WHAT GEOLOGISTS THINK ABOUT CLIMATE CHANGES- TIME IS RELATIVE

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Abstract

The time measuring was probably one of the first things people learned and has been known since ancient Egypt 1500 BC. Besides importance for mankind the time flow is a basic function of many sciences, including geology. Milanković cycles theory has enabled geologists to investigate the past but is also most important part for prediction of future global climate. The significance of Milanković's work for geology is numerous, knowing that it represents the basics for cyclostratigraphy, which enables more precise time determination and calibration between the astronomical and geological time scale. The determination of climate conditions that prevailed during certain geological period is one of the geological tasks. During geological past, the hot and cold periods interchanged several times, while the Cenozoic Paleocene-Eocene Temperature Maximum is an excellent analogue for today's global warming situation. People have managed to recognize their influence in global warming and in recent years a lot of attention has been focused on reducing the negative human effect on climate changes.

Key words: Milanković, Cyclostratigraphy, Astronomic Time Scale, Geological Time Scale, climate changes.

Apstrakt

Merenje vremena je verovatno bilo jedno od prvih stvari koje su ljudi naučili i poznato je još od drevnog Egipta 1500 godina pre nove ere. Pored toga što je značajan za čoveka protok vremena predstavlja osnovnu funkciju mnogih nauka među koje spada i geologija. Milankovićeva teorija ciklusa je omogućila geolozima pogled u prošlost, ali ujedno je i najznačajnija za predviđanje globalne klime u budućnosti. Značaj Milankovićevog rada za geologiju je višestruk obzirom da on predstavlja osnovu ciklostratigrafije koja nam omogućava preciznije određivanje vremena i kalibraciju astronomske i geološke vremenske skale. Jedan od zadataka geologije je i određivanje klimatskih uslova koji su vladali tokom određenih geoloških perioda. U geološkoj prošlosti više puta su se smenjivali topli i hladni periodi, a kenozojski paleocensko-eocenski temperaturni maksimum predstavlja odličan analog za današnju situaciju globalnog zagrevanja. Ljudi su uspeli da prepoznaju svoju uticaj na globalno zagrevanje i poslednjih godina dosta pažnje je usmereno na smanjenje negativnog uticaja ljudi na klimatske promene.

Ključne reči: Milanković, ciklostratigrafija, astonomska vremenska skala, geološka vremenska skala, klimatske promene.

1. INTRODUCTION

There is a big difference in the understanding of the time flow among ordinary people and those who deal with geology. In their work, geologists usually encounter fossils and rocks that are hundreds of millions of years and even billions of years old. At the other side ordinary people are very often impressed by several centuries-old artifacts or historical events from several decades ago. For these reasons, it can be said that geologists have a very clear notion of the time relativity. An additional confusion in the already complex situation brings the fact that in the Serbian language the same word is used for the time and weather conditions.

In recent years, climate changes have been a heated debate both, in the media and scientific circles. People has become aware of its influence on the increased emission of carbon dioxide and temperature rise. As a result, many oil and other large manufacturing companies came under the public attack and were forced to adapt to the new business conditions [1, 2, and 3]. Very often people equate climate with weather conditions. That is why today we can often hear stories in the media about climate change without considering time interval that separates those two. Geologists belong to the group of scientists who are very aware of this difference and the fact that the climate has changed in the past. Our planet has repeatedly gone through various periods from the stage of Snowball Earth to the fireball Earth. Yet despite these dramatic condition changes, life on Earth has been ongoing since it first appeared 3.5 billion years ago. It has always found a way to win, while successful adaptation to the new conditions was the key.

The great Serbian scientist Milutin Milanković, and his cycles theory [4], enabled us to understand the mechanism and reason for climate change. The greatest influence on geology is probably represented by the Astronomical (Milanković) calibration of the geological time scale (GTS) [5, 6]. His astronomical theory of climate change is the base of cyclostratigraphy [7] a subdiscipline of stratigraphy that deals with determining, characterizing, correlating and interpreting cycle changes in the stratigraphic record. The main goal of cyclostratigraphy is application in geochronology by improving the accuracy and resolution of the time-stratigraphic framework.

