GALACTIC AND SOLAR SYSTEM INFLUENCE OVER SEDIMENTARY CYCLES, CLIMATE AND EXTINCTIONS ON EARTH

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The path our Solar System through our Galaxy may affect the number of asteroids and comets buzzing around Earth. Scientists have uncovered possible evidence of this galactic crossing in an apparent periodic cycle, matching the rate of large crater impacts. For example, the frequency of impact fluctuations closely matches the rate at which the Sun (and the whole Solar System) passes through the plane of the galactic disk (Rampino, 2015). Asteroids and comets impact events appear to have played a significant role in shaping Earth's geological history, creating not only craters, possibly causing climate changes and mass extinctions.

Many of these bodies come from the Oort cloud (sometimes called the Öpik–Oort cloud), a spherical envelope of icy bodies in the outer edge of our Solar System, and also from the Kuiper belt, a circumstellar disc in the outer Solar System, extending from the orbit of Neptune (bodies from Oort and Kuiper are collectively referred to as trans-Neptunian objects). Because the Oort cloud and the Kuiper belt are so distant from the Sun, they are highly susceptible to perturbations from gravitational forces coming from other bodies. During the last few decades, there have been indications that the frequency of impacts (comets and asteroids) on Earth oscillates on a timescale of about 25-35 million years, which suggests a connection between the dynamics of our Galaxy, the outer edge of the Solar System and the asteroid/comet shower strikes on Earth (Rampino & Stothers, 1984; Rampino, 2015; Rampino & Caldeira, 2015).

IMPACTS AND MASS EXTINCTIONS

The 25–35 Myr cycle reported in mass extinctions and terrestrial impact cratering have been attributed by many authors to the Sun's vertical oscillations through the Galactic disc, estimated to take around 32 (up to 42) Myr between Galactic plane crossings. Near the Galactic mid-plane, the Solar system's trans-Neptunian bodies could be perturbed by Galactic tidal forces, and possibly a thin dark matter (DM) disc (Randall & Reece, 2014), which might produce periodic asteroid/comet showers and possibly extinctions on the Earth (Rampino, 2015). Passage of the Earth through especially dense clumps of DM, composed of Weakly Interacting Massive Particles (WIMPs) in the Galactic plane, could also lead to heating in the core of the planet through capture and subsequent annihilation of DM particles. This new source of periodic heating in the Earth's interior might also explain a similar ~30 Myr periodicity observed in terrestrial geologic activity, which may also be involved in extinctions. These results suggest that cycles of geological and biological evolution on the Earth may be partly controlled by the rhythms of Galactic dynamics, through the motion of our Solar System (Figure 1) across and around the Milky Way (Rampino, 2015). These perturbations could lead to periodic asteroid/comet showers in the inner Solar system, and hence impacts, and associated mass extinctions on the Earth.

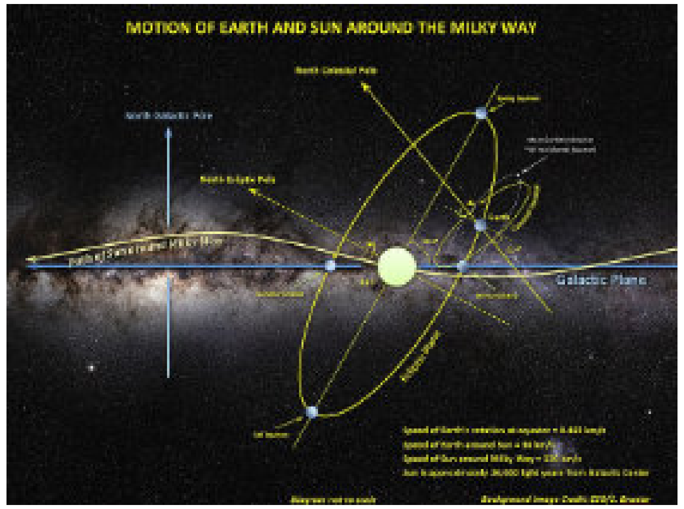

Figure 1. Motion of Earth and Sun across and around the Milky Way.

