Theory of the stratigraphic filter

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Elevation and stratigraphy

Sedimentary rocks record the conditions of Earth's surface at various times in the past. Sediments are retained in the rock record only if they are *never* eroded at some later time. This theory, coupled with the observation that measured sedimentation rates decreases with increasing time span measured over (often called the Sadler effect (Sadler 1981)), lead researchers to try and understand why the stratigraphy records only a vanishingly small fraction of time—in other words, the stratigraphic record is remarkably incomplete (Paola et al. 2018). Tipper (1983) was the first to apply a random walk model to the problem of stratigraphic completeness, wherein he presented a model for how erosional events eliminate positive elevation changes from deposition, and thus preclude large periods of time from the stratigraphic record.

Consider Figure 1, which depicts the surface elevation at a single location over time (black line), where the surface elevation is changed by a random amount (dz) each timestep (dt); thus, the resulting timeseries of elevation is called a *random walk*. The *stratigraphic filter* is the process by which periods of time (typically when the elevation was relatively high) are removed by erosive events. Stratigraphy is calculated by finding the most recent time that the surface elevation was equal to the corresponding stratigraphic position (Schumer, Jerolmack, and McElroy 2011).
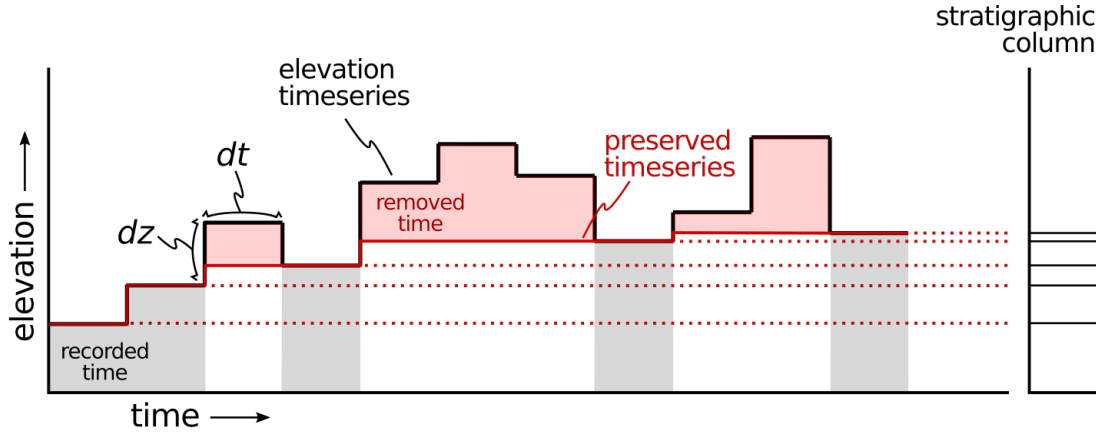

Figure 1: Schematic drawing of a random walk model for stratigraphic development. Each timestep the elevation is changed by adding a randomly drawn Δz value from a probability distribution. The stratigraphy is calculated after the model run is completed, by the routine presented in the following section.

For more information, see the review of time and stratigraphy given by Paola et al. (2018).

Changing the distribution of the random walk

In the model, the change in elevation at a given timestep is drawn randomly from a normal distribution, with mean μ and standard deviation σ. The random walk determined by these elevation changes is geologically analogous to a rough surface—as the surface evolves over time, even if it is simply translated in one direction, the elevation at any one location goes up and down over time, due to the surface roughness.

Variance of elevation change

If the variability of the surface elevation were to increase, it is reasonable to expect a change in the functionality of the stratigraphic filter.

1. Take note of the "fraction of time preserved" for the 500-run statistic: _____.
2. How does the fraction of time preserved change when the standard deviation of the distribution is increased to $\sigma = 2$: _____.
3. Does the mean bed thickness change for an increase from $\sigma = 1 \rightarrow \sigma = 2$? Why or why not?

   _____.
4. How does the functionality of the stratigraphic filter change when the standard deviation is decreased? Explain._____.

Aggradation and "drift"

As discussed above, for sediment to be retained in the rock record, the sediment must never again be eroded. Thus, the farther the vertical distance from deposited sediments to the active surface, the higher the chance of preservation of that sediment. In geologic systems, this concept is formalized by *compensation*, which is a metric of how much space is available for sediment to accumulate (at any one location this "space" is given by a vertical distance). Over long timescales, the geologic system increases or decreases the amount of compensation at any location by a multitude of processes. Regardless of the process, increasing compensation generally leads to *aggradation* of the surface elevation (or an increase in the surface elevation). In the random walk model, this concept is sometimes called the model *drift*, and it can be approximated by simply changing the mean of the distribution from which dz is drawn.

Experiment with how changing the mean and standard deviation each lead to variations in the behavior of the stratigraphic filter. Record some of your observations below:

Further discussion questions

1. How can we learn about what happened on the surface during times when there is no sediment preserved? In the model, the elevation timeseries is still known, despite the stratigraphic filter—is there any way to recover the elevation timeseries from the real rock stratigraphic record?
2. Write an algorithm (or mathematical expression) for calculating the stratigraphy S from a given elevation timeseries Z. Both S and Z should be vectors that have a real number value for each timestep t.

References

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