2. GEOLOGISTS AND THE CONCEPT OF TIME

The planet Earth is 4.54 billion years old and it was believed that the first primitive organisms appeared in the Cambrian (542 million years ago) while the life before that time (during the Precambrian) did not exist. Now we know that first microorganisms appear much earlier (at 3.5 billion years), but the division into Precambrian and Phanerozoic (of which the Cambrian is a part) is still applied.

The usual human understanding of long period of time mainly refers to years or several decades, which is the reason for the lack of a sense of measuring time in millions and billions of years. For these reasons, an understanding of the Precambrian that lasted more than 4 billion years is inconceivable to the common man. If the age of the planet were shown on the clock, the Precambrian would last longer than 21 hours and make up 88% of the geological time (Figure 1). For geologists who study the Earth, its origin, the processes that shaped it and its composition, ancient excavations and archaeological discoveries represent recent events. The period from the first appearance of humans until today is a blink of an eye for geologists, and it would take one minute and seventeen seconds on the 24-hour clock (Figure 1).

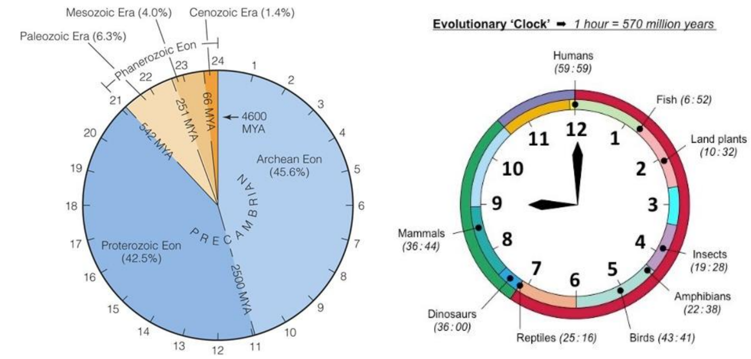


Figure 1. Geological time of planet Earth given at 24-hour clock (left), the evolutionary clock from Phanerozoic Eon until today given on one-hour clock (right).

3. HOW MILANKOVIĆ'S CYCLES HELPED GEOLOGISTS

A precise geological time scale is necessary to understand and decipher the evolution and geological processes of our planet. Milanković cycles are the basis of cyclostratigraphy, one of the youngest stratigraphic disciplines which deals with the determination, characterization, correlation, and interpretation of cycle changes in the stratigraphic record. It uses astronomical cycles of known periods to determine the time of the sedimentary record. The main goal of cyclostratigraphy is increasing the accuracy and resolution of the time stratigraphic frame. Milanković cycles provided an understanding of the last ice age and represent the most important part for the development of a high-resolution astronomical time scale (ATS). In addition, they are a good basis for creating a forecast model of climate changes that awaits us in the future.

The most significant of astronomic cycles are Milanković cycles (precession, obliquity, and eccentricity) which result in perturbation of the Earth's orbit and its rotational axis and have periods ranging from 20 to 400-kyr (Figure 2). These cycles via orbitally induced changes in insolation influence climatic, oceanographic, sedimentary, and biological changes that are potentially preserved in sedimentary records over geological time.

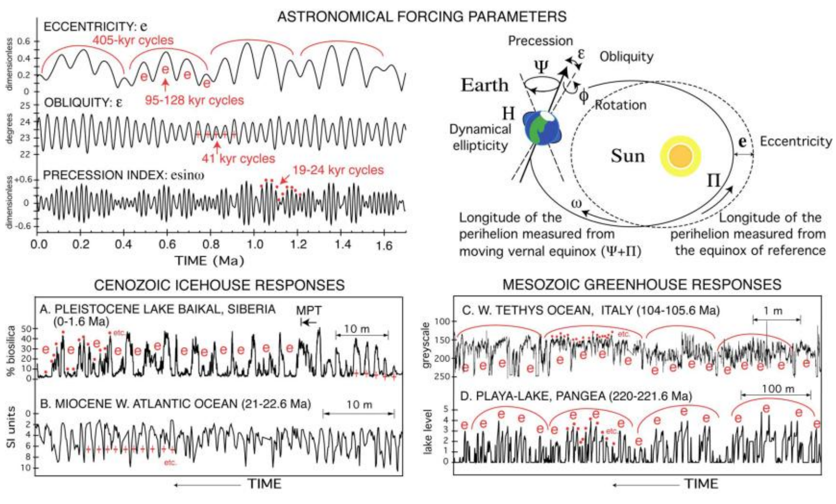


Figure 2. Parameters affecting Earth-Sun position (top right) and oscillations shown for past 1.6 million years (top left) [8]. Main periodicities are indicated in red. Continental and marine sedimentary sequences showing icehouse (bottom left) and greenhouse (bottom right) climate

