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Does the Geological Evidence indicate a Causal Link between CO_2 and Climate Change?

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Abstract

Climate is changing and always has with many and varied recognised drivers. Earth's interaction with our celestial neighbours within the solar system and the solar systems relationships within the galaxy being perhaps the most recognised and important of these primary drivers of climate change at virtually all time scales. On the other hand, GHGs and especially CO_2 are recognised as primary factors in making Earth habitable and providing the fundamental requirements for the evolution of both faunal and floral life. So why is CO_2 attracting such opprobrium and is there any rationale for the current, single minded, global quest to reduce its levels?

The following will examine some of the evidence from the geological records addressing this issue. It will attempt to show how many fundamental geological processes may have at least part of their explanation in terms of Earth's changing climate. And it will also try to demonstrate that over most of the past 600 Ma there has been very little evidence of a direct link between CO_2 and climatic conditions. In addition, it will suggest there is no definitive evidence as to whether CO_2 or climate is responsible for ensuring their close correlation over the past 60 Ma. But the consideration that there are well recognised and scientifically sound explanations for observed cyclic changes in climate, especially over the past 6 Ma, and again rational scientific processes that account for CO_2 following these climate cycles, should surely tip the balance of probability towards climate change being the primary driver of CO_2.

Keywords: Climate change; causal link; CO_2, temperature, phanerozoic eon; cenozoic era

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1. Introduction

Over widely varying time periods, Earth's temperature experiences major cycles driven by the interaction with our celestial neighbours. Our daily interaction with the Sun, resulting from Earth's rotation about its own axis, causes considerable day and night temperature variations. These circadian temperature cycles are of similar orders of magnitude to those experienced through seasonal variations resulting from Earth's axis of tilt relative to the plane of its orbit about the Sun. The temporal variations in the tilt axis and its precession over time periods measured in 10s to 100s ky, interacting with the changing eccentricity of Earth's solar orbit, are in turn now generally accepted as being responsible for the temperature changes accompanying the periodic glacials and interglacials occurring when Earth is experiencing icehouse climate conditions. And the icehouse and hothouse climate periods, having periodicities measured in 10s to 100s My, are believed to at least be partially caused by the variations in the cosmic ray flux (CRF) resulting from the motions of our solar system within and normal to the galactic plane.

These first order extraterrestrial drivers of climate, for which we homo sapiens have no control, are clearly modified by other factors, over which there are some we have limited control, but mostly we don‘t. And of course the particular modifying factor upon which the globe is currently focussed is that of the influence of greenhouse gases (GHG) and in particular whether post-industrial anthropogenic increases in CO_2 have been responsible for recently recorded climate changes. The following contribution will focus upon what the geological evidence tells us about the potential importance of CO_2 as a determinant of climate change.

But before concentrating on the geological perspective as to whether GHGs might have had an impact on climate, it is perhaps worth pausing to acknowledge just how fortunate we are to be living on a planet for which natural processes have provided an atmosphere containing these GHGs. As will be shown, the GHGs over much of the past 600 Ma have been at levels that mean, in contrast with other planets in the solar system, our planet is not perpetually frozen. And despite being far more than levels in our current atmosphere over most of this past 600 Ma, the rich faunal and floral life we currently enjoy was able to emerge. It is therefore no exaggeration to claim that without GHGs, and especially H_2O and CO_2, our planet would be lifeless. So, with both H_2O and CO_2, such vital gases of life, the only issue of current concern is whether the changes in the levels of these recognised GHGs, being produced by human activities that are releasing some of the carbon locked into ancient sediments, are actually upsetting the balance of the natural processes. As will be shown, the evidence from the geological records strongly suggest they are not.

2.The Phanerozoic eon

Because there was such a rich and rapidly developing range of living species over the past 600 Ma, the fossil record buried within the sediments provides a rich resource for understanding how climate has changed and what has been the nature of the atmospheric composition during these changes.

2.1 Climate and CO_2

Over the Phanerozoic eon (the past 540 Ma), proxies of atmospheric CO_2 have shown levels that for most of this period have been 10 to 20 times current concentrations and yet this same period witnessed an explosion of both faunal and floral life. However, over most of this period proxies of ocean temperatures, determined from exhaustive measurement of fossilised calcitic shells, display very poor correlation with these CO_2 levels. For example, while CO_2 levels were at temporal highs around the late Ordovician (-450 Ma) and Jurassic (-160 Ma) periods, Earth was actually experiencing icehouse climate conditions. This can be seen in Fig 1. The upper blue curve provides a measure of the CO_2 levels as reported by Berner[16]. To convert the log scale to absolute values of CO_2 the value of around 1.5 during the Ordovician period translates as 5000ppm – more than 10 times those currently in the atmosphere. During the early part of the Cambrian period the levels reached as high as 7000ppm. This compares with the approx. 420ppm today.

