

Synthetic model building using a simplified basin modeling approach

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ABSTRACT

Generating a realistic synthetic model is a challenging problem in a geophysical research environment. Models are often too simple, lacking much of the character of real data, or too complex making debugging difficult. I propose a different way to generate synthetic models, by allowing the user to specify a series of geologic events such as deposition, erosion, and compaction. The result of each event is approximated on the current model. This approach has the benefit of allowing complex models to be built, easily extendable to multiple model parameters, and allows the user to “turn off” events, conveying the construction of simpler models by stages. Early results indicate that this approach allows complex synthetic models to be generated with minimal effort.

INTRODUCTION

Synthetic models play an important role in geophysical research. Over the last 25 years, SEG and company generated synthetics (Versteeg, 1993) have been used extensively by researchers throughout the world. These synthetics have found such wide use for two reasons. First, generating realistic synthetic models is difficult, particularly 3-D models. Tools such as Gocad (Cain et al., 1998) allow the user to specify layers, faults, and other geologic features before creating a 3-D grid to ease the process, but still require significant experience to use effectively. Second, industry wide synthetics provide a common benchmark to compare results from different companies. These models are useful for final testing of a finished algorithm, but often are too complex to be used in algorithmic development.

Another approach to generating synthetic models is following the methodology of basin modelers. Basin modeling takes a more geologic approach to describing models than the more computer science based approach followed by GoCad and its competitors. Basin modeling attempts to model the geologic history of a given piece of the earth to explain its current properties.

In this paper I introduce a new tool, `Geomodel`, for generating more realistic synthetic models. `Geomodel` builds synthetic models through a user specified set of geologic events (such as deposit, erode, compact, or uplift). By building synthetic models in this manner the user can add or subtract complexity through the algorithmic development process.

OVERVIEW

`Geomodel` builds up a synthetic model in stages. The user begins by specifying an initial homogeneous basement through sampling and size in x and y , spacing in z , as well the sampling, thickness and property value (think velocity) of the basement material.

The rest of the model is then built up by describing a series of geologic *events*. The total number of events is described by the parameter `nevents`, and each successive event is specified by `event#` (`event1`, `event2`, etc.). Currently seven different events can be specified: deposit, erode, compact, uplift, fault, gauss, and emplace. Figure 1 demonstrates several of these features. Additional events might be added in the future. Each event has its own set of parameters. The parameters for each event are differentiated by their event number. For example when describing the layer thickness for the second event you would use the parameter `thick_2`, while describing deposition for the fourth event you would use `thick_4`. As different events are added to the model two grids are maintained. The first contains the earth property at the given location, the second contains what event created this grid cell. The following describes the parameters for each event option along with the methodology used to simulate the event.

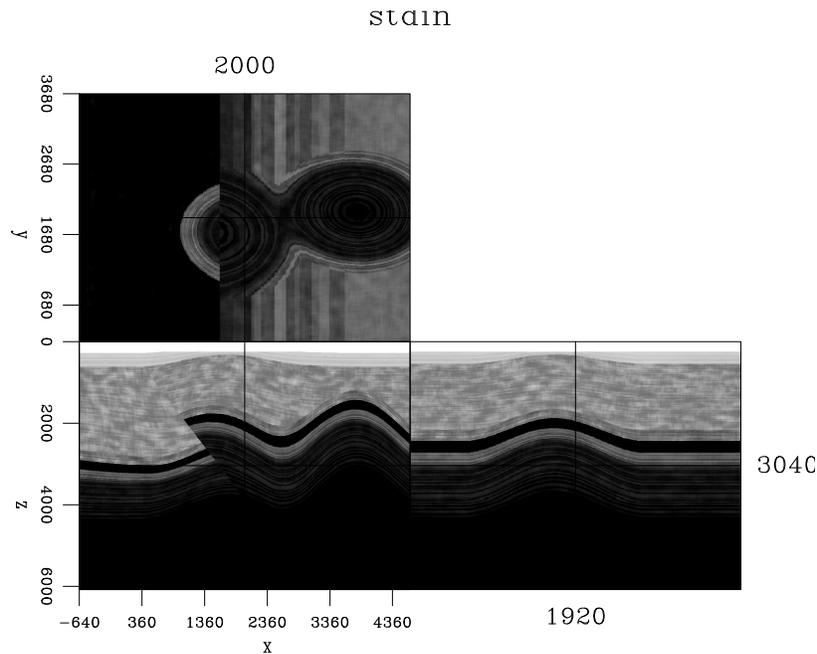


Figure 1: An example model created with `Geomodel`. Note the fault, anticlines, erosion, and deposition visible in this example.