In Figure 2, Rampino (2015) shows that, over the last 260 Myr, 9 of the 13 proposed impact pulses correlate closely with times of mass extinction (including the Late Paleocene warming event), 7 impact pulses correlate with flood-basalt eruptions, 7 flood basalts correlate with mass extinctions and 6 impact pulses can be correlated with estimated times of the Solar system crossing the Galactic plane in the last 260 Myr.

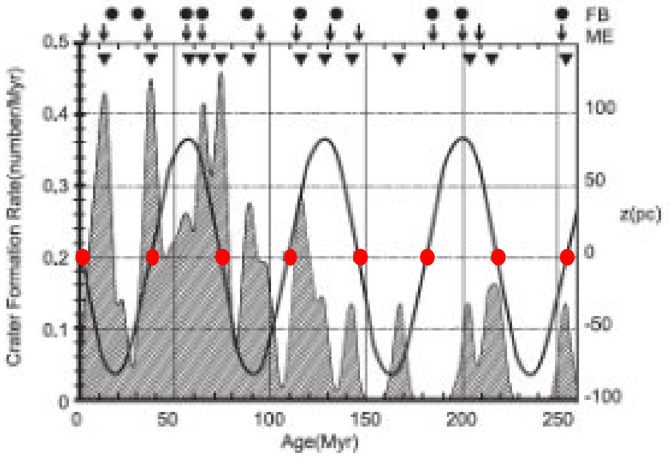

Figure 2. Comparison of ages of impact craters, mass extinctions and floodbasalt eruptions, and relation to estimated times of Galactic plane crossings. Probability distribution of crater-formation rate (hatched) (number of impacts perMyr), for the last 260 Myr. The probability distribution has been smoothed by a Gaussian function. Peaks in the cratering record are indicated by dark inverted triangles; times of mass extinctions (ME); times of continental flood basalts (FB, dots), all plotted against the Sun's estimated height above and below the Galactic plane (Z, in parsec), with a half cycle of ~35 Myr. Estimated times of Galactic plane crossings of the Solar system are marked by red dots. Figure modified from Rampino (2015).

Rampino & Caldeira (1993) extended the study to include the timing of 77 major terrestrial geologic events of various kinds during the past 250 Myr (continental flood basalts, tectonic episodes, extinctions, changes in sea-floor spreading, sea level and oceanic anoxic events) and reported a persistent cycle of ~25–35 Myr in the occurrence of these events (Rampino, 2015; Rampino & Caldeira, 2015). The hypothesis involves a gravitational influence of the dense galactic disk on the Solar System (Randall & Reece 2014). The Sun orbits around the Galactic center, however, this trajectory is not a perfect circle.

The Solar System moves up and down, crossing the plane of the Milky Way approximately every 32 million years, which coincides with the presumed periodicity of the impact variations (Rampino, 2015). Because the density drops off in the vertical direction, there is a gravitational gradient, or tide, that may perturb the orbits of celestial bodies in the Oort cloud, causing some of those bodies to fly into the inner Solar System, attracted by the Sun, raising the chances of collision with Earth. However, as Rampino (2015) pointed out, the problem with this idea is that the estimated galactic tide is too weak to cause many waves in the Oort cloud, so an additional piece of the puzzle has to be included. Randall & Reece (2014) focus on this hypothesis and suggest that the galactic tide could be made stronger crossing a thin disk of dark matter. Here, these researchers consider a specific model, in which our Galaxy hosts a dark disk with a thickness of 30 light years, consistent with astronomical data on our Galaxy.