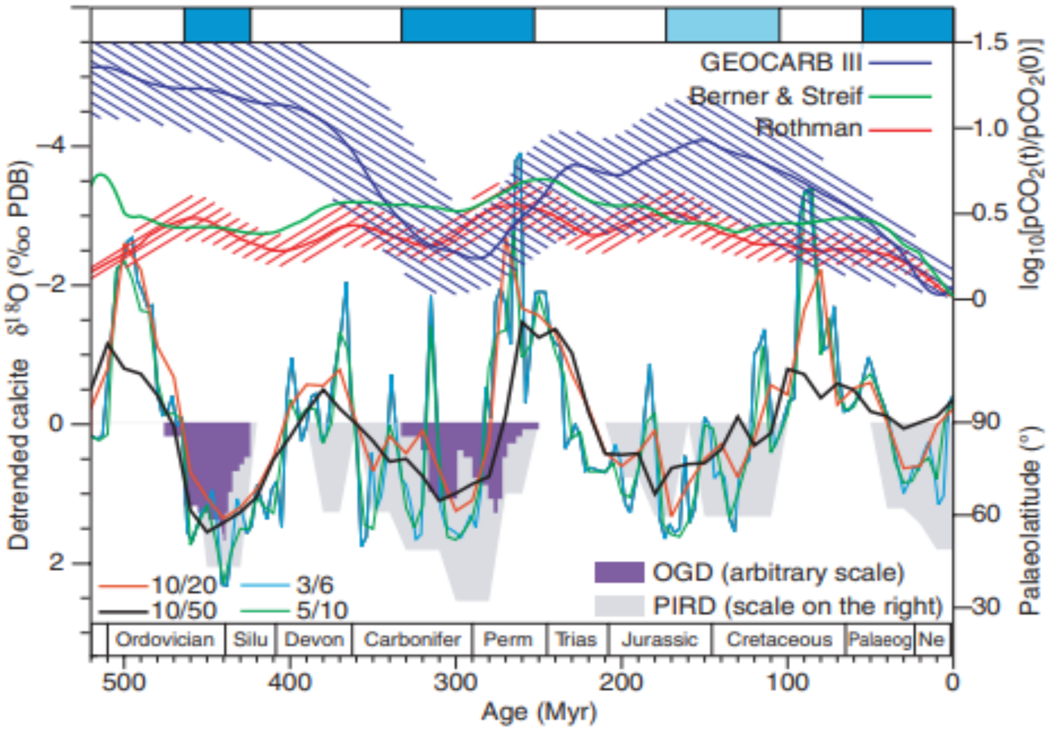

Fig 1 Shows the variation of the CO_2 levels (top blue curve) and sea temperatures (various lower curves) over the Phanerozoic eon. Ice house periods marked by the blue bars at the top. To convert left scale to temperatures and right scale to CO_2 concentrations see text.

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The lower group of curves of Fig 1 plot proxies of ocean temperature, subject to various levels of filtering of the data, taken from the measurements of oxygen isotopes in calcite shells, reported by Veitzer[8,9,24,25]. To translate oxygen isotope levels at the left scale, a value of -2 translates into a temperature change of approximately +4 ºC (see also Fig 2). What Fig 1 demonstrates very clearly is the lack of correlation between CO_2 and ocean temperatures over almost the entire period of the Phanerozoic. It also shows the clear cyclic nature of the climate over this 540 Ma, again showing little relationship with the CO_2 trend. Concentrating on the lower black curve, for which the data points at 10Ma intervals are as plotted as running averages over intervals of 50Ma, the 3 full climate cycles between say -440Ma and -30Ma suggest a long-term periodicity of around 130Ma. We will return to the significance of this climate periodicity in later discussion.

2.2 Climate and the Fossil Record

One of the notable achievements of the painstaking geological research over the past 250 years, since the contributions of Hutton[4], has been the identification of distinct geological periods having dominant time periods of around 60 Ma. Boundaries between these geological periods have been defined from observations, generally over widely dispersed spatial domains, of major discontinuities in the nature of the fossil records. When compared with the patterns of ocean temperature derived from the isotope analysis of marine calcitic fossils, it becomes clear that most of these period boundaries coincide with times at which Earth climate is experiencing extreme levels or major and rapid climate change. This is illustrated in Fig 2. That species might find it difficult to adapt to sudden changes or extremes of temperature is perhaps as would be expected. But in relation to our present discussion, it does underline the cyclic nature of climate over the past 540Ma. A pattern that is certainly not reflected in the CO_2 records shown in Fig 1.

