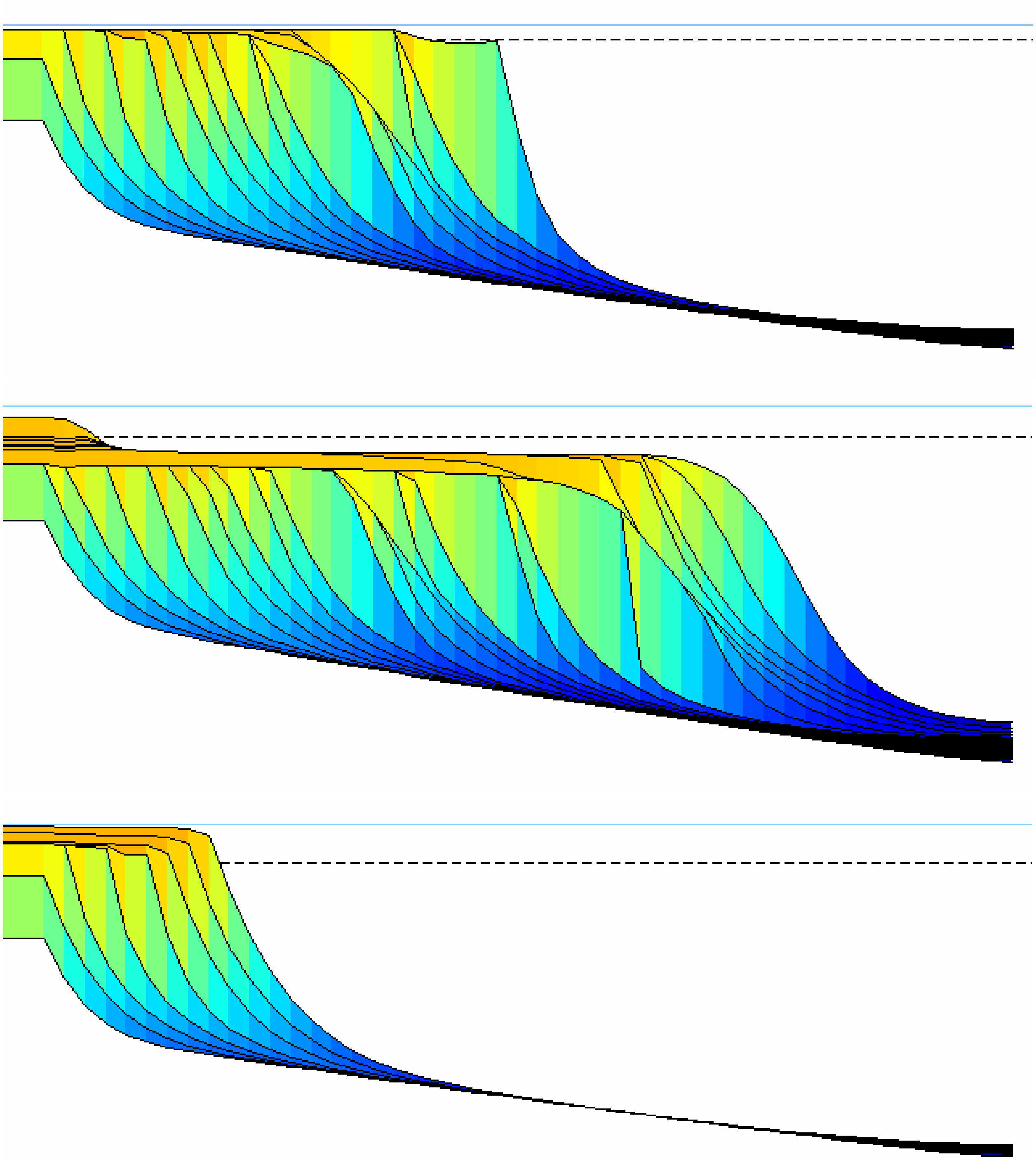
STRATA: TUTORIAL



Please note that the tutorial is not always updated when the package is re-released. A minor result of this is that Strata may have acquired extra capabilities not mentioned in the tutorial. The more important result is that information about how the package appears --- i.e. what files are where and so forth --- is suspect. Please see the Strata User Manual for accurate information on such subjects, the appendix on downloading in particular. The tutorial's information about using Strata is accurate.

Table of Contents

1. Introduction

This tutorial provides users with examples to follow while experimenting with **Strata**. **Strata** is a stratigraphic modeling package composed of four separate programs: 1) a pre-processor, **setbasin**, that allows the user to set the model's parameters, 2) a processor, **simbasin**, that runs the model with the user-defined parameters, 3) a post-processor, **plotbasin**, that displays the model results, and 4) a special utility, **filmbasin**, that combines processing and post-processing to make a movie.

Each section of this tutorial discusses the types of depositional environments, sealevel changes, subsidence histories, isostatic properties, heat flow histories, and seismic response predictions that can be simulated with Strata. The examples used in this tutorial should be found in the Simulations directory if you have properly downloaded the Strata code (see Downloading Strata http://www.jsg.utexas.edu/flemings/intranet/software/strata/strata-download-the-code-manual-and-tutorial/). Throughout each example, reference will be made to the primary controlling parameters (found in setbasin) for the particular example.

At the heart of the simulations is the assumption that sediment transport behaves diffusively (i.e. volumetric flux is proportional to local gradient). For carbonate simulations, the sediment source is proportional to water depth, while for clastic simulations the sediment source is a user-specified function. We strongly recommend that you flip through Jordan and Flemings (1991), Flemings and Jordan (1989), Flemings and Jordan (1990), and Kaufman et al. (1991) to gain a physical insight into this process. The most useful of these for marine simulations will be Jordan and Flemings (1991).

If you need help getting started, the basic instructions for using the four programs that comprise **strata** are found in the Strata2.1 User Manual (http://www.jsg.utexas.edu/flemings/files/Strata_Manual1.pdf). If you are already familiar with **strata** operations, you may want to follow the example simulations found here in each of the figures.

Annotation in this user manual:

- Commands for the user to type in are shown in typewriter font to distinguish them from the rest of the text.
- Controls on the graphics interfaces are indicated by <controlname>.
- Files that are found in the Simulations directory are shown in *italics*.
- A note on units: Any system can be used as long as it is self-consistent. We have been working in a m/k/yrs world, and examples are in m/k/yrs units.

2. Simulating Clastic Deposition

Both marine and non-marine transport rates are controlled by the topographic gradient (Equation 1):

Where q is volumetric sediment flux (l2/t), h is elevation (l), x is horizontal position (l), and k is the diffusion constant (l2/t).

See Jordan and Flemings (1991) and Kaufman et al. (1991) for insight into the meaning of the diffusion constants. To generate a realistic shelf break, the `nonmarine diffusion constant' (Knonmarine) is set to a high value, while the `marine diffusion coefficient' (Kmarine) is set to a much lower value.The following figures demonstrate the effects of varying the diffusion constants. A simple rule of thumb is that to generate steeper clinoforms you should decrease the marine diffusion constant. Jordan and Flemings (1991) found reasonable values for Kmarine to be on the order of 100-1000 m2/yr, while that of the non-marine regime to be on the order of 1e4 to 1e5 m2/yr.

2.1. Non-Marine Clastic Deposition

The library file diff1.dat is used to simulate the development of an alluvial fan. The most important controls on this model are the clastic flux and the diffusion constants (both found in the Clastics Group File).

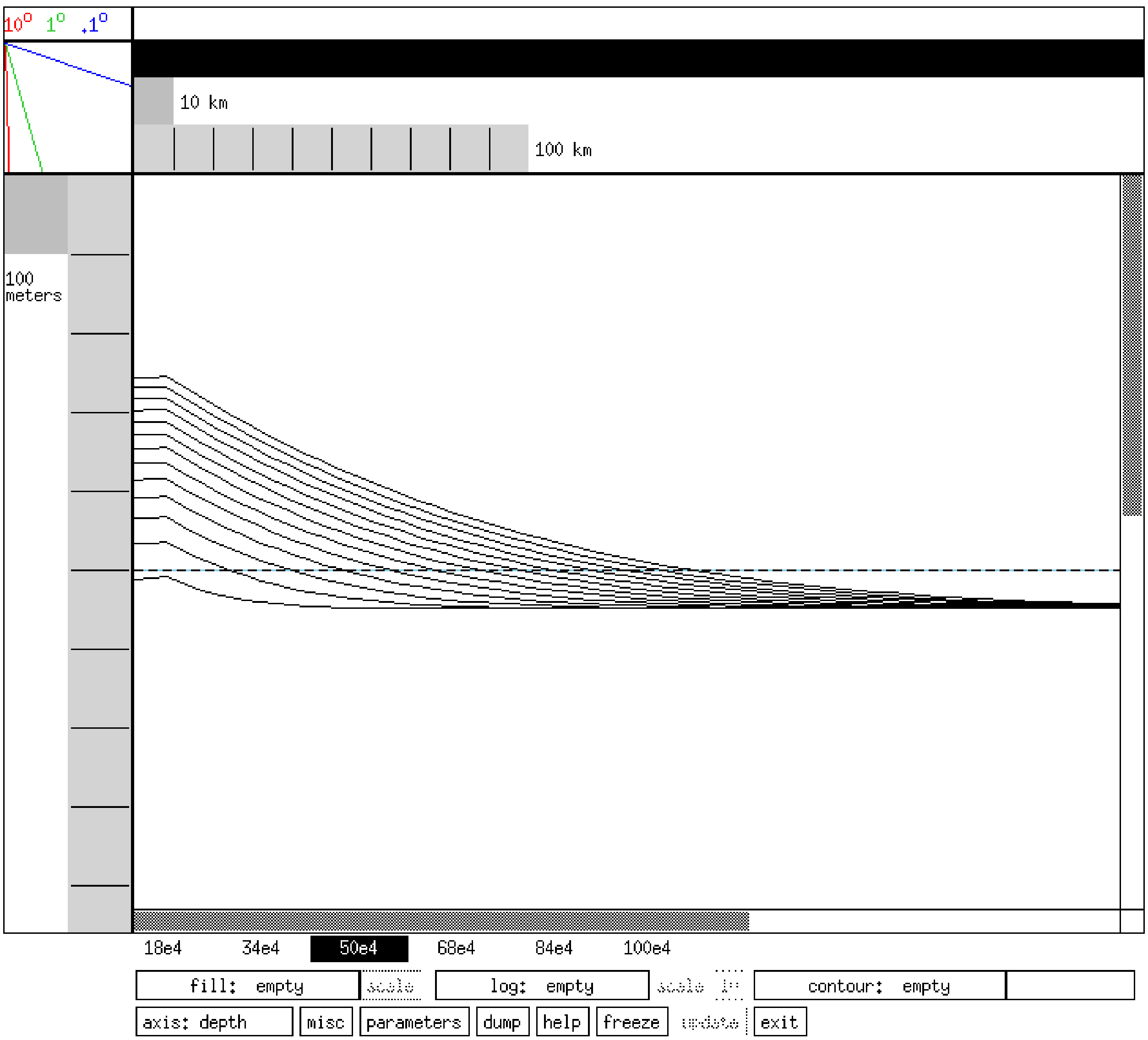


Figure 1: Run in which marine and non-marine diffusion constants are equal. This simulates the development of an alluvial fan. Library file is diff1.dat with skip lines set at 2 and a vertical exaggeration of 200 (in of plotbasin).

2.2. Marine Clastic Deposition

Marine deposition is simulated below with two examples. The effect of diffusion constants on the shelf topography is displayed by holding the non-marine diffusion constant at 50000 m2/yr while varying the marine diffusion constant. It is evident from Figure 2.a, that a smaller marine diffusion constant will generate much steeper shelf breaks.

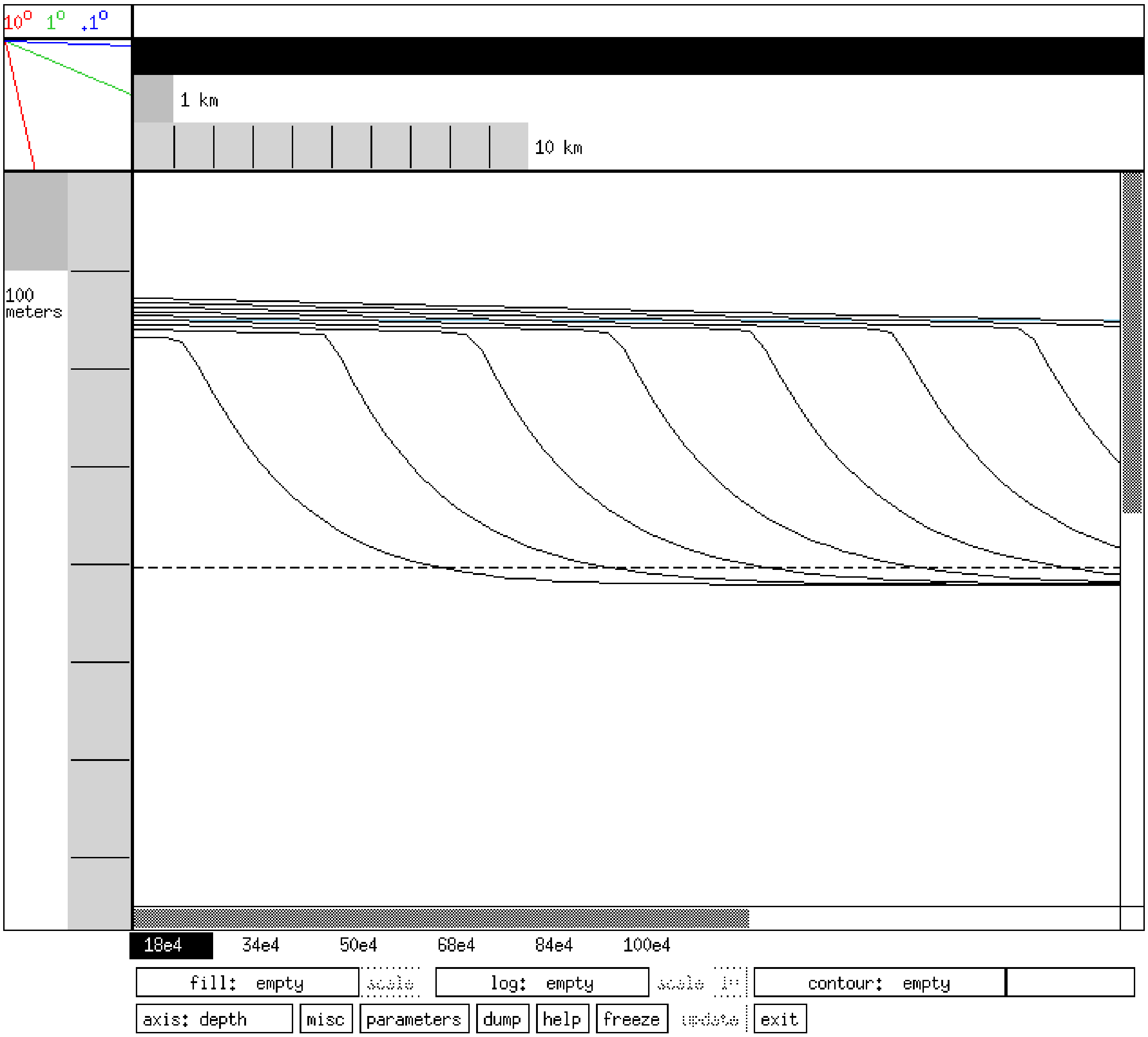


Figure 2.a: Model run of marine diffusion constant = 500 m2/yr; non-marine diffusion constant = 50000 m2/yr. This simulation of a prograding delta exhibits a shelf break marked by the change in slope from near horizontal to steeply dipping. Library file is diff2.dat with vertical exaggeration set to 25.