responses. A- Lake Baikal core [9], B –ODP site 936B core [6], C- Fucoid Marls core [10], D – Newark Series core [11].

Cyclostratigraphy search for evidence of climate change that corresponds to solar cycles which are found in sedimentary rocks layers (Figure 3). It is used to study the stratigraphic and sedimentological response to climate change. At the heart of this method is the recognition of layers according to their glacial or interglacial characteristics, and the translation of a stratigraphic profile or record into a time scale or series. It is important to note that the sedimentation rate spatially and temporary varies and that it depends on palaeoecological and paleogeographic conditions. Generally, fine-grained and more rounded material reflects calm and slow sedimentation, while coarse-grained, angular materials are probably related to fast sedimentation and the existence of short palaeotransport. This create a good starting point for a detailed reconstruction of the conditions under which the given sediments were formed. The reworked sediments, bioturbation, erosions, hiatus (interruptions in sedimentation) could complicate interpretation and can lead to misinterpretation.

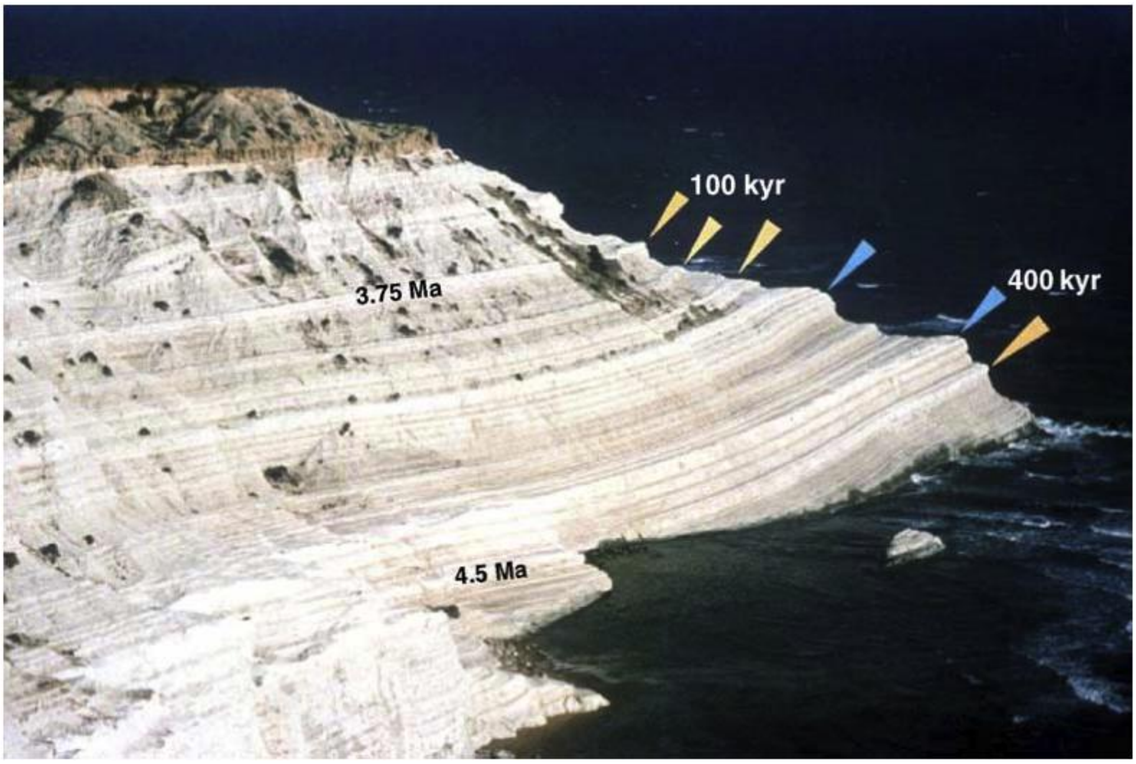


Figure 3. Example of Milanković's cycles at geological section in Spain.