Deposition

Deposition involves laying down a generally homogenous earth property so that the upper bounding surface is completely horizontal. The user specifies the thickness of the layer (`thick_`), which corresponds to thickness in samples added to the current highest portion of the model. The overall average property value for the layer is specified through `prop_`. Starting from this basic homogenous layer the user then has the ability to add different levels of complexity. Interbed layering can be added by describing average interbed layer thickness `layer_`. Each interbed layer property value is randomly assigned a different earth property by scaling the average earth property by a random number scaled by `dev_layer_`. Using a for the average property value, d for the specified deviation, and r for the random number (with a range between -0.5 and 0.5), the property value p for the current layer is specified through $p = (1 + rd)a$. Layer thickness can also be varied using the `dev_layer_` parameter. Using this parameter, layer thicknesses are assigned variable lengths with larger values of `dev_layer_` corresponding to larger variations.

Heterogeneity within layers can also be added. The deposition modeling routine scales the layers property values by $s = 1 + r*v$, where v is the user-specified parameter `dev_pos_` and s is the generated random property scaling parameter. These values are then smoothed using successive box smoothers with a half-width of `nsmooth_`. The resulting layer property is then the result of multiplying s and p at every point in the layer. Figure 2 shows an example of using the deposition option. Note the layering visible in the xz and yz planes, and the spatial variation in the xy plane.

Faults

Currently only planar faults are possible in `Geomodel`. The fault plane is specified by describing the plane in terms of $ax + by + cz = d$, using the parameters `plane1_`, `plane2_`, `plane3_`, and `plane_sum_`. The user then specifies the movement along the fault plane (fault throw) by specifying an initial point lying on the plane (`old1_`, `old2_`, and `old3_`) and where that point moves to (`new1_`, `new2_`, and `new3_`, all in terms of the model's coordinate system. Fault displacement is assumed to decay (described by a cosine taper) as one moves away from (`old_`, `old2_`, `old3_`). Along the fault plane decay distance is defined by the parameter `die_max_` and away from the fault plane by the parameter `die_minor_`. Figure 3 shows an example of applying faulting to a multi-layer depositional model. Note the decay in space of the fault displacement.

Uplift

Anticlines are generally formed from compressional forces and tend to form anticline/syncline patterns. Instead of stress from the side, `Geomodel` modifies earth prop-

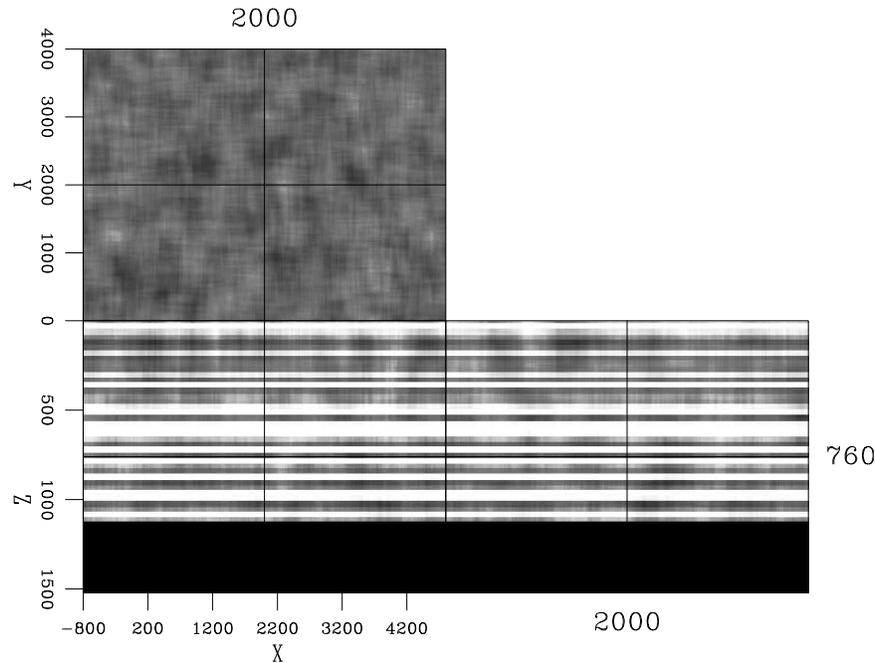


Figure 2: An example of depositing a layer using `Geomodel`. Note the layer visible in the xz and yz planes, and the spatial variation in the xy plane. [ER]

