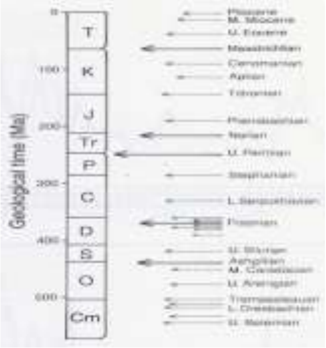
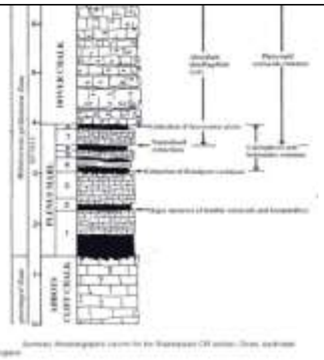
CHANGES IN THE ROTATION AXIS OF EARTH AFTER ASTEROID/COMETARY IMPACTS AND THEIR GEOLOGICAL EFFECTS

(Flavio Barbiero)

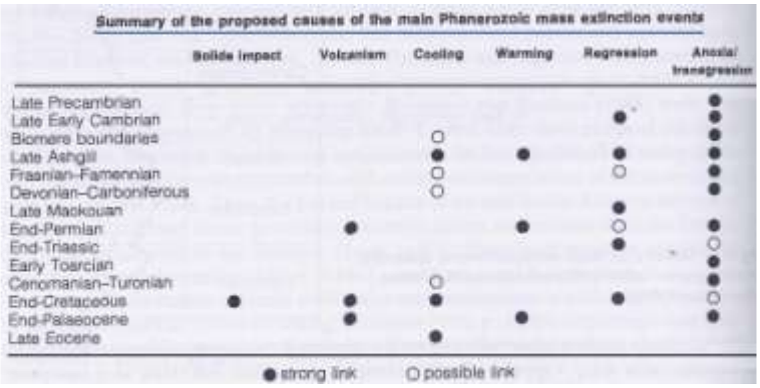
The geological history of Earth is characterised by very long periods of stability, interrupted by short violent crises, during which volcanic eruptions, orogenesis, climatic changes, sea levels variations and inversions of the magnetic field occur, together with mass extinction of species.





Geology is not able, yet, to give an explanation for these recurrent crises; there are, of course, several hypothesis, but no certitudes. Many of the geological phenomena often occur at the same time, and therefore a relation of cause-effect has been suggested between them, but it’s not always clear which is the cause and which the effect. In the last few years the idea that mass extinctions are the result of catastrophic impacts of asteroids or comets is taking ground, as for some of them the coincidence with the impact of a large asteroid has been ascertained.

It should be noted, however, that simultaneity has been ascertained also between mass extinctions and other geological phenomena, like volcanism, cooling, warming, regressions, transgressions and so on, which are maintained by many scientists as responsible for mass extinctions of species. But nobody was able to explain convincingly how such phenomena, whether alone or combined, could have provoked world-wide ecological catastrophes, both on land and on the oceans.



Summary of the proposed causes of the main Phanerozoic mass extinction events

	Bolide impact	Volcanism	Cooling	Warming	Regression	Anoxia/ transgression
Late Precambrian						●
Late Early Cambrian					●	●
Biomere boundaries			○			●
Late Ashgill			●	●	●	●
Frasnian-Famennian			○		○	●
Devonian–Carboniferous			○			●
Late Mackouan					●	
End-Permian		●		●	○	●
End-Triassic					●	○
Early Toarcian						●
Cenomanian–Turonian			○			●
End-Cretaceous	●	●	●		●	○
End-Palaeocene		●		●		●
Late Eocene			●			

● strong link ○ possible link

Above all, nobody was able to explain which was the ultimate cause of all these phenomena: because there **must** be something that triggers the recurrent geological crisis.

The thesis that I am going to propose in the present work is that all these crisis are started by sudden shift of the poles, triggered by impacts on Earth of asteroids and comets.

Catastrophic effects of impacts

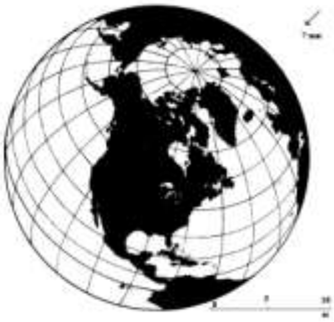
Simultaneity is an important clue in favour of a relation cause\effect between mass extinction and impacts (according to some scholar, a 3 km-wide asteroid is large enough to provoke a world-wide mass extinction), but it has to be explained how such a small object could possibly have a catastrophical effect on the whole of the planet.

According to Tom Gehrels (see: Tom Gehrels, "Collision with comets and asteroids", Scientific American, March 96), a one-kilometre-wide object, colliding with Earth at a speed of 20 kilometres per second, would liberate an energy equivalent to billions of Hiroshima-type nuclear bombs. For a 3 km-wide object this figure should be at least ten times as much. Although devastating at local level, these direct effects are not enough to explain by themselves alone mass extinctions and world-wide geological phenomena like volcanism, orogenesis, circulation cells in the mantle, regressions, inversions of the magnetic field and climatic changes.

Compared to Earth, a 3-km-wide asteroid is like a tiny 7 mm. sphere in front of a 25 metres ball.

Like a grain of sand on a football ground.

Its mass is irrelevant and cannot possibly provoke directly world-wide catastrophic effects.



Scientists assume that an impact would provoke a sudden drop of temperature and other world-wide climatic turmoil, because of the huge amount of matter injected in the atmosphere. But it's difficult to justify the size of the effects in this way. The amount of matter injected into the atmosphere is estimated to be about 100 times the mass of the impacting body. For a 3 km-wide asteroid this mass would be comparable to that injected into the atmosphere by the largest recent volcanic eruption, that of Tambora (Indonesia) on 1815. In fact that eruption had some influence on Earth's climate, as the next summer was unusually cold all over the northern hemisphere (see: Stommel H. and Stommel E.: *The year without a summer*, Scientific American, 240,174,1979). But it was only a ripple on the climate, which provoked minor inconvenience to a limited number of individuals, certainly not a world-wide catastrophe. And there were no recorded effects on the oceans.

Un impact of a large asteroid or comet can have undoubtedly devastating effects; but the size of the area directly affected could be at the most of the order of millions of square miles: a negligible percentage of Earth's surface.

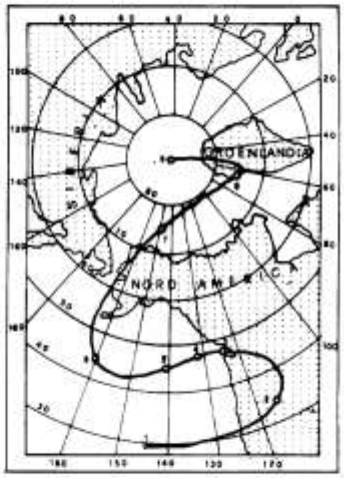
The mass extinctions of the past, instead, and the associated geological phenomena, have been global, as they have affected the whole of the continents as well as the whole of the oceans, both on shallow and deep water. Which is impossible to justify as a direct consequence of an impact, even if it happened on the open sea (but the asteroid that produced the Chicxulub crater, held responsible for the dinosaurs extinction, for example, hit the Earth on a close basin like the Gulf of Mexico).

The only way, in my opinion, to explain the global effects of an impact is by supposing that it can provoke an almost instantaneous change of the Earth's rotational axis, that is a shift of the poles.

Evidence that the poles have shifted

It is well known that the poles have often changed their position on the Earth's surface during the past geological eras. The marks left by thick ice sheets in Africa and India, the residual magnetism in ancient rocks, the old coral reefs' and coal deposits' distribution and so on, all together are compelling evidence that the poles have wandered from what is today's equator to the actual poles.

Scientists account this "wandering" to the drift of continents and to the displacement of large quantities of materials, due to erosion and sedimentation processes, which in theory can provoke a very slow shift of the poles: a few centimetres per year at the most, which in hundreds of millions of years can result in shifts of thousands of kilometres.



