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Correlated variations and periodicity of global CO_2, biological mass extinctions and extra-terrestrial bolide impacts over the past 250 million years and possible geodynamical implications

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Earth's history has been witness to recurrently alternating phases of catastrophic evolution and dominant tectonic deformations, contractions and extension of rifting and spreading leading to quasi-cyclic changes in sedimentary environment and various earth processes. Recent studies have shown quasi-periodicities of 32 ± 2 Million years (Myr) in various endogenic (geomagnetic reversals, magmatic events, mantle convection, various tectonic activities, climate change and biological extinctions) and exogenic (impact cratering) processes indicating a remarkable kinship. We present here time series analysis of the available CO_2 record over the past 250 Myr decoded from global $CaCO_3$ accumulation rates in sedimentary environment. The time series analysis reveals an intriguing evidence of a dominant periodicity of 33 ± 2 Myr which matches closely with a common »catastrophic periodicity« of 32 Myr identified in various terrestrial and extra-terrestrial records. We argue here for a common physical link among the periodic global CO_2 variations, mantle convection, geomagnetic reversals, volcanism, geotectonic cycles and enhanced cometary showers. We also suggest periodic variations in CO_2 as one of the possible terrestrial stimulators for the oscillating »greenhouse effect« and related climatic deterioration that result in quasi-periodic mass extinctions. Identical »catastrophic cycles« of endogenic and exogenic origin enhance the credence of their physical linkages and uphold the »concept of non-uniformitarianism« in earth's processes.

Keywords: Periodicity, global CO_2, geodynamics

Introduction

The search for cycles in geological/geophysical records has a long distinguished tradition and honorable antiquity (Umbgrove, 1947). A phrase »Every thing on the earth operates in cycles« has recently been coined by Hazen and Trefil (1991) and enlisted among the 20 great ideas of science. Modern plate tectonic theory based on a conceptual model provides a common quasi-cyclic link to all major geo-bio-ocean-atmospheric processes (Kearey and Vine, 1990; Caldeira and Rampino, 1991). Recognition of long term periodicity in various biogeochemical records is, therefore, essential in understanding exogenic and endogenic mechanisms. Recently long term cyclicity of the order of 33 ± 2 Myr has been postulated by many researchers in various processes of the earth (Fischer and Arthur, 1977; Seyfert and Sirkin, 1979; Negi and Tiwari, 1983; Raup and Sepkoski, 1984; Rampino and Stothers, 1984a, b; Pandey and Negi, 1987; Negi et al, 1990;199f). Geological records of extra-terrestrial bolide impact cratering also have shown a comparable periodicity of 33 ± 3 Myr (Alvarez and Muller, 1984; Rampino and Stothers, 1988). In particular, Raup and Sepkoski (1984) analysed the marine mass extinction record of the last 250 Myr and suggested a periodicity of about 26 Myr. The same data were analysed by Rampino and Stothers (1984a) who suggested a periodicity of 30 ± 3 Myr. Confusion and negative criticism, however, came from the poor quality of the geological data and uncertainty in the geological time scale (Stigler and Wagner, 1987). As a result, evidence of cyclicity in geological records (Lutz, 1985) and in mass extinctions (whether 30 or 26 Myr) and impact cratering records (Grieve et al, 1985; Stigler and Wagner, 1987) have been questioned by some researchers. A comparison of geological time scale published in the last 10 years, however, shows considerable agreement among the dates with some uncertainty of about 2–7% (Rampino and Caldeira, 1993). Some independent analyses have also indicated large uncertainties in geological dates of stratigraphic turnover which in some cases may be simply unrealistic and misleading (Stothers, 1989). Search for periodicity using improved geological time series and modern analytical techniques of time series analyses have revealed a clear pattern of a 32 ± 3 Myr periodicity in the terrestrial and extra-terrestrial impact cratering records. (Rampino and Caldeira, 1993; Stothers, 1986; Yabusita, 1990; Negi et al., 1990, 1996).