erties by simply uplifting at a given location. The center of the uplift is specified by `center2_` and `center3_`. The amount of uplift is specified by `shift_`. Similar to the fault description uplift also dies out at distance using along two axes using the `die_major_` and `die_minor_` parameters. The `rotate_` parameters allows the user to specify the angle of rotation off the xy -plane for the major and minor axes. Figure 4 shows an example of applying an uplift to the faulted model shown in Figure 3.

Compaction

Compaction can have a significant effect on earth properties such as velocity. Compaction is generally driven by depth and the material making up the layer. `Geomodel` allows the user to specify different compaction for each layer. The default is no compaction in a given layer; to add compaction the user can specify the parameter `compact_i_j` where `i` is the event and `j` is the layer. A property is modified using the formula $p = p * (1 + d * c)$, where p is the property, d is the depth, and c is the compaction parameter for the given layer. Compaction can be added at any stage in model construction. As a result a model can have many different property gradients depending on when compaction is applied. Figure 5 shows an example of applying the compaction parameter. In this case one layer is compacted before uplift, and another, after uplift.

Gauss

Gaussian-shaped anomalies can be added to the model using the `gauss` option. The `center1_`, `center2_`, and `center3_` parameters specify the center of the anomaly. The `vplus_` parameter specifies the maximum amount of the anomaly. The `var_` parameter specifies the variance (in distance) of the Gaussian anomaly. Figure 6 shows an example of adding a Gaussian anomaly to the upper layer of the model shown in Figure 5.

Erode

`Geomodel` simulates two different type of erosion: bowls and rivers. The user specifies which type of erosion using the parameter `erode_type_`. In each case, the depth of the erosion is described by the `depth_` parameter. The user can fill a portion of the eroded event using the `fill_depth_` and `fill_prop_` parameters. These parameters allow the user to simulate events such as a river fill. The location of an erosion bowl event is described the `center2_` and `center3_` parameters. The width of the bowl is defined by the `width2_` and `width3_` parameters.

Meandering river paths are described by summing up to three cosine waves of different spatial frequency (`cosine_wave1_`, `cosine_wave2_` and `cosine_wave3_`) with weighted different amplitudes (`cosine_amp1_`, `cosine_amp2_` and `cosine_amp3_`). The beginning `beg3_` and ending `end3_` of the meandering stream in the third dimension need to be specified along with the angle `angle_` of the stream path. Figure 7 shows an example of both the meandering stream channel and the erosion bowl.

Emplace

Currently `Geomodel` has a rudimentary ability to emplace constant velocity shapes (such as salt). Emplacements are first described on a 2-D rectangular grids whose extents vary from 0,0 to `extent2_`, `extent3_`. The top and bottom of the emplaced object are described by a series of points that are interpolated to fill the entire 2-D grid. The number of points describing the top and bottom are specified using `npts_top_` and `npts_bot_`. The points themselves are defined using the parameters `pts_top_i_j` and `pts_bot_i_j` where `i` is the event and `j` is the number of the current point. Two regular surfaces are then interpolated and everywhere the top surface is above the bottom surface the property value `prop_` is assumed. The 0,0 location of the defined grid is then shifted to `pos2_` and `pos3_` at the angle `angle_`. Sediments to the side and above the emplacement are shifted by `shift_up_` amount. Figure 8 shows an example of emplacing a salt body.

DISCUSSION AND FUTURE WORK

The most obvious is the ability to handle curved faults (though this can be simulated by a series of planar faults). The ability to handle planar unconformity and allowing non-planar deposition should be added. Improving the mechanism for emplacing constant velocity structures and creating anticline-syncline structures would be useful.

