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Research Article

Explosive Volcanism Periodicity Past Cycles Record within the Last 0.8 Mya Evidenced by Tephra and Benthic Foraminifera of IODP Hole U1485AA (Exp. 363 WPWP)

Patricia Beck Eichler-Barker[1,2]*

[1]*Laboratory of Marine Geology and Geophysics and Environmental Monitoring (GGEMMA), Federal University of Rio Grande do Norte (UFRN), Brazil*

[2]*EcoLogicProject.com, Boulder Creek, California, USA*

***Corresponding Author:** Patricia Beck Eichler-Barker, Laboratory of Marine Geology and Geophysics and Environmental Monitoring (GGEMMA), Federal University of Rio Grande do Norte (UFRN), Brazil and EcoLogicProject.com, Boulder Creek, California, USA.

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Abstract

Volcanic eruptions with increase in the amount of carbon dioxide (CO_2) and other gases are responsible for the extinction of many species because of decreased pH and carbonate availability which creates ocean acidification. Here we show how benthic foraminifera have evolved, by studying sediments from U1485A (1145 m water depth) core in the Papua New Guinea (PNG) collected during IODP Expedition 363 in the Western Pacific Warm Pool (WPWP), one of the warmest marine waters of the world. High-stressed environments dominated by low diversity of opportunistic species after volcanic activity was detected by the presence of tephra and volcanic ashes within the last 0.8 Mya. The decrease in the diversity patterns show an inverse correlation to the presence of tephra and ash right after Pleistocene volcanic eruptions in the past. Deep-water fauna is dominated by *Cibicidoides pachiderma*, from the early Oligocene through the Pleistocene, *Uvigerina hispida* from early Miocene through Pleistocene, *U. prosbocidae* from late Oligocene through Pleistocene, and an outer neritic upper bathyal *Uvigerina mediterranea* from high salinities, warm waters, low dissolved oxygen, and high organic matter. *Bolivinita quadrilatera* characteristic of 200-500m depth, Bolivina robusta from 3 to 900m, and the Rotalinoides compressiusculus, a shallow warm water species, from 2-37m depth show higher diversity peaks in interglacial cycles. High-stress conditions with mass extinction after volcanic eruptions leads to enhanced weathering, global warming and cooling afterwards, and ocean acidification, resulting in a crisis in the marine environment in terms of carbonate. Diversity gradients suggested that foraminiferal species responded to the cyclic pulses of volcanic eruptions, and its unstable ecological conditions created by the increase in the temperature and CO_2. Here we show that tephra layers and ash record a periodicity of explosive volcanism within the last 0.8 Myr maintaining a strong 100 kyr periodicity, and that earth's orbital cycles might trigger peaks of volcanic eruptions 41,000-year cycle.

Keywords: Volcanic Eruptions; Extinctions; Organic Material; Temperature; Climate Change; Paleoclimatology; Benthic; Planktonic Foraminiferal Community Dynamics

Introduction

Volcanic activity pulses release huge quantities of greenhouse gases from Earth's inner system. Volcanic activity in the past has released carbon dioxide into the atmosphere as predicted for the 21st century. Volcanic Eruptions are linked to increases in carbon dioxide emissions and changes in faunal patterns, with extinctions observed in the marine sediment cores from these volcanic episodes.

The increase in carbon dioxide and other volcanic gaseous influences global warming and ocean acidification being responsible for the extinction of more than half of species on Earth. The environmental, climatic and faunal patterns after eruptions are associated with timing of mass extinctions and formation of igneous provinces. The dinosaurs were extinct because of "The Deccan Traps", an igneous province on the west-central India, and the Siberian Traps have influenced the end-Permian extinction, where more than 90% of life disappeared.

The estimative of the emissions of carbon dioxide for past eruptions still a challenge, because its volatility, it degasses during magma rise, and subsequent eruption. In addition, other variables should be take into account in order to forecast future climate change. We can at least register that ongoing scenario of carbon dioxide emissions are very similar to those that culminated to the end-Triassic mass extinction.

Deccan eruptions and mass extinctions are correlated showing that more than 50% of plankton foraminifer species disappeared during those episodes prior to the first of four lava mega flows that reached out to the Bay of Bengal, India. The other 50% were extinct after the first mega flow, and the mass extinction was complete with the last mega flow. During those intervals, opportunist species' blooms dominate shallow-marine ecosystems worldwide. Similarly, high-stress environments were dominated by blooms of opportunistic species in the Deccan volcanism phase 3 in the early Danian is followed by fully recovery after volcanism episodes ended. The high-stress conditions and extinction are explained by the intense Deccan volcanism resulting in enhanced weathering, and global warming followed by cooling, intense continental runoff, and ocean acidification, resulting in a carbonate crisis in the marine ecosystem.