The cyclostratigraphy made a great ascent in last thirty years. Over the last decade, astronomical theory has been successfully applied to a continuous high-resolution GTS correlation. The astronomical tuning method advances traditional geological dating methods, such as paleontology, paleomagnetism, and radioisotope dating. On the GTS 2012 [12] most of the Cenozoic era was directly calibrated with the ATS (Figure 4).

ATS based on Milanković forced stratigraphy calibrated with paleoclimatic forcing is well defined for the Cenozoic and Mesozoic. However, for the Paleozoic era, astronomical forcing has not been extensively researched due to the lack of precise geochronology or astronomical modelling. A recent study [13] examined Milanković cycles in the Lower Permian strata in southern China are time-calibrated with high-precision U-Th dating. In this way, empirical knowledge about astronomical parameters is related to events from 250 million years ago. The observed cycles support the existence of a day that lasted 22 hours. This is the first significant piece of evidence in defining the Paleozoic ATS, which is based on absolute time and thus connect the Paleozoic-Mesozoic transition.

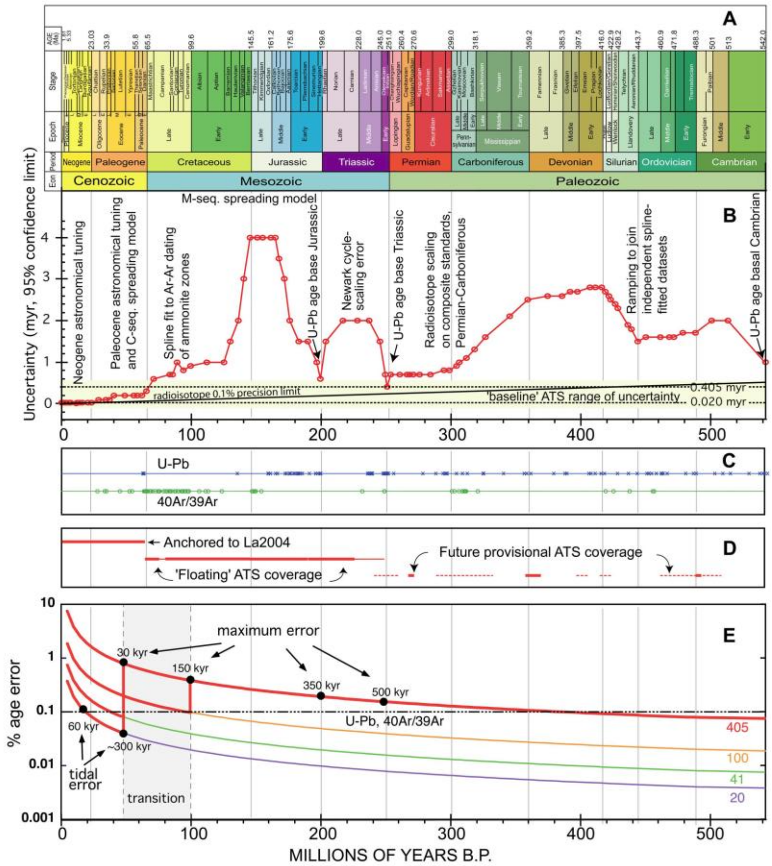


Figure 4. Uncertainty in the Phanerozoic International Geologic Time Scale (GTS) 2004 [14]. A- Standard GTS division. B- Estimated uncertainty (95% level of confidence). C- Distribution of U-Pb and 40Ar/39Ar. D- distribution of astronomically forced cyclostratigraphy during Phanerozoic. Thick solid lines indicate cyclostratigraphy contributing to the absolute ATS, thin solid lines indicate gaps; dashed lines indicate reported cyclostratigraphy with potential to yield ATS information. E -age error percentage.

