The Spiral Arms, Superplumes, Superchrons and Mass Extinctions

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Abstract

A model is presented which relates the geological and paleonthological events of the past 300 million years to the sun's passage through the spiral arms of the Galaxy. It is an extension of the ideas presented by McCrea, Clube & Napier and Begelma & Rees, and is based on a recent work of Leitch & Vasishit which shows that the sun was most probably in the spiral arms at the times of the well-known Cretaceous-Tertiary and Permian-Triassic boundaries. An argument is presented which relates the accretion of the IS gas cloud onto the sun to the change in the solar luminosity, which in turn brings about the changing rotational period of the earth, whereby the boundary layer between the core and the mantle is disturbed to generate a superplume, which leads to flood basalts at the surface; a superchron of the geomagnetic field is brought to a halt by the greater temperature gradient in the layer. The encounter(s) with IS clouds disturbs the Oort cloud of comets, injecting comets into the inner solar system, some of them becoming earth impactors. It is shown that this model is consistent with geological and palaeonthological data so far known.

1. Introduction

The history of the Earth is full of events and episodes, which may have contributed to the evolution of fauna. These include the well-known Milankovich cycles, massive volcanisms, and catastrophic events which have resulted in mass extinctions such as at the Cretaceous/Tertiary (K/T) boundary, and reversals of the geomagnetic field. Thanks to the work of geologists and physicists, much has been learned what could have contributed to these environmental changes. In particular, since the discovery of a layer by Alvarez et al (1980) at the K/T boundary which includes Iridium, the possibility that a bolide impact could play a major role in the earth history has come to be widely accepted. The identification of a crater at Chicxulub (Morgan et al 1997 and references therein) has given further support for the important role of a bolide impact in the evolution of terrestrial fauna. For possible effect of bolide impact, see Toon et al (1997).

On the other hand, there have been arguments that more gradual processes must have also played a role at geological boundaries such as K/T and P/T (Permian-Triassic). Furthermore, these two boundaries are associated with massive flood basalts. The near coincidences of the mass extinctions and the flood basalts (Deccan and Siberian) led some authors, especially those inclined to the gradual extinction scenario to propose that the mass extinctions were due to environmental changes brought about by the volcanisms.

Further, there is another geological feature which, although may be irrelevant to faunal extinctions, may be related to flood basalts. It has long been known that the geomagnetic field reverses polarity, and a long interval of time where no polarity change took place is known as a superchron. A feature which has not attracted much attention is the fact that the superchron ceased at or slightly before the mass extinctions.

One wonders whether a viable model can be conceived which is capable of explaining those aspects of the earth history, which at first glance appear unrelated. We believe that an important clue is provided by the recent work of Leitch & Vasisht (1998) who showed that on a reasonable model of the Galaxy, the sun was in a spiral arm at the times of K/T and P/T boundary events. That the passage of the sun through spirals arms of the galaxy could bring about changes in the terrestrial environment was discussed by McCrea (1975, 1981), Napier & Clube (1979) and Begelman & Rees (1976). McCrea and Napier & Clube paid attention to the possibility that the terrestrial phenomena which recur at intervals of 108 yr may be related to the sun's motion in the galaxy, because it is the time interval between the sun's passage through spiral arms. McCrea (1975) discussed the possible start of ice epochs by accretion of interstellar gas onto the sun via Simpson process (Hoyle & Lyttleton 1939, McCrea 1981) while Napier & Clube (1979) proposed that injection of possible planetesimals into the solar system could start an epoch by bolide impacts on earth, with particular emphasis on the role played by the fragments of the planetesimals. See also Clube & Napier(1990). The finding of Leitch & Vasisht (1998) is important in that the link between these suggestions and the well known geological boundaries has been made more concrete.

In the work of Clube & Napier (1996), a possible relation of the fragmenting planetesimals with the magnetic field reversal is discussed, but a possibility of flood basalts is not, whereas, for the case of the P/T boundary, it is hard to neglect the possibility, as will be discussed in the following, that flood basalts are an important factor in the mass extinction. In the present paper, we wish to argue that the sun' s encounter with spiral arms is capable of explaining all of the features mentioned above, namely, flood basalts, ending of a superchron, and bolide impacts at times close to the mass extinctions. If the model which we develop here is viable, the pace of evolution on earth is controlled by the sun's motion in the Galaxy, in accordance with McCrea and Clube & Napier. Our model, however, differs from that of Rampino et al (1997), who argued that it is the sun's motion perpendicular to the galactic mid-plane, which controls the terrestrial evolution.

