Journal of
Scientific
Exploration

Anomalistics
and
Frontier
Science

RESEARCH
ARTICLE

Toward a New Theory of Earth Crustal Displacement

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SUBMITTED July 16, 2019
ACCEPTED February 3, 20
PUBLISHED May 22, 2022

https://doi.org/10.31275/20221621

PLATINUM OPEN ACCESS

HIGHLIGHTS

Short-term reversals of the Earth's geomagnetic field may 'unlock' the crust to allow tidal forces to move it in the same way they do the oceans. Sea-level changes might thus result from the buildup and melting of polar ice over Ice Ages by the Earth's cyclical orbital movements combined with pole shifts.

ABSTRACT

In previous studies of more than two hundred archaeological sites, it was discovered that the alignments of almost half of the sites could not be explained, and about 80% of the unexplained sites appear to reference four locations within 30° of the North Pole. Based on their correlation with Hapgood's estimated positions of the North Pole over the past 100,000 years, we proposed that, by association, sites aligned to these locations could be tens to hundreds of thousands of years old. That such an extraordinary claim rests on Hapgood's unproven theory of earth crustal displacement/pole shifts is problematic, even given the extraordinary number of aligned sites (more than several hundred) that have been discovered thus far. Using a numerical model we test his hypothesis that mass imbalances in the crust due to a buildup of polar ice are sufficient to displace the crust to the extent required in his theory. We discover in the process that the crust is not currently in equilibrium with the whole earth in terms of its moments of inertia. Based on a review of the literature that reveals a possible connection between the timing of short-term reversals of the geomagnetic field (geomagnetic excursions), super-volcanic eruptions, and glacial events, we hypothesize that crustal displacements might be triggered by geomagnetic excursions that "unlock" the crust from the mantle to the extent that available forces, specifically earth–moon–sun tidal forces, the same forces that move earth's oceans, can displace the crust over the mantle. It is demonstrated how such a model, when combined with existing climate change theory, may be able to explain periodic changes in sea level associated with the buildup and melting of polar ice over past glacial cycles by a combination of Milanković cycles and Hapgood pole shifts.

KEYWORDS

Earth crust displacement, cataclysmic pole shift hypothesis, true polar wander, Milanković cycles, climate change, insolation, geomagnetic excursions, super-volcanic eruptions, moments of inertia, theoretical rotational axis, tidal forces.

INTRODUCTION

In 1958, Charles Hapgood proposed that ice ages are caused by climate changes resulting from displacements of the earth's crust over the mantle that shift the location of the geographic poles (Hapgood, 1958). In previous studies of more than two hundred archaeological sites, it was discovered that the alignments of almost half of the sites could not be explained (Carlotto, 2020a) and that about 80% of the unexplained sites appear to reference four locations within 30° of the North Pole. Based on their correlation with Hapgood's estimated positions of the North Pole over the past 100,000 years, we proposed that, by association, sites aligned to these locations could be tens to hundreds of thousands of years old (Carlotto, 2020b).

That such an extraordinary claim rests on Hapgood's unproven theory of earth crustal displacement is problematic, even given the extraordinary number of aligned sites (more than several hundred) that have been discovered thus far. In this paper, we revisit Hapgood's theory in the context of recent developments in climate science and show that his theory may be the missing link in understanding not only the rise and fall of past civilizations, as we first set out to do, but long-term (ice age) climate changes as well. For discussion, we divide Hapgood's theory into two parts: physical mechanism(s) that could cause crustal displacements, and effects of pole shifts on climate.

The organization of this paper is as follows: In the first section, TRUE POLAR WANDER, we begin by reviewing the theory of plate tectonics and its relation to true polar wander (TPW) to understand how it differs from the first part of Hapgood's theory. The section MILANKOVIĆ CYCLES describes the extent to which known climate cycles can predict changes in sea level, which is inversely related to the amount of ice at the poles. In POLE SHIFTS AND SEA LEVEL CHANGES it is argued that by combining Hapgood pole shifts with Milanković cycles over the past 100,000 years, we can better account for periodic sea-level changes and the associated buildup and melting of polar ice over the previous glacial cycle. The next section, GEOMAGNETIC CHANGES, reviews evidence suggesting a connection between changes in the earth's magnetic field, climate, and TPW events. In CORRELATED EVENTS, dates of geomagnetic excursions (short-term reversals of the geomagnetic field), super-volcanic (TEI 7–8) eruptions, and sea-level changes over the past 100 Ky are compared with the timing of hypothesized pole shifts. A POSSIBLE MECHANISM FOR CRUSTAL DISPLACEMENTS, which addresses the first part of Hapgood's theory, postulates a physical model of how geomagnetic excursions might trigger crustal displacement events and how earth–moon–sun tidal forces could provide the energy needed to displace the crust significant distances over the mantle in a relatively short period of time. New climate data related to the second part of Hapgood's theory is reviewed in CLIMATE EVIDENCE and supports our proposed past pole locations (Carlotto, 2020b) and revised chronology (Gaffney, 2020). The last section discusses reasons why Hapgood's theory has been dismissed by the mainstream scientific community and summarizes how our revised theory, by addressing these concerns, may extend current thinking in climate and geosciences.

TRUE POLAR WANDER

Early in the 20th century, Alfred Wegener and others theorized the continents were once a single large landmass that broke up and slowly drifted apart. Wegener's theory of continental drift explained the complementary shape of coastlines and the similarity in rock formations and fossils along matching coastlines. His theory, now known as plate tectonics, divides the crust into plates that move independently of one another over the mantle. True polar wander (TPW) is the net movement of the crust as a whole relative to the spin axis. The idea that TPW occurs as a result of plate motion was motivated by the early work of Milutin Milanković (1932) who concluded in his analysis of Wegener's theory that "the displacement of the pole takes place in such a way that . . . Earth's axis maintains its orientation in space, but the Earth's crust is displaced on its substratum."

Thus, TPW, like plate tectonics, thought to be driven by convection cells in the mantle (Holmes, 1944), is a slow geological process that occurs over time scales of millions to tens of millions of years (Evans, 2003). Inferring from the estimated movement of earth's magnetic poles (known as apparent polar wander), Kirschvink et al. (1997) hypothesized that a TPW event occurred between 534 million and 505 million years ago that rotated Australia a quarter of the way around the globe. The event occurred around the time of the Cambrian Explosion when most groups of animals first appear in the fossil record and is thought to have been a factor in evolutionary changes that later took place. More recently, Daradich et al. (2017) estimate a steady shift of earth's poles by ~8° over the last 40 million years toward Greenland, which has brought North America to increasingly higher latitudes and caused the climate to gradually cool over this period.

This idea that changing the latitude of a geographic region changes its climate was the motivation behind Hapgood's theory. Where TPW may explain climate changes over long periods, Hapgood attempted to solve the problem of the ice ages, which he did not believe were caused by global temperature fluctuations. Similar to the way TPW is thought to have shifted North America toward Greenland, Hapgood proposed that glacial cycles and ice ages were the results of a much more recent series of crustal displacements driven by physical processes operating over timescales of tens of thousands of years that shifted different geographic regions toward and away from the North Pole.

MILANKOVIĆ CYCLES

In the 1920s, Milutin Milanković proposed that changes in earth's eccentricity, axial tilt (obliquity), and precession result in cyclical variations in the amount of incident solar radiation (insolation) reaching the earth. Insolation is generally assumed to be a major driver of climate change over long periods. From 1–3 million years ago, climate patterns were correlated with the earth's 41 Ky-long obliquity cycle. Then, about a million years ago, patterns began to follow a 100 Ky cycle that is between the 95 Ky and 125 Ky cycles in earth's orbital eccentricity. Why the period of climate patterns changed, the origin of the 100 Ky cycle, and why insolation lags rather than leads climate changes are among some of the problems that cannot be explained by Milanković cycles (https://en.wikipedia.org/wiki/Milankovitch_cycles).