The shift of the North pole during the last 300 million years

However, in order to account for all the phenomena previously described, an almost "instantaneous" (from a geological point of view) shift is required. Even from the diagram above it looks as if the wandering of the poles was not gradual and continuous, but it happened by "jumps".

There is strong evidence that such a "jump" occurred in a very recent past.

The position of north poles during Pleistocene

Between 50 and 12 thousand years ago an impressive ice cap, more than two miles thick, spread from the Hudson area southward, down to the actual New York's latitude, and westward to join, at its maximum extent, glaciers flowing down from the Rocky Mountains, in Alaska. During the same period North Europe was covered by ice caps, which at their maximum extent reached the latitude of London and Berlin. The quantity of water trapped in these ice sheets and in the glaciers scattered around the world was so large, that the sea level was about 130 meters lower than today.

Position of polar ice caps during Pleistocene

The current “scientific” explanation for the existence of these ice caps is that they were due to a cooler climate all over the world.

But this theory is contradicted by the absence of ice sheets in Siberia, which was actually populated, up to its northernmost regions, well inside the Arctic Sea, by one of the most impressive zoological communities of all times. Millions of mammoths roamed Siberia and Alaska, large animals the size of which can be found today only in tropical regions, or in those areas where the supply of fodder is guaranteed all the year round. Together with the mammoths, there were rein-deer, rhinoceros, hippopotamus, bears, lions, leopards and Brezalwski horses. There were also giant beavers and slots, big horn deer, camels, sabre teeth tigers, buffaloes, aurochs bulls and many more. Strong evidence that the climate in Siberia was much milder than today, at least during wintertime.

The most natural explanation for this climatic situation, and in effect the first that was forwarded since the 19th century, is that the poles were on a different position than today. They would have moved very quickly to the actual position at the end of Pleistocene.

I am convinced that if we could analyze the shift of the poles in the distant past with the same scale of time, we would find that they happened in the same way as the recent one, by “jumps”. The “jumps” of the poles, therefore should be a recurrent and very frequent event in the Earth’s history and they would provide that ultimate cause which triggers the recurrent geological crisis.

It remains now to see what could provoke a sudden shift of the poles? The answer can be only one: impacts by asteroids or a comets. Due to the ratio between Earth and a very large asteroid (25 mt vs. 7 mm) this could be look a priori impossible; but a closer analysis of the problem will show that on the contrary this event is almost inevitable.

Earth is an inherently **unstable** planet, so much that a kick (we will see later with some calculation how small) is enough to start a process that in a few days, or weeks at the most, that is almost instantaneously in geological time, would provoke a permanent shift of the planet with respect to its rotational axis (and therefore a shift of the poles) of great magnitude, possibly in the order of dozens of degrees (which means a shift of the poles of thousands of kms.)

Besides, this shift always brings about also a variation of the tilt, that is the inclination of the rotational axis with respect to the ecliptic.

On the possibility of quick shift of the poles

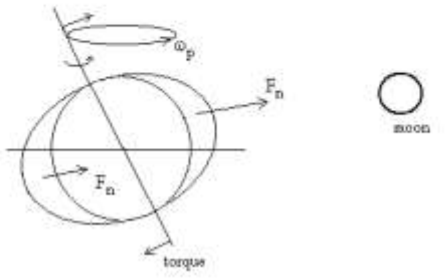
The hypothesis that the inclination of the terrestrial axis in relation to the ecliptic and the position of the poles might change, has been taken into consideration since the 19th century. Some of the greatest scientists of the time, including J.C.Maxwell and Sir George Darwin (son of the famous Charles Darwin), considered this problem and decided that the stabilising effect of the equatorial bulge was so great that no conceivable force could make the Earth shifting on its axis, except for the collision with another planet. They therefore dismissed the idea of any shift of the poles as impossible and, in fact, not worth discussing. Their influence has been so highly felt that to this day no one has seriously considered again such an hypothesis. Even the possibility of a change of the tilt is openly refused, based on that principle of Dynamic, which states that in an isolated system the momentum of the quantity of motion cannot change.

For one thing Maxwell was right: that the stability of Earth is provided only by its equatorial bulge. If Earth was a perfectly homogeneous and spherical body, a single person walking on its surface would be sufficient to make the poles shift for whatever magnitude. What Maxwell did not take into account (he was not a naval engineer) is the presence on Earth's surface of a very large free liquid layer, which in every system provokes instability. We have seen during a recent tsunami in Asia that the poles underwent a small temporary shift, due to the movement of water. If a huge tide (let's say of some hundred meters) of oceanic water would move from the equator, the poles would shift of several degrees, with unpredictable consequences.

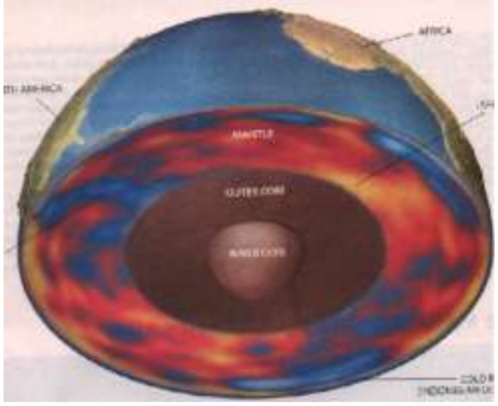
Besides Maxwell did not know the internal composition of Earth; the principle of conservation of the momentum cannot be applied to it in the same way as to a solid body. In fact the Earth's momentum can change and actually changes in every instant, both in quantity and direction, due to its internal structure.

Also the assumption that the tilt cannot change is patently wrong. First because Earth is not an isolated system; a tiny aster like the moon is responsible almost entirely for a very ample variation of the direction of the Earth's rotational axis with respect to fixed stars, due to precession. Even the axis' inclination with respect to the ecliptic changes of a couple of degrees every 90.000 years, due the phenomenon called "nutation".

The movement of precession is due to the gravitational attraction on the equatorial bulge of sun and moon, which exerts a perturbing torque 9 million times smaller than the stabilizing torque provided by the bulge itself. A very tiny torque, which, however, has a major effect on the momentum of the whole Earth, due to its internal composition.

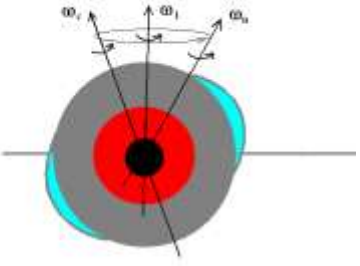


Let’s see why.



Earth is made by a solid metallic nucleus, with a diameter of about 2.780 km, followed by a liquid layer, also metallic, 2080 km thick, and finally by a solid rocky shell of 2.900 km, on top of which there is a tiny layer of water. The liquid metallic layer separates the two solid parts so as to preclude direct transmission of motion between them.

The luni-solar attraction acts exclusively on the bulge of the **external shell, not on the liquid layer or on the central nucleus**. The movement of precession, therefore, is made only by the external shell. Of course it induces convective circulation on the liquid metallic layer underneath, and in the end the variations of motion of the external shell are transmitted to the central nucleus, but with great delay. Due to the masses concerned and the mechanism of transmission of the angular motion, this delay is certainly of the order of thousands of years, or even more.



In theory, due to the movement of precession, the axis of the central nucleus could be diverted, in the actual situation, as much as 45 degrees with respect to the rotational axis of the external shell. And that of the liquid layer in between of as much as 20 degrees.

At a much smaller scale also the momentum of the ocean as a whole does not coincide in direction with the rotational axis of the external shell, because of the oceanic streams.

Therefore, the direction of the angular momentum of Earth as a whole is certainly much different from the rotational axis of the external shell, and it is constantly changing in direction, because each of the four layers moves independently from the others. Also its quantity is always decreasing, because of dissipation of energy due to the attrition between them and inside each of them.