CONCLUSIONS

Complex synthetic models are useful not only for benchmarking but in the code development process. Complex models can be built up by simulating a series of geologic events such as deposition, erosion, and faulting. `Geomodel` represents an initial attempt to simulate geologic phenomena that can build multi-parameter earth models.

REFERENCES

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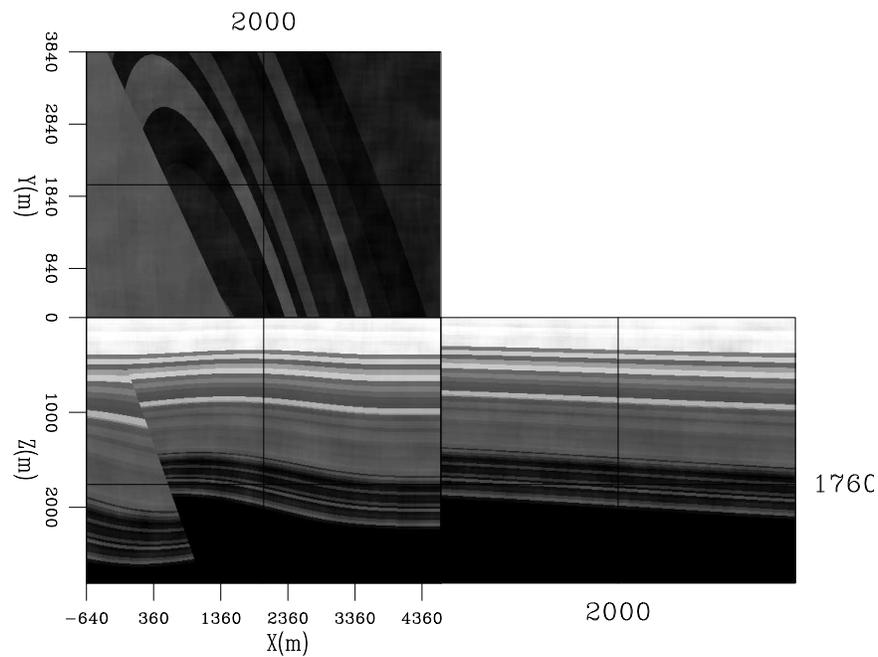


Figure 3: An example of applying faulting to a layered model. Note the decay in fault displacement as we move away from the fault. [ER]

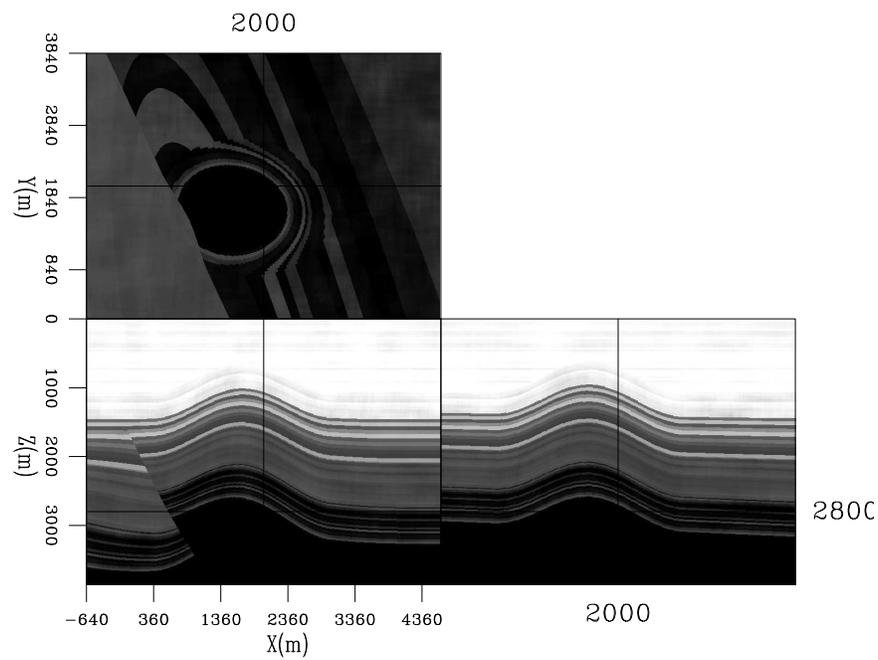


Figure 4: An example of applying uplift, simulating an anticline, to the faulted model shown in Figure 3. [ER]