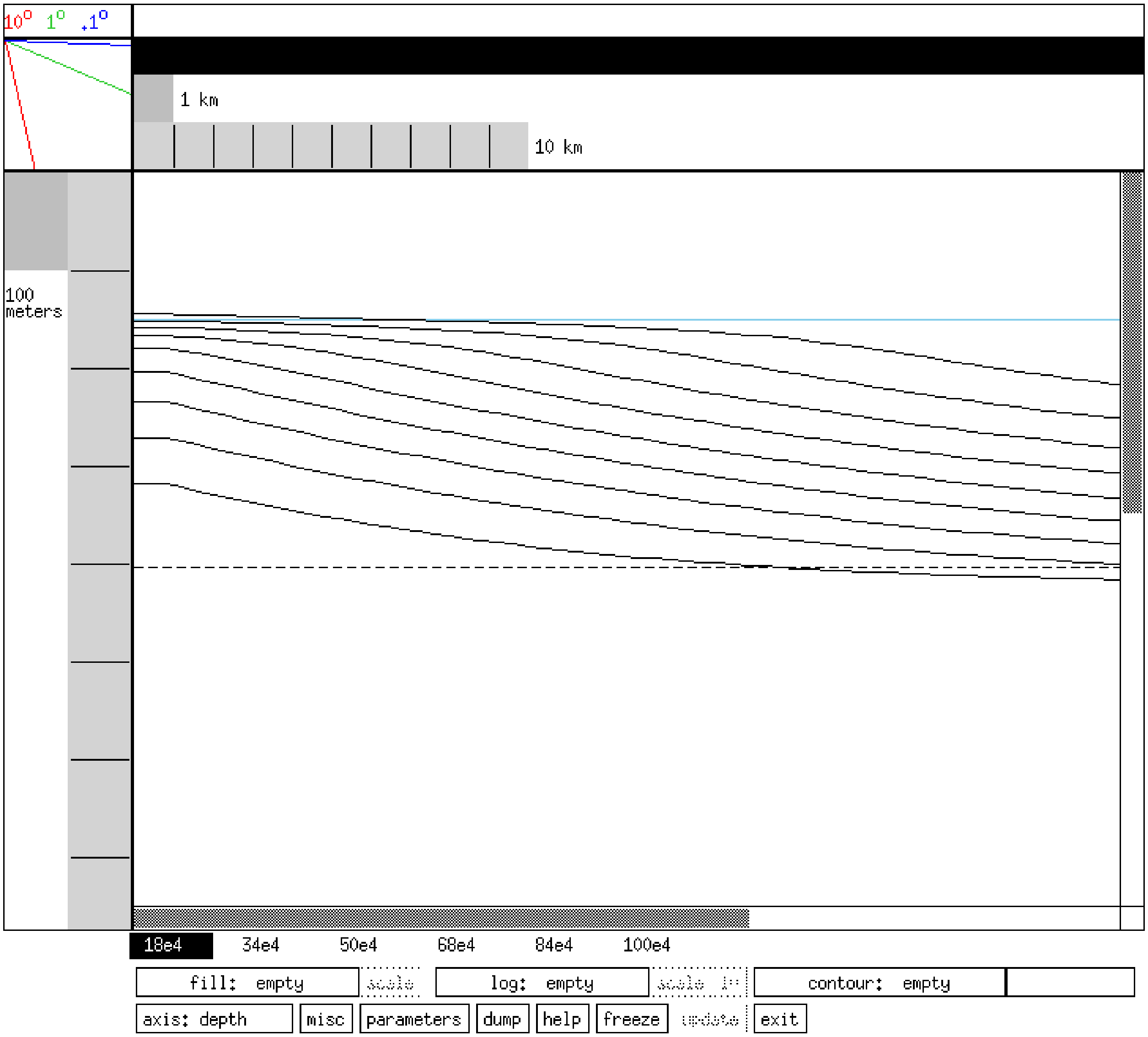


Figure 2.b: Model run of marine diffusion constant = 5000 m2/yr; non-marine diffusion constant = 50000 m2/yr. The marine diffusion constant is higher than in figure 3.b, therefore the marine slopes are lower. Library file is diff3.dat with a vertical exaggeration of 25.

If the user wishes to change the rate of clastic flux through time, a clastic flux file can be used in place of a constant flux. If none is specified, the model uses the constant clastic sediment flux values specified by `left clastic flux' and `right clastic flux.'

Example of a clastic flux file:

0	10.00
1e6	17.08
2e6	20.00
3e6	17.08

4e6	10.00
5e6	2.93
6e6	0.01

Clastic flux file notes:

1) The first column is the age with 0 as the beginning of the simulation
2) The second column is the clastic flux in L2/T
3) Fluxes between given points are linearly interpolated

2.3. Composition

There are two ways to calculate percent sand in the model: by linear interpolation of the diffusion values (Figure 3.a), where the highest value is set to 100% sand and the lowest to 100% shale, or as an exponential function of water depth (Figure 3.b). In order to have the model linearly interpolate values, set `cutoff for sand composition' (Compaction Group File) to a negative number. Alternatively, you may set it to a cut-off water depth value (positive number) and give the `decay constant for composition' (Compaction Group File) a value. The percent sand will then decline exponentially as a function of water depth (from 100% sand) from the cut-off water depth.

For example, if `cutoff for sand composition' is set to 10, and `decay constant for composition' is set to 0.1, then above 10 meters water depth the composition will be 100% sand and below 10 meters water depth, the composition will decline exponentially from 100%.

The `decay constant for composition' line determines the rate at which the sand composition will exponentially decline from a given cutoff depth set in `cutoff for sand composition.' Figure 3.b shows the effect of setting a cutoff depth and decay constant.

Figure 3.a: Example where sand composition is calculated as a linear interpolation between the maximum and minimum diffusion values in the model. (library file sand_linear.dat with skip lines set to 49 and composition contoured at 0.1)

Figure 3.b: Example where sand composition is defined as an exponential function of specified cut-off depth (here set to 15m). (library file sand_cutoff_15m.dat, with the same line skip and contouring as 3.a) In this example this has had the effect of distributing more sand seaward than in Figure 3.a. Dashed lines indicate increments of ten percent sand (increasing to left).

3. Simulating Carbonate Deposition

The fundamental difference between CaCO3 sedimentation and clastic sedimentation is that the magnitude of the CaCO3 source term is dependent on water depth and CaCO3 sedimentation can occur anywhere along the cross-section being modeled. In contrast, clastic sedimentation is defined by an input flux on the left-hand or right-hand side of the model. In either case, material is redistributed by slope-dependent diffusion. See Gildner and Cisne (1990) for more details.

Two carbonate deposition algorithms are possible and can be mixed (i.e. can be specified at different locations on profile): epeiric sedimentation (Equation 2, Figure 4a) and oceanic sedimentation (Equation 3, Figure 4b). The oceanic algorithm has a cut-off value (lag-depth) above which sedimentation rate is a constant value (C1). Setbasin has a facility (explained therein) to allow you to view the shape of the curves defined by each carbonate equation with your parameters:

Equation 2: Epeiric (exponential-depth) sedimentation, where c1 is the `epeiric CaCO3 maximum sedimentation rate' and w0 is the `epeiric CaCO3 depth of the maximum sedimentation rate.' See Gildner and Cisne (1990) for a detailed explanation.

Equation 3: Oceanic (lag-depth) sedimentation, where c1 is the `oceanic CaCO3 maximum sedimentation rate'; c2 is the `oceanic CaCO3 exponential decay constant'; w0 is the `oceanic CaCO3 depth of maximum sedimentation rate.' See Gildner and Cisne, 1990.

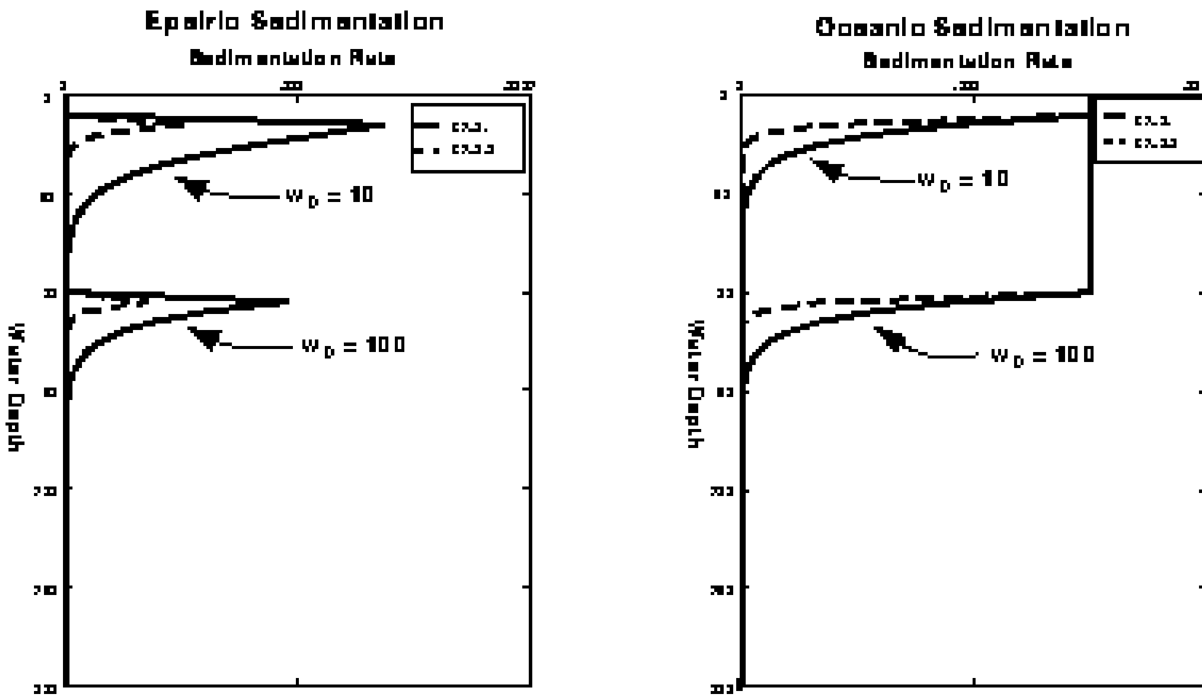


Figure 4.a,b: Displays of the functions used for epeiric and oceanic sedimentation in the model. Each different depths of maximum sedimentation rate (w0) of 10 and 100m.

3.1. Carbonate Deposition Files

We illustrate two carbonate examples of the oceanic carbonate deposition model. First, we illustrate the generation of a steady-state shelf break (Figure 5a) and second we illustrate the same setting with the addition of a 25 m sinusoidal sea-level change with a period of 4 million years (Figure 5b).

Example of a simple carbonate file (oceanic.carb, Figure 5.a,b):

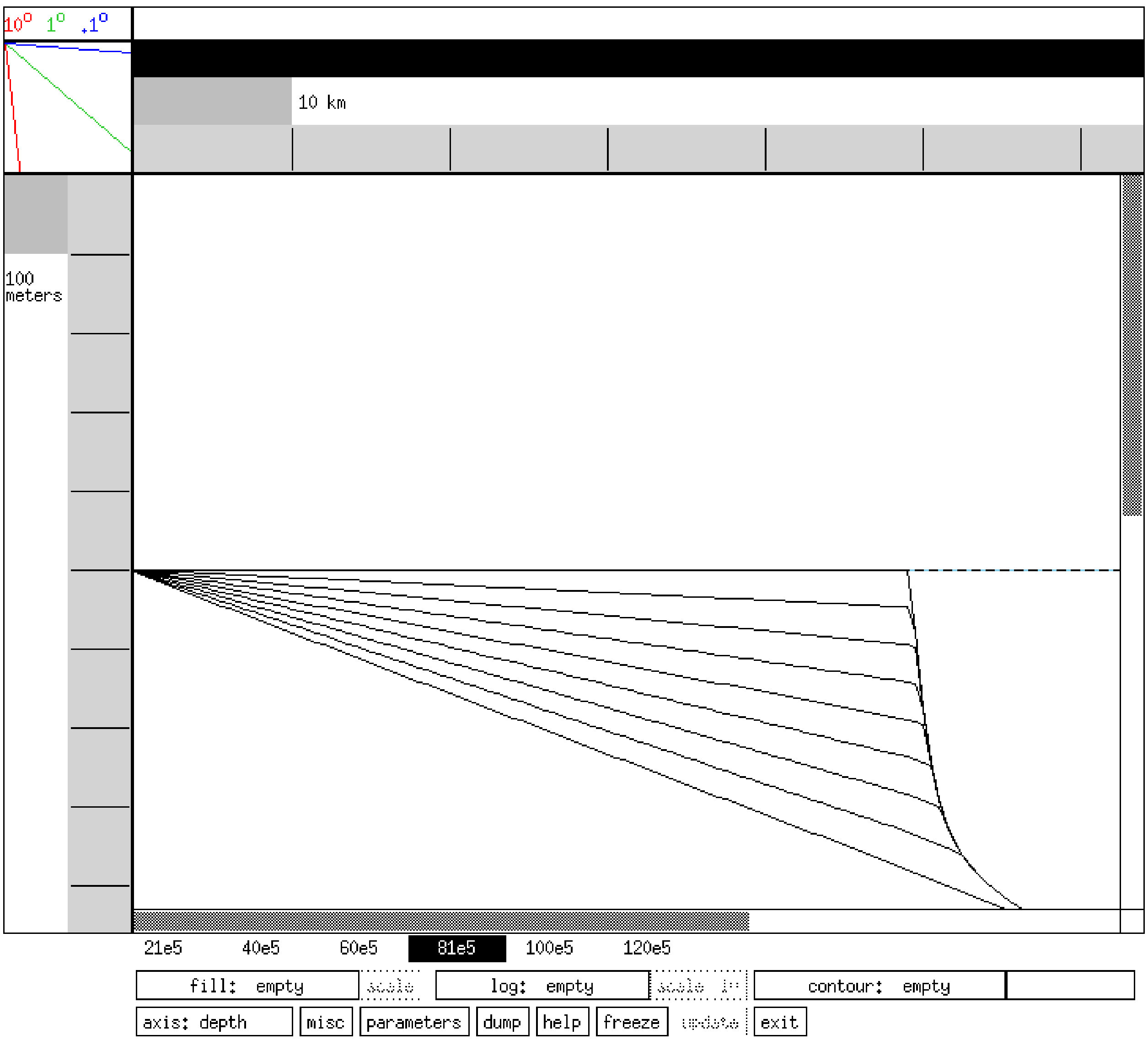
```
0    O    0    0
```

and a more complex file:

0	E	0	0
10e3	O	5	0
20e3	N	0	0

Carbonate file notes:

1) The first column is the horizontal position
2) The second column is type of carbonate deposition: E, epeiric, O, oceanic, N, neither
3) The third column is the lagtime
4) The fourth column is the lagdepth



