【Technical Notes】

The Sun's Encounter with the Spiral Arms as the Causes of Cretaceous-Tertiary and Permian-Triassic Boundary Events

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Abstract

The most dramatic faunal extinction during the Phanerozoic took place 65 million (K/T boundary) and 250 million years(P/T boundary) ago, respectively. The galactic model of Leitch & Vasisht which shows that the sun encountered the Sagittarius-Carina and Scutum-Crux arms 65 and 250 Myr BP respectively is adopted and possible mechanisms of the extinctions are discussed. First, it is shown that the Ir deposit actually detected in the K/T boundary layer is far greater than the amount inferred from the impact structure at Chicxulub, and the discrepancy is interpreted as evidence of massive accretion of interstellar matter. Second, physiological effect of possible declining O_2 pressure in the atmosphere due to accreted H_2 is discussed and its possible cause for the disappearance of gigantic insects and dinosaurs is suggested. Third, fullerrenes containing IS He recently found at a P/T boundary is interpreted as evidence of accretion of IS matter during the sun's penetration of a GMC in the Scutum-Crux spiral arm. During the accretion, the earth's orbit is immersed in the neutral IS gas, and the geomagnetic field is disconnected from the solar wind. It is argued that this will affect the dynamo action, which in turn generates a super-plume at the mantle-core boundary; when it reaches the surface, it will cause massive eruptions and possible connection with the Deccan trap (65 Myr BP) and Siberian eruption(250 Myr BP) is suggested. In this way, it is possible to have a consistent picture of the sun's motion in the galaxy, geological evidence and faunal extinctions.

1 Introduction

The possibility that the earth is bombarded by celestial bodies was first discussed by Russell, Dugan & Stewart (1945) in their well-known text book. They calculated the probability of a comet hitting the earth from the number of comets inferred to exist from observation. However, they concluded that nothing dramatic would take place, because the model of comets then current was a swarm of small particles ranging from a few millimeters to at most 10 meters.

Later, Urey (1973) showed the correspondence between geological boundaries and large craters. His argument was based on the icy nucleus model of comets proposed by Whipple and on the recognition that a vast amount of energy is released upon impact. The comet he considered as an impactor had an orbit similar to Halley's comet, which, because of the retrograde orbit, would have a velocity close to 70 km/sec relative to the earth and the radius of 10 km was assumed. The energy of impact would then be 2×10^{31} erg, which would be sufficient to raise the atmospheric temperature by almost 300 degrees centigrade. It was later realized that this energy is equivalent to 500 million megatons of TNT or one megaton of TNT per square kilometer of the Earth's surface.

Urey's paper was unfortunately not seriously considered by geologists and geophysicists until 1980 when Alvarez et al. (1980) found an excess Iridium in the clay collected from Gubbio, Italy which corresponds to the well-known Cretaceous/Tertiary (K/T) boundary where a large number of species including dinosaurs died out. Following the finding of the Ir anomaly, minerals such as tektites apparently associated with the impact structure at Chicxulub had their ages determined at 65 million years BP and the crater gradually came to be regarded as the site of the impact which was responsible for all of the events which took place at the time.

Furthermore, Raup & Sepkoski (1984) published a controversial paper in which they claimed that extinction of species did not proceed uniformly or randomly, but periodically. The period they derived was 27 million yrs and since it is unlikely that biological evolution is periodic by itself they encouraged a search for a cosmic mechanism. Alvarez & Muller (1984) then claimed to have detected a periodicity in the ages of large craters then known. Their claim had stimulated a number of researchers to find a mechanism whereby bolides hit the earth periodically. At present, the motion of the sun above and beyond the galactic mid-plane with a half-period close to 30 million years is suspected as the mechanism which gives rise to the claimed periodicities in cratering and the resulting faunal extinctions (Rampino et al 1997). Rampino et al. regard the mechanism as a unified model of mass extinctions, thus relating the terrestrial evolution of fauna to the sun's z motion in the galaxy.