4. CLIMATE CHANGES IN THE GEOLOGICAL PAST

When you mention global warming to geologists, they may reciprocate by asking you what global warming you mean. If you mention today's global warming to them, they will tell you that we are currently in the interglacial period of the ice age. All in all, it can be said that for geologists, time is relative both in terms of the flow of time and in terms of weather conditions (in Serbian the same word is used for period of time and weather). In the history of our planet, there have been much warmer as well as much colder periods than today.

The five most important glaciations from the geological past are: the Huronian (2.4-2.1 billion years), the Cryogenian (850-635 million years), the Andean-Saharan (460-430 million years), the Karoo (360-260 million years) and the Quaternary (2.58 million today) (Figure 5). In the last million years, a dozen glaciations have occurred, from which the largest one was 650,000 years ago and lasted 50,000 years. The last glacial period reached its peak 18,000 years ago, before the beginning of the Holocene interglacial.

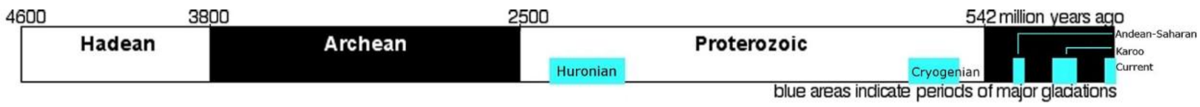


Figure 5. Timeline with five most important glaciations marked in blue. Between them are greenhouse conditions.

The planet Earth has undergone through warm (greenhouse) and cold weather conditions (icehouse) several times (Figure 6) during its history. The greenhouse period, in which Earth has been 85% of time (Figure 5), is a time when there are no continental glaciers and the level of carbon dioxide and other greenhouse gases (including water vapor and methane) are high.