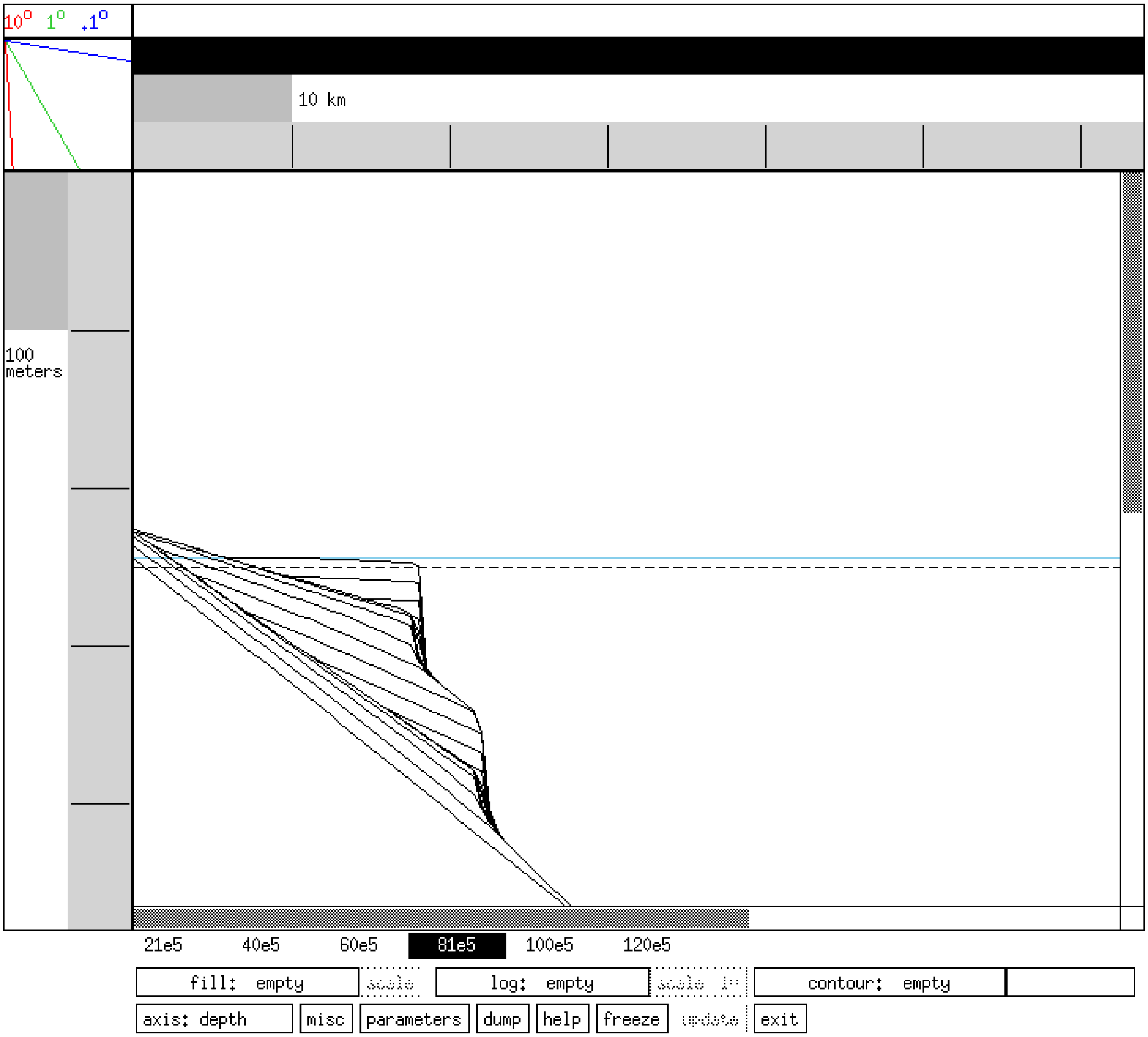


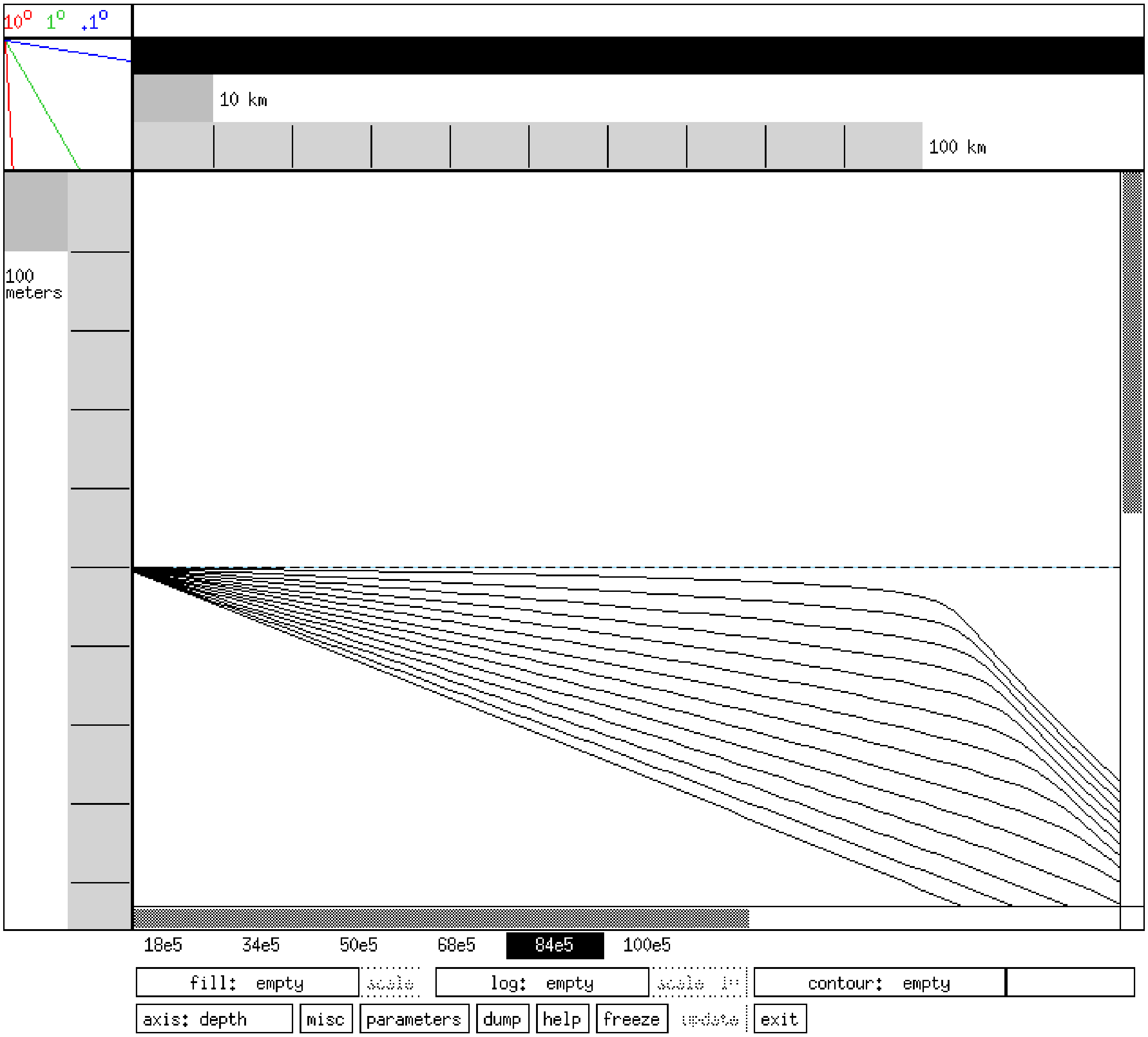
Figure 5.a: & Figure 5.b Displays of carbonate sedimentation without (carb_noeu.dat - set skip lines to 4 and vertical exaggeration to 50) and with (carb_eu.dat) eustatic sea level change. Carbonate file oceanic.carb was used to generate the carbonate sedimentation in both simulations.

4. Simulating Sealevel Changes

A `sealevel file' (filename.sea) defining a eustatic sealevel curve can be input or a simple function can be specified. There are two types of sealevel files: Points or Waves. Point sealevel files linearly interpolate sealevel between given elevation points. Wave sealevel files define sine waves that oscillate around the `datum for sealevel oscillation' set below. If none is used for sealevel file, then the sealevel character can be set in the other sealevel parameters.

4.1. Simple Sinusoidal Sealevel Functions

A simple eustatic sealevel curve can be added to the model by adding values to the lines in the Sealevel Group File and leaving sealevel file as none. Figure 6.b shows the dramatic change in geometry that results from setting `sealevel oscillation amplitude' to 50 (meters) in comparrison to Figure 6.a which has no sealevel change incorporated.



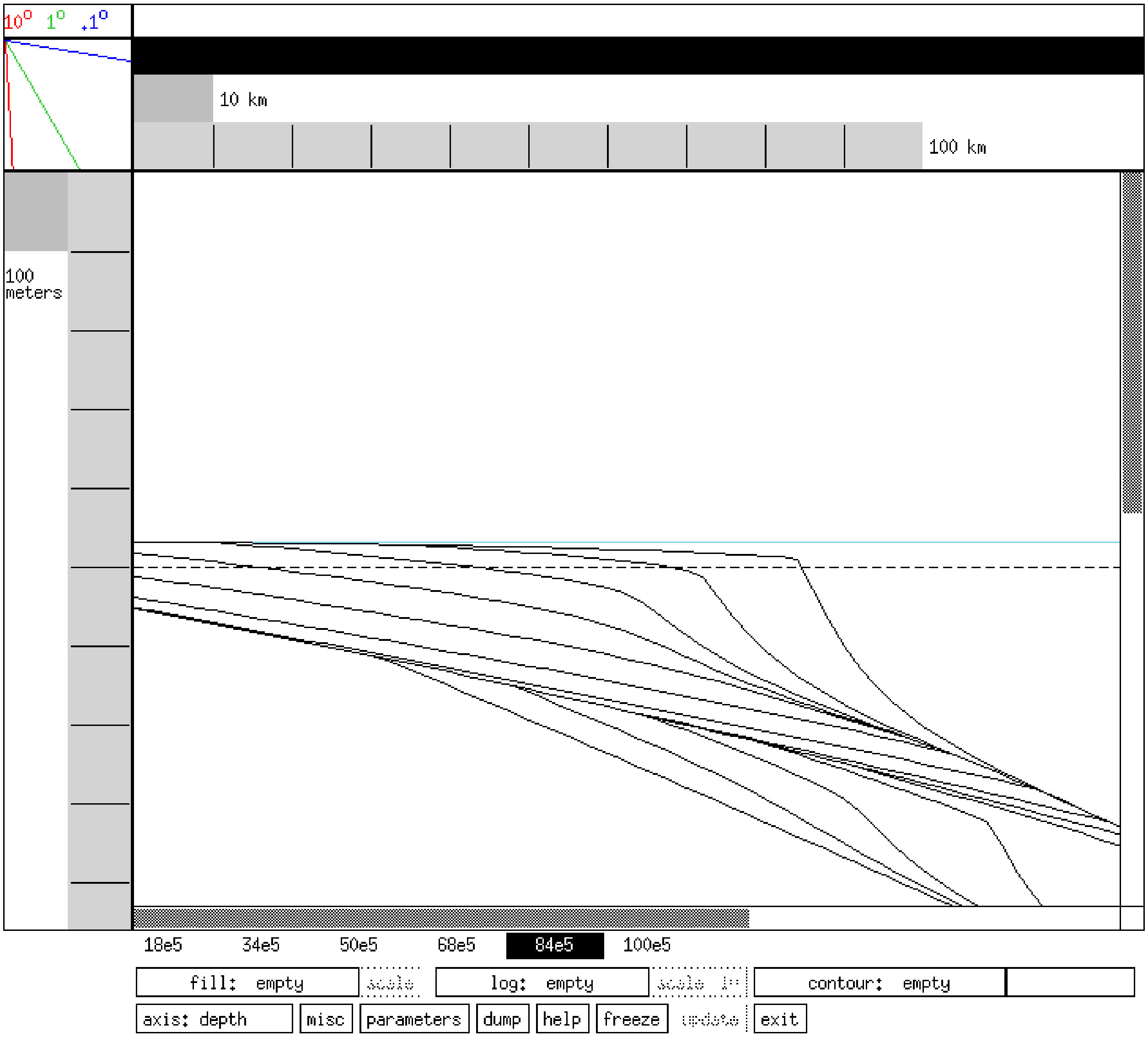


Figure 6.a & figure 6.b Model run without eustatic sea level change (*runex.dat* with skip lines 3) and a model run using a eustatic sea level curve with amplitude = 50 meters, period = 8 million years (*runex_eu50.dat* with skip lines set to 3).

4.2. Wave Sealevel Files

A wave sealevel file allows the user to use multiple sealevel sine waves that can have different amplitudes and periods applied over different time intervals.

Example of simple wave sealevel file (sealevel.sea):

**Wave
s**

0 20e6 50 8e6 0

0 20e6 10 8e6 0

Wave sealevel file notes:

1) The first line must be the word `Waves'

2) The first and second columns set the ages that the sine wave will contribute to sealevel

3) The third column is the amplitude, the fourth column is the period and the fifth column is the offset of the sealevel sine wave

The file *sealevel.sea* specifies the two waves which are to be summed over the range of the simulation. Both sealevel curves act over the range 0 to 20 million years, however, a higher frequency, lower amplitude wave has been added to the 50 meter, 8 million year frequency curve. This can be seen by clicking in plotbasin. If the scroll bar is pulled to the bottom and the window stretched to fit the screen, the user will see the diagram in Figure 7. The composite sealevel curve from the wave sealevel file *sealevel.sea* can be seen on the right of Figure 7.

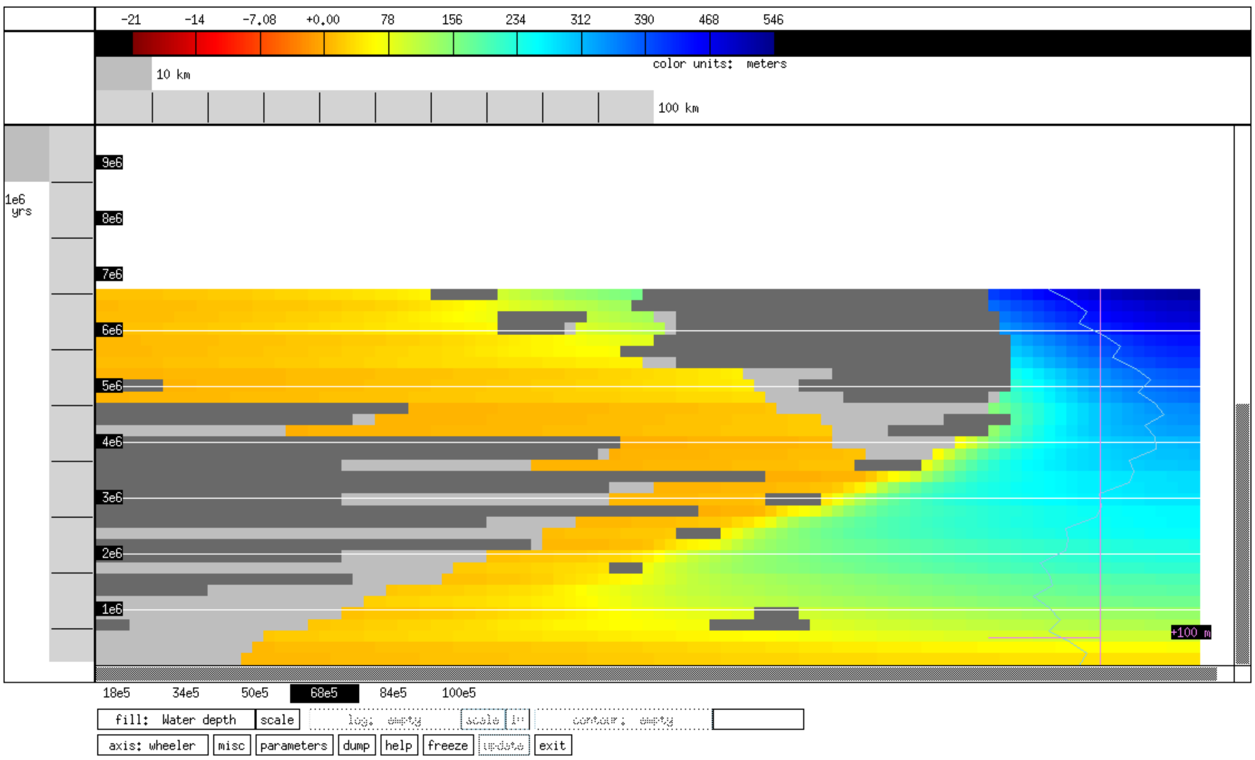


Figure 7: Wheeler diagram display illustrating the result of using a user-defined eustatic curve file (specified in line 1 of the setbasin Sealevel window). The setbasin library file used to generate this model run is sealevel.dat. The sealevel file *sealevel.sea* (shown above) was the wave file used to create the sealevel curve.