In order to examine these claims, a number of papers have been published discussing whether the periodicity hypothesis can be substantiated by detailed statistical investigations, and it seems fair to say that the periodicity derived in cratering record with a period close to 30 Myr is not compelling - one can find some kind of apparent periodicity even from a uniform series of random numbers. The same applies to the extinction records, although to a lesser degree. Furthermore, the Iridium anomaly actually found for the K/T boundary may not be consistent with the size of the impactor that can be inferred from the crater at Chicxulub, because the recent investigation by Morgan et al (1997) has revealed that the crater size is significantly smaller than had hitherto been suspected. It seems thus appropriate to examine alternative models to see if the geological and palaeontological evidence may be better explained. A clue is provided by a recent paper of Leitch & Vasisht (1998) who showed that on a reasonable model of the galaxy, the K/T boundary event took place when the sun was in the Sagitarius-Carina spiral arm, while another mass extinction (the Permian-Triassic (P/T) boundary event 250 million yrs BP) took place while the sun was in the Scutum-Crux arm. Compared with these boundaries, other extinction peaks may be regarded as minor incidents.

In the following, we shall first review the claims for periodicity in cratering and extinction records as well as statistical tests so far carried out. It will be shown that the periodicity (or periodicities) are not to be regarded as well substantiated. We then calculate the amount of Iridium predicted to be deposited by the impactor which caused the crater at Chicxulub and show that there is a significant discrepancy between the prediction and the deposit actually observed. Thirdly, we will review other geological evidence such as fullerenes and anoxia in relation to the impact model. It will be argued that the astronomical model which appears consistent with these records is the sun's encounter with the spiral arms and that encounters with and penetration of one of the giant molecular clouds in the arms are more consistent with the records.

2 Periodicities

Here we review the periodicities claimed to exist in the cratering and extinction records and show that they should not be regarded as well-established.

Raup & Sepkoski (1984) claimed that there appears to be a period in the rate of extinction of marine fauna. The data of Raup & Sepkoski showed that the peaks in the extinction rate appear to be separated by some 27 million years. Since biological evolution is unlikely to be periodic, unless enforced to be so by external disturbances, they called for such explanations. Alvarez & Muller (1984) derived a similar period in the ages of large craters then known and argued that the periodicity in the extinction is related to that in the cratering. Rampino & Stothers (1984) noted that the sun's motion above and below the galactic plane has a similar half-period and argued that the sun's crossing of the galactic mid-plane is the controlling mechanism; since stars and interstellar clouds are concentrated toward the plane, disturbance of the Oort's cloud of comets as the sun crosses the plane may give rise to a periodicity. Although a number of models which might give rise to the periodicity were proposed, the galactic model is still the most viable over many periods.

In Oort's original theory for long period comets, new comets were deflected from the Oort cloud into the observable region of the solar system, and earth crossing orbits, by the perturbation of stars which pass nearby the solar system. However, as Byle (1983) pointed out, the gravitational field of the galaxy as a whole and in particular the vertical (z) component of the disk is more effective in deflecting the orbits, with the exception of occasional perturbations by stars which go through the cloud itself. If the Sun's z-motion is to give rise to a periodic variation in the flux of the comets in the earth crossing orbits, it is essential that the galactic gravitational field varies with the Sun's motion. In other words, matter ought to be concentrated near the Galactic plane and the amplitude of the sun's z-motion ought to be greater than the scale-height of the matter distribution. It is precisely at this point where ambiguities come in. Some authors (Matese et al 1995) assume the presence of dark matter with a scale-height less than that of visible matter and obtain periodic modulation of the potential impactor flux. Stothers (1998) compiled various determinations of the mass distribution within the galaxy and derived a mass density which would give rise to a period of 37 Myr; he argues that this is in agreement with the period derived from the record of 11 craters with diameters greater than 35 km.

	Period Myr	**record**
Alvarez & Muller (1984)	28	large craters
Stothers (1986)	30	65creaters
Stothers (1998)	36	craters with D > 35km
Yabushita (1996)	31	craters regardless of diameter
	27.5	craters with D > 10 km
Rampino (1998)	30	D > 5 km
	35	D > 35 km
Napier (1998)	27	craters & extinctions combined
Raup & Sepkoski (1984,86)	26 and 27	extinction of marine fauna
Yabushita (1994)	27	extinction data compiled by Rampino & Caldeira (1992)
Rampino et al. (1997)	27.3	extinction events
Yabushita(1998)	14.5	extinction data of Sepkoski (1995)

Table. 1 Periods derived from craterring and extinction records.

