

# Extraterrestrial Impacts and Geomagnetic Reversals

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## Abstract

The existing data on the confirmed extraterrestrial impacts and geomagnetic reversals are examined. Differential rotation of the inner core of the Earth relative to the rest of the planet has been observed through seismic records. Differential rotation between the inner and outer core is thought to be related to the geomagnetic field of the Earth. Extraterrestrial impacts with the surface of the Earth have been shown to cause changes in this differential rotation. It is shown in this paper that there is a strong correlation between the dates of major impacts and geomagnetic reversals. This strongly supports the possibility of major extraterrestrial impacts being one of the causes of geomagnetic reversals as has been suggested previously.

## Keywords

Earth, Extraterrestrial, Impact, Geomagnetic, Reversal

## 1. Introduction

It has been known that the inner core of Earth exhibits a differential rotation compared to the rest of the planet. By examining two types of seismic waves traveling through Earth's solid and fluid cores, in 1996, Song and Richards discovered a differential travel time between the two waves [1]. This temporal change was later attributed to superrotation of the Earth's solid inner core relative to the rest of the planet [2] [3], which was further supported by subsequent studies [4] [5] [6] [7].

Magnetic coupling between the Earth's inner and outer cores, as well as the anomalous variation in the inner core orientation that temporally coincided with a sudden change of the Earth's magnetic field in 1969-1970 [8], suggests a correlation between the Earth's magnetic field and the inner core superrotation. Oth-

er theories have also been suggested for the superrotation of Earth's inner core that are based on processes taking place internal to Earth. For example, Glatzmaier and Roberts [9] have suggested that the inner core rotates in response to the combination of a magnetic torque and a viscous torque. None of these internal theories, however, are supported over the others by experimental evidence.

Tidal forces are among the external factors responsible for the inner core superrotation [10] [11], since dissipation of tidal energy in oceans can exert torque on the mantle, resulting in a change in its angular velocity [12]. However, yet another external factor that can significantly contribute to the superrotation of Earth's inner core is bolide impacts. As evidenced by visible impact craters on nearby objects such as the Moon, Earth has been bombarded by a very large number of impactors since its formation about 4.5 billion years ago. In 2015, Mohazzabi and Skalbeck [13] investigated the effect of extraterrestrial impacts and showed that such impacts can result in a change in the Earth's inner core superrotation.

If extraterrestrial impacts can result in a change in the Earth's superrotation, and if there is a correlation between the Earth's magnetic field and the inner core superrotation, then there should be a correlation between extraterrestrial impacts and geomagnetic reversals. This prompted us to investigate such a correlation, which is reported in this article.

One should note that not every major impact necessarily results in a change in Earth's superrotation and geomagnetic reversal. For example, if the velocity vector of an asteroid passes through Earth's rotation axis, it does not change the angular velocity of the Earth's rotation since the asteroid does not have an angular momentum about that axis. There will, however, be a change of the angular velocity due to the change of moment of inertia of the crust-mantle system. This change, nevertheless, is extremely small. This is because the moment of inertia of a solid sphere is given by

$$I = \frac{2}{5}MR^2 \quad (1)$$

where  $M$  is the mass of the sphere and  $R$  is its radius. Therefore, that of a hollow sphere is given by

$$I = \frac{2}{5} \left( \frac{4}{3} \pi R_2^3 \rho \right) R_2^2 - \frac{2}{5} \left( \frac{4}{3} \pi R_1^3 \rho \right) R_1^2 = \frac{8\pi\rho}{15} (R_2^5 - R_1^5) \quad (2)$$

where  $R_1$  and  $R_2$  are the inner and outer radii of the hollow sphere, and  $\rho$  is its mass density. Taking this hollow sphere to be the crust-Mantle system, after an asteroid impact the moment of inertia would be

$$I' = \frac{8\pi\rho}{15} (R_2^5 - R_1^5) + mR_2^2 \quad (3)$$

where  $m$  is the mass of the asteroid. Assuming a spherical asteroid, we can write this equation as

$$I' = \frac{8\pi\rho}{15} (R_2^5 - R_1^5) + \left(\frac{4}{3}\pi r^3 \rho_a\right) R_2^2 \tag{4}$$

where  $r$  is the radius of the asteroid and  $\rho_a$  is its density. Now, according to conservation of angular momentum, we have