Perhaps the greatest shortfall of Milanković's theory is the inability of insolation in itself to accurately account for the periodic buildup and melting of polar ice over glacial cycles. Figure 1 plots the average daily mean top of the atmosphere (TOA) insolation at 65°N over the past 250 Ky. Using sea level as a climate proxy, which is inversely related to the amount of polar ice, Figure 2 plots global sea level over the same period. The two time series are weakly correlated ($R = 0.14$). There is a somewhat higher ($R = 0.33$) correlation between insolation and temperature, and an even greater correlation ($R = 0.63$) between insolation and changes in sea level as a function of time. The reason for the increased correlation is that as insolation increases, temperatures increase, polar ice melts, and sea levels rise. Conversely, as insolation decreases, temperatures decrease, precipitation freezes and accumulates at the poles, and sea levels fall. Exploiting this correlation, we can estimate mean sea level change $\Delta s(t)$ as a linear function of insolation $Q(t)$ from the time-series data

$$\Delta s(t) = Q(t) \times 0.12 - 58.85$$

that when summed provide an estimate of sea level as a function of insolation over time

$$s(t) = s(0) + \sum_{t'=0}^{t} \Delta s(t')$$

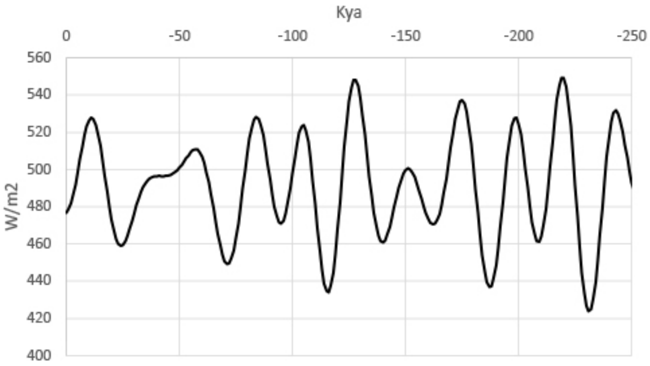


Figure 1. Average daily mean TOA isolation at 65°N over the past 250,000 years. http://vo.imcce.fr/insola/earth/online/earth/earth.html

Figure 2. Global sea level obtained by averaging first principal components from short and long records over the past 250,000 years. https://www1.ncdc.noaa.gov/pub/data/paleo/contributions_by_author/spratt2016/spratt2016.txt

The result plotted in Figure 3 shows that over the last two glacial cycles, insolation tends to underpredict sea level (overpredict polar ice) at the beginning of a cycle and overpredict sea level (underpredict polar ice) at the end. In other words, a greater amount of ice melts at the beginning and accumulates at the end of a glacial cycle than what is predicted by insolation.

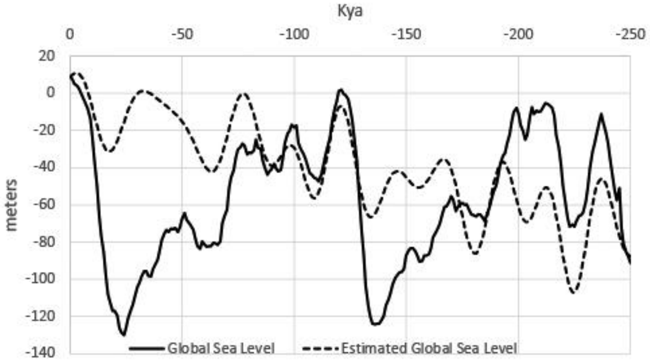
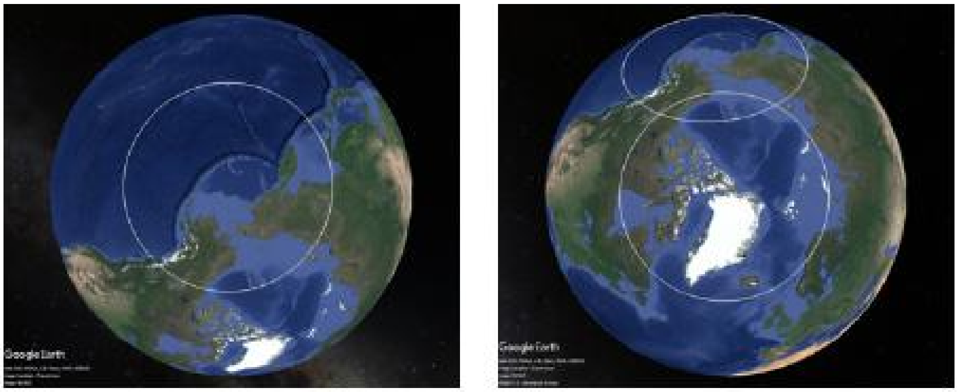


Figure 3. Global sea level estimated from insolation over the past 250,000 years.

POLE SHIFTS AND SEA-LEVEL CHANGES

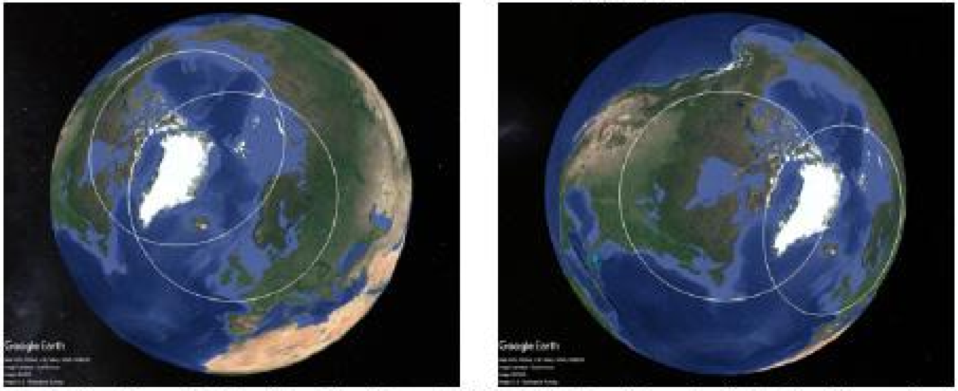
Insolation varies with the cosine of the solar zenith angle and so increases as we move toward the equator. Allowing the geographic location of the earth's poles to shift relative to the rotational axis as Hapgood proposed provides an additional degree of freedom that can potentially account for the difference between the two sea-level curves in Figure 3. Before the start of a glacial cycle, a large amount of water is stored in an ice sheet around the pole. If the crust displaces enough to move the ice sheet out of the polar zone, the increased amount of solar radiation at lower latitudes will cause the ice to melt, raising sea levels. After a period, an ice sheet begins to form at the new pole, causing sea levels once again to fall.

Figure 4 shows the displacement of the crust south for five hypothesized pole shifts (Carlotto, 2020b). Sea levels decrease in stages during a glacial cycle suggesting



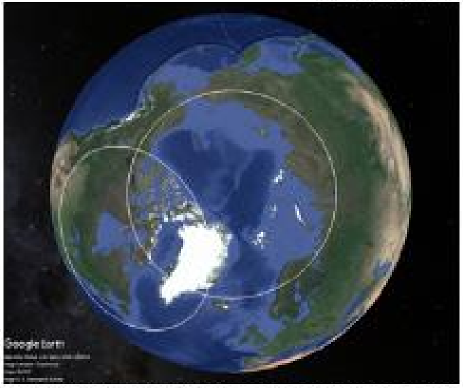
a) *Bering Sea circle*

b) *New Greenland circle with old Bering Sea circle shifted south*



c) *New Norwegian Sea circle with old Greenland circle shifted south*

d) *New Hudson Bay circle with old Norwegian Sea circle shifted south*



e) *The current Arctic circle with the previous Hudson Bay circle shifted south*

Figure 4. Crustal displacements cause former polar regions to shift south toward the equator. (Google Earth)

a continued buildup of ice near the poles. Notice the land area around the pole is different at different pole locations. Since ice forms and accumulates more readily on land than over the ocean, if the land area at the new pole is greater than the land area at the old pole, sea levels after a pole shift should eventually fall to a lower level as there is a greater land area for ice to accumulate. Based on measurements of land area in the Arctic circle and former polar regions, there is a strong correlation between the size of the ice sheet (assumed to be determined by land area) and sea level for the current and four prior pole locations (Figure 5). Successive increases in available land area following the Bering Sea to Greenland pole shift have led to successive decreases in sea level. This suggests that the magnitude of crustal displacements during a glacial cycle, i.e., before the last glacial maximum (LGM) and penultimate glacial maximum (PGM) were small enough to keep the accumulating mass of ice in the polar zone. The precipitous rise in sea level after the LGM and PGM suggests that larger magnitude crustal displacements shifted the ice sheet farther south to melt a significant fraction of the accumulated ice.

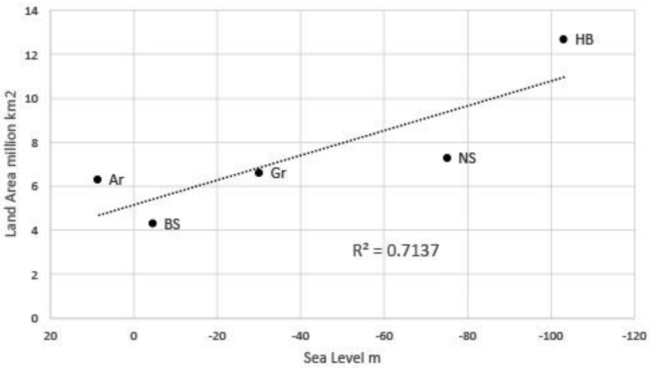


Figure 5. Relation between sea levels and land areas at former poles.

