On the antipodal symmetry and seismic activity.

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Abstract. The article discusses the global aspects of the (almost) antipodal symmetry on Earth which should have been widely known by now but somehow managed to stay unnoticed.

Key words: Antipodal symmetry, seismic activity, continental drift, tectonics.

In 1596 Abraham Ortelius noticed that the shapes of continents on opposite sides of the Atlantic Ocean, most notably Africa and South America, seem to fit together; since then a number of scientists had discussed the observation and provided numerous explanations. Three centuries later Alfred Wegener put all these theories together to what is now known as the theory of Continental Drift, [8]. The theory of Continental Drift had not been completely accepted until 1950s when it was finally validated and expanded into more general theory of Plate Tectonics. In this article we present three similar observations concerning geological structures and their antipodes; we will refrain from discussing what geophysical mechanisms might be behind them. What we discuss here is quite simple and it is very surprising it has gone unnoticed until now.

The *antipodal point*, or simply *antipode*, of a point $\lambda^o N/S, \phi^o E/W$ on the surface of the Earth is the point $\lambda^o S/N, (180-\phi)^o W/E$ located diametrically opposite, so that a line drawn from the one to the other passes through the center of the Earth. The *antipodal shadow*, or simply

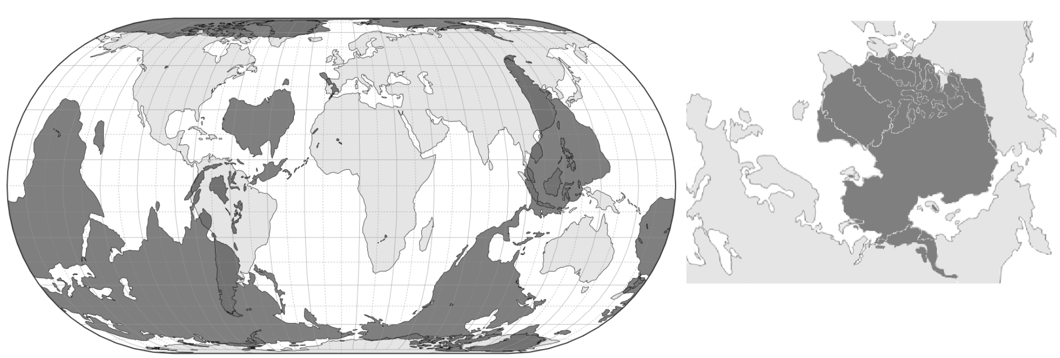

Figure 1: The left frame shows the map of the world with the antipodes of continents shown in black. The right frame shows the map of the Arctic with the antipode of Antarctica shown in black. The maps were produced using [1].

antipode, of a geographic place (continent, island, sea, etc.) is the set of all points antipodal to the points of the original geographic place. A good interactive map of the world with antipodes of the continents may be found at [1], a snapshot is shown in Figure 1. Given the heterogeneity of the Earth, one should not expect exact antipodal symmetry, but does there exist 'almost antipodal symmetry', i. e. are there 'almost antipodal events', that is events which take place at almost antipodal locations at almost the same time? The answer is known to be positive; an example of an almost antipodal event is high/low tide which appears at almost antipodal locations at almost the same time. Some geographical features appear almost antipodally, e. g. 1) the Morokweng Crater at $26.4667^o S, 23.533^o E$ and the Vredefort Crater at $27^o S, 27.5^o E$ are almost antipodal to seismically active region of Hawaii centered at $21.3^o N, 157.8^o W$; 2) volcano Mount Sabancaya at $15.78^o S, 71.85^o W$ is almost antipodal to Mount Pinatubo at $15.1417^o N, 120.35^o E$; 3) crescent-like lake Baikal stretching from $51.7^o N, 103.7^o E$ to $55.9^o N, 109.7^o E$ is almost antipodal to a tectonic line stretching from $52^o N, 76.5^o E$ to $56^o N, 72^o E$; etc. A number of theories, e. g. antipodal volcanism, shock dynamics, were put forward to explain the almost antipodal symmetry of such phenomena. All known displays of almost antipodal symmetry are local, in the sense that they appear in small regions of the Earth's surface, e.g. high/low tide, volcanoes. Here we will concentrate on global displays, i. e. the phenomena which illustrate the almost antipodal symmetry on the planetary scale.

