Why Seismicity in Ireland Is Low: A Possible Geometric Explanation

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Abstract For each geographic location, its seismicity level is usually determined by how close this location is to the boundaries of tectonic plates. However, there is one notable exception: while Ireland and Britain are at approximately the same distance from such boundaries, the seismicity level in Ireland is much lower than in Britain. A recent paper provided a partial explanation for this phenomenon: namely, it turns out that the lithosphere under Ireland is unusually thick, and this can potentially lead to lower seismicity. However, the current explanation of the relation between the lithosphere thickness and seismicity level strongly depends on the specific details of the corresponding hypothetical mechanism. In this paper, we provide a general geometric explanation of this relation, an explanation that does not depend on the specific geophysical details.

1 Formulation of the problem

Irish vs. British seismicity: a puzzle. It is well known that earthquakes are mostly concentrated on the boundaries of the tectonic plates. However, some seismic activity is happening inside the plates as well. In general, closeness to the plate boundary determines the level fo seismic activity. However, there is a known exception: Ireland.

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Ireland is located very close to Britain, at almost the same distance from the plate boundaries, but the level of seismicity in Ireland is much smaller than the level of seismicity in Britain – and, in general, much smaller than in other areas at similar distance from the plate boundaries.

A recent partial explanation. A partial solution to this puzzle appeared in a recent paper [4]. Namely, it turns out that the lithosphere beneath Ireland is unusually thick – and it turns out that, in general, the level of seismicity decreases when the lithosphere becomes thicker.

Remaining question and what we do in this paper. The remaining question is why the thickness of the lithosphere affects the seismicity level. The paper [4] provide possible physical mechanisms explaining this dependence. However, the resulting explanation strongly depends on the specifics of this hypothetical mechanism, and it is not clear whether possible variations of this mechanics would still preserve the observed dependence.

It is therefore desirable to come up with an explanation that would not depend on the specific details, a more first-principles explanation. In this paper, we provide such explanations based only on geometry and related symmetries.

2 Our explanation

Main idea behind our explanation. Many phenomena in the world have some invariance properties. For example, equations of motion do not change if we shift all the involved bodies to a different location or rotate them all by the same angle around the same axis. Electric interactions do not change if we replace all positive charges with negative ones and vice versa. The corresponding invariances – that physicists call *symmetries* – are one of the fundamental features of physics; see, e.g., [1, 6].

Many states are invariant with respect to the corresponding transformations – at least locally. For example, many materials are homogenous and isotropic – meaning that their properties do not change if we go from one location to another (i.e., perform a shift) or if we rotate the object.

Many such invariant configurations are reasonably stable, but with time, random fluctuations may eventually lead to the breaking of – at least some of – the corresponding symmetries. For example, if we start with a glass of water – which is homogeneous – and start boiiling it, eventually bubbles will appear in some of the locations – but not in others, so this invariance will be broken.

Such symmetry breaking – caused by random fluctuations – are studied by statistical physics, a branch of physics that describes the effect of random processes on physical objects. According to statistical physics, the transition from a fully symmetric state to a state with no symmetries at all is highly improbable. Much more probable (and thus, much more frequent) are transitions in which the resulting state retains some of the original symmetries. In general, the fewer symmetries are broken, the more probable the corresponding transition; see, e.g., [1, 6].

This idea is actively used in physics: for example, it explains shapes and relative frequencies of celestial bodies form galaxies to configuration of planets; see, e.g., [2, 3, 5]. In this paper, we show that the same idea can explain the relation between seismicity and the thickness of the lithosphere.

Let us apply this idea to our problem: what are original symmetries. From the geometric viewpoint, thin lithosphere means that – at least locally – ir loos like a plane, while thick lithesphere means that we can no longer ignore its 3-D nature and have to consider it locally as a 3-D body.

It is easy to see what are the symmetries in both cases. In both cases, the configuration is reasonably homogeneous and isotropic, i.e., invariance with respect to shifts and rotations.

In the 2-D case, the configuration is invariant with respect to all shifts in a 2-D plane – which form a 2-parametric family, and with respect to all the rotations in a plane – which form a 1-D family. So overall, we have a 3-parametric family of symmetries.

In the 3-D case, the configuration is invariant with respect to all shifts in the 3-D space – which form a 3-parametric family, and with respect to all the rotations in space – which form a 3-D family. So overall, we have a 6-parametric family of symmetries.

How does an earthquake changes the symmetries. An earthquake means, in geometric terms, that a fault line appears on the surface of the Earth, a fault line that goes deep inside the Earth. In the 2-D case, it means that instead of the plane with nothing on it, we now have – locally – a plane with a fixed straight line in it. Similarly, in the 3-D case, it means that instead of the 3-D space with nothing on it, we now have – locally – a space with a fixed plane in it.

What are the symmetries of the resulting configurations?

In the 2-D case, the only remaining symmetry is shifts along the line. These shifts form a 1-parametric family. So, instead of the original 3-parametric family of invariances, we now have a 1-parametric family – thus, we lose $3-1=2$ parameters.

In the 3-D case, the remaining symmetries are shifts in the directions of the plane – which form a 2-parametric family – and rotations around an axis orthogonal to this plane – which form a 1-parametric family. These symmetries form a 3-parametric family. So, instead of the original 6-parametric family of invariances, we now have a 3-parametric family – thus, we lose $6-3=3$ parameters.

This explains the relation between seismicity and the thickness of the lithosphere. We have shown that an earthquake in a thin lithosphere means losing 2 parameters of symmetries, while an earthquake in a thick lithosphere means losing 3 parameters of symmetries. As we have mentioned earlier, the fewer invariances we lose in a transtion, the more probably – and thus, more frequent – this transition. Since we lose fewer symmetries in the case of a thin lithosphere, this means that seismic events are more probable and more frequent for ares with thin lithosphere than in areas with thick lithosphere. This is exactly what we tried to explain.

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