It is interesting to note that the current distribution of ice in the Arctic is not centered on the pole but tends to be shifted toward Greenland, the largest landmass in the region. This asymmetry existed even at the time of the LGM relative to the current Arctic Sea pole (Figure 6a,b). If ice buildup continued during the Greenland, Norwegian Sea, and Hudson Bay poles, the spatial distribution of net ice can be approximated by the union of three circles—areas like today's Arctic Circle that were within approximately 23.5° of the poles at the time (Figure 6c). Notice the union of the three former northern polar climate zones (areas above 50°N relative to the former poles) contains all of the ice in the northern hemisphere during the LGM (Figure 6d).

GEOMAGNETIC CHANGES

A growing body of evidence suggests changes in the earth's magnetic field may influence climate. Over the last 83 million years, 183 geomagnetic reversals have taken place in which the poles changed polarity. Geomagnetic reversals occur, on average, 450 Ky years apart. Courtillot and Olson (2007) show that long periods (millions of years) in which the magnetic poles do not flip preceded the four largest extinctions on earth: the Cretaceous-Tertiary (KT), Triassic-Jurassic (TJ), and the Permo-Triassic (PT) and Guadalupian-Tatarian (GT) doublet. Mitchell et al. (2021) report a late Cretaceous true polar wander oscillation around 84 Mya (million years ago) where the earth's geographic poles shifted about 12° and returned to their original position over about 6 million years. Muttoni and Kent (2019) report an even greater shift during the Jurassic period.

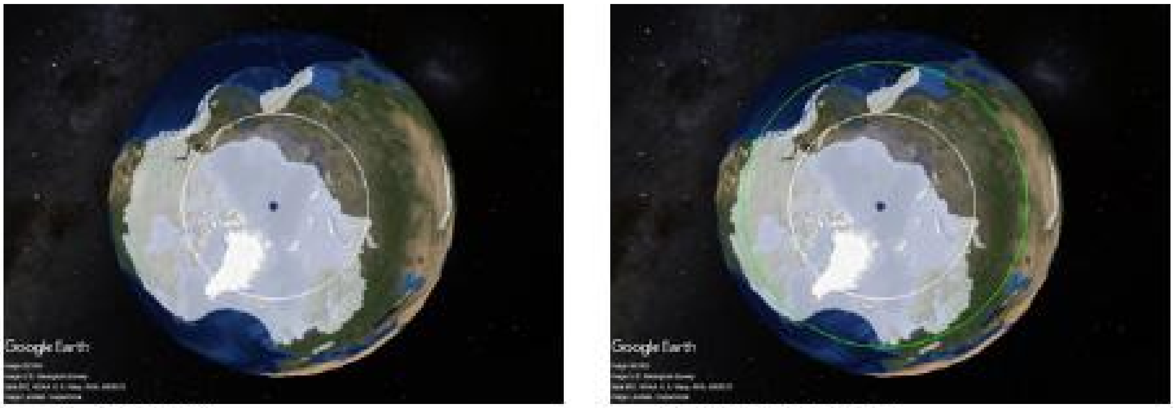
Between geomagnetic reversals, events known as geomagnetic excursions take place where the field temporarily reverses for a shorter period (thousands of years or less). Channell and Vigliotti (2019) argue changes in magnetic field strength during geomagnetic excusions lead to variations in ultraviolet radiation, which have influenced mammalian evolution. Rampino (1979) proposes that there is a connection between geomagnetic excursions and Milanković cycles, showing that four recent geomagnetic excursions closely follow times of maximum eccentricity of earth's orbit and precede periods of sudden cooling and glacial advance.

If long-duration TPW events follow geomagnetic reversals, could short duration Hapgood pole shifts follow geomagnetic excursions?

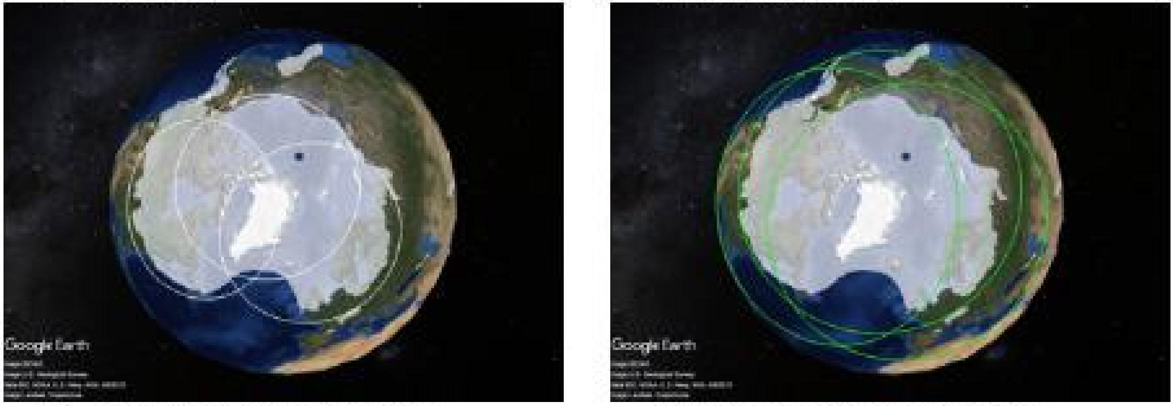
CORRELATED EVENTS

Table 1 gives an approximate chronology of recent geomagnetic excursions, super-volcanic eruptions, and glacial events. The Blake geomagnetic excursion occurred 15–20 Ky after the PGM. The Volcanic Explosivity Index (VEI) is a relative measure of the explosiveness of volcanic eruptions (https://en.wikipedia.org/wiki/Volcanic_Explosivity_Index). The next two geomagnetic excursions were each followed by massive VEI 8 magnitude volcanic eruptions. The most recent Toba eruption 73–75 Kya followed the Norwegian-Greenland Sea excursion. The Oruanui eruption of New Zealand's Taupo volcano followed the Lake Mungo excursion 28–30 Kya. The somewhat smaller VEI 7 Phlegraean Fields eruption followed the Laschamp event 40–42 Kya.

Although the trigger mechanism for geomagnetic reversals is not clear, crustal shifts could provide an explanation for earthquake activity, volcanic eruptions, and other



a) *Arctic circle* b) *North polar region*



c) *Polar circles of three prior poles* d) *Polar regions of three prior poles*

Figure 6. North polar circles and regions superimposed on estimated ice sheet circle 18 Kya. (Ice sheet visualization, Zurich University of Applied Sciences. http://waikiki.zhaw.ch/radar.zhaw.ch/bluemarble3000_en.html

TABLE 1. Correlation of Geomagnetic, Super-Volcanic, and Glacial Events with Proposed Pole Shifts

Kya	Geomagnetic Excursion	Super-Volcanic Event	Glacial Event	Pole Shift
12.3	Gothenburg (Rampino, 1979)			
22			LGM	Hudson Bay to Arctic?
26.5		Taupo (VEI 8)		
28–30	Lake Mungo (Barbetti & McElhinny, 1976)			Hudson Bay to Arctic?
32–34	Mono Lake (Hambach et al., 2008)			
40		Phlegraean Fields (VEI 7)		
40–42	Laschamp (Hambach et al., 2008)			Norwegian Sea to Hudson Bay
73–75		Toba (VEI 8)		
70–80	Norwegian-Greenland Sea (Langereis et al., 1997)			Greenland to Norwegian Sea
115–120	Blake (Hambach et al., 2008)			Bering Sea to Greenland
135			PGM	? To Bering Sea