$$I\omega = I'\omega' \tag{5}$$

where  $\omega$  and  $\omega'$  are the angular velocities of the crust-mantle system before and after the impact, respectively. Therefore,

$$\frac{\omega'}{\omega} = \frac{I}{I'} \tag{6}$$

Using Equations (2) and (4), we get

$$\frac{\omega'}{\omega} = \frac{1}{1+k} \tag{7}$$

where the dimensionless constant  $k$  is given by

$$k = \frac{5}{2} \frac{\rho_a}{\rho} \frac{r^3 R_2^2}{R_2^5 - R_1^5} \tag{8}$$

Using  $\rho_a \approx 2000 \text{ kg/m}^3$  [14],  $\rho = 4500 \text{ kg/m}^3$  [15],  $R_1 = 2.9 \times 10^6 \text{ m}$  [16],  $R_2 = 6.37 \times 10^6 \text{ m}$ , and assuming an asteroid of radius  $r = 1.0 \times 10^4 \text{ m}$ , we obtain  $k = 4.38 \times 10^{-9}$ . Therefore,

$$\frac{\omega'}{\omega} = \frac{1}{1 + 4.38 \times 10^{-9}} \approx 1 - 4.38 \times 10^{-9} \tag{9}$$

Because the angular velocity of Earth is

$$\omega = \frac{2\pi}{24 \times 3600} = 7.27 \times 10^{-5} \frac{\text{rad}}{\text{s}} = 0.0131 \frac{\text{deg}}{\text{s}} \tag{10}$$

Therefore,  $\omega'$  would be less than  $\omega$  by  $0.0131 \times (4.38 \times 10^{-9}) \times (365 \times 24 \times 3600) = 0.0018 \text{ deg/yr}$ , which is much smaller than the differential angular velocity of the inner core superrotation of 0.27 - 0.53 deg/yr [17]. Therefore, regardless of the geographical location of the impact, axial or nonaxial, the change of moment of inertia of Earth is negligible.

In addition to the axial impacts, it is possible that multiple impacts take place on opposites sides of the Earth's rotation axis in a short geological time so that the effects cancel out, resulting in no geomagnetic reversal.

## 2. Extraterrestrial Impacts and Geomagnetic Reversals

Because of their vicinity, Earth and the Moon have been impacted by nearly the same number of extraterrestrial objects per unit area. The craters created by such impacts are visible on the surface of the Moon but not on Earth. This is because these craters have been hidden or destroyed by weathering, oceans, and tectonic processes. As a result, some of the largest impact craters on Earth were not discovered until very recently. For example, the Vredefort Dome in South Africa, which is the largest verified impact crater on Earth (more than 300 km across when it was formed), was originally believed to have been formed by a volcanic

explosion. However, in the 1990s it was revealed that it was in fact the site of a large asteroid impact about two billion years ago [18] [19]. Therefore, in addition to the craters that have been discovered on Earth and verified, there can be many more that are either invisible, destroyed, or eroded away.

In 1986, Muller and Morris [20] suggested that large extraterrestrial impacts can produce a geomagnetic reversal as a result of climate change due to dust from the impact crater and soot from fires. They argue that the redistribution of water from near the equator to ice at high altitudes results in a change of the rotation rate of Earth's crust and mantle. However, they also indicate that this may not be the sole cause of geomagnetic reversals.

The alternative mechanism proposed by Mohazzabi and Skalbeck is based only on direct mechanical consequences of extraterrestrial impacts [13]. The idea is that an impact can alter the rotation rate of the crust and mantle relative to the inner core. As a result, the differential rotation rate of the inner core relative to the crust and mantle, which is currently a superrotation of about 3 degrees per year [8], can increase, decrease, or even change from superrotation to subrotation and vice versa. The coupling of inner core's differential rotation and Earth's geomagnetism can then result in a geomagnetic reversal.

In this article, we examine the correlation between the existing data on extraterrestrial impacts and Earth's geomagnetic reversals regardless of the mechanism behind the latter events.