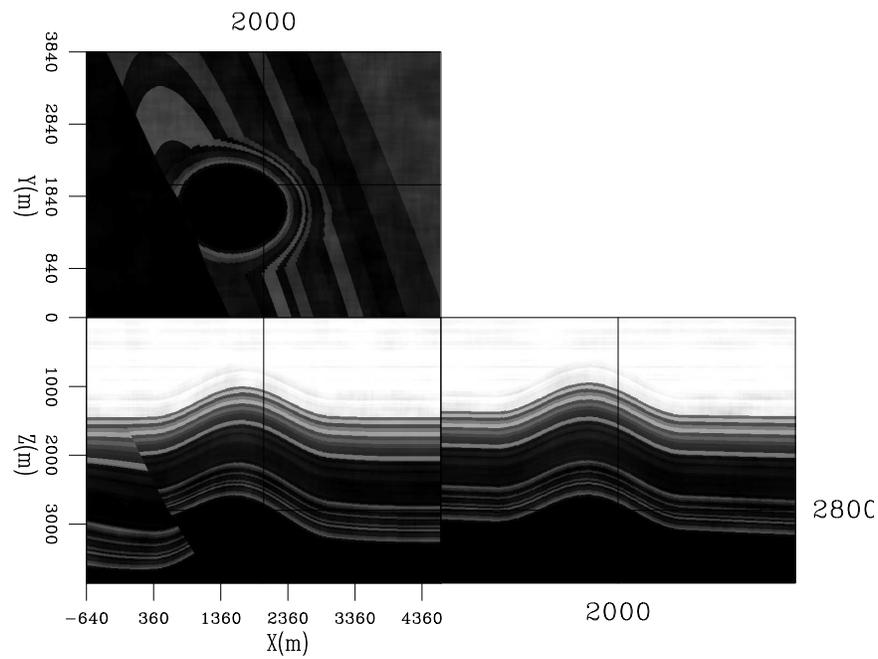


Figure 5: An example of applying the compaction parameter. In this case one layer is compacted before uplift, and another, after uplift. [ER]

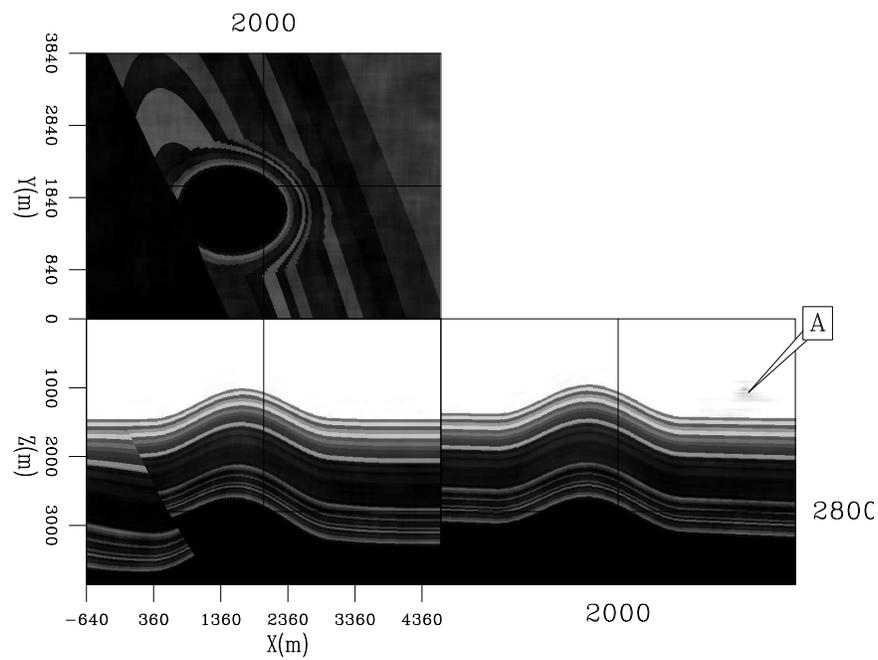


Figure 6: The result of adding a Gaussian anomaly to the model shown in Figure 5. The Gaussian anomaly can be seen at 'A' [ER]