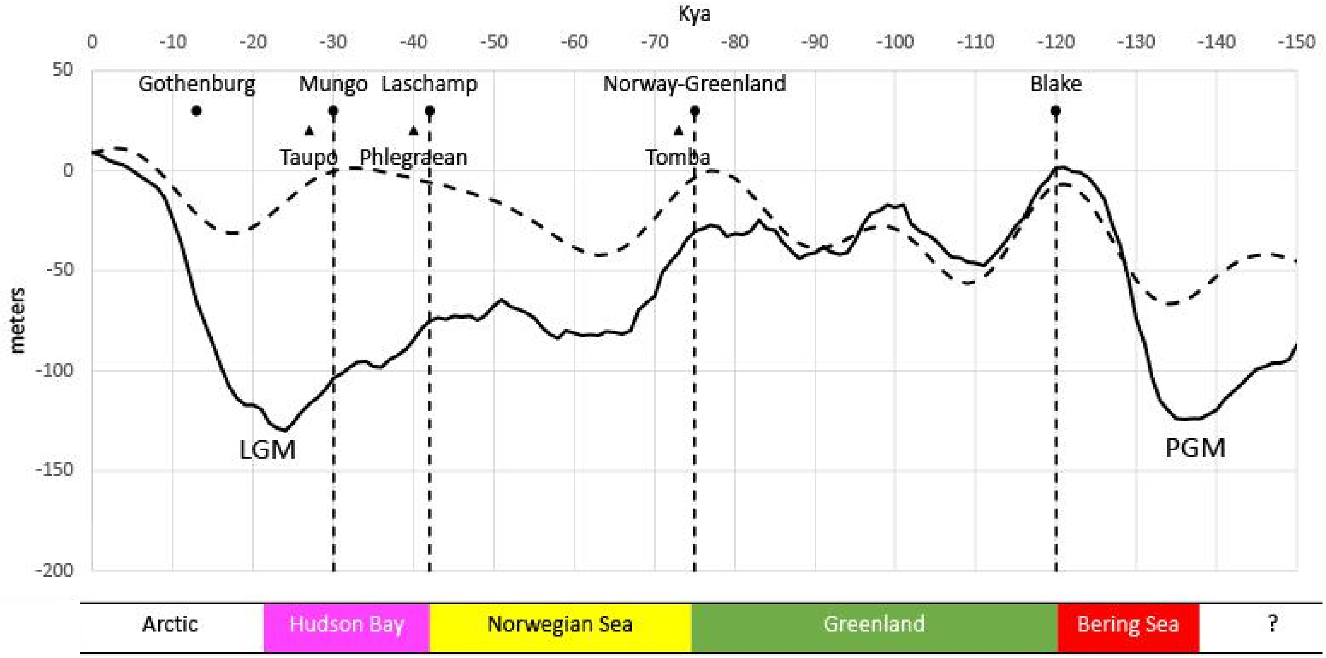


Figure 7. Hypothesized pole shift sequence based on times of geomagnetic excursions, super-volcanic eruptions, and glacial events. The top curve (dotted line) is the prediction from Figure 3. The bottom curve (solid line) is the difference between global sea levels (Figure 2) and their predicted value from insolation (Figure 1).

events that follow geomagnetic excursions. Figure 7 proposes a sequence of six pole shifts based on these events. Four previous pole locations estimated from archaeological site alignments (Carlotto, 2019) are listed in Table 2 along with estimated dates. The Blake, Norwegian-Greenland Sea, and Lachamps geomagnetic excursions precede three episodes of sea level decline/increase of polar ice. The Lake Mungo geomagnetic excursion occurs just before the LGM after which global sea levels began to rise to current levels. According to the model, crustal displacement(s) triggered by the Mungo Lake and possibly the Gothenburg geomagnetic excursions shifted most of the ice sheet that had formed up to the LGM almost 2,000 miles south well into the temperate zone leading to rapid melting and sea-level rise. The Younger Dryas event (Firestone et al., 2006) was also likely a significant contributor to glacial melt. All four events appear to be somewhat correlated with Milanković cycles evident in the insolation curve. Three precede major volcanic eruptions.

A POSSIBLE MECHANISM FOR CRUSTAL DISPLACEMENTS

In his original theory, Hapgood proposed that polar ice creates mass imbalances that can cause the crust to slip over the mantle shifting the geographic location of the North Pole. Einstein later argued that the force of the ice was not sufficient to cause a crustal displacement (Martínez-Frías et al., 2005). It is now possible using models of the crust and ice sheets at the LGM to estimate the degree

TABLE 2. Estimated Locations and Dating of Previous Poles

Name	Latitude	Longitude	Dating (Kya)
Hudson Bay	59.75°	–78°	25–42
Norwegian Sea	70°	0°	42–75
Greenland	79.5°	–63.75°	75–120
Bering Sea	56.25°	–176.75°	120–135

to which the ice could have affected the earth's moments of inertia. As shown in the Appendix, if the crust were free to move, the ice would have shifted the pole by less than 0.25° relative to its present position. If the first part of Hapgood's theory is wrong, that ice cannot move the pole, and TPW is too slow a process to affect glacial cycles, are there any other ways to save the rest of his theory?

As discussed in the Appendix, an analysis of alternative mass distribution models (Caputo & Caputo, 2012) reveals the crust's theoretical axis of rotation (TRA), which is based on its moments of inertia, deviates significantly from the whole earth's rotational axis and so may not be in equilibrium with the earth. Using a numerical model described in the Appendix, we have determined the crust's TRA is at 1.21°N, 18.52°W. This location lies in the zone of the tropics almost on the equator. At the equinox, the equator is parallel with the ecliptic plane. At other times of the year, the ecliptic passes through the earth's equatorial region between the tropics of Cancer and Capricorn. The path of the sun, moon, and most other bodies in the solar system lies along the ecliptic. That the crust's TRA points in this direction suggests the possibility the crustal disequilibrium may have an external (i.e., extraterrestrial) cause.

The influence of the moon, and to a lesser extent, the sun, are responsible for the earth's tides (Figure 8). The balance between gravitational and centrifugal forces causes the earth (primarily its oceans) to elongate in the direction of the moon by 1.34 meters and the direction of the sun by 0.61 meters (https://farside.ph.utexas.edu/teaching/celestial/Celestial/node53.html). As the earth rotates, tidal forces cause the oceans to rise and fall twice a day. These forces also pull on the crust. It has been proposed that tidal forces acting on the crust could be a possible trigger for certain kinds of earthquakes (Ide et al., 2016).

Tidal torques τ acting on the earth and moon dissipate energy at a rate

$$\dot{E} = \tau(\omega - \Omega) < 0$$

since $\Omega > \omega$, where Ω and ω are the angular velocities of the earth and moon, respectively (https://farside.ph.utexas.edu/teaching/celestial/Celestial/node54.html). With the crust "locked" to the mantle, the energy loss manifests as the frictional heating of the crust and oceans. If, however, the crust became "unlocked," the effective work could result in a displacement of the crust over the mantle.

The key to crustal displacement thus becomes the question of whether there is a way for the crust to become unlocked from the mantle. One possibility is that changes in the magnetic field during a geomagnetic reversal/excursion may affect the ease with which the crust can move over the mantle. Magnetic dipoles of ferromagnetic minerals in the crust normally line up in the same direction as those in the core resulting in continental ferromagnetic fields (Lorenzen, 2019). It is conjectured that when the core magnetic field flips during a geomagnetic excursion, the dipoles in the crust temporarily point in the opposite direction to produce a repulsive force between the crust and core fields (Figure 9). If this force, perpendicular to the crust, is sufficient to reduce the frictional force between the crust and mantle, it may be possible for forces acting on the crust parallel to the surface to move the crust over the mantle while the geomagnetic field is reversed. When

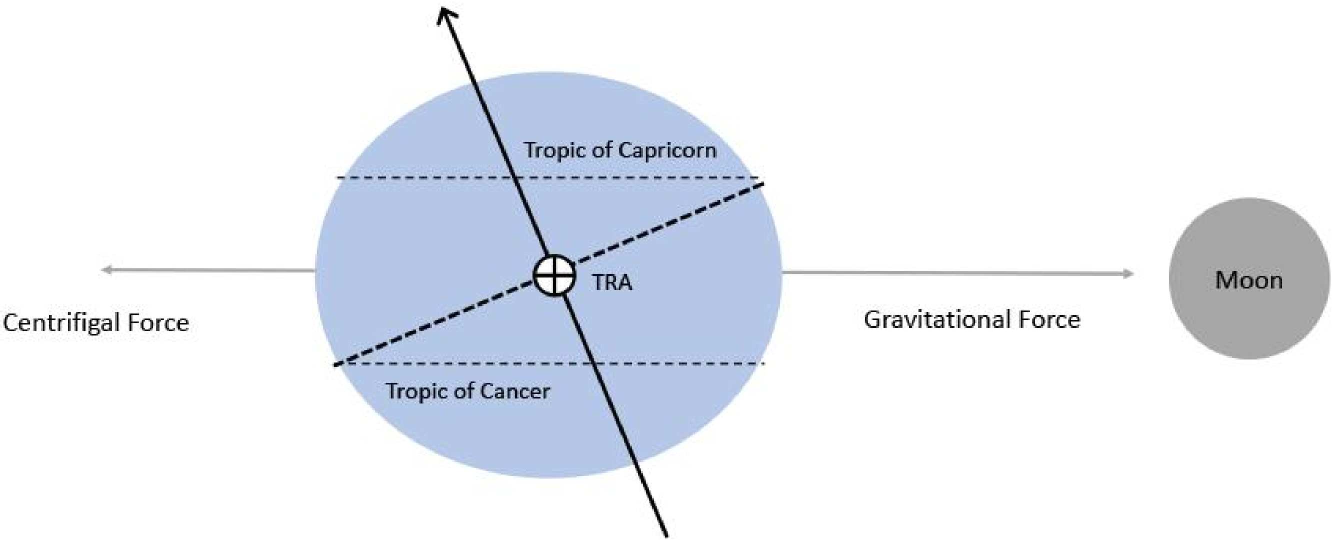


Figure 8. Possible role of tidal forces in changing the position of the crust's TRA.