The explosive volcanic activity generates unstable habitat colonized by few species. In an active volcano at the NW Rota-1 Seamount, mats of microbes, vent shrimp and crabs are the only resilient organisms [1]. In addition, lava flows and eruptions destroy benthic communities [2]. Events like this create a 'time zero', a Krakatau-like reset of the ecosystem [3], with communities recovery to pre-disturbance conditions taking place within a decade [4-6].

The increase in the CO_2 concentrations in the atmosphere results in low pH and low carbonate availability in the ocean, known as ocean acidification. The ability of marine invertebrates' organisms to tolerate high acidity are the 'eyes in the future' to understand.

Data is available to look at Earth's paleo patterns of four and half billion-year history of climate change, to provide insight into modern climate change, which includes volcanic past cycles and extinctions of benthic foraminiferal community dynamics as indicators.

Cluster analysis of Expedition 363 sites and their hydrographic parameters recorded by [7] on the sensitivity of benthic foraminifera to carbon flux show that site U1485A is grouped in sites with more than >1400 m of water depth with carbon fluxes >3.5g C m -2 year -1 and bottom water temperatures >3.5°C. Here we explain how communities have evolved in the past 0.8 Mya at the Western Pacific Warm Pool (Exp. 363) among ashes and tephra. We hypothesize that glacial to interglacial variations in the Walker and monsoonal circulation also lead to changes in the run-off from the continents via these two river systems. Enhanced river discharge, for example including glacial mega-dam break floods, would decrease the sea surface salinity at the sites and increase the nutrient input evidenced by changes in benthic foraminiferal assemblages and their carbon isotope values [8]. Thus, the faunal data will provide means to reconstruct variations in the atmospheric systems in response to changes in climatic extremes.

Glacial and interglacial cycles within marine isotope oxygen stages (MIS)

Marine isotope stages (MIS), marine oxygen-isotope stages, or yet oxygen isotope stages (OIS), in a globally synchronous onset of glacial marine isotope oxygen stages that within the variability, reflects alternating warm and cool periods in the Earth's paleoclimate, during 5.5 million years in the Pliocene. The variability of the frequency and intensity in one of the warmest times that our world has ever seen reflects changes in temperature and are derived from shells of benthic and planktonic from deep-sea sediment core. Studying backwards from the present, stages with even numbers have high levels of oxygen-18 and represent cold glacial periods, while the odd-numbered stages are troughs in the oxygen-18 figures, reflecting warm interglacial intervals in 800Ka within the Pliocene.

Due to their high sensitivity to the environmental changes in the modern and past sediments, foraminiferal species reflects the amount of ice in the world. These habitats created by temperature differences in the past record paleo cycles in the Western Pacific Warm Pool (WPWP), one of the warmest marine waters of the world nowadays. Our data evaluates special characteristics of the paleo record to highlight the influences that the temperature differences are having on the onset of MIS.

Pleistocene eruptions

In the 2.588 ± 0.005 million years BP, approximately when the Quaternary period and Pleistocene epoch begin, massive volcanic eruptions of the River flood basalts released CO_2 into the atmosphere and triggered a decline in ocean pH. With global temperatures rising because of this, sea levels also rose, flooding continental areas, creating conditions to sediment high quantities of carbon accumulated from marine debris, and transfer volcanic carbon from the atmosphere to the ocean. The last episodes of volcanism have been linked to mass extinctions and oxygen depletion in the oceans.

The high marine productivity and carbon burial aids removal of some carbon dioxide from volcanoes and is a negative feedback, mitigating some, but not all, of the climatic effects associated with the release of volcanic CO_2. This is why we have an opportunistic fauna dominating when volcanic pulses occur.

Extinctions causes vary depending on taxa and region; sometimes extinctions are linked to hunting, while others show consistency response from ecological effects of climate change, or yet a combined effect of both hunting and climate change are thought to be responsible. The main positive effect that volcanoes episodes have on the ecosystem is to provide nutrients to the soil. Volcanic ashes contain minerals, which are beneficial to plants, and very fine ash is able to be broke down quickly and be easily integrated into the soil.