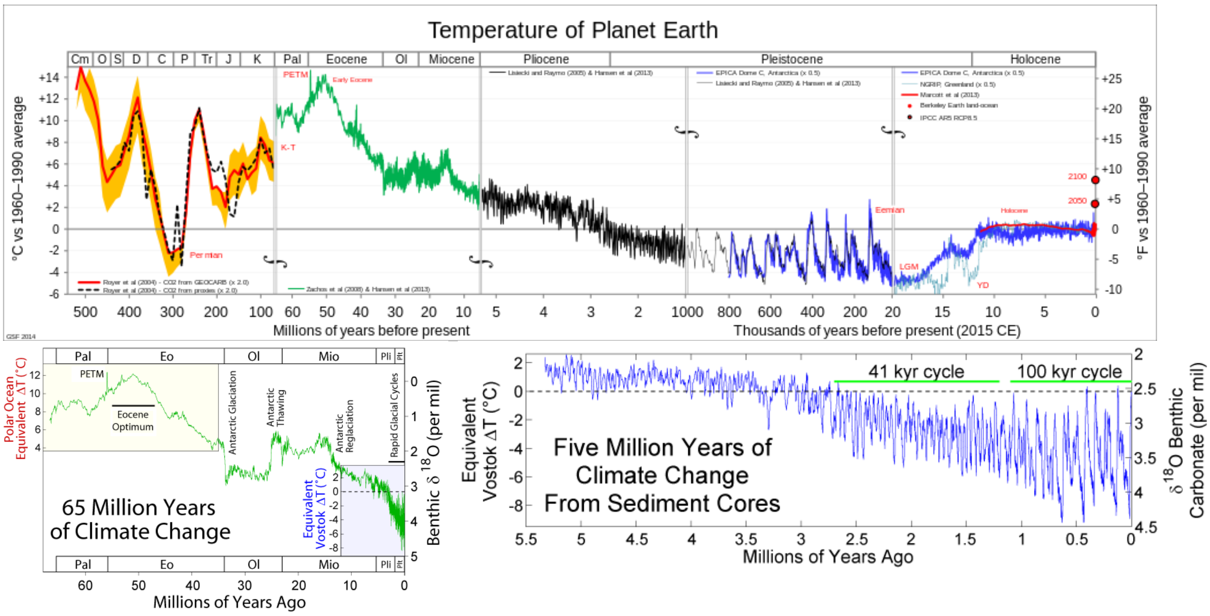


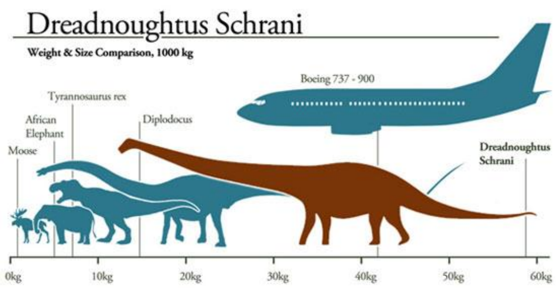
Figure 6. Assumed temperature- from the Phanerozoic to the present (top), the Cenozoic to the present (bottom left) and in the last 5.5 million years (bottom right).

There are several theories about the greenhouse Earth origin. The sedimentology record contains data on a high carbon dioxide levels and other greenhouse gases in the geological past. For example, during Ordovician Period (485.4-443.8 million years), the amount of carbon dioxide was 14-16 times higher than today. What is known for sure is that the plate tectonics was very active during the greenhouse period. Due to the disintegration of continental plates (rifting), volcanic activity was significantly more pronounced, producing more carbon dioxide and warming the Earth's atmosphere. In the last 500 million years, the Earth has spent more than 80% of time in a greenhouse condition.

The Earth's icehouse are periods in which there were at least two ice sheets on the planet, at the poles, the Arctic, and the Antarctic. These covers increased and decreased during a shorter times known as glacial periods (with the formation of additional ice sheets besides to the two at the poles) and interglacial periods (without additional ice sheets). During the icehouse period, greenhouse gases are less present in atmosphere and temperature show a global decline. The Earth is currently in a cold period that began 33.9 million years ago with the beginning of the Late Cenozoic Ice Age. The part of this ice age is the last glacial Würm, which was recently completed (115,000 -11,700 years) and left behind the still present non-polar ice sheets in the Alps, the Himalayas, Patagonia, etc. This period will probably be followed by another interglacial that will be similar to the last known one (Eemian, 130-115,000 years ago), during which we had warm temperature forests in Scandinavia, while animals of today's African continent characteristics inhabited Western Europe. After that, the periods of glacial and interglacial, that will have the same lengths as the previous ones, will continue to alternate until the two ice sheets at the poles disappear, which will mark the end of the icehouse and the onset of the next greenhouse period.

The reasons for the icehouse are hotly debated, because essentially not much is known about the transitions between these two climate states and the reasons that lead to it. Certainly, one obvious reason is the evident reduction in carbon dioxide presence in the atmosphere due to decreased volcanic activity. Another significant reason is plate tectonics activity which influenced the opening and closing of ocean passages. This seems to have played a key role in the formation of the icehouse due to the upwelling of cold water from the deeper parts of the water column that aided the formation of ice sheets. An example of this event is the opening of the Tasmanian Passage (36.5 million years ago), separating Australia and Antarctica, which together with opening of Drake Passage between South America and Antarctica is believed to have caused the Cenozoic ice age. At the other side, the Isthmus of Panama and closing of the Indonesian seaway about 3-4 million years ago may be the main cause of the current icehouse period. Additionally, tectonic activity forms mountains (for example Himalayas, about 50 million years ago) and the formation of new soil that acts as a carbon dioxide absorber significantly affects the amount of greenhouse gases in the atmosphere.

Despite the widespread opinion that harsh temperature conditions (no matter high or low) would lead to mass extinction, the ability to adapt to different environments influenced the fact that during extremely high temperatures on our planet ruled the largest reptiles ever, while in the period of intense glaciation lived the largest known mammals (Figure 7). The Pleistocene (2.58-0.012 million years ago) is generally recognized as a time of land mammalian gigantism.



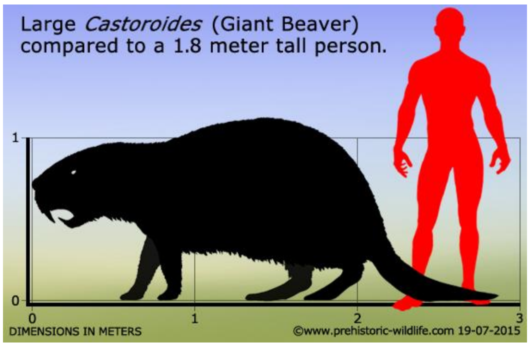


Figure 7. Examples of gigantism during Cretaceous high-temperature (left) and last ice age (right).