It is interesting to note that a 33 Myr periodicity in terrestrial record compares well with the best astronomical estimates of the half period of the solar system's vertical oscillation about the plane of the galaxy (time between one plane crossing and the next), which is approximately 33 ± 3 Myr (Rampino and Stothers, 1984). This indicates a possible extra terrestrial influence of sun's motions on the various earth's processes including biotic crises. Some researchers believe in non-cyclic biotic crises related to endogenic forcing such as volcanism, sea level changes and climate etc., (Officer and Drake, 1983). Several other researchers, however, observed that a periodicity of the order of 30 ± 3 Myr does exist (Raup and Sepkoski, 1986, 1988) in biological mass extinction record and may be related to the extra-terrestrial origin (impact cratering) (Rampino and Stothers, 1984a; Alvarez and Muller, 1984). This has, therefore, led to a considerable confusion with respect to (i) evidence of periodicity in the geological record and (ii) possible causes and effects of biological mass extinction. It is difficult to single out an independent possible cause for periodic biological crisis. It has become imperative, therefore, to discuss alternative geophysical evidences and ideas indicative of biological crises. The main goal of the present paper is (i) to examine evidence of periodicity in the available long term CO_2 record and (ii) to discuss its possible linkages with various terrestrial and extra-terrestrial phenomena as well as mass extinction, global CO_2 variation and climate changes during the past 260 Myr.

The CO_2 data

It is known that relative changes in the volume of carbonate rocks in sediments reflect changes in atmospheric CO_2, (Budyko and Ronov, 1979). A detailed compilation of such a record, based on a complete inventory of existing sediments on the platforms, geosynclines and slope and rise (pelagic sediments) has been presented by Hay (1985). The masses of CO_2 present as carbonate in other sedimentary rocks (clay, sands and evaporites) and carbon contents in pelagic sediments other than carbonate oozes is also included. (Hay, 1985). The CO_2 record also comprises much information from the continental margin and open ocean. In addition to these data most recently published CO_2 data are also compared for the past 100 Myr. The anomalous values of CO_2 at 81, 86, 93 Myr. 59–60 Myr and 15–20 Myr (Compton and Mallinson, 1996) are taken into consideration for our present analysis. We note here however, that there are some caveats with the geological records which must be spelled out prior to any quantitative analysis. The anomalous atmospheric CO_2 levels are difficult to identify in the geological record due to following reasons. First, enhanced degassing of CO_2 is countered by increase in weathering or organic carbon burial and secondly increases in chemical weathering show up in the net global carbonate burial flux. Here, the problem is two fold. First we have to have a reasonable estimate of both the carbonate and organic carbon net burial fluxes through time. But unfortunately these fluxes are very difficult to quantify through geologic time because of preservation bias (younger rocks better known than older rocks) and summing up all of the deposits both pelagic, margin and terrestrial. These are some of the problems which limit the interpretation of CO_2 record. Nevertheless, we feel confident that available episodic CO_2 data of Hay (1985) might serve as possible guide to understand CO_2 variation in relation to other similar geological episodic and tectonic records. Global CO_2 accumulation rates data are presented in Table 2. which reveal high CO_2 accumulation rates during the Pliocene 2–5 Myr, Eocene 37–58 Myr, upper to mid-Cretaceous 66–98 Myr, upper Jurassic 144–163 Myr, mid Triassic 230–249 Myr, and early Permian 258–286 Myr. The available total CO_2 record entails enough precision homogeneity and completeness for the time series analysis. Long term global CO_2 variation, one of the major climatic controllers on planet earth, has been neglected in empirical studies. A meaningful quantitative analysis of the available data may thus shed some light on its evolution and understanding of its linkage to various other related phenomena.

Impact cratering, cyclic CO_2 variations and biological mass extinctions: A geodynamic perspective

Long term global CO_2 variation has been linked to the various processes of the earth's interior (e. g:, lithospheric dynamics, mantle rheology etc.). The ocean-atmosphere carbon mass has been recycled on hundred thousand year time scales. Enhancement of CO_2 is mainly due to faster spreading rates due to broadening of the oceanic ridge system. Significant changes in the pattern of ocean floor spreading can be inferred from the studies of marine magnetic anomaly pattern, age determination of ocean crust and bend in linear island segment chain. The dates of recognised major discontinuities in global sea floor spreading and major orogenic events are given by Rampino and Caldeira (1993 and references therein). In order to tie the episodic enhancement dates of CO_2 variations with already well known existing geodynamic dates, we present here a comparison of well known dates of the plate motions and sea floor spreading (Table 1). It is remarkable to note that almost every episode of initiation of CO_2 events seem to be associated with distinct kinematic; events of plate motions. Certain coincidences are rather compelling; e. g. mid-Cretaceous and late Jurassic sea floor spreading and associated volcanism, (Arthur et al., 1985). During these periods worldwide sea floor spreading, rifting and extensive plate reorientation started. Thus the comparison of these anomalous CO_2 dates with major tectonic events (Table 1) shows that the CO_2 record contain an unbiased and distinct history and have been recognised as times of high CO_2 turn over.