In sections 2 and 3, a brief review of geological and paleonthological records will be presented, which appear to require explanations. We shall then proceed to argue that the sun's encounter with spiral arms can provide a viable model for these features.

2. Phenomena that require explanation

In this section, we provide a brief review of geological features which require special attention K/T boundary (65 Myr BP). The Iridium anomaly is well known. See Alvarez et al (1980) for the iridium in the clay layer collected at Gubbio, Italy which corresponds to the K/T boundary. Kyte & Wasson (1984) have measured the amount of Ir in the core of the Pacific Ocean and have shown that there is a marked peak in the Ir concentration at the depth corresponding to the K/T boundary. For the crater at Chicxulub, see Morgan et al (1997) and for amino acid, see Zahnle & Greesnspoon (1990). The nature of the impactor is a matter of controversy. Some authors (Napier & Clube 1996) favor the comet as the imapactor, while majority of geologists argue that the impactor was an asteroids (Alvarez et al 1980, Kyte 1998). Jeffers et al (2001) discussed the iridium deposit in relation to the crater size and argued that it was a large comet with a short periodic orbit. Geochemical evidence is not sufficient to decide on the nature of the impactor (see Shukolyukov & Lugmair 1998).

Apart from these geological signatures, the K/T boundary is coincident with the formation of the Deccan trap in India. Duncan & Pyle (1998) measured the ^{40}Ar-^{39}Ar ratio of the basalts taken from the thickest sequence of the Deccan trap, and have obtained the formation time of 66.6 to 68.5 Mry BP, somewhat earlier than the age of Chicxulub crater, which is 64.980±0.05 Myr.

Next, we consider the frequency of the reversal of the geomagnetic field. Over a long interval of time before the K/T boundary, there was a long period of time where there was no magnetic reversals. This period is known as a superchron and the K/T boundary event took place soon after the geomagnetic reversal began to take place (see Fig. 5 of Clube & Napier (1996), Fig. 4(a) of Yabushita (1998), Fig.4 of Courtillot & Besse (1987)). Courtillot & Besse (1987) had paid a special attention to the situation that the Deccan traps in India were formed just at the end of the long reversed superchron (LRS) and they ascribed the volcanism which led to the Deccan traps as some kind of instability in the core of the Earth, although no suggestion had been presented as to the cause of the instability. Of course it is possible to argue that this is a mere chance, but a similar situation exists in the case of P/T boundary and it may very well be a feature which needs to be accounted for P/T boundary. At the Permian-Triassic boundary which took place 250 Myr BP, a large number of species died out. Nearly 85% of marine species and 70% of terrestrial vertebrate genera became extinct. For a review of mass extinctions, see Sepkoski (1995).

From geological material collected from southern China, Bowring et al (1998) used uranium-lead method to determine the age of the boundary. Their U/Pb method yielded that the P/T boundary took place at 251.4±0.3Myr BP. Before going into the geological and paleontological changes that took place at the boundary, we first note that the boundary took place after a long normal superchron (LNS) had just ceased (see Fig. 4 of Courtillot & Besse 1987). This is a feature common to the K/T boundary.

The P/T boundary is also characterized by wide-spread anoxia. Wignall et al (1996) studied rocks collected from Spitsbergen, Italy and Slovenia and found that the late-Permian ocean is characterized by anoxia in shallow seas. In addition to this result, Isozaki (1997) studied cherts of southwest Japan and British Columbia, Canada, and found that the deep sea anoxia prevailed over the P/T boundary and had lasted for some 20 Myr. Again, the climax of anoxia characterized by gray cherts, siliceous claystone and carbonaceous claystone lasted for more than 10 Myr. Thus, the P/T boundary is characterized by long lasting anoxia. The picture of the P/T boundary is that it was a gradual process, although a bolide impact may have played a role in the long lasting phenomena. It is an interesting feature of the P/T boundary that a superchron ended almost simultaneously with the boundary and the Siberian flood basalt (see Fig.1). Thus, we have super-anoxia, massive flood basalts (Reichow et al 2002, Duncan & Pyle 1988), ending of a superchron at the P/T boundary. According to Reichow et al (2002), the volume of lava erupted in Siberia at the time of P/T boundary is as much as $3.9*10^6$ km^3, far greater than had been accepted. It is difficult to imagine that it did not play a role in the mass extinctions at the P/T boundary.