Almost antipodal continental fit. It is well-known that the continents/continental shelves almost fit each other like in a jigsaw puzzle, we shall refer to it as the *direct continental fit*; its numerous illustrations may be found online, e.g. [8]. Remarkably, the antipodes of the continents/continental shelves also fit with the adjacent continents/continental shelves in similar manner. Figure 2 illustrates how the boundaries of the antipodes of the continental shelves of Africa; southern Eurasia, including the islands of South Pacific Asia; and Australia fit the West and South Costs of North America; the eastern boundary of the North American continental shelf and the western part of the Eurasian continental shelf just west of Ireland. The maps in Figure 2 are in the Mercator projection which preserves local directions but stretches regions at latitude λ by the reciprocal of $\cos\lambda$.

Figure 3 shows the contours of the antipode of the Australian continent also fit nicely with the contours of the North American, South American and African continents and in two different

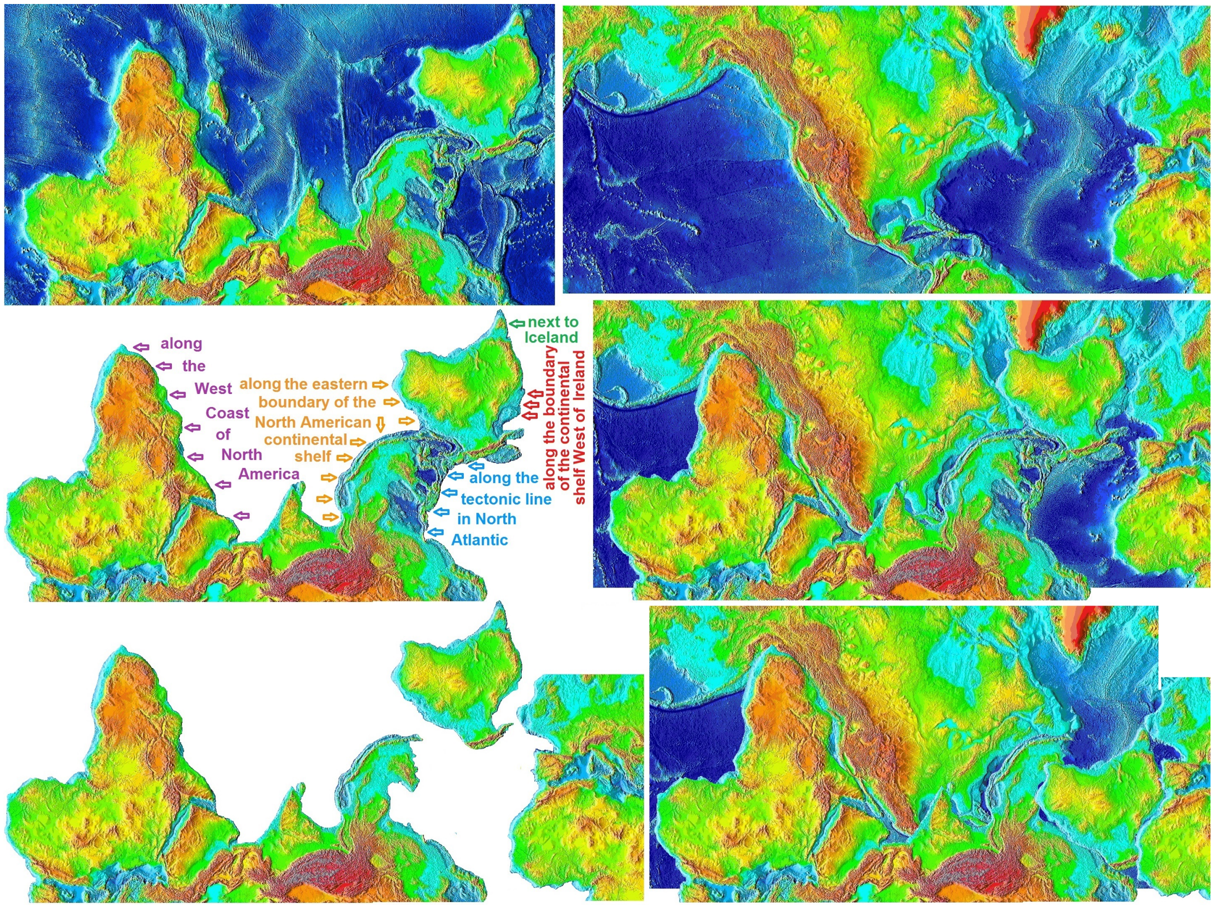

Figure 2: The top left frame is the antipodal map of the region containing Africa; southern Eurasia, including the islands of South Pacific Asia; and Australia. The top right frame is a map of North America and the adjacent regions of the Pacific and Atlantic. The middle left frame shows the antipode of the continental shelf of Africa; the antipode of the continental shelf of southern Eurasia, including the islands of South Pacific Asia; and the antipode of the continental shelf of Australia. The middle right frame shows the image from the middle left frame superimposed on the map in the top right frame. The arrows in the middle left frame indicate corresponding parts of the map in the top right frame. The bottom let frame shows the antipode of the continental shelf of Africa and Eurasia, including some of the islands of South Pacific Asia; the antipode of the continental shelf of Australia and the continental shelves of Africa and Europe. In the bottom right frame we superimposed the antipode of continental shelves of Africa and Eurasia on the top right map, then added the antipode of Australian continental shelf, and then added the continental shelf of Africa and Europe. The images are in the Mercator projection, which preserves angles but expands lengths at latitude x by the reciprocal of $\cos x$. The maps are from [4].