Table 2 shows the dates of major episodic changes and time domain correlation of high CO_2 (initiation dates) with mass extinction events, tectonic events, bolide impact cratering and time of galactic plane crossing of solar system. The events are taken from Rampino and Caldeira (1993) and Sepkoski (1989). The extinction data include all peaks in the percentage genera extinction rate which are based on all 70, 500 genera in latest data set (Rampino and Caldeira, 1993). Rampino and Stothers (1988) have presented updated data of initiation of times of eleven continental flood basalts which represent the largest outpourings of mafic magma. These data are absolute ages based on more than 900 published radiometric and isotopic age determination. According to these workers, eruption of most of the basalts takes place within 2–3 years at most indicating catastrophe recurrence of events.

Comparison of these data shows a remarkable correlation, although one-to-one correspondence of these events in time domain may not be expected

Table 1. Correlation of major/minor extinction with anamolous CO_2 and tectonic activity

S. No.	Extinction Data Ma. B. P (Major/Minor)	Anomalous global CO_2 data (Ma)	Major tectonic initiation activity (Ma)
1	11	2–5	Overall increase in tectonic activity along eastern Pacific and Indian Ocean rift system, and vigorous volcanic activity (Kennett and Thunnell, 1975).
2	37	37	Extensive Pacific volcanism and global plate reorientation in the world. Abrupt increase in world spreading rates, Labrador sea opened. (Force, 1984). Eurasia and North America began to move apart, counterclockwise rotation of India started. Seychelles left India (Pandey and Negi, 1987).
3	66	66	Initiation of spreading in Red Sea. Reorientation along Pacific Farralon ridge. Galapagos rise. (Handschumacher, 1976).
4	91	91–95	Major changes in plate motions noticed. Rapid northward flight of India commenced. Evidence of high volcanic/magmatic activity.
5	144	132	Sea floor spreading between India and Antarctica-Australia began. Simultaneously separation started between South America and Africa resulting in the beginning of the formation of South Atlantic (Pandey and Negi, 1987) oceanic crust forms as Atlantic opens (Vogt and Perry, 1981).
6	176	168	Pangea breaks up and initial Atlantic rifling (Craddock, 1982).
7	219 ± 12	210	Coalescence of Pangea completes, major shifting of northern margin of Gondwana (Tibet-Iran-Turkey).
8	248 ± 08	258	Marks the beginning of the break-up of the super continent.

probably due to the fact that different geological processes exhibit different relaxation times. The possibility, however, might indicate that various earth's processes (e. g., volcanism, sea level changes, climate, extra-terrestrial impact cratering and atmospheric processes) form a complex interactive cyclic loop with a certain characteristic time scale. It is prudent, therefore, to present these data with cycle number.

In a reprojection of mass extinctions, orogenic events, sea floor spreading separately and volcanic episodes and CO_2 dates with age and cycle numbers, we find an interesting correlation in Figure 1 (a, b, c, d). The dates of impact cratering (bolide impact) of extra-terrestrial origin on the surface of the earth and galactic plane crossings time also clearly show a remarkable coincidence with the distribution of high CO_2 accumulation rates by age and cycle num-

Table 2. Time domain correlation of CO_2 episodes with mass extinction, impact crateiing and galactic disc crossing time

Geological age[a]	Geological disc crossing[b]	Impact cratering[b]	Enhanced CO_2 rate[c]	Orogenic events[d]	Mass extinctions[e]	Sea floor spreading[d]	Flood basalt[d]	Cycle No.
Mid-Miocene	0	7	5	0.6, 2.5, 4.5, 12.5	11	2, 10, 17	17	0
Late Eocene	31	38	37	25, 40	36.6	40, 53	35	1
Late Cretaceous	64	78	66	65	66	63, 77	62, 66	2
Early Cretaceous	100	98	93	80, 87	91	94, 112	92, 110	3
Late Jurassic	135	133	132	100, 145, 155	144	148	130, 135	4
Bajocian	166	160	–	–	176	–	170,	5
Pleinsbachian	197	184	168	–	193	–	190, 200	6
Norian	227	214	210	220	217	–	–	7
Dzhulfian	259	–	258	250	245	–	–	8

[a] Raup and Sepkoski (1984)
[b] Rampino and Stothers (1984a)
[c] Hay (1985), Compton and Mallinson (1996)
[d] Rampino and Caldeira (1993)
[e] Sepkoski (1989).