3. Patterns and causes of extinction

Patterns of faunal extinction could give a clue as to the mechanism which caused the boundary event concerned. The most instructive is the time scale involved. If the extinction was sudden, the cause would have been catastrophic, whereas if the extinction had been gradual, the cause itself would have been so.

As to the Cretaceous-Tertiary boundary, there has been much debate as to the time-scale of the extinction involved. Kaiho & Lamolda (1999) analyzed records of planktonic foraminiferal species collected from Caravaca, Spain and concluded that the extinction over the K/T boundary was abrupt and sudden changes occurred within the pelagic ecosystem (See also references therein).

On the other hand, from multidisciplinary studies of K/T boundary section of at Saharan platform in Tunisia, Keller et al (1998) concluded that the long-term stresses due to climatic, sea-level, nutrient, oxygen and salinity fluctuations which started 200-300 kyr before the K/T boundary led to mass extinctions and that the boilde impact played a minor role in the extinction. Padro et al (1999) investigated planktic formanifera and clay mineralogy of Kazakhstan and found that long-tem climatic changes may have been the principal factor that led to gradual disapperance of the spcecies in the Paratethys and that majority of the indigenous Cretaceous species survived into the tertiary period. See also Keller (1997).

Again, Officer et al (1987) had earlier pointed out that although calcareous plankton extinction took place in a short period of time of 10,000 yr or as short as 200 yr, other marine extinctions took much longer. In this respect, we may note the investigation of Marshall & Ward (1996) of marine fossils. They found that of outer-shelf microfossils of the European Tethys, a major extinction took place near or at the K/T boundary but a gradual extinction had already taken place well before the boundary. It appears then that although a number of species died out at the boundary, many were already in decline before the K/T boundary and the rest had survived into the Tertiary. Depending on which aspect of extinction is paid more attention, one is led to a short-time scale catastrophic event as the cause for extinction or a cause taking place gradually, geologically speaking.

Thus, if the sudden extinction is regarded as the major feature, a catastrophic event represented by a bolide impact would be acceptable, while if one pays more attention to a gradual extinction process, another cause such as volcanism would be deemed more reasonable. Officer & Drake (1985) had earlier argued that the K/T extinction lasted for 10 Kyr and regarded the volcanism that made up the Deccan traps as the major cause that led to faunal extinction.

As to the P/T boundary, the Siberian flood basalts have long been suspected as the cause. Renne et al (1995) recalculated the initiation time of the Siberian vulcanism, one of the most massive in the Earth history, at 250.1±0.3 Myr, and argued for the synchrony of the flood basalt initiation and the P/T boundary.

One remarkable feature of the Siberian basalt is that it is most likely to have originated from the lower mantle. According to the work of Basu et al (1995), the $^3He/^4He$ ratio in the rock collected from Maimecha-Katui in Siberia is up to 12.7 times higher than the atmospheric value, which strongly suggests their origin as a plume coming from lower mantle. As to the mechanism of the mass extinction, Bowring et al (1998) suggested initial cooling due to volcanic ashes and subsequent warming by the greenhouse effect and that this kind of climatic changes have exerted tension upon the fauna. Wignall & Twitchett (1996) regarded the anoxia in the shallow as well as deep oceans as the cause of extinction. The warming of the earth brought about by the volcanism had decreased the temperature difference between the polar region and the equator, thus weakening the oceanic circulation, which is regarded as the prime cause of the anoxia.

To summarize, even in the case of K/T boundary, some of the species were already in decline and a bolide impact now recognized by the Chicxulub crater probably played a final blow to the already declining species. For the P/T boundary, there seems to be a consensus that the boundary event was gradual which is supported by both palaeonthological and geological evidence. Furthermore, the two boundaries are associated with massive flood basalts; the Deccan traps for the K/T and Siberian basalts for the P/T. We also note that each event took place after a superchron. Thus, what is needed is a model which can provide explanations for 1. bolide impact, 2. massive volcanisms and 3. ending of superchrons.

We believe that any model which is capable of providing explanations only for a gradual or a sudden extinctions is not consistent with paleonthological evidence. There were two processes operating over the boundaries, gradual and sudden. In the following, we shall show that the sun's passage through a spiral arm can provide a unified account of these aspects of the boundary events.