Precession as cause of periodical Earth’s warming and cooling

The principle of conservation of momentum can be applied only to an isolated system, which does not emit matter or energy. In the case of Earth, the fact that the external shell and the central nucleus have diverging rotational axis, induces turbulence on the liquid layer in between, with consequent dissipation of energy as heath (and probably magnetic field), at the expense of the angular momentum; therefore it provokes a variation of the global momentum of Earth, both in quantity and direction.

With the present angle of precession, the divergence between the axis of rotation of the external shell and that of the central nucleus could vary periodically from 0 to 46 degrees. The wider the angle between them the greater is the amount of energy dissipated, and therefore the heath radiated through the external shell. This could account for a periodical warming and cooling of Earth, due to the variation of the angle between the internal and the external axis of rotation.

In the extreme hypothesis that the axis of rotation of the external shell would result reversed with respect to that of the central nucleus (which in principle is quite possible), the angular momentum of both of them would be dissipated as heath because of the attrition of the liquid layer in between. This is what could have happened to Venus, a planet which should have the same rotational speed as Mars and Earth and a surface of the same order of age. Instead, the rotational speed of Venus is almost nil and its actual surface became solid no more than one billion of years ago. For some reason the external shell and the central nucleus of this planet could have turned in counter-phase, reciprocally nullifying their angular momentum, and the heath developed in this process should have been sufficient to completely melting the external shell.

How the poles could shift

To conclude, the statement that the tilt can change only if Earth is hit by a planet-size body is baseless. And equally baseless is the idea that a planetary-size body is necessary to provoke a shift of the poles, that is, to provoke a shift of the rotational axis with respect to the planet itself. For this to happen it’s enough to “reshape” the equatorial bulge, that is to induce on the surface of Earth deformations relatively insignificant (the expanse of the bulge is only 0,3% of the terrestrial radius, absolutely not perceptible from the eye. Significant shifts of the poles can be obtained with deformations of no more than 0,03% of the Earth’s radius).

We have to see now how the equatorial bulge could be “reshaped”. Not very difficult to understand, if we take into account the fact that about 30% of the bulge itself is made by water, that can be easily displaced from one side to another by relatively week forces (free liquid surfaces, in fact, are always a major factor of instability). A tide of some hundred meters moving from the equator would displace the poles by several degrees. All we have to do, now, is to find what mechanism could provoke such a tide.

We have already seen that the existing geological evidence is pointing to a shifting of the poles by “jumps”. We have to see, now, what could be the cause of a “jump”. I am going to show that impacts with asteroids and comets can start a process which in the end results in a permanent shift of the poles.

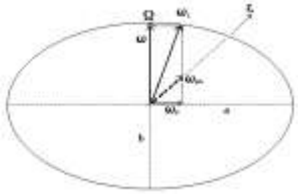
Due to the large disproportion between the two bodies (in scale, 7 mm. for a 3-km-asteroid vs 25 m. for Earth) the possibility that such an impact could induce a shift of the poles seems to be out of the question. The mass of an asteroid, and the associated energy, cannot provoke directly a shift of the poles higher than a few centimetres.

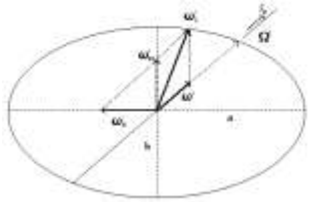
However, if mass and energy of the asteroid can be neglected, the same cannot be done for the torque developed by the impact. In order to understand why, we have to consider (as pointed out firstly by Maxwell himself) that the stabilising torque of the Earth is developed not by the entire mass of the planet, but only by the equatorial bulge, that is, by a ring of matter which at the equator has a thickness of no more than 14 km.

Thus the disproportion between the mass of the equatorial bulge and that of an asteroid is by far smaller than that between the same body and the whole mass of Earth. Therefore, due to the very high speed of the asteroid (more than 20 km/sec), the impulsive torque developed by the impact could reach a peak value so high as to equalise, for a very short instant, the reaction torque developed by the equatorial bulge.

The impulsive torque is too short in time to provoke permanent effects on a normal gyroscope, completely solid and inelastic. Earth, however, is not a normal gyroscope. First it's covered by a liquid layer, which reacts immediately to every change of motion, even if very small. Second, also the crust is not rigid and can easily be reshaped by the centrifugal force. It can be demonstrated that because of these characteristics, an impulsive torque with a certain direction and intensity could "trigger" a process which in the end result in a shift of Earth's rotational axis.

We can study the behaviour of a gyroscope through its *ellipse of inertia*, in a case that was never examined by scientists, because of no technical interest: that of a gyro disturbed by a torque of the same order of magnitude of the stabilizing torque developed by the equatorial bulge. In the mathematical appendix, it's demonstrated that when the disturbing torque equalises the stabilizing torque, the axis of precession becomes permanent axis of rotation of the gyro. The gyro recovers its previous axis only if and when the disturbing torque becomes nil again.





An impact produces an impulsive torque. If its value is higher than a threshold value, Earth changes instantly its axis of rotation and recovers the old one as soon as the impulsive torque vanishes completely. However, if the disturbing torque does not vanish completely, that is if there is a residual torque with the same direction, Earth keeps "memory" of the impact and of its direction. This "memory" consists in a rotational component, very small, less than 1 millionth of the normal rotation. What is particular in this rotational component is that it is fixed with respect to Earth.

Under the effect of this tiny rotational component, seawater begins to move towards a circle perpendicular to that rotation (the new equator). Very little indeed: if that was the only component, the resulting equatorial bulge would be of a few meters only. But as this happens, the value of the rotational component increases, at the expenses of the main rotation, therefore increasing the centrifugal force which makes more water move towards the new equator, thus increasing the force and so on. This process starts very slowly, but accelerates progressively, until the centrifugal force developed by this rotational component grows strong enough to induce deformations of the Earth's mantle.

From here on the equatorial bulge is quickly “re-shaped” around the new axis of rotation and Earth will soon be stable again, with a different axis of rotation and different poles.

This mechanism shows that the Earth’s poles, contrary to what has always been postulated, can make “jumps” in a matter of days (that is almost instantaneously) of thousands of kilometres, due to the effects of forces at first sight negligible, such as the impact of a medium size asteroid.

It is important to note that this process requires the presence of a liquid layer over a plastic external shell, easily adjustable, so as the equatorial bulge could be quickly re-shaped. Therefore, in the present solar system such a process could happen only on Earth, because it’s the only body with liquid oceans on a plastic shell. All the other bodies of the system either do not have oceans, like Mercury, the present-day Venus, Mars, the Moon etc., either they don’t have a solid shell within reach of an impact, like Jupiter and the other external planets.

What happens in case of a pole’s shift

A world–wide catastrophe can be justified only if we suppose that the impact of a small object like an asteroid or a comet can provoke a macroscopic shift of the poles in very short time. The effects of the shifts are of course related to their magnitude, and above all to the variation of the tilt (which is independent from the first). The magnitude of the shift is not directly related to the magnitude of the impacting body. Also the site of the impact has little influence on its outcome. Due to the very high speed of the impact (normally more than 20 km/sec) water behaves and transmit the shock like a solid surface (at this speed the matter in front of the impacting body doesn’t have the time to move aside: it vaporises instantly, forming a pocket of high pressure gas that finally explodes). Let’s see what would happen in this case:

First of all there would be a very quick “reshaping” of the equatorial bulge around the new axis of rotation. (Actually, the reshaping of the equatorial bulge is a necessary condition for a shift of the poles, and therefore it cannot be considered as a consequence, but rather as the cause of a shift; the two go necessarily together).

This is achieved in a first moment, as we have seen, through a shift of water only, and soon after through an adjustment of the mantle, due to centrifugal force. As a consequence, some areas of the Earth’s crust would rise, some would be flattened, while others would undergo very small deformation or nothing at all. For a 20-degrees-shift the maximum deformation of the crust would be of the order of 1 km (distributed over an arch of 20.000 km, which means a rise of 5 cm per km). Very small, compared to the diameter of Earth, but nonetheless of great consequence on the surface. In particular, where there would be an increase of the bulge there could be fractures of the crust, with subsequent earthquakes and possible pouring of magma.