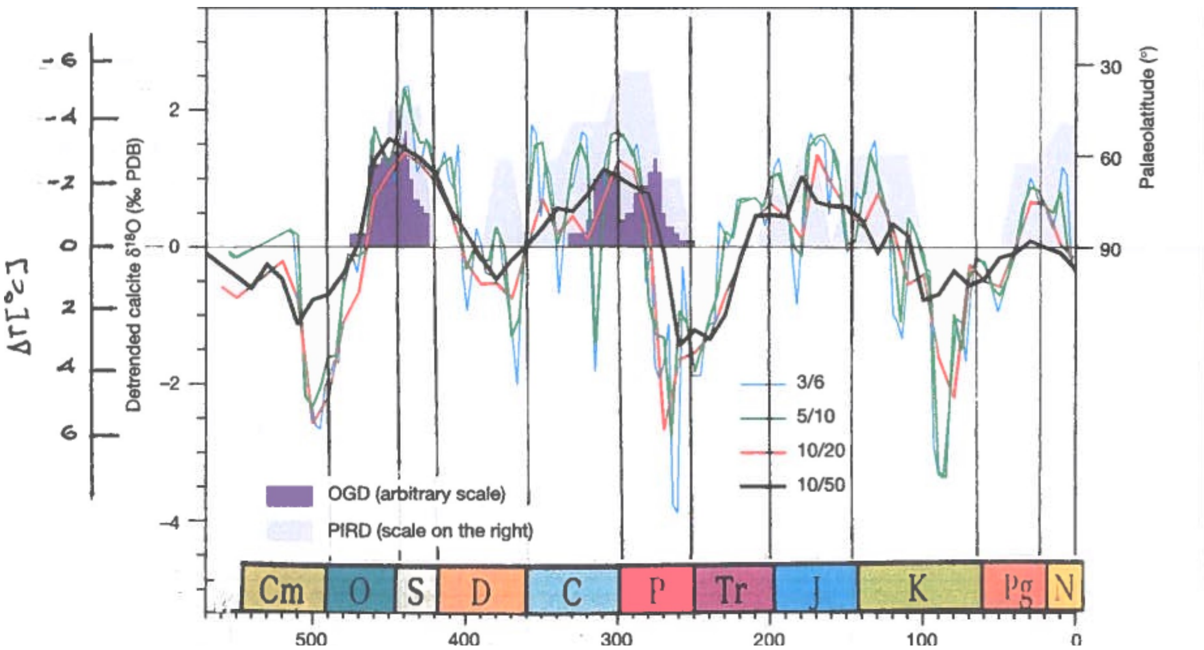

Fig 2 Climate cycles over the Phanerozoic (with cold icehouse conditions above!) showing how the majority of the geological period boundaries coincide with times at which Earth climate is undergoing rapid and extensive climate change or experiencing extremes in hot or cold climate.

It is of related significance that in many cases these periods of massive and sudden climate change correspond with times at which mass extinctions occur. The recorded levels of mass extinction are shown in Fig 3[17]. These blue bars record the percentages of marine genera that became extinct over the period of time indicated by the widths of the respective blue bars.