4. Effects caused by sun's encounter with interstellar gas clouds

What will happen to the sun and the earth when the solar system encounters an IS cloud appears to have been first investigated by Hoyle & Lyttleton (1939). They were concerned with the suggestion of Simpson, who noted that an ice epoch could be brought about by a temporary increase in the solar luminosity, because to accumulate ice near the polar regions, as it is now, an increase in precipitation is needed. And McCrea (1981) has argued, once the earth plunges into an ice-epoch, the Milankovich cycle begins to operate and the experiences a series of ice ages, as it does at present. So what is needed is a process whereby the earth is brought into an ice epoch, and the accretion of IS gas to the sun is a mechanism which operates in the required manner.

The earth as well as other planets may also capture the gas, but we first discuss the effect of the change in the solar luminosity. An ice age is characterized by a large amount of ice near the polar regions.

Olausson & Svenonius (1973) calculated various dynamical effect that are brought about by the change in the moment of inertia of the earth resulting from the movement of water from the equatorial to polar regions. This effect is different from the tidal friction, which operates in one way and uniformly. Let it be first noted that they were concerned about the reversal of the geomagnetic filed and argued that the changing moment of inertia and the resulting change in the rotational period of the earth is the mechanism which drives the magnetic field reversals. Below, we list some of the result calculated by them; $dT \sim 0.5x/100$ where dT is the change in the length of the day in units of second, and x is the lowering of the sea level in metres. It is assumed that the entire earth behaves as a solid body. If the fluid core behaves independent of the mantle motion, the dT will be somewhat greater. At the maximum of glaciations, x takes on a value close to 150 m, so that $dT \sim 0.8$s.

The change in the rotational velocity at the bottom of the mantle for zero latitude is $dv \sim 0.147*(0.5x/100)$ cm s^{-1}, while the change in the angular velocity is given by $d\omega = -(2\pi/T^2)\, dT$, so that a typical velocity difference (for x=150 m) is 0.1 cm s^{-1}. The velocity may appear small, but if this value is inserted into the equation of dynamo theory, the term representing the dynamo action is far greater than the diffusion term (Lowrie 2000); in other words, the velocity of flow in the core is most likely far smaller than 0.1 cm s^{-1}.

Now, the earth cannot remain in a state where there is a difference between the angular velocities of the core and the mantle. Even in the absence of magnetic field, a circulation other than a mere rigid rotation is induced which carries angular momentum from the core to the mantle and vice versa (Bondi &

Lyttleton 1948). Let it be supposed that eventually, a final state will be reached where the two angular velocities are equal. If $d\omega$ denotes the difference between the angular velocities of the mantle and the core, the difference between the rotational energies of the final state to the one with unequal angular velocities is found to be $dE = -(1/2)(J_1+J_2)\omega^2(d\omega/\omega)^2 J_1J_2/(J_1+J_2)^2$ where J_1 and J_2 are the moments of inertia of the core and mantle, respectively and where ω is the angular velocity of the earth. The product of the first three factors represent the rotational energy of the earth ($=2.1365*10^{29}$J). For the earth, $J_1J_2/(J_1+J_2)^2=0.71$ (Olausson & Svenonius 1973) so that $dE=0.204*10^{20}$ J for dT=1 second. A fraction of this energy could be converted to heat at the core-mantle boundary by frictional coupling, but not large enough to influence the energy budget at the core-mantle boundary.

Now the earth undergoes a Milankovich cycle, where warm and cold periods alternate with a time interval of the order of 10,000 yrs. The present earth is in the Quaternary period (ice epoch) which started some 1 million yrs BP. The earth is likely to have experienced the acceleration and retardation in the rotation during this period.

The earth may have plunged into the ice epoch by encountering the Orion arm of the Galaxy (Napier & Clube 1979). It may be noted that the earth may plunge into an ice epoch by another mechanism, namely, the injection of dust released from disintegrating comets into the terrestrial stratosphere, even without large scale bolide impacts (Clube & Napier 1990), regardless of the ultimate origin of the comets (capture from IS molecular clouds or from the Oort cloud).