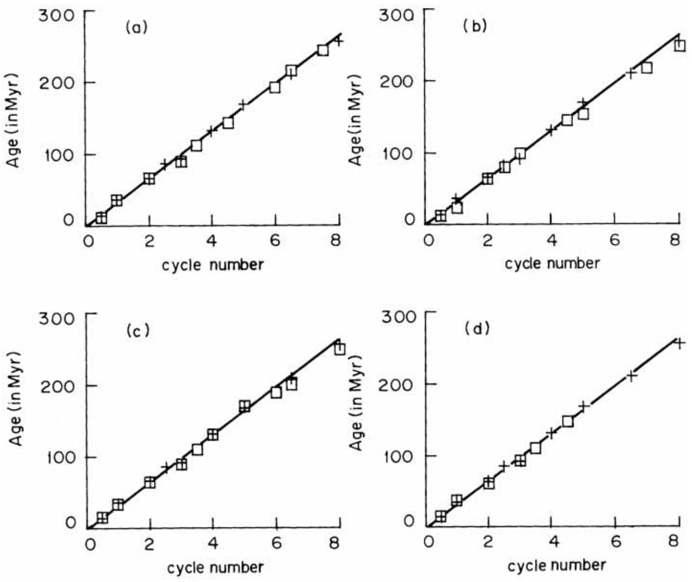

Figure 1. Correlation of global CO_2 data (×) with (a) mass extinction, (b) orogenic events, (c) volcanic episodes and (d) ocean floor spreading over the past 250 Myr. The episodic ages are plotted with respect to cycle numbers.

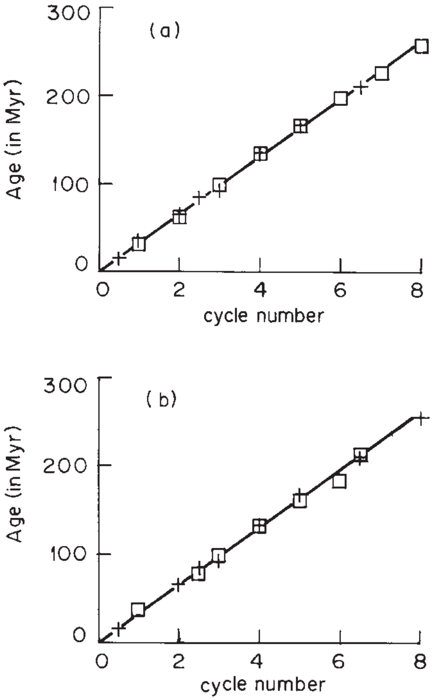

Figure 2. Correlation of global CO_2 (×) over the past 250 Myr with the dates of (a) galactic plane crossings and (b) impact cratering.

ber for the past 250 Myr (Figure 2a, b). Interestingly, Figure 1 a, b shows an almost obvious average cycle of about 30 ± 2 Myr for at least five cycles. We further examine the stability and significance of 30 Myr cycle in CO_2 record using appropriate time series analysis technique.

Time series analysis

Deciphering hidden cyclicity patterns from the raw geological/geophysical data by visual inspection may not be appropriate for various reasons including dating errors and sampling problems. Statistical analysis of ages therefore is an objective approach for quantification of cyclic patterns in geological records (Rampino and Caldeira, 1993). In order to have more confidence in periodicity in CO_2 time series record, we performed a quantitative analysis of initiation times of anomalously enhanced CO_2 dates (Table 2). As the available CO_2 data are episodic in nature, it does not permit us to treat them by using traditional methods of spectral analyses. We have, therefore, chosen an alternative method based on a non-parametric approach which could be applied to identify periodicity from such episodic data series (Stothers, 1979). Accordingly, a non-parametric method of time series analysis has been specially designed by Rampino and Stothers for such records in which just the dates (and not the amplitudes) of the events are recorded and noise is a problem. In this method, the observed dates t_i (i = 1, 2, 3, ... are fitted to a linear formula of the type $t = t_o + \mathrm{n}p$ (where p is trial penod, t is trial phase for most recent epoch and n is an integer). The resulting sums of the squares of the residuals are minimized at each trial period to obtain a best fit for selected trial period as computed residual index $(\sigma - \sigma_c)/P$ where $\sigma_C / P = [(\mathrm{N}^2 - 1)/12\mathrm{n}^2]^{1/2}$. The result is displayed m Figure 3 which apparently reveals a 33 ± 3 Myr periodicity. Following Stothers (1986), the statistical reliability test was performed by generating a number of random artificial time series from the dates selected within time interval 0–260 Myr. The comparison of spectrum of the residual index for each time series with original spectra, reveal that peak at 33 Myr is significant at >90% confidence level.