The periods presented in the Table have been derived by various means, such as the Broadbent method, Fourier power spectrum, etc. However, the Table is sufficient to show two features. One is that the extinction records appear to give rise to a period close to 27 Myr. The period of 14.5 Myr derived by Yabushita (1998) is an exception, however; the data of Sepkoski(1995) adopted for the testing spans a longer period than other datasets. The second feature is that the cratering record gives different periods depending on what dataset one adopts - the results of Stothers (1998) and of Rampino et al(1998) show that really large craters appear to give rise to a periodicity of 35-37 Myr. The fact that one gets different periods when smaller craters are taken into account seems reasonable. According to Shoemaker et al(1990), craters with diameters greater than 30-50km are due to comets, while smaller ones are both cometary and asteroidal origin, and asteroids contribute a greater fraction of the impactors (Steel 1987). The discrepancy between the periods derived from extinction and cratering records is likely due to the fact that 3 large craters(Kara-Kul(25MyrBP),Montagnais (50.5MyrBP) and Tookoonooka (128Myr BP)) do not have corresponding mass extinctions while for the latest two extinctions(1.6Myr and 11.2Myr BP in Rampino & Caldeira 1992), the corresponding large craters are yet to be found.

There is another feature which need be considered. Cratering records show a marked concentration of young and small craters(ages less than 5 Myr and diameters smaller than 5 km, Yabushita (1996)), while the present epoch is free of massive faunal extinction. A peak in the extinction rate at 11.2Myr BP is not as conspicuous as others and another at 1.6Myr BP is hardly recognizable in Fig.7 of Sepkoski (1996), which gives the extinction rate of families in percentage . On the galactic crossing model, this is not consistent with the present position of the sun, which is very close to the galactic plane. Thus, the proposed astronomical mechanism (galactic plane crossing) seems a less convincing mechanism of driving the biological evolution than claimed.

3 Geological evidence

3.1 Iridium anomaly

Apart from cratering, iridium anomaly is the most indisputable geological evidence which can be put to quantitative investigation. We first note that apart from the K/T and P/T boundaries, there are no worldwide excess Ir deposits. The Ir anomaly at the K/T boundary is the most conspicuous and universal. Here we show that the simple impact model is largely inconsistent with the deposited Ir.

Thanks to the work of Kyte & Wasson (1986), the amount of Ir deposited on earth can be estimated without much uncertainty. Excess Ir at the K/T boundary in the core from the Pacific Ocean north-east of Hawaian Islands (which gives most complete information on the Ir deposition rate from the Cretaceous to Oligocene) is 70 ng cm^{-2} and when this is multiplied by the surface area of the earth, the deposited Ir is calculated at 3.57×10^8 kg.

It was argued by Yabushita & Allen (1998) that the impactor was most probably a comet and not an asteroid. On this supposition, it is possible to estimate the size of the impactor adopting a scaling law which provides a relation between the impactor size and the resulting crater. Although three scaling laws are available, the most reliable appears to be that of Schmidt, which reads(Melosh 1989, p.121);

$$D_{\rm at} = 1.8(\rho_{\rm P})^{0.11}(\rho_{\rm t})^{-1/3} g^{-0.22} L^{0.13} W^{0.22}, \quad (1)$$

where $\rho_{\rm P}$ and $\rho_{\rm t}$ are the densities of the projectile and the target respectively, g the gravity on the target, L the diameter of the impactor, W the energy of impact; Dat is the diameter of the transient crater (the transient crater collapses under gravity to form the final shape). The coefficient is for SI units. Needless to say, a smaller value of impact energy (smaller value of impactor's velocity) gives a smaller crater diameter.

The most likely impact velocity for short-period comets is 28.9 km/s (Steel 1987), so that the mass of the impactor has been calculated for the resulting crater's transient diameter under the premise that the impactor had a velocity of 28.9km/s. Fig.1 shows the dependence of the impactor mass on the diameter of the transient crater.

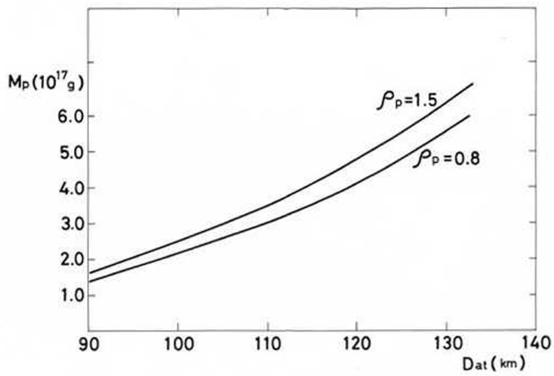

Fig. 1 Impactor mass, M_P is plotted against the diameter of the transient crater, calculated by the formula in sec.3.1. ρ_P is the projectile density in g cm^{-3}.