Before going to discuss the causes of superchrons and superplumes, it is perhaps worthwhile to refer to two alternative models of the reversal of the geomagnetic field. The first is a model of Courtillot & Besse (1987). They assume that above the core-mantle boundary (CMB), hot thermals (locally hot portion) are released from the thermal boundary layer (often designated by D''), which ascend to become hot spots. The rate of release of thermals being greater when the thickness of D'' is larger. Below the CMB. cold thermals are emitted from the thin core boundary layer, which bring about reversals of the geomagnetic field. A superchron is interpreted as a period when thermal conduction from the core to mantle is large and the layer D'' increases thickness. The second model is by Larson & Olson (1991). They assume that when the layer D'' has become sufficiently thick, a plume is produced from D'', with consequent thinning of the layer D''; since the temperatures at the bottom and top of D'' remain unchanged, the temperature gradient in D'' becomes greater, which would lead to more vigorous convection in the core. According to them,when the convection is sufficiently vigorous, the reversals no longer take place. In these models, it is not clear what triggers the generation of hot thermals (or plumes) from the thermal boundary layer.

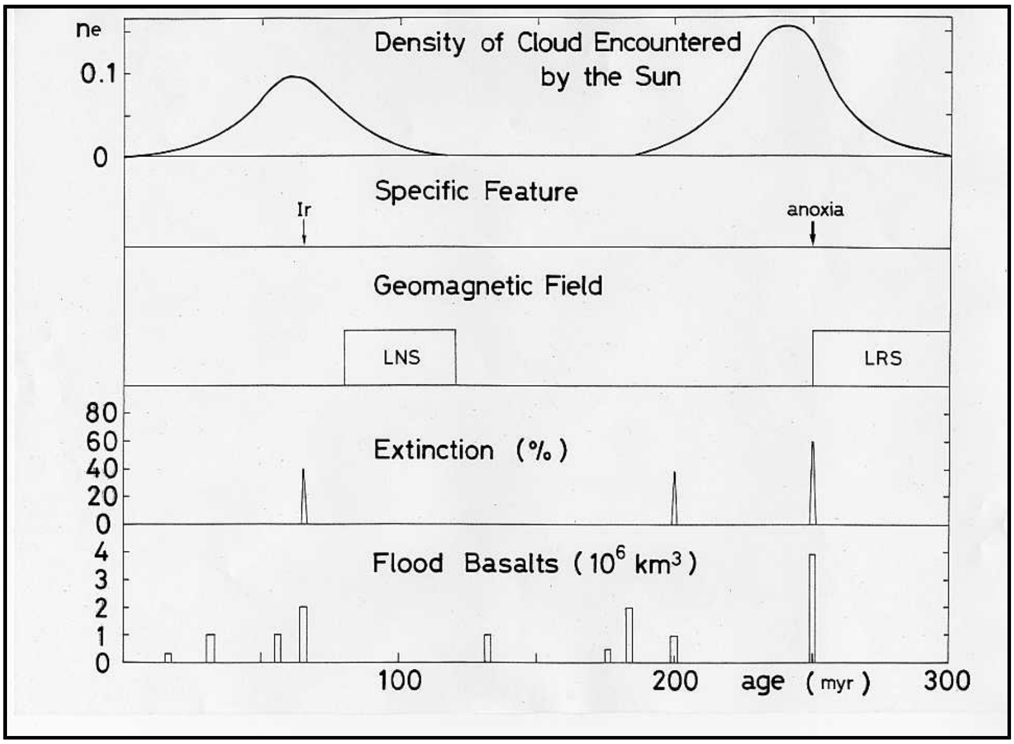
5. Generation of a superplume

During the Phanerozoic, two instants of superplumes are recognized. One of these corresponds to the volcansim which led to the formation of the Deccan traps 65 Myr BP and the other to the Siberian Flood basalts at 250 Myr BP, which coincides with the P/T boundary. It is commonly accepted that the superplumes are generated from the thermal boundary layer, commonly designated as D''. Yuen & Peltier (1980) investigated the stability of the thermal boundary layer and showed that there are modes which are unstable to slight perturbations. The fastest growing mode has a growth time of 10^6 yr and spatial scale of 10^2 km. The result would imply that when sufficient heat is stored in the D'', a plume is generated when an external disturbance is applied.

As to the superplume generation, another mechanism has been suggested by Williams (1994). He argued that when the earth rotation had a period of 22.2 hours, the free nutation of the fluid core would have resonated precisely with the earth retrograde annual forced nutation by the solar torque, and this could have amplified the core rotation and velocity, thus leading to temperature rise in the thermal boundary layer, D''. Williams (1994) argued that this could provide a mechanism for generating superplumes within the D''. There is a similar calculation by Greff-Lefftz & Legros (1999) that the rotational eigen frequency of the fluid core and the solar tidal waves were in resonance around $3.0*10^9$, $1.8*10^9$, and $3*10^8$ yr BP. These authors argued that because of the strong frictional coupling between the core and the mantle at these times, energy of enhanced motions was dissipated into heat at the D'', which led to the formation of superplumes. Although interesting, this model predicts a time of resonance somewhat different from the actual age of the Siberian flood basalts.

