Why Geological Angular Unconformity Is Usually Horizontal: A Geometric Explanation

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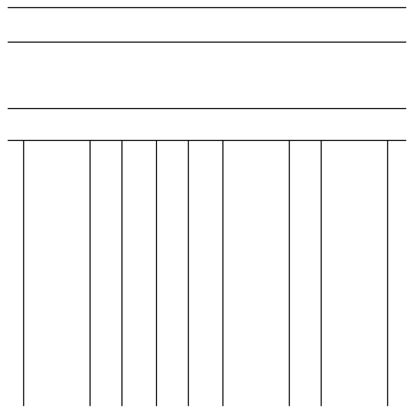
Abstract

In several locations, geologists have observed the presence of two differently oriented rock masses, one horizonal (or almost horizontal) and the other somewhat inclined; this phenomenon is known as angular unconformity. Based on the detailed analysis of geophysical processes, geologists conclude that usually, horizontal rock masses are much newer. This is known as the law of original horizontality. From the fundamental viewpoint, it is desirable to take into account that geophysics is a developing science, its models get modified and adjusted as time progresses. It is therefore desirable to come up with an explanation of this phenomenon that would be maximally independent on any specifics of a geophysical model. In this paper, we show that the law of original horizontality can be derived by using only the general geometric symmetry ideas.

1 Formulation of the Problem

What is angular unconformity. In the late 18th century, geologists found several locations where two differently oriented rock masses were present. For example, in an angular unconformity at Siccar Point, Scotland – one of the first to be discovered – one of the masses is horizontal and another one is vertical:



Analysis of possible geological processes that could lead to such unconformities was one of the factors leading geologists to conclude that a large period of time has passed between the formation of the two rock masses – and thus, adopt a longer (and more accurate) time scale for geological processes.

The discovery and analysis of unconformities was an important step in developing modern geology, so important that most textbooks contain a picture of an unconformity – usually the Siccar Point one – and, as a result, most geologists can recognize this picture.

Empirical fact. Since the last 18th century, many different angular unconformities have been discovered. In different unconformities, we have different angles of both rock masses. In some cases, the newer rock masses are horizontal – as in Siccar Point, in other locations, the newer rock masses are vertical. The orientation of older rock masses also differs from one location to another.

Interestingly, in the vast majority of locations, the newer rock masses are horizontal (or almost horizontal). This is known as "the law of original horizontality"; see, e.g., [5] and references therein.

How is this empirical fact explained now. The law of original horizontality is usually explained by specifics of geological processes.

Why a more general explanation may be desirable. Geology is an evolving discipline. Our understanding of geological processes becomes more accurate with any new discovery, with new observations, with new data processing techniques. It is therefore desirable to come up with an explanation that does not depend on the specifics of our current understanding of geological processes, an explanation that will remain valid if our understanding slightly changes (as it inevitably will change).

What we do in this paper. In this paper, we show that this law can be explained by general geometric symmetry-based arguments, without the need to involve the specifics of geological processes.

2 Our Explanation

Main idea behind our explanation. The main idea behind our explanation is that usually, the initial state of any physical system – be it the Universe as a whole or the geological structure of the Earth – has a lot of geometric symmetries, i.e., is invariant with respect to several rotations and/or shifts.

Such symmetric structure is often unstable: a disturbance appears at some location(s), this disturbance grows, and the system is no longer invariant with respect to all original symmetries. In principle, it is possible that the system goes from the original highly symmetric state to the state with no symmetries at all. However, according to statistical physics (see, e.g., [1, 6]), it is much more probable that the new system retains some of the original symmetries – and the more symmetries remain in a state, the more probable is a transition to this state.

Eventually, in this new less-symmetric state, a new disturbance appears that eventually leads to a state with even fewer symmetries, etc. We can therefore gauge the relative age of different states by comparing their symmetries: younger systems usually have more symmetries, while older systems usually have fewer symmetries.

Comment. This idea has many applications. For example, it explains the shapes of celestial objects, the dynamics of this shape, and – on the qualitative level – the relative frequency of different shapes; see, e.g., [2, 3, 4].

Resulting explanation. Planets has approximately spherical form – so locally, the planet's surface is approximately a plane. This shape is invariant with respect to shifts and rotations around a vertical line. In line with the above general idea, the original shape of the upper surface of a rock mass should be invariant with respect to all these transformations. One can easily see that every two points on a plane can be transformed into each other by an appropriate shift. So, the only surface that is invariant with respect to all these symmetries is a horizontal plane.

With time, some symmetries are violated, so we get a shape with fewer symmetries. An inclined plane is an example of such a less-symmetric shape: – it is no longer invariant with respect to rotations around a vertical axis.

So, it makes sense to conclude that, in general:

- horizontal rock masses correspond to more recent rocks, that did not yet have time to deviate from the original symmetry, while

- the inclined rock masses correspond to older rocks, that have already gone through the corresponding symmetry violations.

This is exactly what the law of original horizontality says.

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