The sudden displacement in latitude of continental masses would provoke the sudden insurgence of strong tangential forces of these masses against the mantle, (due to centrifugal forces), with the consequent possibility that new cells of circulation would be started in the mantle, and new fragmentation of continents initiated. These would start a new orogenetic phase, if and where the appropriate conditions exist.

There would also variations of the climatic conditions, due to the change of latitude of the continents and to the change of the tilt (we will see that it has a tremendous influence on the climate), with variations of the size of the terrestrial ice caps and consequently of the sea level. And finally there would be perturbation of the terrestrial magnetic field, with possible inversion of its polarity, due to changes of circulation in the liquid outer core of Earth.

The effects on the ecological systems and on living species would depend, of course, on the size of the shift. The wider the shift the more dramatic would be its effects.

We have to make, however, a clear distinction between the immediate and the long term effects. Let's consider the case of a wide shift, of the order of 15/20 degrees.

Immediate mass- killing

- First we have the devastation provoked directly by the impact; normally the area affected is very restricted, so this is not significant at world-wide level.
- Much more catastrophic are the wide variations of the sea level that occur during the first phases of the shift. In some areas there would be a tide of several hundred meters (there is evidence, at the end of Pleistocene, of a tide of 350 mt on the Haway and 700 on Alaska), with destruction of land habitats.
- other areas would remain dry, with destruction of maritime habitats. Furthermore, there would be everywhere a sudden surge of deep oceanic water, cool and anoxic, with dramatic effects on all maritime biota.
- As for the continents, volcanism and earthquakes would require their toll; but the major factor of destruction would be violent winds and torrential rains all over the world. On the whole the atmosphere follow the rotational movement of Earth, but it's not tied to it. If Earth suddenly changed the direction of its rotation, the atmosphere would, at first, keep its previous motion, thus provoking hurricane force winds and exceptional rains. Therefore we would have catastrophical floods all over the continents, with massive destruction of flora and fauna (this would provide a significant sample of the life in that moment, because the carcasses are amassed by the floods in some particular places and covered by silt).
- A temporary cooling of the climate, due to the combined effect of all these phenomena, is also expected, although not so dramatic as depicted by some geologists.

Permanent climatic changes

The immediate destruction of fauna and flora can be very important, but normally not at the point of provoke directly the extinction of a significant number of species. If the environmental condition after the shift were established as before, the species would quickly recover and reconstitute the previous ecosystems, with minor differences.

However, in many cases the new climatic conditions are completely different from the previous ones.

The shifting of poles implies a shifting of the climatic zones, the melting of polar ice caps and the formation of new ones; there would be also changes on the course of winds and oceanic streams, with further local climatic variations. If the tilt would remain the same as the previous one, this would provoke only a migration of species from one site to the other. Natural obstacle and temporary difficulties could provoke the extinctions of a number of species, unable to migrate; but those dominant species that occupy large areas would not have problems.

Quite different is the case if the shift would provoke a huge variation of the tilt .

The most important element, in fact, in order to evaluate the climatic conditions following a shift of the poles, is the inclination that the new axis of rotation will assume with respect to the ecliptic, which has a tremendous effect, on the seasonal changes of climate, on the ice accumulation and the diffusion of flora and fauna. A high value of the tilt would imply long cold winters, followed by very hot summers; in these conditions there would be very limited accumulation of ice, because the winter's snow would be inevitably melted by high summer temperatures at whatever latitude. Therefore the polar ice caps and the mountain glaciers would be reduced to a minimum and sea level would increase. Flora and fauna would be highly dependent on latitude, because the number of species able to overcome the critical winter (or summer) period would decrease with the increase of latitude.

On the contrary, a small value of the tilt would determine an enormous growth of ice at high latitudes and altitudes, with subsequent lowering of the sea level, because there would not be snow thawing during summer. On the other hand the climate would be much more stable then it is today, with very limited (or non-existent) seasonal climatic differences and uninterrupted vegetation's growth. This would bring about the disruption of today's climatic barriers, with subsequent spreading of tropical species towards northern regions and vice versa.

These climatic variations, together with the initial mass-killing, would bring about deep changes in the ecosystems, and therefore the possibility of extinction of species non-specifically adapted to the new climatic conditions and the spreading of new ones more adaptable.

A shift of the poles, therefore, opens the possibility to mass extinction and to the beginning of an evolutionary process, with radiation of new species all over the world.

It is important to note that Earth could not possibly maintain for ever its rotational axis vertical with respect to the ecliptic, due to the presence of the moon. The moon's orbit has an inclination of 5 degrees with respect to the ecliptic, therefore it would exert a disturbing torque on Earth, forcing it to precede: the tilt would increase up to 12-15 degrees and then decrease again, with a period of about 15/20 thousand years.

As the tilt increases, the seasonal cycles are re-established and summers become warmer, increasing the melting rate of ice. Therefore the polar ice caps and all the mountain glaciers retreat, to re-advance again when the tilt goes back to verticality. Inevitably there would be periodical advances and retreats of the ice caps all over the world, as it has been observed during the last Pleistocene glaciations. To these macroscopic periodical variations we have to add the effects of other factors which have some influence on the climate, like Milankovitch cycles, variations of green-house gases a.s.o.

As we are talking about green-house gases, it's interesting to note that the ice carrots of Antarctica and Greenland show that their concentration in the atmosphere always changes **after** a climatic modification, never before. This means that for each climatic condition of Earth there is a specific concentration of green-house gases in stable equilibrium with those conditions. Today the equilibrium is broken by the massive production of CO2, because of human activity. This certainly has some effect on Earth's climate, but it shouldn’t be permanent. When the humans will stop to introduce greenhouse gases into the atmosphere, their concentration should go back, soon or later, to the equilibrium condition.

Probability of a shifting of the Poles due to an asteroid impact

The following conditions have to be fulfilled in order that an asteroid’s impact could trigger a shift of the poles:

First, the torque developed by the impact must be higher than the maximum Earth reaction torque, even if for only one instant. This means that the asteroid must not only have size and speed of sufficient magnitude, but the arm of the torque, as well, has to be long enough. If the impact is directed exactly towards the centre of Earth, there is no torque at all, regardless of the size and/or the speed of the asteroid. On the other hand, even a small object can develop a very high torque if it hits Earth at an angle almost tangential to the surface.

Second, when the impulsive torque due to the impact vanishes, there must be a residual torque, no matter how small, with the same direction; otherwise, there will not be “memory” of the impact. This residual torque can be provided for by the sun-moon gravitational attraction on the bulge, the same responsible for the precession. If the direction of this torque is opposite to that of the impact, the shift would not be triggered.

The Apollo objects

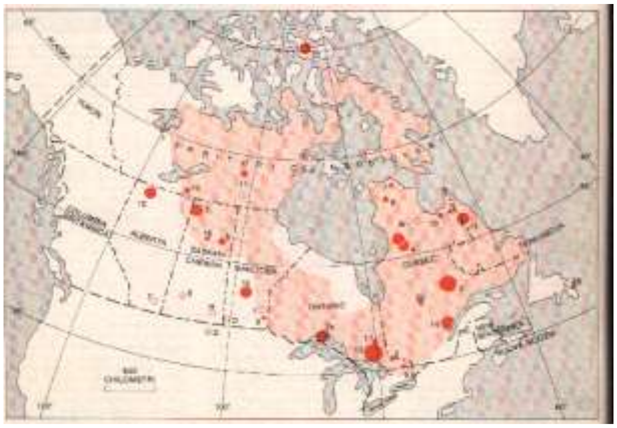
The probability that Earth could be hit by an one km-wide asteroid are rather high. Responsible for that is a particular category of celestial bodies, named by astronomers “Apollo objects”, or even NEOs (Near Earth Objects), that is a class of asteroids whose perihelion lies inside the orbit of Earth.

The total number of NEOs with a diameter of one kilometre or more is estimated to be between 1.000 and 2.000.