Raup and Sepkoski (1984) have also developed a similar method in which they search for the arithmetic mean of the residuals that is closest to zero. Lutz (1985) made a circular transformation to obtain phases of the observed data, the dispersion of which is then minimized by performing trigonometric summations as in Fourier analysis. Lutz (1985) variation method allows a correction to be made for unique weighting of the dates which considerably biases time series analysis (Stothers, 1986). One of the advantages of the technique used here is that it tolerates well a moderate amount of irregularity in the periodicity as well as some noise in the time series dates and random gaps (Stothers, 1979). The method used here to analyse CO_2 data therefore seems appropriate and unbiased.

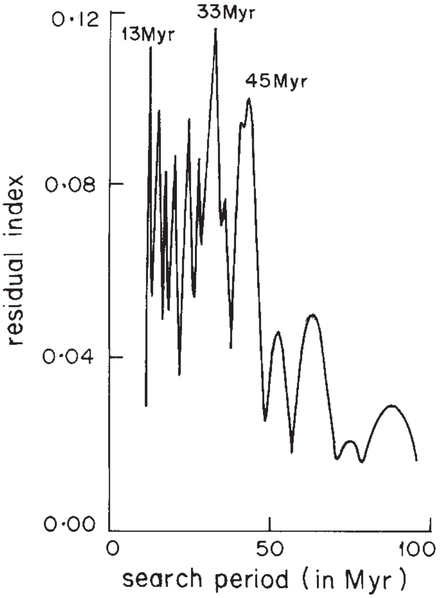

Figure 3. Non-parametric fit to the episodic CO_2 data in Table 2. Best fit to the data given for 33 Myr periodicity.

Discussion of the results

The foregoing analysis reveals possible evidence of the 33 ± 2 Myr periodicity in the global CO_2 variations for the past 260 Myr which is similar to the periodicity of 31 ± 2 Myr in several other terrestrial/extra-terrestrial phenomena. A conceptual unifying model of pulsation tectonics proposed by Sheridan (1983, 1987) suggest possible relations among sea floor spreading, outbreaks of hotspots (flood basalts, rifting, orogeny etc.), sea level changes, composition of ocean chemistry, and atmospheric processes (including atmospheric CO_2) through perturbation of carbon silicate cycle. Results based on various types of data analysis fully agree with Sheridan's cyclic model. The driving mechanism for major tectonic oscillations might be the changing configuration of earth's plate or internal core mantle dynamic processes. This also might have affected the geomagnetic field as well (Courtillot and Besse, 1987). Loper and McCarteney (1986) provided evidence for a 30 Myr periodicity in mantle convection due to instability of the thermal boundary layer (D'') at the base of the mantle. They have also provided evidence for periodic thickening and thinning of D'' layer which eventually affect the activity of the core processes and hence the periodic geomagnetic reversals. Recent investigations have suggested the possible evidence of periodicity in the geomagnetic reversal record. Negi and Tiwari (1983) constructed a telegraphic signal model of observed percentage of normal and reversed polarity during different Phanerozoic time intervals. Walsh spectroscopy of telegraphic signal has revealed several significant periodicities notably around 285 Myr and 32–34 Myr. Interestingly, 285 Myr and 32–34 Myr cycles nicely match with the »cosmic year term« and a time constant of vertical oscillations of the solar system at the plane of the galaxy. Raup (1985) used the dates of individual reversals for the past 160 Myr to propose a 30 Myr periodicity in frequency of geomagnetic reversals. An evidence of 15 Myr periodicity has also been suggested by Mazaud et al. (1983) which may possibly be the harmonics of basic 30 Myr cycle. Raup (1985) has retracted his original claim following criticism by Lutz (1985). However, Stothers (1986) presented a much fuller analysis of the reversal record and showed that a statistically significant period of 30 Myr does formally exist. Like Stothers (1986), we also strongly believe that the available data and their appropriate analysis do suggest a common cycle of about 33 ± 2 Myr. Thus the major tectonic processes, driven by thermal structures and convective pattern of the mantle could be the possible cause of periodic fluctuations in various related earth processes.