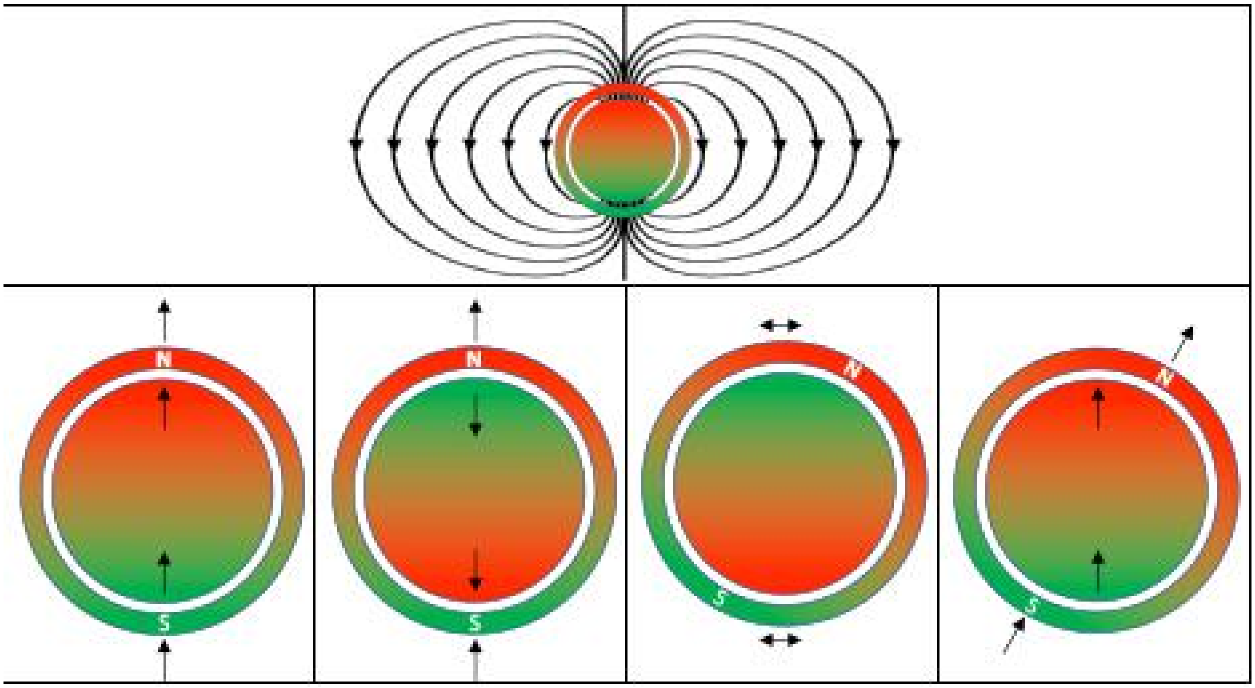


Figure 9. Earth's magnetic field (top). Bottom left to right shows the normal polarity of core and crust, polarity during a geomagnetic excursion, rotation of crust, and return to original field polarity.

the geomagnetic field flips back the crust is once again locked to the mantle maintaining disequilibrium.

If the crust were to displace over the mantle, its TRA would shift as well. As shown in Figure 10, the crust's TRA is roughly within the zone of tropics for all four prior estimated locations of the North Pole. Considering the last pole shift from Hudson Bay to the Arctic, Figure 11 plots different hypothetical pole shift paths along with the corresponding paths of the crust's TRA. Notice the most gradual pole shift path is associated with the movement of the TRA along the ecliptic. This suggests the possibility that if the crust did become unlocked during a geomagnetic excursion, tidal torques could have shifted it along with the geographic pole such that the crust's TRA would have remained in the equatorial zone under the influence of the moon and sun.

CLIMATE EVIDENCE

If the second part of Hapgood's crustal displacement theory is correct, pole shifts should cause climate zones[1] and habitats to change relative to the new poles. Gaffney (2020) tested this hypothesis using mammal assemblage zone (MAZ) biostratigraphy in Britain over the late Pleistocene (Currant & Jacobi, 2001, Gilmour et al., 2007). Figure 12 plots the approximate dates of five assemblages. The oldest in the Joint Mitnor Cave, dated to the early marine isotope stage (MIS) 5, which began about 130 Kya, contains bones of the hippopotamus and spotted hyena, animals who live in sub-tropical climates. According to our model, this period corresponds to the time when the North Pole was in the Bering Sea. With a pole at this location, Britain's latitude would be approximately 20°N at the northern edge of the tropical zone.

The next assemblage, Bacon Hole, contains bones of animals that live in temperate climates such as the vole and woolly mammoth. Its estimated age, 80–110 Kya, is during the time the North Pole is estimated to have been in northern Greenland. With the pole at this location, Britain's latitude would be approximately 57°N at the northern edge of the temperate zone. Based on our estimated chronology, a pole shift from the Bering Sea to northern Greenland 110–130 Kya that shifted Britain's geographic location 37° north from the sub-tropical to temperature zone would explain this change in climate.

Fossils in the Banwell MAZ include animals that live in cold climates such as Arctic fox and reindeer. Its estimated age, 50–79 Kya, corresponds to the time when the North Pole was in the Norwegian Sea. With the pole at this location, Britain's latitude would be shifted north to 75°N, well inside the polar region. The last two assemblages at Pin Hole and Gough's Cave contain fossils of animals such as horses and woolly mammoths who live in temperate climates. The dating of these assemblages is consistent

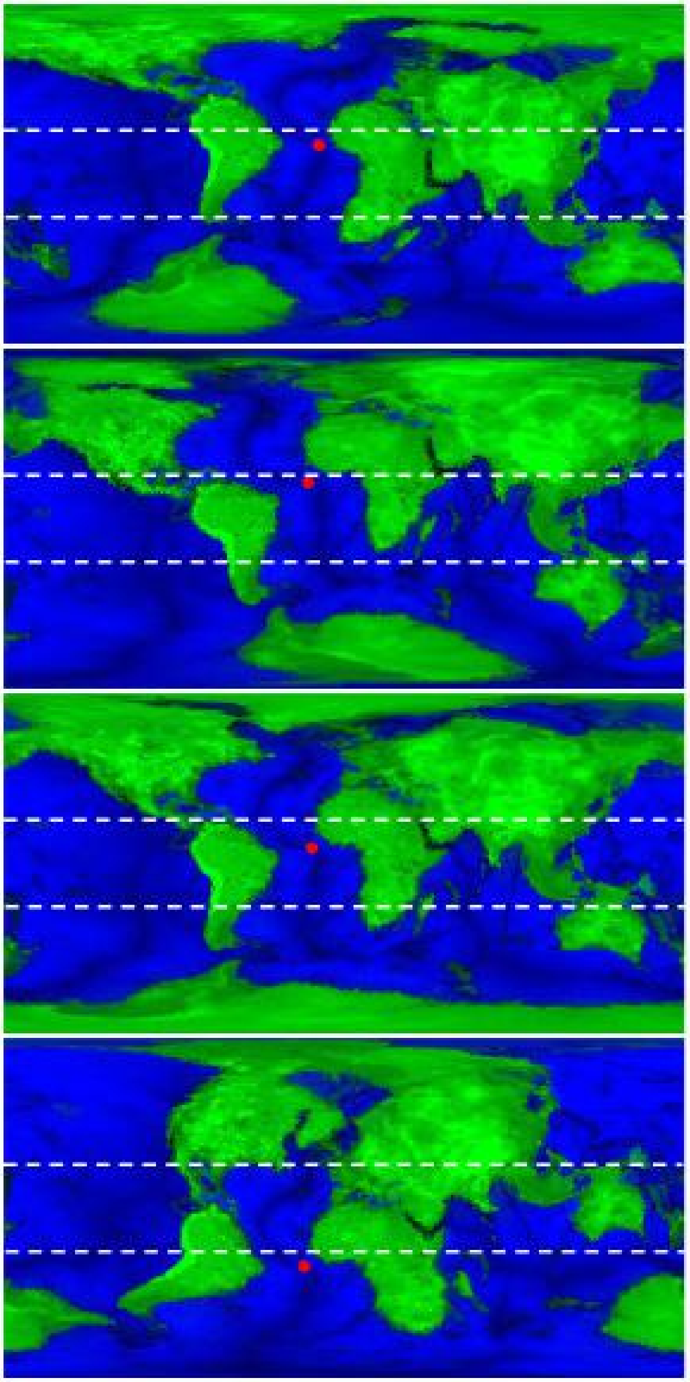


Figure 10. Location of crust TRA (red dot) for poles (from top to bottom) in Hudson Bay, the Norwegian Sea, Greenland, and the Bering Sea. Dotted lines delimit the tropical zone (23.4°N to 23.4° S).

with subsequent crustal displacements that shifted Britain south, back into the temperate zone.