4.3. Point Sealevel Files

Point sealevel files linearly interpolate sealevel between known points. Example of point sealevel file:

Point
s

.5e6 100

1e6 -50

2e6 55

Point sealevel file notes:
1) The first line must be the word `Points'
2) The first column is the age
3) The second column is the sealevel elevation

4.4. Haq's Exxon Sealevel Curve

Another option is to use the built-in sea-level curve from Haq et. al (1987). We give an example run (Figure 8) from 100 - 80 ma below, using the sealevel file exxon.sea.

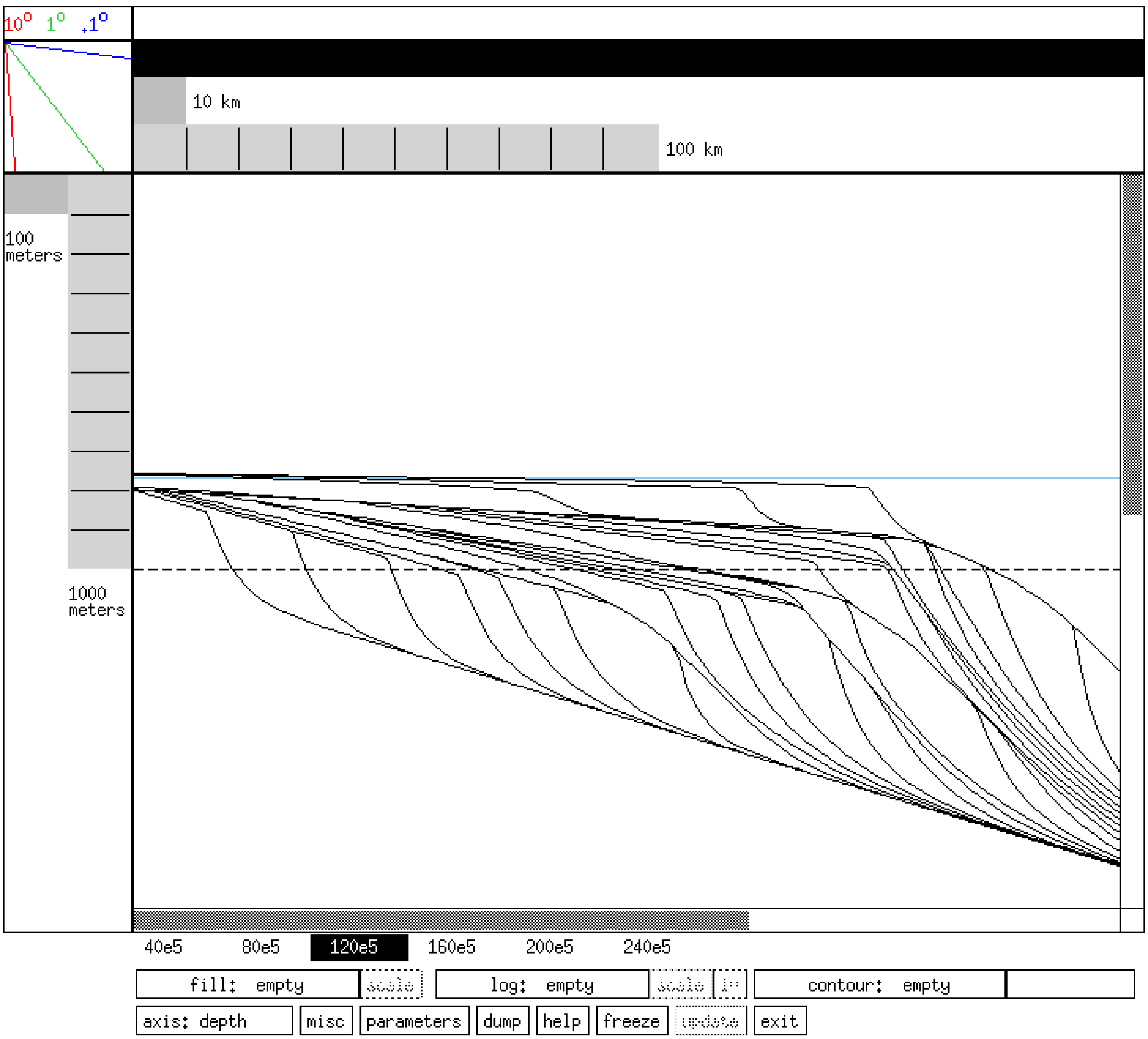


Figure 8: Model run using the Exxon sea level curve (*exxon.sea*) beginning 100 ma. The library file used for this run is *exxon_ex.dat* with skip lines set to 2 and a vertical exaggeration of 75.

Note the method of using the Haq (1987) sea-level curve in this model is a bit non-intuitive due to the format of Haq's curve file. In this example it was necessary to 1) specify `sealevel file' as *exxon.sea*, and 2) set the time to start eustatic curve file (`time offset') at -100e6. This has the effect of starting the simulation with the sea level curve at 100 ma and forward modeling from that point in time (i.e. if it is a 20 m.y. simulation, the model will use the Haq (1987) curve from 100 to 80 ma).

5. Simulating Subsidence

`Subsidence rate' allows for either a constant subsidence rate, or the entry of a subsidence file name (filename.sub). If a subsidence file is specified, the user is essentially inputting the subsidence history at specific points (such as well locations).

5.1. Constant Subsidence

Along with the subsidence rate, the user also determines which profile(s) should be used by specifying passive, foreland, or cratonic in `profile (name).'

Figures 9.a and 9.b illustrate a foreland and cratonic profile, respectively. The passive profile was illustrated in Figure 6.a, with the file runex.dat. For simplicity, each of these examples has sediment entering the system from the left edge only (right clastic flux is set to zero).

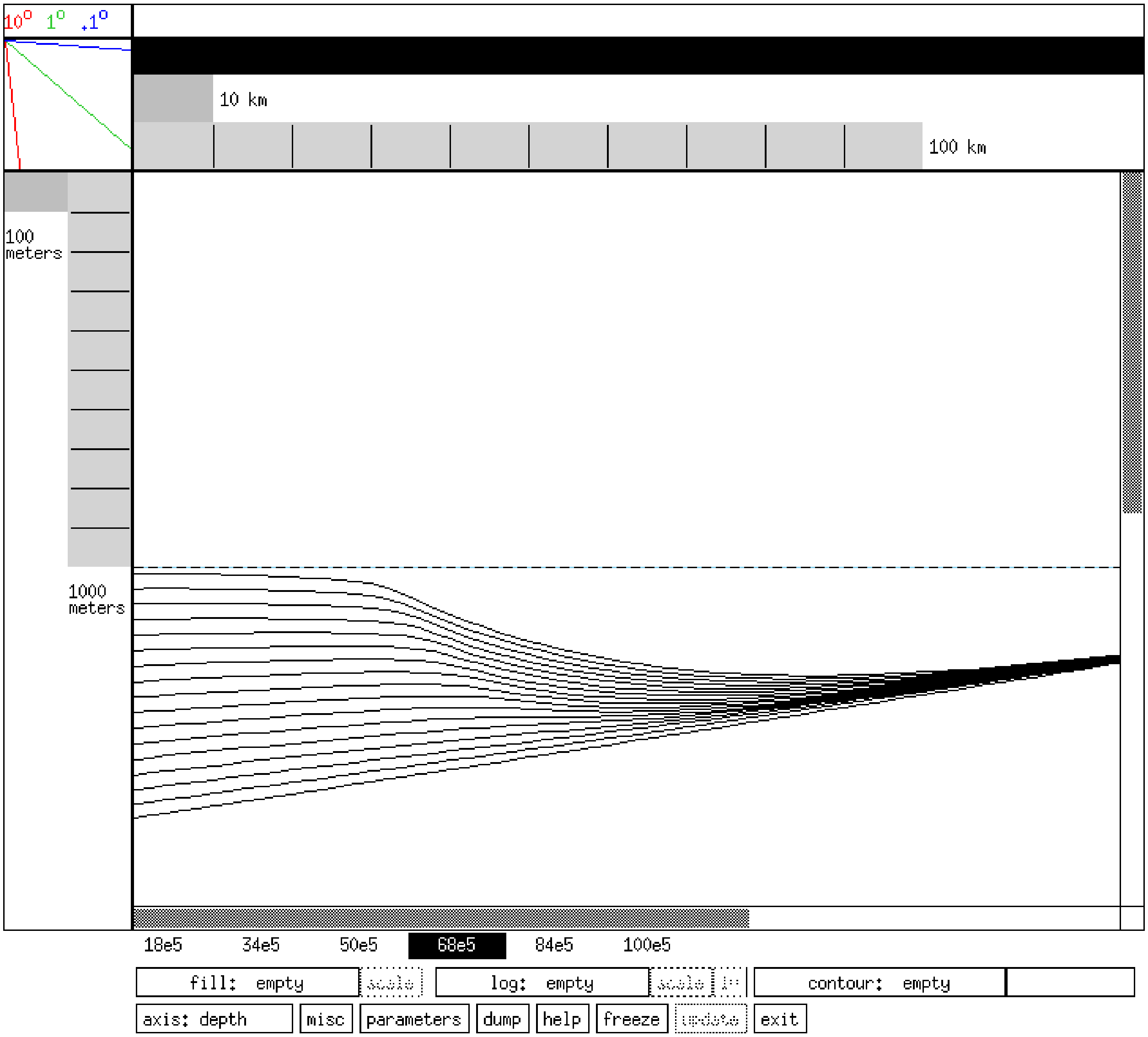


Figure 9.a Foreland basin profile. The library file used for this display is foreland.dat with skip lines set to 2 and a vertical exaggeration of 50.

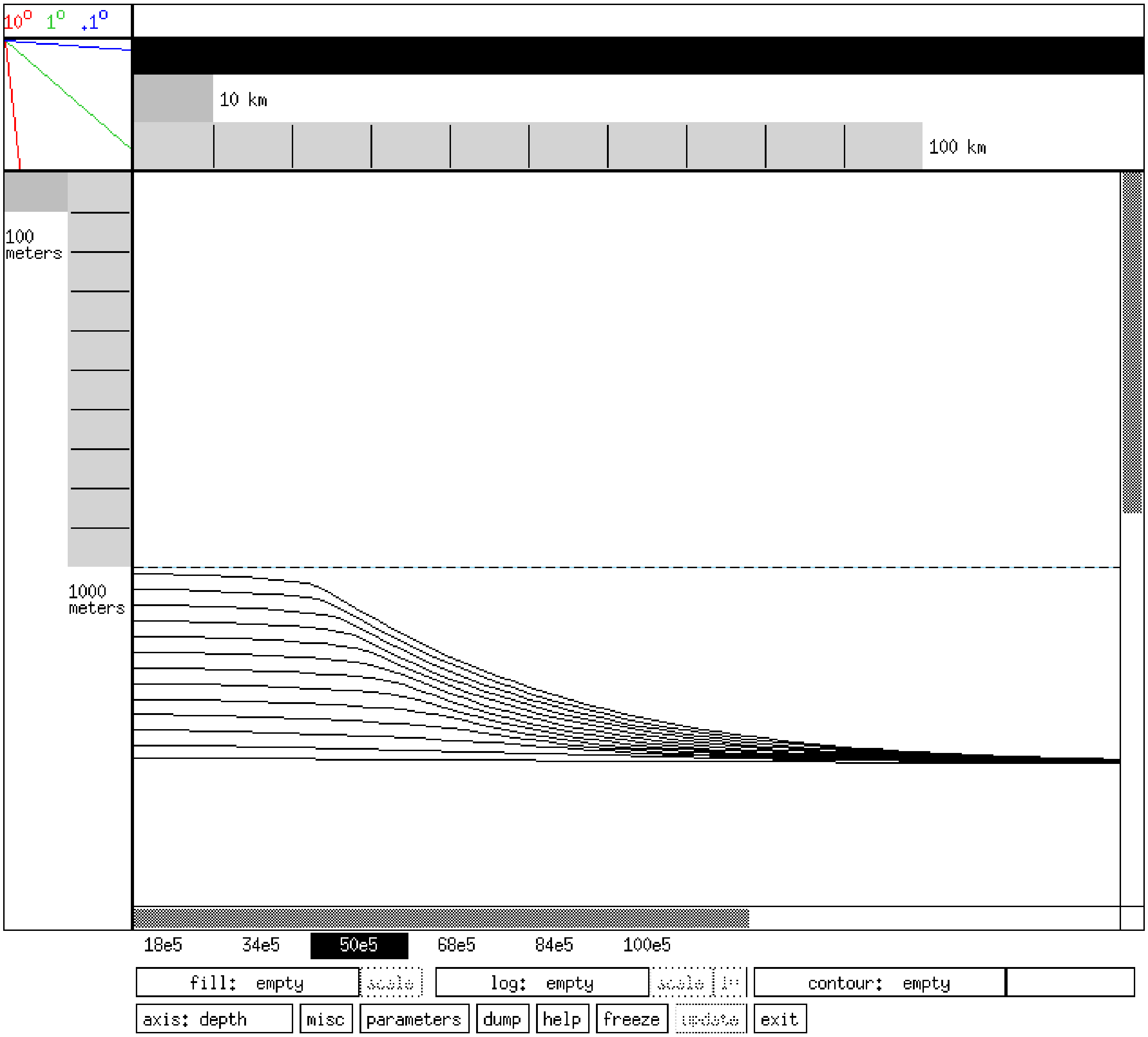


Figure 9.b: Cratonic profile. Subsidence is constant along the profile. The library file used for this run is cratonic.dat with skip lines set to 2 and a vertical exaggeration of 50.

5.2. Subsidence History Files

The user can specify subsidence that varies spatially and temporally through the use of subsidence files (labelled as filename.sub). Within the subsidence files are a series of `well' locations where the subsidence history is specified through time. the form of these well histories is that of a `backstripping' analysis where the depth to basement (or the base of the basin) is specified through time. Our vision is that the user will apply backstripping to a given basin and use those backstripping results as input into the forward model. Between the wells, linear interpolation is used to determine the subsidence history. In locations to the right or left of the last well (or if there is only one well), the subsidence of the last well is used up to the edge of the basin. Note, only vertical subsidence can be specified. Thus, the closest one can come to simulating a fault is to have two adjacent wells have very different subsidence histories as we have shown below.

Figures 10.a and 10.b show examples of images created using user-defined subsidence files. The subsidence files entered in the `subsidence rate' line to create the profiles in Figures 10.a and 10.b are shown below (subsid_ex1.sub & subsid_ex2.sub)

Example of subsidence file subsid1.sub

Well One:

0e3 0e3

-14e6 0.

0 500

Well Two:

100e3 100e3

-14e6 0.

