Galactic triggering of geologic events in earth's history

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Only by combining the knowledge 'readable' in the geologic record with the physical understanding of cosmic-ray-forced processes and astronomical research, we can make progress in each of the participating fields of science.

— Jens Wendler

In the earth's 4.5 billion years of evolution, several spells of major events had occurred shaping the geological, biological and atmospheric structure. Studies in the past had attributed earth-bound processes for their occurrences, but in the wake of the strong evidences advanced in the 1980s for an extraterrestrial agent behind the *K–T* mass extinction, researchers began probing the role of cosmic agents in precipitating many of these events. Astrophysical and geophysical researches in the succeeding decades soon established connections and identified certain temporal patterns for these events with the galactic forces of our home galaxy – the Milky Way galaxy. Thus, recurring mass extinctions of both terrestrial and marine species[1,2], global ice ages[3], major meteorite impacts[4], periodic boosts in fossil diversity[5], formation of large igneous provinces (LIPs), climatic changes causing perturbations to global carbon cycle leading to carbon isotope excursions (CIE), are all now interpreted as the earth's responses to various galactic forces acting upon the sun and the planets while they orbited the galaxy[3,6–8].

The Milky Way galaxy, with a staggering size of about 100,000 light years in diameter with an average thickness of about 1000 light years, is the home galaxy of the solar system. The galaxy has a spiral armed structure with four major arms Cygnus-Norma, Crux-Scutum, Carina-Sagittarius and Perseus (Figure 1 *a*), all of them orbiting the galactic centre at different velocity rates. These arms are actually made up of stars in various stages of formation, supernovae, black holes and interstellar clouds and exhibit strong magnetic fields. Presently, the solar system is located in a smaller arm or spur, the Orion arm, between Perseus and Sagittarius arms. The sun takes about 250 m.y. to complete one orbit around the galactic centre and has a rotational speed slightly faster than the four spiral arms[3]. The orbit is roughly elliptical and perturbed due to the heterogeneous distribution of mass in the galaxy. Besides, the solar system is also known to oscillate up and down the galactic plane, each of these motions and locations relative to the galactic centre correlate with some of the geological events in the earth's history. Further, the fixed symmetrical structure of these galactic arms and the successive crossing of these four arms by the solar system result in the recurrence of these earthly events. A synthesis of galactic, geological, biologic and atmospheric data available so far has shown that these events had occurred at intervals of ~176 m.y., which is the time taken by the solar system to travel from one arm to the same position in the next arm[3,6,7]. However, a shortening of this interval is observed progressively since the arms also orbit around the galactic centre at rates different from that of the solar system and also owing to the non-circular orbit of the solar system[3,6].

During its ~250 m.y. orbit around the galactic centre crossing all the four arms, the earth, as part of the solar system, experiences turbulent spells marked by catastrophic geologic events alternating with relatively quieter phases with stable conditions free from large inputs of cosmic ray flux (CRF) and geomagnetic reversals. The former turbulent phase is found to correspond with the solar system's passage through the spiral arms, while the latter quieter phase predominates during its inter-arm traverse and this period, which is known as superchrons, lasts for 20 m.y. or more. Three such superchrons in the earth's geologic past are now well established and they are the Cretaceous long normal superchron lasting for 36 m.y. between 120 and 84 Ma, Kiaman reversed superchron lasting for 48 m.y. in the late Carboniferous and late Permian between 312 and 264 Ma, and the Moyero superchron[9] in the lower to middle Ordovician for 22 m.y. between 485 and 463 m.y. (Figure 1 *b*).

The superchron periods are notable for global superplume activity, emplacement of LIPs as well as prolonged periods of sedimentation in several continents. A statistical study of some 154 LIP occurrences shows a strong ~176 m.y. frequency between 1600 Ma and the present, and increasingly more in still older periods[10]. Some of the notable LIP events (Figure 1 *b*) are the Panjal, Emeishan (250–260 Ma), Central Atlantic, Karoo-Ferrar (180–200 Ma), Parana-Etendeka, Ontong-Java (120–130 Ma), Caribbean (90 Ma), Deccan and North Atlantic (60–70 Ma)[8,11]. Events such as spells of major sedimentation, incidence of true polar wander (TPW), deposition of coal, oil and gas, and a boost in the biological diversity helped by the modulation of adverse CRF and shielding by the galactic magnetic fields are some of the other events taking place during the inter-arm passage[5,8]. The Cambrian explosion of life or the fossil diversity which began since early Phanerozoic (542 Ma) exhibits a 62 ± 3 m.y. cyclicity and this had occurred during the inter-arm passage after crossing the Perseus arm.