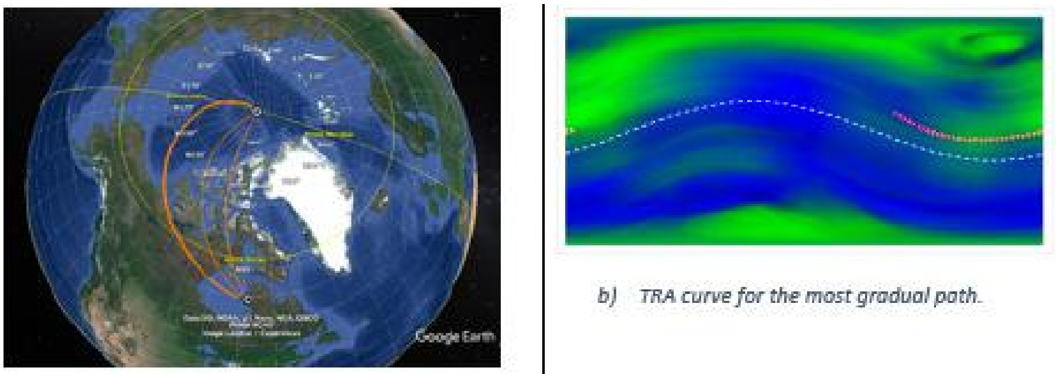
The Arabia Desert, the largest in Asia, and the fifth-largest in the world, occupies most of the Arabian Peninsula. In the south, between Yemen and Oman, lies the Rub'al Khali (The Empty Quarter), one of the most extreme environments on earth. Yet, it is clear from satellite imagery (Figure 13) that this part of the word has not always been arid. Extensive and well-developed drainage patterns seen in satellite imagery prove rivers once flowed throughout a much different landscape. Crassard et al. (2013) present geochronological data supporting the existence of a paleolake in the Mundafan region at the western edge of the Rub'al Khali. Lacustrine samples dated using carbon-14 and optically stimulated luminescence suggest the paleolake first formed during MIS 5 (80–130 Kya). The presence of freshwater mollusks indicates the lake existed over an extended period. Significant changes in climate resulting from pole shifts would likely have affected human populations as well at the time. Groucutt et al. (2015) discovered signs of prolonged human occupation in this area during MIS 5 (80–130 Kya) that they believe constitute evidence of early human dispersals out of Africa and across the Arabia peninsula. According to Hapgood's theory, Arabia would have had a wet tropical climate 75–135 Kya during the times of the Bering Sea and Greenland poles.

DISCUSSION

Figure 14 summarizes the key elements of our revised version of Hapgood's theory of crustal displacement. As stated at the outset, there are two parts to his theory. In the first part, which concerns possible mechanisms, we replace Hapgood's polar ice/mass imbalance hypothesis with a new model that postulates crustal displacements are triggered by geomagnetic excursions and driven by tidal forces. We refine the second part of his theory based on a linear model, which predicts the extent to which Milanković cycles can account for sea-level changes over the previous glacial cycle and hypothesize that the difference between what is observed and what is predicted is due to the effect of crustal displacements that modulate incident solar radiation during Milanković cycles.

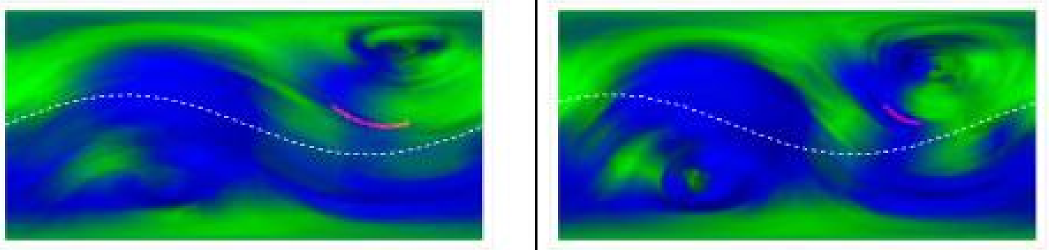
It has been suggested that increased amounts of cosmic radiation during periods of geomagnetic collapse could lead to increased ionization in the atmosphere and cloud formation, which would reduce the amount of solar radiation reaching the surface. Although this explains why the climate grows colder and sea levels fall during a glacial cycle, it cannot explain how ice can later melt and sea levels rise in a cold world (Berger, 2012). Crustal shifts provide the missing piece (nonlinear factor) sought in many climate theories needed to melt ice in a cold world by simply moving the ice to a lower latitude so that it can melt.

Historically, Hapgood's theory has been dismissed by the mainstream science community for several reasons. Foremost is the lack of a physical process capable of shifting the crust thousands of miles over timescales of tens of



a) Three hypothetical pole shift paths from Hudson Bay. Most gradual path in bold.

b) TRA curve for the most gradual path.



c) TRA curve for a less gradual path.

d) TRA curve for the least gradual path.

Figure 11. Different hypothetical paths of geographical pole shifts (top left) and corresponding crust TRA displacement curves (top right, bottom left, and bottom right). TRA curves (red lines) that follow ecliptic paths (dotted white line) are consistent with the tidal hypothesis.

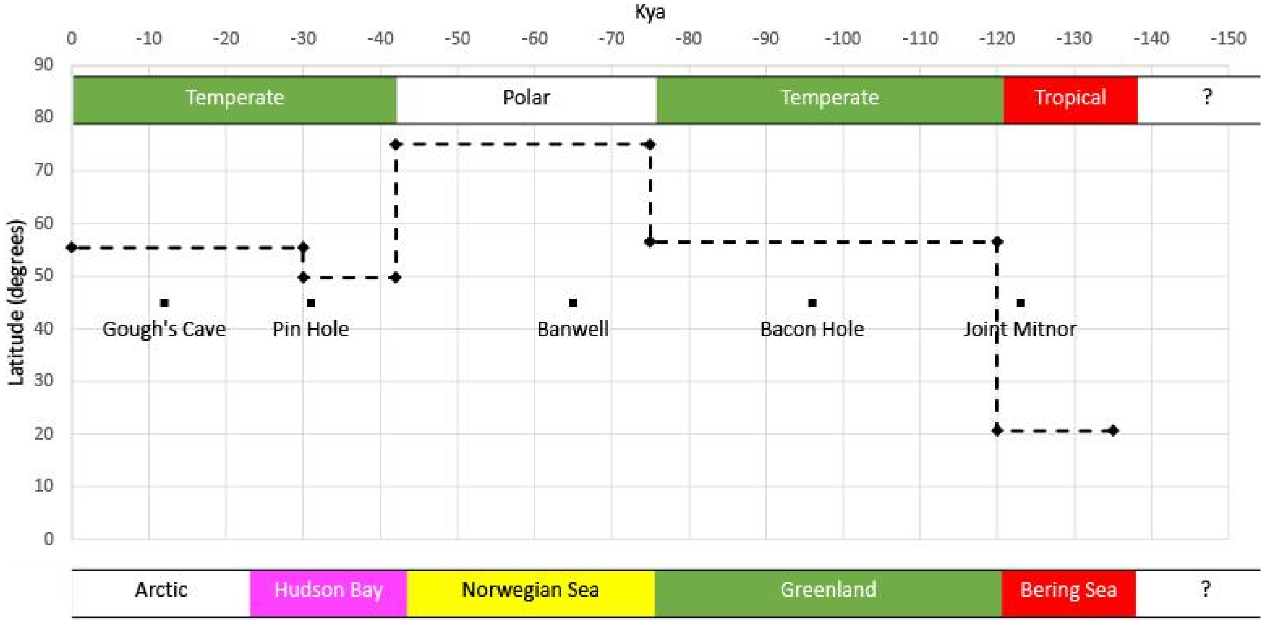
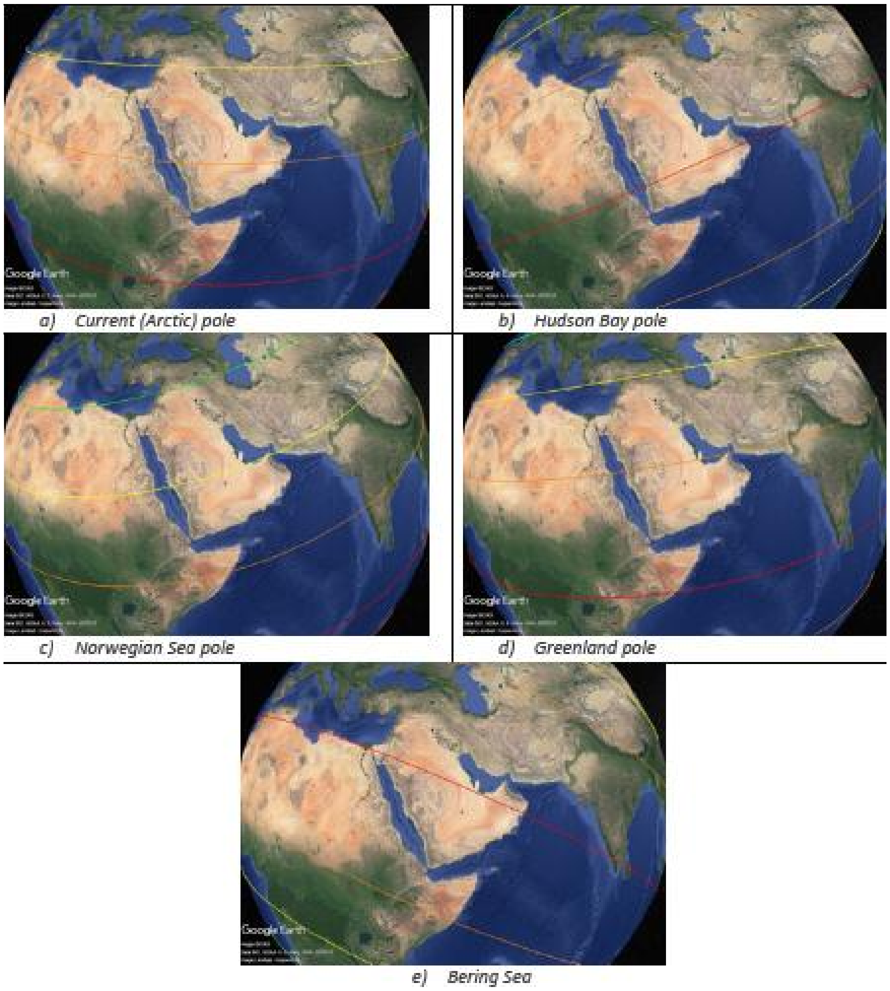