0 500

Well Three:

101e3 101e3

-14e6 0.

0 1000

Well Four:

200e3 200e3

-14e6 0.

0 500

end: -1

Example of subsidence file subsid2.sub:

Well One:

-14e6 0.

-8e6 300

0 750

Well Two:

-14e6 0.

-8e6 300

0 750

Well Three:

-14e6 0.

-8e6 750

0 1200

Well Four:

-14e6 0.

-8e6 300

0 750

end: -1

Subsidence file notes:

1) The first line for each well is comprised of comments, followed by a colon

2) The second line is the horizontal position of the well

3) The following lines are age/depth pairs with the age in years measured from the present (therefore negative or 0). For example, 10 million years ago is -10e6.

4) Be sure that the first age in each well is equal to the starting time of the simulation

5) If the final age in each well is not zero, the depth at the most recent age will be used until t=0

6) Be sure to have a line space between each well

7) Be sure to end the subsidence file with the end line

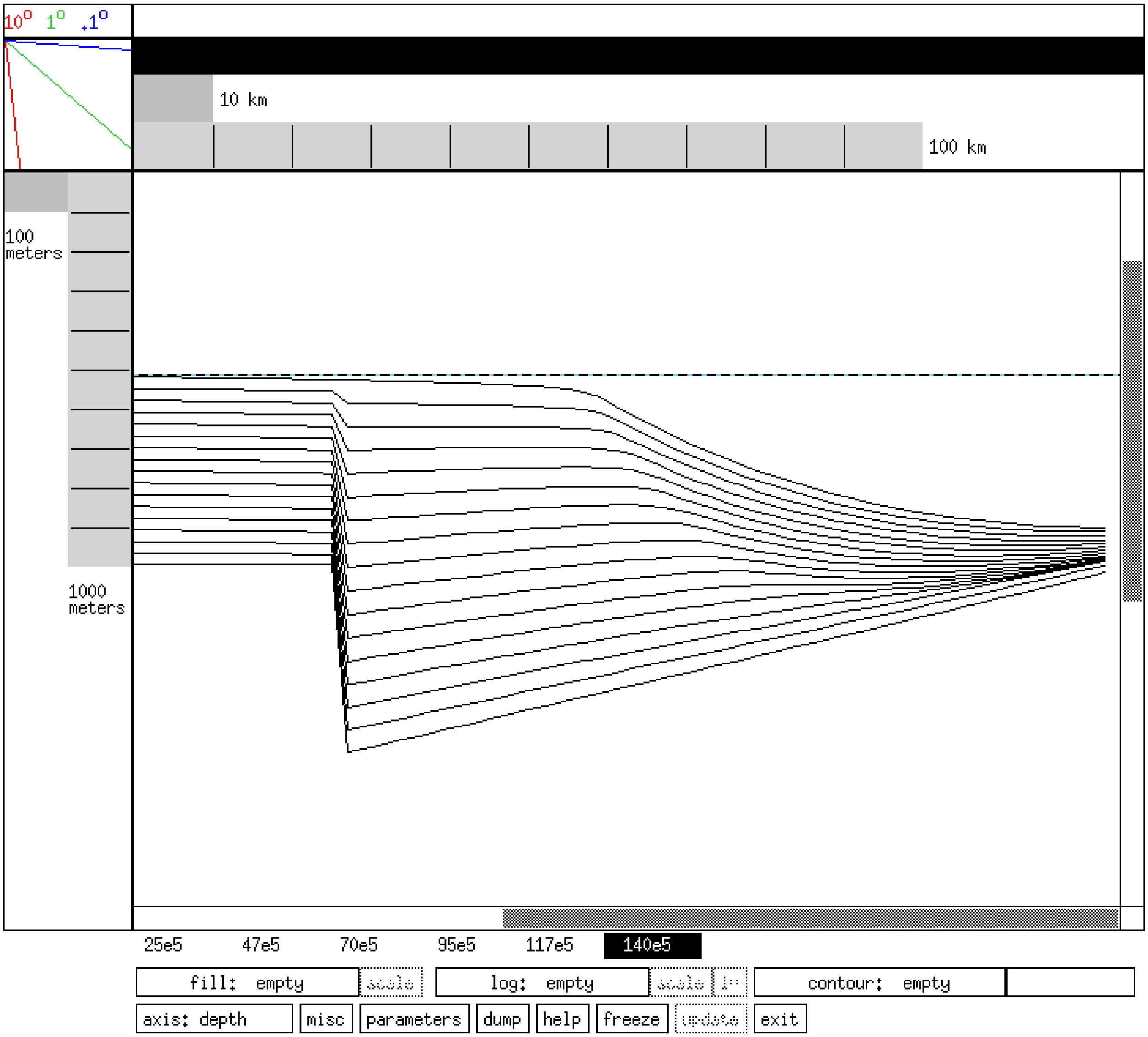


Figure 10.a: Example of a subsidence profile generated by a user-defined subsidence file, subsid1.sub. The library file used in this run is subsid_ex1.dat with skip lines set to 3 and a vertical exaggeration of 50. In a crude sense this is meant to simulate a growth fault. Any number of subsidence histories, defined with "wells" at positions along the profile, can be specified.

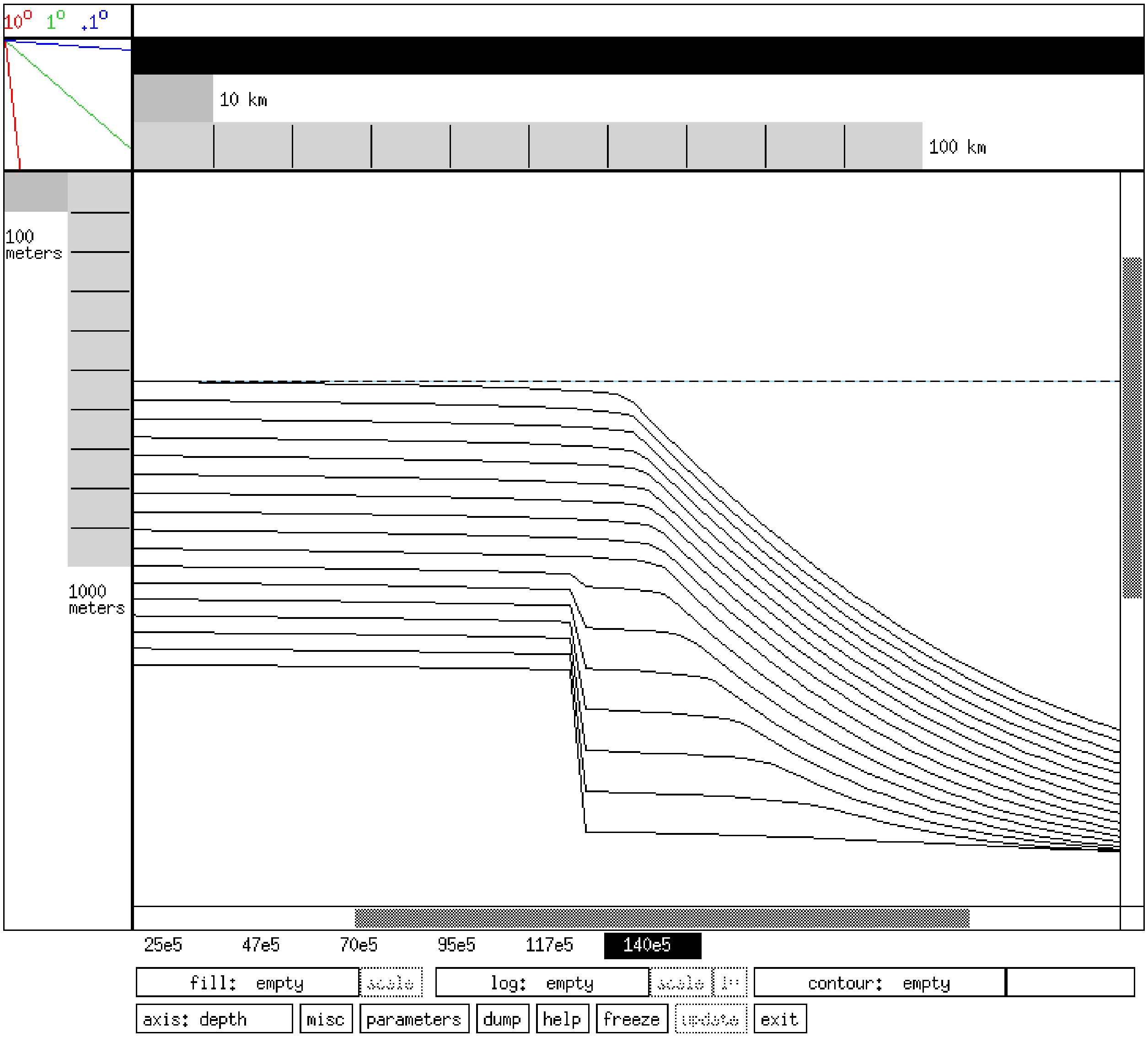
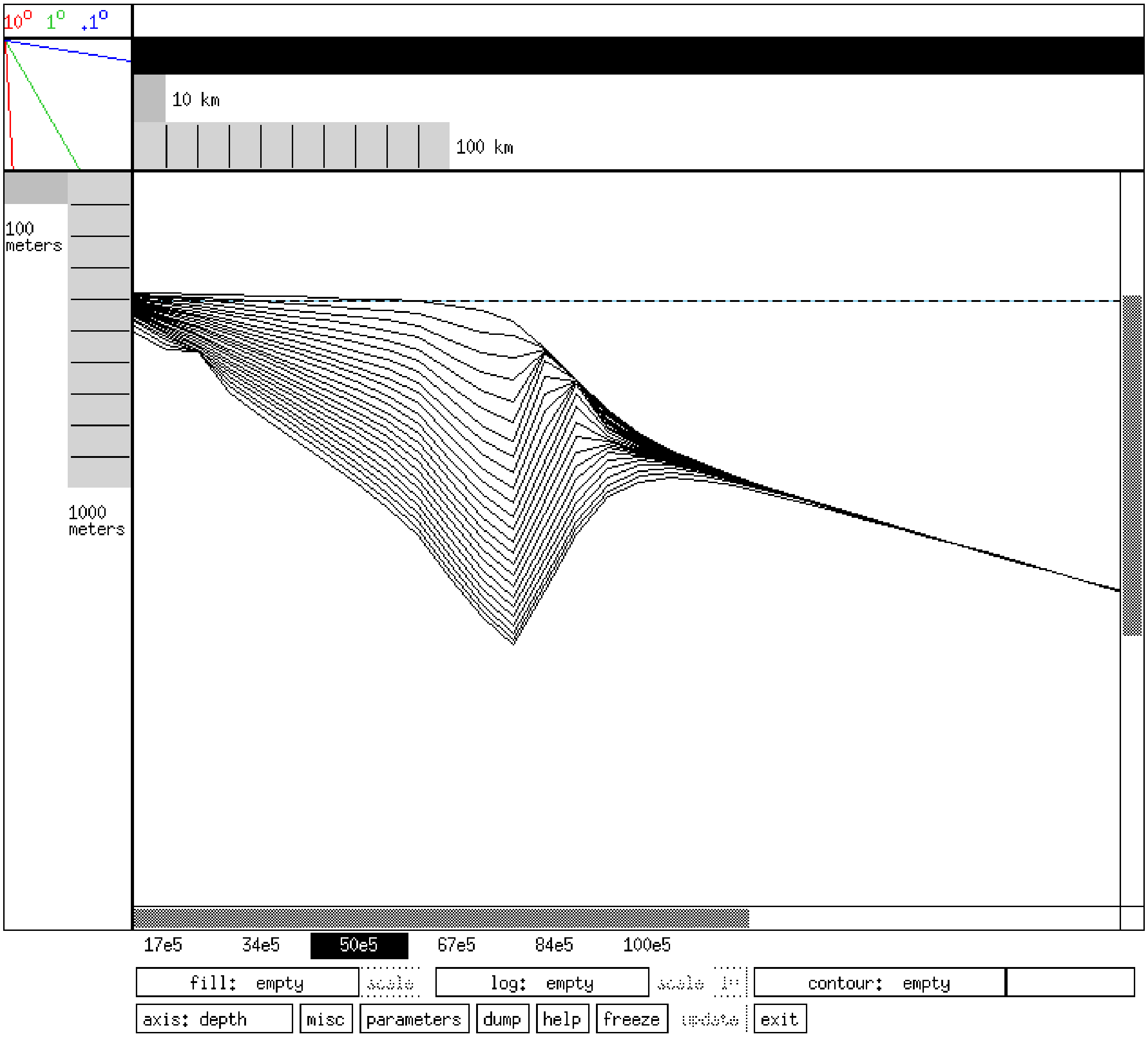


Figure 10.b: Example of a subsidence profile generated by a user-defined subsidence file, subsid2.sub. (Note that for this example the subsidence rate varies through time.) In a crude sense this is meant to simulate a growth fault that becomes inactive. The library file used for this model run is subsid_ex2.dat with the skip lines set to 3, vertical exaggeration of 50.

6. Simulating Isostacy

`Flexural isostatic compensation?' (Subsidence Group File) allows the user to specify whether the lithosphere behaves as an elastic plate, with perfect "airy" isostacy, or whether no isostacy will occur. If true (T, t, or true) is chosen, then a flexural rigidity value must be input in the `flexural rigidity' line. You may enter 0 and generate perfect isostacy, or some reasonable value (e.g. 1e23) to have the lithosphere behave as an elastic beam. Note, values between 0 and 1e20 are very weak plate strengths. (**simbasin** will crash if very weak plate values from ~1 to ~1e14 are chosen)

Figure 11 shows the results of activating flexural isostatic compensation with perfect isostacy Figure 11.a, flexural rigidity=0) and a reasonable plate rigidity (Figure 11.b, flexural rigidity=1e23).