In general, it can be said that climate changes have the greatest impact on organisms that live in shallow seas, since the expansion of glaciers or the flooding of their ecological niches are the first one to be hit.

4.1.THE CLIMATE – WHAT AWAITS US

The Paleocene-Eocene temperature maximum (PETM) is of special importance for climatologist since it represent the excellent analogue for climate prediction modelling. It is calculated that by year 2300 the concentration of carbon dioxide in the atmosphere will exceed 2000 ppmv [15] due to emissions from the consumption of fossil fuels. The carbon emission into the atmosphere and oceans corresponds to one which occurred on the Paleocene-Eocene boundary (55 million years ago) and led to intense global warming. The increase of carbon dioxide emissions into the atmosphere, which in 2011 exceeded 390 ppmv [16], has not been recorded in geological history. The climate and biogeochemical response to such a rapid and large increase in carbon dioxide in the atmosphere will be very harsh (heatwaves, droughts, floods), especially on continents that are settled at high latitudes. Additionally, the effect of it will be noticeable in the oceans, where the increase of acidity and dissolved calcite will affect marine organisms with carbonate shells [17, 18, and 19]. This increase in vertical gradients can lead to a decrease of the Oxygen Minimum Zone (OMZ) and the formation of almost anoxic conditions such as those in the Black Sea or the Gulf of Mexico. Based on foraminifera analyzes a similar situation was confirmed during PETM [20, 21].

CONCLUSIONS

The age notion and duration of certain periods in the history of the planet Earth has so far been mainly solved based on paleontological fossil records, magnetostratigraphy and radioactive decay of certain elements. The greatest progress in recent years has been made with the help of an astronomical time scale and its calibration with a geological time scale. The basis of the astronomical time scale as well as one of the newest geological sciences – cyclostratigraphy are Milanković cycles.

Besides enabling us to return to the past, Milanković's work also allows insight into the future. His work provides a basis for climate change prediction. Unfortunately, human impact and emissions of carbon dioxide and other greenhouse gases, deforestation and other technogenic activities are accelerating this otherwise natural process. In general, it can be said that what will happen to the climate in the future is not a novelty, but a repetition of conditions that were present in the geological past of the planet before. Nevertheless, although it is believed that the harsh conditions caused by climate change lead to mass extinctions, life has always managed to adapt to the new conditions. It is certain that the human species will not be the first to be hit by climate change, just as it is certain that it is the only one that is aware of its impact on accelerating this process. Therefore, increasing public attention and a large amount of intellectual and financial resources are focused on activities to reduce greenhouse gas emissions.

REFERENCES

[1] Skjærseth JB, Skodvin T.: 2003, Climate change and the oil industry Common problem, varying strategies Issues in Environmental Politics, Manchester University Press.

[2] Nasiritousi, N.: 2017, Fossil Fuel Emitters and Climate Change: Unpacking the Governance Activities of Large Oil and Gas Companies. Environmental Politics 26(4), 621–647.

[3] Radivojević, D.N.: 2020, Naftna industrija i klimatske promene, Tehnika, 75 (1), 31-37.

[4] Milanković, M.: 1920, Théorie mathématique des phénomènes thermiques produits par la radiation solaire, XVI, 338 S. – Paris: Gauthier-Villars.

[5[Schwarzacher, W.: 1993, Cyclostratigraphy and the Milankovitch theory, Developments in Sedimentology, 52 Astronomical (Milankovitch) calibration of the geological time-scale, 1999. In Shackleton, N.J., McCave, I.N., Weedon, G.P. (Eds.), Phil. Trans. R. Soc. Lond. A, Vol. 357, 1731–2007.

[6] Shackleton, N. J., McCave I. N., and Weedon G. P.: 1999, Preface to Astronomical (Milankovitch) calibration of the geological time–scale. A Discussion Meeting held at the Royal Society on 9 and 10 December 1998

[7] Strasser, A.H., Hilgen F. and Heckel, P.H.: 2006, Cyclostratigraphy concepts, definition, and application. Newsletters on Stratigraphy, 42(2), 75-114.