The probability that a NEO collides with Earth is estimated at $5.\ 10^{-9}$ per year per single NEO. Therefore we have a probability of at least 4 collisions per million years with objects as large as one kilometre or more. As the size of the objects becomes smaller, this probability grows exponentially to become of one impact every few centuries for objects of 100 to 200 metres diameter.

The calculated probability is in good accordance with the number of impacts occurred on Earth in the last 600 million of years (G.W. Wetherill, “Gli Oggetti Apollo”, Scientific American ,Maggio 79 - Tom Gehrels, “Collision with comets and asteroids”, Scientific American, march 96). If the Earth didn’t have oceans and atmosphere its surface would be marked with craters like the Moon and Mercury . On our planet, instead, erosion and sedimentary processes delete very quickly the marks of collisions by meteorites.

Only where recent ice sheets have scraped the surface, thus uncovering the traces of ancient collisions, as in Canada, it is possible to count the craters accurately. Based on this count G.W. Wetherill (see: G.W. Wetherill, "The Apollo Objects", Scientific American May 79) has estimated that in the last 600 million years the planet has been hit at least by 1500 objects with a diameter larger than one kilometre.



A very conservative calculation (see the mathematical appendix) shows that a one km-wide lithic asteroid can develop a torque largely sufficient to trigger a shift of the poles. Based on this calculation, we can realistically maintain that objects of half that size, or even smaller, are large enough to develop perturbing torques higher than the required threshold.

The probability that Earth could be hit by a body of this size is ten times as much, that is forty or fifty impacts per million years. Therefore the shift of the poles should be a very frequent event on Earth's history.

Most of the impacts occur on the ocean and leave no evident marks, unless it's a very large body on shallow waters. Therefore the coincidence between the starting of a geological crisis and an impact can be ascertained only in a small percentage of them.

But there is no doubt the impacts of bodies large enough to trigger a shift of the poles occur frequently; if the mechanism proposed for a shit is right, **this phenomenon should play a major role in Earth geological history and it appears to be the main responsible for evolution of life.**

How life evolves

During long periods of environmental stability, the ecosystems reach a stable equilibrium with the environmental conditions and the existing species evolve in order to occupy all the available ecological niches, attaining the most possible biodiversity. Once the equilibrium is achieved and all the available niches are filled, the evolution stops, until something disruptive happens. A shift of the poles ravages the ecosystems of the whole planet: a great number of animals succumb during the immediate catastrophic events. The survivors have to adapt to new environmental conditions; a number of ecological niches are no more available and the related species decline into extinction. The more adaptable species emerge and fill the niches that become available, while the ecosystems gradually reach an equilibrium with the new environmental conditions.

Therefore, after an initial decline in the number of species, there is a rapid evolution and diversification of the survived species, until the maximum possible biodiversity is reached again; as this happens evolution relents and finally stops. Then a new shift starts the process again, and again, and again, until there will exist the possibility of impacts on Earth.

MATHEMATIC APPENDIX

Rotational components in a disturbed gyroscope

The rotational components in a disturbed gyroscope are connected to each other by the following equation, due to Laplace, which expresses the principle of conservation of energy:

1) $J_o \Omega^2 = J_o \omega^2 + J_p \omega_p^2 = J_i \omega_i^2$

where: Ω = speed of rotation of the undisturbed gyroscope

ω = speed of rotation of the gyroscope around its main axis

ω_p = speed of precession

ω_i = speed of instantaneous rotation

J_o = main momentum of inertia

J_p = momentum of inertia related to the precession axis

J_i = momentum of inertia related to the axis of instantaneous rotation

The value of the torque developed by a disturbing force F_p, applied to the main axis of the gyroscope with an angle β, is evidently given by:

2) $C_p = R\ F_p \operatorname{sen}\beta$

where R is the arm of the force, that is the distance of his point of application from the centre of the gyroscope.

Instant by instant the gyroscope precedes around an equatorial axis, but the resulting motion of he main axis describes a cone, with the axis parallel to the force, an opening angle of 2 β and its vertex at the centre of the gyroscope. The main axis, therefore, appears to rotate with angular speed ω_{pa} around an axis parallel to the disturbing force.

The value of ω_{pa} is given by the following equation:

3) $$\omega_{pa} = \frac{\omega_p}{sen\beta}$$

Equations 1), 2) and 3) allow us to study exhaustively the behaviour of a disturbed gyroscope, by means of an essentially graphic method.

Given a gyroscope let's draw, on the basis of its inertia ellipse, another ellipse whose semi-axis are respectively:

$$a = \sqrt{\frac{J_o}{J_p}}\ ; \qquad b = \sqrt{\frac{J_o}{J_o}} = 1$$

Every radius of the ellipse, *r(θ)* , where: $\theta = 0 \div 2\pi$, would obviously have the value:

$$r_\theta = \sqrt{J_o / J_\theta}$$

where J_θ is the momentum of inertia of an axis forming an angle θ with the main axis.

If we put $\Omega^2 = 1$, for equation 1) every radius *r(θ)* is proportional to the speed of rotation that the gyroscope has to have around axis θ to keep its initial energy unchanged.

The end of the arrows representing Ω and ω_i, therefore, always fall on the ellipse, while all the other rotational components have to be found inside the ellipse. This ellipse allows us to analyse exhaustively the behaviour of all the rotational components of the gyroscope, bound as they are by equation 1) (see fig.1).

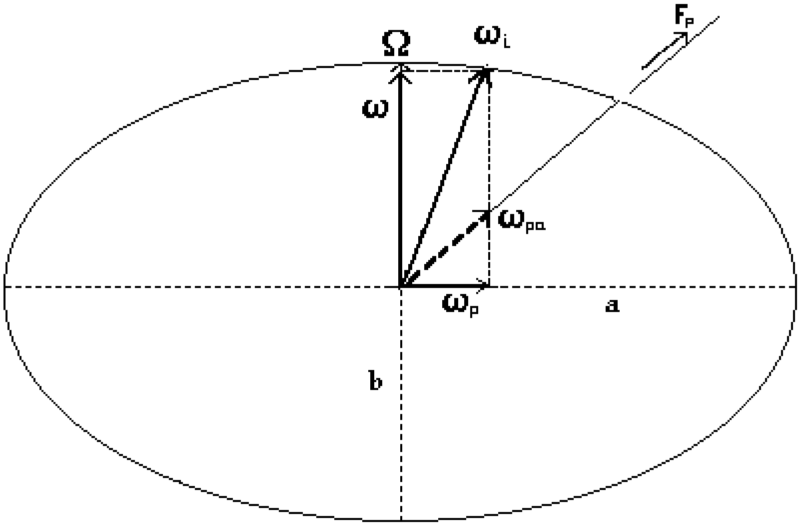


fig.1

The meaning of the rotational components shown in fig. 1 is easily understood. A gyroscope subjected to a disturbing torque reacts generating an exactly equal and opposed torque. This is achieved by means of a precession movement, ω_p, around an equatorial axis, which makes the gyroscope rotate "unbalanced", that is rotate instant by instant around an axis, which forms with the main axis an angle β proportional to the disturbing torque. The instantaneous rotation, ω_i, is given by the sum of the rotation around the main axis, ω, plus the rotation of precession, ω_p.

When a gyroscope is subjected to a disturbing force F_p, of increasing value, ω_p grows and as a consequence ω_i moves towards ω_{pa}.

When F_p reaches a certain value F_{pa} (see calculations further on), we will have:

$\omega_i = \omega_{pa}$

At that precise moment the axis of instantaneous rotation coincides with the axis of apparent precession, and becomes fixed with respect to both, the space and the gyroscope. This is a very special condition in which the system composed by the gyroscope and the disturbing torque behaves like a non-disturbed gyroscope, with only a single rotational component, Ω' (see fig. 2). This axis, therefore, becomes the new axis of rotation of the system.