10° 1° .1°
10 km
100 km
100
meters
1000
meters
17e5
34e5
50e5
67e5
84e5
100e5
fill: empty
scale
log: empty
scale
contour: empty
axis: depth
misc
parameters
dump
help
freeze
update
exit

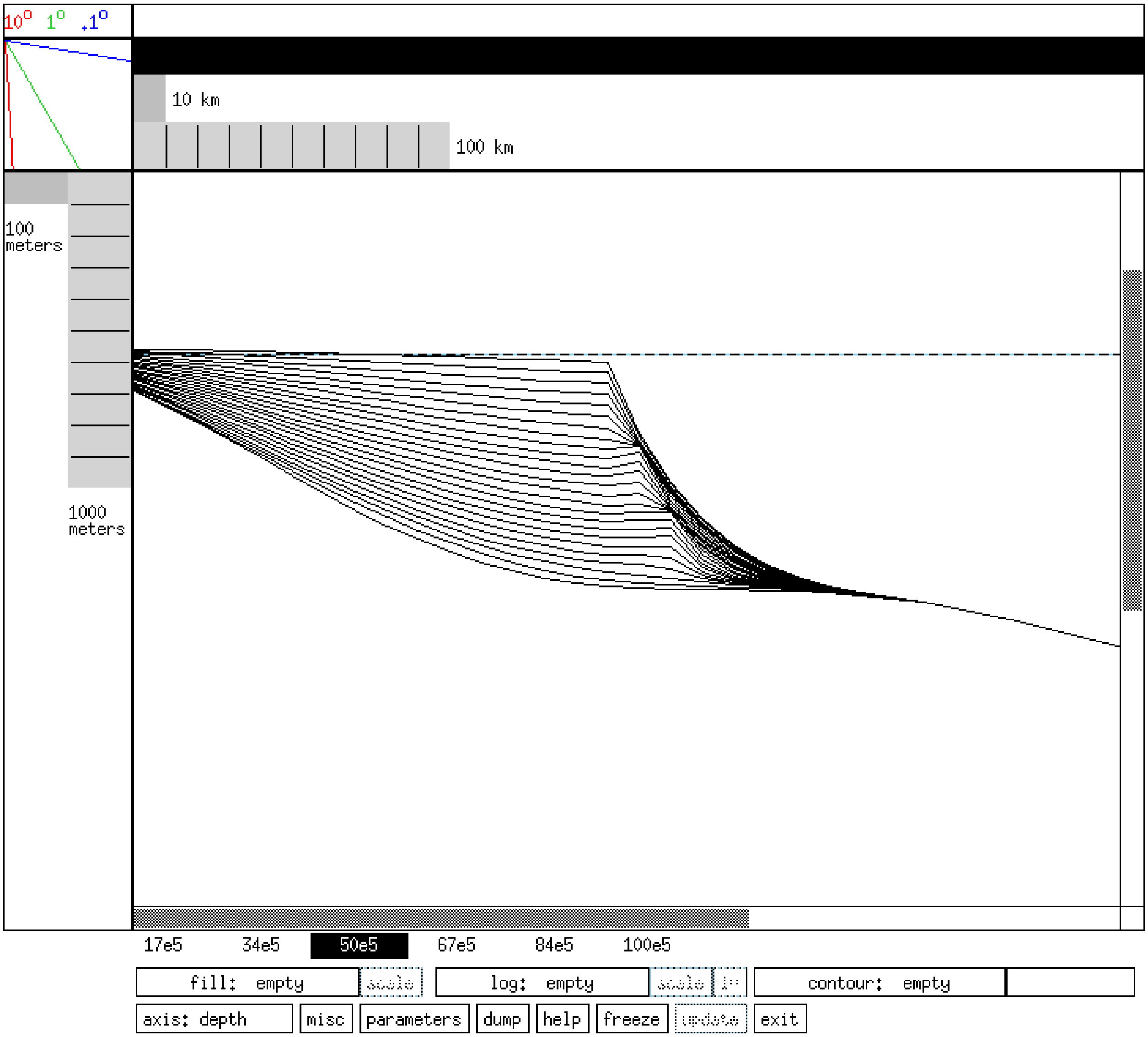


Figure 11.a &Figure 11.b Result of flexure with perfect isostacy (left, *flex.dat*) and a reasonable plate rigidity (right, *flex2.dat*). Skip lines was set to 2.

7. Simulating Compaction

If `compact sediments' is set as true (Compaction group file), the user can specify initial porosities of sand and shale as well as the decay constants.

The user can also specify whether or not erosion will have an effect on the compaction of sediments. If erosion affects compaction, the compaction is irreversible (i.e. it does not expand when the overburden is decreased). See Hart et al. (1995) for a discussion of this behavior.

7.1. Porosity

We follow the approach of Sclater and Christie (1980) and assume porosity is an exponential function of depth:

fi is the percent sand (assuming only sand and shale are present), lshale is the parameter scaling the rate of compaction with depth (defined as `decay constant for shale compaction'), *f0shale* is the surface porosity of the shale (as defined by `initial porosity for shale'). Similarly, *lsand* is the parameter scaling of the rate of compaction of the sand with depth (defined as `decay constant for sand compaction') and *f0sand* is the surface porosity of the sand (defined as `initial porosity for sand').

We note that the default values from Sclater and Christie (1980) are:

$\phi_{0,shale}$	0.63
$\phi_{0,sand}$	0.49
$\phi_{0,chalk}$	0.70
λ_{shale}	$0.51 \cdot 10^{-3}\ m^{-1}$
λ_{sand}	$0.27 \cdot 10^{-3}\ m^{-1}$
λ_{chalk}	$0.71 \cdot 10^{-3}\ m^{-1}$

If porosity is turned on and contoured at an increment of 0.02, the user should see the effects of compaction on the porosity for the example comp.dat (Figure 12).

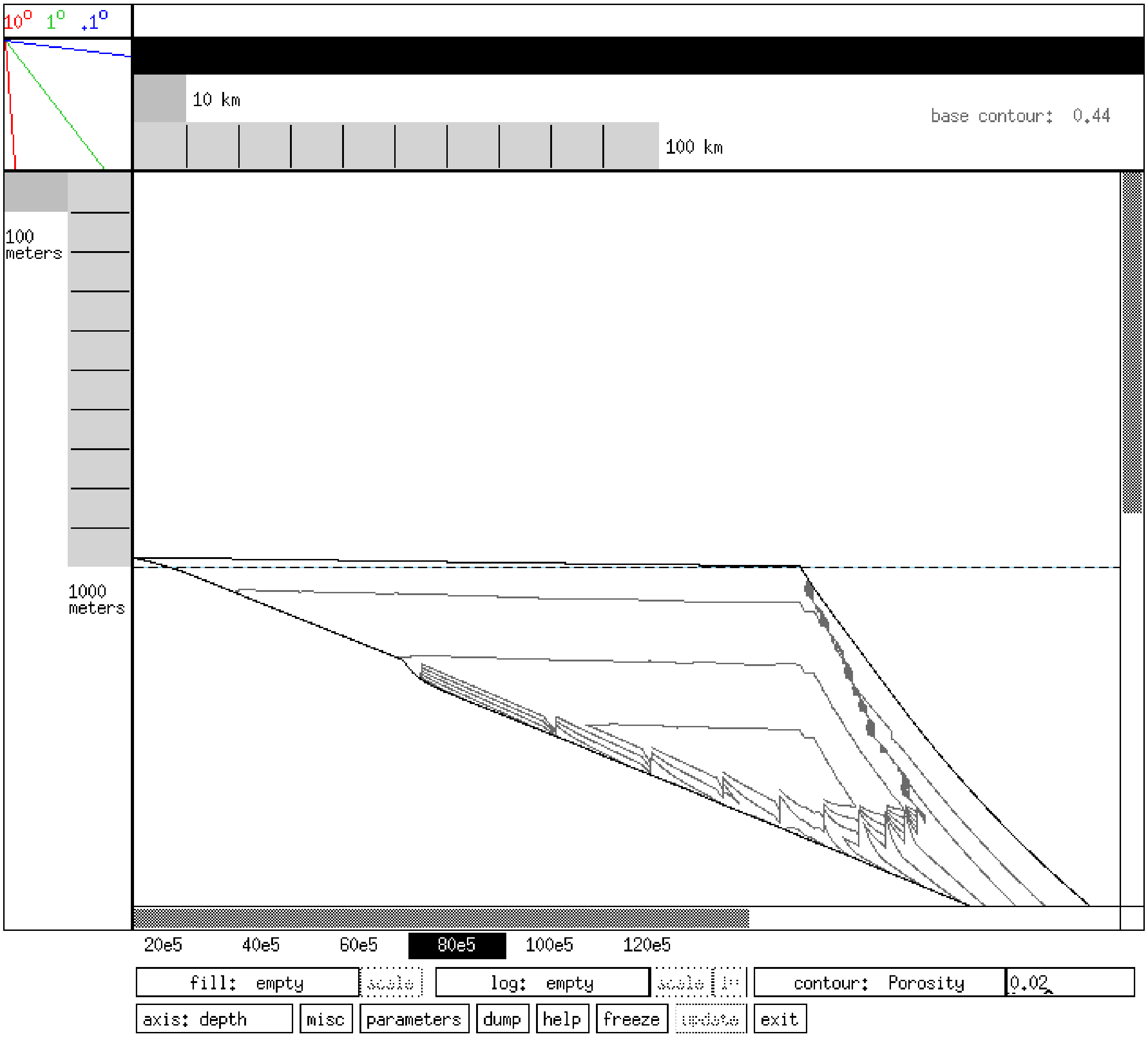


Figure 12 Result of compaction (library file comp.dat with skip lines set to 39 and a vertical exaggeration of 75). Porosity has been contoured here with an increment of 0.02.

8. Simulating Heat Flow

The `thermal flux' parameter in the Heat Flow Group File allows for the input of a constant heat flux entering at the base of the basin, or the input of an existing thermal flux file (filename.therm) that allows the user to vary the heat flow through time.

$$q = -k\frac{dT}{dz}$$

Strata2.1 has the capability of calculating the temperature distribution of each time step and the thermal evolution (integrated time-temperature history) of the simulations. A simplistic steady-state model is used. Heat transport is assumed to occur only vertically. The only heat source is the flux supplied at the base of the basin. The temperature distribution is calculated from:

$$T = T_{air} - \alpha z$$

where, *k* is the thermal conductivity (W/moK), *T* is temperature (degrees), and *q* is the heat flux (W/m2). Because this is a steady-state problem, given *q* and *k* we can calculate the temperature gradient at any point. The last boundary condition we set is the temperature at the sediment surface. From this we can calculate the temperature at any location.

The thermal conductivity is assumed to vary as a function of lithology and porosity.

$$k = \phi \cdot k_{fluid} + (1 - \phi) \cdot (f \cdot k_{sand} + (1 - f) \cdot k_{shale})$$

where, *fsand* is the fraction of the matrix that is sand, *fshale* is the fraction of the matrix that is shale, and *f* is the porosity. *ksand*, *kshale*, and *kfluid* are the thermal conductivities of the matrix. We work in MKS units. Typical thermal conductivities are listed below (Turcotte and Schubert, 1982) :

$$\begin{aligned} k_{sand} = \quad & k_{quartz} = \quad 3.00 \ \frac{W}{m^2} \\ k_{shale} = \quad & k_{illite} = \quad 3.01 \\ k_{fluid} = \quad & k_{water} = \quad 0.50 \end{aligned}$$

8.1. Constant Thermal Flux Files

The `thermal flux' parameter allows the user to specify a constant heat flux entering at the base of the basin. Typical continental heat fluxes are 56.5 mW/m2 (Turcotte and Schubert, 1982). Typical oceanic heat fluxes are 78.2 mW/m2 (Turcotte and Schubert, 1982). Note: syn-rift heat fluxes are typically higher than continental heat fluxes (Turcotte and Schubert (1982), Waples (1985)). No thermal calculations will be performed if there is not a positive value set for the `thermal flux.' The resultant temperature contours from a continental heat flux of 56.5 mW/m2 are show in Figure 13.

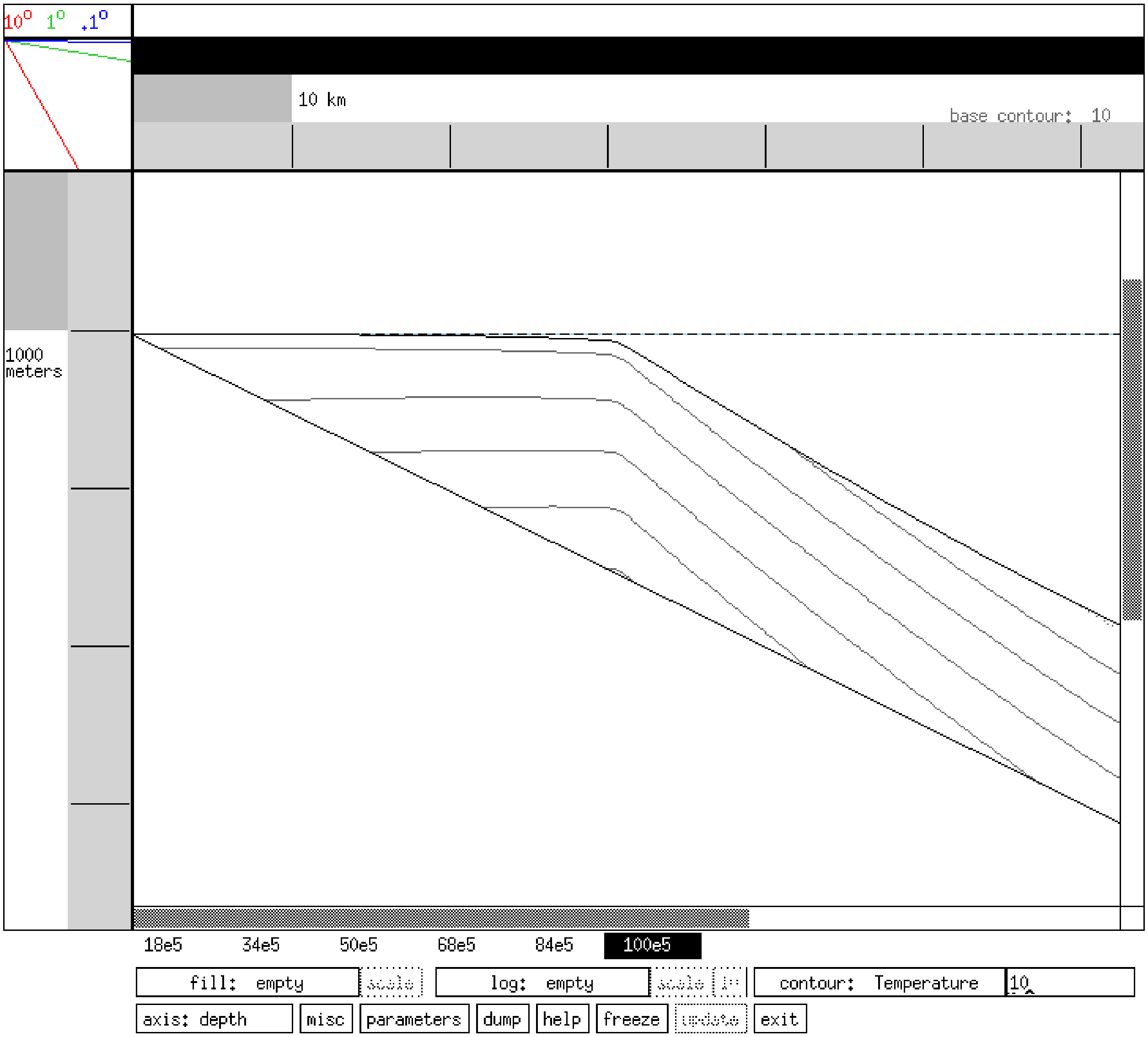


Figure 13: Contour display of temperature profile, illustrating the temperature field for one simulation (*temp.dat*). Note: Temperature contours are displayed at 10o intervals, vertical exaggeration is set to 10, and skip lines is set to 49. The thermal flux of 0.056 is specified in *temp.dat* and can be changed in setbasin under the Heat Flow group file.

8.2. Thermal Flux Files

Thermal flux files can be used if the user wishes to generate a more realistic simulation with changing heat fluxes over time.

Example of thermal flux file (nsea.therm):

0	0.08
60e6	0.08
61e6	0.05

165e6 0.05

Thermal flux file notes:

1) the first column is the age with 0 as the beginning of the simulation
2) the second column is the thermal flux in M/T^3
3) fluxes between given points are linearly interpolated
4) Note - unlike the subsidence file, time is now positive

We simulate an example from Waples (1985), using a subsidence file (*nsea.sub*) based on the history of Well North 30/4-1, Viking Graben (North Sea) and the heat flux shown above. The flux drops from .08 (M/T3) to .05 at 6.1 million years into the simulation. Click on temp.l grad. and contour at .001 to examine the thermal gradient just before and just after the change (Figure 14a, b).