Methods

Here we show how benthic foraminifera communities have evolved by studying sediments from U1485A (1145 m water depth) core with average sedimentation rate of 67 cm/kyr located north of the mouth of the Sepik River in PNG collected during IODP Expedition 363 [9,10] in the Western Pacific Warm Pool.

Our research plan for Expedition 363 (Western Pacific Warm Pool) to study benthic foraminifera as tracers of volcanic patters and glacial to interglacial changes during the late Pleistocene (0-0.6 Ma) is based on the faunal analyses of benthic foraminiferal tests to trace relative changes in near shore hydrography (temperature, salinity, nutrients) associated with the freshwater plumes of the Sepic River (Papua New Guinea, Site 1485A). We have generated a high-resolution record that captures variations in volcanic patterns as well as river runoff in response to glacial to interglacial climate extremes. To meet this goal, we have sampled the amount of $20cm^3$ at a rate of 1 sample every 75 cm (e.g., 1 sample in each of sections 1, 3, and 5 in each core) with 173 samples.

Results and Discussion

Causal links between volcanism and Earth's climate remains controversial, partly because most of the studies covers only one glacial cycle. Here we show tephra and ash layers of U1485A (IODP Exp. 363 WPWP) record periods of explosive volcanism within the last 0.8 Myr. Mechanisms triggering these mass flow deposits may include earthquakes, tsunamis, or shelf/slope sediment instabilities times of rapid deposition similar to river flood events. This supports that the silt and sand fractions at Site U1485A are current being transported from the PNG shelf. Although the shelf itself is very narrow, over longer timescales, probably the sea level played a role in the storage and release of sediment from the PNG shelf, and from the paleo-valley of the Sepik River. Also, the presence of different of amounts of silt-sized siliciclastic particles within the hemi pelagic clay suggests other transport pathways are contributing to the flux of terrigenous material to U1485A. The winnowing of silt-sized particles from the shelf by inter annual and seasonal changes in the direction and strength of the New Guinea Coastal Current (NGCC), and the New Guinea Coastal Undercurrent (NGCUC) is one of the possible sources of fine sediment to U1485A [11]. Seasonal variations in freshwater discharge, the spatial extent of sediment plume in combination with coastal currents dynamics might provide another source of sediment.

Sedimentation changes correspond to variations in the pattern of terrigenous material, may due to uplift of the mountains in the Sepik-Ramu watersheds resulting from tectonic activity on the Bewani-Torricelli and Ramu-Markham faults [12], a change in precipitation patterns in the Sepik-Ramu River watersheds, or yet a change in the currents responsible for mixing sediments in the ocean. Another hypothesis is that the change in sedimentation corresponds to change along the past in the mouth of the Sepik River, which might have been located inland and sediment accumulated within the paleo-Sepik embayment.

Twenty five (25) tephra layers and the occurrence of ash as a minor component mixed with silt and clay minerals recorded throughout U1485A (Figure 1) indicate the influence of pyroclastic sedimentation throughout the depositional history of the site. The tephra layers consist of bubble wall shards, vesicular glass fragments, micro-pumice, with fragments of glass in the upper part of the site. The basal tephra layers varies from sharp to gradual depending on the current winnowing processes and the degree of bioturbation.