Here wish to propose an alternative model which is based on a series of changes in the rotational period of the mantle resulting from glaciations at the surface. As will be seen from Fig.1, massive flood bassalts occurred after a period of long chron (superchron), when there were no magnetic reversals. Like Courtillot & Besse (1987), we assume that this period corresponds to the time when energy transmitted to the mantle from the core is gradually stored in the thermal boundary layer, and after a sufficient time, the layer would have become thick and unstable as shown by Yuen & Peltier (1980). For a superplume to be generated, what is needed is a mechanism which perturbs the layer to such an extent that the instability actually develops. We would here argue that the changing period of the earth mantle could provide the required disturbance at the core mantle boundary. As mentioned in section 4. once ice forms in the polar regions, the Milankovich cycle brings about warm and cold periods, and the changing period of the rotation of the mantle continues until the polar ice disappears.

Fig.1. Geological and astronomical events during the past 300 million yr. The cloud density encountered by the sun is based on Fig. 2 of Leitch & Vasisht (1998). ne is the the number of electrons per cubic centimetre encountered by the sun, as it moves in the Galaxy. Extinction rate per stage (multiple- interval marine genera) is taken from Sepkoski (1995); less significant extinctions are not presented.Flood basalt data are taken from Self & Rampino (2002), except for the basalt for P/T boundary (250Myr BP), for which the data of Reichow et al (2002) are used.



[figL.gif]

This could provide the disturbance to the layer at the CMB, when it had become already unstable. One can conceive of two mechanisms whereby the difference in the velocities can give rise to the disturbance within the layer, D''. One is the electromagnetic coupling between the core and the lower mantle, if the latter were semi-conducting, as is discussed by Runcorn (1982) in relation to the irregular fluctuation of the Earth' rotation. Another mechanism is the possible existence of bumps of the core-mantle boundary (Malin & Hide 1982); the undulation of some 1 km of the core mantle boundary owing to mantle convection.

Once the plume reaches the surface to become flood basalts, a large amount of carbon dioxide is released, with the resulting warming of the earth. The ice that had formed will disappear, and the earth will remain in the normal warm condition until the sun encounters one or several interstellar clouds.

6. Ending of a superchron

A superchron is an interval of the earth history where the geomagnetic field does not change polarity for at least tens of millions of years. Two superchrons are well established; the long reversed superchron (LRS, which ended near the P/T boundary) and the long normal superchron (LNS during the Cretaceous period).

We now present a model which relates the ending of a superchron with the changes in the rotational period of the earth and the resulting generation of a superplume within the layer, D''. The geomagnetic field is maintained by the dynamo action in the earth core. The mode of the fluid motion in the core is not known, so a mechanism of dynamo action is inferred from paleo-magnetism including the secular wonder of the magnetic poles. The convective motion of the core fluid carries heat from the inner core, so it is reasonable to expect that when the temperature gradient of the boundary layer is large, the convection is vigorous, whereas when the gradient is small, the convective motion is weak. Now when a plume is generated, the layer, D'' will become thinner. As Loper & McCartney (1986) have shown, the temperatures at the top and bottom of the layer will remain almost the same even after the plume generation.

The temperature gradient will then be greater, and the convection in the core will become more vigorous. Now, it seems widely accepted that reversing magnetic field requires more heat transport in the core than the field without reversals. The reasons are given in Loper & McCartney (1986). In this model, a superchron will cease when a large plume is generated from the thermal boundary layer and the temperature gradient in the layer has become large. This will continue until such a time is reached that the original thickness of the layer is restored. From the distribution of the length of intervals between reversals, it has been found (Consolini et al 2000) that the magnetic field reversal can be regarded as a transition between metastable states. In other words, each state of the fluid motion which gives rise to the magnetic field is not very stable and jumps from one meta-stable state to another. This situation is only consistent with a fluid motion where a pattern of convection cells in the core is replaced by another pattern of convection cells, which is probably consistent with a larger temperature gradient in the D'' layer and vigorous energy transport in the core.