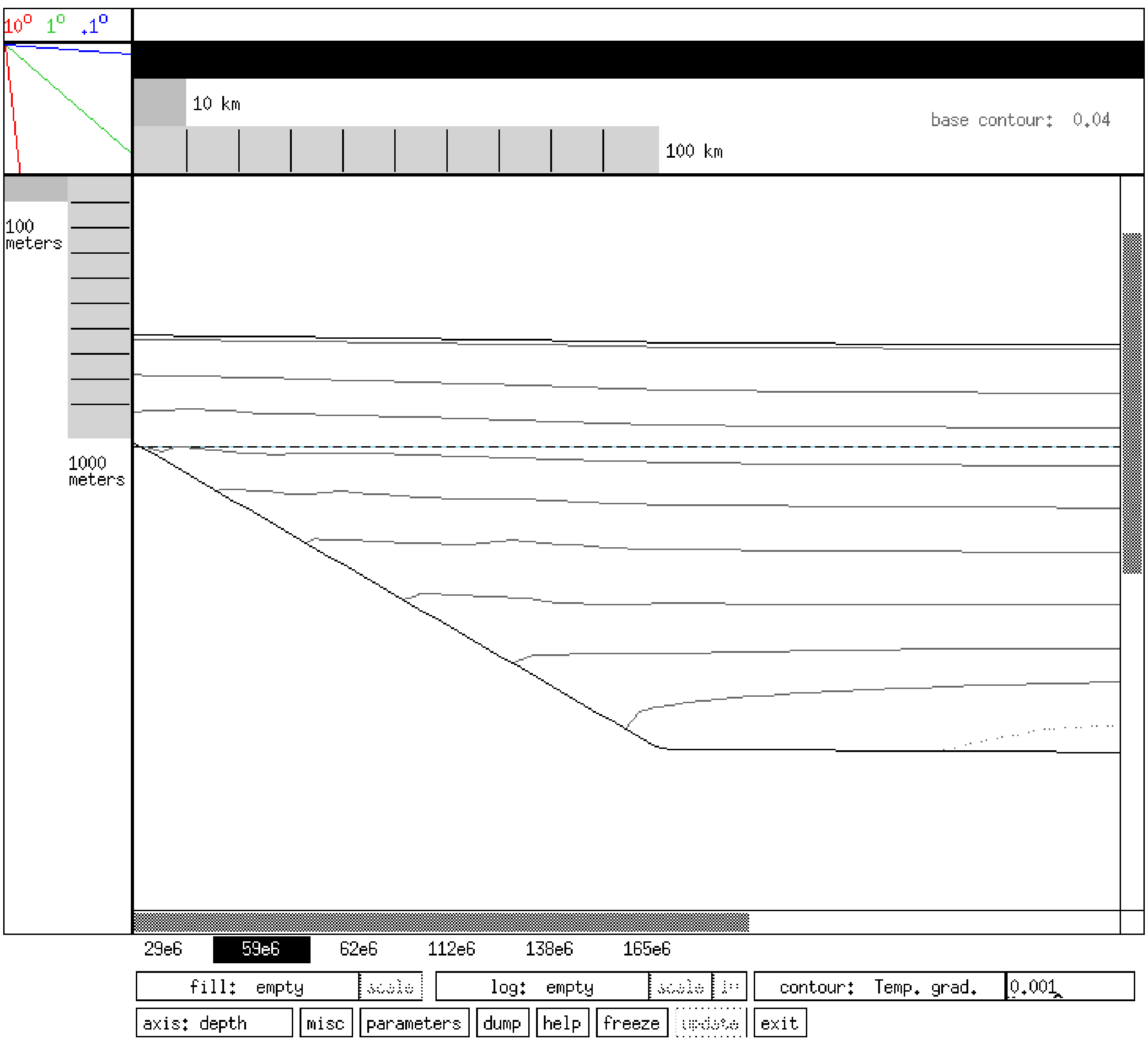


Figure 14.a: Contour display of thermal gradient from the simulation nsea.dat at 59 MY. Skip lines was set at 17,

vertical exaggeration at 50, and the gradient contoured at .001. The thermal flux file nsea.therm and subsidence file *nsea.sub* were used for the simulation.

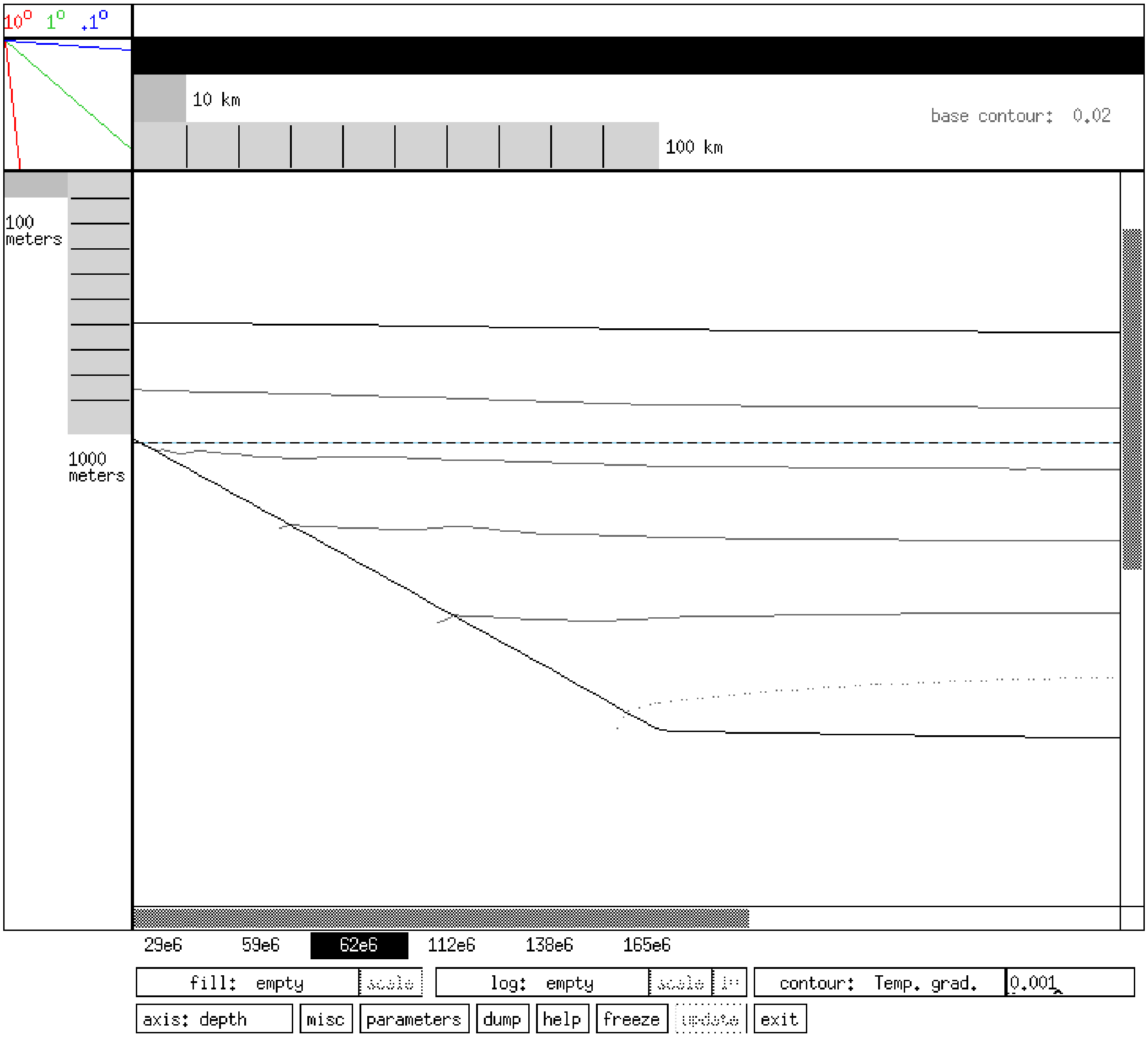


Figure 14b: Same contour display for the *nsea.dat* simulation at 62 MY. Note that the base contour is .02 (not .04) and there are fewer contours.

8.3. Time-Temperature Index

Strata calculates the Time-Temperature Index (TTI) as: 2 (T - 100) / 10Dt to estimate the thermal maturation of the basin. This is a continuous version of the empirical equation: Dt*2n, where n(T) has been crudely found to be approximated by:

<

Temp. interval (°C)	**n**
30-40	-7

40-50	-6
50-60	-5
60-70	-4
70-80	-3
80-90	-2
90-100	-1
100-110	0
110-120	2

The basic assumption here is that the reaction rate will double when temperature increases by 10oC. (In fact, the actual quantity calculated by the simulator is S 2 (T - 100) / 10Dt, i.e. a continuous interpolation of the above.)

The values of the TTI indicate how much the sediment has matured in that temperature interval. The sum of the TTI is thus the total maturity of the sediment. The following table shows the interpretation of the sum TTI values. (Note that they are typically given in megayears, not years.)

<

Sum TTI	**Interpretation**
10 ma	early oil generation
40	peak oil generation
75	late oil generation
180	wet gas (has liquid generation)
900	dry gas

Continuing the North Sea example, we used a present day percent of vitrinite reflectance value calculated for the well North 30/4-1 of 1.3 at a deep location in the basin. According to a correlation table from Waples (1980), this corresponds to a TTI value of approximately 160. Change skip lines to forty-nine, vertical exaggeration to 25, and toggle to Sum TTI. If the contour interval is set to 10, your Sum TTI contours for the North Sea simulation should look like Figure 15. The model-derived sum TTI values coincide with previous burial history calculations (Pegrum and Spencer, 1990).

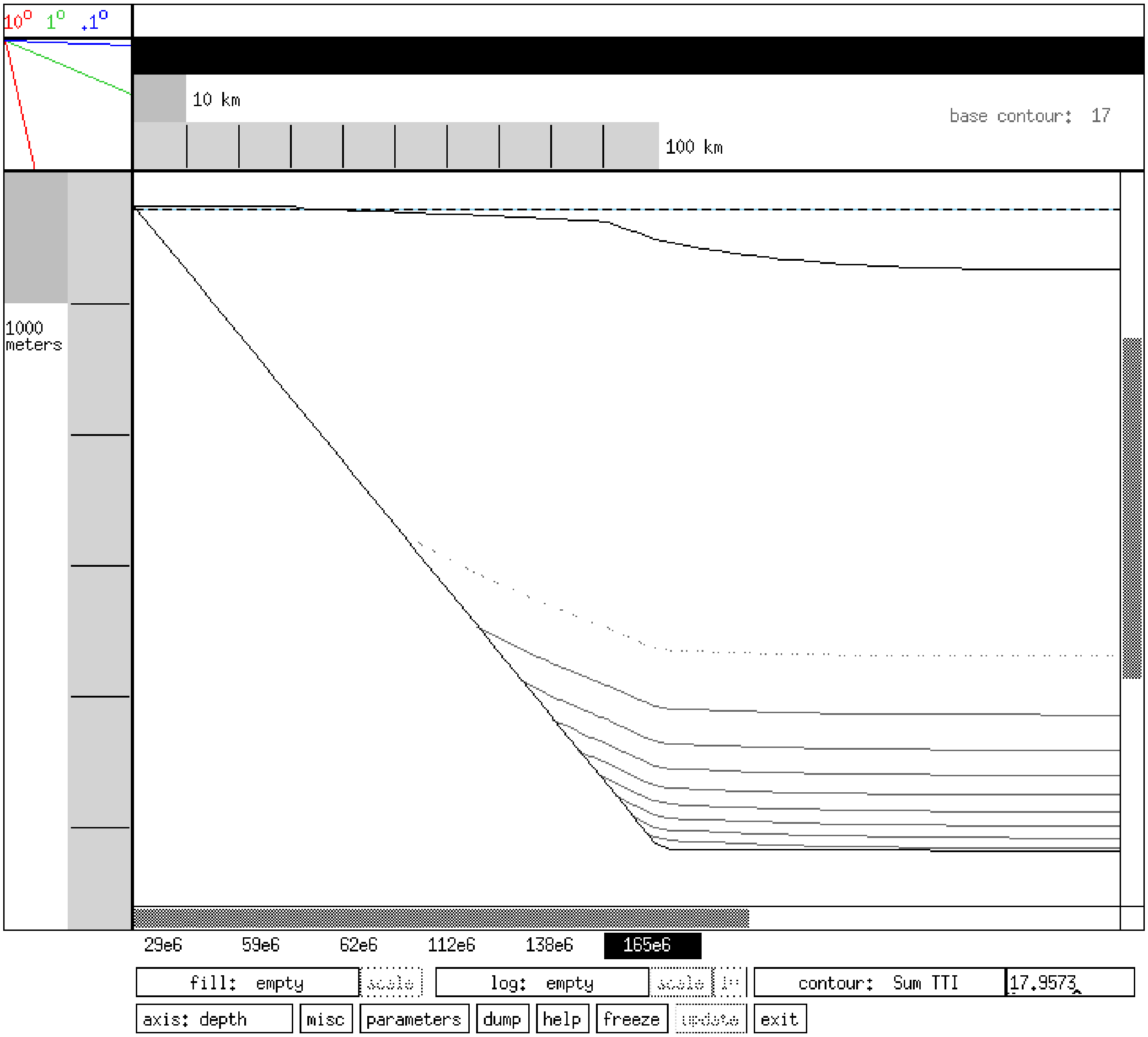


Figure 15: Contour display of sum TTI from library file *nsea.dat*. Skip lines is set to 49 and sum TTI is contoured at 10. Note that the contour interval is 20, therefore sum TTI near the bottom of the basin is around 160. (vertical exag = 25)

9. Seismic Response Features

Strata has the ability to predict the seismic response of the modeled basin. Strata can determine the velocity and density of the basin sediments as long as the porosity is everywhere defined (if compaction was used -- if compaction was turned off in setbasin, seismic response will not be available in plotbasin) and composition of the sediments is known. In our case we determine the composition by either the diffusion or the water depth (see help entry in setbasin). Velocities are determined from the Wylie equation:

$$\begin{aligned}\frac{1}{v_b} &= f \cdot \left(\frac{\phi}{v_{fluid}} + \frac{1-\phi}{v_{sand}}\right) + (1-f) \cdot \left(\frac{\phi}{v_{fluid}} + \frac{1-\phi}{v_{shale}}\right) \\ &= \frac{\phi}{v_{fluid}} + (1-\phi) \cdot \left(\frac{f}{v_{sand}} + \frac{1-f}{v_{shale}}\right)\end{aligned}$$

where, *f* is the percentage of sand in the sediment; *vsand*, *vshale*, and *vwater* are the velocities of sound through those materials; *vb* is the bulk velocity of the sediment. Typical acoustic values of sand, shale, and water are (from Schlumberger, 1987):

v_{sand} = 5487 m/s
v_{shale} = 4545 m/s
v_{water} = 1604 m/s

Bulk density is determined from the following equation:

$$\begin{aligned}\rho_b &= f \cdot (\phi\rho_{fluid} + (1-\phi)\rho_{sand}) + (1-f) \cdot (\phi\rho_{fluid} + (1-\phi)\rho_{shale}) \\ &= \phi\rho_{fluid} + (1-\phi) \cdot (f\rho_{sand} + (1-f)\rho_{shale})\end{aligned}$$

9.1. Impedance Display

We illustrate the use of the seismic tool with the file *seis.dat*. The first exercise is to view the simulation in two-way travel time by clicking on the button in plotbasin and selecting . The user may wish to alter twtmax and/or twtmin (in the parameters window) to expand/contract the view. The user can now view any of a range of properties in log, fill, or contour format, including velocity, porosity, density, diffusion, and impedance. We show one example of the log image of the impedance in Figure 16.a. This display was created by first selecting to display the curve and then by selecting in the menu. The log node sampling, controlled in the parameters window, was set to five. The amplitude scale is changed by placing the cursor arrow over the scale value and using button 1 on the mouse to increase the value, or button 3 to decrease the value. Click on to redraw the image.