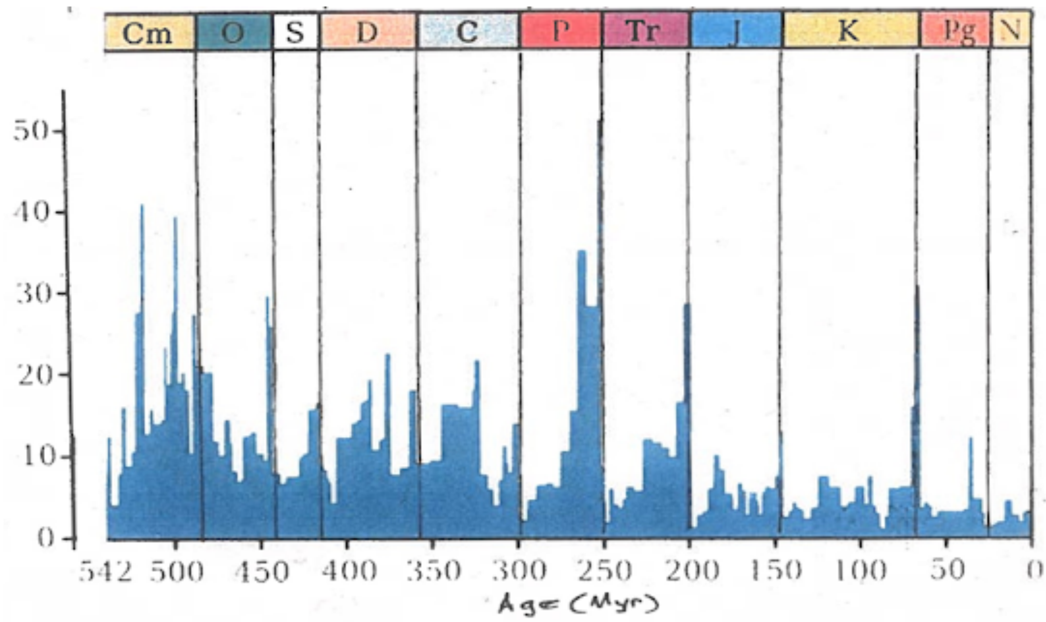

Fig 3 Shows the percentage of marine genera that become extinct in the time period represented by the widths of the vertical blue bars and their relationship with the boundaries between geological periods and by extension climate cycles.

2.3 Possible Causations for Climate Cycles

There is no universal agreement on what has caused these cycles of climate over the Phanerozoic eon. From the above it is clear it is not CO_2. Perhaps the most convincing explanation is that related to the intensity of the cosmic ray flux (CRF) experienced by the solar system. This has been discussed by many but one of the most comprehensive discussions of the science underpinning CRFs impact on climate is that of Shaviv[9]. Quite independent of the work of Veizer, this study of the CRF revealed in meteorite evidence has been found to produce temperature predictions, based upon the cyclic pattern of the CRF data, that almost overlays the temperature proxies from the study of calcitic shell fossils[8]. This is shown in Fig 6 where the black, filtered, plot of oxygen isotope proxies of ocean temperature[8,9] shown by the broken curve is closely related to the predictions based upon CRF shown by the full black cycles. On the reasonable surmise that changes in calcitic shell fossils are not driving the motions of our solar system through and about the galactic plane, considered to be the explanation for the cycle patterns of CRF variation, it seems reasonable to assume that at least a major contribution to Phanerozoic climate derives from variations in CRF.

2.4 Climate and Tectonics

There are of course other reasons why the geological records of fossils undergo sudden breaks. It has been extensively documented that the sedimentary record shows well defined discontinuities at which there are missing times between adjacent layers of sediments. Often, these „unconformities "have been shown to display synchronicity over very widely spaced geographical areas[5-7]. Often, the missing time between adjacent sediments indicates the onset of vertical tectonics resulting from the seabed being raised above sea level commonly associated with sudden lowering of sea level to expose the seabed. Either way, there is growing evidence and geophysical explanations for many first order tectonic processes being directly linked to the long-term climate cycles experienced over the Phanerozoic[13-15]. So that for example, periods during which recorded pulses of epeirogenic uplift and associated mountain building occur, usually over widely dispersed spatial domains, are closely related to periods when Earth climate is experiencing icehouse conditions. And similarly, initiation of deposition of megasequences of sediments, often overlying distinct unconformities in the sedimentary records and also often over widely dispersed geographic regions, show a strong association with periods when Earth's climate is moving out of an icehouse and into a hothouse period. None of these first order geological processes over the past 540 Ma appear to have any relationship with recorded CO_2 levels. But as will be demonstrated by a recent reconsideration of the evidence so dramatically revealed within and adjacent to the Grand Canyon, there does appear to be a strong association between climate cycles and many first order geological processes.

2.5 Case Study of Grand Canyon

A recent reconsideration of the geology exposed within the Grand Canyon[15] and the surrounding plateau has provided fascinating evidence suggesting climate change, driven by Earths interaction with our solar system and galaxy, might be responsible for a great number of what seem to be clear but often poorly understood geological processes.

Fig 4 The Grand Canyon showing the clear stratigraphic sequences and the remarkably horizontal strata deposited over a time span of 540Ma upon lower eroded Precambrian sediments of age 1.6Ba.

The Colorado Plateau is distinctive in that the relatively recent uplift has allowed a deep incision to be created by the erosion caused by the Colorado River. This incision has exposed a treasure chest of geological evidence going back more than 1.6 Ba. A summary within one typical cross section is shown in Fig 5. The geology of this area has recently been interpreted[15] as a test of a newly proposed thermal mechanical model attempting to explain the rather poorly understood and surprisingly little recognised geological processes accounting for the ups and downs of both oceanic and continental lithosphere[13,14]. In the present context this study is revealing in relation to what it seemingly tells us of the profound influences long term climate changes have had on the evolution of Earth's lithosphere and in controlling major tectonic processes.