The projectile density was somewhat arbitrarily chosen to see how the crater-projectile mass relation varies depending on the density. Thus, to produce a crater of a given size, although the projectile diameter may differ depending on the density, the projectile mass is determined almost independent of the density.

Now, Morgan et al. (1998) have determined the size of the crater at Chicxulub. It has a transient diameter Dat of 100 km, smaller than had earlier been estimated. For instance, Sharpton & Marin (1997) had derived D_{at} close to 130 km.

From Fig.1, it may be easily noted that the mass of the projector which could have created a crater as large as Chicxulub(D_{at} = 100 km) is 2.2 to 2.5$\times 10^{14}$ kg on the presumption that it had an orbit of a short-periodic comet. The estimated mass would be far smaller, if the projectile had an orbit of a long-periodic comet. For the following discussion, we adopt 2.6×10^{14} kg as the maximum mass for the projectile.

We now proceed to estimating the mass of Iridium in the impactor that can be retained by the earth. First, we note that Si relative abundance in the dust of Halley's comet is 3.6% (Geiss 1988), while the abundance of Si (non-volatile component) in CI chondrite is 10% (Kallemeyn & Wasson 1981). Thus, the chondrite component in a comet is about 36%. Next one has to take into account what fraction of the impactor mass can be retained by the earth. Vickery & Melosh (1990) finds that for mass close to 10^{14} kg and impact velocity close to 30 km/sec, the retained mass around 20%. Then, the total chondritic component of the impactor retained by the earth turns out to be 87×10^{13} kg. Now, the Ir content in a CI chondrite is 592 ng/g. Thus the amount of Ir retained to the earth from the impactor is thus 1.1×10^7 kg which must be compared with the 3.6×10^8 kg estimated for IR deposits. It is apparent that there is a discrepancy of about 30 between the deposited Ir and the Ir mass which is theoretically derived, and that even if 100% of the Ir in the impactor were retained there would remain a discrepancy of a factor of 6.

Apart from the K/T boundary, Permian-Triassic (P/T) is the only boundary where Ir is detected in various parts of the world (Rampino et al. 1997 Table 1). Note that the Oligocene-Eocene boundary is associated with Popigai (100.2 km) and Chesapeake Bay (95 km) craters, but Ir deposit cannot be seen in the Pacific Ocean cores (Kyte & Wasson 1986).

3.2 Fullerenes

Fullerenes (Kroto et al. 1985) are clusters of carbon atoms with cage-like structures. They were discovered in attempts to simulate the vicinity of carbon stars, where various molecules are being formed. The extra-terrestrial fullerenes are found in Allende meteorites (Becker et al 1999) and are found in clay sediments of the K/T boundary(Heyman et al 1994) as well.

Recently, similar fullerenes have been found in the P/T boundary layer exposed at Sasayama, Tanba of Western Japan (Becker et al 2001). The extra-terrestrial nature of the fullerens is evidenced by ^{3}He/^{4}He abundance ratio contained in the structure. Becker et al (2001) regard them as evidence of a large impact at the P/T boundary where such impact related products as shocked minerals, have been detected but this is still regarded as equivocal, although it is a boundary where Ir is detected worldwide. It may be noted that similar fullerenes are found in the Sudbury impact structure, which is 1.85 billion years old (Becker et al 1996).

From the fact that the fullerene C_{60} has been detected in the spectra of stars, Foing & Ehrenfruend (1994) estimate that 0.3 to 0.9% of interstellar carbons are in the form of fullerenes . It is only conceivable that the fullerenes are gradually collected onto the surfaces of interstellar grains and this is how they are taken into carbonaceous chondrites such as Allende, as the grains accrete to each other and grow.

4 Paleontoligal evidence

On the simple impact model of mass extinctions, fauna died out owing to the initial blast, worldwide fire caused by heated impact fragments and possibly climatic change due to the decline in the temperature caused by the dust injected into the atmosphere. Since the dust grains precipitate out within a matter of a few years, the fauna would have died out in a short interval of time, geologically speaking. This means from a few years to at most a few tens of years. The question which one naturally asks is whether this model is consistent with paleontological evidence. We first consider the K/T boundary . Another boundary(P/T) will be considered later.

Whether the mass extinction at the K/T boundary was instantaneous or gradual has a long history. Here we refer to dinosaurs and marine fauna which appear to support the gradual extinction scenario.

Sloan et al (1986) noted that of 12 genera of dinosaurs alive in Montana, Alberta and Wyoming just before the K/T boundary, between 7 and 11 survived into the Palaeocene. Again, dinosaur fossils are found 1.3 m above the Ir rich layer and with the estimated sedimentation rate, this corresponds to 40,000 yr after the impact.