### 3. Data and Correlation

Although several references have reported confirmed and unconfirmed extraterrestrial impact craters, currently there seem to be 200 impact sites that have been recognized on Earth, with several more being discovered each year. Relatively recently, the data on these impacts have been compiled by Schmieder and Kring [21]. The normal polarity reversals for Earth's geomagnetism were reported by Ogg [22] and go back to 84 million years ago. We have used data from these sources to compile **Table 1**. In doing so, we have considered only major impacts with crater diameters of 10 km or more, in accordance with a related previous work [13], which showed bolide diameters of 10 km or greater could lead to impact-induced superrotation of the Earth's inner core.

**Figure 1** shows the geomagnetic reversals as a function of impact dates and their uncertainties indicated by error bars. A linear least-squares analysis of the data generates a slope of  $0.979 \pm 0.006$  and an intercept of  $0.26 \pm 0.28$  Ma, with a correlation coefficient of 1.000.

**Figure 2** shows a histogram of the frequency of events as a function of magnitude of time difference between impacts and geomagnetic reversals. The last event from **Table 1** is intentionally left out in this histogram because of relatively large difference between the impact date and the reversal date, which might be due to large uncertainty in the data. This diagram shows the frequency of the reversal in intervals of 0.1 Ma. For example, 3 reversals have taken place in the time interval of 0.1 to 0.2 Ma from impact.

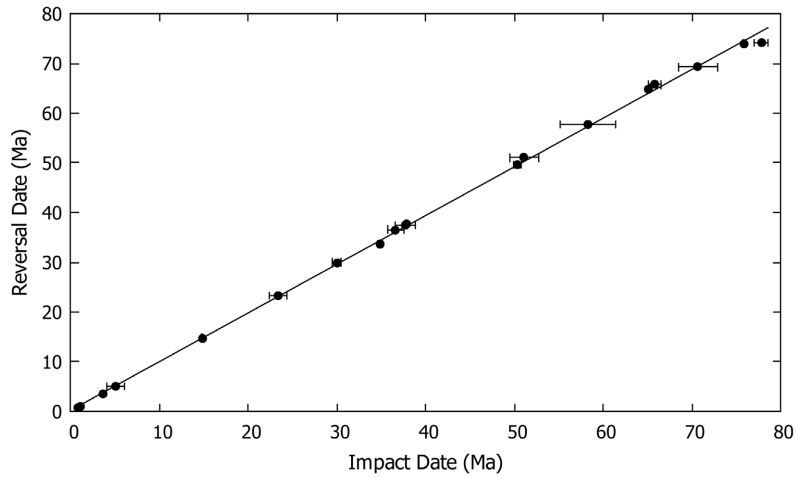


Figure 1. Geomagnetic reversal date as a function of impact date.

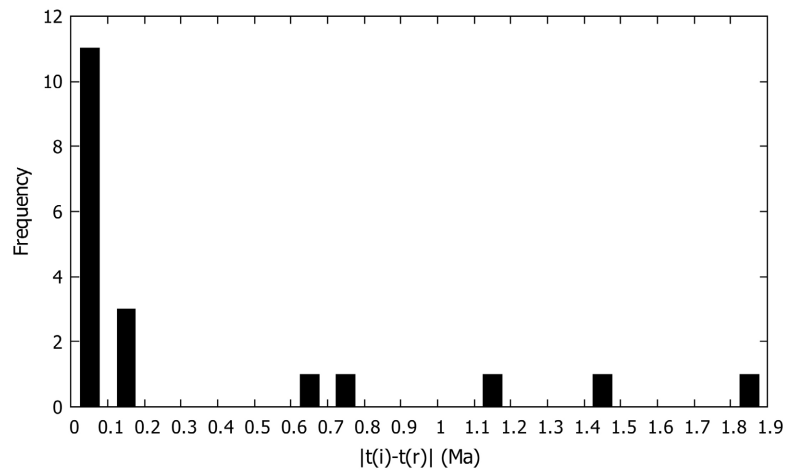


Figure 2. Frequency of geomagnetic reversals as a function of time interval from impact.

Table 1. Impact names, dates, and the dates of geomagnetic reversals (chron age).