If at this point force F_p diminishes again, the system behaves like a gyroscope to which is applied a torque of value:

$C'_p = C_{pa} - C_p$

Therefore the new axis of rotation begins to precede around the main axis, moving on the surface of a cone. As a consequence ω_i' moves back towards the main axis, following the same path it has run along in the previous journey. Value and direction of the gyroscope's rotational components in this case are represented in fig.2

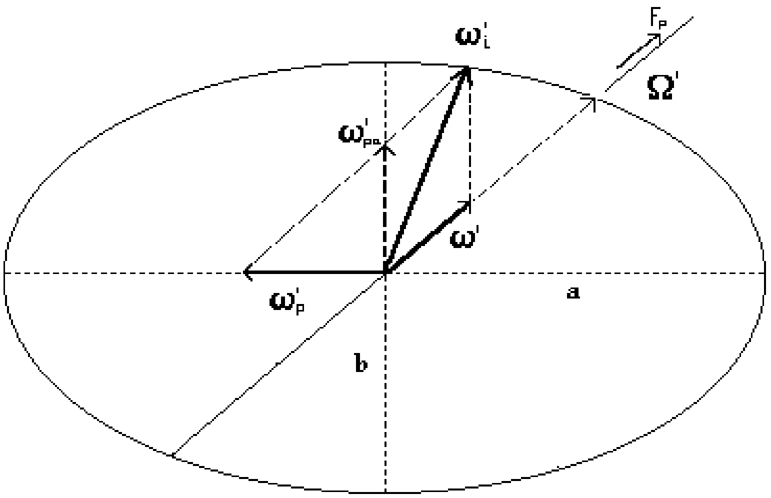


fig.2

Due to the principle of conservation of energy we will evidently have:

$$J_{pa}\,\Omega'^2 = J_o\,\omega'^2 + J'_p\omega_p'^2 = J_i\,\omega_i'^2 = J_o\,\Omega^2$$

For each value of the disturbing force, F_p, the speed of the instantaneous rotation is exactly the same both ways, there and back, that is $\omega_i' = \omega_i$. The other rotational components, instead, change considerably and ω'_p has direction opposite to that of ω_p . This is justified by the fact that while F_p is growing, the main axis rotates around axis $\omega_{pa.}$ In the "return journey " the contrary happens: it is the axis of ω' (now fixed in respect to the body of the gyroscope) that rotates around the main axis.

The most important fact is that along the ω' axis we have a rotational component which is fixed in respect to the gyroscope. This means that the gyroscope keeps "memory" of the position of the new axis of rotation. That rotational component, therefore the "memory", is cancelled only if and when F_p is completely zeroed. If F_p should not be zeroed , the gyroscope would keep this rotational component, and therefore the "memory", indefinitely.

Behaviour of a semifluid gyroscope like the Earth

The behaviour of the Earth as a gyroscope is subject to some peculiarities due to the fact that the planet is not a homogenous and rigid solid, but is made up of liquid parts inside and outside an intermediate plastic shell.

Suppose the planet is hit by large celestial bodies at high speed. The impact develops an impulsive torque, that according to the size and speed of the impacting mass can have a very high peak value, as high as the highest reaction torque possibly developed by Earth.

Graphics of fig.1 and fig.2, can help us to understand what happens in this case.

As soon as the torque developed by the impact starts growing, the ω_i moves in the direction of ω_{pa}, parallel to the direction of impact. If the impact develops a torque of sufficient value, ω_i will coincides with ω_{pa}. On that instant the axis of ω_{pa} becomes axis of permanent rotation. As soon as the torque value decreases, the axis of ω_i returns quickly towards the main axis, but following a different path as shown in fig. 2. As soon as the shock ceases, an instant later, the Earth should again return to rotate around its natural axis, without any further repercussion. But it is not necessarily so.

To cancel the "memory" of the new axis of rotation, and have the gyroscope rotating again around the main axis, it is necessary that the torque be completely spent. Unfortunately, there are good probabilities that this may not happen. We know that the Earth is permanently subjected to a torque generated by the gravitational forces of the sun and the moon on the equatorial bulge. This torque is millions of times smaller than the one developed by the impact, but its role is fundamental.

If at that moment it has a different direction than the one developed by the impact itself, as soon as the shock is exhausted, the Earth instantly recovers its previous axis of rotation and all ends there. If, instead, the torque due to the Sun-Moon attraction has the same direction of the torque caused by the celestial body, it is added to this, and contributes in its small way to the instantaneous change of the position of the poles. A few instants later the shock exhausts itself while the Sun-Moon gravitational attraction continues, and however small, it nonetheless develops a torque higher than zero. Therefore the “memory” of the axis around which the Earth has rotated during the impact, even for a very short moment, cannot be cancelled.

In this case the Earth actually behaves like a gyroscope whose main axis coincides with the one adopted during the impact, subjected to a disturbing torque equal but opposite to the torque generated by the impact. The overall motion is apparently exactly the same, but in reality there are fundamental differences, as illustrated in fig.3 .

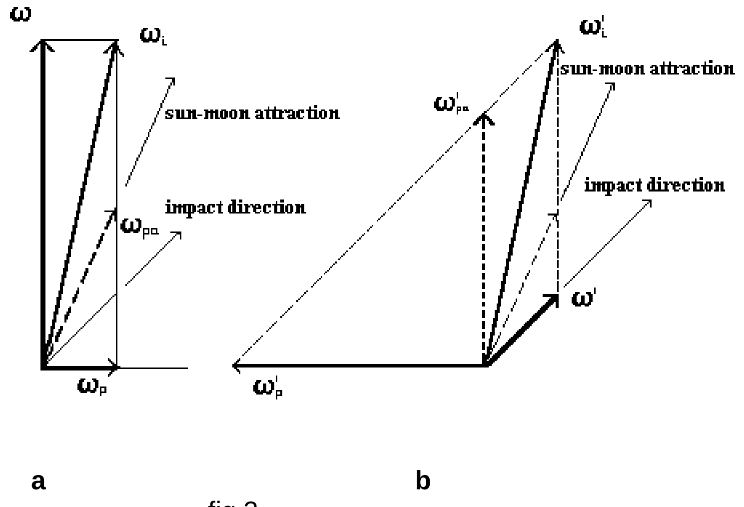


fig.3

Graphics n. 3.a and 3.b represent the situation of Earth’s rotational components immediately before (3.a) and after (3.b) the impact, in the case in which the Sun-Moon disturbing force has the same direction of the force developed by the impact. (To make it easier to represent them, the precession rotational components in the illustration are greatly exaggerated; in reality they are more than one million times smaller than the main rotation. The rationale however does not change).

Apparently the situation has not changed, because ω_i is exactly equal to $\omega'_{i,}$ and ω’ has the same magnitude as the previous precession speed $\omega_{pa.}$ There is however a crucial difference: at this point ω’ is the only rotational component “fixed” with respect to the Earth’s body. Thus, the axis of ω’ has become axis of permanent rotation. The rotation around it is extremely small (one million of times smaller than the main rotation), but it develops in any case a centrifugal force strong enough to form an equatorial bulge (of a few meters) around its axis of rotation.

If the Earth was a solid gyroscope, this situation would last indefinitely unchanged. The planet, however, is covered by a thin layer of water, which reacts immediately to any change of motion.

Sea water begins to move towards the new equator, and as this happens, the value of ω’ increases again, therefore increasing the force which makes the water move towards the new equator, which in turns makes more water move towards the equator and so on. This process gradually accelerates, until the centrifugal force developed by ω’ grows strong enough to induce deformations of the Earth’s mantle.

From here on the equatorial bulge is quickly reformed around the new axis of rotation and Earth will soon be stable again, with a different axis of rotation and different poles.