However, more realistic information is obtainable from the investigation of marine fauna over the K/T boundary, because fossils of marine fauna are better conserved. First, Pardo et al(1999) investigated changes in the environment over the K/T boundary using data for planktic foraminifera and clay mineralogy in Kazakhstan and concluded that long-term climatic changes, rather than sudden change brought about by a bolide impact, were responsible for the gradual demise of the Cretaceous planktic foraminifera in the eastern boreal Paratethys.

Keller et al (1998) took a multidisciplinary approach to the transition over the K/T boundary of shallow Saharan platform and found that oxygen, salinity fluctuations and sea level changes as well as the change in rainfall and humidity which started some 1-2 x 104 yr before the K/T boundary were the causes for the decline of the shallow sea water fauna at the site. They concluded that some of the species began to disappear $1 - 2 \times 10^4$ yr before the K/T boundary, thus arguing that a bolide impact played a minor role as long as the marine fauna are concerned. A similar result had been obtained by Zachos et al. (1989) who measured ^{13}C/^{12}C gradient in seawater over the K/T boundary and concluded that there was a period lasting for 0.5 Myr across the boundary of complete breakdown in the marine productivity ; they also showed that the environmental change including cooling started 200 kyr before the boundary and a peak warming occurred 600 kyr after the boundary.

It appears then that if one looks at the paleontological data carefully, it is difficult to accept the impact model as it stands. We have elsewhere (Yabushita & Allen 1983,1998) given other considerations to the selectiveness of the faunal extinctions. See also Officer et al. (1988). It is perhaps worthwhile in this respect to refer to a paper by Graham et al. (1995) who like us argued that the changing O_2 pressure in the atmosphere would have effect on the biological evolution in that a higher pressure would allow insects to grow bigger because of easier respiration. If the reverse should take place, as might have been so at the K/T boundary, the larger animals would certainly be severely affected.

We now consider the P/T boundary. Extinction at the end of the Permian (250 Myr BP) was even more severe than at the K/T boundary. Nearly 90% of species died out. The pattern of extinction seems somewhat more complicated. Because the Siberian flood basalts is contemporary with the extinction, scenarios ascribing the environmental change owing to CO_2 released by the volcanic activity are suggested (Renne et al. 1995, Bowring et al. 1998). For instance, Bowring et al. (1998) considered the possibility that there was initial cooling owing to ashes released by the volcanoes followed by warming due to the greenhouse effect of CO_2; a cycle of this kind could have exerted tension of the fauna. Their argument is that the already declining species were finally killed by a bolide impact, although no impact structure with the corresponding age has not been found.

On the other hand, another feature which characterizes the end-Permian is wide-spread anoxia. Many boundary sections contain oxygen-restricted facies and in order to verify the possibility of shortage of oxygen, Wignall et al. (1996) investigated rocks from Spitsbergen, Italy and Slovenia and found that the end-Permian period is characterized by anoxia in shallow as well as deep sea water. As the cause of the anoxia, they suggested a rapid decline in oceanic circulation rate but it is not clear what really caused the decline in the oceanic circulation.

In this respect, we wish to point out an argument which relates biological evolution to the possible changes in O_2 pressure in the atmosphere (Graham et al 1995). They accept that the O_2 pressure was higher during the time preceding the end-Permian era suggested by a geological model of Berner et al. (2000) and argued that the high O_2 pressure led to the evolution of large insects because of easier respiration. Note that this suggestion is similar to the one presented earlier (Yabushita & Allen 1983). One may then argue that if anoxia evidenced in the sea water was actually due to the decline in O_2 pressure in the atmosphere as well, the extinction of land fauna at the end-Permian can easily be explained. We thus propose that the end-Permian mass extinction was largely due to the shortage of O_2 both in the sea and in the atmosphere.

5 Spiral arms

As mentioned in section 2, the most severe extinctions of fauna took place 65 Myr (K/T boundary) and 250 Myr (P/T boundary) BP. In the later boundary, nearly 90% of species died out. It is just remarkable that the two boundaries have three common features. These are Iridium deposit, the fullerenes and evidence of anoxia (air in ancient amber,Landis et al. 1995 for the K/T boundary), although the evidence is not firmly recognized for the K/T boundary. One may ask why these two boundaries are so distinguished from the other minor extinction peaks, and it is precisely here that astronomical consideration may be required.