Alternatively, a likely possible link involving a combination of exogenic and endogenic forcing has been suggested by Sepkoski (1986). Accordingly an internally generated 30 Myr period in the earth's tectonism and climate possibly arised due to random extra terrestrial impacts that sometimes greatly amplify the quasi periodic oscillation in environment (Rampino and Caldeira, 1993). Time series analysis of terrestrial impact cratering (Rampino and Stothers, 1984a; Alvarez and Muller, 1984; Yabusita, 1991) suggests a possible 3o Myr periodicity. The significance of detected periodicity in cratering have been questioned by Grieve et al. (1987) although the most recent work maintain that periodicity may be robust even under stringent criteria (Rampino and Caldeira, 1993). Melosh (1989) has provided a more quantitative measure and convincing argument to the effect of impact on the earth surface and its possible consequences on geological processes. Accordingly the planetesimal impact represents the most energetic events that can perturb the earth. As also mentioned by Rampino and Caldeira (1993), an ~10 km diameter impactor, which are estimated to strike the earth at rate of one every 20–100 Myr (Stothers and Rampino, 1990; Barlow, 1990), provides a total of at least 10^{24} J with 0.01 % or 10^{20} J going instantaneously into seismic energy (eventually dissipated as heat). According to these workers, this is 100 times greater than the yearly release of terrestrial seismic energy (10^{18} J) and the rate of energy input (10^{20} J s^{-1}) is 10^7 times the rate of global heat flow. The impact seismic energy is equivalent to a magnitude of 11–12 earthquakes with oscillating ground motion of hundreds of meters even further than 1000 km from the impact site (Melosh, 1989; Rampino and Caldeira, 1993).

A plausible explanation for cometary impacts on the earth's surface has been suggested by Rampino and Stothers (1984), Melosh (1989). Accordingly, the solar system bobs up and down through the Milky way galactic disc. Terrestrial upheaval including biotic crises may have arisen as a result of collision (or close encounters) of the solar system with intermediate-sized to large-sized interstellar clouds of gas and dust which are sufficiently concentrated towards the galactic plane. A nearby interstellar cloud would gravitationally perturb the solar system's family of comets (Oort cloud) and thereby increase the flux of comets and comets derived bolides near the earth leading to large body impacts. Impact cratering (>10 km diameter on the surface of the earth) may have perturbed the mantle flow including several other consequences such as fracturing the crust and generating vigorous mantle plume activity (Rampino, 1987). Increased outgassing of mantle CO_2 during sea floor spreading, high tectonic activity, sea level changes and intense volcanism may have profoundly raised the level of atmospheric CO_2 causing the periodic enhanced »greenhouse« warming leading to global climate changes and mass extinction (Campsie et al., 1984; Mclean, 1985; Arthur et al., 1985,). Hence, the high CO_2 level associated with high rates of sea floor spreading may directly be related to the mantle convection induced by impact cratering, and hence to the rates of subduction and subduction related volcanism and magma generation (Berner et al, 1983; Arthur et al, 1985). Similarly, the observed long term sea level changes may be attributed to the changes in sea floor spreading rates and the ridge volume (Hays and Pitmnan, 1973; Morner, 1980). There is evidence of a 32 ± 2 Myr cycle in paleo-temperature possibly due to CO_2 variation (Dorman, 1968), sea level changes record (Negi et al., 1990), climate change (Shackleton and Imbrie, 1990) and in secular variation of dolomite abundance (Negi et al., 1996). From Table 2, however, one can clearly visualize mismatching dates of episodes of the various pro-