ways.

Figure 4 shows how the boundaries of the Antarctica continental shelf fit the boundaries of the Arctic also in two different ways. The first fit is obtained by rotating the antipode of Antarctica

Figure 3: The first two frames show two ways to fit the antipode of the Australia's continental boundaries to the boundaries of North America, South America, and Africa. The third frame shows the fit of the antipode of the Australian continental shelf to the continental shelves of North America, South America, and Africa, somewhat similar to the middle frame. The images are from [1], [4].

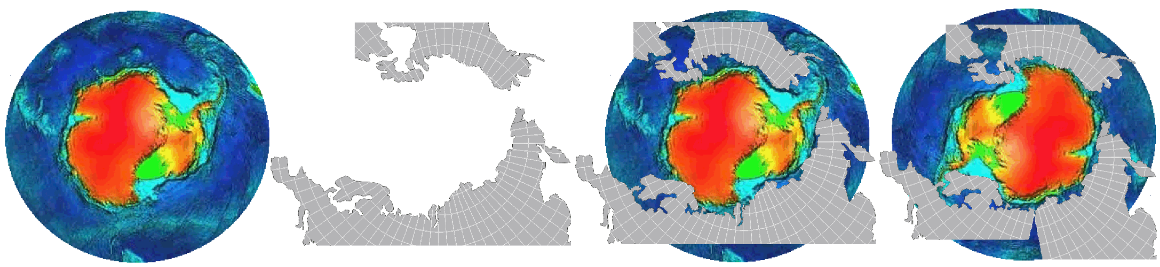

Figure 4: The first frame shows how the antipode of Antarctica continental shelf, while the second frame shows the contours of the Arctic continents. The third frame shows how contours of the Arctic continents wrap up around the antipode of the Antarctica continental shelf shown in the first frame. The fourth frame shows how the contours of the Arctic continents wrap up around the antipode of the Antarctica continental shelf from the first frame but rotated by 180^o. The opening in North Atlantic between Europe and North America is filled with the antipode of the Australian continental shelf as shown in Figure 2. The images are from [1], [4].

by $\approx 63^o$ eastwards, the second fit is obtained by rotating the antipode of Antarctica by $\approx 60^o$ westwards.

We shall refer to the fit of the antipodes of the continents/continental shelves to the adjacent continents/continental shelves as the *antipodal continental fit.* The antipodes of the continents/continental shelves have no business to fit the continents/continental shelves so well, yet they do; and that cannot be dismissed as merely accidental.

Figures 2, 3, 4 involve almost all continents and their boundaries, the only ones missing are South America and the eastern border of Eurasia from Japan to Kamchatka. Although there are several ways to include South America and the eastern border of Eurasia in our picture, none is as good and as natural as the fits in Figures 2, 3, 4.