A first feature to note is the massive regional uplift of the sedimentary sequences covering the 525 Ma from the Cambrian deposits of the Tonto Group (-525 Ma) through to the residual late Mesozoic sequences of the Grand Staircase (-40 Ma). Not shown clearly in Fig 5 at the left of the Brian Head, is a steeply sloping fault within which the sedimentary sequences beneath Brian Head have been uplifted by around 2 km relative to the matching sequences to the left. Furthermore, at some time after -40 Ma the post Cambrian sequences in the Grand Canyon area have been domed-up by as much as 2.2 km relative to the area beneath Brian Head. Whatever induced these post -40 Ma, massive, relative motions clearly involved tremendous tectonic forces. It is worth emphasising that this 4 km depth of sediments would have been laid down horizontally and remained so up to some time after -40 Ma when various processes of erosion kicked in.

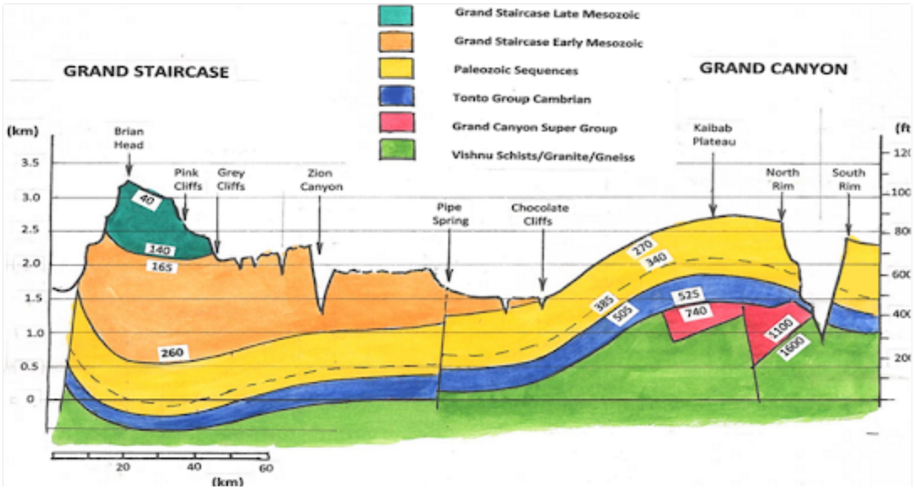

Fig 5. Shows a simplified cross section through the Grand Canyon, up through the Grand Staircase to Brian Head - close to Bryce Canyon

Fig. 5 is a stylised cross-section linking the relatively high point at Brian Head down through the Grand Staircase to the incision of the Grand Canyon created by the recent (geologically speaking) erosion by the Colorado River[5-7,10-12]. The vertical scale is exaggerated by around 20-fold relative to the horizontal scale to emphasise some of the important tectonic features.

A second feature of note is the existence of a number of well-defined unconformities within the sedimentary record, with the missing time indicated by the ages (in Ma before present) of the sediments below and above the unconformities. How much of the sediments beneath the unconformities have been lost through erosion is of course uncertain. What is more certain are the ages of sediments immediately above and the fact that these represent the times at which epeirogenic vertical motions saw the lithosphere again sinking below sea level, probably accompanied by rising sea levels, to initiate a renewed pulse of sediment deposition. The times at which renew pulses of sediment deposition commenced are shown above the unconformities in Fig 5 and are depicted by the start of the black sections of the lower yellow bar chart in Fig 6.

Fig 6 summarises the pulses in deposition for which the most robust temporal signals of the crustal elevation, relating to the vertical movements of the Earth's lithosphere, are the commencement of deposition caused by subsidence beneath average mean sea level (amsl). These periods of deposition are indicated by the black sections of the lower yellow bar chart of Fig 6. The renewed pulses of deposition will have followed a hiatus, marked by the existence of unconformities, in which there was either no sedimentation occurring or erosion after uplift has removed the evidence of any sedimentation that had occurred. At the intra-cratonic location of the Grand Canyon, subsidence below sea level, likely combined with indeterminate moderate to large rises in sea level, saw as shown in Fig 5 the commencement of new cycles of sedimentation occurring over the Phanerozoic at -525 Ma, -385 Ma, -260 Ma, and -140 Ma.

