Theoretical Morphology – Modeling the Growth of Clonal Organisms

GEOL 305 - PALEOBIOLOGY

The aim of modeling the morphology of organisms (or anything else) is to set up a "simple" description of the real world using explicit assumptions and then see what happens in the virtual world. This approach makes predictions about what we expect to see in the real world, if the assumptions are correct. By collecting data (i.e., measuring the real world), we can test to see if the model system is a good description or not. Note that just because a model is a good description of the real world does not necessarily mean it is true. Once we are satisfied that the assumptions reflect the important processes that occur in reality, we can use the model to explore the full range of variations we would expect to see under any given circumstances. This can give us insight into the processes controlling a system as well as reveal patterns that do not exist (thereby spurring us to ask why they do not exist).

The system that we will be modeling is the growth of stromatoporoids, which are an extinct group of sponges that built massive, carbonate skeletons. Kershaw (1988) provides a brief introduction to the glories of these organisms. The reason to care about these extinct sponges is that at certain times in Earth's past, they were major rock formers. In the Devonian and Silurian and parts of the Mesozoic they formed reefs that are 100-1000s of meters thick or formed fields of bioherms (biologically created features that protrude above the sediment surface; small organic reefs) across broad platforms 10's of km wide. Their morphology is thought to reflect the conditions of sedimentation (Kershaw, 1988) and this is what you will be modeling.

Stromatoporoid growth can be simulated using a "probabilistic accretionary model" (Swan and Kershaw, 1994). Despite the complex name, the idea is very simple: start with one square "cell". Assume that the likelihood of the cell multiplying into an adjacent square space in a given unit of time has a certain probability (let's say, 0.7). For each space adjoining a flat side of the square cell (not the corners), we pick a random number between 0 and 1. If the random number is below the probability value, then we fill the previously empty space with a new cell. If the random number is above the probability value, then the empty cell remains empty. We "roll the dice" in this manner for every space adjacent to an already occupied cell. Those cells that are filled as a result of this process represent new growth on the sponge. The virtual sponge continues to grow by repeating this process again and again (a process called "iteration"). In cases where an empty space is adjacent to two or more filled cells, assume that the probability of growth into that space is higher than if it was adjacent to just one cell (this makes intuitive sense but is one of the fundamental assumptions of this model). We can let this model run for as many time steps as we like and see what grows. Note that growth by the addition of identical units is "accretionary" and choosing random numbers makes this a "stochastic" or "probabilistic" model (as opposed to a deterministic model in which mathematical equations allow only one possible outcome), hence the name "probabilistic accretionary model". Details of how this algorithm (i.e., a set of computer instructions) is implemented are described in detail by Swan and Kershaw (1994).

Building on this basic model, we can simulate *geotropism* by altering the probability of growth in the vertical and horizontal directions (negative geotropism is growth away from the Earth – in other words, upward growth; positive geotropism is growth toward the Earth). We can add sedimentation and assume that sediment kills the sponge where the organism is covered (i.e., growth stops) or that the sponge grows faster along those edges that are adjacent to the sediment (because there is a supporting surface to grow on). Once sedimentation is incorporated, we can change the rate and continuity of deposition to see how the morphology of stromatoporoids might be expected to change.

Exercises

Definitions:

Random seed = this number starts the sequence of random numbers used by the model. Different values will produce slightly different results.

Geotropism = this must be a positive number greater than zero. Values greater than 1 increase the rate of vertical growth relative to horizontal growth (negative geotropism). Values between 0 and 1 decrease the rate of vertical growth relative to horizontal growth.

Effect of Sediment = values greater than 1 increase the probability of accretion by cells adjacent to the sediment surface (i.e., the sponge grows faster along the sediment surface).

Sedimentation Increment = if deposition is occurring, how much is dumped in a single event.

Interval Between Sedimentation Increment = number of iterations between deposition events.

Start-up Interval = number of iterations before first depositional event.

In the following exercises the values you should use to answer each question are given in parentheses. For example, (#,1,0,16,20,40) means that the random seed can be any value you choose, geotropism is 1, effect of sediment is 0, sedimentation increment is 16, interval is 20, and start-up interval is 40. Note that these are in the same order that the program requests them. You should use the same random seed for all your simulations (it can be you birth date, phone number, student id, lucky number, or anything else you like) – this means that the string of random numbers is the same for each simulation and differences in each run are not due to the vagaries of randomness.

1.) (#,1,0,0,0,0) – Run five base line simulations under the same conditions but with different strings of random numbers (i.e., vary the random seed). How much variation is there due to just random differences? What are the similarities? Rerunning a model to see if the results differ when using different starting points or different random number strings is called "sensitivity analysis".

For the rest of the exercises, do just one run using the same random number for each exercise.

2.) (#,10,0,0,0,0) – What is the effect of negative geotropism?

3.) (#,0.1,0,0,0,0) – What is the effect of positive geotropism?

4.) (#,1,10,0,0,0) – How does a positive effect on growth of cells in contact with sediment influence the shape of the sponge? (Compare to those in exercise 1 and 3)

5.) (#,1,0,1,2,20) – How does sedimentation change the shape and growth characteristics of the sponge? Calculate the net rate of sedimentation (Increment/Interval).

6.) (#,1,0,10,20,20) – How does intermittent sedimentation change the growth of the sponge? Calculate the net rate of sedimentation. How does it compare to the shape in exercise 5?

7.) (#,1,0,4,5,40) – What is the net rate of sedimentation? What is the shape of the sponge? What is the rate of sedimentation relative to the rate of sponge growth?

8.) (#,1,0,8,10,40) – What is the difference in parameters between this run and exercise 7? How does it influence the shape of the sponge?

9.) (#,1,0,16,20,40) – What is the difference in parameters between this run and exercises 7 and 8? How is the shape of the sponge changed?

10.) (#,1,0,1,1,40) – What is the difference in parameters between this run and exercise 5? How is the shape changed. How could you tell a shape like this from one generated in exercise 2?

11.) (#,1,0,10,10,40) – What is the difference in parameters between this run and exercise 10? How has the shape changed?

12.) Redo exercise 8 but use start-up times of 10, 20, and 30. What is the influence of start-up time on the growth history of the sponge? In this model, we have assumed a constant growth rate of the sponge during a period of no sedimentation at the start. If sedimentation does not stop, how else could we get the same effect?

To be handed in:

1.) Answer the questions above (include a figure of each run).

2.) Summarize your findings focusing on interpretation of stromatoporoid shape in the rock record. What might particular morphologies tell you about sedimentation conditions? Use these clues to interpret the four specimens of stromatoporoids and chaetetids (another group of sponges that grew in a similar manner). Include a well justified interpretation of specimens 734, 9156, 1044, IC-7, and IC-9, comparing each with the other specimens.

References

Kershaw, S., 1988, Stromatoporoids: A Beginner's Guide. Geology Today, p.202-206.

Kershaw, S., 1998, The Applications of Stromatoporoid Palaeobiology in Palaeoenvironmental Analysis. Palaeontology, v. 41, p. 509-544.

Swan, A.R.H. and Kershaw, S., 1994, A Computer Model for Skeletal Growth of Stromatoporoids. Palaeontology, v. 37, p. 409-423.