Impact Name	Impact Age (Ma)	Chron Age (Ma)	Chron Number	Impact Name	Impact Age (Ma)	Chron Age (Ma)	Chron Number
Pantasma	$0.815 \pm 0.011$	0.773	C1n	Wanapitei	$37.7 \pm 1.2$	37.530	C17n.1r
Zhamanshin	$0.91 \pm 0.14$	0.773	C1n	Mistastin	$37.83 \pm 0.05$	37.781	C17n.2n
Bosumtwi	$1.13 \pm 0.10$	1.070	C2r.1n	Kamensk	$50.37 \pm 0.40$	49.666	C22n
El'gygytgyn	$3.65 \pm 0.08$	3.596	C2An.3n	Montagnais	$51.1 \pm 1.6$	51.047	C23n.1r
Karla	$5 \pm 1$	4.997	C3n.3r	Marquez	$58.3 \pm 3.1$	57.656	C25n
Nordlinger(Ries)	$14.808 \pm 0.038$	14.775	C5ADr	Chicxulub	$65.052 \pm 0.043$	64.862	C28r
Haughton	$23.4 \pm 1.0$	23.318	6Cn.3n	Boltysh	$65.80 \pm 0.67$	65.700	C29n
Logoisk	$30.0 \pm 0.5$	29.970	C11n.2n	Kara	$70.7 \pm 2.2$	69.271	C31n
Chesapeake Bay	$34.86 \pm 0.32$	33.726	C13n	Manson	$75.9 \pm 0.1$	74.051	C32r.1n
Popigai	$36.63 \pm 0.92$	36.573	C16r	Lappaajärvi	$77.85 \pm 0.78$	74.201	C32r.2r

Finally, regarding the geological location of the impacts, the highest latitude recorded is about 75° N [21]. This can be explained by the fact that all planets in the solar system move virtually in the same plane, and that nearly all asteroids impacting Earth originate within the solar system. Therefore, an asteroid approaching Earth would be moving in the ecliptic plane and hence has a near zero probability of impacting the poles.

#### 4. Discussion and Conclusion

According to the data in **Table 1**, for nearly every major impact, there is a geomagnetic reversal within the uncertainty of the impact date. However, other references have listed older geomagnetic reversals that we have not included in our work due to the fact that the palaeomagnetic data from studies on igneous and sedimentary rocks are conflicting [22].

In addition, depending on the direction of impact, it is quite possible that even a major extraterrestrial impact may not result in a change in relative rotation between the core and the crust and thus may not result in a geomagnetic reversal [13].

Nevertheless, the strong correlation between the impact and reversal dates in **Table 1** is a strong indication that major extraterrestrial impacts could very likely be a possible cause of the geomagnetic reversals, as have been suggested previously. Furthermore, the linear graph of **Figure 1** with a slope of 1.014 and correlation coefficient of 1.000 shows that, on average, geomagnetic reversals have taken place at dates that are very close to impact dates, a fact that is further supported by the histogram of **Figure 2**.

Finally, as pointed out earlier, in addition to the craters that have been discovered, there can be many more that are either invisible or have been destroyed. This can be estimated from the number of craters on the Moon which is in the close proximity to Earth in space. According to the International Astronomical Union, there are currently 9137 recognized impact craters on the Moon [24]. Since the surface area of a spherical object is given by  $A = 4\pi R^2$ , where  $R$  is the radius of the sphere, and that the number of the impact craters is proportional to the surface area, if  $R_e$  and  $R_m$  are the radii of Earth and the Moon, respectively, we have

$$\frac{A_e}{A_m} = \left(\frac{R_e}{R_m}\right)^2 = \left(\frac{6.37}{1.74}\right)^2 = 13.4 \quad (11)$$

Therefore, the number of impact craters on Earth is estimated to be  $13.4 \times 9137 \approx 122000$ , but there are only 200 confirmed craters on Earth as of 2020 [21].

Furthermore, there were several bolide impacts in our data set that were recorded to have occurred in a wide range of time, or their standard deviations were very large. For these reasons, there are several other geomagnetic reversals not listed in our table that could very likely correspond to these invisible and undiscovered impacts, or bolides with uncertain dates.

Finally, according to a previous estimate, perturbations in superrotation of the inner core as a result of impacts should damp out in a few tens of thousand years [13]. Therefore, based on this estimate, a geomagnetic reversal should take place during these timescales. The data in **Table 1** show that more than half of these reversals have taken place in 100,000 years or less after the impact. But some reversals, especially those further back in geological distant past, have taken longer. This, however, can be attributed to the uncertainty in the age of impact, which increases with their age.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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