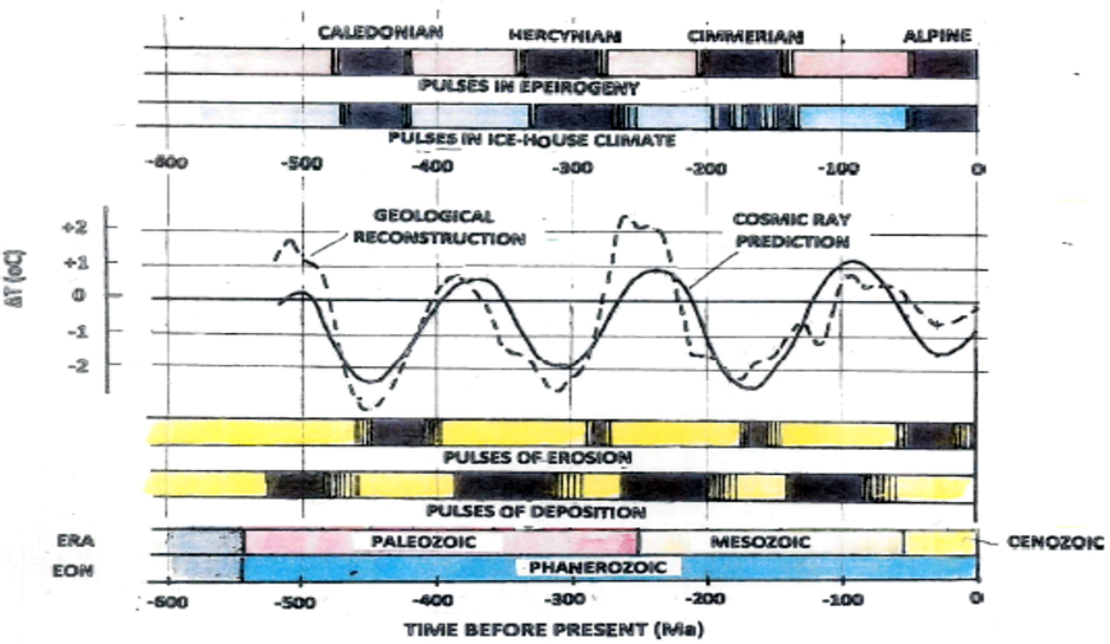

Fig 6 Cycles of average earth surface temperatures over the Phanerozoic showing the correlation between: 1. the onset of ice-house periods and pulses of epeirogenic uplift and mountain building (black sections of the upper blue bar charts); and 2. the onset of hot-house periods and pulses of deposition (the black sections of the lower yellow bar chart).

These ages at which renewed pulses of sedimentation started, immediately above unconformities, are well defined and consequently marked with strong black bars on the lower yellow bar chart of Fig 6. The black bars indicate the periods known to have produced continuous deposition. However, when sedimentation ceased or when uplift and erosion started are rather less well defined and so the ending of the deposition is marked with alternating black and yellow pulses signifying either non-deposition or uplift and erosion.

Also plotted in Fig 6 are the geological reconstructions of the average surface temperatures over this same time period[8] along with predictions of surface temperatures based upon analysis of the variations in cosmic ray flux[9] experienced by the solar system. What is noteworthy in these plots are: the close, and possibly causal[8,9], relationships between the intensity of cosmic rays and climate cycles; and the correlation between the onset of deposition as recorded by strata immediately above major unconformities and their consistent phasing within the climate cycles. In each case, deposition is seen to commence soon (in geological terms) after earth climate emerges from an ice-house period, shown by the black sections of the lower of the upper bars in Fig 6, and enters into a period of hot house - shown perhaps confusingly as blue sections. After a long period of glacial and inter-glacial cycles during the ice-house period, it might be anticipated that erosion including that due to possible ice sheets will have reduced continental land surface elevations to near sea level often resulting in peneplanation. This means that moderate rises in average sea levels, due to the full melting of ice sheets and permafrost accompanying the transition from average ice-house climate to hot-house, might be expected to inundate the low continental land surfaces – a clear precondition for the onset of marine sedimentation. The ending of the icehouse periods is seen to be synchronised with the start of the new pulses of sedimentation.

As previously mentioned, there are what appear to be compelling thermal-mechanical arguments suggesting a link between icehouse climate periods and the onset of epeirogenic uplifts of lithosphere, whether continental or oceanic. The onset of icehouse climate would be accompanied by a lowering of sea level, resulting from a locking-up of water into ice sheets and permafrost. These changes in the disposition of surface water being replaced by either overlying atmosphere or ice has the effect in the areas so affected of increasing the insulation to the outward flow of geothermal energy as represented by geothermal flux. The consequential lowering of the geothermal flux will over long periods (measured in many Ma) give rise to a thickening of the lithosphere due to a process aggradation of its lower boundary. This aggradation would be the result of phase change of sections of the asthenosphere and upper mantle, giving rise to a lowering of the average density and a consequential isostatic rise of the lithosphere. If this model has any credence, it would be anticipated that epeirogenic uplift would be the result of the lowering of sea level and possible icesheet coverage of crust associated with the transition of Earth climate from hothouse to icehouse conditions.