ENCOUNTERS OF THE SOLAR SYSTEM WITH DARK MATTER

Since a disc of DM is expected to be strongly concentrated in the plane of the Galaxy (Randall & Reece 2014), encounters of Earth with dense clumps of DM should preferentially occur when the Solar system is crossing the Galaxy's mid-plane, and hence would give those encounters an underlying periodicity calculated by those authors of ~32 Myr. Collar (1996) op cit., by

Rampino (2015) further suggested that in passing through a dense clump of DM, increased doses of radiation, such as alpha particles, fast neutrons and heavy ions could also contribute directly to major extinctions in our planet.

Larson & Olson (1991) suggested that mantle plumes control magnetic reversal frequency by a sequence of events, and concluded that episodic heating of the Earth's core might affect the functioning of the geodynamo and thus the frequency of geomagnetic reversals. Excess heat near the core-mantle boundary might trigger upwelling plumes of mantle material that could rise to the surface in possibly as short as a few million years, depending on mantle viscosity. These plumes would perturb mantle convection, create volcanic hotspots, rift apart continents and possibly leading to pulses of tectonic unrest, changes in direction and rate of sea-floor spreading, and associated changes in volcanism, sea level and of course climate. Thus, large meteorite and cometary impacts may well increase the amount of volcanism from already active mantle plumes (Abbott & Isley, 2001), and periodic encounters of the Earth with dense clumps of DM particles may also partially explain the episodic nature of terrestrial volcanism, geomagnetism and plate tectonics (Rampino, 2015). Geologic events that have been thought of as independent occurrences might have common roots, and might be partly related galactic forces.

THE GALACTIC CYCLE OF EXTINCTION

But global extinction and geological events not only have been linked with galactic events such as galactic plane oscillations as we discussed previously. Some intriguing data point out also to spiral arm crossings. Svensmark (2006) and Gillman & Erenler (2008) identified three time zones of high geological activity which relate to the timings of the passage of the Solar System through the spiral arms of our Milky Way (Perseus, Carina-Sagittarius, Crux-Scutum and Cygnus-Norma). These zones are shown in Figure 3 to include a significantly large proportion of high extinction periods. Global mass extinction and geological events occurs at predicted midpoints and end crossing of the spiral arms. The repetition of extinction events at the same points in different spiral arm crossings suggests a common underlying galactic cause of mass extinctions, through galactic effects on geological processes. The mean difference between successive values in the sequences was 175.96 Myr, which is interpreted as the time to move from a point in one galactic arm to the same point in the next arm. With a total time of 703.8 Myr to pass through the four arms and inter-arm gaps of the whole Milky Way (Gillman & Erenler, 2008).

The same authors mapped the major extinction events to the position of the arms (Figure 3). Three high extinction events and associated geological periods (end-Ordovician 444 Myr, end-Permian 251 Myr and end-Cretaceous 65.5 Myr) are placed approximately at the midpoints of the last three arms (Carina-Sagittarius, Crux-Scutum and Cygnus-Norma) crossed by the Solar System. The remaining three mass extinction events originally identified by Raup & Sepkoski (1982) occur at later positions after passing through the Perseus, Cygnus-Norma and Crux-Scutum arms (start of the Cambrian, Late Devonian and Late Triassic, respectively). In conclusion, a coherent pattern of mass extinction emerges from these studies, with the galactic forces as the possible causal mechanism (Gillman & Erenler, 2008). These results accounts not only for past events but may act as a predictor of future extinctions.