Figure 12. Correlation of mammal assemblage zones and climate zones in Britain associated with prior poles. Dates for Pin Hole, Banwell, and Bacon Hole are average values of ranges compiled by Gaffney (2020).



a) Current (Arctic) pole

b) Hudson Bay pole

c) Norwegian Sea pole

d) Greenland pole

e) Bering Sea

Figure 13. Changes in the climate zone of the Arabia peninsula and surrounding areas due to pole shifts. Wet tropical climates are in the zone between red and orange lines, arid climates in the zone between orange and yellow lines, temperate climates in the zone between yellow and green lines, and polar climates north/south of green lines. (Google Earth)

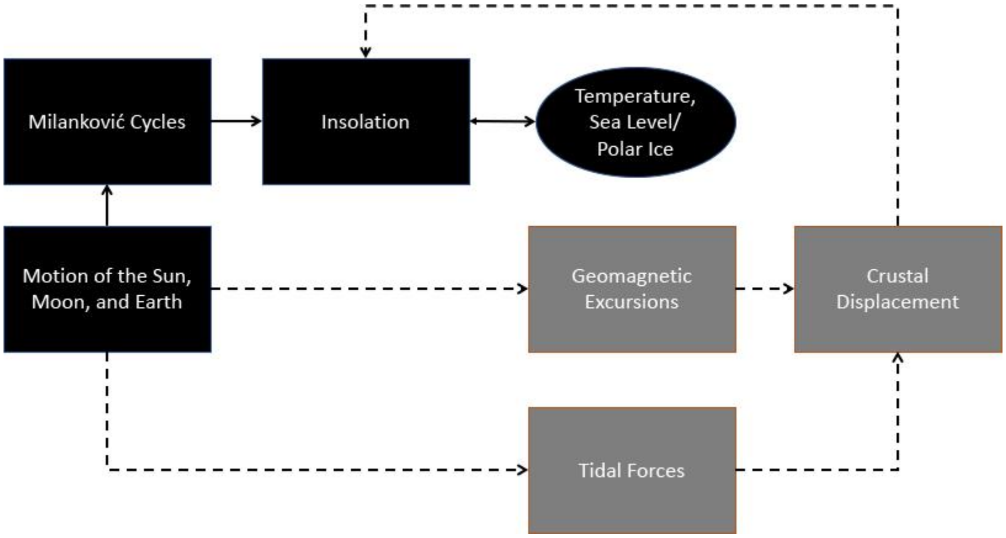


Figure 14. Summary of a new theory builds upon Milanković climate cycles (black boxes and solid lines) incorporating a revised version of Hapgood's theory in which crustal displacements are triggered by geomagnetic excursions and driven by tidal forces (gray boxes and dotted lines).

thousands of years. We address this problem with a new hypothesis—that crustal displacements are triggered by geomagnetic excursions, which occur over the appropriate timescales, and are driven by tidal forces of the earth–moon–sun system, the same forces that move the earth's oceans.

A second "problem" with Hapgood's theory is the lack of geophysical (paleomagnetic) evidence (Brass, 2002). Lack of paleomagnetic data does not disprove the existence of short-duration pole shifts, only that such techniques are incapable of detecting them. Radiometric dates for rock samples typically have a temporal uncertainty of a half-million years, far too coarse to temporally resolve events occurring on timescales of tens of thousands of years. Radiocarbon techniques cannot date archaeomagnetic samples older than 50,000 years. In place of geophysical evidence, Gaffney's analysis of MAZ data using marine isotope stage dating provides strong (albeit circumstantial) evidence of significant climate change events in Britain over the past 100+ Kya that are consistent with the pole shift hypothesis.

The problem of "hot spots"—locations on the earth's surface not on plate boundaries that have experienced active volcanism for long periods—is a third reason Hapgood's theory has been rejected by mainstream science. While some hot spots such as Yellowstone have not moved, others have, resulting in the creation of chains of volcanic islands. Wilson (1963) postulated that the formation of the Hawaiian Islands resulted from the slow movement of a tectonic plate over a stream of anomalously hot magma rising from the Earth's core-mantle boundary in a structure called a mantle plume. Assuming the position of a mantle plume is fixed relative to the earth's spin axis, hot spot tracks are records of plate motion and TPW (Woodworth & Gordon, 2018).

That hot spot tracks do not record Hapgood pole shifts is seen as a fundamental problem with his theory (Wilson & Flem-Ath, 2000). An alternative to the mantle plume theory is the plate theory (Foulger 2010) that postulates the mantle beneath a hot spot is not anomalously hot, rather the crust above a hot spot is weaker allowing molten material from shallower depths to rise to the surface. If this theory is correct, hot spot tracks result from lithospheric displacements within plates and move with the crust.

IMPLICATIONS AND APPLICATIONS

If longer-term TPW/plate tectonic events occurred with periods of increased volcanism and mass extinction events following long-term geomagnetic reversals, correlations between short-term reversals (geomagnetic excursions) and super-volcanic events suggest the possibility that shorter-term pole shifts such as those suggested by Hapgood could have occurred. If so, we show how Hapgood pole shifts working in conjunction with Milanković cycles provide a possible explanation for climate changes over past glacial cycles. That the crust does not appear to be in equilibrium with the whole earth in terms of their moments of inertia suggests the possibility that an unknown force could be at work. We propose earth–moon–sun tidal forces may be responsible, and that these forces, which move the earth's oceans, might provide sufficient energy to displace the crust a significant distance during a geomagnetic excursion. It is our hope that the preliminary results presented in this paper will lead to further work in these and other related areas of research.

NOTE

[1] The climate depends on temperature and precipitation, which depend in large part on latitude. The zone of the tropics (tropics of Cancer and Capricorn), which have warm and wet climates, extend 15–25° from the Equator. Dry climates tend to exist 15–35° from the Equator. In the Northern Hemisphere, this zone is wider than in the Southern Hemisphere. Arabia together with northern Africa lie in a dry belt approximately 20° wide (from 15–35° N). Australia and Southern Africa lie in a thinner dry belt that is only 15° wide from (20 to 35° S). Temperate climates are on average 35–50° from the Equator, and polar climates are above 50°.