The periodic interchange of the earth's N–S poles or the geomagnetic reversals are believed until now to be driven by structural changes in the earth's interior combined with total heat flux over the core–mantle boundary, which affected the geodynamo (magnetic field generation in the outer core). Now, the galactic tides and galactic magnetic field are also believed to modulate the earth's magnetic field triggering the occurrences of the reversals[8]. The inter-arm passage of the solar system is also correlated with marine transgressions, closure of ancient seas and TPW, resulting in the shifting of the earth's geoid with respect to its rotational axis[12]. The variable acceleration of the earth's rotational speed during its passages through the spiral arms and the inter-arm zones is also considered responsible for changes in the earth's geomagnetic fields and influencing the earth's atmospheric physics[8].

In contrast to the relatively stable earth conditions during the superchron periods, catastrophic events were observed to have occurred whenever the solar system crossed the spiral arms. The four large mass extinctions – the Cretaceous–Tertiary (65 Ma), Triassic–Jurassic (204 Ma) and the double extinction event separated by

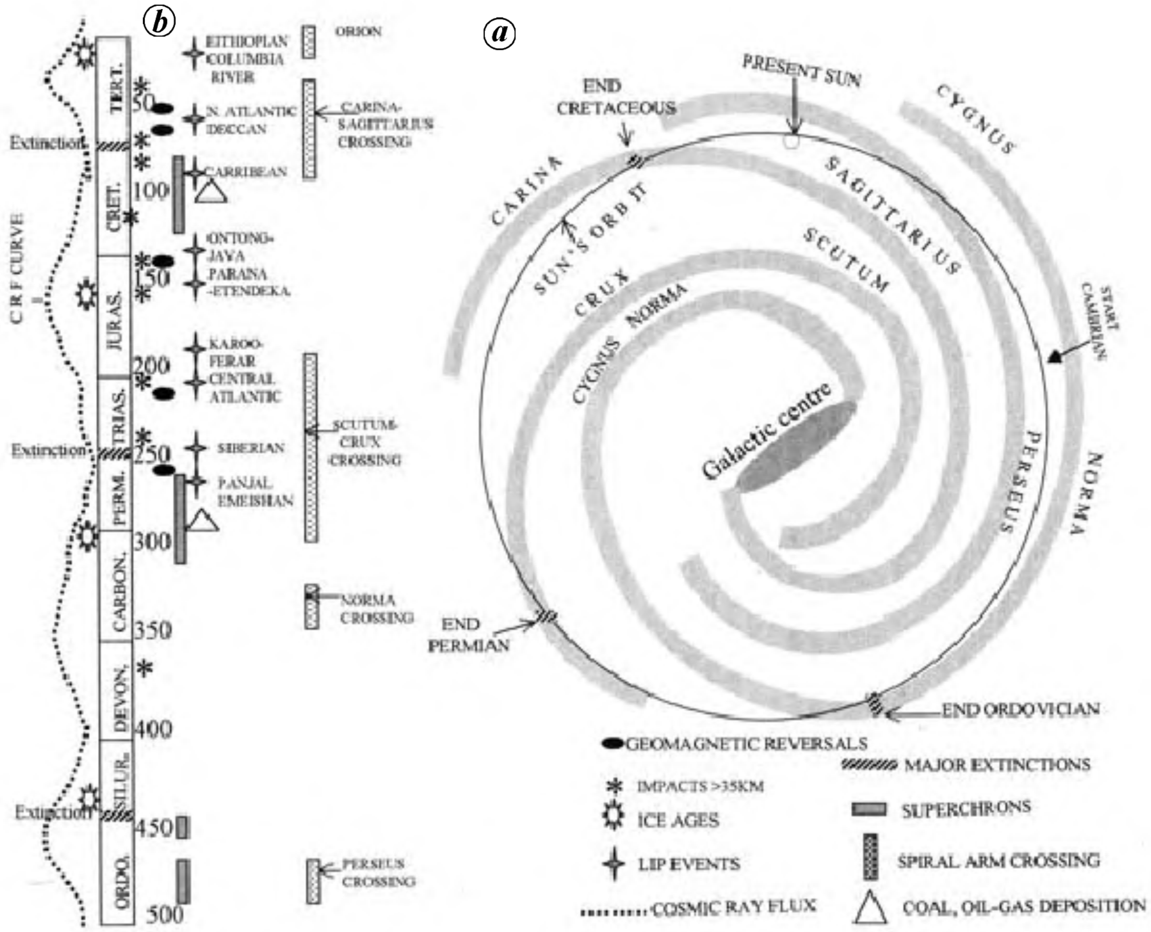

Figure 1. ***a***, Schematic view of the Milky Way Galaxy showing the orbit of the solar system crossing the spiral arms. (adapted from Gillman and Erenler[7]). ***b***, Coincidences of Phanerozoic geological events on the earth in relation to galactic motion of the solar system (adapted from Wendler[8]).