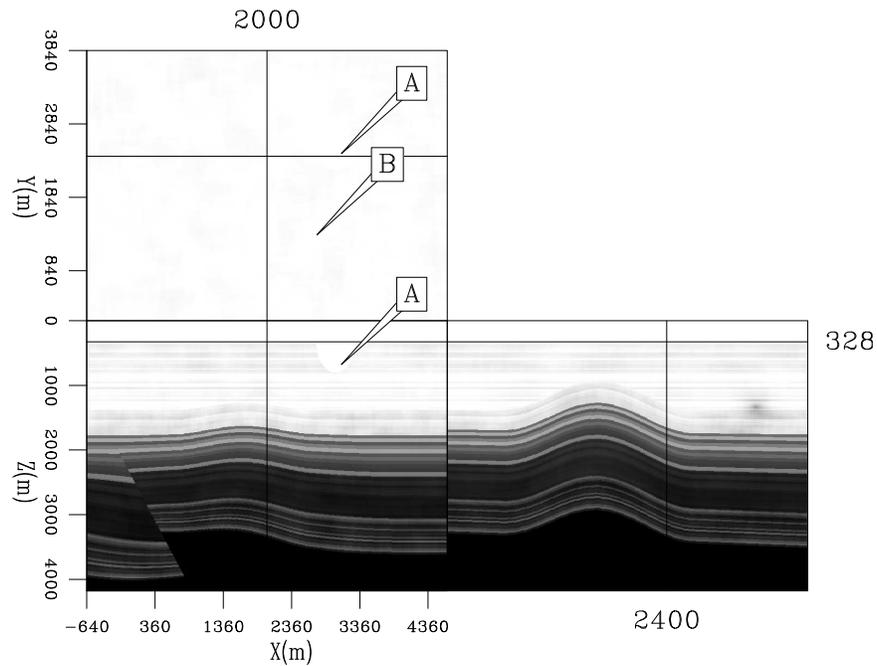


Figure 7: An example of the two type of erosion possible with **Geomodel**. Note how the river channel and the bowl are partially filled in with lower velocity sediment. 'A' marks the bowl erosion, while 'B' shows the river channel. [ER]

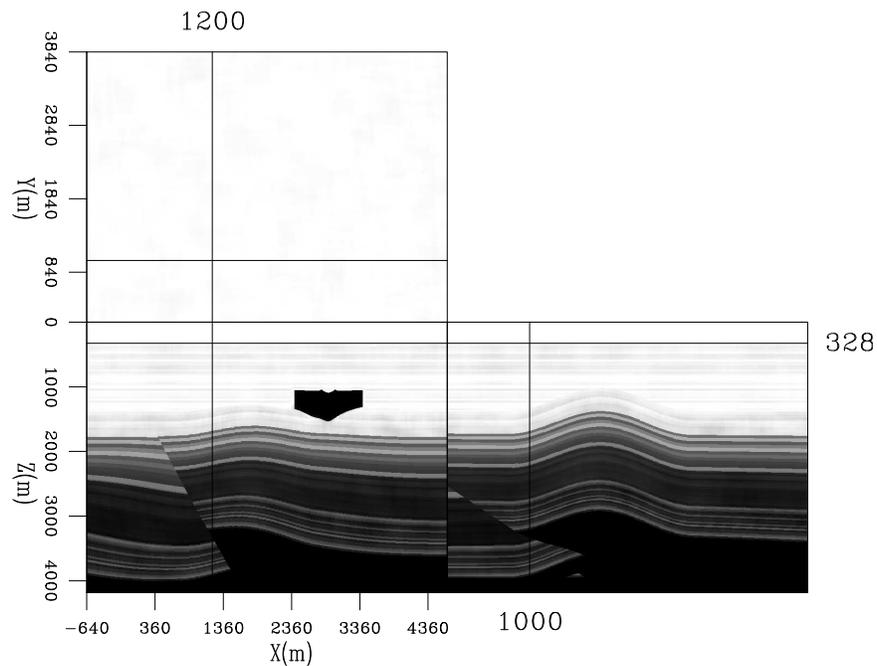


Figure 8: An example of emplacing a salt body into a model. Note how the sediments to the side have been shifted up. [ER]