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APPENDIX

Computing the Principal Moments of Inertia of Earth's Crust

Key to understanding the movement of the earth's crust relative to the mantle are the moments of inertia, which determine the rotational axis. The moments of inertia defined in earth-centered earth-fixed (ECEF) coordinates are

$$
\begin{aligned}
I_{xx} &= \sum_{x,y,z} (x-\mu_x)^2 m(x,y,z)\\
I_{yy} &= \sum_{x,y,z} (y-\mu_y)^2 m(x,y,z)\\
I_{zz} &= \sum_{x,y,z} (z-\mu_z)^2 m(x,y,z)\\
I_{xy} &= \sum_{x,y,z} (x-\mu_x)(y-\mu_y) m(x,y,z)\\
I_{yz} &= \sum_{x,y,z} (y-\mu_y)(z-\mu_z) m(x,y,z)\\
I_{xz} &= \sum_{x,y,z} (x-\mu_x)(z-\mu_z) m(x,y,z)
\end{aligned}
$$

where $m(x, y, z)$ is the mass distribution, and (μ_x, μ_y, μ_z) are the centers of mass. In practice, the moments are computed by adding up volume elements $r\Delta\theta \times \Delta\lambda r\cos\theta \times \Delta r$ of density $\rho(r,\lambda,\theta)$ in polar coordinates

$$
\begin{aligned}
I_{xx} &= \sum_{r,\lambda,\theta} (X(r,\lambda,\theta,h)-\mu_x)^2 m(r,\lambda,\theta)\\
I_{yy} &= \sum_{r,\lambda,\theta} (Y(r,\lambda,\theta,h)-\mu_y)^2 m(r,\lambda,\theta)\\
I_{zz} &= \sum_{r,\lambda,\theta} (Z(r,\lambda,\theta,h)-\mu_z)^2 m(r,\lambda,\theta)\\
I_{xy} &= \sum_{r,\lambda,\theta} (X(r,\lambda,\theta,h)-\mu_x)(Y(r,\lambda,\theta,h)-\mu_y) m(r,\lambda,\theta)\\
I_{yz} &= \sum_{r,\lambda,\theta} (Y(r,\lambda,\theta,h)-\mu_y)(Z(r,\lambda,\theta,h)-\mu_z) m(r,\lambda,\theta)\\
I_{zx} &= \sum_{r,\lambda,\theta} (X(r,\lambda,\theta,h)-\mu_x)(Z(r,\lambda,\theta,h)-\mu_z) m(r,\lambda,\theta)
\end{aligned}
$$

where $m(x, y, z)$, and (μ_x, μ_y, μ_z) are the ECEF coordinates as a function of radial distance r, longitude λ, latitude θ, and height h above the ellipsoid.

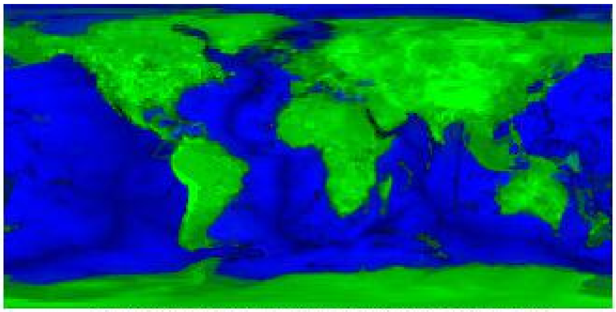
A 1° by 1° global model, CRUST1.0 (https://igppweb.ucsd.edu/~gabi/crust1.html) provides estimates of crustal thickness $t(\lambda,\theta)$ and depth $d(\lambda,\theta)$ to the Moho discontinuity between the earth's crust and its mantle. This sets the latitude and longitude quantization, $\Delta\theta$ and $\Delta\lambda$. Gridded elevations $h(\lambda,\theta)$ derived from the Global Land One-km Base Elevation (GLOBE) project (https://www.ngdc.noaa.gov/mgg/topo/globe.html) are referenced to the WGS84 reference ellipsoid. Ice maps $g(\lambda,\theta)$ representing the extent of ice sheets at the LGM were generated from global climate data visualizations (http://waikiki.zhaw.ch/radar.zhaw.ch/bluemarble3000_en.html).

The mass distribution $m(r,\lambda,\theta)$ is computed over a series of spherical shells Δr = 250 meters thick, using density values of 2.7 g/cm^3 for the continental crust, 3 g/cm^3 for ocean crust, 1 g/cm^3 for water, and 0.9 g/cm^3 for ice according to the logic in Appendix Table 1.

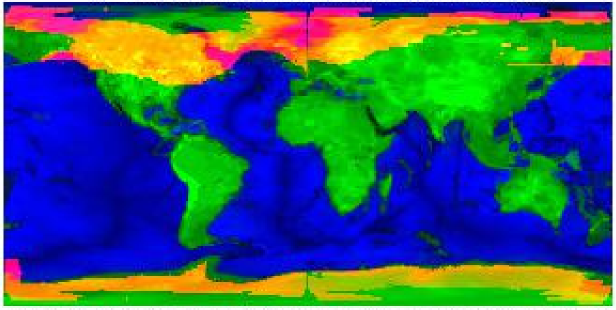
APPENDIX TABLE 1

Above Moho?	Land/water?	Ice?	Radius, r	Density, $\rho(r,\lambda,\theta)$
$r > d(\lambda,\theta)$	$h(\lambda,\theta) > s$		$r \le h(\lambda,\theta)$	2.7
		$g(\lambda,\theta) > 0$	$r \le h(\lambda,\theta) + g(\lambda,\theta)$	0.9
	$h(\lambda,\theta) \le s$		$r \le d(\lambda,\theta) + t(\lambda,\theta)$	3
			$r \le s$	1
		$g(\lambda,\theta) > 0$	$r \le s + g(\lambda,\theta)$	0.9
otherwise				0

Figure 15 is a cylindrical projection of the summed mass distribution of the crust. Also shown are estimated ice distributions at the time of the last glacial maximum (LGM) when the ice sheets were at their maximum extent and thickness (4500 meters) and sea levels were 140 meters below current levels.



a) Ice-free model (sea level 70 meters above current levels)



b) Estimated ice sheets at the last glacial maximum (sea level 140 below current levels)

Figure 15. Crust/ice models used to assess Hapgood's original hypothesis. Depth of water is depicted in blue, thicknesses of the crust in green, and ice sheet in red. Ice over water appears pink and ice on land orange. The small gap in the ice sheet at the prime meridian (middle) is an artifact in the shapefile.

We are interested in understanding the degree to which the LGM ice sheet could have affected the crust's moments of inertia and rotational axis. The inertia tensor

$$\boldsymbol{I} = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix}$$

summarizes an object's moments of inertia with respect to the center of mass. The eigenvalues of the inertia tensor are the principal moments of inertia, and the corresponding eigenvectors define their direction. The longitude and latitude of the crust's rotational axis are

$$\lambda = \tan^{-1}(b/a)$$
$$\theta = \tan^{-1}\left({}^{c}\Big/_{\sqrt{a^2+b^2}}\right)$$

where $[a\ b\ c]$ is the eigenvector corresponding to the largest eigenvalue.

To assess Hapgood's original hypothesis that polar ice sheets created a mass imbalance that could have caused the crust to move over the mantle shifting the location of the geographic poles, we estimated the moments of inertia of the crust with and without LGM ice. Using our implementation of the CRUST1.0 model, the crust's rotational axes with and without LGM ice are:

(θ_1,λ_1) = 1.32°N, 18.41°W)
(θ_0,λ_0) = 1.12°N, 18.62°W)

The difference (shift) in the rotational axis is

$$\Delta\sigma = \cos^{-1}(\sin\theta_0 \sin\theta_1 + \cos\theta_0 \cos\theta_1 \cos\Delta\lambda)$$

If the crust were free to move over the mantle, the change in the moments of inertia caused by the ice could have caused it to move approximately 0.195° or 21.68 km. It thus would seem unlikely that Hapgood's hypothesis in its original form is correct.

What is particularly interesting is that the crust's rotational axis is not where we expected to find it. In analyzing different crustal mass distribution models, Caputo and Caputo (2012) plot the value of the maximum moment of inertia (MMI) of the crust as a function of its theoretical rotational axis (TRA) (Figure 16) and discover that the TRAs with the largest MMIs tend to be far from the geographic pole. Our model places the crust's TRA almost at the equator. A possible implication of this finding relative to Hapgood's theory is discussed in the paper.

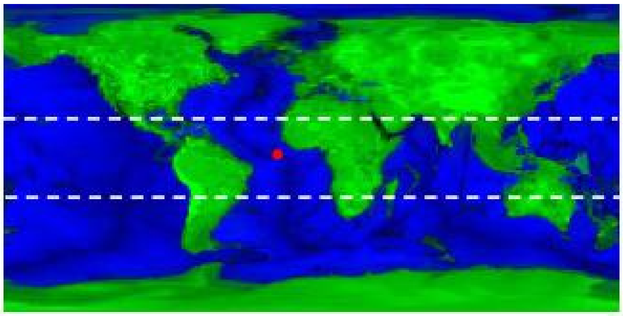


Figure 16. Location of the theoretical rotational axis of the crust (red dot in center) is at 1.21° N, 18.52° W. Dotted lines delimit the tropical zone (23.4°N to 23.4° S).