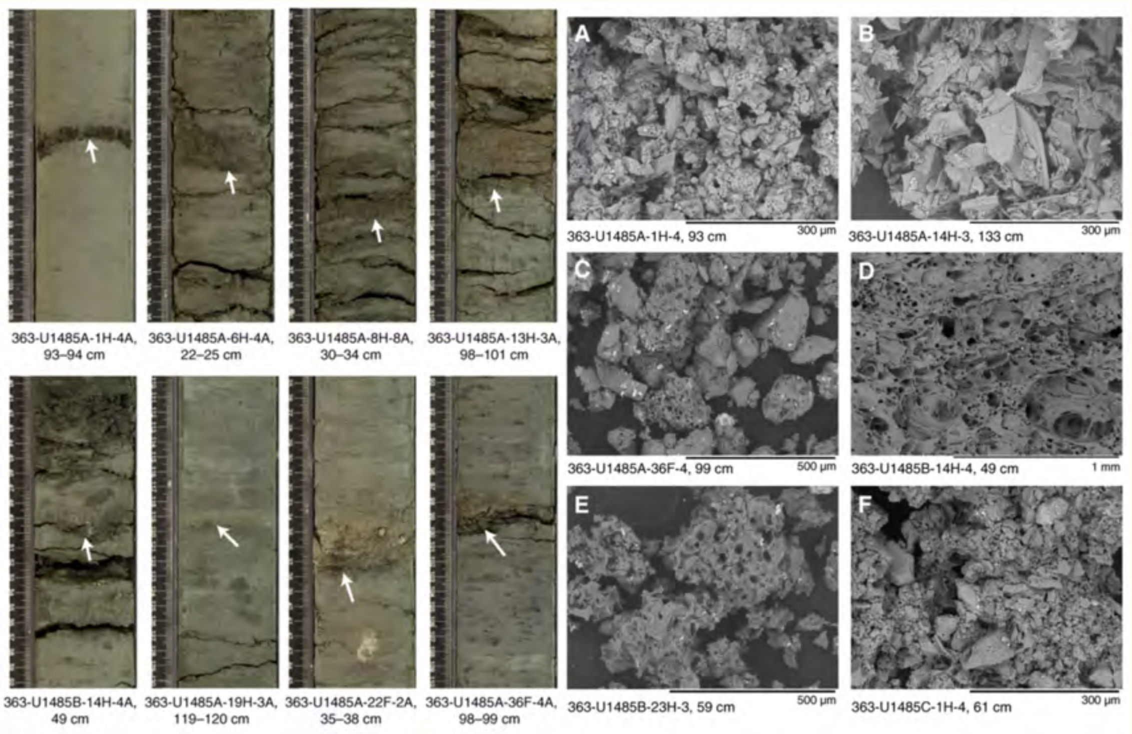

Figure 1: Tephra layers observed throughout Site U1485A, the occurrence of ash as a minor component mixed with silt, and clay minerals indicate the influence of pyroclastic sedimentation throughout the entire depositional history of the site. The thickness of the tephra layers ranges from 0.5 to 4.0 cm, with maximum grain sizes ranging from 60 to 250 µm. Tephra records maintains a strong 100-kyr periodicity. (Retired from [13]).

The continuous accumulation of hemi pelagic clay and biogenic materials at U1485A is faster deposited and distributed with coarser grained sand as well silty sand. Clastic shelf sediment from freshwater source is carried to U1485A by mass gravity flow [10]. Earthquakes, tsunamis and shelf/slope sediment dynamics during times of fast deposition similar to river flooding events are possible triggering mechanisms for those mass flow deposits. There is presence of volcanic ash in some intervals of the U14845A core. The 34Hcc, 35Hcc, 36Hcc and 39Hcc intervals present ashes, tephra, and we can pinpoint changes in the fauna pattern at least after these volcanic episodes recorded. The timing of the massive grain-flow deposits at Site U1485 occur in two separate intervals between ~280 and ~235 ka and between ~230 and ~210 ka. In tropical regions, the position of the Intertropical Convergence Zone (ITCZ) controls the strength of the hydrological cycle. Prior to

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~370 ka the deposition of pelagic mud on the continental margins occurred because most of the riverine sediment draining to the New Guinea Highlands, which includes a "proto" Sepik River, was registred before reaching the ocean by an epicontinental sea that settled the location of the modern Sepik Valley, not because of the drier weather. For the last ~300 kyr, it was filled with sediments, and the Sepik successor basin was affected by global changes in sea level. During low sea level, the Sepik River discharged further offshore directly onto the shallow continental margins, producing seafloor instability and promoting mass-gravity flows. During extreme high sea level conditions following deglaciations, the mouth of the Sepik River was located further inland, away from the shelf. The shallow internal basin reverted back to marine conditions and river discharge was confined to the basin causing silt/sand starvation on the continental margins and a return to pelagic mud sedimentation under high-and low-rainfall conditions, hence irrespective of the mean position of the ITCZ and of the strength of the hydrological cycle [14].

