The geological processes are imitated by successive evaluations of equations and decision-making operations.

Restrictions, range: Maxima are: 50 by 50 grids in x- and y- direction or 2500 total grid units; 100 cycles of deposition.

Computer manufacturer: IBM

Model: 360/65

Programming language: FORTRAN IV

Memory required: 131 K

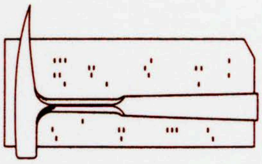
Approximate running time: 20 minutes for sample case

Special peripheral equipment required: CALCOMP Plotter-offline

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

CALCOMP plot package required for plotter output.

NEED HELP?



TRY TRY TRY TRY TRY

Try a Computer Application!

Write TODAY **For A** COMPLETE LIST **of** PUBLICATIONS

Editor
Computer Contributions
Kansas Geological Survey
The University of Kansas
Lawrence, Kansas 66044

NOW IN COOPERATION WITH THE

AAPG