Again, looking to the evidence of the Grand Canyon, pulses of sub-aerial erosion following the cessation of deposition could have occurred during icehouse climate prior to the initiation of renewed pulses of sedimentation. These icehouse periods shown by the black bars of the lower top bar chart can be seen to correspond with periods of recognised mountain building activity, Caledonian through to Alpine, shown in the top bar chart.

While the evidence from the Colorado Plateau cannot be regarded as conclusive, it does appear to support a model in which very long-term climate cycles could be providing an important contribution to the clear geological evidence of ups and downs of both continental and oceanic lithosphere. Could this be at least a partial answer to the challenge laid down to the gathering of the distinguished Plate Tectonics pioneers at the 2017, William Smith Meeting[1-3] discussed in Reference 15?

3. The Cenozoic era

In support of the narrative that CO_2 is driving climate change, much has been made of the more recent (in geologic terms) very close relationship between CO_2 levels and temperature cycles over the Cenozoic era, during which Earth has been emerging from hothouse climatic conditions into the icehouse interglacial climate conditions we are currently experiencing. There is however considerable disagreement as to whether this close correlation indicates climate following CO_2 or the opposite. Regrettably, the proxies for both temperature and CO_2 levels are insufficiently precise to be able to resolve this issue.

However, there are sound reasons to suppose it is the latter. As observed above, over most of the Mesozoic and Palaeozoic eras CO_2 concentrations were orders of magnitude higher than todays, while climate cycled between icehouse and hothouse periods with temperatures not inconsistent with those of today. In other words, it was clear that climate was not being driven by CO_2 levels. After the Paleogene thermal maximum, around 66 Ma ago, the CO_2 levels and ocean temperatures started to show a much higher degree of correspondence. And of course, much has been made of this in support of the current prevailing narrative. Fig 7 for example reproduces a graphic showing the close relationship between CO_2 levels, the black curve, and a colourful depiction of an averaged surface temperature over the 66 Ma of the Cenozoic era. Just as in the short period (geologically speaking) in the late Carboniferous period, when CO_2 levels were closer to current levels, there has clearly been an undeniable close association between CO_2 levels and Earth temperature over the past 66 Ma. What this demonstrates is that this association only occurs at times when geological processes are not pumping up the atmospheric concentrations of CO_2 to levels orders of magnitude higher than present. It would be a logical conclusion from this evidence that when low CO_2 levels are not being driven by geological processes such as vulcanism and degassing, it is the thermally driven release of CO_2 from the oceans that drive the atmospheric concentrations. In other words when other sources of CO_2 are low, it is climate that dominates in the determination of atmospheric CO_2.

Such an interpretation seems consistent with the more precise data revealed by the Antarctic and Greenland ice cores.

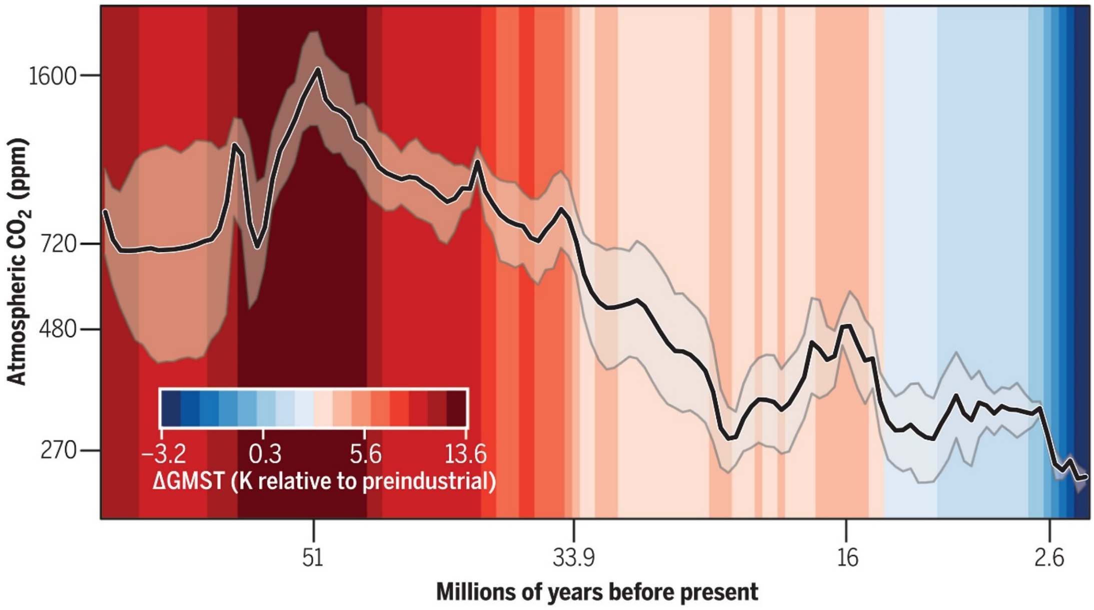

Fig.. 7 Shows in graphic form the close association between climate and CO2 over the Cenozoic Period. What it does not demonstrate is that CO2 is the driver of this climate change. Taken from Toward a Cenozoic history of atmospheric CO_2 SCIENCE 8 Dec 2023 Vol 382.