Planktonic foraminifera's fauna and age

The very top of the core U1485A, the mudline, sample 1H-1 contains typical diverse open-ocean tropical assemblage. The marker species *Globorotalia truncatulinoides* is absent down to 7Hcc (65.01 mbsf), 1Hcc to 4Hcc (7.53-36.56 mbsf) from the uppermost portion of Subzone Pt1b (<0.07 Ma) are based on the absence of *Globigerinoides ruber* and *Globorotalia flexuosa*. Bio horizon top *G. flexuosa* (0.07 Ma) from 4Hcc and 5Hcc (36.56-45.99 mbsf), and Bio horizon top *G. ruber* (0.12 Ma) is defined between 8Hcc and 9Hcc (75.02-84.49 mbsf). Bio horizons base *Globigerinella calida* (0.22 Ma) and *G. flexuosa* (0.40 Ma) are hard to locate because of the rarity of the markers and because distinguishing both forms from related species requires fine taxonomic discrimination. The former Bio horizon from 15Hcc and 16Hcc (138.99-148.77 mbsf) and the latter between 38Hcc and 39Hcc (273.2-277.78 mbsf). The bottom of the hole at 44Hcc (300.75 mbsf) is found to be within Subzone Pt1b (<0.61 Ma) based on absence of *Globorotalia tosaensis*, a marker for the top of Subzone Pt1a. This is a fact confirmed by *Pulleniatina* genera populations which have strong dextral dominance throughout the core, indicating that the whole succession are above the L1 sinistral excursion (<0.80 Ma). Figure 2 shows Benthic Foraminifera diversity along bio zones defined by Planktonic Forams. The decrease in Benthic diversity along different times and especially after Pleistocene volcanic eruptions is recorded after the presence of volcanic ashes and tephra in some intervals (34Hcc, 35Hcc, 36Hcc and 39Hcc) showing changes in the fauna pattern at least after these volcanic episodes.

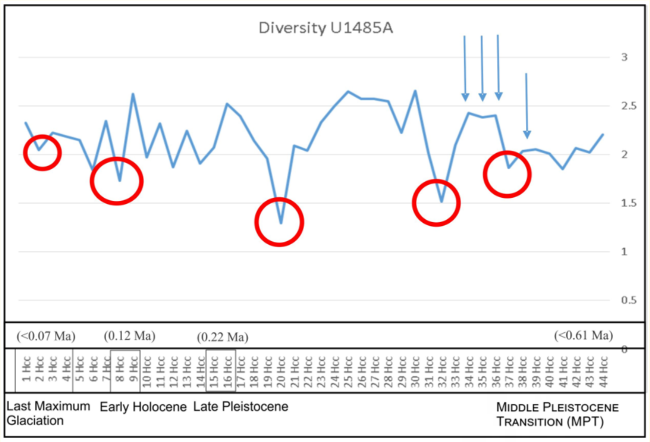

Figure 2: A Diversity curve on the Biozones markers of age for U1485AA, Samples 1Hcc to 4Hcc (<0.07 Ma) it marks the Last Maximum Glaciation, Samples 8Hcc and 9Hcc (0.12 Ma), recording the Early Holocene, Samples 15H-cc and 16Hcc (0.22 Ma) with the Late Pleistocene, and the 44Fcc (<0.61 Ma) younger than the Middle Pleistocene Transition (MPT). Volcanic ash in 34Hcc, 35Hcc, 36Hcc, and 39Hcc showing at least two decreases in Benthic diversity after these Pleistocene volcanic eruptions (Retired from [13]).

Benthic foraminifera fauna from Site 363-U1485A

Table of absolute frequency of benthic species sampled on the U1485A is showing on table. Changes in patterns shows deep (cold) and shallow (warm) benthic foraminifer's fauna alternated patterns along time in the past (Figure 3) with warmer periods in the present.

All deep and shallow water indicator species characteristics cited below were described by [15,16]. The deep-water fauna is dominated by *Cibicidoides pachiderma* [17], an upper bathyal species, from the early Oligocene through the Pleistocene, *Uvigerina hispida* [18] from early Miocene through Pleistocene,