7. Encounter with spiral arms and geological sequence

Having reviewed possible consequences of encounter of the sun with IS gas clouds, we now wish to argue that the geological events are explicable in terms of the sun's encounter with spiral arms of the Galaxy. The starting point of the argument is the sun's encounter with a spiral arm. Adopting the galactic model of Leitch & Vasisht (1998), the sun was in Sagittarius-Carina and Scutum-Crux arms at the times of K/T and P/T boundary events. The time series of events discussed are summarized in Fig.1. The sun must have passed through some of the IS clouds while it was in the Scutum-Crux arm, some 250Myr BP. The earth would have experienced ice epochs, and a superplume would have been generated and at the same time, a superchron (long reversed superchron) came to an end. The superplume reached the surface, where it became the Siberian flood basalts,largest so far known with a volume of 3.9*10 km^3 (Reichow et al 2002). The flood basalts released a large amount of CO_2, and because of the greenhouse effect, the earth temperature was raised, leading to anoxia in the oceans according to the manner described by Wignall et al (1996) and mentioned in section 3 of the present paper. As the CO_2 in the atmosphere was gradually absorbed by plants and by the oceans, the temperature would drop to that of the normal earth.

The sun again started to enter the region of high cloud density some 100 Myr BP and probably encountered some IS clouds at 80 Myr BP, while in the Sagittarius-Carina arm. The superplume generated then would have become Flood basalts of the Deccan traps, and the generation would have brought about the ending of a superchron (LNS). In this case, the sun entered a core region of a molecular cloud which had probably disturbed the Oort cloud of comets, causing a comet shower in the inner solar system, one of them hitting the earth to produce the crater at Chicxulub and probably a large amount of IS gas and dust were accreted to the earth (Yabushita & Allen 1989, 1997), bringing about selective extinction of fauna and depositing the iridium layer.

8. Discussions

We have argued that the sun's passage through two of the spiral arms of the Galaxy have brought about geological events recognized as K/T and P/T boundaries, and presented arguments which relate the encounters to flood basalts and cessions of superchrons to the encounters. On this model, a major difference between the K/T and P/T boundaries is that in the former case (65 Myr BP), the sun entered a core region of a molecular cloud, whereas for the latter, the sun did not enter a core region, although the sun did enter some of the molecular clouds. Our view is that the large amount of Iridium involved in the K/T boundary layer is due to accretion,whereas an alternative model of Jeffers et al (2001) is possible. As mentioned, they assumed a comet in a short period orbit as the impactor. In this case, the comet may have come not from the Oort cloud, but have come from the Edgeworth-Kuiper belt, and if so, that the sun was in the Sagittaius-Carina arm at the time of the impact would be a mere coincidence.

There seems no consensus as to whether an impact event played a major role at the P/T boundary. Fullerenes are detected in the spectra of IS gas cloud (Foing et al 1994) and Becker et al (2001) regard the fullerenes collected from Sasayama, Southwest Japan as evidence of an impact, but Chijiwa et al (1999) who collected a larger amount of fullerenes from the P/T boundary layer in another part of Japan regard them as product of wild fire in an oxygen poor atmosphere. Isozaki (2001) reviewed geological evidence which Becker et al (2001) regarded as indicating an impact.

He questioned the origin of the fullerenes claimed to have been detected in the work of Becker et al (2001) and pointed out a possibility that they may have been produced during the measurement process. Also, the Iridium detection from the P/T boundary layer has so far been marginal (Yi et al 1985). Thus, unlike the K/T boundary, the evidence for a large bolide impact at the P/T boundary is still uncertain. In our model of the P/T extinction being largely due to Siberian flood basalts, there is no need for a large impact precisely coincident with the boundary. There is in fact a crater, Araguainha Dome, with an estimated age of 249±19 Myr BP and diametre 40 km. From the size, the impactor was probably a comet, but not large enough to have brought about the P/T boundary event. Then, the comet could have been injected into the inner solar system by the disturbance of the Oort cloud due to an encounter with an IS cloud, which has at the same time given rise to the change in the solar luminosity by accretion.

Our model has further implications. Another major extinction (upper Botomian) which took place 500Myr BP (Sepkoski 1996) coincides with the sun's passage through the Norma arm, according to the galactic model of Leitch & Vasisht (1998). Johnson et al (1995) suggested a superchron in the Ordovician which started 502 Myr and ended at 470 Myr BP. With uncertainties associated with age determinations, one could regard the ending of the superchron and the mass extinction being related to the sun's passage through the spiral arm.

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