Leitch & Vasisht (1998) pointed out that on a reasonable model of the Galaxy based on the rotation curve and the density wave theory, the sun was in the Sagittarius-Carina arm and in the Scutum-Crux arm 65 and 250 Myr BP,respectively. The arms are the sites where many interstellar clouds exist and where new stars are continuously being born. Napier & Clube (1979) had earlier suggested that the sun , while passing through spiral arms, might have captured the long-period comets which would fragment in the earth vicinity, causing catastrophes. The arms are site where the sun is most likely to encounter ordinary clouds as well as giant molecular clouds and supernovae. We note however that as long as the K/T boundary is concerned, the possibility of radiation from a nearby supernova has been excluded from the causes of the extinction on the ground that the amount of the element ^{244}Pu found in the boundary clay is not consistent with the supernova explosion model (Alvarez et al. 1980).

The possible effect of the accretion of IS matter on the terrestrial environment as the sun penetrates one of the giant molecular clouds(GMC) was discussed by us (Yabushita & Allen 1989). It was argued that not only the accreted IS grains shield the solar radiation thereby cooling the earth but a fraction of the oxygen in the available biosphere CO_2/O_2 cycle is lost as oxygen molecules react with the accreted hydrogen molecules. The amount of accreted IS grains as estimated from the sun's speed relative to the GMC is consistent with the amount of Iridium deposited in the core of the Pacific Ocean.

As referred to, a certain fraction of carbon in IS matter is in the form of fullerenes and it is only natural to find them in the accreted IS matter. The feature which distinguishes the bolide impact from the accretion of IS matter is the predicted decline in the O_2 pressure in the atmosphere which, as mentioned, would have *selective effect* on the extinction of fauna. A simple impact model, on the other hand, cannot offer reasonable explanations for the *selectiveness* of the extinction and the time scale of the boundary event.

Finally, we wish to refer to the volcanisms which took place almost simultaneously with the two major extinctions. The Siberian flood volcanism is coincident with the P/T extinction (Renne et al. 1995),while the initiation of the Deccan trap formation took place just before the K/T boundary. Because of near coincidence of the Siberian volcanism with the mass extinction at the P/T boundary, a possible causal relation between the two has been proposed (Bowring et al. 1998). Here we wish to suggest a possible relation between the volcanism and the spiral arm passage. The continental volcanism such as Siberian or Deccan is due to a hot material (superplumes) generated at the core-mantle boundary(Courtillot & Besse 1987). These volcanisms took place just after the end of long normal and long reversed superchrons (intervals of no geomagnetic reversals, see Fig.4 of Courtillot & Besse 1987).

Now, it takes several million years for the sun to pass through the spiral arms of the galaxy (Fig.2 of Leitch & Vasisht 1998). It is thus expected that the sun will first encounter one or two IS gas clouds of moderate density (10^2 to 10^3 H^2/cc). As Begelman & Rees (1976) showed, the solar wind is then suppressed to within 1 astronomical unit from the sun. Now, the lines of force of the geomagnetism are distorted and asymmetrical about rotational axis; they are carried away by interaction with the solar wind (see Lockwood 1997). If the solar wind is suppressed within 1 AU from the sun, the asymmetry would no longer persist and the geomagnetic field would become a dipolar field at a distance from the earth. This could affect the fluid motion in the earth core through dynamo action and might trigger the generation of a superplume at the core mantle boundary, where the temperature gradient is large. With the estimated ascent velocity of 1 m per year (Courtillot & Besse 1987), the plume would take a few million years to reach the surface. By the time the plume reaches the surface, the sun would still be in the spiral arm and would encounter a giant molecular cloud. This scenario could explain the near coincidence of the two major volcanisms and the mass extinctions. Further, another major extinction (upper Botomian) which took place 500 Myr BP (Sepkoskii 1996) coincides with the sun's passage through the Norma arm according to the galactic model of Leitch & Vasisht (1998). According to Johnson et al. (1995), the Ordovician superchron which started 470 Myr BP ended at 502 Myr, although not yet fully confirmed. If so, we have a situation very similar to the K/T and P/T boundary events.

That the two major extinction events in the Phanerozoic (from present to 500Myr BP) and possibly the uBoto extinction coincide with the times of the sun's encounters with the spiral arms of the galaxy does not appear to be a mere coincidence, and the giant molecular cloud encounter model appears to provide a consistent explanation for the patters of extinction, geological records and the astronomical theory.

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