[8] Laskar, J., Robutel, P., Joutel, F., Gastineau, M., Correia, A., Levrard, B.: 2004, A long-term numerical solution for the insolation quantities of the Earth. Astron. Astrophy. 428, 261-285.

[9] Prokopenko, A. A., Hinnov l. A., Williams D.F. and Kuzmin M.I.: 2006, Orbital forcing of continental climate during the Pleistocene: a complete astronomically tuned climatic record from Lake Baikal, SE Siberia, Quaternary Science Reviews, Volume 25, Issues 23–24, 2006, Pages 3431-3457, ISSN 0277-3791, https://doi.org/10.1016/j.quascirev.2006.10.002.

[10] Grippo, A., Fischer, A.G., Hinnov, L.A., Herbert, T.D., Premoli Silva, I.: 2004, Cyclostratigraphy and chronology of the Albian stage (Piobbico core, Italy). In: D'Argenio, B., Fischer, A.G., Premoli Silva, I., Weissert, H., Ferreri, V. (Eds.), Cyclostratigraphy: Approaches and Case Histories: Society for Sedimentary. Geology Special Publication, pp. 57-81.

[11] Olsen, P. E., Kent D. V., Cornet B., Witte W.K. and Schlische R.W: 1996, High-resolution stratigraphy of the Newark rift basin (early Mesozoic, eastern North America). *GSA Bulletin*; 108 (1): 40–77. doi: https://doi.org/10.1130/0016-7606(1996)108<0040:HRSOTN>2.3.CO;2

[12] Gradstein, F.M.: 2012, Introduction. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), The Geologic Time Scale 2012. Elsevier B. V., Amsterdam, pp. 1e29.

[13] Wu, H., Zhang, S., Hinnov, L. A., Jiang, G., Feng, Q., Li, H., & Yang, T.: 2013, Time-calibrated Milankovitch cycles for the late Permian. *Nature communications*, *4*, 2452. https://doi.org/10.1038/ncomms3452

[14] Gradstein, F.M., Ogg, J.G., Smith, A.G.: 2004, A Geologic Time Scale 2004. Cambridge University Press, Cambridge.

[15] Caldeira, K. and Wickett, M. E.: 2003, Anthropogenic carbon and ocean pH, Nature, 425, 365, doi:10.1038/425365a, 2003.

[16] Tans, P. P. and Keeling, R.: 2011, National Oceanic and Atmospheric Administration: Earth System Research Laboratory and Scripps Institution of Oceanography, available at: www.esrl.noaa.gov/gmd/ ccgg/trends/.

[17] Thomas, E.: 1998, The biography of the Late Paleocene benthic foraminiferal extinction, In: Late Paleocene-early Eocene biotic and climatic events in the marine and terrestrial records. Aubry, M.-P., Lucas, S. & Berggren. W.A. (Eds.), p. 214-243, Columbia University Press.

[18] Thomas, E.: 2003, Extinction and food at the seafloor: A high-resolution benthic foraminiferal record across the initial Eocene Thermal Maximum, Southern Ocean Site 690. GSA Spec. Paper, 369, 319-332.

[19] Thomas, E., 2007: Cenozoic mass extinction in the deep sea; what disturbs the largest habitat on Earth? In: Large Ecosystem Perturbations: Causes and Consequences: Monechi, S., Coccioni, R., & Rampino, M. (Eds.) GSA Special Paper, 424, 1-24.

[20] Chun, C. O. J., M. L. Delaney, and J. C. Zachos: 2010, Paleoredox changes across the Paleocene-Eocene Thermal Maximum, Walvis Ridge (ODP Sites 1262, 1263, and 1266): Evidence from Mn and U enrichment factors, Paleoceanography, 25, PA4202, doi:10.1029/2009PA001861.

[21] Nicolo, M. J., G. R. Dickens, and C. J. Hollis: 2010, South Pacific intermediate water oxygen depletion at the onset of the Paleocene-Eocene Thermal Maximum as depicted in New Zealand margin sections, Paleoceanography, 25, PA4210, doi:10.1029/2009PA001904.