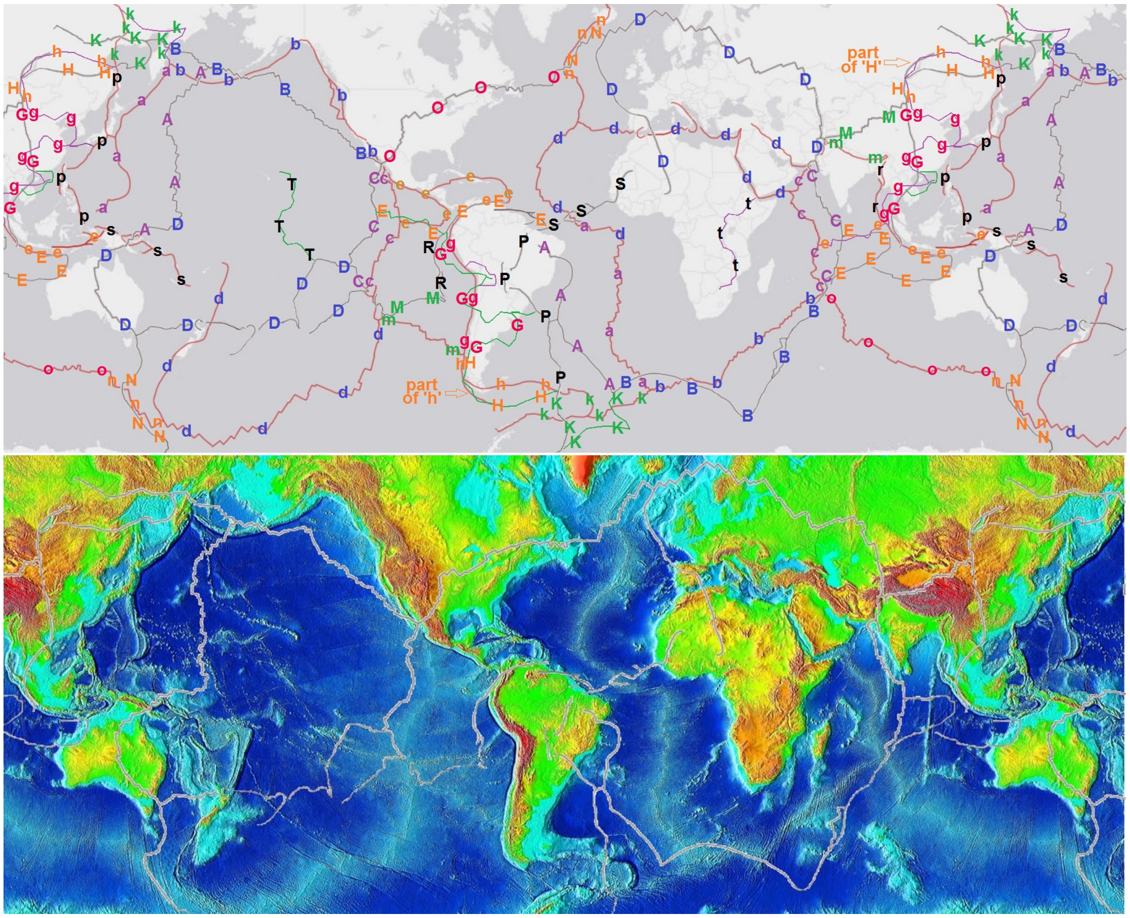

Figure 5: The top frame shows major tectonic lines in maroon, the antipodes of the major tectonic lines in dark grey, long rift lines in purple and the antipodes of the long rift lines in green, [6], [2]. The bottom frame shows the antipodes of the major tectonic lines superimposed on the geographic map, [4]. Two almost antipodal tectonic lines are labeled by the same small letter, their antipodes by the same capital letter. Some tectonic lines slightly overlap. The shapes of 'a' and 'A' lines even look alike, as do 'b' and 'B', 'c' and C', 'd' and 'D', 'h' and 'H', 'n' and 'N'. Tectonic line 'o' does not have an almost antipodal tectonic line; its antipode runs across North America along the Saint Lawrence rift system, Midcontinent rift system and the eastern border of the North American Mountains. The 'r' line may be viewed as a branch of the 'g' line, as may be the 'p' line. Part of the 'E' line by Australia fits between Australia and Indonesia; the 'M' line in Asia closely follows the Himalayan landscape. The 't', and 's' lines do not seem to have antipodal matches.