3.1 The Quaternary Period

For example, the 800 ka of data over the Quaternary, derived from the analysis of the air bubbles trapped within Antarctic and Greenland icesheets, is considered by many to provide the definitive evidence that climate is being driven by changes in the concentrations of atmospheric CO_2. And of course, much has been made of this close association in support of the current climate change narrative – such as the graphic shown in Fig 8 taken from Al Gore’s influential video. In contradiction, it has been argued that more sensitive analysis of what this data from the ice cores tells us is that there is a time lag between the observed temperature changes and the CO_2 levels that are shown to follow.

Fig 8 Chart taken from Al Gore's presentation "An Inconvenient Truth" Dec 2006. Temperature cycles (lower green curve) and CO2 levels (upper red curve).

At present it seems impossible to judge from the research literature noise which thesis is right. However, it needs to be recalled that there is a perfectly sound extraterrestrial, physics based, explanation for the regular glacial/interglacial periods[18-23]. Furthermore, in support of the claim that climate is the driver of CO2, there is a perfectly rational physical explanation of how the CO_2 levels would follow this widely accepted, scientifically based explanation for the climate cycles. But, so far as this writer has been able to ascertain, there is no other known process that could explain how CO_2 levels have been experiencing such regular cyclic changes. Without such an alternative cause, it surely must be concluded that over the Cenozoic period the evidence strongly points to the driver being Earth's kinematic interactions with the Sun as driving climate – and not the other way round.

There is perhaps insufficient recognition that the person who first explained the glacial and interglacial periods, recently confirmed by the clear evidence not only in ice cores but also in the sedimentary records, was James Croll[18-21]. However, Croll's explanation in the mid-19th C was itself questioned for a long period until a civil engineer by the name of Milan Milankovich was able to repeat and refine the calculations some 60 years later[22,23].

4. Some closing comments

I realise that in making the arguments I have in this paper I am liable to be labelled by many as a climate denier - or worse. This is a very sad reflection of the state of current scientific discourse that in this context I will refrain from elaboration. However, in my defence, if such is needed, I would hope that the contents of this paper make it clear that far from underplaying the importance of climate I am actually suggesting it has played a much greater part in the evolution of planet Earth than is currently recognised. In this sense, I am a passionate climate advocate. This does not of course preclude me from also being a passionate respecter of all that CO_2 has contributed.

5. Conclusions

For the greater part of the Phanerozoic eon, and certainly over the Palaeozoic and Mesozoic eras (the past 540Ma to 66Ma), there was very little correlation between levels of atmospheric CO_2 and Earth's climate as recorded from proxies of ocean temperature taken from fossilised calcite shells. While CO_2 levels were at levels at least an order of magnitude higher than present, Earth's temperature followed well recognised cycles of hot and cold not dissimilar to those experienced over the quaternary period (the last 2.6Ma) and being experienced in the present. CO_2 over this time frame was certainly not driving climate and climate was certainly not determining CO_2 levels.

Over much of the Cenozoic (past 66Ma), while CO_2 has been at levels much closer to those present, there has been a convincing correlation between levels of CO_2 and climate as measured by ocean temperatures. However, for the most of this period the raw data seems insufficiently precise to conclusively resolve the issue as to whether it is CO_2 driving climate or the other way around.

More detailed records over the Quaternary period have been put forward by proponents of these alternative explanations to claim either CO_2 or climate is the definitive driver. Again, there seems insufficient precision in the data for a definitive conclusion. However, there is a well-recognised, scientifically verified and calibrated, astrophysical explanation as to why Earth 's climate has experienced the clearly observed cycles of glacial and interglacials. Furthermore, there is an equally robust scientifically credible explanation as to how these cycles of Earth climate can cause the release of CO_2 to produce their closely correlated changes. In contrast, there is no recognised, scientifically based, explanation known to this writer, as to how and why CO_2 would be experiencing these observed cyclical changes.

The evidence from the geological records outlined above strongly suggest that where there is a correlated relationship between levels of atmospheric CO_2 and Earth climate, it is climate that is controlling the levels of CO_2.

Guest editor: Stein Storlie Bergsmark

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