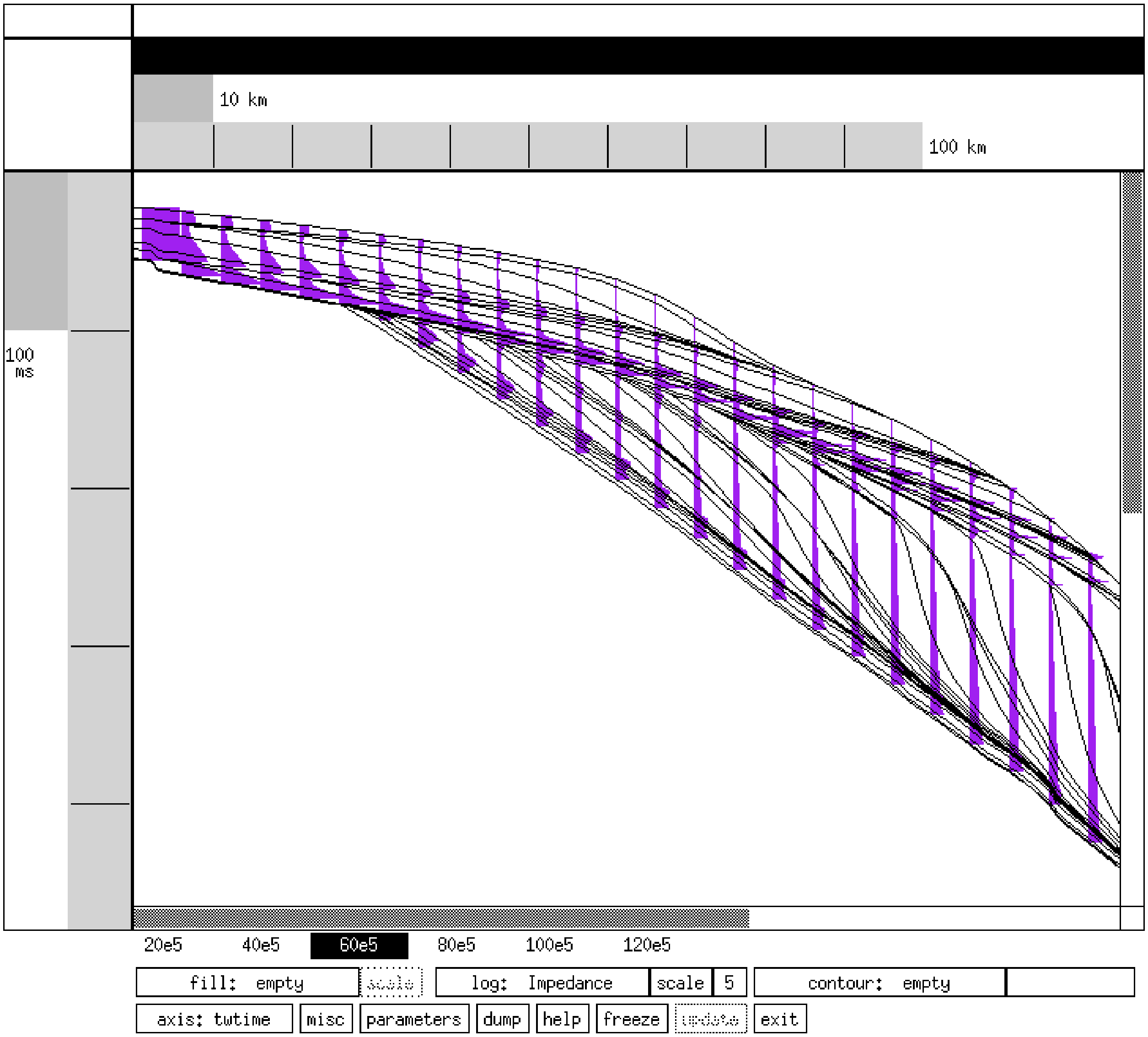


Figure 16.a: Example of impedance display. This image was displayed by changing the amplitude of the curve to 5 and changing skip log nodes in parameters to 5.

9.2. Reflection Coefficients

The next step is to calculate the reflection coefficients. Change back to empty and toggle the reflection coefficients entry on (i.e. so that it shows `reflec coeffs visible'). An example of the reflection coefficients display is shown in Figure 16.b. The reflection coefficients are defined by:

$$RC = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1}.$$

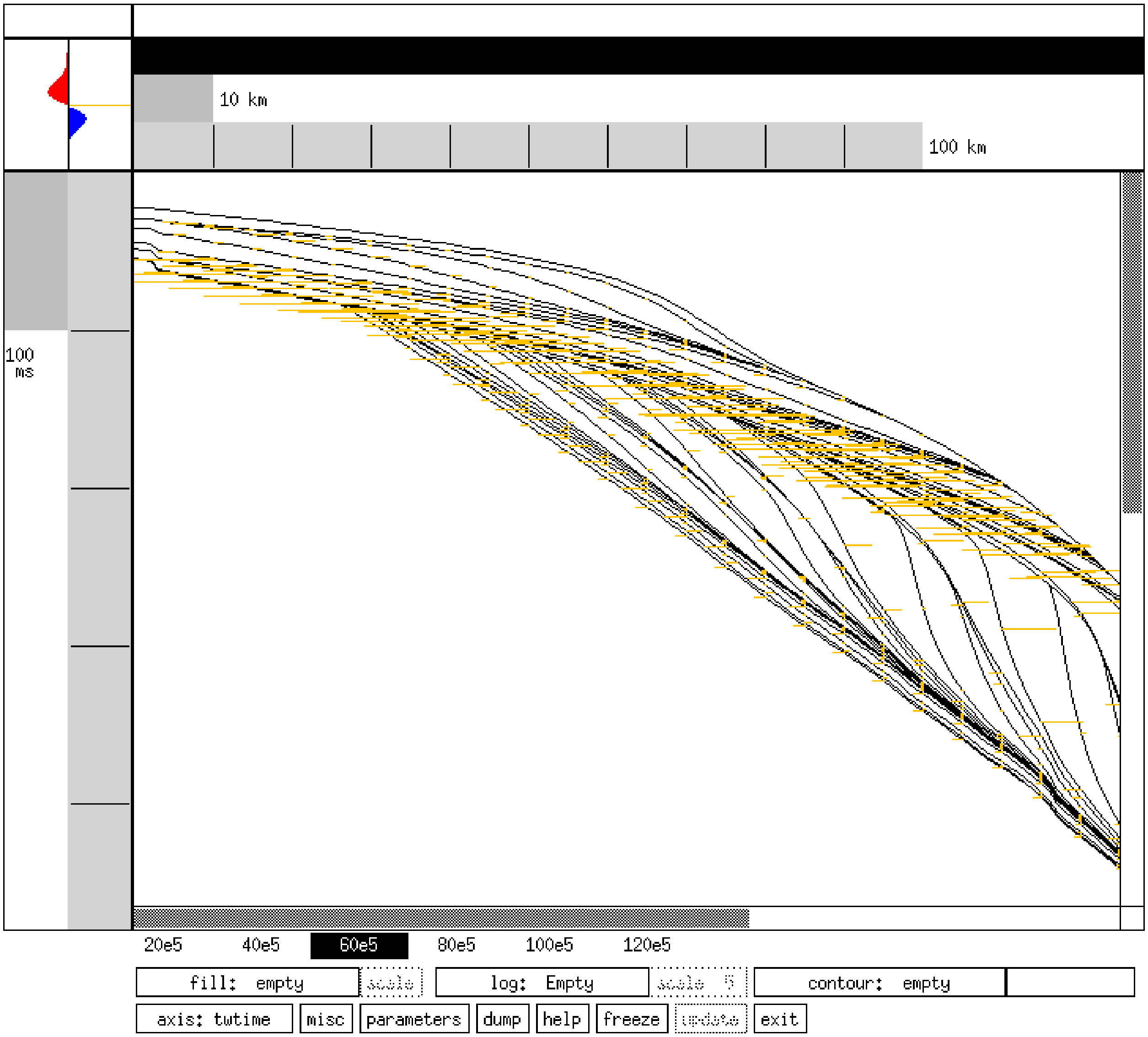


Figure 16.b: Display of reflection coefficients (seis.dat).

9.3. Convolved Seismic Traces

The final step is to convolve the input signal with the reflection coefficient plot. First click on and select `signal'. This step will take a few moments as the model does the convolution. Toggle off the reflection coefficient entry if you wish to clear some clutter from the display. Reduce the scale to two, go back into parameters and change skip log nodes to 2 and the resulting image is shown in Figure 16.c. This can also be shown as a color `field' by selecting . (Signal cannot be contoured.)

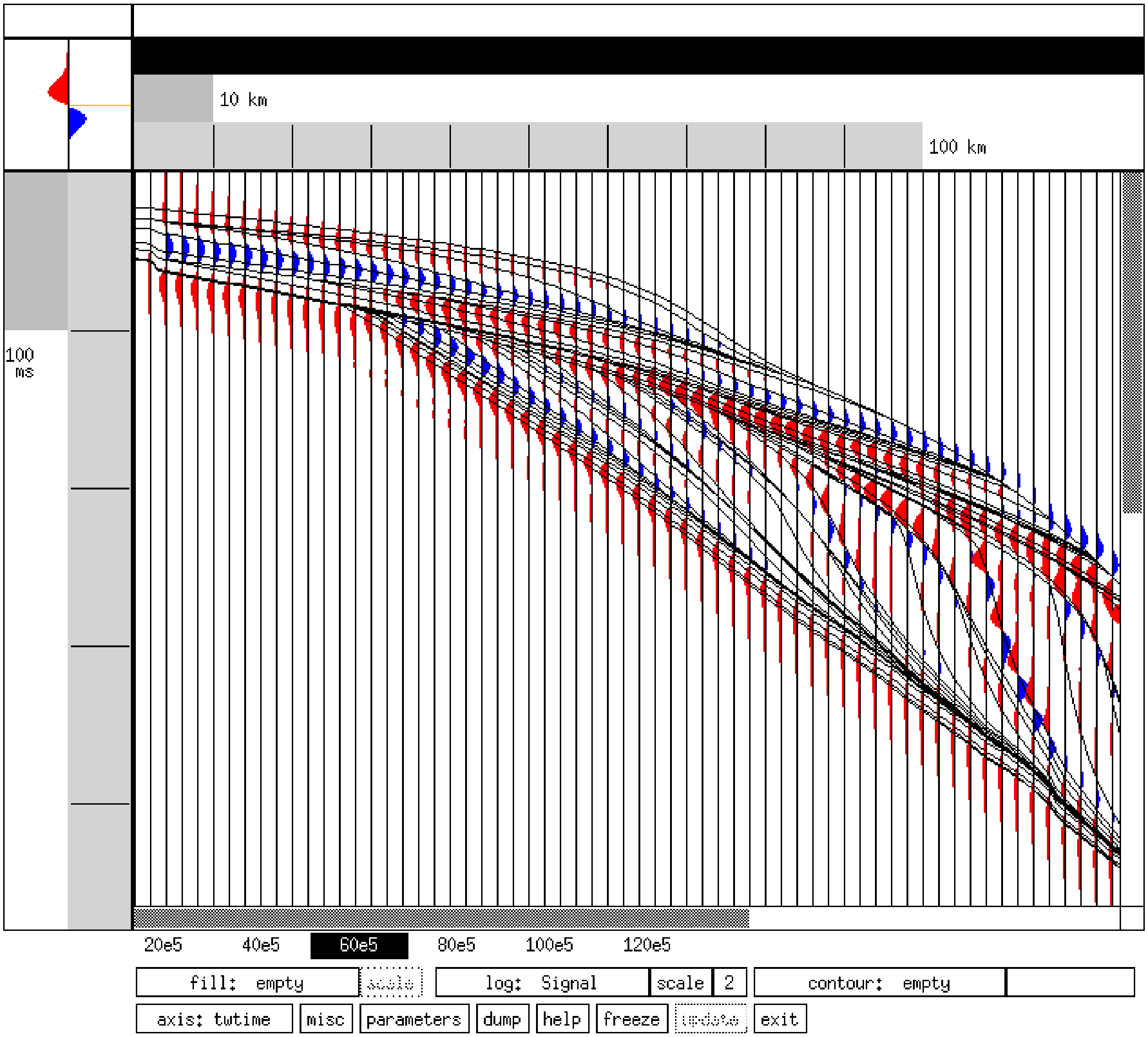


Figure 16.c: Convolved traces resulting from reflections (*seis.dat*). For this display, the scale was changed to 2 and skip log nodes in parameters was changed to 2.

Please note that it is not necessary to go through all of the above exercises to view the convolution; the model will do whatever calculations are necessary to display the data selected.

10. References

Flemings, P.B. and T.E. Jordan, 1990, Stratigraphic Modeling of Foreland Basins: Interpreting Thrust Deformation and Lithospheric Rheology, *Geology* 18: 430-434.

Flemings, P.B.and T.E. Jordan, 1989, A Synthetic Stratigraphic Model of Foreland Basin Development, *Journal of Geophysical Research* 94: 3851-3866.

Gildner, R.F. and J.L. Cisne, 1990, Quantitative Modeling of Carbonate Stratigraphy and Water-Depth History Using Depth-Dependent Sedimentation Function in Cross, T.A. (ed.) *Quantitative Dynamic Stratigraphy*. Prentice Hall, New Jersey.

Haq, B.U., Hardenbol, J., and P.R. Vail, 1987, Chronology of fluctuating sea levels since the Triassic, *Science*. 235: 1156-1187.

Hart, B.S., Flemings, P.B., and A. Deshpande, 1995, Porosity and pressure: Role of compaction disequilibrium in the development of geopressures in a Gulf Coast Pleistocene basin, *Geology*. 23 (1): 45-48.

Jordan, T.E. and P.B. Flemings,1991, Large-Scale Stratigraphic Architecture, Eustatic Variation, and Unsteady Tectonism: A Theoretical Evaluation, *Journal of Geophysical Research* 96 (B4): 6681-6699.

Kaufman, P., Grotzinger, J.P., and D.S. McCormick, 1991, Depth-dependent diffusion algorithm for simulation of sedimentation in shallow marine depositional systems in Franseen, E.K., W.L. Watney, C.G.S.C. Kendall, W. Ross (eds.) Sedimentary modeling: Computer simulations and methods for improved parameter definition, *Kansas Geological Survey*.

Log Interpretation Principle/Application, 1987, Schlumberger Educational Services, Houston, 198 p.

Pegrum, R.M. and A.M. Spencer, 1990, Hydrocarbon Plays in the northern North Sea in Brooks, J. (ed.) *Classic Petroleum Provinces, Geological Society Special Publication, London*, 570 p.

Ross, W.C., Watts, D.E., and J.A. May, 1995, Insights from Stratigraphic Modeling: Mud-Limited Versus Sand-Limited Depositional Systems, *AAPG Bulletin* 79(2): 231-258 (1995).

Sclater, J.G. and P.A.F. Christie, 1980, Continental Stretching: An Explanation of the Post-Mid-Cretaceous Subsidence of the Central North Sea Basin, *Journal of Geophysical Research*. 85 (B7): 3711-3739.

Turcotte, D.L, and Schubert, G., 1982, *Geodynamics: Applications of continuum physics to geological problems*, John Wiley&Sons, New York, 450 p.

Waples, D.W., 1985, *Predicting Thermal Maturity, in Geochemistry in Petroleum Exploration*, International Human Resources Development Corporation, 232 p.

Last Modified: 05:59pm EST, February 21, 1996 - Steven E. Nelson