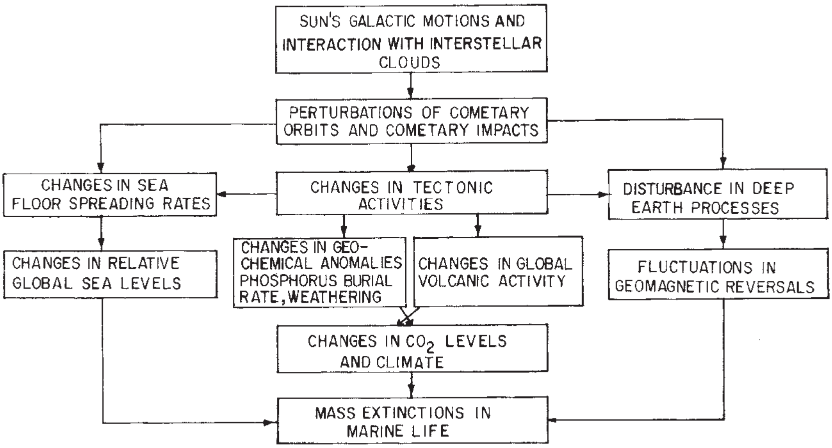

Figure 4. A simplified geo-galactic model relationship of terrestrial catastrophism and the Sun's motion in the galaxy.

cesses which might lead to considerable phase lags. We note that bobbing the solar system up and down through the Milky way disc would be a very much hit or miss phenomena. The amplitude of the perturbation would also vary according to the size of impacts. In addition to this one would expect a time lag between cause and effect for many of these events. For instance, degassing of CO_2 will depend on global. rating of metamorphism, subduction volcanism etc. and yet many of these changes will spread over million years after the impact events. We mention that because it is not prudent to speculate over the issues of time lags due to errors involved in dating of the geological records. Our data do not exactly constrain the causes rather it provides a unified view of cyclicity in geological records. Impact induced changes of terrestrial processes, although highly debated at this stage, seems to be revolutionary for future studies. Figure 4 shows a conceptual model of the proposed chain.

Conclusions

(i) Time series analysis of available anomalous CO_2 dates for the last 260 Myr reveals a dominant periodicity of 33 ± 2 Myr. In view of obvious links between mass extinction cycle, CO_2, climate and sea level changes, it may be suggested that these processes may be governed by a common time constant of 30 ± 2 Myr. Periodic CO_2 changes seem to be one of the main endogenic stimulators, through climate change, of biotic extinction.

(ii) Matching quasi-periodicity of CO_2 variations and various other earth's processes and bolide impact cratering with periodicity of galactic vertical motion of the solar system enhances credence of endogenic and exogenic links and provide a new dimension for the understanding of the geo-bio-chemical cycles on earth in a framework of the plate tectonic paradigm.

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SAŽETAK

Korelacije između periodičnosti promjena globalnog CO_2, masovnih izumiranja vrsta i udara izvanzemaljskih bolida tijekom proteklih 250 milijuna godina s mogućim geodinamičkim posljedicama

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U Zemljinoj povijesti izmjenjivale su se faze evolucije kao posljedica prirodnih katastrofa s dominantno tektonskim deformacijama, kontrakcijama i širenjima, što je dovelo do pojave kvazi-periodičkih promjena u sedimentima, kao i kod mnogih sa Zemljom povezanih procesa. Nedavne studije ukazale su na kvaziperiodičnost od 32 ± 2 milijuna godina pri raznim endogenim (geomagnetske izmjene polova, vulkanizam, konvekcija u plaštu, tektonska aktivnost, klimatske promjene i izumiranja vrsta) i egzogenim (udarni krateri) procesima, sa zamjetnim sličnostima. Prikazat ćemo analizu vremenskih nizova dostupnih podataka o količini CO_2 tijekom proteklih 250 milijuna godina, o čemu je zaključeno na temelju globalne akumulacije $CaCO_3$ u sedimentima. Analiza otkriva intrigantnu periodičnost od 33 ± 2 milijuna godina, što je vrlo slično »periodičnosti katastrofa« od 32 ± 2 milijuna godina koja je evidentirana u raznim nizovima zemaljskog i izvanzemaljskog podrijetla. Predlažemo zajedničku fizikalnu vezu između globalne varijacije količine CO_2, konvekcije u plaštu, promjena geomagnetskih polova, vulkanizma, geotektonskih ciklusa i pojačanih meteorskih rojeva. Također predlažemo mogućnost da je periodička varijacija količine CO_2 jedan od mogućih Zemaljskih stimulatora promjenljivosti »efekta staklenika« i s time povezanog pogoršanja klime koje dovodi do masovnog izumiranja vrsta. Identični »ciklusi katastrofa« endogenog i egzogenog podrijetla dokaz su više u prilog njihovoj fizikalnoj povezanosti i u skladu s konceptom neuniformnosti pri procesima na Zemlji.

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