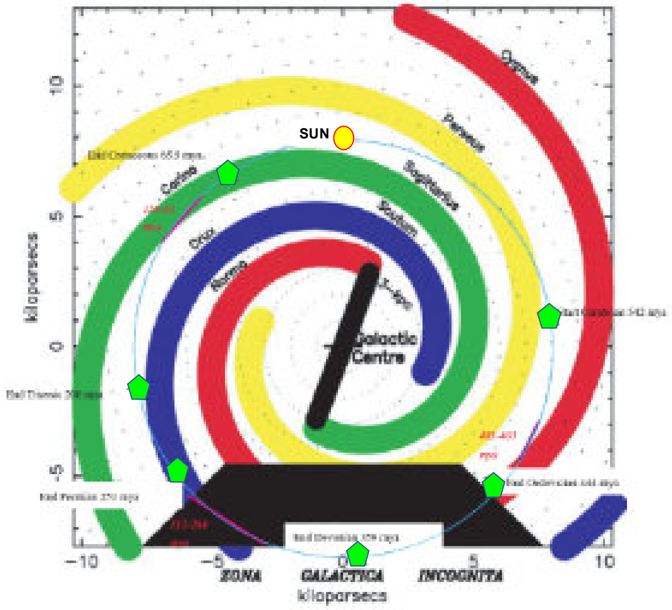

Fig. 3. Cycle of high extinction events in a four-spiral arm model of the Milky Way Galaxy. The current position of the Sun is indicated with an approximately circular orbit shown by the light blue circle (yellow dot). The positions of the six extinctions (green pentagon) are determined from a cycle of 703.8 Myr (175.96 x 4), as the time to pass through all four arms. Figure modified from Gillman & Erenler (2008).

THE SOLAR SYSTEM INFLUENCE ON THE SEDIMENTARY RECORD

Concerning our backyard (the Solar System), very interesting studies have been developed during the last two decades about the relationship between sedimentary cycles on earth and the influence of different planets of the solar system. To a first approximation, the orbital planes of the planets are slowly deformed by the gravitational forces of the other celestial bodies in our Solar System, in a quasiperiodic way, that can be decomposed into a series of secular fundamental frequencies, representing roughly each planet's contribution to the deformation of the orbits (Olsen et al, 2019).

Years ago, Olsen (1986) and Olsen & Kent (1999) described long periods Milankovitch cycles from the Late Triassic and Early Jurassic of eastern North America, and this observed cyclicity, using refined Fourier analysis techniques, was related by those authors, with long term behavior of planets within our solar system. The same authors studied more than 7,000 meters of core rock with a 30% stratigraphic redundancy to produce a 4,600 meters' composite section of continuous cores from a continental sedimentary environment (lacustrine to fluvial), of Late Triassic-Early Jurassic (200-227 Myr), located in the Newark Rift Basin, North America (Figure 4).

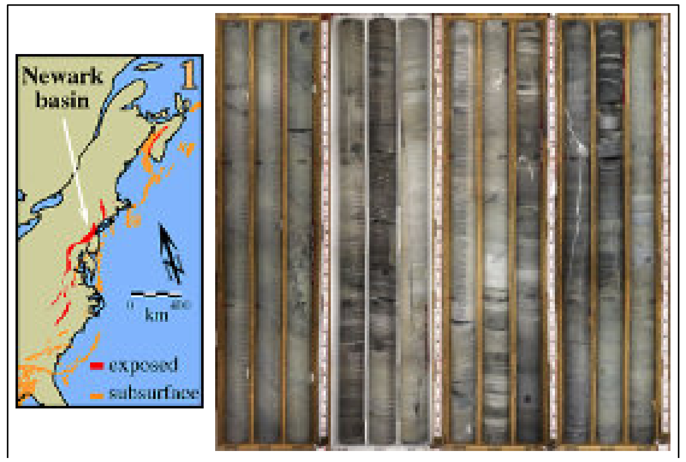

Figure 4. Location of the Newark Basin and example of an extracted core interpreted as lake sediments, spanning about 40,000 years (modified from Callier, 2019)

The stratigraphic study defined a very clear cyclicity, that can be characterized by facies classification or depth ranks, as a measure of lake depths, based on a classification of water-depth-related sedimentary facies suitable for statistical analysis. The cyclicity is also evident in the color of the strata which reflects redox conditions of the sediments and other physical lithological characteristics.