Value of the reaction torque developed by Earth

The value of the reaction torque developed by a gyroscope, when rotating around an axis different from the main, can be calculated (see fig, 4) reckoning the torque developed by the element of mass, dm, rotating around the axis of ω_i:

$C_i = F_i b$

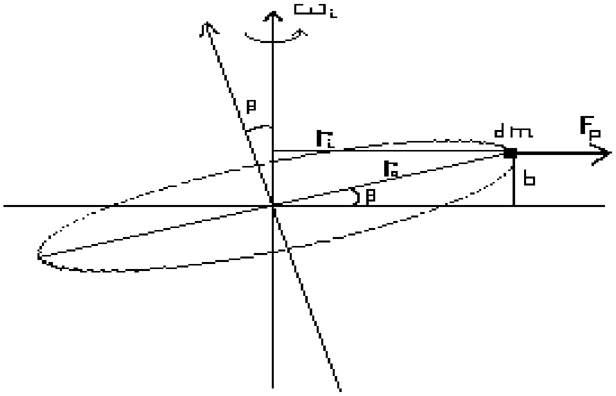


FIG. 4

where:

$F_i = dm\,\omega_i^2\, r_i = dm\,\omega_i^2\, r_o \cos\beta$ is the centrifugal force;

$b = r_o\, sen\beta$ is the arm of the torque.

We have therefore:

$C_i = dm\; r_o^2\, \omega_i^2\, sen\beta \cos\beta = dJ_o\, \omega_i^2\, sen\beta \cos\beta = ½\, dJ_o\, \omega_i^2\, sen2\beta$

where $dJ_o = dm\; r_o^2$ is the momentum of inertia of mass dm with respect to the main axis.

For a ellipsoid of revolution we will have therefore:

4) $\mathbf{C = (J_o - J_p)\, \omega_i^2\, sen\beta\cos\beta = ½\; J_r\, \omega_i^2\, sen2\beta}$

where $J_r = (J_o - J_p)$ is the momentum of inertia of the bulge.

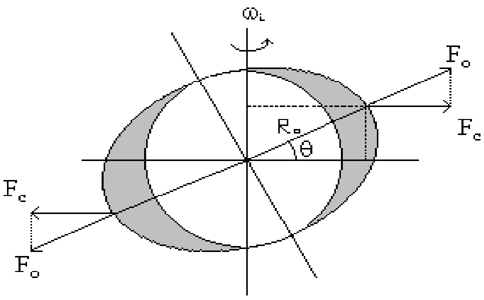


fig 5

Equation 4) shows that a gyroscope may develop a reaction torque only if $J_o \neq J_p$. In the case of it being perfectly spherical, it would rotate indifferently around whatever axis and it wouldn't have any stability.

This is due to the fact that in a rotating homogenous sphere, all centrifugal forces balance each other and there is no reaction torque, no matter what the axis of rotation is. Only the equatorial bulge can develop a reaction torque

Value of the stabilising torque developed by the equatorial bulge

From equation 4) we see that the maximum reaction torque possibly developed by a gyroscope is reached when $\beta = 45^o$:

$C_m = ½ J_r \ \omega_i^2$

For Earth the value of ω_i is almost equal to that of the main rotation, so we can assume that:

$\omega_i^2 \ \cong \ (2\pi / 8{,}64)^2 \ 10^{-10} = \ 5{,}28 \ . \ 10^{-9}$ sec.$^{-2}$

The calculation of J_r can be made by using the value of the centrifugal force, $F_{o,}$ developed by the equatorial bulge due to the Earth's rotation, as calculated by Gallen and Deininger for Hapgood (see insert at the end):

$F_o \ = \ 4{,}1192. \ 10^{19}$ kg.

For an approximate calculation we can put:

$J_r \cong M_r \ R_o^2$

$F_o \ \cong M_r \ \ \omega_i^2 \ R_o = J_r \ \omega_i^2 / R_o$

where M_r is the mass of the bulge and R_o the radius of the Earth.

We have then:

$J_r \cong \ \ F_o \ R_o / \omega_i^2 \cong 5 \ 10^{34}$ kgmt^2

And finally, thanks to equation 4) we have:

4') $\mathbf{C = \ ½ \ \ J_r \, \omega_i^2 \ sen2\beta = \ 1{,}38 \ \ 10^{26} \ sen2\beta}$ kgmt

For $\beta = 45^o$ we have :

$C \cong \ 1{,}38 \ \ 10^{26}$ kgmt

which is the maximum reaction torque possibly developed by Earth.

Calculation of the size an asteroid should have to cause the shifting of the poles

According to equation 4) to displace the axis of rotation for instance of 20^o, an asteroid hitting the Earth must develop an impulsive torque of the following value:

$C_{20°} \ = \ 8{,}87 \ . \ 10^{\ 25}$ Kgmt.

It is therefore easy to calculate the size and speed that such an asteroid must have.

The impulsive force F_i developed on impact with Earth by the asteroid is given by:

$F_i = M_a.a$

where:

$a = dv/dt$ is the acceleration the asteroid undergoes on impact

M_a is the mass of the asteroid

To calculate the acceleration, a, we can assume the asteroid has, on impact, a speed:

$v = 5 \ . \ 10^{\ 4}$ mt/sec.

To calculate dt we have to rely on an estimate. In a conservative way, considering the depth of known craters, we can presume that the depth of the crater caused by that impact to be 500 m, which means that the speed of the asteroid decreases from 5.10^4 to 0 mt/sec, in a space of 500 meters. The time in which this happens is approximately one hundredth of a second, that is:

$dt \ = 0{,}01$ sec.

The average acceleration of the asteroid will therefore be:

$a_m \ = \ dv/dt \ = \ \ 5.10^4 / 0{,}01 \ = 5. \ 10^6$ *m/sec*^{2}

The acceleration peak is certainly much higher. In a conservative calculation we can assume it to be double the average value. We will have then:

$a = 5.10^{\ 4} \ / \ 0.005 \ = \ \ 10^{\ 7}$ mt/sec^2

And therefore:
$F_i = M_a \,.\, 10^7$ kg
The torque developed by this force will obviously be:
$C_i = F_i \,.\, R_i$
where R_i is the arm of the torque.

The value of R_i can be between 0 and $R_o \cong 6{,}4\ 10^6$ mt, that is the radius of the Earth. For statistical reasons we can put:
$R_i = ½\ R_o = 3{,}2\ 10^6$ mt
The mass of the asteroid will therefore be:

$$M_a = \frac{F_i}{a} = \frac{C_i}{R_i a} = \frac{8{,}87.10^{25}}{3{,}2.10^6.10^7} = 2{,}77\ 10^{12}\ \text{kg}$$

If the density of the asteroid is of 3 Kg/dm^3, we will have a volume of:
$V_a = 0{,}92\ \text{km}^3$
that is then a lithic asteroid of approximately a 1000 metres diameter. This calculation is very conservative. We can realistically suppose that an object of half that size is enough to develop a torque of sufficient value for a shift of the poles.

Gallen's calculation of the stabilising centrifugal effect of the equatorial bulge of the Earth

Let the equations of the sphere and the ellipsoid of revolution be:

1) $x^2 + y^2 + z^2 = b^2$
2) $\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$

where the axis of y is the axis of revolution. Take as the element of mass, dM, the ring generated by revolving the rectangle dxdy about the axis of y. We have:
3) $dM = 2\pi\delta x\, dxdy$
where δ is the density. For each particle of the ring the centrifugal acceleration is the same, being equal to $\omega^2 x$, where ω is the constant angular velocity in radiants per second.
The element of centrifugal force, dF, exerted by the ring is then:
$dF = \omega^2 x\, dM = 2\pi\delta\omega^2 x^2\, dxdy$
Integrating equation (4) with respect to x and y, there results:

5) $$F = 2\pi\delta\omega^2 \int_{-b}^{b} \int_{\sqrt{b^2-y^2}}^{\frac{a}{b}\sqrt{b^2-y^2}} x^2 dxdy = \frac{\pi^2\delta\omega^2}{4} b\left(a^2 - b^2\right)$$

In equation (5) F is expressed in dynes when δ is given in grams per cubic centimeter, and a and b in centimeters. The quantity ω may be replaced by $2\pi n$, where n is revolutions per second. The Earth makes one complete revolution in 86,164.09 mean solar seconds.