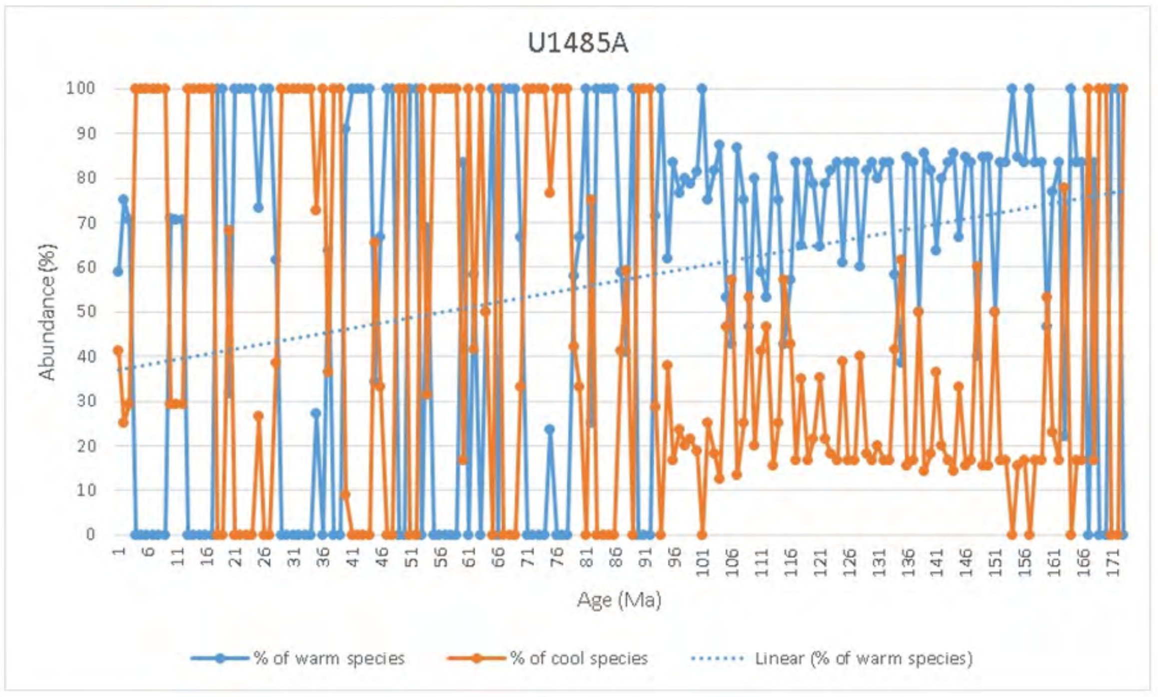

Figure 3: Changes in patterns shows balance of alternating deep (cold) and shallow (warm) benthic foraminifer's fauna along time in the past.

U. prosbocidae [18] from late Oligocene through Pleistocene) both bathyal, and *Uvigerina mediterranea*, an outer neritic upper bathyal form characteristic of warm waters, high salinities, little dissolved oxygen, and high levels of organic matter. *Bolivinita quadrilatera* [18] characteristic of 200-500m depth and *Bolivina robusta* [19] (Brady, 1881) from 3 to 900m, and the *Rotalinoides compressiusculus* [20], a shallow (warm) water Benthic foraminifera species, characteristic of 2-37m depth are present along the core intervals 13Hcc and 17Hcc, both showed higher diversity peak on Figure 4, and probably an interglacial cycle.

The five decreases in diversity peaks in the past show that the response of the benthic community to adverse climate is an alteration in their ecological dynamics. Changes in the distribution of Uvigerinidae species in the past 775 kyr in the Japan Sea were recorded by [21] Das., *et al*. (2018) and shows that the abundance and ecological preferences of these species suggest dysoxic conditions and high influx of organic matter between 775 and 475 ka resulting from the enhanced flow of the Tsushima Warm Current. The end of MIS 13 marked the onset of extreme glacial and interglacial climate cycles in the Japan Sea. Glacial and interglacial alternations of *Uvigerina peregrina* and *Trifarina angulosa* from 475 ka in the Holocene indicate large fluctuations in productivity and circulation in this basin. Both *U. peregrina* and *T. angulosa* respond to 100 kyr variability, reflecting the global ice volume changes and paleo climatic shift related to the Middle Pleistocene Transition.

Dominance of epifaunal taxa *Cibicidoides, Miliolinella, Triloculina, Pyrgo*, and *Quinqueloculina* particularly indicate possible episode of high Phyto detritus input and oxygen concentration [22-25].

Organic matter influx related to Phyto detritus was higher during glacial stages than the interglacial MIS 5. Epifaunal species are related to higher phyto detritus inputs and oxygen concentration during the Pleistocene (glacial period).

Miliolids are associated with oxygen-rich North Atlantic Deep Water [26] and the increase in infaunal taxa *Globocassidulina* and

Melonis during Holocene indicates high concentrations of organic carbon and nutrient, and low dissolved oxygen. [27] showed that calcareous-infaunal indicates high carbon influx and low dissolved-oxygen, whereas porcelaneous rate indicate high dissolved-oxygen. Higher abundances of *Uvigerina* sp., *Uvigerina peregrina*, *Uvigerina auberiana, Melonis barleeanum*, and *Globocassidulina subglobosa* are related to increased availability of organic carbon during warm intervals [24]. High percentage of *Uvigerina* has been observed in high surface productivity and organic carbon rich sediments. The high abundances of *Uvigerina proboscidea* during the Pleistocene demonstrate high surface productivity [7].

Uvigerina proboscidea characterizes areas of high carbon flux and low dissolved-oxygen concentration [27].