The fundamental lithofacies variation is called the Van Houten cycle, which is recognized on a stratigraphic scale of 3 to 6 m in the cores (Figure 5). This cycle was confirmed by Olsen (1986) and Olsen & Kent (1996) to correspond to lake level variations (due to climate) at a precessional periodicity of 20 kyr, close to today's 21 kyr average period because of recession of the Moon (Kent et al, 2017).

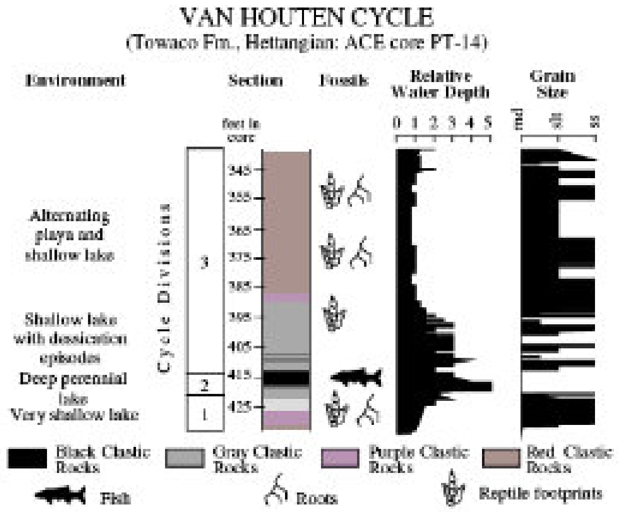

Figure 5. Example of the fundamental Van Houten cycle based on core PT-14 in New Jersey (Kent et al, 2017).

Olsen & Kent (1999) and Kent et al (2017, 2018), using different proxies for water depth estimation and hence climate, sedimentary structures and sediment colors, calibrate the sedimentary sections with radiometric data, stablishing highly significant periods of climatic precession modulation mainly at 1,75 Myr, 1,0 Myr, 700 kyr and 405 kyr.

In a more recent study published in the Proceedings of the National Academy of Science, Olsen et al (2019) argue that astronomical cycles of the planets definitely can be measured in sedimentary rock from our planet. Cores extracted from the subsurface, covering thousands of meters and spanning millions of years, contain traces of the influence of other planets gravity, allowing scientists to estimate the historical positions of planets hundreds of millions of years ago. Today we know that a sedimentary section may contain the record of past climates, and those climates were influenced by celestial movements called Milankovitch cycles. The Earth's rotation around its axis, and the revolution around the Sun, evolve over time due to gravitational interactions with other planets in the solar system, which influence Earth's trajectory around the Sun, including the shape of its elliptical path (eccentricity), as well as the tilt (obliquity) and wobbling (precession) of our planet axis.

Olsen (1986), Olsen & Kent (1999) and Kent et al (2018) discovered that for example, the long cycle of 1,75 Myr was a period orbital cycle caused by the interactions between Mars and Earth. Their analysis also revealed that the 405 kyr cycle in celestial mechanics was caused by the interaction of our planet with Jupiter and Venus.

In Olsen et al (2019) the authors also include the analysis of other geological expressions (natural radioactivity, rock density and sonic velocity) of these cycles in the same basin. Geophysical measurements of the core holes point out that synthetic seismic traces generated from borehole data exhibit the same big cyclicity. When tied deep exploratory borehole records from the Newark Rift Basin, to seismic, both the Jupiter–Venus 405 kyr and Mars–Earth 1,75 Myr cycles can be clearly seen as the most coherent components of the seismic profiles across the basin.

CONCLUSIONS

Understanding the relationships of the Earth rock record with celestial bodies, with the solar system itself, and with our Milky Way galaxy, is going to become a crucial element to understand what controlled the long-term sedimentary record, the long-term climate, even the extinctions; and all these ideas, will contribute to enhance the understanding of the Earth's climate system and has the potential to help us better understand past, present and future. climate behavior, and even potential hazards from our own galaxy.

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