Mrs. Deininger's computation based on Gallen's calculus

Computation of centrifugal force produced by rotation of the bulge,
A. Essential data:

1. The attached formula should apply to the bulge taken as 13.3443 miles at the equator, not the bulge as it would be if there were no flattening at the poles.
2. In making the calculation, Hapgood asked Mrs Harriest Deininger, of the Smith College faculty, to subtract three miles from the depth of the bulge, because he was concerned with a purely mechanical action of stabilisation, in which water could not have effect. (He later recognised that he subtracted about three miles too much, because he had disregarded isostasy, which in this case makes it probable that the rock under the oceans has a density higher than the density of the rock of the continents; so he should have subtracted the weight rather than the volume of the water. This however is a minor correction)
3. Mrs. Deininger actually took the depth of the bulge as nine miles, without the water.

B. Calculation:

$$F = \frac{\pi^2 s w^2}{4} b\left(a^2 - b^2\right)$$

where s = density in gm/cc
a = radius of Earth at bulge in cm
b = radius of Earth at poles in cm
w = 2 - n r = rps

2) $F = \pi^4 s n^2 . b(a^3 - b^3)$

where π = 3,1415
s = 2,7 gm/cm^3
n = 1/86.164
b = 6,402 . 10^8 cm
a = 6,4165 . 10^8 cm (using nine miles or 1,450,000 cm as depth of bulge)

3) ***F* = *4,0368 . 10^{25} dine = 4,1192. 10^{19} kg.***

◆

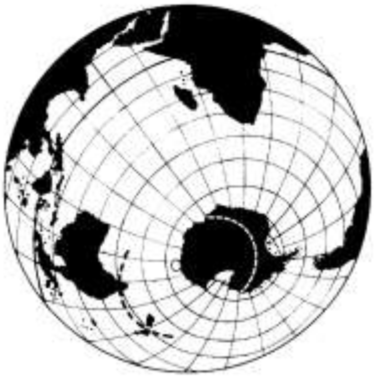
How to find evidence

In recent past a major shift should have occurred about 11,5 thousand year ago, putting an end to Pleistocene. This shift is recent enough to allow us to find compelling evidence of it.

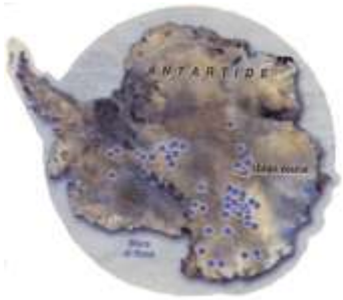
In my opinion there is available geological evidence enough to convince whoever who's mind is not biased by the current dogma of unchangeability of the Earth's momentum. We could built some mathematical or even physical model showing how poles can change in a body like Earth; but I am afraid that the outcome would be exactly the same: it would be ignored.

There is something, however, that nobody could ignore, and would defeat immediately the current scientific paradigm: finding some archaeological remains that could not be explained in other ways.

Very briefly (I have written a all book about this): look at the Earth's climatic situation as it should have been before the end of Pleistocene, with the poles in different position.



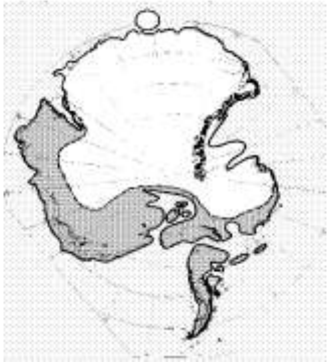
The side of Antarctica towards Atlantic ocean was ice-free and enjoyed a temperate climate. Most of the scientists strongly deny it; but it's a matter of fact, well known by all of them, that in all this area there isn't a single piece of ice older than 10.000 tears. This part of the Antarctic ice-cap is very recent, as it is demonstrated also by the distribution of the sub-glacial lakes. There are 1,500 known of them, all under the ancient ice-cap.



Distribution of sub-glacial lakes on Antarctica

Due to the different position of the south pole, different tilt and the lower level of the sea (130 mt), the profile of Antarctica was more or less like the one represented aside, with three main characteristics:

- a large ice cap on south;
- a strip of the coast ice-free (a part glaciers coming from the main ice-cap), with a mild climate;
- the peninsula separated by the main island.



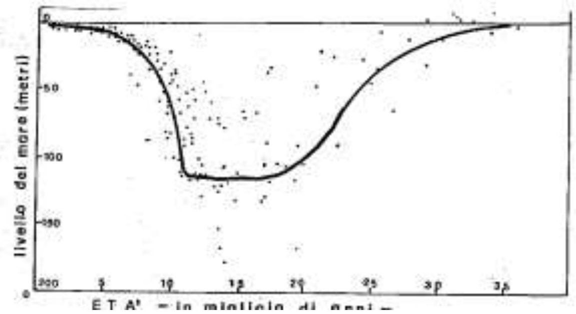
Profile of Antarctica at the end o
Pleistocene

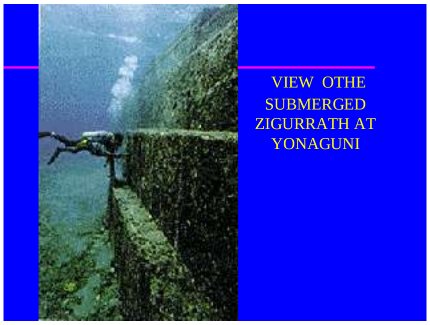
Earth geography was like in the side picture. An oceanic stream flowed from East Asia towards South America and Antarctica . Along this stream the same people that colonized Australia around 50/40.000 years ago should have arrived to the coasts of Antarctica.

Here, in complete isolation, they should have created the first human civilisation. Then, at the end of Pleistocene, Antarctica was destroyed by the flood; survivors arrived onboard of several ships on the coasts of America, Africa and Asia, giving origin to all Neolithic cultures.

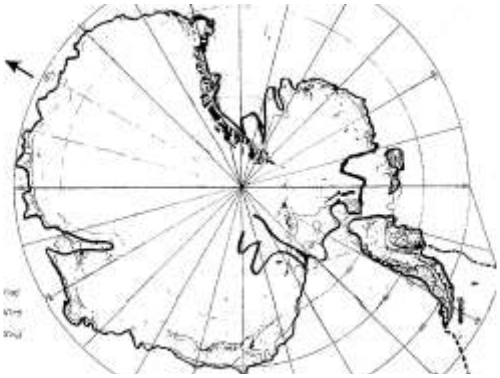
Evidence of this is provided (amongst a lot of others) by the fact that agriculture arose at the same time, immediately after the end of Pleistocene in the six different areas shown on the map aside (due to Cavalli- Sforza), independently from each other.

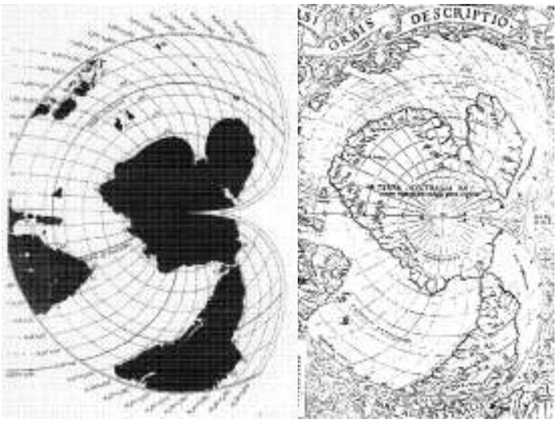
During the first millennia after the flood, several groups of survivors created some kind of civilisations along the coats. Their archaeological remains have been submerged by the rising of the sea level and are now on the continental shelf





There is lot of evidence about the existence, on a distant past, of an advanced civilisation in Antarctica. Medieval planispheres and renaissances geographical maps are some of the most impressive. For example the maps of Finnaeus and Mercator show Antarctica as it was 10.000 years ago, enlarged enough to make the Peninsula coincide with the tip of South America.





An *ad hoc* research in Antarctica could provide some archaeological evidence, thus proving beyond any doubt the possibility of quick shifts of the poles.