about 5 m.y. during Permian–Triassic (251 Ma)[13] have all taken place while the sun crossed the spiral arms, e.g. Carina–Sagittarius transit notable for the 65 Ma extinction, Crux–Scutum passage for the end-Triassic and end-Permian extinctions, and Cygnus–Norma for the late Devonian (Figure 1 *b*). Similarly, major impact events have also been recorded at 440 ± 2 Ma (Cygnus–Norma crossing), 247 ± 5.5 and 214 ± 1 Ma (Crux–Scutum crossing), 142.5 ± 0.5, 73.8 ± 3 and 65 ± 2 Ma (Carina–Sagittarius crossing), whereas smaller impacts of size <35 km do not exhibit any periodicity. The impacts also coincide with geomagnetic events[4,6,7] at 247.5, 222.5, 152.5, 72.5 and 62.5 Ma. It is suggested that these impacts may be the result of the galactic quasi-periodic gravitational perturbations on the Oort cloud, the source for the earth-impacting materials, during the orbit of the solar system along the galactic plane[14].

Among the galactic triggers that can influence and modulate the earth's climate, a number of studies have stressed the role of both CRF and geomagnetic reversals[3,7,8,15]. During the traverses of the solar system through the spiral arms of the galaxy, it encounters a flux of high-energy particles (essentially protons) generated by the ongoing processes of star formation, supernovae and black holes. A large part of these particles, as well as some from reactions within the sun remain within the arms confined here by the strong magnetic fields present and the earth is thus exposed to increased flux of these particles. These energetic particles get modulated by the interplanetary field of the sun and the earth's magnetic field, and reach the atmosphere as cosmic rays[3,7]. The CRF noticeably reduces during the inter-arm passages. A plausible model[3], though much debated, attributes increased galactic CRF in the vicinity of the earth for the occurrences of ice ages over the earth. Their increase here promotes extensive cloud formation and consequent reduction of global temperature leading ultimately to the onset of ice ages, their severity proportional to the severity and length of the star formation episode in the spiral arm[3,15]. That the ice ages are galactically forced appears evident from the fluctuations in the abundance of cosmogenic isotopes like ^{10}Be, ^{14}C, δ^{18}O seen in sediments of corresponding geological ages. The production of these isotopes is generally higher during spells of higher CRF over the earth due to the lower shielding by the interplanetary magnetic fields and geomagnetic intensity lows[8].

Phanerozoic major ice ages have occurred corresponding to high or low interplanetary and solar magnetic activity during 20 ± 10 Ma (Tertiary), 160 ± 10 Ma (Jurassic), 310 ± 20 Ma (Carboniferous) and 446 ± 10 Ma (Ordovician) and prior to these ice ages, the Proterozoic period snowball earth phase[3] between ~700 and 900 Ma. Prolonged global warming during the interglacial periods had led to rapid dissociation of continental methane hydrates, ocean anoxia and extinction of a large proportion of marine species during early Jurassic (183 Ma). This event had also coincided with a significant perturbation in the global carbon cycle or the occurrence of CIE[1].

The concept of galactic forces acting on the earth and triggering various major events periodically corresponding to the location of the solar system, either within or outside the spiral arms of the galaxy, appears probable. Perhaps these forces were the prime triggers for initiating the events on the earth and thereafter to be completed in tandem by the earth's geological processes. Though good correlation is established with regard to certain of the Phanerozoic earth events and the galactic parameters during this period of the sun's orbit, the conclusions, particularly regarding their cyclicity appear to be different for different models of solar orbital parameters[6]. The solar system, has no doubt, made several orbits around the galaxy prior to the Phanerozoic times, and it is hoped that with the availability of more data, future studies will be able to apply and substantiate the 'galactic trigger' model for the preceding Proterozoic period also, where records on similar geologic, biologic and atmospheric events are available.

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MEETINGS/SYMPOSIA/SEMINARS

Catalysis for Sustainable Energy and Chemicals (CATSYMP-19)

Date: 18–21 January 2009
Place: Pune

Themes include: Clean fuels including biofuels; Natural gas to chemicals and fuels; CO_2 as raw material for fuels and chemicals; Specialty and fine chemicals through green chemical routes; Photocatalysis; Biocatalysis; New materials as catalysts and adsorbents; Catalysis for better environment; Structured catalysts and membrane reactors; Scientific computation and modeling.

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11th CRSI National Symposium in Chemistry

Date: 6–8 February 2009

3rd CRSI-RSC Symposium

Date: 5 February 2009
Place: Pune

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