The 'warm' species abundances used by [7] are high and covary with *Uvigerina proboscidea*, evidencing the use of this index as a tracer for carbon flux, contributing to enhance the relationship between benthic foraminiferal assemblages and carbon export flux in the WPWP (Figure 4).

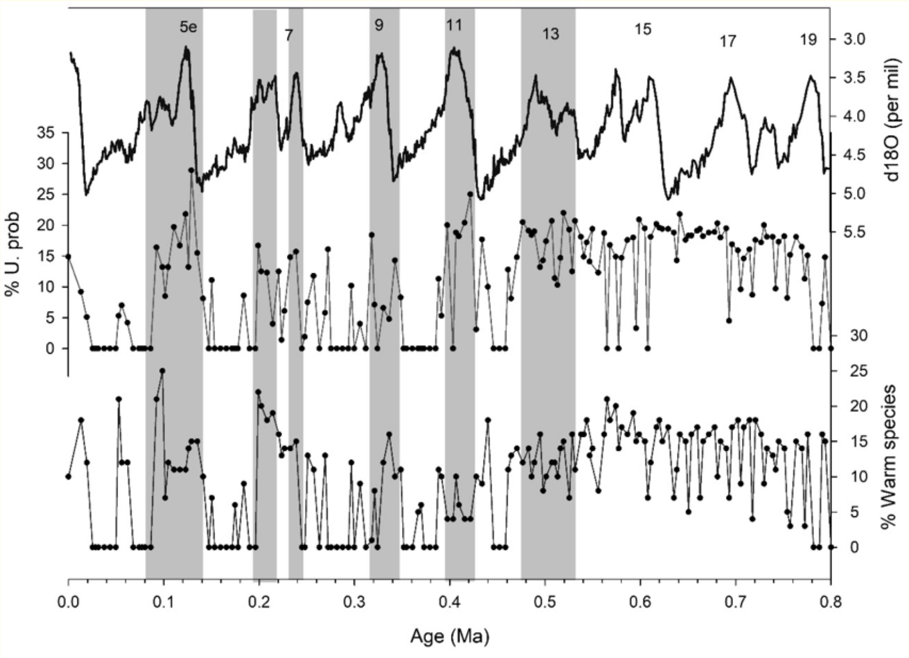

Figure 4: The 'warm' species abundances co vary with the percent abundance of Uvigerina proboscidea.

To further show that the 'warm' index can be used as a tracer for paleo productivity, we have compared and applied the same approach (% *U. proboscidea*. and % warm species) as [7] and there is an inclination for the % *U. proboscidea* and warm species to be higher during the interglacial intervals. They go out during the extreme glacial after 0.5 Ma. It is probably more consistent with the more recent glacial being extreme and dry, maybe less nutrients via the Sepik River-less runoff.

Melonis barleeanum indicates moderate organic flow with intermediate to high seasonality. High abundances of *Melonis barleeanum* characterize high productivity with sustained flow of organic matter. The environmental change observed in the upper portion of the core, which corresponds to the Holocene, with increase of infaunal foraminifera (e.g., *Uvigerina, Globocassidulina*, and *Melonis*) indicate reduction in the organic matter input and, probably, increase in bacteria density and depletion in dissolved oxygen in the sediment. *Globocassidulina subglobosa* also indicates well-oxygenated deep waters and good carbonate preservation.

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Typical bathyal paleoenvironment, as indicated by *Cibicidoides wuellerstorfii, Melonis pompilioides, Globocassidulina subglobosa*, and *Pyrgo murrhina* [28,29,30].

Cibicidoides wuellerstorfi and *Pyrgo murrhina* suggests a cold and highly oxygenated scenario [31]. *Cibicidoides wuellerstorfi* characterizes cold environments with active currents, low to intermediate organic flux, and high oxygenation [24].

Pyrgo murrhina lives in low organic carbon environments [25] and prefers cold and well-ventilated waters [22,24,32] According to [27], *Pyrgo murrhina* indicates cold and well-oxygenated environment, low influx of carbon to the sea floor is low, and reduced food availability.

Species of *Quinqueloculina* are highly mobile in fine-grained sediments both in shallow [33] and deep waters [34]. These movements are probably a response to the oxygen depletion in deeper sediment layers combined with the presence of labile food at water-sediment interface [35]. *Quinqueloculina* sp. feeds on phyto detritus, miliolids fast consume of algal debris might cause bloom in response to phyto detritus input [36,35].