Almost antipodal symmetry of tectonic lines. Tectonic lines are the boundaries of the tectonic plates; their almost antipodal symmetry is illustrated in Figure 5. Remarkably, almost the antipode of almost each tectonic line is geographically close to another tectonic line of almost the same shape.

Almost antipodal symmetry of seismic activity. Although there is no example of a pair of earthquakes with epicenters at two exactly antipodal locations, there are many which struck at almost antipodal locations at almost the same time; here are some examples according to [6]:

1) magnitude 8.0 earthquake near Peru at $14.0^oS, 78.0^oW$ on December 12, 1908 at 12:08 UTC and magnitude 7.0 earthquake in Myanmar at $26.5^oN, 97.0^oE$ on December 12, 1908 at 12:55 UTC;

2) magnitude 6.5 earthquake near Taiwan at $24.0^oN, 121.6^oE$ on December 11, 1912 at 18:07 UTC and magnitude 7.3 earthquake in Argentina at $29.0^oS, 62.5^oW$ on December 7, 1912 at 22:47 UTC;

3) magnitude 6.9 earthquake in Argentina at $31.0^oS, 70.0^oW$ on July 27, 1917 at 2:52 am UTC; and magnitude 7.3 earthquake in China at $29.0^oN, 104.0^oE$ on July 30, 1917 at 23:54 UTC;

4) magnitude 7.7 earthquake in India at $23.419^oN, 70.232^oE$ on January 26, 2001 at 16:40 UTC and magnitude 5.4 earthquake in East Pacific Rise at $24.046^oS, 115.395^oW$ on January 29, 2001 at 15:26 UTC;

5) magnitude 6.1 earthquake in Taiwan at $24.069^oN, 122.264^oE$ on May 28, 2002 at 16:45 UTC and magnitude 6.0 earthquake in Argentina at $28.937^oS, 66.797^oW$ on May 28, 2002 at 4:04 am UTC;

6) magnitude 7.3 earthquake near Sumatra at $2.433^oN, 93.21^oE$ on January 10, 2012 at 18:37 UTC and magnitude 5.0 earthquake near Ecuador at $0.74^oS, 80.28^oW$ on January 10, 2012 at 18:07 UTC;

7) magnitude 6.0 earthquake in Venezuela at $10.905^oN, 62.315^oW$ on October 12, 2013 at 02:10 UTC and magnitude 7.1 earthquake in the Philippines at $9.880^oN, 124.117^oE$ on October 15, 2013 at 00:13 UTC;

8) eruption of volcano Tungurahua in Ecuador at $1.467^oS, 78.442^oW$ on April 15-21, 2015 and eruption of volcano Sinabung in Indonesia at $3.17^oN, 98.392^oE$ on April 6-12, 2015;

9) each one of the four magnitude $\geqslant 9.0$ earthquakes in 1900-2015 was accompanied by considerable seismic activity in the antipodal region; and many more.

The eruption of Mount Pinatubo at $15.141667^oN, 120.35^oE$ in mid-June 1991, the second largest volcanic eruption of the 20th century, coincided with the 1991 increase in activity in a prolonged 1990 - 1995 eruption of Mount Sabancaya at $15.78^oS, 71.85^oW$. The eruptions were accompanied by a magnitude 7.0 earthquake at $13.108^oS, 72.187^oW$ on July 6, 1991; a magnitude 7.7 earthquake at $15.679^oN, 121.172^oE$ on July 16,1990; and a magnitude 7.1 earthquake at $11.76^oN, 121.899^oE$ on June 14, 1990. A magnitude 7.3 earthquake on June 23, 1991 at $26.802^oS, 63.349^oW$, and a magnitude 7.1 earthquake on April 5, 1991 at $5.982^oS, 77.094^oW$ struck somewhat farther away from the volcanoes, but the mid-point of the epicenters at $\approx$

$16.4^o S, 70.2^o W$ was very close to Mount Sabancaya.

Conclusion. The observations discussed here point to the greater importance of the almost antipodal symmetry than is currently believed. A number of recent research articles show the presence of the almost antipodal symmetry in the Earth's interior, e. g. [3], [5], [7]. There are a number of older theories attempting to explain almost antipodal symmetry of some specific local phenomena, e. g. antipodal volcanism, shock dynamics; but none can explain the global phenomena discussed here.

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