High oxygen concentration in the Pleistocene, and low oxygen concentration with oxygen depletion in sediment during the Holocene. Natural clues about past climate are buried in the sediments at the bottom of the oceans, put away in coral reefs, iced in glaciers, and preserved in tree's rings, and each of these provide information about temperature, precipitation, and much more.

Conclusions

The amount of carbon dioxide released into the atmosphere by volcanic activity is linked to faunal patterns changes, with marine extinctions observed in sediment cores after volcanic episodes. The increase in carbon dioxide and other volcanic gaseous results on global warming and ocean acidification. They are responsible for the extinction of more than half of the species of the past.

To forecast future climate change we need to understand patterns, however we can predict that the modern ongoing carbon dioxide emissions are close to those that led to the end-Triassic mass extinction.

The importance of understanding the past of Earth's deep water is to be able to predict how it will respond to future climate alterations. The mass extinction and high-stress conditions after the intense Deccan volcanism leading to enhanced weathering and rapid global warming and cooling, increase of continental runoff, and ocean acidification, resulting in a crisis in the marine environment in relation to the carbonate. The explosive volcanic activity give rise to unstable benthic habitat colonized by few species. The enhanced atmospheric CO_2 concentrations resulted in decreased pH and carbonate availability in the ocean, known as ocean acidification. Low foraminiferal diversity occurred when volcanic activity was in place detected by the presence of tephra and volcanic ashes. High foraminiferal density and diversity in PNG is similar to those observed on the Great Barrier Reef; however, diversity decreases when ashes and tephra are detected. Agglutinate taxa that do not rely on calcification, and they will probably replace calcifying species, and we might call it a fauna replacement. Agglutinate taxa also decline, however is less marked than calcifying taxa where pH is low. Dissolution of foraminifera in marine sediment under elevated pCO_2 shows other direct ecological impacts such as dissolution and loss of biogenesis of carbonate by other organisms that will reach a problematic real-time scenario.

Because of the rate of increasing pCO_2 we expect that the temperature increase in the Holocene will make the world the warmest Pliocene climate with consequences of living in a warmer than optimum world until 2100. In addition, if history may teach us anything, it is how to react to and prepare for crisis rather than repeat mistakes. Our oceans, lakes and rivers are getting empty of life because of humanities greedy-mindedness. We are approaching disastrous effects of a sixth Anthropocene extinction, but we can surmount the challenges of biodiversity loss and climate change and alter the trajectory if we are able to pinpoint, mitigate and remediate problems in the near future. As average temperatures rise, the frequency of warm years increases, the impacts of fragmentation and habitat loss become more apparent. We are entering a sixth mass extinction event because of the biodiversity decline. The majority of these species inhabit environmentally delicate areas susceptible to human impacts. This is a situation where extinction of one species impacts other species that rely on it for survival, thereby also placing them at a 'domino effect' risk of extinction as part of a destructive chain reaction. We must stop burning and cutting forests, stop trade of wild species, and study areas to be able to preserve and conserve our biodiversity.

The unstable ecological conditions created by the increase in the CO_2 in the past suggested that diversity gradients of foraminiferal species responded to the cyclic pulses of volcanic eruptions in the past. If an ocean is still warming, it is likely to occur an increase in CO_2, which will extinct all calcareous species at the CO_2 conditions predicted for the year 2100. We fear that the best scenario is unlikely to occur, because it requires large and immediate emission cut-offs and negative net emission (carbon sequestration) at least until the end of this century.

The increase of natural pCO_2 in previous times occurred in one to two orders of magnitude slower and were always associated with low pH and less reduced calcite saturation. Our data suggests that the induced ecological extinction of shallow benthic foraminifera by 2100 is similar to extinctions observed in the geological past.

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Highlights

Massive environmental and climatic changes created by eruptions responsible for ocean acidification

Presence of tephra and volcanic ashes within the last 0.8 Mya and ocean acidification related to extinction of calcareous species.

High-stressed environments dominated by low diversity of opportunist species after volcanic activity

Diversity decreases, showing inverse correlation to high presence of ashes and tephra in the past

Changes in diversity shows alternating deep (cold) and shallow (warm) foraminiferal species along past timelines.

Ash and tephra records shows periodicity of explosive volcanism within the last 0.8 Myr maintaining a strong 100 kyr periodicity.

Cycles of Earth's orbital trigger peaks of volcanic episodes in a 41,000-year cycle with Earth's tilt matching up with peak volcanic activity.

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